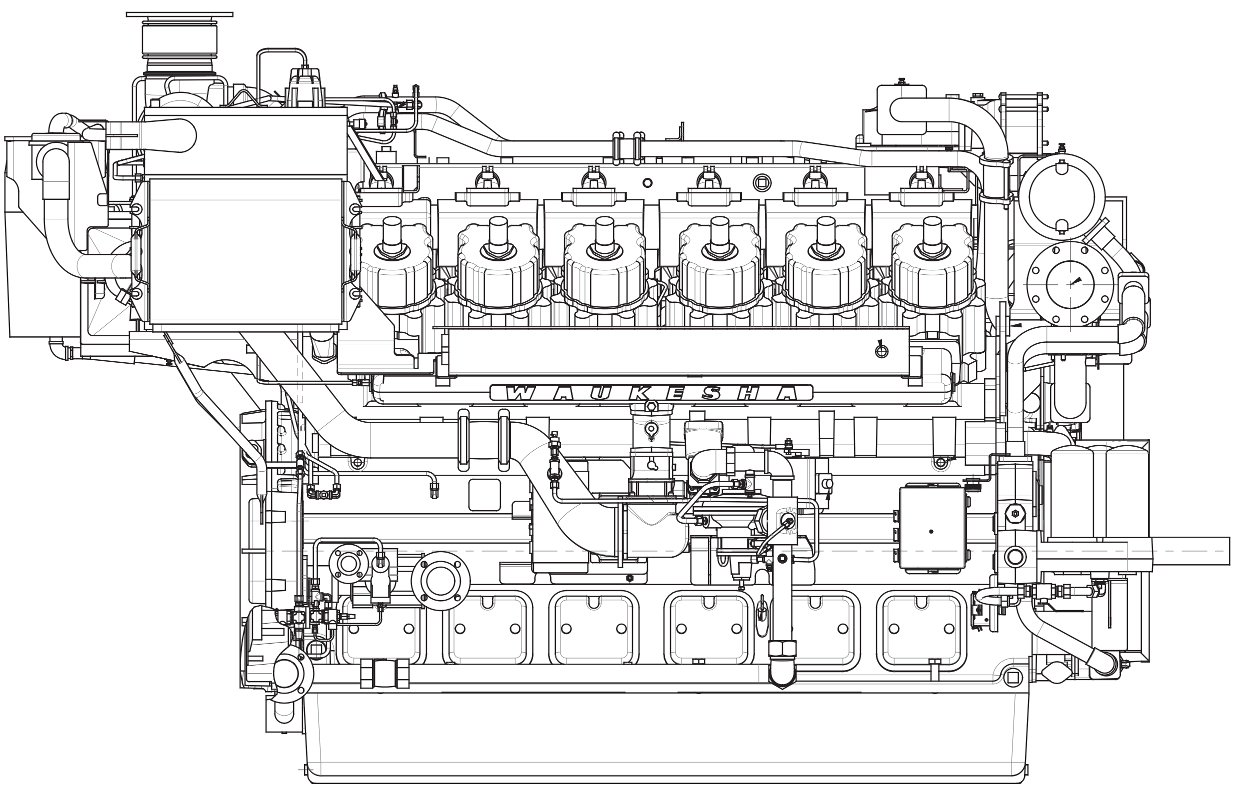
Waukesha Gas Engines

VHP* Series Five Packaging Guide

with ESM*2 and AFR2

General packaging guidelines to help meet the best recommended practices for the application and use of Waukesha* VHP L7042GSI S5 and L7044GSI S5 engines with ESM2 and AFR2.

Form 10083-1



Disclaimer

INNIO's Waukesha gas engines ("Waukesha") is providing the following packaging guidelines to help you meet best recommended practices for the application and use of Waukesha engines. Waukesha strongly recommends that engines not be started or operated until all packaging guidelines are met. Operating engines in applications that do not meet packaging guidelines has the potential to cause engine damage and/or personal injury. Waukesha will not be held liable or take any responsibility for any damage or incidents that occur due to operation of an engine that does not meet the packaging guidelines.

CONTENTS

CHAPTER 1 - SAFETY

SAFETY INTRODUCTION

The following safety precautions are published for your information. Waukesha does not, by the publication of these precautions, imply or in any way represent that they are the sum of all dangers present near industrial engines or fuel rating test units. If you are installing, operating, or servicing a Waukesha product, it is your responsibility to ensure full compliance with all applicable safety codes and requirements. All requirements of the Federal Occupational Safety and Health Act must be met when Waukesha products are operated in areas that are under the jurisdiction of the United States of America. Waukesha products operated in other countries must be installed, operated and serviced in compliance with any and all applicable safety requirements of that country.

For details on safety rules and regulations in the United States, contact your local office of the Occupational Safety and Health Administration (OSHA).

The words DANGER, WARNING, CAUTION and NOTICE are used throughout this manual to highlight important information. Be certain that the meanings of these alerts are known to all who work on or near the equipment.

Follow the safety information throughout this manual in addition to the safety policies and procedures of your employer.

This safety alert symbol appears with most safety statements. It means attention, become alert, your safety is involved! Please read and abide by the message that follows the safety alert symbol.

DANGER

Indicates a hazardous situation which, if not avoided, will result in death or serious injury.

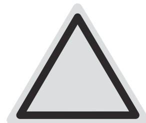
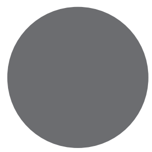
WARNING

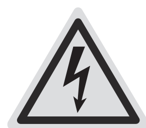
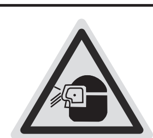
Indicates a hazardous situation which, if not avoided, could result in death or serious injury.

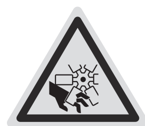
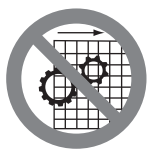
CAUTION Indicates a hazardous situation which, if not avoided, could result in minor or moderate injury.

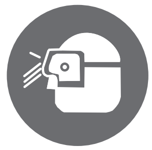
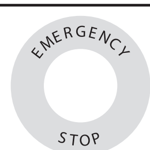
NOTICE Indicates a situation which can cause damage to the engine, personal property and/or the environment, or cause the equipment to operate improperly.

***NOTE**: Indicates a procedure, practice or condition that should be followed in order for the engine or component to function in the manner intended.*

Symbol	Description
	A black graphical symbol inside a yellow triangle with a black triangular band defines a safety sign that indicates a hazard.
	A black graphical symbol inside a red circular band with a red diagonal bar defines a safety sign that indicates that an action shall not be taken or shall be stopped.
	A white graphical symbol inside a blue circle defines a safety sign that indicates that an action that shall be taken to avoid a hazard.
Warnings	
	Safety Alert Symbol
	Asphyxiation Hazard
	Burn Hazard
	Burn Hazard (Chemical)
	Burn Hazard (Hot Liquid)
	Burn Hazard (Steam)
	Burst/Pressure Hazard
	Crush Hazard (Hand)

	Crush Hazard (Side)
	Crush Hazard (Side Pinned)
	Crush Hazard (Top)
	Electrical Shock Hazard
	Entanglement Hazard
	Explosion Hazard
	Fire Hazard
	Flying Object Hazard
	Hazardous Chemicals
	High-Pressure Hazard
	Impact Hazard
	Pinch-Point Hazard

	Pressure Hazard
	Puncture Hazard
	Sever Hazard
	Sever Hazard (Rotating Blade)
Prohibitions	
	Do not operate with guards removed
	Do not leave tools in the area
	Drugs and Alcohol Prohibited
	Lifting/Transporting only by qualified personnel
	Welding only by qualified personnel

Mandatory Actions	
	Read Manufacturer’s Instructions
	Wear Eye Protection
	Wear Personal Protective Equipment (PPE)
	Wear Protective Gloves
Miscellaneous	
	Emergency Stop
	Grounding Point
PE	Physical Earth
	Use Emergency Stop (E-Stop); Stop Engine

WARNING

The safety messages that follow have WARNING level hazards.

SAFETY LABELS

All safety labels must be legible to alert personnel of safety hazards. Replace any illegible or missing labels immediately. Safety labels removed during any repair work must be replaced in their original position before the engine is placed back into service.

EQUIPMENT REPAIR AND SERVICE

Always stop the engine before cleaning, servicing or repairing the engine or any driven equipment.

- If possible, lock all controls in the OFF position and remove the key.
- Put a sign on the control panel warning that the engine is being serviced.
- Close all manual control valves.
- Disconnect and lock out all energy sources to the engine, including all fuel, electric, hydraulic and pneumatic connections.
- Disconnect or lock out driven equipment to prevent the possibility of the driven equipment rotating the disabled engine.

Allow the engine to cool to room temperature before cleaning, servicing or repairing the engine. Some engine components and fluids are extremely hot even after the engine has been shut down. Allow sufficient time for all engine components and fluids to cool to room temperature before attempting any service procedure.

Exercise extreme care when moving the engine or its components. Never walk or stand directly under an engine or component while it is suspended. Always consider the weight of the engine or the components involved when selecting hoisting chains and lifting equipment. Be positive about the rated capacity of lifting equipment. Use only properly maintained lifting equipment with a lifting capacity that exceeds the known weight of the object to be lifted.

ACID

Always read and comply with the acid manufacturer's recommendations for proper use and handling of acids.

BATTERIES

Always read and comply with the battery manufacturer's recommendations for procedures concerning proper battery use and maintenance..

Batteries contain sulfuric acid and generate explosive mixtures of hydrogen and oxygen gases. Keep any device that may cause sparks or flames away from the battery to prevent explosion.

Always wear protective glasses or goggles and protective clothing when working with batteries. You must follow the battery manufacturer's instructions on safety, maintenance and installation procedures.

BODY PROTECTION

Always wear OSHA-approved body, sight, hearing and respiratory system protection. Never wear loose clothing, jewelry or long hair around an engine.

CHEMICALS

GENERAL

Always read and comply with the safety labels on all containers. Do not remove or deface the container labels.

CLEANING SOLVENTS

Always read and comply with the solvent manufacturer's recommendations for proper use and handling of solvents. Do not use gasoline, paint thinners or other highly volatile fluids for cleaning.

LIQUID NITROGEN

Always read and comply with the liquid nitrogen manufacturer's recommendations for proper use and handling of liquid nitrogen.

COMPONENTS

HEATED OR FROZEN

Always wear protective equipment when installing or removing heated or frozen components. Some components are heated or cooled to extreme temperatures for proper installation or removal.

INTERFERENCE FIT

Always wear protective equipment when installing or removing components with an interference fit. Installation or removal of interference components may cause flying debris.

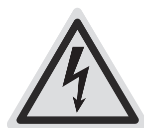
COOLING SYSTEM

Always wear protective equipment when venting, flushing or blowing down the cooling system. Operational coolant temperatures can range from 180° – 250°F (82° – 121°C).

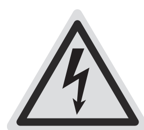
Do not service the cooling system while the engine is operating or when the coolant or vapor is hot. Operational coolant temperatures can range from 180° – 250°F (82° – 121°C).

ELECTRICAL

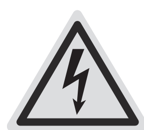
GENERAL



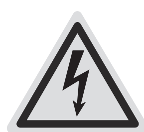
Equipment must be grounded by qualified personnel in accordance with IEC (International Electric Code) and local electrical codes.



Do not install, set up, maintain or operate any electrical components unless you are a technically qualified individual who is familiar with the electrical elements involved.

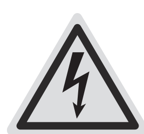


Disconnect all electrical power supplies before making any connections or servicing any part of the electrical system.

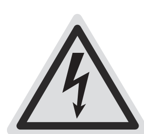


Always label “high voltage” on engine-mounted equipment over 24 volts nominal.

IGNITION



Avoid contact with ignition units and wiring. Ignition system components can store electrical energy, and if contacted, can cause electrical shock.



Properly discharge any electrical component that has the capability to store electrical energy before connecting or servicing that component.

EMERGENCY SHUTDOWN

An Emergency Shutdown must never be used for a normal engine shutdown. Doing so may result in unburned fuel in the exhaust manifold. Failure to comply increases the risk of an exhaust explosion.

EXHAUST

Do not inhale engine exhaust gases. Ensure that exhaust systems are leak-free and that all exhaust gases are properly vented to the outside of the building.

Do not touch or service any heated exhaust components. Allow sufficient time for exhaust components to cool to room temperature before attempting any service procedure.

FIRE PROTECTION

See local and federal fire regulations for guidelines for proper site fire protection.

FUELS

GENERAL

Ensure that there are no leaks in the fuel supply. Engine fuels are highly combustible and can ignite or explode.

GASEOUS

Do not inhale gaseous fuels. Some components of fuel gas are odorless, tasteless and highly toxic.

Shut off the fuel supply if a gaseous engine has been cranked excessively without starting. Crank the engine to purge the cylinders and exhaust system of accumulated unburned fuel. Failure to purge accumulated unburned fuel in the engine and exhaust system can result in an explosion.

LIQUIDS

Use protective equipment when working with liquids and related components. Liquids can be absorbed into the body.

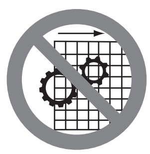
INTOXICANTS AND NARCOTICS

Do not allow anyone under the influence of intoxicants and/or narcotics to work on or around industrial engines. Workers under the influence of intoxicants and/or narcotics are a hazard to both themselves and other employees.

PRESSURIZED FLUIDS /GAS/AIR

Never use pressurized fluids/gas/air to clean clothing or body parts. Never use body parts to check for leaks or flow rates. Observe all applicable local and federal regulations relating to pressurized fluids/gas/air.

PROTECTIVE GUARDS



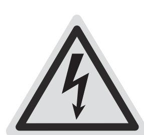
Provide guarding to protect persons or structures from rotating or heated parts. It is the responsibility of the engine owner to specify and provide guarding. See OSHA standards on “machine guarding” for details on safety rules and regulations concerning guarding techniques.

SPRINGS

Use appropriate equipment and protective gear when servicing or using products that contain springs. Springs, under tension or compression, can eject if improper equipment or procedures are used.

TOOLS

ELECTRICAL



Do not install, set up, maintain or operate any electrical tools unless you are a technically qualified individual who is familiar with them.

HYDRAULIC

Do not install, set up, maintain or operate any hydraulic tools unless you are a technically qualified individual who is familiar with them. Hydraulic tools use extremely high hydraulic pressure.

Always follow recommended procedures when using hydraulic tensioning devices.

PNEUMATIC

Do not install, set up, maintain or operate any pneumatic tools unless you are a technically qualified individual who is familiar with them. Pneumatic tools use pressurized air.

WEIGHT

Always consider the weight of the item being lifted and use only properly rated lifting equipment and approved lifting methods.

Never walk or stand under an engine or component while it is suspended.

WELDING

Comply with the welder manufacturer’s recommendations for procedures concerning proper use of the welder.

CAUTION

The safety message that follows has a CAUTION level hazard.

Ensure that all tools and other objects are removed from the unit and any driven equipment before restarting the unit.

NOTICE

The safety messages that follow have NOTICE level hazards.

Ensure that the welder is properly grounded before attempting to weld on or near an engine.

Table 1-1: Disconnect the ignition harness and electronically controlled devices before welding with an electric arc welder on or near an engine. Failure to disconnect the harnesses and electronically controlled devices could result in severe engine damage.

CHAPTER 2 - GENERAL INFORMATION

The L7042GSI S5 and L7044GSI S5 VHP Series Five engines are 4-cycle, 12-cylinder vee-configured engines. All engines rotate in the standard counterclockwise direction, as viewed from the rear (flywheel) end. “GSI” engines are rich combustion (stoichiometric) engines equipped with turbochargers that “force” high-velocity ambient air through the intercoolers, carburetors, and intake manifolds before entering the combustion chamber.

SCOPE OF SUPPLY

A scope of supply list for the engines are available in the Appendix.

BASIC ENGINE DESCRIPTION

AFR2

Waukesha’s next generation air/fuel ratio controller for rich-burn engines. Control is based on pre-catalyst O2 setpoints. System includes fuel control valves (instead of steppers), an enhanced O2 sensor optimized for gaseous fuels, and Human/Machine Interface (HMI) display panel. The ouch screen panel provides on-screen AFR2 setup instructions, real-time engine operating parameters without a laptop, and screen to adjust the system richer or leaner.

EMPACT EMISSION CONTROL SYSTEM (emPACT)

Waukesha’s complete emission solution for rich-burn engines capable of achieving 0.5 g/bhp-hr NOx/1.0 g/ bhp-hr CO or 0.15 g/bhp-hr NOx / 0.30 g/bhp-hr CO. Includes engine, 3-way catalyst, and enhanced air/fuel ratio controller. Control is based on post-catalyst O2, allowing system to automatically adjust air/fuel ratio based on feedback from emissions coming out of catalyst, simplifying compliance across range of speeds, loads, and other operating conditions. System includes fuel control valves (instead of steppers), enhanced pre- and post-catalyst O2 sensors optimized for gaseous fuels, pre- and post-catalyst temperature and pressure sensors, and Human/Machine Interface (HMI) display panel. The display panel provides onscreen emPact setup instructions, real-time engine operating parameters without a laptop, and buttons to adjust the system richer or leaner.

CRANKCASE

The crankcase is a gray iron casting. For assembled rigidity, the main bearing caps are attached to the crankcase with both vertical studs and lateral tie bolts. This feature makes the crankcase assembly more rigid and lengthens the life of the main bearings.

For ease of operation and overall serviceability, the sides of the engine are clear of components and piping. The crankshaft covers can be easily removed.

The oil level in the sump is below the crankshaft covers, so the covers can be quickly removed and the crankshaft inspected or the bearing caps positioned without draining oil.

Optional crankcase pressure relief valves are mounted on the side of the crankcase.

CRANKCASE BREATHER SYSTEM

The breather system is a closed self-regulating breather system which is piped to the engine air intake system to maintain a slight negative pressure in the crankcase. The negative pressure rids the crankcase of harmful water vapors and combustion gases, and helps to prevent sludge buildup and oil contamination. Maintaining a negative crankcase pressure is important to prevent oil leaks and vacate harmful vapors, but too much vacuum pulls in environmental dust and dirt. Vacuum lines from both turbocharger compressors create the draw past engine seals that pulls the gases from the crankcase. The gases go through a pre-separator and main (coalescing) separator to remove oil vapor from the gases prior to being drawn into the engine. The separated oil is returned to the crankcase through a return tube which contains a one-way check valve that prevents backflow of oil and/or vapor back into the separator. The crankcase pressure is regulated by the pressure regulator valve so the specified negative pressure in the crankcase is maintained.

CRANKSHAFT

The underslung crankshaft is made of a low alloy, high tensile strength forged steel. The crankshaft is counterweighted to achieve a near perfect balance of rotating forces.

A viscous vibration damper is installed on the forward end of the crankshaft along with a gear that drives the front end gear train and accessories. The flywheel, with ring gear, is installed on the rear end of the crankshaft and is machined to accept several options.

CONNECTING RODS

The connecting rods are machined to ensure maximum strength, precise balance and consistent weight between cylinders. They are made of a low alloy, high tensile strength forged steel, and are rifle-drilled to supply pressurized lube oil from the crankshaft to the piston pin bushings. The split line of the rod and cap allows for removal of the connecting rod assembly up through the cylinder sleeve bore.

The serrated split line ensures precise alignment and transfer of loads. The caps and rods are match-numbered to ensure that each cap is mated with the correct blade during reassembly.

The connecting rod cap fasteners, like all critical fasteners used on the engine, are torqued to specific values.

PISTONS

The pistons are machined from one-piece castings. The dimension of the piston skirt at room temperature is slightly larger at a point 90° to the piston pin bore. This feature allows the piston to expand from a shape that is somewhat oval to one that is almost perfectly round when operating at stabilized engine temperatures.

CYLINDER SLEEVES

Each wet-type cylinder sleeve has a flange at its upper end to locate it in the crankcase upper deck. The sleeves have three external ring grooves to hold the lower crankcase bore seals.

CAMSHAFT

With the integration of Miller Cycle engine technology, a new camshaft lobe profile improves fuel efficiency and engine performance, while reducing exhaust emissions.

CYLINDER HEAD AND VALVES

The cylinder heads used on VHP Series Five engines has four valves, two intake and two exhaust. The cylinder heads offer several features including improved cooling, superior valve life, increased overhaul interval, and rigid valve bridge assembly.

TURBOCHARGER

The 12-cylinder engines have two turbochargers, one for each cylinder bank. The turbocharger is wastegate-controlled and uses a watercooled center section. The center section consists of a main shaft that connects the intake compressor and exhaust turbine wheels. The intake compressor is mated to the intake manifold, and the exhaust turbine is mated to the exhaust manifold. With the engine running, hot exhaust gases are forced into the exhaust turbine wheel, causing it to rotate at high speed. This causes the intake compressor wheel to rotate at the same speed because of the main shaft connection. The high-speed rotation of the intake compressor wheel creates compressed air that is forced into the carburetor.

INTERCOOLER

The intercoolers cool the inlet air after the turbochargers to provide denser air to the engine combustion chambers.

CARBURETOR

One carburetor is mounted on each bank just below the center of each intake manifold. The carburetor produces a combustible mixture by automatically mixing fuel from the FCV and air from the turbocharger.

INTAKE MANIFOLD

The air/fuel mixture passes through the intake manifolds on each side of the engine, one for each bank, where it is distributed to the individual cylinders.

EXHAUST MANIFOLD

Each water-cooled exhaust manifold assembly is composed of six individual segments. One exhaust manifold segment is joined to the next by a manifold pilot. The exhaust port of each cylinder head is connected to one water-jacketed segment of the exhaust manifold. Exhaust gas flows through the exhaust manifold to the turbocharger turbine.

WATER CIRCULATION SYSTEM

Auxiliary Circuit – The auxiliary circuit provides cooling to the intercooler, oil cooler, and turbocharger bearings. The system uses a 130° F (54° C) auxiliary water temperature control valve and bypass, belt driven centrifugal type water pump, mounted intercooler, and mounted oil cooler.

Engine Jacket – The jacket circuit provides cooling to the cylinder sleeves, cylinder heads, and the exhaust manifolds. This system includes mounted 180°F (82°C) jacket water temperature control valve with mounted bypass and gear driven centrifugal type water pump.

ESM2

The ESM2 integrates spark timing control, speed governing, knock detection, start-stop control, air/fuel control, diagnostic tools, continuous data logging and engine protection. ESM2 system automation and monitoring provides:

• Better engine performance

• Extensive system diagnostics

• Simplified troubleshooting of engines

• Local and remote monitoring capability used to trend engine performance.

ENGINE MONITORING DEVICES

The shipped loose HMI panel must be mounted in a customer supplied panel and wired to ESM2. The HMI provides the interface to the fuel system. It displays status, settings, alarms and history.

Commands are performed directly on the HMI's screen.

The HMI interfaces with the ECU through CAN communication for displayed values, faults and calibrations. The temperature rating for the HMI panel is -40° to 140°F (-40° to 60°C).

Wired sensors for exhaust O2, lube oil pressure and temperature, intake manifold temperature and pressure, overspeed; main bearing temperature, exhaust cylinder temperature, jacket water temperature; crankcase pressure, boost pressure and exhaust temperature post turbocharger; all accessible through ESM2. Sensors meet Canadian Standards Association Class 1, Division 2, Group A, B, C, & D (Canada & US) hazardous location requirements. ESM continually monitors combustion performance through accelerometers to provide detonation protection. Dual magnetic pick-ups are used for accurate engine speed monitoring.

ESM2 provides predictive spark plug diagnostics as well as advanced diagnostics of engine and all ESM2 sensors and logs any faults into non-volatile flash memory. K-type thermocouples for individual cylinder exhaust temperatures, pre and post turbocharger and main bearing temperatures are controlled by ESM2.

Waukesha preprogrammed HMI panel for engine and AFR2 control readout, which provides direct interface for AFR2 setup and monitoring. All ESM2 and AFR2 information with alarm and shutdown faults are displayed. All ESM2 and AFR2 parameters are available via a MODBUS RS485 signal.

CHAPTER 3 - TECHNICAL DATA

WHERE TO FIND TECHNICAL DATA

Technical data for Waukesha engines can be found on the website, *https://customer.innio.com*. Access to the website can be requested by completing the form found by clicking the "Register" link on the top of the page. Permission must be granted to receive a username and password, and once access is granted, you will be able to login.

Table 3-1: Technical Data Sheets Available on https://*customer.innio.com*

	L7042GSI S5	L7044GSI S5	SHEET NAME
SPECIFICATIONS	S-5585-8	S-5585-7	Engine Specification Sheet
RATINGS & STANDARDS	C-278-16	C-278-15	Engine Rating and Fuel Consumption
HEAT REJECTION	S-6124-106	S-6124-104	Heat Rejection & Emissions with AFR2
	S-6124-107	S-6124-105	Heat Rejection & Emissions with emPact Code 1005
COOLING SYSTEM	S-5136-34		Jacket Water Pump Performance
	S-6543-36A		Auxiliary Water Pump Performance
	S-6699-7		Cooling System Guidelines
	S-7424-1		Inlet Pressure Requirement for Jacket Water Pump
	S-7610-3		Water Treatment Guidelines
	S-8472-2		Cooling System Schematic
	S-8473-2		Elevated Ambient Air Temperature and Altitude Correction to Heat Rejection
CONTROL SYSTEM	S-8382-3		Alarm and Shutdown Setpoints
DRIVE DATA	SA-2905-H		Definitions for Varioous Types of Duty
	S-4052-13		Front End Drive Data
	S-6900-3		Flywheel Information
	S-8467-2		Maximum Unbalanced Inertia Forces and Moments
SOUND DATA	S-8205-9		Bare Exhaust Sound Data
	S-8205-10		Engine Sound Data
EMISSIONS DATA	S-8483-6		Gas Engine Emissions Levels
INTAKE & EXHAUST SYSTEMS	S-8117-2		Engine Exhaust Recoverable Energy Calculations
	S-8242		Exhaust System Installation Guide
POWER ADJUSTMENTS & WKI*	S-8154-101		Power Adjustments for Altitude and Ambient Air Temperature
	S7079-41	S7079-42	Power Adjustments for Fuel Quality (WKI* Curve)
FUEL SYSTEM	SA-434-D		Engine Mechanical Efficiency Calculation
	SA-6656-L		Gas Solenoid Valve Selection
	S-5806A		Gas Flow Data in Piping
	S-6656-23		Gas Pressure Limits to Engine Mounted Regulator
	S-7032-2		Procedure for Calculating Fuel Gas SLHV
	S-7884-7		Gaseous Fuel Specification
	S-7898-2		Glossary of Gaseous Fuel Terms
LUBRICATION SYSTEM	S-1015-30		Lube Oil Recommendations
	S-3549-J		Allowable Engine Angle for Operation
	S-7382-56		Prelube and Postlube Requirements
STARTING SYSTEMS	S-7447-8		Air Volume and Pressure Guidelines for Air Starter

Table 3-2: Engine Specifications

ENGINE SPECIFICATIONS	
Description	**L7042GSI S5** **L7044GSI S5**
Type	4-cycle, rich-burn
Aspiration	Turbocharged, intercooled
Number of Cylinders	V-12, 4 valves per cylinder
Bore x Stroke	9.375 x 8.50 in. (238 x 216 mm)
Displacement	7040 cu. In. (115 L)
Compression Ratio	9.7:1
Mean Piston speed @ 1200 RPM	1700 ft/min (8.64 m/sec)
Speed Range	900-1,200 rpm
Low Idle	700 RPM
Maximum Sound Pressure Level	105 dB(A)
Firing Order	1R-6L-5R-2L-3R-4L-6R-1L-2R-5L-4R-3L
OIL SYSTEM	
Sump Capacity, Including Filter & Cooler	190 gal (719 L)
Deep Sump Oil pan (Low level mark)	152 gal (575 L)
Deep Sump Oil pan (Full level mark)	173 gal (655 L)
Main Filter	26 micron @ 98.6% absolute efficiency
Normal Oil Pressure	50 - 60 psi (345 - 414 kPa)
Low Oil Pressure Alarm Setpoint	35 psi (241 kPa)
Low Oil Pressure Shutdown Setpoint	30 psi (207 kPa)
PRE / POSTLUBE	
Prelube Duration	Recommend: 3 minutes before starting. Required Min: 30 sec. or until pressure is obtained
Prelube Pressure in Header	1 - 4 psi (7 - 31 kPa)
Postlube Duration (after hot shutdown)	5 minutes
Normal Oil Header Temperature	180°F (82°C)
Oil Header Temperature Alarm Setpoint	190°F (88°C)
Oil Header Temperature Shutdown Setpoint	200°F (93°C)
Prelube Inline Lubricator Lubricant	SAE 10W oil at 32°F (0°C) and above. Use No. 2 Diesel Oil below 32°F (0°C)
Pneumatic Prelube Motor, Inline Lubricator	0.5 pint (0.2 liter)
CRANKCASE BREATHER SYSTEM	
Crankcase Vacuum	-3 (negative) to 0 inch H2O (-76 to 0 mm H2O)

COOLING SYSTEM	
Normal Jacket Water Outlet Temperature	180° F (82° C)
Normal Intercooler Inlet Temperature	130°F (54°C)
Jacket Coolant Capacity, Engine Only	107 gal (405 L)
Auxiliary Circuit Capacity, Engine Only	12 gal (45 L)
FUEL SYSTEM	
Natural Gas Pressure at Regulator	40 - 60 psi (276 - 414 kPa) 43 – 60 psi (296 – 414 kPa) for > 5000ft elevation
EXHAUST SYSTEM	
Maximum Permissible Back Pressure	20 in. (508 mm) H2O at 178 BMEP/1200 RPM
AIR INDUCTION SYSTEM	
Maximum Permissible Restriction	15 inch-H2O (381 mm-H2O)
Required Filtering Efficiency (Coarse Dust Per SAE J726 / ISO 5011, Latest Version)	99.70%
STARTING SYSTEM	
Electric Starting - Oil heaters required if ambient temperature is below 65° F (18.3° C)	24 volts DC
Air Starting Pressure - Oil heaters required if ambient temperature is below 50° F (10° C)	150 psi (1034 kPa) MAX
MISCELLANEOUS	
Recommended Minimum Spacing Between Engines	36 in. (914 mm)
Recommended Minimum Distance to Wall	36 in. (914 mm)
Recommended Minimum Overhead Clearance	60 in. (1,524 mm)
Engine Without Shipping Skid	24,600 lb (11,158 kg)
Heaviest Engine Part, Top Overhaul, Cylinder Head	235 lb. (107 kg)

1. Turbocharger life can be shortened if this prelube is shorter.
2. Sufficient height to permit use of a chain hoist for removal of heavier components.

ENGCALC

For engine data at site specific conditions and fuel, EngCalc is available to download off the website *ge-distributedpower.com*. When downloaded, there will be 2 files which must be saved in the same directory together and requires Microsoft Excel version 2003 or newer. This program will provide site specific engine data based on a user's input of site conditions and a fuel analysis. The data provided by EngCalc must be used when sizing radiators, catalysts, and other auxiliary components. Data from EngCalc can be printed out in a report format.

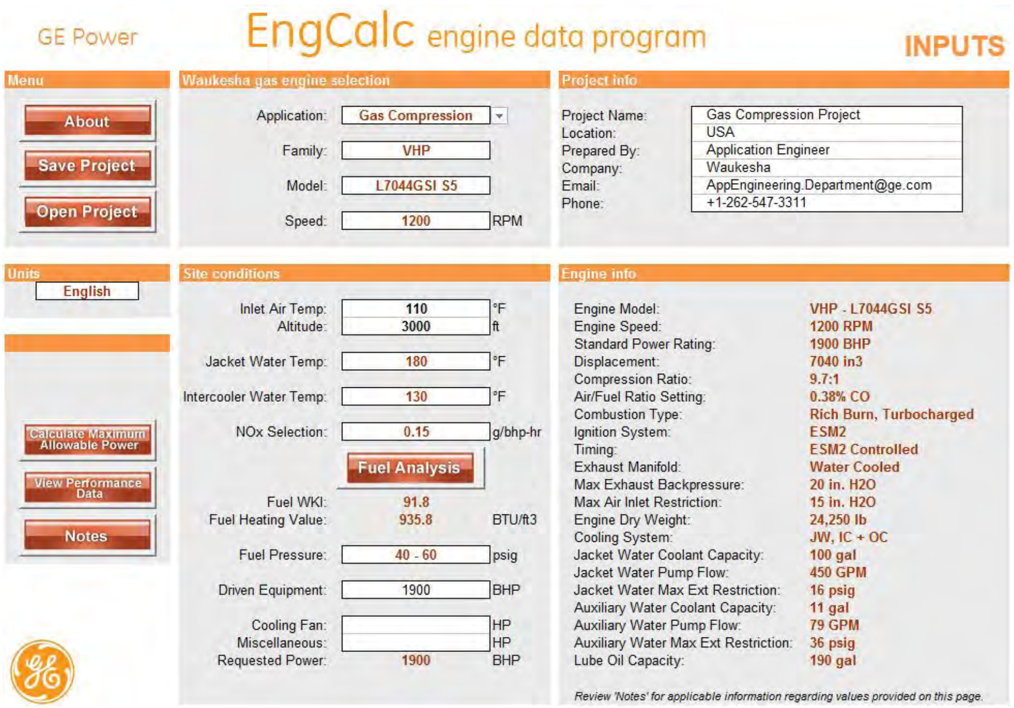


Figure 3-1: EngCalc Inputs Page

OUTLINE DRAWINGS

Outline drawings are available on *ge-distributedpower.com*. The outline drawings are organized engine model, and will show dimensions, connection sizes, and component identifications. These outline drawings are just for the base engine with no option codes. If option codes are ordered, and they change components from the base engine, there will be an option code outline drawing listed on the page by option code number. These option code outline drawings should be overlaid over the base engine drawing and the changes called out on the option code drawing should be made. (*e.g. Replaces engine connections 14 and 15 on standard pricecode installation drawing*.)

Outline drawings are also available for engines ordered as “Gas Compression Spec” which have option codes installed as standard which are commonly used in gas compression applications. Refer to the Scope of Supply section for details of what is included on Gas Compression Spec engines.

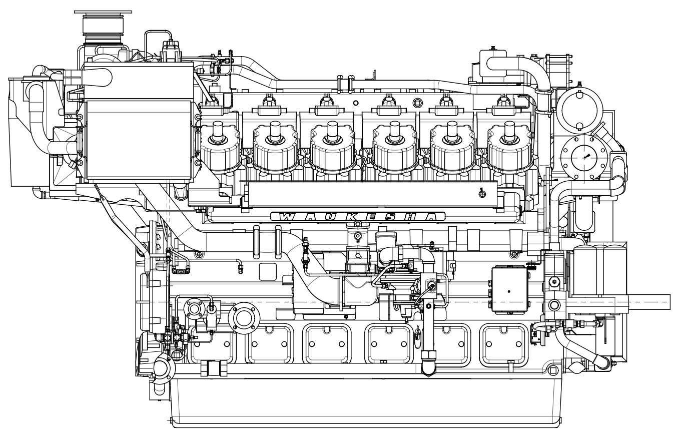


Figure 3-2: L7044GSI S5/L7042GSI S5 Base Engine Outline Drawing (no options)

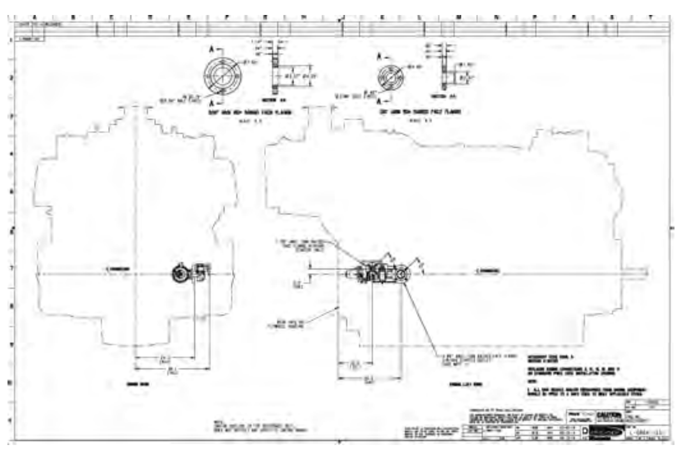


Figure 3-3: L7044GSI S5/L7042GSI S5 Option Code 9208 Outline Drawing

The outline drawings page also has wiring diagrams for the ESM2 system and HMI Installation.

SERVICE BULLETINS

Waukesha releases Service Bulletins to update the field on changes, retrofits or new offerings that are applicable to existing engines. The Service Bulletin Index is available on the Waukesha website www.ge-distributedpower.com. There is also a registry list for people who want to receive an e-mail when a new Service Bulletin is released. To register for these notifications please e-mail AppEngineering.Department@ge.com.

3D MODELS

There is a Support Central website set up that contains 3D models for the base engine. This model is only of the base engine, and may not fully represent the engine that is ordered. Separate access will need to be granted for these 3D models. Please contact application engineering at AppEngineering.Department@ge.com.

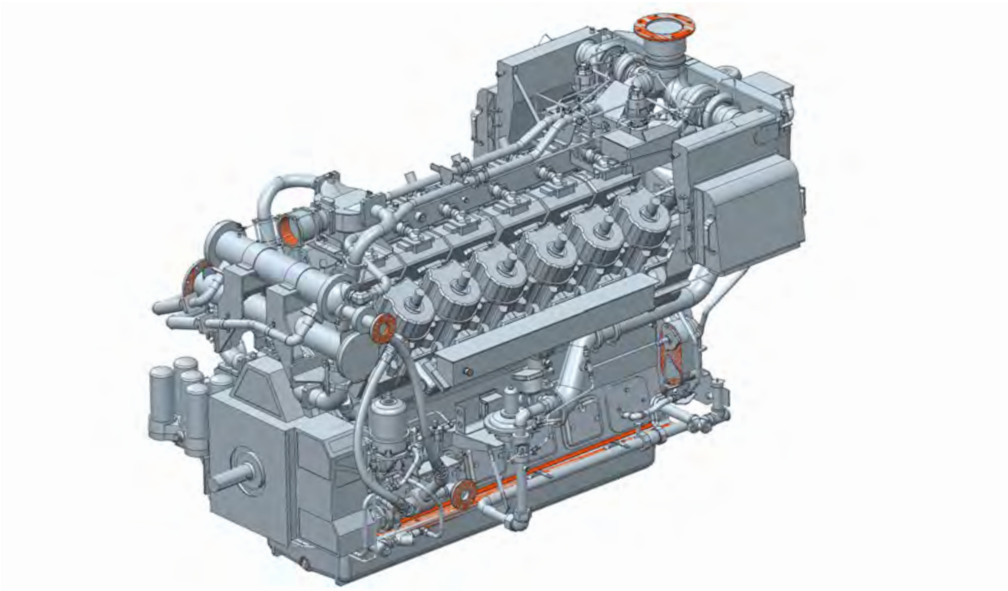


Figure 3-4: L7044GSI S5 3D model

MANUALS

The available manuals for the engine are shown in “Table 3-3: Manuals”. Each engine will come with a set of manuals shipped loose with the engine, but if additional manuals are required please contact application engineering at AppEngineering.Department@ge.com.

Table 3-3: Manuals

MANUAL FORM NUMBER	Cyl.	TYPE	DESCRIPTION
10063-1	12	O & M	VHP Series Five 12-Cylinder with ESM2 O&M
10064-1	12	Parts	VHP 12 Cylinder with ESM2 Parts Catalog
10065-1	12	R & O	VHP 12 Cylinder with ESM2 Repair and Overhaul

CHAPTER 4 - ENGINE BASE DESIGN

When a base (also referred to as a “skid”) is not supplied by Waukesha gas engines, the packager assumes responsibility for the base design. Any package being assembled outside of the engine manufacturer should have a vibration study performed and tests completed for assurance of installation integrity against vibration at the site. Information on engine unbalanced forces and moments can be found in the Waukesha gas engine technical data; vibration limits can be found in the Application and Installation section of Waukesha gas engine service bulletins.

It is strongly recommended that the driven equipment be mounted on a common-skid with the engine. By mounting both units on the same skid, a common plane for the engine and driven equipment is created. The equipment is less likely to lose alignment, because the driven equipment cannot shift relative to the engine.

When designing bases to be used with Waukesha gas engines, the engine base must be a rigid design to maintain alignment between the engine and the driven equipment. Base flexing due to lack of torsional rigidity is a major cause of misalignment. When designed correctly, the base must offer rigidity adequate to oppose the twist due to torque reaction on drives for driven equipment mounted on the base assembly and not bolted to the engine. The design must prevent any excessive bending forces that could be transmitted to the engine block and any components in the drive train. A modal and torsional analysis must be performed to validate the base design using Mass Elastic System Data (MESD) and maximum unbalanced forces and moments data for the engine. MESD can be ordered as an option code (refer to the Price Book). A third party engineering firm may be required to perform this analysis. shown below, is an example of the skid used by Waukesha for power generation packages.

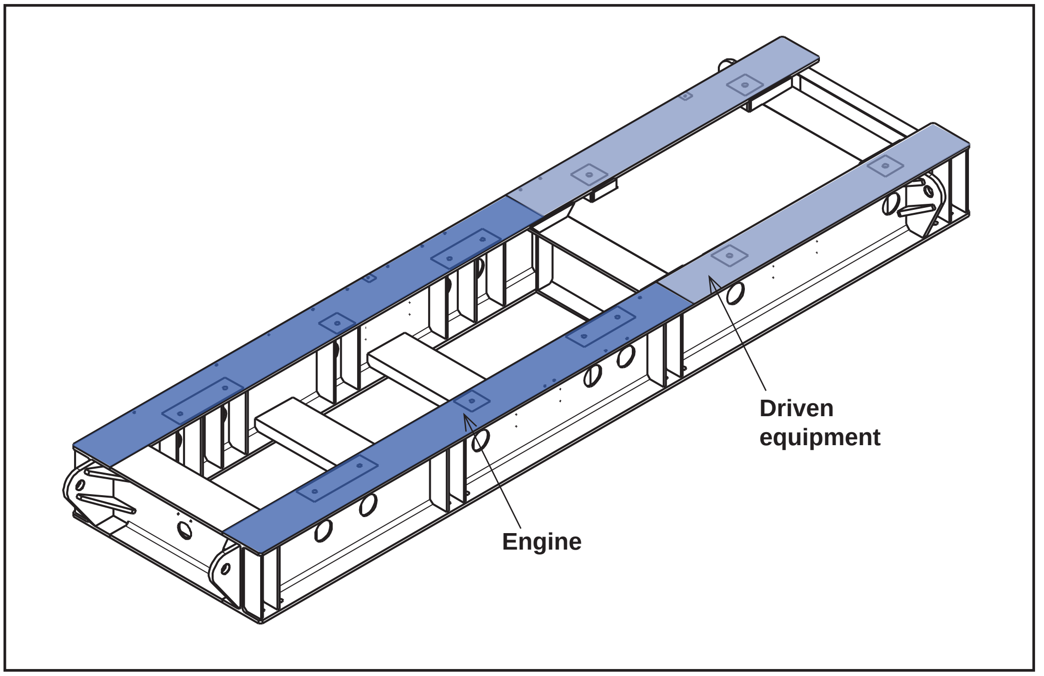


Figure 4-1: Example of genset base

The base must be designed according to the following:

- The entire package must be able to withstand normal handling during transportation without permanently distorting the base or causing misalignment of the engine or driven equipment.
- The base must limit torsional and bending moment forces caused by torque reaction and flexing of the foundation substructure or vibration isolators under the base.

- The base must be free of linear and torsional vibration in the operating load and speed range of the engine, and have a natural frequency such that resonance does not occur during the machinery's normal work.

- The base must maintain engine and driven equipment alignment under all operational and environmental conditions.

Designs that rigidly mount the base to the foundation are preferred over using vibration isolators. The use of isolators causes the base to react all of the transmitted torque and eliminates the "path to ground" for the engine's unbalanced forces.

Special consideration must be taken for bases designed for vibration isolators to ensure the base is designed to limit torsional and bending moment forces and prevent flexing of the base while mounted on vibration isolators. The base must maintain equipment alignment under all conditions.

Vibration isolators between the driven equipment and skid, or engine and skid are not acceptable for use with Waukesha gas engines.

Skid designs with a step down base feature between the engine and driven is not recommended and as an alternative, it is recommended that the mounting feet of the driven equipment are modified to use a continuous I-beam skid design with one level plane for mounting the engine and driven equipment. Separate skids for the engine and driven equipment are not recommended due to the torque which is transmitted and must be reacted by the engine and driven equipment skid. Also the risk of misalignment between the engine and driven equipment increases when the skids are separate.

Mounting of any ancillary components by a packager may result in unwanted vibration of those components. Appropriate lifting capability for lifting the complete package must be provided as part of the base design. Engine lifting eyes are not to be used for lifting of a packaged unit.

CHAPTER 5 - TORSIONAL ANALYSIS

All equipment with rotating components have inherent torsional vibrations that occur at various speeds. Manufacturers design their equipment so these inherent vibrations are below set limits and/or well outside its operating speed range. However, when equipment is combined (i.e., engine to driven equipment, generator, compressor etc…) the combination will have its own torsional characteristics where the torsional vibrations may exceed the limits in the equipment's operating range. This is why it is extremely important to perform or have a torsional analysis performed on every unit.

Crankshaft torsional vibration refers to the angular twisting of the crankshaft relative to the center of rotation. Since torsional vibration cannot be seen or felt by hand, it must be measured with special equipment.

The following engine situations may lead to excessive torsional vibration:

- Misalignment
- Bank to bank imbalance
- Uneven firing pressures
- Cylinder misfires
- Uneven ignition timing
- Incompatibility of the engine, couplings, and driven equipment
- Faulty vibration damper

To help limit the possibility of damage to the crankshaft, gear train, or coupling, vibration dampers are mounted on the front of the engine to reduce torsional vibration. Dampers will lose their ability to dampen as they age and therefore must be replaced. However, since damper life cannot easily be determined, it is recommended that they be replaced at the bottom-end overhaul service interval or in the event of a crankshaft failure.

A torsional analysis must be performed to determine compatibility of the drive line components when the components are used together for the first time. Waukesha can complete a torsional analysis when supplied with the coupling and driven equipment information or the engine mass elastic information can be supplied if another company will be doing the torsional analysis.

Contact Waukesha's Application Engineering department (*AppEngineering.Department@ge.com*) to request either the mass elastic system data or a complete torsional analysis.

CHAPTER 6 - INSTALLATION

MOUNTING AND ALIGNMENT SUMMARY

- Properly designed and constructed inertia block
- Skid designed and analyzed for engine forces and vibrations
- Engine aligned per Waukesha's procedure using correct shims and bolts
- Driven equipment aligned to the Waukesha engine

PREPARATION FOR MOUNTING

Waukesha engines should be mounted on an inertia block or a concrete pad with spring isolators. These types of mounting are important as they help to isolate the engine and its vibration from the surrounding structure and from other machines. The inertia block or pad provides a level surface on which to mount the engine as well as a high level of isolation, which reduces the noise and vibration level transmitted to surrounding buildings and machines. Waukesha recommends bolting the engine skid directly to the inertia block, without spring isolators, to reduce the amount of vibration seen by the engine. The concrete upper face shall be painted with hydrocarbon resistant paint to avoid concrete resistance properties alteration and/or finishing coping mortar stratification.

It is strongly recommended that the driven equipment be mounted on a common skid with the engine (see "Figure 6-1: Engine and driven equipment on common skid"). By mounting both units on the same skid, a common plane for the engine and driven equipment is created. The equipment is less likely to lose alignment, because the driven equipment cannot shift relative to the prime mover (engine).

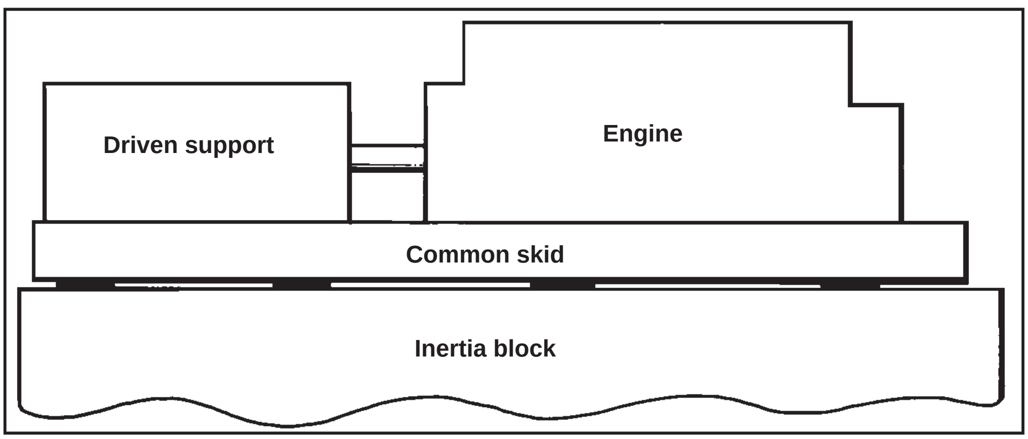


Figure 6-1: Engine and driven equipment on common skid

Waukesha strongly recommends the packager analyze skid design to determine that the structural integrity of the skid does not incur harmful natural frequencies for constant speed applications and throughout the speed range for variable speed applications.

To meet these demands, the inertia block or pad (spring isolated) must be of both adequate size and mass to support the engine/driven equipment and to absorb vibration. The engine/driven equipment common skid must rest on a surface of sufficient density to support both the common skid and the equipment mounted on it. The inertia block or mounting pad must have an accurately finished, level mounting surface. To secure the engine/driven equipment to the inertia block or mounting pad, properly sized retaining bolts must be installed in the correct spots to align with the holes in the engine base or common skid.

DETERMINING INERTIA BLOCK OR PAD SIZE RECOMMENDED MINIMUM STANDARDS

Width of the inertia block or pad (W)

The inertia block or pad width is to be at least one foot (30.5 cm) wider than the base of the engine or the common skid to be installed.

Length of the inertia block or pad (L)

The inertia block or pad length is to be at least one foot (30.5 cm) longer than the combined length of the base of the engine and driven equipment to be installed.

Height of the inertia block or pad (H)

With the length and width of the inertia block controlled by the package dimensions, the height will be controlled by the desired weight of the block. Waukesha recommends using a foundation specialist to determine what inertia block weight and isolation will be required to minimize vibration transmitted to the surrounding environment. Waukesha provides engine unbalance forces and moments in the *Drive Data* section of the *Tech Data*. This information, along with the driven machine unbalance information would be required to properly calculate vibration transmission.

In the absence of calculations for the proper inertia block weight, Waukesha recommends the weight of the inertia block equal 1.3 to 1.5 times the weight of all equipment mounted on the inertia block or pad.

This includes accessory equipment and the weight of all liquids (coolant and oil) supported by the inertia block.

Weights of Liquids

Water .... 8.03 lb/gal (1.00 kg/liter)

Water/Glycol .... 8.55 lb/gal (1.02 kg/liter)

Lube Oil .... 7.60 lb/gal (0.91 kg/liter)

Engine capacities are listed in “Table 6-1: Engine liquid capacities”; any additional volumes in customer supplied equipment or piping must be added if mounted on the inertia block.

Table 6-1: Engine liquid capacities

	Jacket & Aux Water		**Lube Oil**	
	gallons	**liters**	**gallons**	**liters**
VHP 12-Cylinder	119	450	190	719

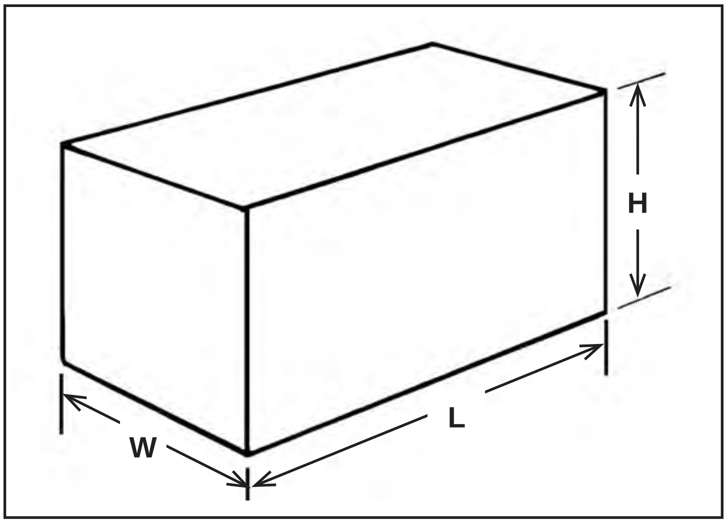


Figure 6-2: Schematic of inertia pad

The depth of the inertia block can be found using the following:

$$H = \frac{(1.3 \text{ to } 1.5)M}{(L)(W)135}$$

H = Depth of the inertia block

M = weight of engine in pounds

L = Length of inertia block (common skid length plus one foot)

W – Width of common inertia block (common skid width plus one foot)

135 = Density of concrete [lbs/ft^3]

DETERMINING REQUIRED SOIL BEARING LOAD

The next step is to determine if the weight of an inertia block or pad of this size plus the weight of the engine (and driven equipment, if mounted on a common skid) exceeds the safe soil bearing load.

Sample calculations for determining the require soil bearing load can be found in the Appendix.

“Table 6-2: Soil bearing capacity” can be used to estimate if the supporting material at the site will be sufficient to carry the required load. If the required soil bearing load exceeds suggested standards, footings may have to be incorporated to give the inertia block or pad a larger support area (see “Figure 6-3: Footing for poor bearing soil”).

Table 6-2: Soil bearing capacity

Nature of Supporting Material	Safe Bearing Capactiy	
	(Lbs. per square ft.)	kG/m^2
Hard rock – Granite, etc.	50,000 – 200,000	240,000 – 980,000
Medium rock – Shale, etc.	20,000 – 30,000	100,000 – 150,000
Hard pan	16,000 – 20,000	80,000 – 100,000
Soft rock	10,000 – 20,000	50,000 – 100,000
Compacted sand & gravel	10,000 – 12,000	50,000 – 60,000
Hard clay	8,000 – 10,000	40,000 – 50,000

Nature of Supporting Material	Safe Bearing Capactiy	
	(Lbs. per square ft.)	kG/m²
Gravel & coarse sand	8,000 – 10,000	40,000 – 50,000
Loose, medium and coarse sand, compacted fine sand	6,000 – 8,000	30,000 – 40,000
Medium clay	4,000 – 8,000	20,000 – 40,000
Loose fine sand	2,000 – 4,000	10,000 – 20,000
Soft clay	2,000	15,000

Note: This table gives approximate values for average conditions. Building code requirements may vary and should be consulted for a particular locality.

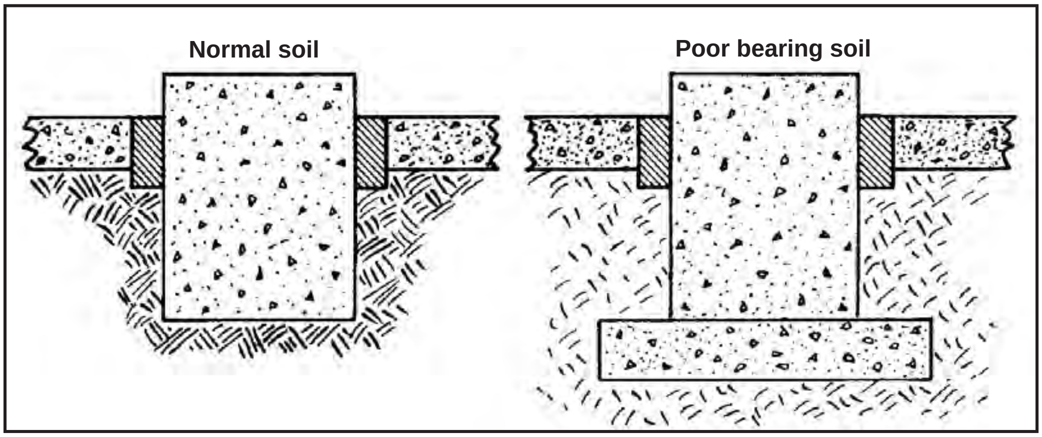


Figure 6-3: Footing for poor bearing soil

A suggested concrete mixture of one part cement, two parts sand and three parts aggregate by volume, with a maximum slump of 4 inch (100 mm) providing a 28-day compressive strength of 3000 psi (211 kg/cm2).

INERTIA BLOCK REINFORCEMENT

The concrete reinforcing network should be a 10 in. x 10 in. (254 mm x 254 mm) steel wire fabric or equivalent which is 0.155 in. (3.9 mm) diameter minimum. It should be placed 2 inches (51 mm) from the top and bottom surfaces with each level spaced 6 in. (152 mm) apart.

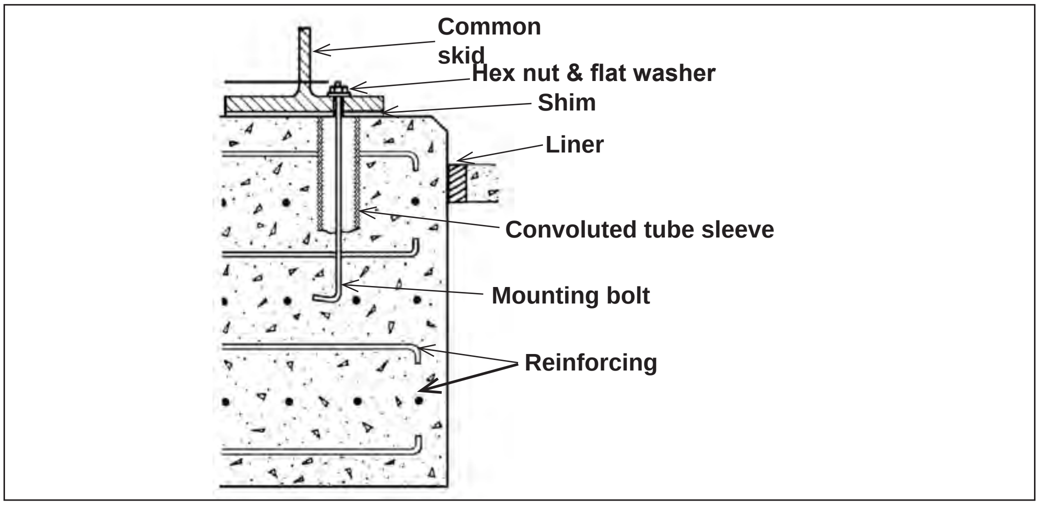


Figure 6-4: Common skid mounted directly

An alternate method of reinforcing is to place a level of 3/4 in. (19 mm) diameter reinforcing rod, or equivalent, on 6 in. (152 mm) centers in both directions. A level should be placed 2 inches (51 mm) from the top and bottom surfaces. Rod placement should take into consideration interference with inertia block or pad mounting bolts and sleeves.

VIBRATION ISOLATION

The inertia block or pad (spring isolated engine) is an important factor in isolating engine vibration from the surrounding structure. Many times however this is not enough. There are several additional techniques that can be used to isolate the vibration.

Isolating Liners

A liner can be fabricated and used to line the pit into which the concrete inertia block is poured (see “Figure 6-5: Cross section of concrete inertia block”) A number of suitable liners are available commercially. Consult the liner manufacturer for specific information. The principle for all liners is the same – line the bottom and sides of the pit, and pour the concrete inertia block inside of the isolator lining. The engine and/or common mounting skid will still vibrate, but the vibration is dampened and largely confined within the liner.

Be sure to construct the liner so that no liquid concrete can flow into gaps between the liner slabs. If concrete seeps between the inertia block and the pit, the vibration absorption value of the liner will be greatly reduced.

Other materials such as sand or gravel may be used as isolating mediums. One foot of well tamped, settled gravel under the inertia block will be satisfactory.

Do not bridge the gap between the inertia block and the surrounding floor with concrete or a similar solid material. If for reasons of neatness or appearance it is necessary to close this gap, use an expansion joint or a similar resilient material.

Isolation of inertia block from the building, convoluted tube sleeve and anchor bolt placement, and a mounting pad area greater than engine base area may be noted in this illustration.

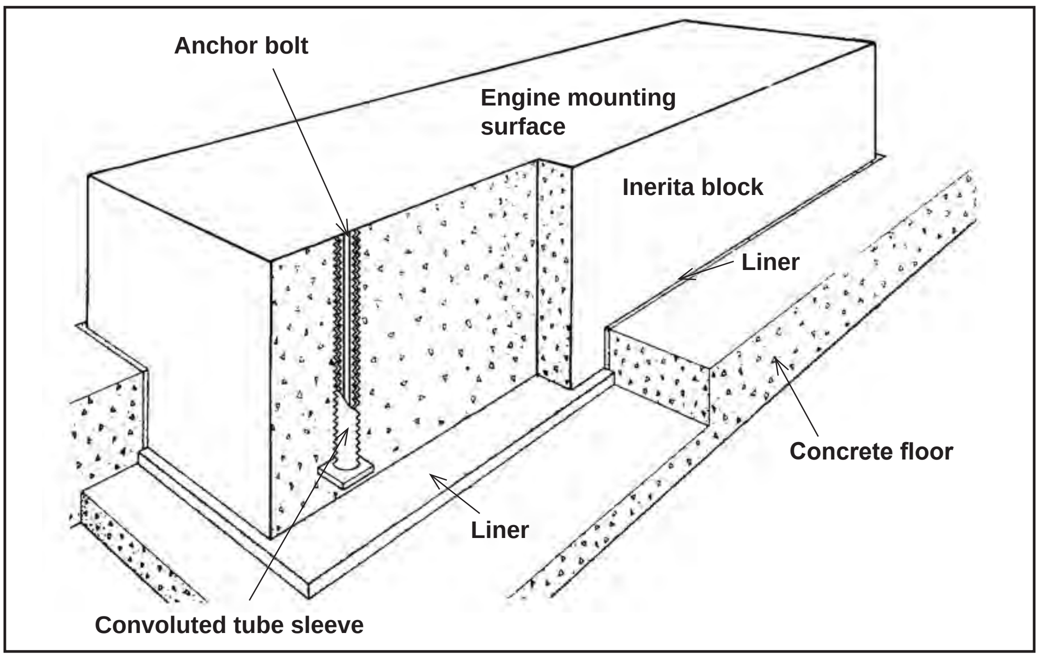


Figure 6-5: Cross section of concrete inertia block

Spring and Rubber Mounts

Spring and rubber mounts of various sizes and resiliencies are available for installation purposes. These mounts can be positioned between the common skid and the inertia block or pad or between the inertia block and bottom of the pit (see “Figure 6-6: Schematic of spring isolator mounting pad construction”). As with the isolating liners, we recommend contacting the manufacturer of the mounts for specific instructions.

For units installed in basements or on ground floors (no other floors beneath), neoprene waffle type pads (50% vibration reduction) or the sandwich type pad of rubber and cork (75% vibration reduction) can be used. Where engine-generator sets are to be installed above the ground floor, the more critical type of isolators should be used.

Larger units should use spring type vibration isolators that provide about 95% isolation. All percentages are approximate and exact information for your particular application should be discussed with your Waukesha Distributor to be certain that the right type of isolator is selected.

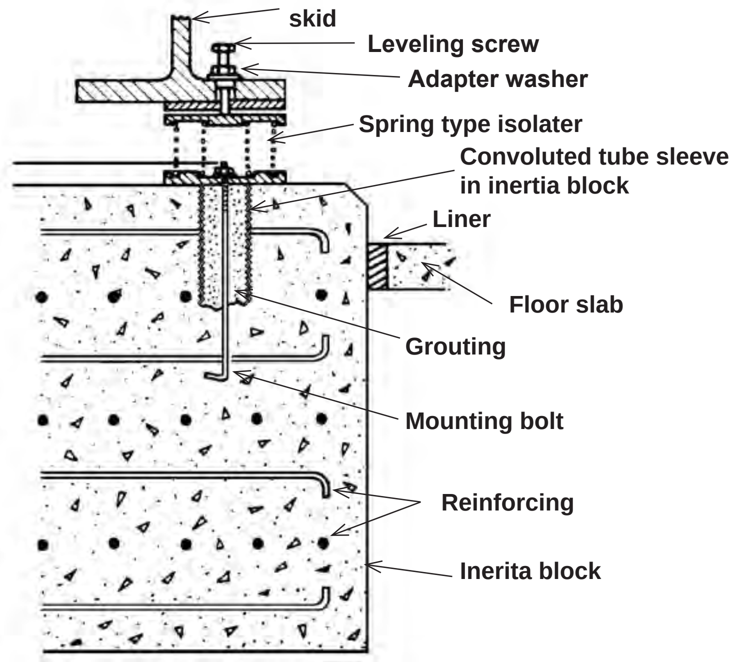


Figure 6-6: Schematic of spring isolator mounting pad construction

INERTIA BLOCK BOLT OR PAD MOUNTING BOLT INSTALLATION

The inertia block or pad mounting bolts should be a minimum of SAE grade 5 bolt material. The bolt diameter will be determined by the hole diameter in the engine mounting base or common skid frame. The bolts should be long enough to provide a minimum embedded length of 30 times the bolt diameter, plus 3 – 4 in. (76 – 102 mm) for a hook. (The bolt should have a “J” or “L” shaped hook on the non-threaded end to increase its holding power.) Approximately seven more inches (178 mm) are needed to protrude above the top surface of the inertia block or pad. These seven inches (178 mm) will provide the length needed for:

• The grout, (if used), 2 inches (51 mm)

• Sole plate, (if used), 3/4 inch (19 mm)

• Chock, 1/2 inch (13 mm)

• Shims and engine base, 1-3/4 inches (44.5 mm)

• Washer, nut and small variations in levelness, 7/8 inch (22 mm)

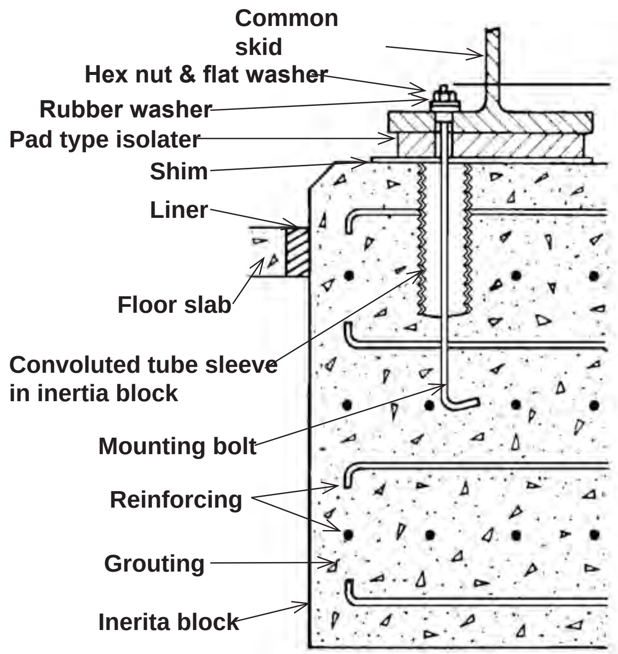


Figure 6-7: Common skid mounted on pad type vibration isolators

For a common skid mounted engine, only 7 inches (140 mm) of bolt need protrude above the inertia block or pad surface (see “Figure 6-8: Mounting bolt”).

Bolt placement in the inertia block or pad can be determined by making a template from 1 x 6 inch (25 x 1 52 mm) boards. Consult a Waukesha installation print for template information. (A certified installation print can be made for your engine if ordered when the engine is ordered.) Suspend the template over the inertia block or pad and hang bolts and sleeves through the template holes (see “Figure 6-9: Template”). Seven inches (178 mm) of bolt must extend from the top surface of the inertia block or pad.

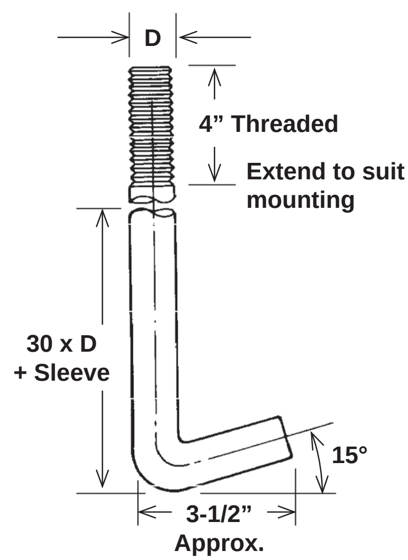


Figure 6-8: Mounting bolt

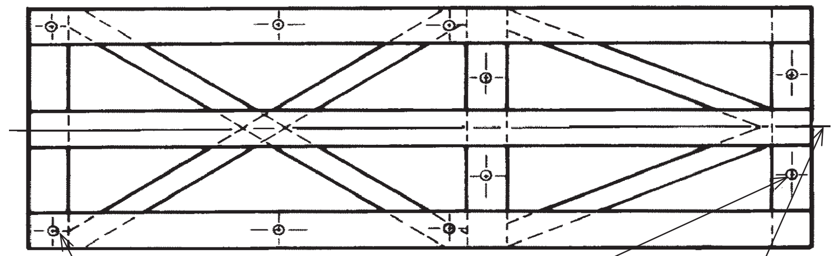


Figure 6-9: Template

A sleeve of convoluted plastic tubing 2 – 3 inches (51 – 76 mm) in diameter, should be placed around the bolts before they are embedded in the concrete (see “Figure 6-10: Mounting sleeves embedded in concrete”). This will allow the bolts to bend and conform to the dimensions of the sole plate (if used) if the template was not exact. The sleeve may be 10 – 12 in. (254 – 305 mm) long. The top end of the sleeve should be slightly above the top level of the inertia block or pad so that the concrete will not spill into the sleeve and interfere with bolt adjustments.

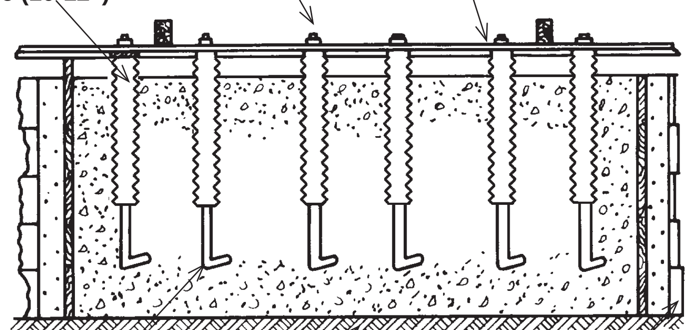


Figure 6-10: Mounting sleeves embedded in concrete

CURING THE INERTIA BLOCK OR PAD

Once the inertia block or pad is poured, it should be kept moist and protected until fully cured according to the supplier’s requirements. A longer curing period may be required in adverse weather.

Inertia blocks or pads poured in the winter must be insulated against the cold or have calcium chloride incorporated into the mix.

Before the concrete curing advances too far, rough up the concrete surface to provide a good bonding surface for the grout (if used).

SOLE PLATES

Sole plates can be used to mount the engine to the inertia block (see "Figure 6-11: Cross section of mounting using sole plates"). The plates distribute the weight of the engine evenly over the top of the inertia block or pad. They also make up for any variations of the concrete from level. When selecting material stock for the sole plates, select cold rolled steel 3/4 – 1 inch (19 – 25 mm) thick, and 4 inches (102 mm) wide minimum. The plates should run the full length of the engine.

If the engine is common skid mounted, it may be less expensive to use several shorter sole plates (if required). The plate should be as wide as the common skid flange. Sole plate lengths are available on Waukesha installation drawings.

The sole plates should be clean and free from rust and scale. Mounting holes in the plates should be drilled and tapped according to the instructions provided. Jack screws are to be used in these holes which keep the sole plates in position while pouring the grout. Before the inertia block or pad is fully cured, the surface should be roughened up to provide for a good bond between the concrete and the grout. Position the sole plate over the inertia block or pad bolts, and level the plates, keeping them a minimum of 2 inches (51 mm) above the inertia block or pad surface. Plates must be level lengthwise, and crosswise, relative to each other. After leveling, tighten the nuts on the inertia block or pad bolts finger tight. This will help keep the sole plates level while installing the grout.

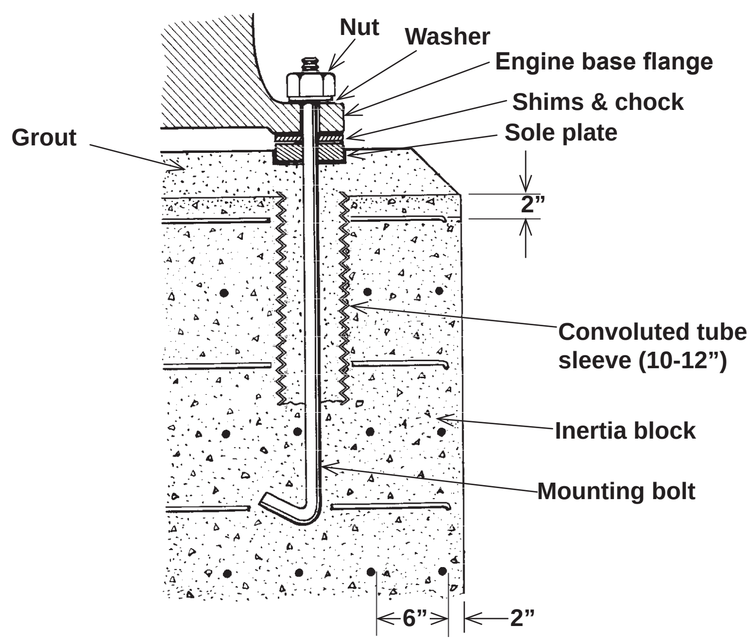


Figure 6-11: Cross section of mounting using sole plates

GROUTING

Grouting can be done only after the installation of the inertia block or pad has fully cured and the sole plates (if used) have been positioned and leveled (see “Figure 6-12: Grouting the inertia block”). On sole plate installations, grouting is important as it anchors the sole plates in place. Since the sole plates support the engine, it is important that the grout be installed properly to hold the plates level.

Engines and common skids can be mounted directly to the grout without the use of sole plates. When this is done, the engine must be mounted and leveled before the grout is poured. Shim and level the engine as described in Chapter 7: Mounting and Alignment. Pour the grout under the engine base or common skid. After all grout has cured, back out the jacking screws and fill with grout.

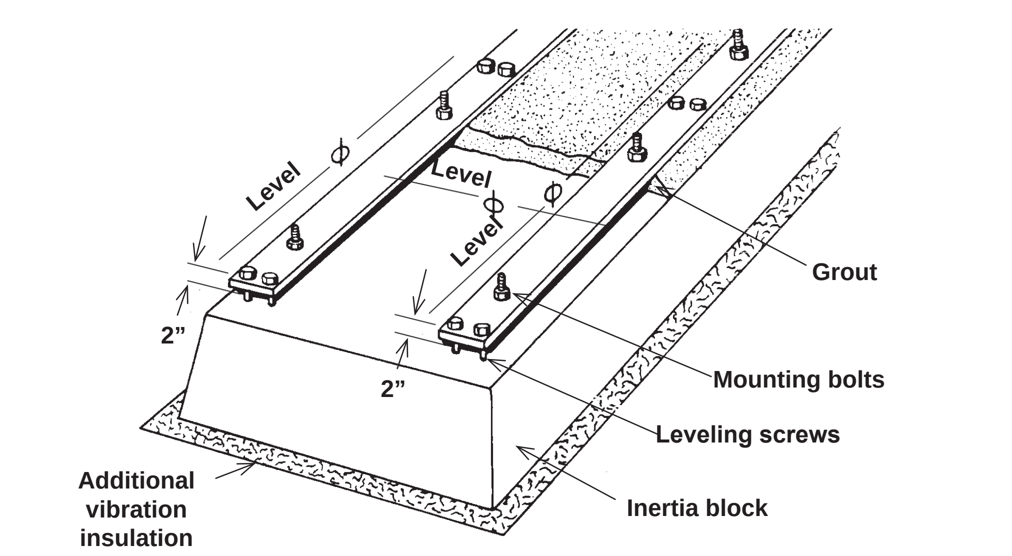


Figure 6-12: Grouting the inertia block

GROUTING PROCEDURE

Make a form around the inertia block or pad. If possible, pour the grout from one point on the inertia block or pad only, and allow the grout to flow under the common skid or engine base rails. This pouring procedure will help lessen the chances of air pockets being trapped between the engine and the inertia block or pad. Air pockets will lessen the contact area between the grouting and the engine base or common skid, reducing support for the engine. Also, a metallic based grout will expand into these spaces and force the engine out of alignment. If the pour point on the engine or common skid is slightly higher than the rest of the inertia block or pad, the grout will flow more easily under the engine or common skid.

The best way to install a concrete, metallic based grout is to form wedge shaped grout pads (see “Figure 6-13: Rear view of mounted engine”). These pads should run the length of the engine or common skid. Slope the grout outward in a wedge shape towards the inertia block or pad to provide better support. Sole plates can be embedded in this run of grout, or the engine base can be installed directly on it.

The advantage of this grouting technique is that it will keep grout out from under the engine. The grout will not be able to expand up into the hollow area under the engine base and force the engine out of alignment.

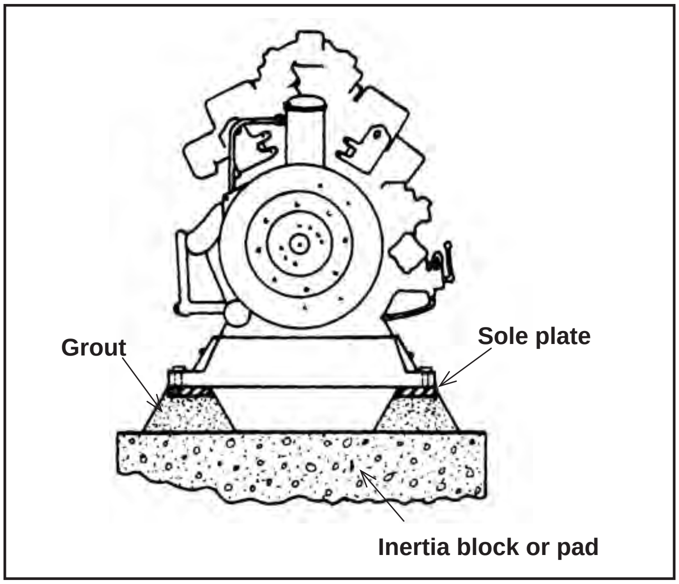


Figure 6-13: Rear view of mounted engine

Grouting should be worked into place using rods or chain lengths. Work the material gently to avoid air entrapment.

When using sole plates, pour in enough grout to embed the plates 1/2 inch (13 mm) into the grout. When sole plates are not used, never allow the grout to come up over the engine base or common skid, to allow for future adjustments.

Follow the grout manufacturer's instructions for applying the grout, and recommendations for curing times. Concrete grouts must be sealed after curing. All metallic based grouts should be sealed to prevent rust from destroying the grout.

If the grout is allowed to settle at a slight outward slope, oil and water will be able to run off the inertia block or pad.

After the grout has cured, remove the leveling screws and remove any accumulation from the common skid or engine base. Save enough grout to pour into the inertia block bolt sleeves after the engine has been aligned.

Many epoxy grouts are also available which provide superior performance for these applications.

CHAPTER 7 - MOUNTING AND ALIGNMENT

MOUNTING SURFACE

This section discusses mounting surface requirements for Waukesha VHP engines.

Waukesha VHP engines require a very smooth and level mounting surface. This is to prevent distortion of the main bearing bores in the crankcase and prevent movement from vibration and thermal growth. Using shims to correct a rough distorted surface does not provide adequate support under the engine.

"Figure 7-1: Machined surface mounting", illustrates a surface leveled by machining then shimmed and a surface leveled by shims alone.

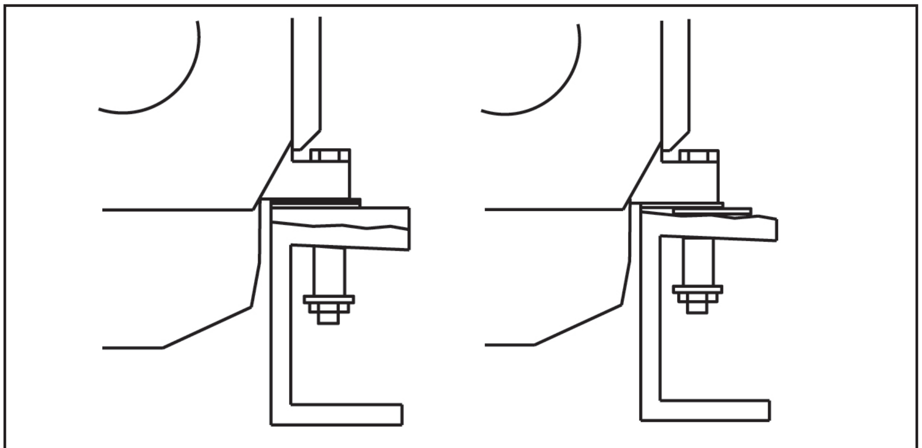


Figure 7-1: Machined surface mounting

The machined surface provides a much better support.

A level mounting surface can be provided by attaching 175 mm x 175 mm x 65 mm (7" x 7" x 2.5") chocks to the skid by welding or grouting. The engine mounting surface of the chocks must be flat, smooth, and their planes parallel within 0.08 mm (0.003") with a surface finish of 500 RMS.

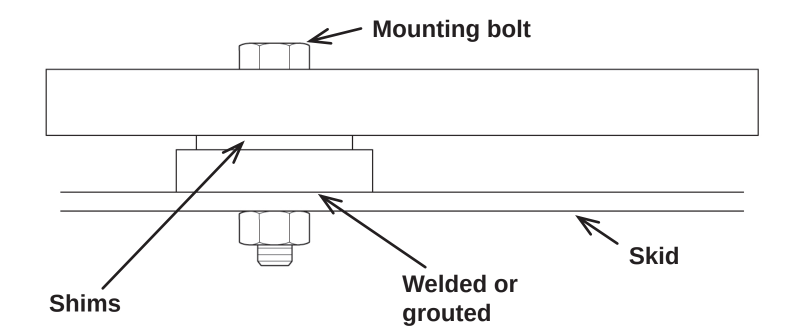


Figure 7-2: Shimming an engine

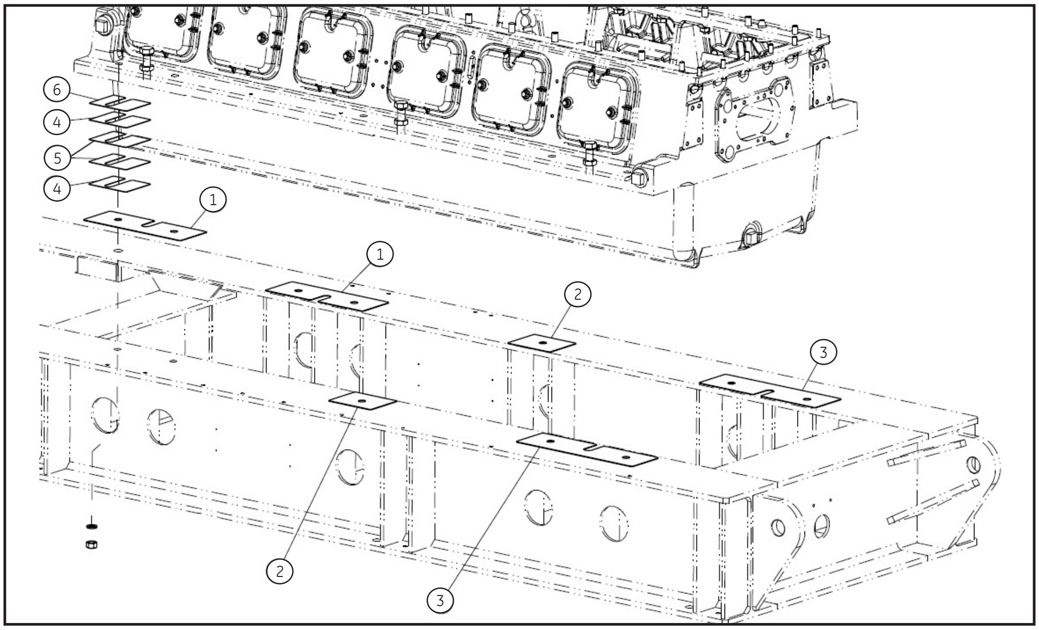
Shims of 127 mm x 127 mm (5" x 5") are then used at each mounting bolt to correct base deflection and alignment. Appendix C *"VHP stainless steel spacers and shims"* describes proper shimming procedures and lists shims available from Waukesha.

Adjustable engine shims or chocks are suitable for mounting Waukesha gas engines provided the installer follows the sizing and installation guidelines of the adjustable shim manufacturer. VHP engines require Vibracon SM24 or equivalent size. All original engine mounting holes must be used, and the correct size for the size of the engine must be used. It is not acceptable to use a smaller size shim to allow for clearance around the engine mounting pad or original jacking bolt.

Adjustable engine shims may loosen over time, and engine alignment must be checked periodically to ensure engine is in correct alignment at all times.

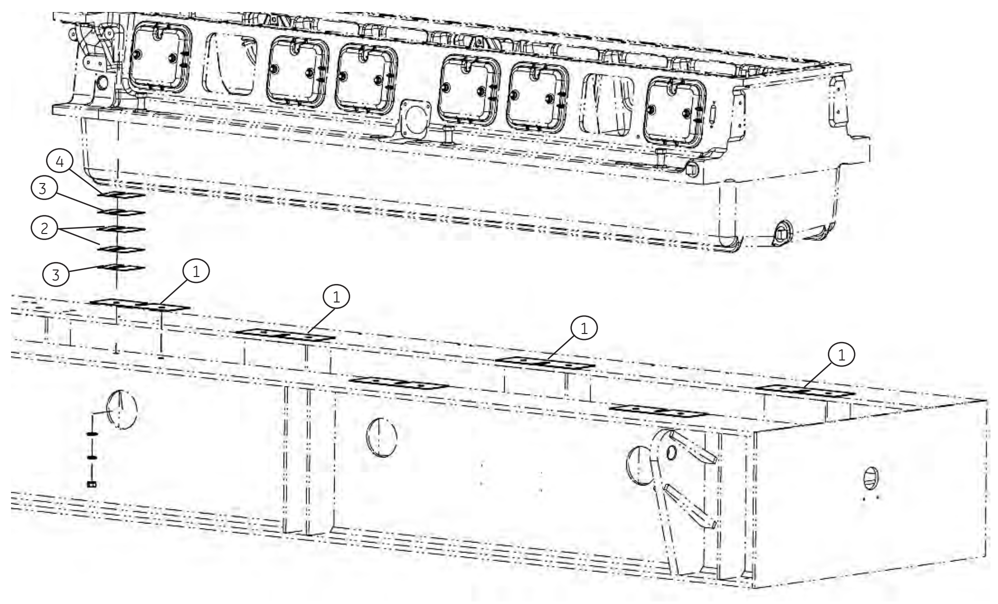
All of the mounting bolt positions are required to properly secure the engine. The jacking bolts are used to raise the engine to shim for final crankshaft web deflection and alignment. An anti-seizing dry lubricant must be applied to the jacking bolts before adjusting to prevent the threads from locking. The jacking bolts can be removed and mounting bolts installed once the engine is aligned to provide additional clamping force. If the jacking bolts are to remain in place, they must be backed off to allow proper forging of the mounting bolts.

Mounting bolts should not be a tight fit through the holes in the engine and skid. The bolts should either be slightly smaller than the engine mounting hole or the through hole in the skid should be slightly larger than the bolt. The VHP engine mounting holes have a 7/8 in. diameter. Bolts must be torqued base on what grade or class is used. Spacers should also be implemented as seen in “Figure 7-1: Machined surface mounting”, to allow for proper bolt stretch. Bolt stretch helps to keep tension on the bolt and prevents the bolt/nut from loosening due to the vibrations of the engine.



Item	Description	Qty	Part Number
1	Spacer, Engine VHP 0.060 (Rear)	2	P316793
2	Spacer, Engine VHP 0.060 (Middle)	2	P316794
3	Spacer, Engine VHP 0.060 (Front)	2	P316795
4	Shim, Engine, 0.010 (Thick)	20	P310122
5	Shim, Engine, 0.005 (Thick)	20	P310121
6	Shim, Engine, 0.030 (Thick)	10	P310123
7*	Shim, Engine, 0.002 (Thick)	10	P310316
*Not shown - required for alignment during installation, prior to startup			

Figure 7-3: Shim locations for VHP 12-cylinder



Item	Description	Qty	Part Number
1	Spacer, Engine VHP 0.060 (Rear)	6	P316793
2	Shim, Engine, 0.010 (Thick)	24	P310121
3	Shim, Engine, 0.005 (Thick)	24	P310122
4	Shim, Engine, 0.030 (Thick)	12	P310123
5*	Shim, Engine, 0.002 (Thick)	12	P310316
*Not shown - required for alignment during installation, prior to startup			

Figure 7-4: Shim locations for VHP 16- cylinder

See Appendix C for spacer and shim specifications.

MOUNTING PROCEDURES

SHIMMING

When shimming to adjust base deflection or alignment specifications, the shim packs should contain no more than four of one size shim. If more than four are required, the next larger thickness shim should be used. On VHP engines, separate shim packs must be used at each mounting bolt and may not always be the same thickness.

DIAL INDICATOR MOUNTING

On skid mounted packages, tightening, loosening, and jacking of an engine mount during the shimming process will cause deflection of the I-beam flange. Because of this, it is important that the magnetic base or other clamping device for the dial indicator is attached to the web of the I-beam base rather than to the flange (dial indicator kit tool #494288).

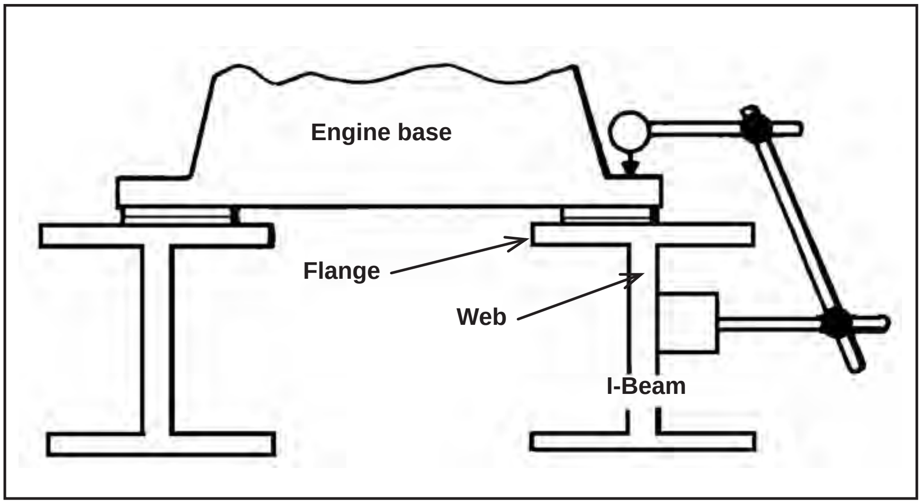


Figure 7-5: Correct Mounting

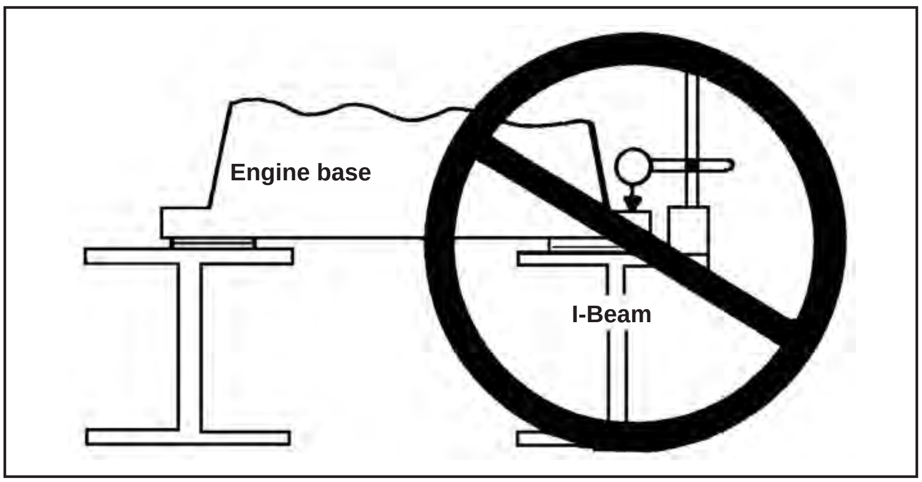


Figure 7-6: Incorrect Mounting

LEVELING AND BASE DEFLECTION

SOLID MOUNTED PACKAGES

Solid mounted packages can be found in two arrangements:

- Engine and driven equipment are on a common skid which is bolted or grouted directly to an inertia block or support structure.
- Engine and driven equipment are individually bolted or grouted to sole plates on an inertia block.

Leveling – Common Skid-to-Inertia Block

1. Using a glass bubble level, check to see that the inertia block or support structure is even and level at all mounting points. Use spacing plates or shims where necessary.
2. Install the package on the inertia block. Use a glass bubble level to determine if the unit is level front to rear and side to side. Shim as required.
3. When unit is level, use a feeler gauge at each mounting point to determine if any air gaps exist. Shim as required.
4. Add shims under the center mounts of the common skid to eliminate any sag.
5. Tighten the common skid to the inertia block mounting bolts.
6. For grouting, see Chapter 1 “Preparation For Mounting”.

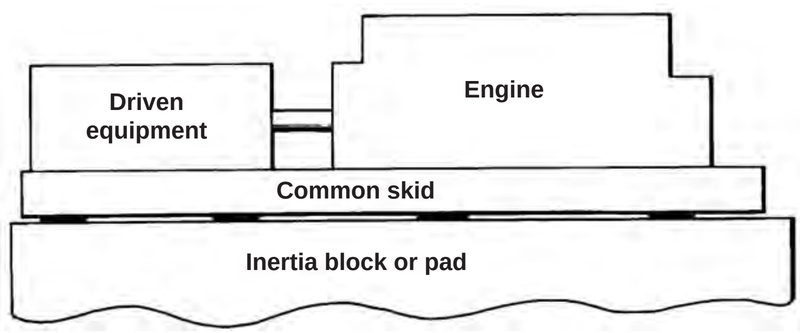


Figure 7-7: Leveling – Common Skid-to-Inertia Block

Leveling – Individual Mounting

Follow common skid procedures for each unit.

Engine Base Deflection

Checking engine base deflection is important to assure that the main bearing bores are in perfect alignment. Misaligned main bearing bores can cause premature failure of bearings and/or bending and breakage of the crankshaft. On solid mounted packages, the “Corner Lift Method” described below is quick and accurate for leveling an engine base and is, therefore, the preferred method. The “Release Method” is described for your information but is not considered as accurate as the “Corner Lift Method” for leveling an engine base on solid mounted packages.

Corner Lift Method

The following procedure provides a simple, quick method for 6 point mounting on solid mounted installations.

1. The engine should be resting on four corner shim packs at least 0.125 in. (3.175 mm) thick. Using the front or rear of the engine as a starting point, tighten the four corner bolts (two each side, on one end). The four bolts at the opposite end should be loosened or removed.

If a single bearing generator is attached, loosen the bolts connecting the generator adapter pilot ring to the flywheel housing.

The center shim packs and mounting bolts must not be used at this point. If they are installed, they should now be removed.

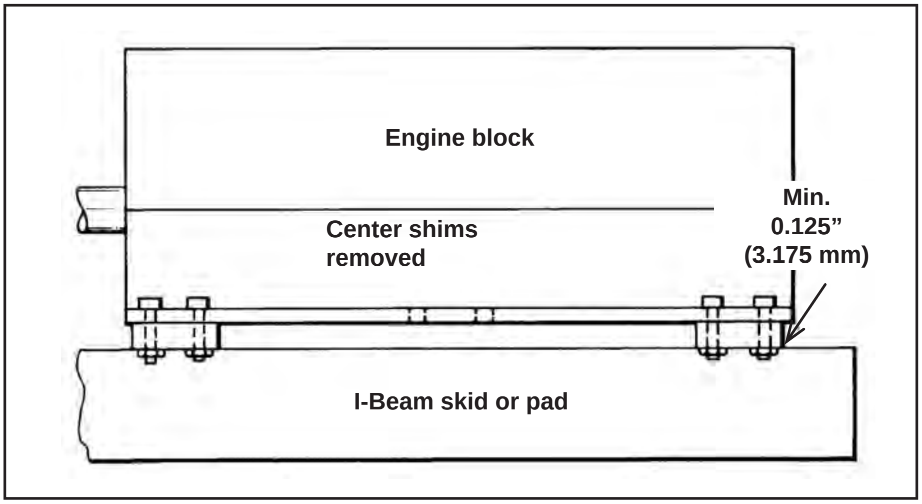


Figure 7-8: Corner Lift Method

2. Set up two dial indicators on the free end as shown below and zero the dials.

3. Using the jack screw, raise the left free corner of the engine until the indicator on the right free corner reads 0.001 in. (0.025 mm). Record the left free corner indicator reading (see Figure 2-9). Lower the left free corner of the engine back onto its shim pack.

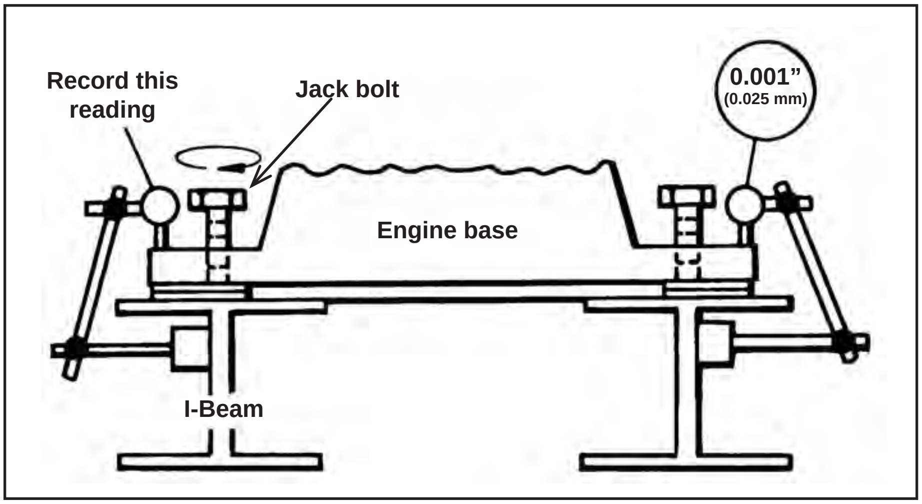


Figure 7-9: Record the Left Free Corner Indicator Reading

4. Raise the right free corner until the left indicator reads 0.001 in. (0.025 mm). Record the right free corner indicator reading (Figure 2-10).

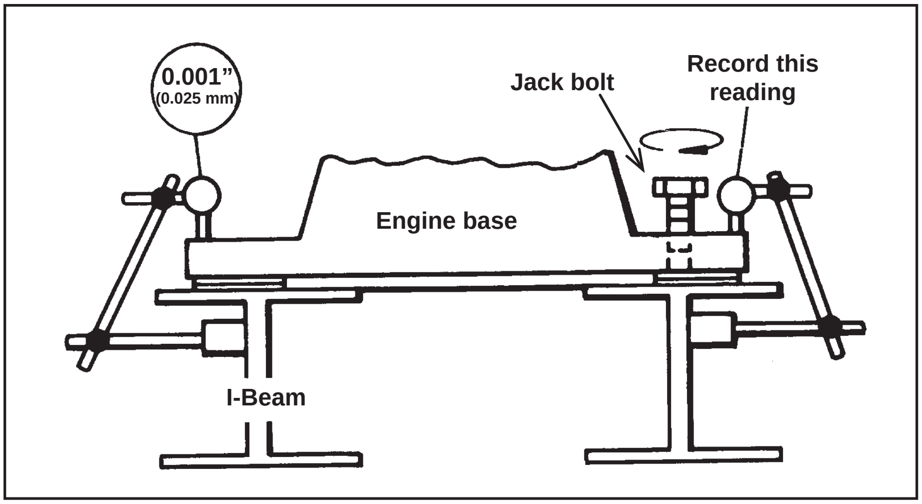


Figure 7-10: Record the Right Free Corner Indicator Reading

5. Calculate the difference between the two recorded corner readings. If the difference is less than 0.010 in. (0.254 mm), the base deflection is satisfactory and the free corners may be bolted down. If the difference is 0.010 in. (0.254 mm) or more, add shims equal to 1/2 of this difference under the corner that had the highest reading. Recheck per steps 2 and 3. Readings should now be within 0.010 in. (0.254 mm), and the corners can be bolted down. The four corners are now in the same plane. Checking the opposite end is not necessary.

6. The mounting points in the center of the engine now need to be shimmed. These are the final two points in the six point mounting. These center support points will have some amount of natural crankcase sag. While the engine is supported on the ends, the middle of the case is unsupported, and it may sag (see Figure 2-11). This sag has to be compensated for with the shimming procedure.

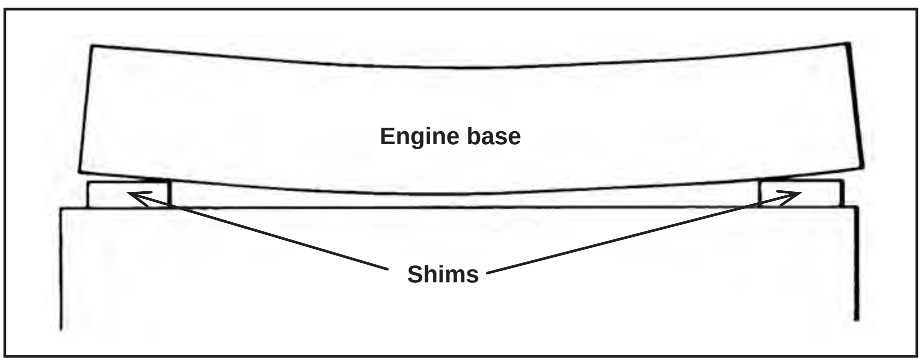


Figure 7-11: Natural Crankcase Sag

- Verify all corner mounts are properly torqued (center bolts removed).
- Set up a dial indicator at the center mount. Zero the dial.
- Add enough shims under the center mounts to fill the air gap. Be careful not to bump the dial indicator during this procedure.
- Replace the center bolts and torque the center mounts and then record the dial indicator reading.

- Loosen a front or rear mount and install shims under the center mount as required until the dial indicator reads:

  +0.000 in (0.000 mm) for a VHP 12-cylinder Extender Series*
  +0.004 in. (0.102 mm) for a VHP 12-cylinder with base style oil pan*
  +0.000 in. (0.000 mm) for a VHP P9394GSI*
  *** With the center mounts properly torqued.**

- If the dial indicator has not been moved or bumped, it should read positive by the amount indicated above, compared to when it was first zeroed. The engine base is now level with all the natural sag removed (see"Figure 7-12: Level Engine Base With Natural Sag Removed").

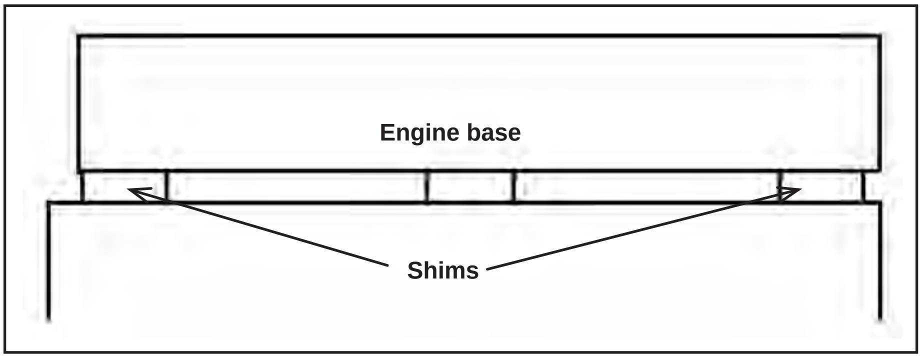


Figure 7-12: Level Engine Base With Natural Sag Removed

Release Method

1. The release method is used to verify that base deflection is correct by measuring spring up of each mounting point.
2. Starting at any engine mounting point, mount a dial indicator and zero the dial.
3. Loosen the mounting bolts at this point and record the dial reading.
4. Re-torque and verify that the dial indicator returns to zero.
5. Repeat for all mounting points.
6. Compare measurements from all 6 points. The 4 corners should have sprung equally within 0.005 in. (0.127 mm).

NOTE: *Spring-up at the center mounts should be zero because of the shims added to compensate for crankcase sag.*

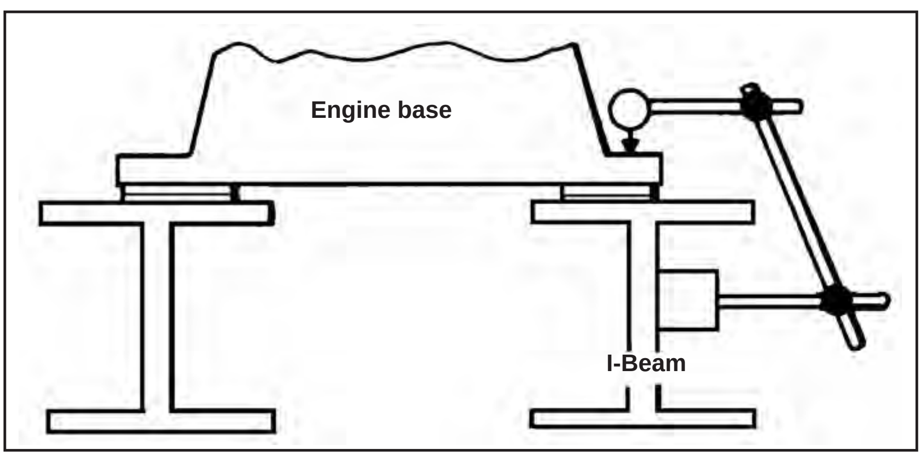


Figure 7-13: Release Method

Crankshaft Web Deflection

This check measures the deflection of a crankshaft during a revolution. It is the most direct method of determining if the shaft is being bent by a deflected crankcase or driven equipment misalignment. Web deflection measurements are required in marine engine applications. This procedure should also be used as a final check for base deflection and alignment especially on packages where the “Corner Lift Method” is too difficult to use.

All current production VHP crankshafts have center punch marks to indicate the proper web deflection gauge mounting locations. These marks are 5 in. (127.0 mm) from the connecting rod journals and can be added to an unmarked crankshaft by using the counterweight parting line as a reference point. On all fully counterweighted VHP crankshafts, the marks are punched 0.185 in. (4.7 mm) inside the counterweight parting line.

1. Mount a web deflection gauge (tool #494424 digital or #494292 analog) in the punch marks. Carefully twirl the gauge to make sure it is properly seated. All pistons and connecting rods should be in place during this procedure.

NOTE: *Interference with the connecting rods will not allow measurement during the full 360× shaft rotation.*

2. Position the crankshaft so the deflection gauge hangs freely next to the connecting rod, but as close to the rod as possible. Zero the gauge dial.

3. Slowly rotate the crankshaft until the gauge is in position 2, on the horizontal. Record any positive or negative reading attained.

NOTE: *Always check web deflection by rotating the crankshaft in the direction in which the engine is rotating*

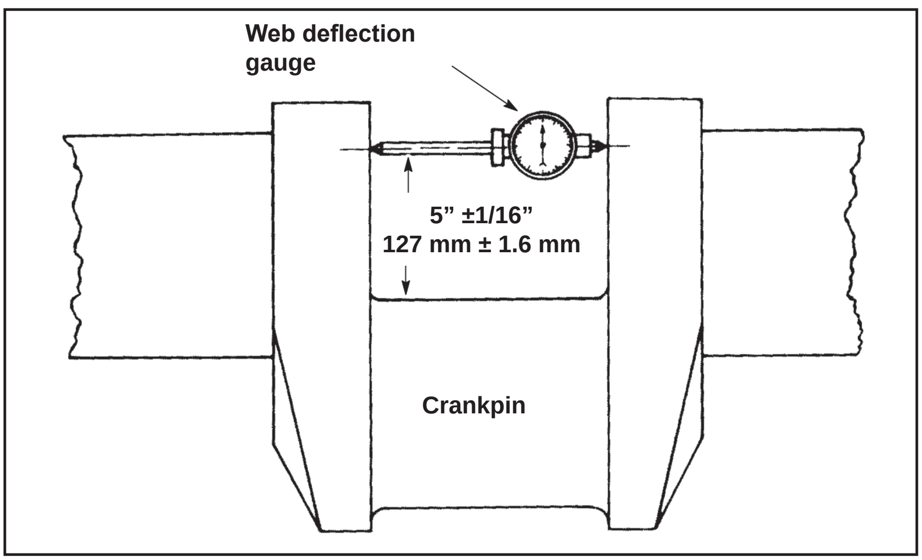


Figure 7-14: Crankshaft Web Deflection

4. Rotate the crankshaft to positions 3 and then 4, recording any readings. Now rotate the shaft further until the gauge is as high as possible, and yet still hangs free, without contacting the connecting rod. Record this reading.

5. Remove the deflection gauge, and repeat this procedure on the other crankshaft webs.

- A total of 0.001 in. (0.025 mm) deflection, from positive to negative, is allowable on all but the rear crankshaft throw. The rear throw will typically have 0.0015 in. (0.381 mm) deflection due to the effects of the flywheel weight.

- If deflection of the center throws exceeds 0.001 in. (0.025 mm), this can be corrected by shimming the center mounts. Adding shims will close the crankshaft web at the bottom while removing shims will open the crankshaft web at the bottom.
- High deflection on the rear throws could be caused by drive/driven-shaft misalignment or by an excessively heavy single bearing machine.
- High deflection on the front throws could be caused by overtightened accessory belts.

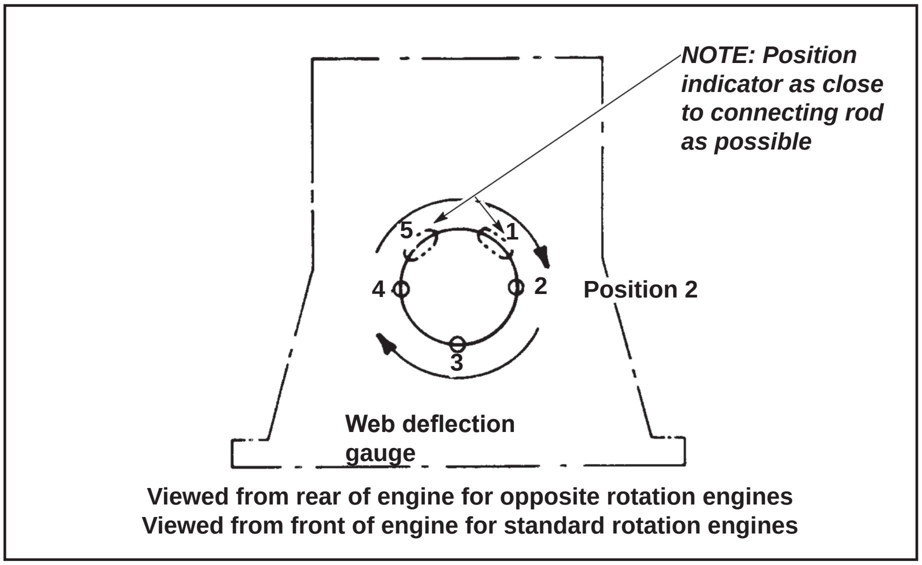


Figure 7-15: Locations For Checking Crankshaft Deflection

SPRING ISOLATED PACKAGES

On spring isolated packages the engine and driven equipment are solidly mounted to a common skid which rests on spring isolators. Beneath the spring isolators is a concrete mounting pad, inertia block, or steel support structure.

Spring isolation is used to isolate the surrounding environment from engine and driven equipment vibration. To do this effectively, the mounting points must be correctly spaced around the center of gravity and the isolators adjusted properly.

Generator sets from Waukesha Power Systems have the isolator mounting holes correctly spaced for uniform support of the package when filled with coolant and lube oil. When supported uniformly, the spring lengths on all the isolators will be equal. The following is a general procedure for adjusting spring type vibration isolators. For more specific instructions, see the spring isolator manufacturer's instructions.

Spring Isolator Installation

1. Check that all points where spring isolators will be fitted are even and level. Build up any low spots using steel chocks until all isolator base plates are within 0.125 in. (3.175 mm) elevation of each other.
2. Install spring isolators and bolt down, if required.
3. Loosen horizontal chocks (snubbers), if used.
4. Place engine/driven equipment package on the isolators. All isolators should have the isolator top plate contacting the isolator base.
5. Turn the adjustment on each isolator down 2 full turns at a time until all isolators have at least 0.125 in. (3.175 mm) between the top plate and the base.

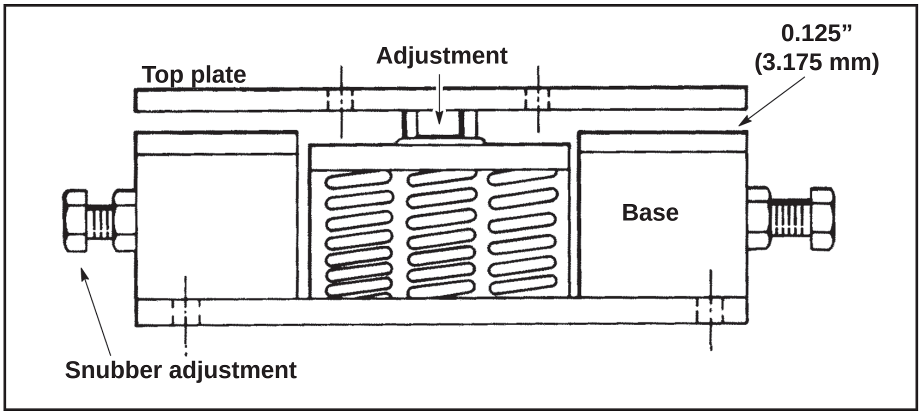


Figure 7-16: Spring Isolator Mount

6. If the package is not level after adjusting the isolators, this will be corrected with further adjustments. To level a unit side-to-side, make equal adjustments to all the isolators on one side. Leveling a unit front to rear, where the isolators are spaced evenly, can be accomplished as follows:

- Turn the adjustment screw one turn on the pair of isolators next to the high end isolators.
- Turn the adjustment screw 2 turns on the third pair, 3 turns on the fourth pair, etc. Repeat this as many times as necessary to level the skid.

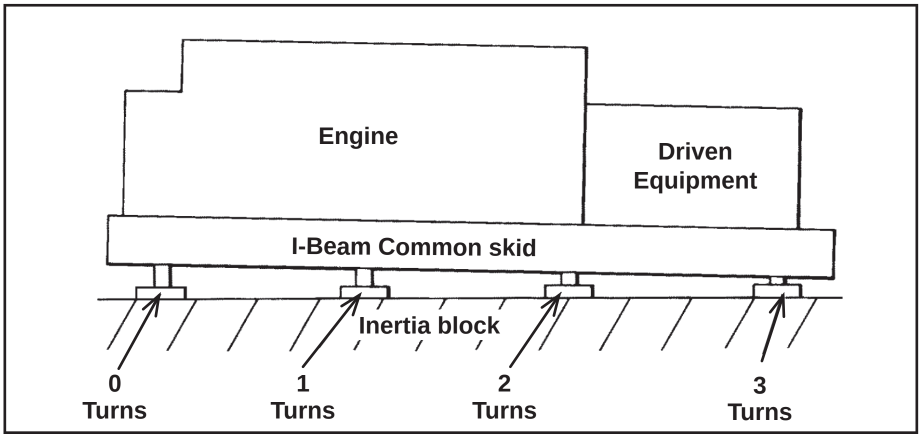


Figure 7-17: Leveling Spring Isolators

7. With the engine running, adjust the horizontal chocks (snubbers), if equipped, for a minimum of horizontal movement (minimal or no gap). Lock the adjustment bolt in place with the lock nut.

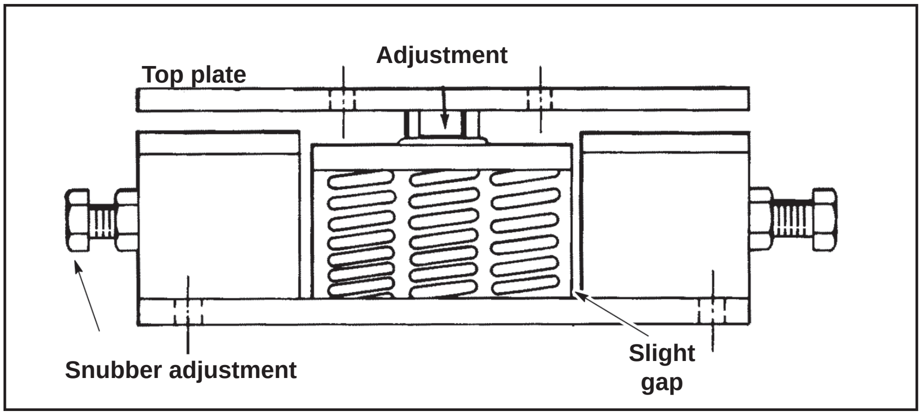


Figure 7-18: Spring Isolator Mount

As stated earlier, when spring isolators are adjusted correctly, the spring lengths on all the isolators will be equal. The formula below calculates what this spring length should be:

$$L_L = F_L - \frac{W}{K \times n}$$

Where:

L_L = Length of springs when engine package is resting on them (inches) - loaded length

F_L = Length of springs while unloaded (inches) - free length

W = Weight of engine package wet (lbs)

K = Spring constant of isolators (lbs/inch)

n = Number of isolators under package

When one isolator is compressed too far, it can be relieved by adjusting the surrounding isolators down or by adjusting up on the subject isolator. Always maintain a minimum 0.125 in. (3.175 mm) gap between the isolator base and top plate on all isolators.

Engine Base Deflection

Checking engine base deflection is important to assure that the main bearing bores are in perfect alignment. Misaligned main bearing bores can cause premature failure of bearings and/or bending breakage of the crankshaft.

Release Method

This method is used to determine base deflection by loosening each mounting point and measuring spring-up. This procedure may be used when the skid is positioned on the adjusted spring isolators.

1. Remove center shim packs.
2. Starting at any corner, mount a dial indicator and zero the dial.
3. Loosen the mounting bolts at this point and record the dial reading.
4. Re-torque the bolts and verify that the indicator dial returns to zero.
5. Repeat this step at the remaining 3 corners.
6. Compare the measurements from each of the 4 corners and then shim until the corners spring equally within 0.010 in. (0.254 mm).
7. The mounting points in the center of the engine now need to be shimmed. These are the final two points in the six point mounting. These center support points have some amount of natural crankcase sag (see Figure 2-19). While the engine is supported on the ends, the middle of the case is unsupported, and it will sag. This sag will be compensated for in the shimming procedure.

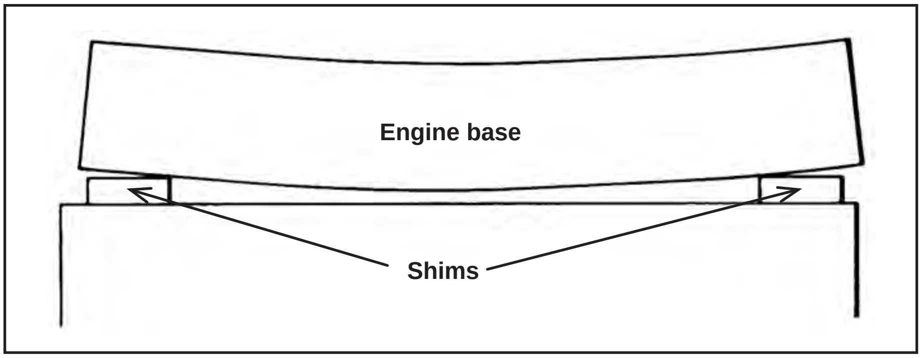


Figure 7-19: Natural Crankcase Sag

- Verify all corner mounts are properly torqued.
- Set up a dial indicator at the center mount. Zero the dial.
- Add enough shims under the center mounts to fill the air gap. **Be careful not to bump the dial indicator during this procedure.**
- Re-torque the center mounts and then read the dial indicator.
- Loosen a front or rear mount and install shims under the center mount as required until the dial indicator reads:

  +0.000 in (0.000 mm) for a VHP 12-cylinder Extender Series*
  +0.004 in. (0.102 mm) for a VHP 12-cylinder with base style oil pan*
  +0.000 in. (0.000 mm) for a VHP P9394GSI*
  *** With the center mounts properly torqued.**

- If the dial indicator has not been moved or bumped, it should read positive by the correct amount from when it was first zeroed. The engine base is now level with all natural sag removed (see Figure 2-20).

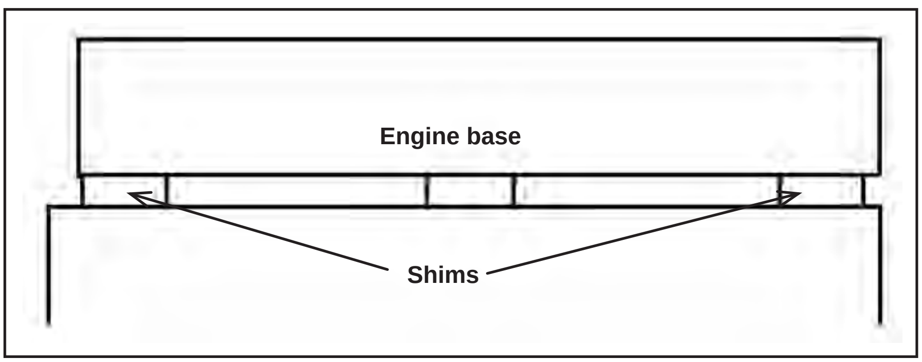


Figure 7-20: Level Engine Base With All Natural Sag Removed

Crankshaft Web Deflection

This check measures the deflection of a crankshaft during one revolution. It is the most direct method of determining if the shaft is being bent by a deflected crankcase or misalignment. Web deflection measurements are required in marine applications. This procedure should be used as a final check for base deflection and alignment on packages where the “Release Method” is too difficult to use.

All current production VHP crankshafts have punch marks to indicate proper web deflection gauge mounting locations. These marks are at 5 in. (127.0 mm) from the connecting rod journals and can be added to an unmarked crankshaft by using the counterweight parting lines as a reference point. On all fully counterweighted VHP crankshafts, the marks are punched 0.185 in. (4.69 mm) inside the counterweight parting line.

1. Mount a web deflection gauge (tool #494424 digital or #494292 analog) in the punch marks. Carefully twirl the gauge to make sure it is properly seated. All pistons and connecting rods should be in place during this procedure.

2. Position the crankshaft so the deflection gauge hangs freely next to the connecting rod, but as close to the rod as possible. Zero the gauge dial.

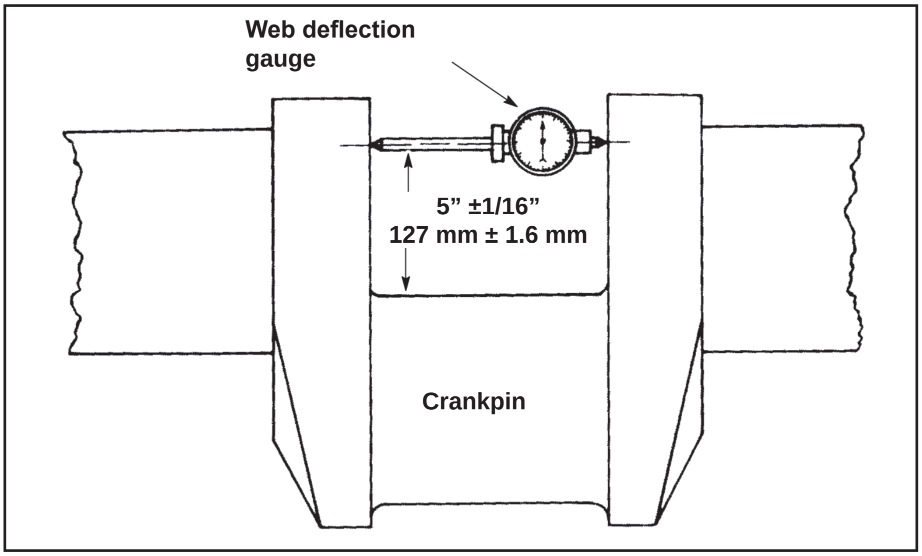


Figure 7-21: Crankshaft Web Deflection

3. Slowly rotate the crankshaft until the gauge is in position 2, on the horizontal. Record any positive or negative reading attained.

4. Rotate the crankshaft to positions 3 and then 4, recording any readings. Now rotate the shaft further until the gauge is as high as possible, and yet still hangs free, without contacting the connecting rod. Record this reading.

5. Remove the deflection gauge, and repeat this procedure on the other crankshaft webs.

- A total of 0.001 in. (0.025 mm) deflection from positive to negative is allowable on all but the rear crankshaft throw. The rear throw will typically have 0.0015 in. (0.381 mm) due to the affects of flywheel weight.

- If deflection of the center throws exceeds 0.001 in. (0.025 mm), this can be corrected by shimming the center mounts. Adding shims will close the crankshaft web at the bottom. Removing shims will open the crankshaft web at the bottom.

- High deflection on the rear throws could be caused by drive / driven shaft misalignment or an excessively heavy single bearing machine.

- High deflection on the front throws could be caused by overtightened accessory belts.

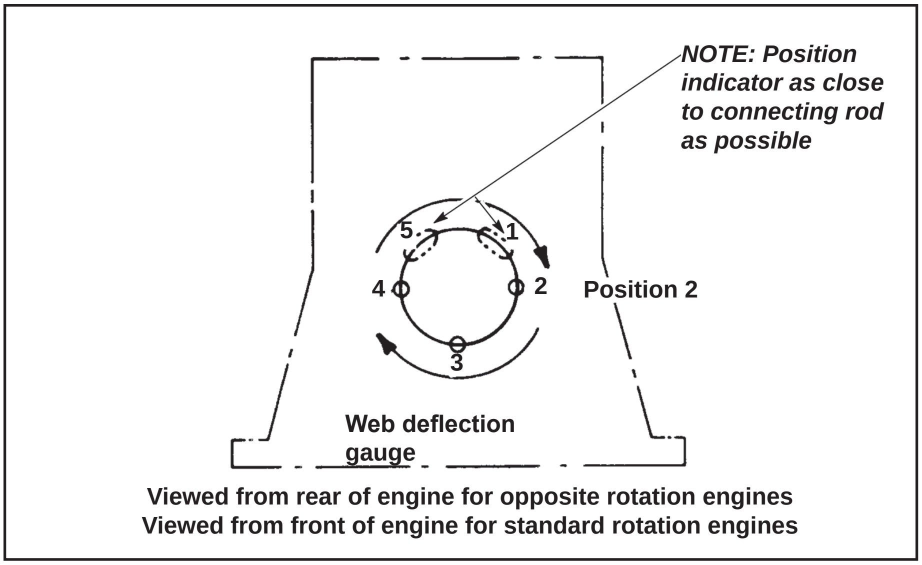


Figure 7-22: Location For Checking Crankshaft Deflection

Driven Equipment Base Deflection

Use the driven equipment manufacturer’s procedures and limits if available. Base deflection can also be measured and adjusted using a “Release Method” similar to that described for the engine.

1. Starting at any corner, mount a dial indicator and zero the dial.
2. Loosen the mounting bolts at this point and record the dial reading.
3. Re-torque and verify that the dial indicator returns to zero.
4. Repeat this procedure at the remaining 3 corners.
5. Compare measurements from the 4 corners and shim as required. When all corners spring to within 0.005 in. (0.127 mm) of each other, the procedure is completed.

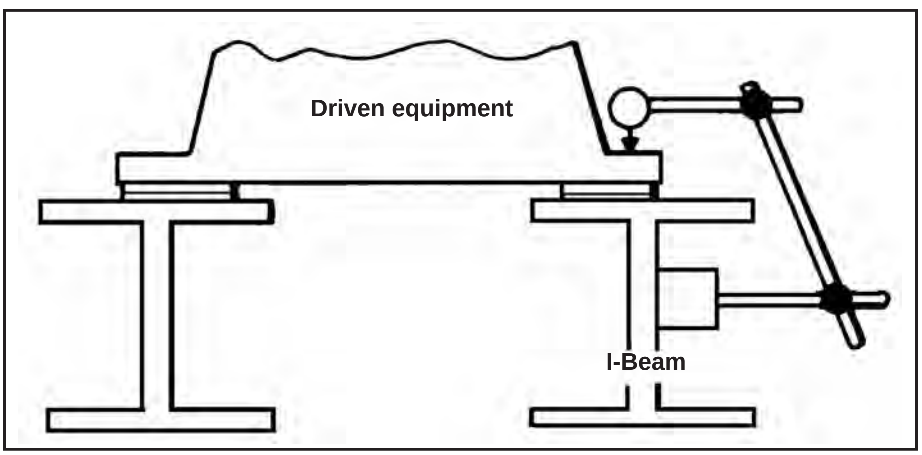


Figure 7-23: Driven Equipment Base Deflection

ALIGNMENT

SINGLE BEARING GENERATOR AND SIMILAR SINGLE BEARING EQUIPMENT ALIGNMENT

Aligning single bearing equipment involves two steps: first, the driven shaft must be centered in the flywheel pilot and second, the engine crankshaft and driven shaft must form a straight line when viewed both horizontally and vertically.

Centering Pilot (Parallel Alignment)

To measure how well a shaft is centered in the flywheel pilot, a dial indicator must be clamped to the flywheel housing or driven machine body. The dial indicator will then read the total runout of the driven equipment input shaft.

1. Clean the shaft of any dirt, grease, rust or paint. Use emery cloth if necessary to insure a smooth surface to measure from.
2. Mount a dial indicator to the flywheel housing or generator barrel and take the reading from the shaft. Check for clearance before rotating the shaft.
3. Bar the engine over counterclockwise (facing the flywheel) and take your readings every 90×. A maximum of 0.005 in. (0.127 mm) Total Indicator Runout (TIR) is acceptable.
4. If runout exceeds 0.005 in. (0.127 mm) TIR.

- Roll the highest point to the top.
- Loosen the coupling bolts at this point to allow the shaft and coupling to drop in the flywheel counterbore. Once all the bolts are loose, re-torque the bolts.

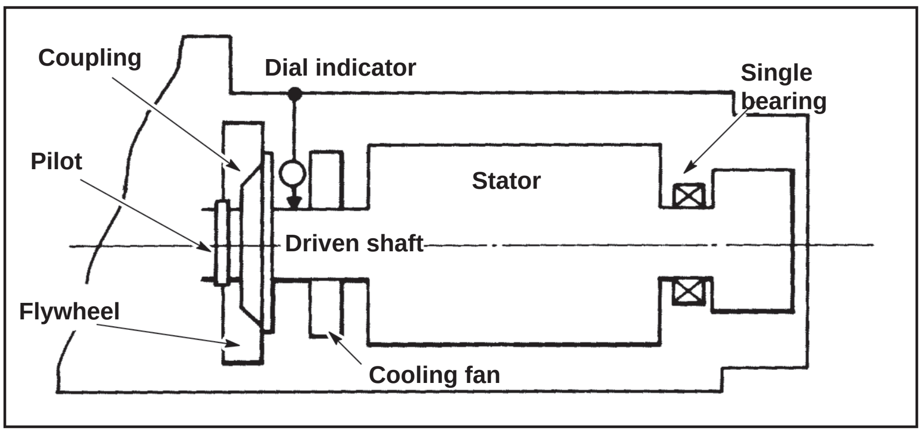


Figure 7-24: Single Bearing Generator

5. Repeat steps 2 and 3, and if TIR is still unacceptable the coupling bolts must be removed and the driven equipment shaft rotated 90× with respect to the engine flywheel. Further adjustments can be made by rotating in additional 90× increments, until the specifications are achieved.

Angular Alignment

To measure angular alignment, a dial indicator is mounted on the shaft of one machine and reads against the shaft face on the other machine. In the case of a single bearing generator, the dial indicator can be clamped to the fan and measures from the flexplate-to-flywheel mounting bolt.

Before taking readings, roll the shaft in reverse rotation 45×, then back 45×, and zero the dial indicator. This sets the axial position of the crankshaft and the driven machine shaft.

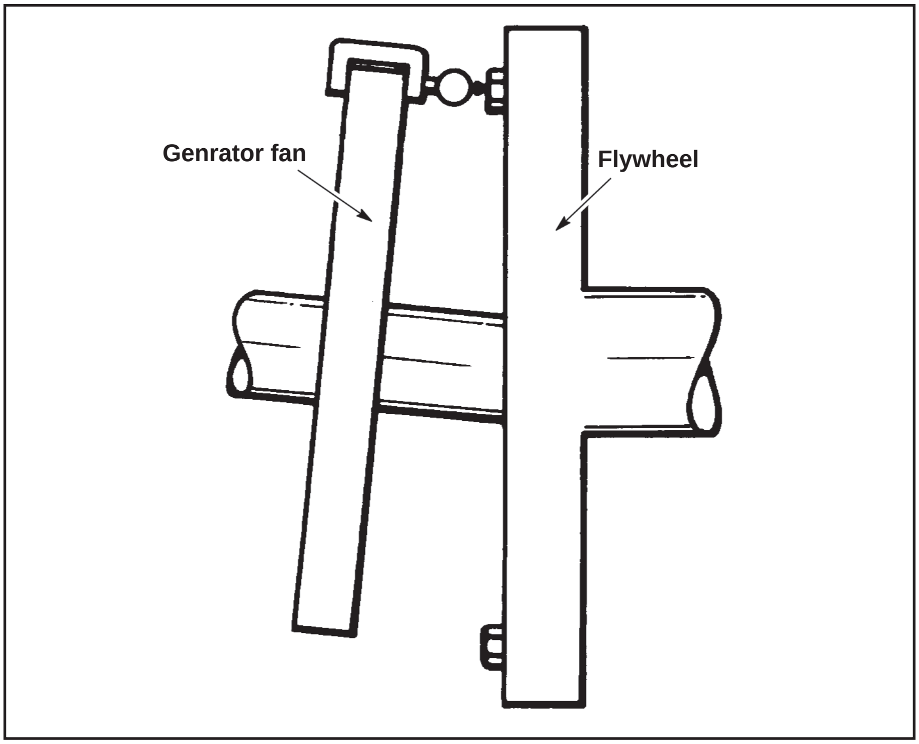


Figure 7-25: Angular Alignment-Single Bearing Generator

To measure the angular alignment, four dial indicator readings are required; one each at the 12:00, 9:00, 6:00, and 3:00 o'clock positions. Readings at the 12:00 and 6:00 o'clock positions determine the vertical alignment and readings in the 3:00 and 9:00 o'clock positions determine the horizontal alignment (see "Figure 7-26: Dial Indicator Reading Positions When Measuring Angular Alignment").

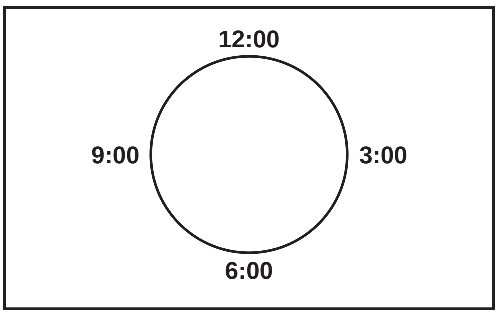


Figure 7-26: Dial Indicator Reading Positions When Measuring Angular Alignment

A total indicator reading (TIR) is the difference between two readings on opposite sides of the shaft. In the example illustrated (see "Figure 7-27: Total Indicator Reading (TIR)"), the horizontal TIR is (-0.009) and (+0.004) which is a difference of 0.013 in. (0.330 mm) or 13 thousandths of an inch TIR. Vertical TIR is (0) and (+0.005) which is a difference of 0.005 in. (0.127 mm) or 5 thousandths of an inch TIR.

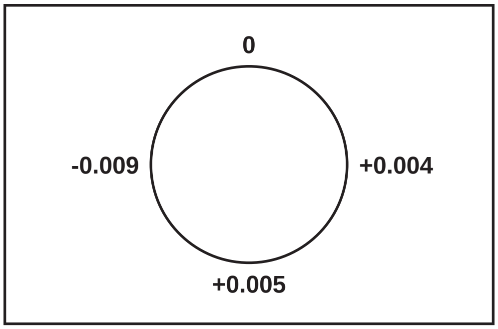


Figure 7-27: Total Indicator Reading (TIR)

The shaft shown (single bearing machine) is angularly misaligned from that of the engine. This could be either vertical or horizontal misalignment. In the case pictured, the distance “S” divided by the distance to the bearing (or rear mount) “L” is equal to 1/2 TIR divided by the radius from the dial indicator to the center of the shaft “R”.

More simply:

$$\frac{S}{L} = \frac{1/2\,(TIR)}{R}$$

Thus, we find that the amount of shimming or horizontal sliding required is:

S = L × (1/2 TIR)/R

This relationship is used with the outboard mount or any inboard mount (closer to the flywheel) as long as the distance to the required mount is used for “L”.

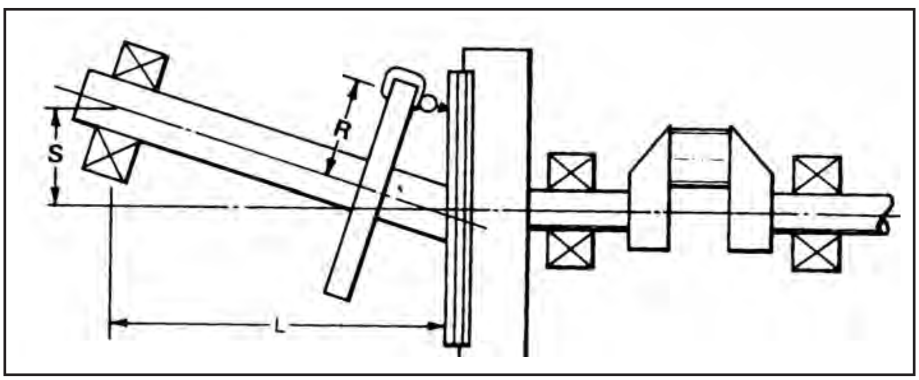


Figure 7-28: Exaggerated Example

Vertical adjustments are made by adding or removing shims from the mounts on each end of the machine. The L.H. and R.H. inboard mounts are adjusted the same, and the L.H. and R.H. outboard mounts are adjusted the same.

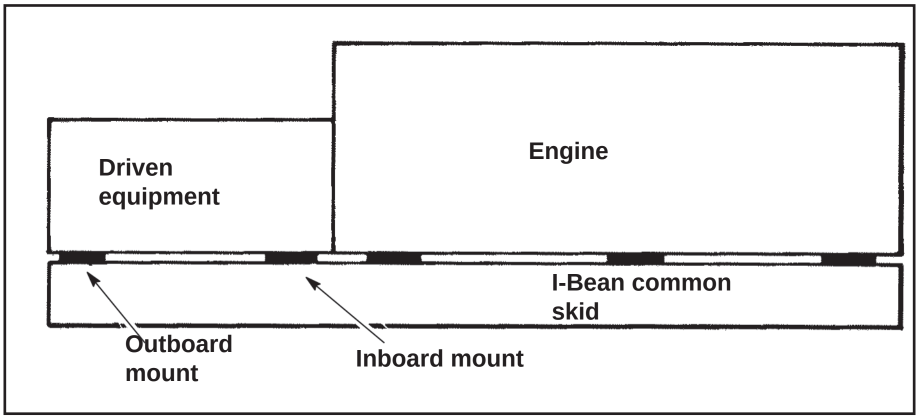


Figure 7-29: Add Or Remove Shims From The Mounts On Each End Of The Machine To Make Vertical Adjustments

Horizontal adjustment is made by loosening all the mounting bolts and physically forcing the driven equipment to the desired side. This can be done with a jacking screw or a pry bar in the bolt hole. Dial indicators should be set up to monitor how far the machine is moved, or as an alternate method, the shaft can be rotated to the 3:00 or 9:00 o'clock position and adjustments made until 1/2 TIR is indicated by the angular dial indicator.

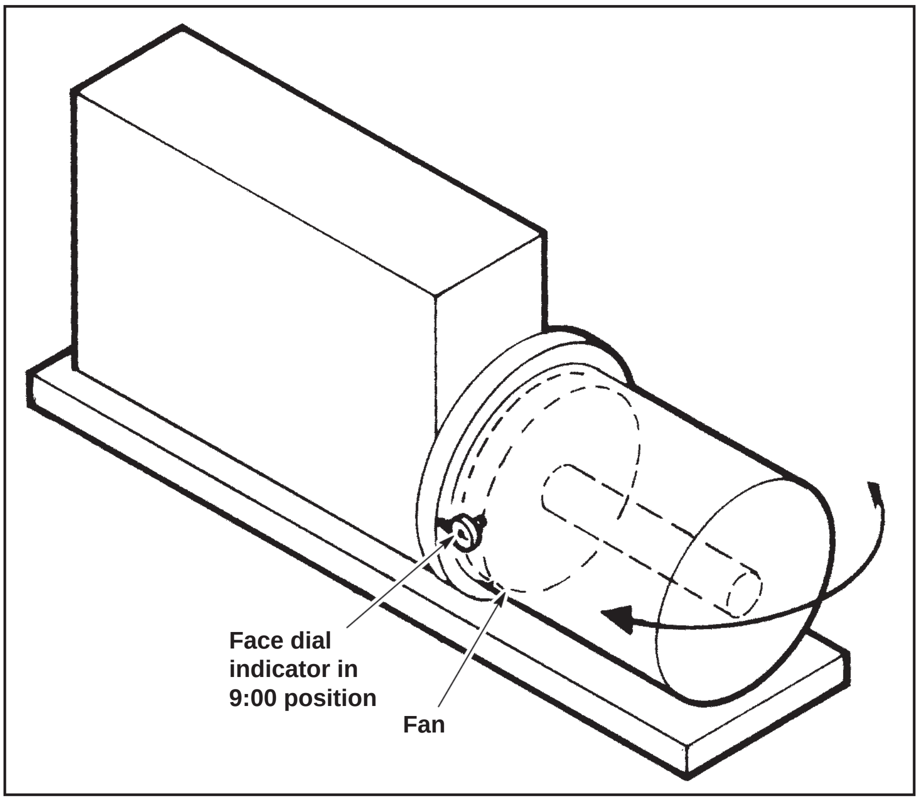


Figure 7-30: Dial Indicator Positioning

Angular alignment is acceptable when the TIR in all directions is less than 0.005 in. (0.127 mm) measured at the flexplate-to-flywheel bolt which is 14 in. (355.6 mm) from the shaft center.

Thermal Growth

Once the drive/driven shaft alignment is acceptable, the vertical thermal growth of the engine and driven machine must be compensated.

The following table lists the changes in crankshaft height that will occur due to the temperature change from 70° F (21° C) to normal operating temperatures. This is measured from the mounting surface of the base type oil pan on VHP engines.

Table 7-1: Thermal Growth

ENGINE MODEL	INCREASE IN CRANKSHAFT HEIGHT	
	INCHES	mm
VHP 12-Cylinder	0.014	0.36

Thermal growth information for the driven machine should be available from the manufacturer. If not, it can be calculated with the following formula:

$G_m = (T_m - 70) \times h \times E$ for °F or $(T_m - 20) \times h \times E$ for °C

Where:

G_m = amount of growth expected (inches or mm)

T_m = operating temperature of driven machines (°F or °C)

h = height from machine mounting surface to center of shaft (inches or mm)

E = thermal expansion coefficient for material machine is made from:

6.5×10^{-6} (0.0000065) in/in °F or 1.2×10^{-6} mm/mm °C for steel

5.8×10^{-6} (0.0000058) in/in °F or 1.1×10^{-6} mm/mm °C for cast iron

To compensate when there is a growth difference, align the machine with less growth higher than the machine with more growth.

For example, if a generator grows 0.005 in. (0.127 mm) and an engine grows 0.014 in. (0.356 mm), the generator should be shimmed 0.014 in. (0.356 mm) – 0.005 in. (0.127 mm) = 0.009 in. (0.229 mm) higher than the engine. This is done after the machines are initially aligned. The shims go under all mounts of the generator. When checking angular alignment, the vertical TIR will now be off but will fall within the limits once the engine and generator reach operating temperature.

Crankshaft End Play

After completing the cold alignment, the crankshaft end play should be checked.

1. Clamp a dial indicator to the flywheel housing and read against the crankshaft or flywheel face.
2. Pry the shaft forward and zero the dial indicator. (It may be necessary to remove an oil pan door and wedge a pry bar between a crankshaft web and main bearing cap to move the shaft forward).
3. Pry the shaft rearward. The shaft should not “bounce” forward and the dial indicator should read within the service manual specifications. For VHP 12-cylinder engines the crankshaft endplay should be between 0.005 and 0.016 inches (0.127 and 0.406 mm).

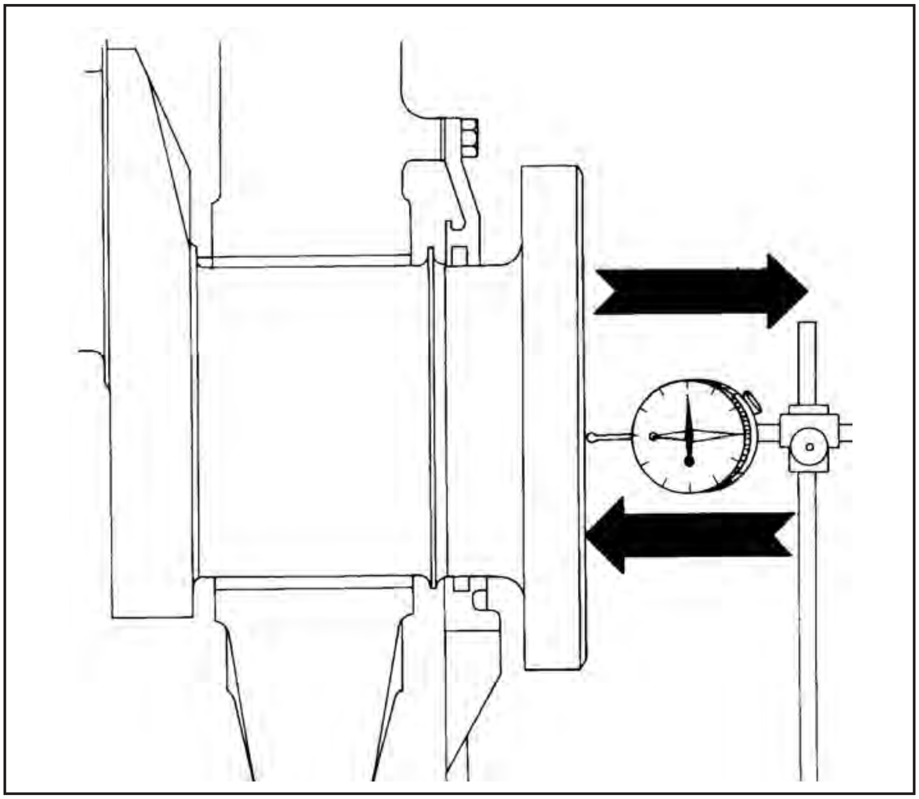


Figure 7-31: Checking Crankshaft End Play

Air Gap

On single bearing generators, the air gap between the stator and armature and at the exciter should be checked to verify that adequate clearance exists. Correcting the air gap is accomplished by adjusting the position of the inboard feet of the generator. Single bearing induction generators have a very small clearance so it is important that these be checked very carefully.

Some generator fans use set screws to hold the axial position of the fan. Verify that these set screws are tight and that the fan hub bolts are properly torqued.

Hot Check

When the alignment, end play, and air gap are adjusted, the engine and generator set should be run up to operating temperature under load for at least one hour. Then shut down the unit and check alignment, end play, and air gap. If it is within specifications, then the alignment is complete.

Periodic Inspection

Engine base deflection and alignment must be checked periodically, at least once a year. Installations which are subject to settling of the concrete must be checked monthly initially, to determine if settling is causing any misalignment.

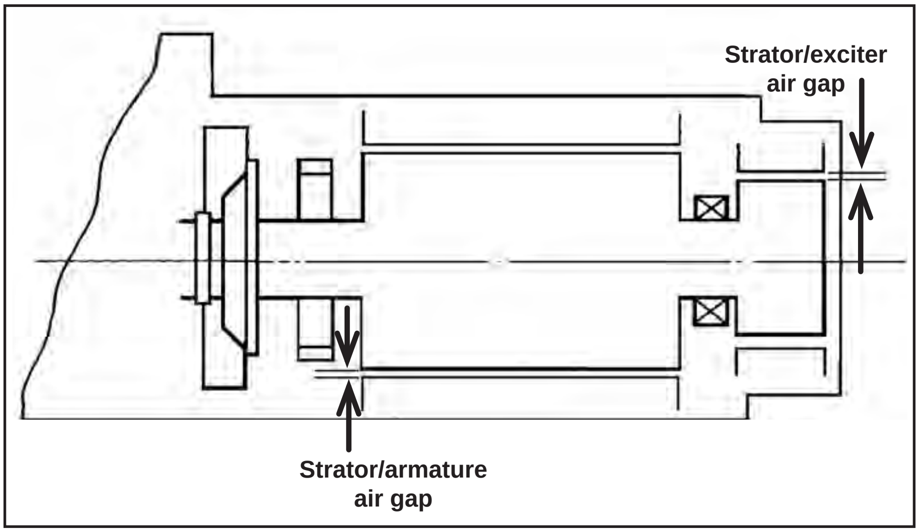


Figure 7-32: Single Bearing Generator

Multi-Bearing Machines

A multi-bearing machine is one which fully supports its own shaft, and does not rely on the engine shaft to support the driven end.

Three areas must be adjusted to accurately align a multi-bearing machine to an engine, which is also a multi-bearing machine. These are: End Play, Angular Alignment and Parallel Alignment.

When aligning two multi-bearing machines, one machine must be designated as the stationary machine, and one as the movable machine. Deciding which machine will be stationary will depend on size, weight, and connections. All adjustments will be made on the movable machine.

Adjusting angular and parallel alignment on multi-bearing machines requires correcting the angular alignment first and then the parallel. Once alignment is acceptable, the machines must be shimmed to compensate for thermal growth.

The Waukesha alignment computer (Part Number 475063 or most current) finds djustments for angular and parallel alignment as well as thermal growth, after the user inputs the dimension, growth and measuring information. Only one or two adjustments are normally required to place the units within the alignment specifications, when this tool is used.

If the alignment computer is not available, the following procedures will provide an accurate alignment.

End Play

To adjust end play:

1. Roughly position the two machines and install the shaft coupling. Adjust the distance between the two machines so that there is no apparent tension or compression on the coupling. Properly space gear type couplings per the coupling manufacturer's specifications.

2. Set up a dial indicator on the machine with the least end play (normally the engine). Clamp the dial indicator to the engine flywheel housing and read against the flywheel face.

3. Pry the crankshaft fully forward, and zero the dial indicator. (Moving the crankshaft on a VHP engine may require removing an oil pan door and prying between a main bearing cap and crankshaft cheek or web).

4. Pry the shaft rearward and read the dial indicator. Crankshaft end play should be within service manual specifications and the shaft should not spring-back when the bar is removed.

5. If there is insufficient end play or if spring-back occurs, adjust the distance between the machines until it is resolved.

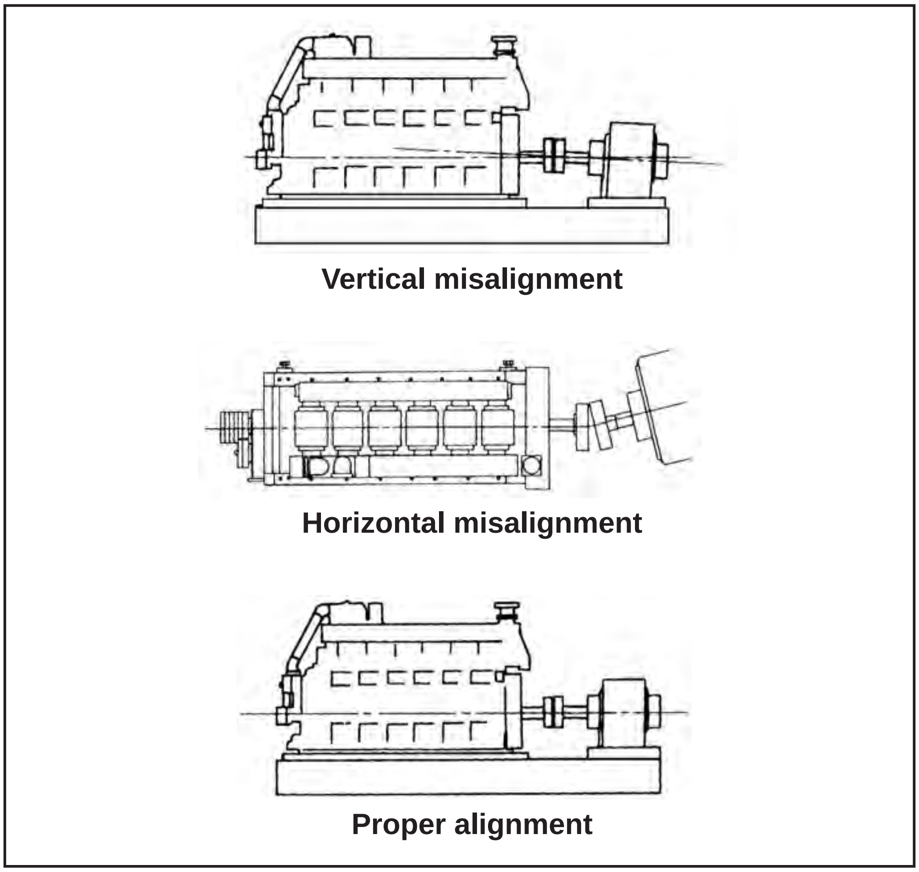


Figure 7-33: Angular Alignment

Angular Alignment

To measure the angular alignment, a dial indicator is mounted to the coupling half of one machine to read against the coupling half face of the other. The coupling should be installed or the shafts bound together so they both turn together while taking the alignment measurements.

The radius “R” from the center of the shaft to the dial indicator should be at least 7 in. (177.8 mm).

Before taking readings, roll the shaft 45° in reverse rotation and then back 45° in standard rotation and zero the dial indicator. This sets the axial position for both the engine and driven machine shafts.

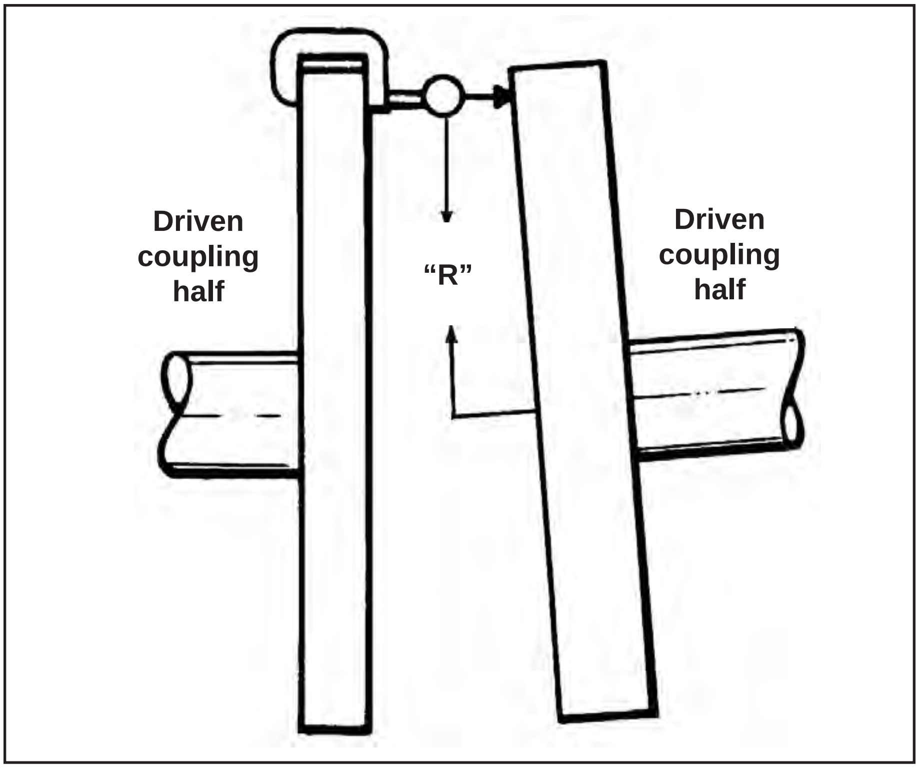


Figure 7-34: Measuring Angular Alignment

To measure angular alignment, four dial indicator readings are required; one each at the 12:00, 9:00, 6:00 and 3:00 o'clock positions which are taken while turning the engine in the standard direction of rotation.

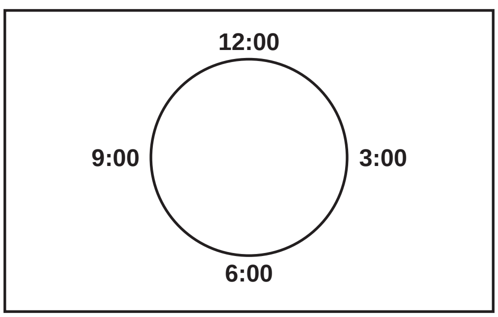


Figure 7-35: Dial Indicator Reading Positions When Measuring Angular Alignment

Readings taken at the 12:00 and 6:00 o'clock positions determine vertical angular alignment and readings in the 3:00 and 9:00 o'clock positions determine horizontal angular alignment. A total indicator reading (TIR) is the absolute difference between two readings on opposite sides of the shaft. In the illustration, the horizontal TIR is (-0.009) and (+0.004) which is a difference of 0.013. Vertical TIR is (0) and (+0.005) which is a difference of 0.005 in. (0.127 mm).

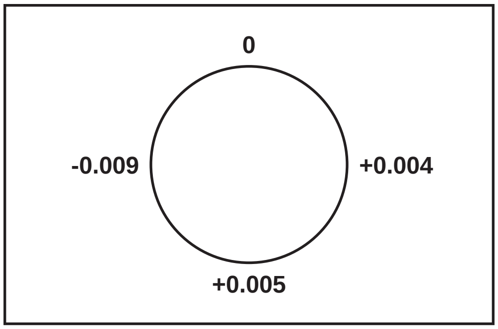


Figure 7-36: Total Indicator Reading (TIR)

The illustration shows the shaft of a multi-bearing machine with both angular and parallel misalignment.

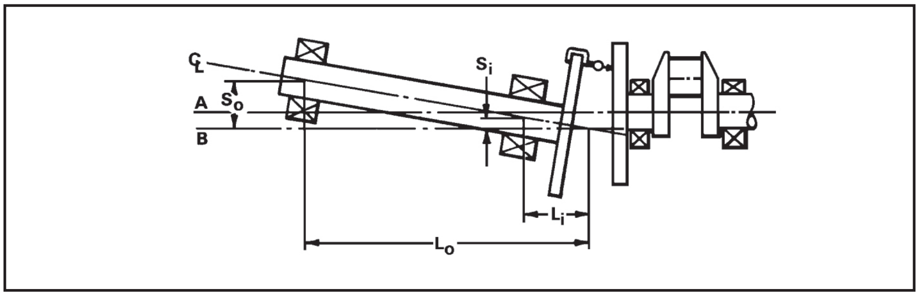


Figure 7-37: Multi-bearing driven equipment

This could represent either vertical or horizontal misalignment since the principles are the same for both.

Correcting this misalignment first involves correcting angular alignment, thus getting the shaft centerline to line up on line B.

The amount of correction required to bring the centerline into alignment with line B, can be determined from the dial indicator TIR, radius to the indicator "R", and distance "L" from the coupling to the mounts.

Outboard mount Inboard mount

$$\frac{1/2(TIR)}{R} = \frac{S_o}{L_o} = \frac{S_i}{L_i}$$

Therefore:

$$S_o = \frac{L_o x 1/2(TIR)}{R}$$

and

$$S_i = \frac{L_i x 1/2(TIR)}{R}$$

"So" is the amount of adjustment at distance "Lo" which is the distance from the center of the coupling to the center of the outboard mount.

"Si" is then the adjustment at a mount distance of "Li" from the coupling.

The adjustment should be made to close the open side of the coupling (see “Figure 7-38: Adjusting coupling”).

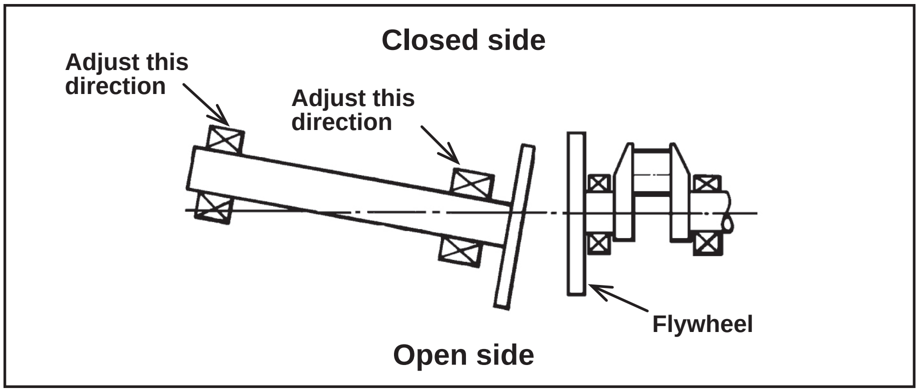


Figure 7-38: Adjusting coupling

Adjustment for angular alignment should then take place as follows:

1. Set up two dial indicators, one to monitor horizontal movement of the inboard mounts, one to monitor horizontal movement of the outboard mounts. Zero the indicators (see “Figure 7-39: Adjusting for angular alignment”).

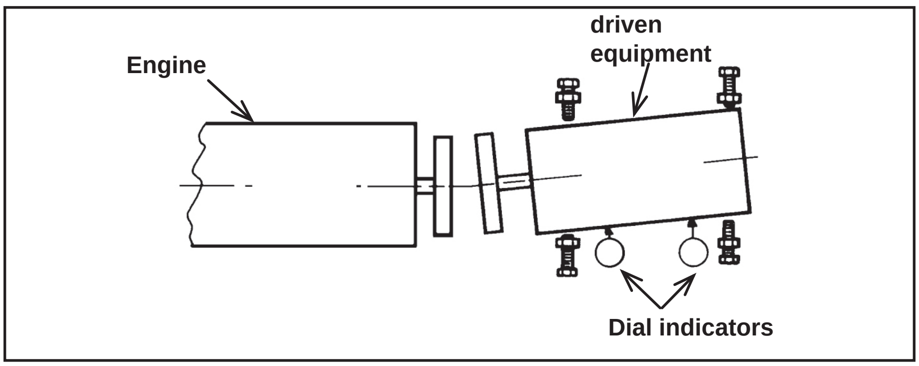


Figure 7-39: Adjusting for angular alignment

2. Going to one corner at a time, loosen the mounting bolt and shim as calculated, then tighten the mounting bolt. Center mounts will have to be shimmed in conjunction with corner mounts. Note any horizontal movement that may occur on the dial indicators.

3. After shimming, loosen both mounts on one end and all center mounts. It may also be necessary to loosen one mount on the fixed end but do not loosen both. Slide the free end the amount calculated, then re-torque the bolts (see “Figure 7-40: Slide free end”).

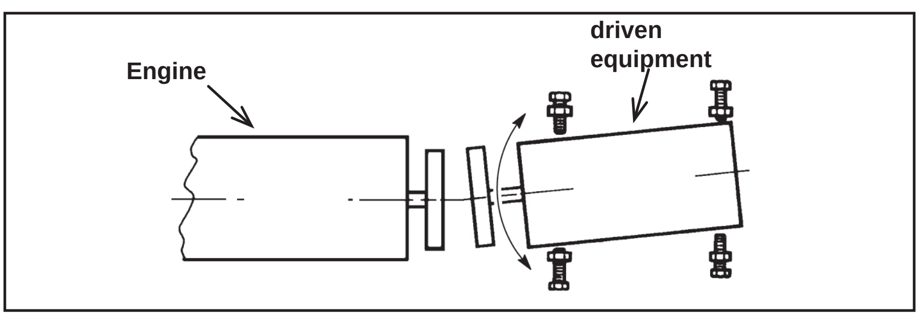


Figure 7-40: Slide free end

4. Loosen both bolts on the opposite end and move as calculated. Re-torque all mounting bolts (see “Figure 7-41: Move opposite end”).

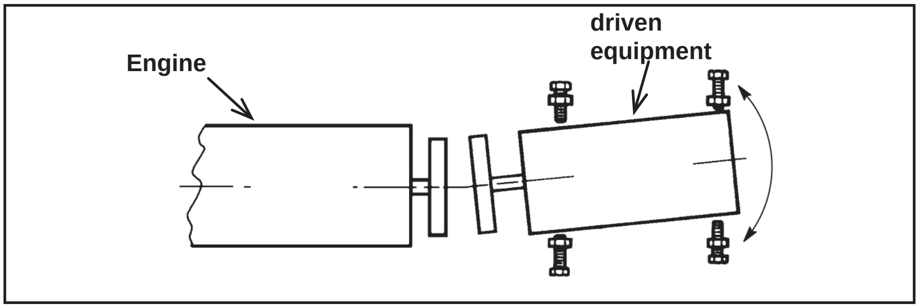


Figure 7-41: Move opposite end

5. Check angular alignment again using the same procedure as used previously. Angular alignment is correct when total indicator runout is less than 0.005 in. (0.127 mm) per foot of radius from center of shaft to where the dial indicator reads (see "Figure 7-42: Correct angular alignment").

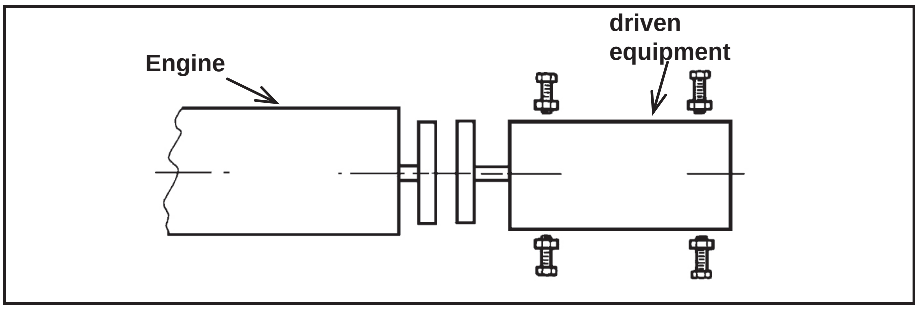


Figure 7-42: Correct angular alignment

Parallel Alignment

Parallel alignment can be checked and adjusted after angular alignment has been completed. It will, however, be necessary to re-check angular alignment after each adjustment. The following procedure can be used to measure parallel alignment.

1. Set up a dial indicator to read parallel alignment. If available, set up a second dial indicator to read angular alignment. This will allow you to rotate the shafts only one time to get both readings (see "Figure 7-43: Measuring For Parallel Alignment").

2. Rotate both shafts to the 2:00 o'clock position (facing the flywheel) then back to the 12:00 o'clock position. Zero the indicator(s).

3. Rotate the shafts to the 9:00 o'clock position and record the readings.

4. Rotate the shafts to the 6:00 and 3:00 o'clock positions and record the readings.

5. Rotate the shafts back to the 12:00 o'clock position and verify that the indicators return to zero.

The amount of parallel misalignment is one-half the TIR (total indicator reading) for each direction.

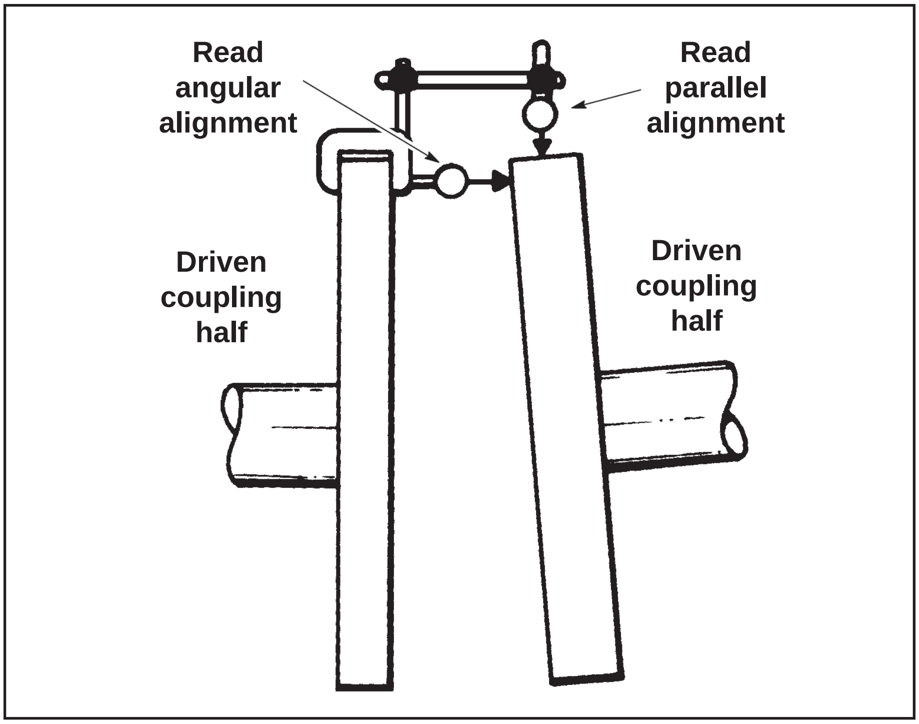


Figure 7-43: Measuring For Parallel Alignment

In this example, the vertical TIR is 0.020 in. (0.508 mm), thus the machines are vertically misaligned by 0.010 in. (0.254 mm). Horizontal TIR is the difference between (+0.015) and (+0.005) which is 0.010 in. (0.254 mm). Horizontal misalignment is 1/2 of the TIR which is 0.005 in. (0.127 mm). All mounts should get the same amount of adjustment, 0.005 in. (0.127 mm) in this case, to move the machine without losing angular alignment.

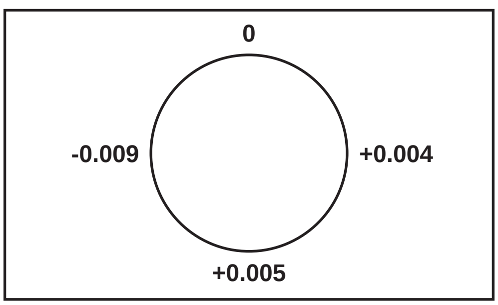


Figure 7-44: Total Indicator Reading (TIR)

Adjustment for parallel alignment is similar to that for angular and should be accomplished as follows:

1. Set up two dial indicators; one to monitor horizontal movement of the inboard mounts, and one to monitor horizontal movement of the outboard mounts. Zero the indicators.

2. Going to one corner at a time, loosen the mounting bolt(s) and shim as calculated, then torque the mounting bolt. Center mounts will have to be shimmed in conjunction with corner mounts.

3. After shimming, loosen both mounts on one end and all center mounts. It may also be necessary to loosen one mount on the fixed end but do not loosen both. Slide the free end the amount calculated then re-torque the bolts.

4. Loosen both mounts on the opposite end and move the same. Retorque all mounting bolts.

5. Check parallel alignment again using the same procedure as used previously. Parallel alignment is correct when total indicator runout is less than 0.005 in. (0.127 mm).

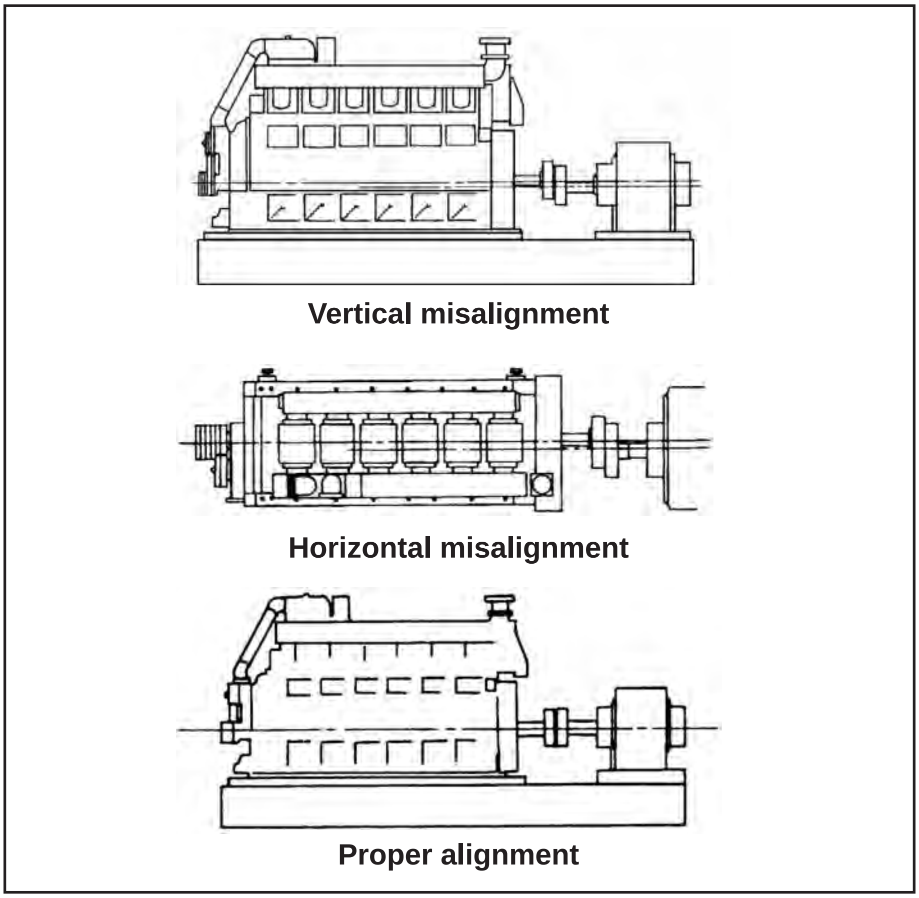


Figure 7-45: Parallel alignment

Thermal Growth

After angular and parallel alignment are satisfactory, it will be necessary to adjust alignment to compensate for thermal growth. This will allow the machines to be in good alignment after they reach operating temperature.

Crankshaft Growth

The following table lists the changes in crankshaft height that will occur due to the temperature change from 70° F (21° C) to normal operating temperatures (measured from the mounting surface of the base type oil pan).

Table 7-2: Thermal Growth

ENGINE MODEL	INCREASE IN CRANKSHAFT HEIGHT	
	INCHES	mm
VHP 12-Cylinder	0.014	0.36

Heat growth information for the driven equipment should be available from the manufacturer. If not, it can be calculated with the following formula:

$G_m = (T_m - 70) \times h \times E$ for °F or $(T_m - 20) \times h \times E$ for °C

Where:

G_m = amount of growth expected (inches or mm)

T_m = operating temperature of driven machines (°F or °C)

h = height from machine mounting surface to center of shaft (inches or mm)

E = thermal expansion coefficient for material machine is made from:

6.5 x 10-6 (0.0000065) in/in °F or 1.2 x 10-6 mm/mm °C for steel

5.8 x 10-6 (0.0000058) in/in °F or 1.1 x 10-6 mm/mm °C for cast iron

To adjust for thermal growth take the difference in machine growths and add that amount in shims under the machine which grows least. In the case of cooling compressors, the compressor gets cold when loaded and shrinks. This will require a further offset to compensate for engine growth and compressor shrinkage. The growth formula still applies for a cold compressor since the growth number will be negative.

To add the shims, loosen one mount at a time and add the shims then re-torque the bolts before moving on to the next mount. This prevents horizontal alignment from changing while adding shims. Parallel dial indicator readings will now indicate the machine which grows least is higher than the machine which grows more but the machines will be aligned when they reach operating temperature.

Check end play to verify that the alignment procedure did not eliminate end thrust.

Doweling

If doweling of the machines is required, the following information is offered as a guide.

Doweling is a practice often used after aligning two machines to mark their correctly aligned positions. When dowels are placed correctly, they also determine the direction of thermal growth of the machines. The drawing below illustrates where dowels should be placed to cause thermal growth in a direction which will not affect crankshaft end play and will maintain correct alignment.

Tapered dowels are recommended for this purpose because they have the following advantages over straight dowels;

1. Tapered dowels will not fall through the skid from vibration or a slight gap between the hole and dowel.

2. If alignment changes from shipping of the complete package or settling of its foundation, the machines can be realigned and the tapered holes reamed deeper to fit the dowel in its new position.

3. Tapered dowels are removed easily by driving the pin out the large end.

Dowel holes should be drilled through the mounting foot, shim pack and the skid Ibeam flange. No gaps should exist between the engine base and the skid.

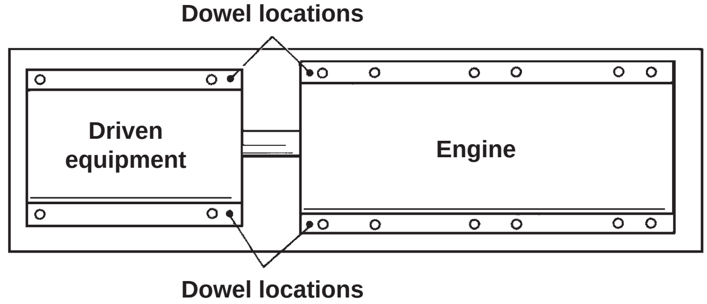


Figure 7-46: Dowel Placement

WARNING

Engine components and fluids are extremely hot after the engine has been shut down. Contact with hot components or fluids can cause severe personal injury or death. Wear protective clothing and eye protection protection during the hot check of crankshaft deflection.

Hot Check

Once the machines are aligned and offset for thermal growth, they should be checked when hot.

1. Start the engine and apply load.
2. Allow machines to run for one hour after reaching their operating temperatures.

WARNING

Ensure that all tools and other objects are removed from the unit and any driven equipment before starting the unit. Running equipment can eject objects at great force, resulting in severe personal injury or death.

3. Shut down and immediately check angular and parallel alignment and end play. Alignment TIR should now be less than 0.005 in. (0.127mm) for the VHP, both parallel and angular.
4. Adjust alignment and end play if necessary.

Periodic Inspections

Engine base deflection and alignment must be checked periodically, at least once a year. Installations which are subject to settling of the concrete must be checked often (initially – monthly) to determine if settling is causing misalignment.

ALIGNMENT CHECKLIST

Single Bearing Machine

NOTE: Values in the checklist are mentioned for VHP.

1. Install and level engine or common base ___________________________

2. Adjust spring isolaters (if used) ___________________________

3. Adjust base deflection at the four engine corners.

0.______ in. (mm)	0.______ in. (mm)	0.______ in. (mm)
0.______ in. (mm)	0.______ in. (mm)	0.______ in. (mm)

4. Shim center mounts

+0.000 in (0.000 mm) for a VHP 12-cylinder Extender Series*
+0.004 in. (0.102 mm) for a VHP 12-cylinder with base style oil pan*
+0.000 in. (0.000 mm) for a VHP P9394GSI*
*** With the center mounts properly torqued.**

5. Measure crankshaft web deflection (optional)

All except rear throw 0.001 in. (0.025 mm) TIR max.
Rear throw approximately 0.0015 in. (0.038 mm) TIR.

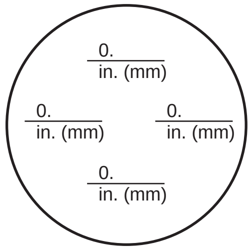
Throw	**1**	**2**	**3**	**4**
TIR	0.____ in (mm)	0.____ in (mm)	0.____ in (mm)	0.____ in (mm)

Throw	**5**	**6**	**7**	**8**
TIR	0.____ in (mm)	0.____ in (mm)	0.____ in (mm)	0.____ in (mm)

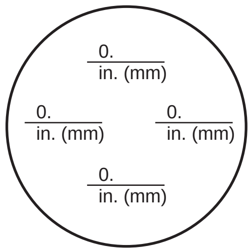
6. Adjust base deflection at four corners of driven machine.

0.______ in. (mm)	0.______ in. (mm)
0.______ in. (mm)	0.______ in. (mm)

7. Check and adjust shaft pilot centering (parallel alignment). Maximum 0.005 in. (0.127 mm) TIR.



8. Check and adjust angular alignment. Maximum 0.005 in. (0.127 mm) TIR at flywheel bolt.



9. Adjust for vertical growth

Engine Growth _____________ in. (mm) minus

D. M. Growth _____________ in. (mm) =

Cold Alignment Offset _____________ in. (mm)

10. Check crankshaft end play _____________ in. (mm) should be within service manual specifications.

11. Check air gap and fan set screws (single bearing generator) _____________

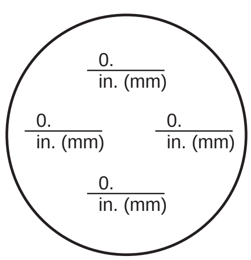
12. Start engine, run loaded, allow to warm up 1 hour minimum _____________

13. Shutdown and check hot angular alignment and end play

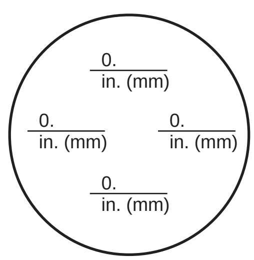
End play (Hot) _____________ in. (mm)

Alignment:

Parallel (Hot)



Angular (Hot)



Multiple Bearing Machine

1. Install and level engine or common skid ______________________________

2. Adjust spring isolaters (if used) _____________________________________

3. Adjust base deflection at the four engine corners.

0. ____ in. (mm)	0. ____ in. (mm)	0. ____ in. (mm)
0. ____ in. (mm)	0. ____ in. (mm)	0. ____ in. (mm)

4. Shim center mounts

+0.000 in (0.000 mm) for a VHP 12-cylinder Extender Series*
+0.004 in. (0.102 mm) for a VHP 12-cylinder with base style oil pan*
+0.000 in. (0.000 mm) for a VHP P9394GSI*
*** With the center mounts properly torqued.**

5. Measure crankshaft web deflection (optional)

All except rear throw 0.001 in. (0.025 mm) TIR max.

Rear throw approximately 0.0015 in. (0.038 mm) TIR.

Throw	**1**	**2**	**3**	**4**
TIR	0.____ in (mm)	0.____ in (mm)	0.____ in (mm)	0.____ in (mm)

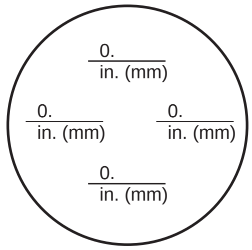
Throw	**5**	**6**	**7**	**8**
TIR	0.____ in (mm)	0.____ in (mm)	0.____ in (mm)	0.____ in (mm)

6. Adjust base deflection at four corners of driven machine.

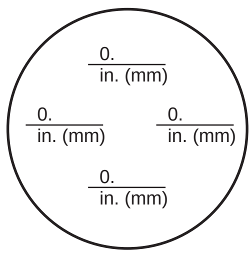
0. ____ in. (mm)	0. ____ in. (mm)
0. ____ in. (mm)	0. ____ in. (mm)

7. Check for crankshaft end play.

8. Check and adjust angular alignment. Maximum 0.005 in. (0.127 mm) per foot of radius from center of shaft to dial indicator read point.



9. Check and adjust parallel alignment. Maximum 0.005 in. (0.127 mm) TIR.



10. Adjust for thermal growth

Engine Growth _____________ in. (mm) minus

D. M. Growth _____________ in. (mm) =

Cold Alignment Offset _____________ in. (mm)

11. Recheck crankshaft end play _____________ in. (mm)

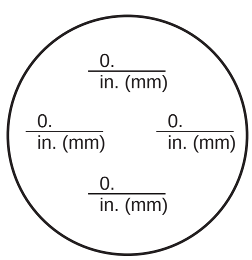
12. Start engine, run loaded, allow to warm up 1 hour minimum _____________

13. Shutdown and check hot angular alignment and end play

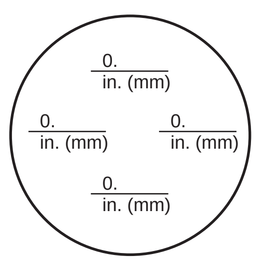
End play (Hot) _____________ in. (mm)

Alignment:

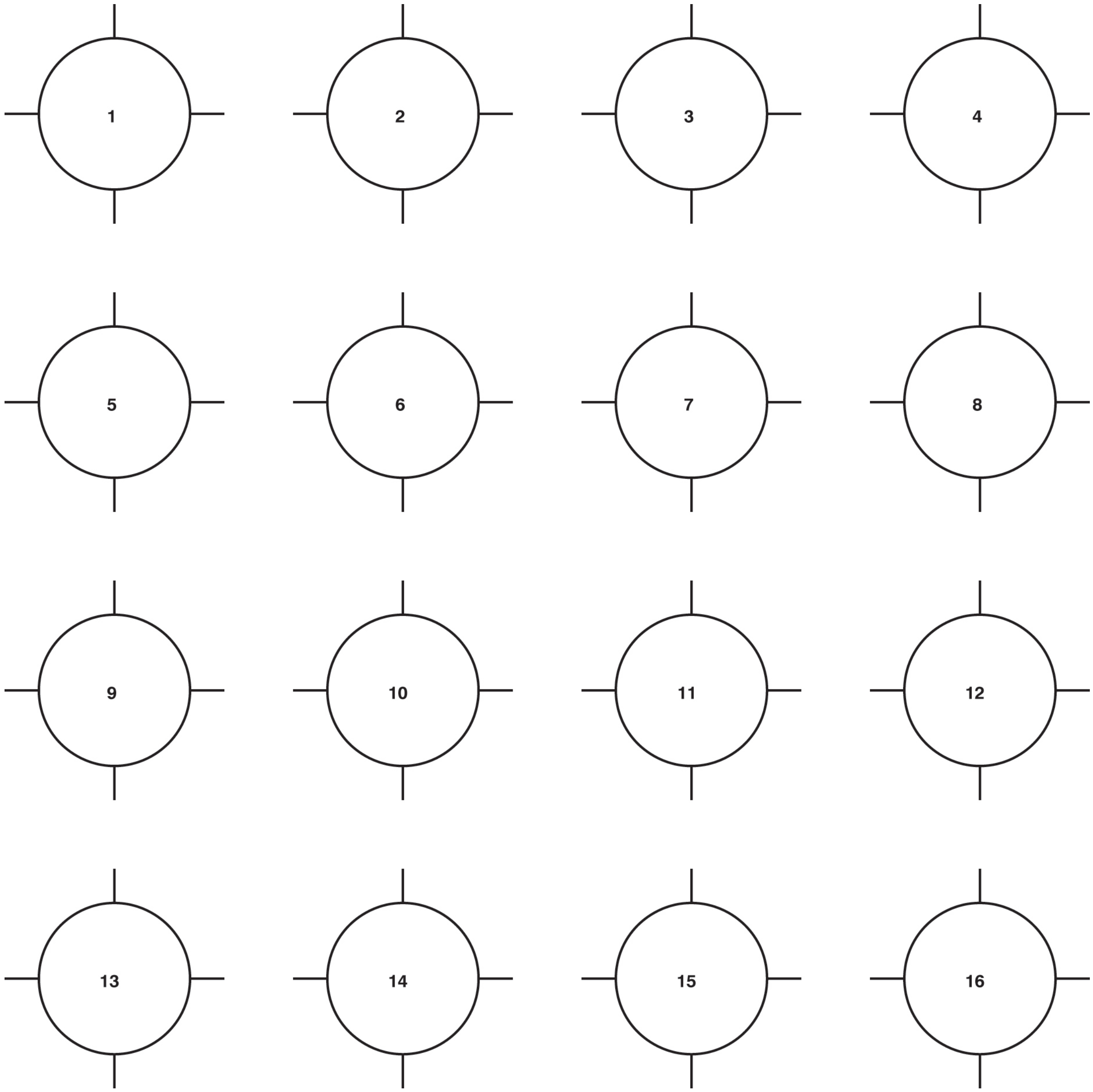
Parallel (Hot)



Angular (Hot)



14. Dowel inboard machine mounts (if required).



Endplay before alignment ______________________

Engine model ______________________

Driven machine make ______________________

Customer's observer ______________________

Date ______________________

End play after alignment ______________________

Serial No. ______________________

Model No. ______________________

Performed by ______________________

Figure 7-47: Alignment progression chart

CHAPTER 8 - ENGINE LIFTING

WARNING

Exercise extreme care when moving the engine or its components. Never walk or stand directly under an engine or component while it is suspended. Always consider the weight of the engine or the components involved when selecting hoisting chains and lifting equipment. Be positive about the rated capacity of lifting equipment. Use only properly maintained lifting equipment with a lifting capacity which exceeds the known weight of the object to be lifted.

ALWAYS include the weight of the engine, the components and the lifting device to ensure the lifting equipment's capacity is not exceeded when calculating the weight to be lifted.

WARNING

Always inspect lifting device and hardware for cracks and or other damage before attempting to lift the engine.

VHP engines will be supplied with a skid that is suitable for shipping but is not to be used for mounting or operating the engine.

VHP Enginators include the generator and a skid suitable for shipping and mounting. Specific lifting instructions will be provided with each Enginator order.

The lifting eyes on the VHP engines are bolted to the engine crankcase and do not need to be removed during normal engine operation. A 9-1/2 ton W.L.L. (Working Load Limit) standard anchor shackles equipped with screw pins are required to be used with lifting the engine. The shackles are not supplied by Waukesha. The engine lifting eyes are only meant for lifting the engine. Do not use to lift driven or auxiliary equipment that may be attached to the engine.

VHP 12-cylinder engines must be lifted with the lifting chains/cables/straps attached from the lifting device (for example, spreader bar) to the lifting lugs in a near vertical angle, not to exceed 5 degrees in a front-to-back direction or 27 degrees out from the lug (see "Figure 8-2: Proper Chain Angle for Lifting Engine" on page 3). The lifting lugs are NOT designed to be lifted at greater angles, which could result in failure. Do not perform a single-point lift; four chains/cables/straps attached from each lug to a single point (for example, crane hook).

Lifting chains should be positioned so that they do not rub or bind against parts of the engine. A properly rigged engine will be able to be lifted in such a manner that the chains will not damage the engine. Spreader beams are also available for purchase from Waukesha, refer to the latest Special Tools Catalog for more information.

Table 8-1: Lifting specifications

Engine	Weight	
	LB	KG
L7042GSI S5	24,760	11,230
L7044GSI S5	24,760	11,230

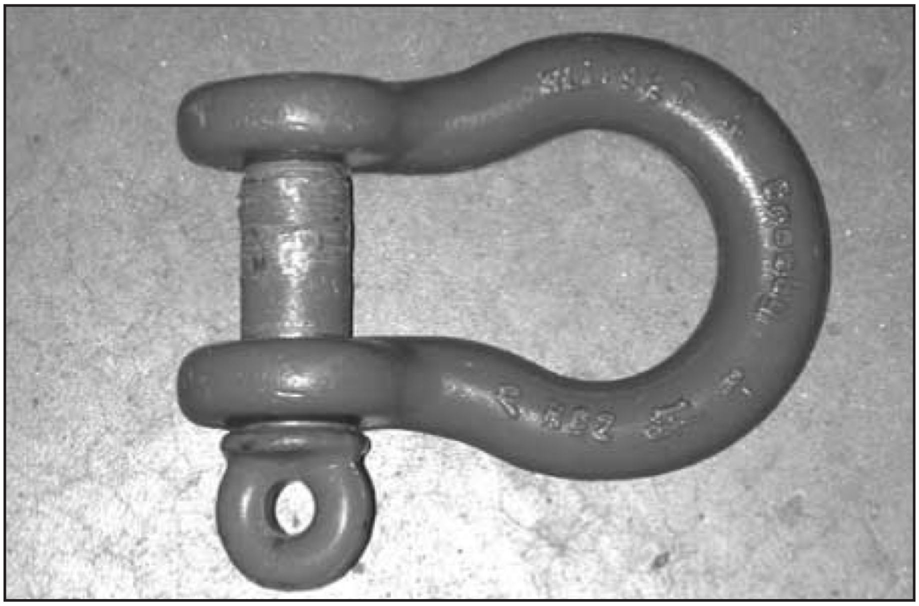


Figure 8-1: Typical lifting shackle

WARNING

Follow approved rigging procedures to ensure that no undue strain is placed on the lifting eyes and hoisting chains/cable sling when the engine is raised. Use the proper spreader beam to avoid damage to the engine.

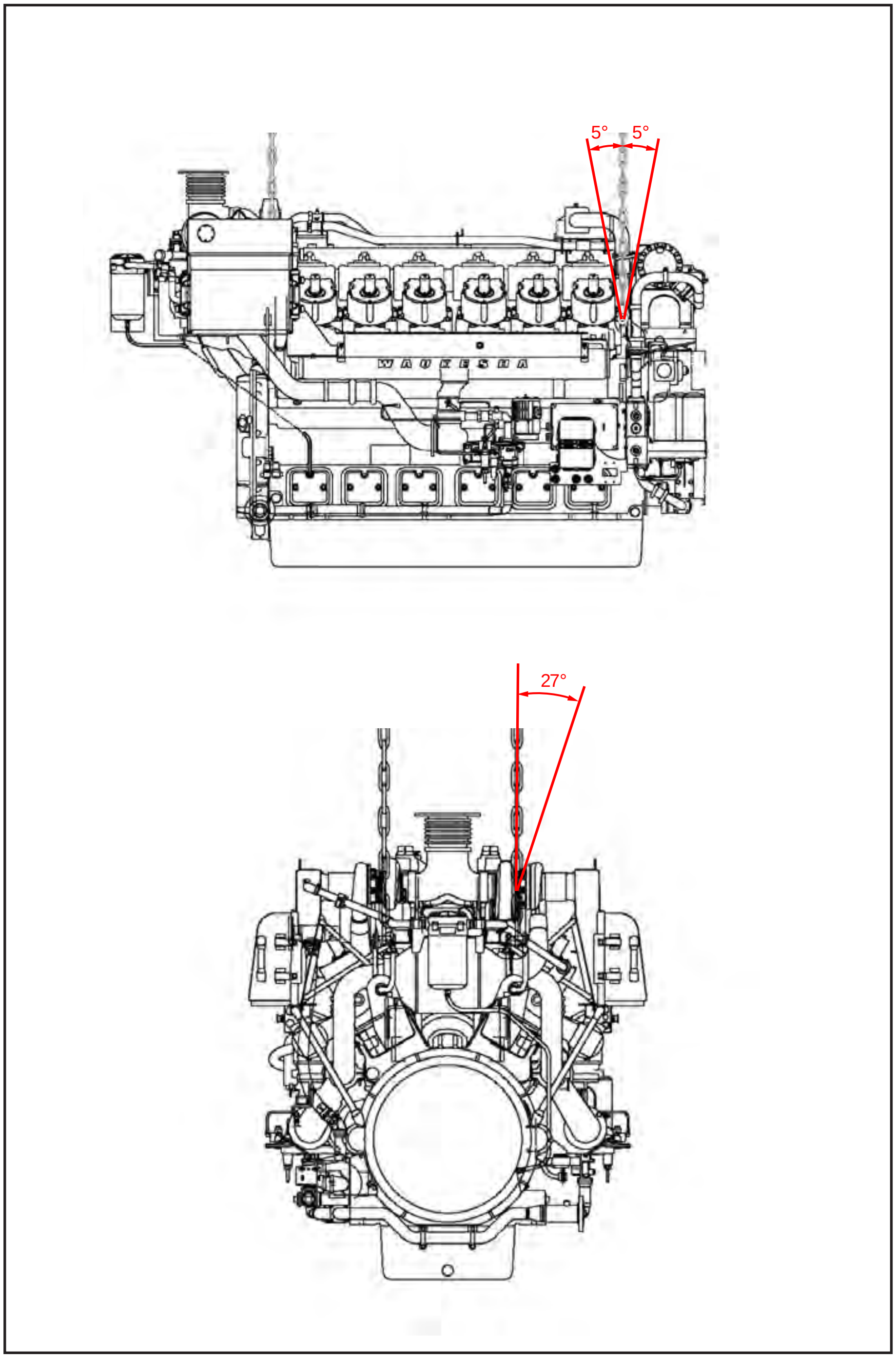


Figure 8-2: Proper Chain Angle for Lifting Engine

CHAPTER 9 - COOLING SYSTEM

COOLING SYSTEM REQUIREMENTS

- Radiator sized using site specific engine data from EngCalc or Special Application Approval (SAA)
- Radiators installed considering prevailing winds at the site. Install radiators so they are not adversely affected by other heat sources on site.
- Static pressure lines connected to the inlet of each pump providing a static inlet pressure of 2 – 22 psig (0.14 – 1.5 bar), or 4.6 – 50 ft (1.4 – 15.2 m) of water head.
- Vent lines installed at high points of the engine for both JW and AW circuits
  - Vent lines continuously sloping upwards to expansion tank
  - Vent lines should be 1/4” in diameter on systems with vent lines less than 10 feet (3 meters) long, or 1/2” diameter with a 1/4” orifice on systems with vent lines more than 10 feet (3 m) long.
- Separate expansion tank for each circuit sized for desired coolant makeup volume plus an additional air space equal to 11% of total cooling system volume. The air space will allow for coolant expansion as it heats up and allows air to compress and increase the coolant system pressure. A 7 psig (0.48 bar) pressure cap should also be included.
- Flexible connections installed on all connections to the engine including static pressure lines and vent lines.
- Jacket water heater systems installed when ambient air temperature is less than 50°F (10°C)
- Piping properly supported not to exert any additional forces on engine connections
- External cooling system restriction is less than maximum external restriction limits published in tech data on S-5136-34 and S-96543-36
- Industrial natural gas engine coolant that meets Waukesha’s water treatment guidelines in technical data document S-7610-3

SUPPORTING DOCUMENTS

S-6699-7	Cooling system guidelines
S-7610-3	Water treatment guidelines
S-7424-1	Inlet Pressure Requirements for Jacket Water Pump
S-8472-2	Cooling system schematic
S-8473-2	Elevated Ambient Air Temperature and Altitude Correction to Heat Rejection
EngCalc	Engine data program for site specific heat rejection
S-5136-34	VHP 12-cylinder jacket water pump performance
S-6543-36A	VHP 12-cylinder auxiliary water pump performance
S-8473-2	Elevated Ambient Air Temperature and Altitude Correction to Heat Rejection

COOLING SYSTEM OVERVIEW

VHP engines consist of two separate cooling circuits, one circuit for the engine jacket water, one circuit for the intercooler and oil cooler. Both circuits include engine gear driven water pumps, mechanical thermostats, and bypass piping. The jacket water circuit consists of cool- ing the engine cylinders, cylinder heads, and turbocharger bearing housings and maintains an engine outlet temperature of 180°F (82°C) with the engine mounted thermostat. The aux- iliary water circuit cools the charge air intercooler and lube oil cooler while maintaining an engine inlet temperature of 130°F (54°C).

RADIATOR SIZING

Engine cooling is typically performed using an externally mounted radiator or cooler. For gas compression applications, this is typically a separate core cooler that is used to cool both the jacket water and auxiliary water circuits on the engine as well as the gas compression stages. When sizing the cooler for the engine circuits, EngCalc or a Special Application Approval (SAA) must be used to determine site specific engine data which is dependent on the ambient temperatures, site elevation, engine operating point, and fuel composition. Engine heat rejection data will be provided for all systems, and it is recommended to use the high end of the heat rejection data tolerance, as well as an additional safety and fouling factor to ensure the cooler is sized to prevent overheating the engine.

The temperature rise across the engine will vary with operating conditions, but it is recommended to maintain a fairly consistent temperature differential across the engine. Large temperature differentials across the engine can cause cyclical temperature changes, or even thermal shock the engine if extremely cold coolant suddenly enters the engine which can cause engine damage.

Typical coolant temperatures:

Jacket Water inlet: 160-165°F (71°C – 74°C)
Jacket Water outlet: 180°F (82°C) (thermostatically controlled outlet temperature)
Auxiliary water inlet: 130°F (54°C) (thermostatically controlled inlet temperature)
Auxiliary water outlet: 145°F – 150°F (63°C – 66°C)

COOLING SYSTEM PIPING

Cooling system piping must be sized to allow the coolant to flow without excessive restriction. The piping material must be suitable for the temperatures and pressures encountered, as well as vibration from the operating engine. Flexible connections are recommended at all connection points to the engine. This will isolate the engine and piping components from high stresses due to vibration. Engines mounted on spring isolators or other soft mounting systems must have cooling system connections with flexibility sufficient to handle the motion normally encountered. Flexible connections for the Jacket and Auxiliary water circuit inlet and outlet connections are to be provided by the packager. Cooling system piping must also be properly aligned and supported on the package to not exert any external forces on the engine connections. Flexible connections are not designed to accommodate for misaligned piping.

Dresser and Flexmaster couplings have the ability to join pipes which are not closely aligned. These couplings flex to join the pipes. However, they become very stiff when clamped in place. Waukesha does not consider these as flexible couplings for isolating components from excessive vibration.

Piping restriction depends on the pipe diameter, pipe length, number of elbows and transitions, and the piping material used. A procedure for calculating the cooling system piping restriction is available in Appendix A in this manual. This procedure uses the EDL (Equivalent Duct Length) Method, however there are other methods or computer based simulations that may also be used.

CIRCUIT EXTERNAL RESTRICTION, BOOSTER PUMP

If the external restriction of the cooling system is too high, an additional cooling system booster pump is required to ensure adequate flow through the cooling system. The two pump system, illustrated in "Figure 9-1: Two pump system", is used in circuits where the engine water pump has insufficient capacity to flow coolant through the engine and heat recovery components. A system water pump is installed downstream of the engine thermostat, and a common pipe must be installed between the inlet of both the system pump and the engine pump. The common pipe is used to equalize the pressure at the inlet of both pumps and the static pressure line is installed at the common pipe. The system pump is sized to deliver the required flow through all cooling components other than the engine. The engine water pump needs to overcome restriction of the engine, the thermostat, and the common pipe.

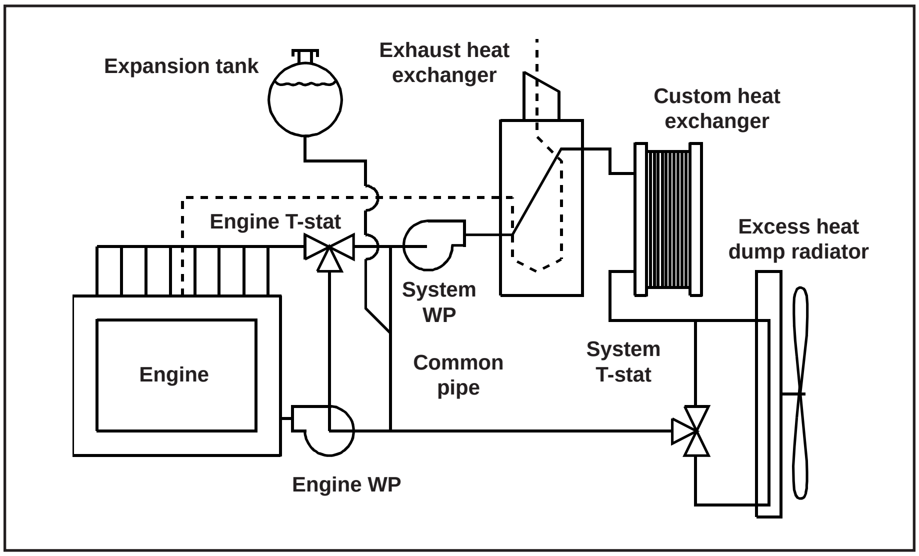


Figure 9-1: Two pump system

EXPANSION TANK

Each cooling circuit requires an expansion tank sized for the desired coolant makeup volume (typically 5%) plus an additional air space equal to 11% of total cooling system volume. The air space will allow for coolant expansion as it heats up and allows air to compress and increase the coolant system pressure. A 7 psig (0.48 bar) pressure cap should also be included. The expansion tank should be mounted at the highest point in the system, and high enough to provide at least 2 psig (4.6 feet) static head pressure to the inlet of the engine mounted pumps. The expansion tank provides the function of de-aerating the coolant , controlling cooling system pressures, allows for coolant expansion, and provides coolant reserve. An expansion tank is a single chamber tank located at the highest point in the cooling system. Vent lines are connected from high points in the cooling system to the expansion tank below the water line. These vent lines allow trapped air to escape to the ex- pansion tank where the air bubbles out of solution, thus de-aerating the coolant (see "Figure 9-2: Cooling system schematic").

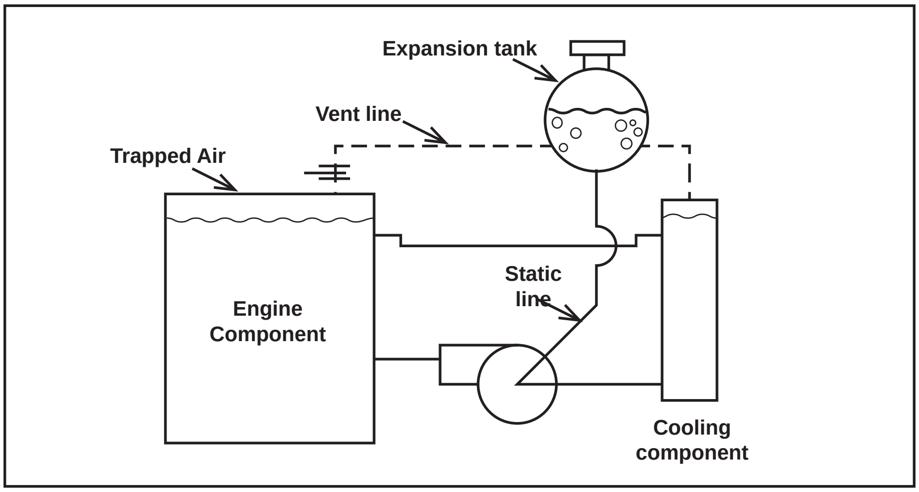


Figure 9-2: Cooling system schematic

Vent lines should be 1/4" in diameter on systems with vent lines less than 10 feet (3 meters) long, or 1/2" diameter with a 1/4" orifice on systems with vent lines more than 10 feet (3 m) long.

Vent lines on the VHP engines should be connected to the high points on the engine for the circuit. For the Jacket Water circuit, the vent line should be connected to the two water manifold pipes on the top of the engine and is shown on the general engine outline drawing available on *www.ge-distributedpower.com* or Waukesha One under outline drawing section. The auxiliary water circuit vent connections are in the piping to the oil cooler, and at the top of the intercooler near the front side of the engine.

All vent lines must have flex connections, or other provisions, to prevent stress on the lines due to engine vibration. The vent lines must also be properly supported so their weight is not being supported by the flexible connection. Failure to properly relieve these stresses may result in a broken vent line which could cause a glycol fire. Each circuit may have multiple vent lines and they may be combined into one common vent line. Vent lines between the individual jacket and auxiliary water circuits may not be combined.

Automatic degassing systems or automatic bleeders are not recommended by Waukesha. Also bladder pressurization systems are not preferred as they can be difficult to maintain constant pressure, and they do not provide a reservoir for additional coolant if a leak were to occur.

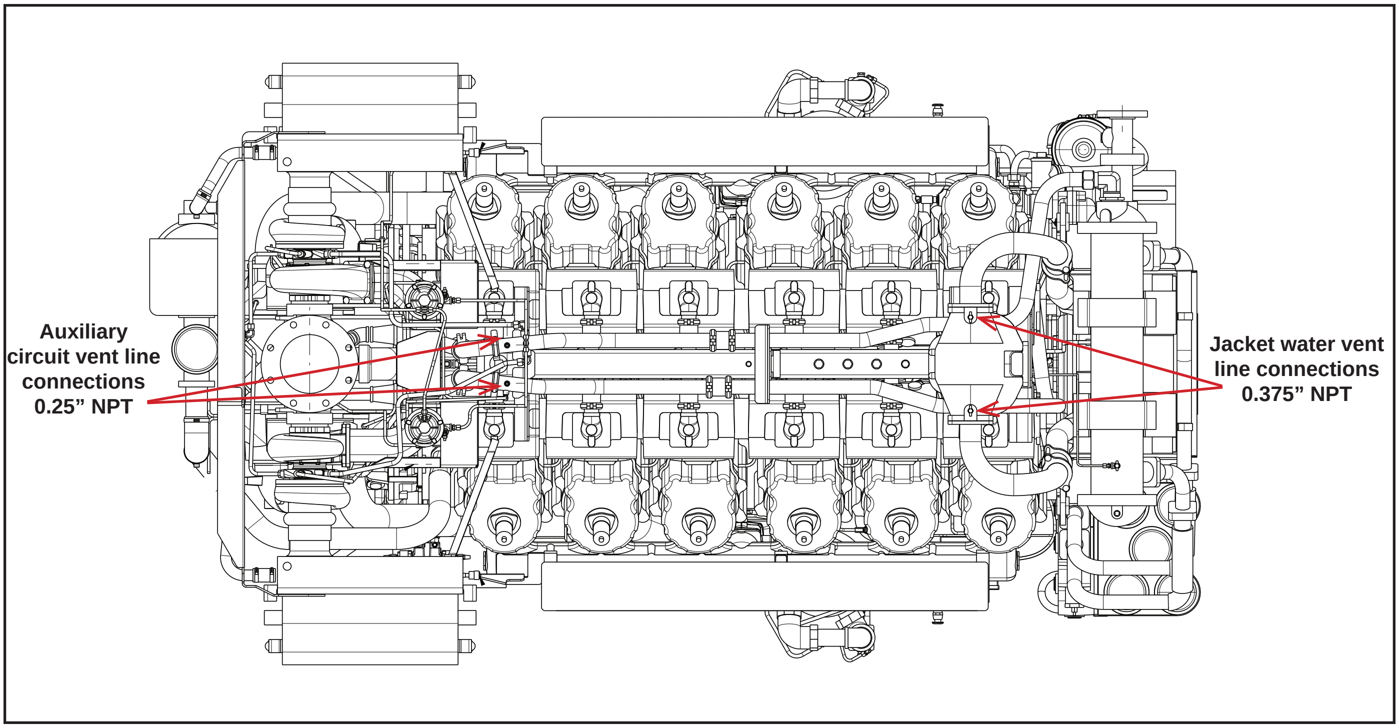


Figure 9-3: Vent line connections

A static line from the bottom of the expansion tank to the water pump inlet controls the pump inlet pressure. The static inlet pressure must be between 2 - 21 psig (0.2 – 1.4 barg), or 4.6 – 50 feet (1.4 – 15.2 m) of H_2O.

JACKET WATER STATIC INLET CONNECTION

The static pressure line should be connected as close as possible to the inlet of the Jacket Water pump.

12-Cylinder JW Static Line Connection

There is a 1.25” NPT connection on the water pump inlet, this is the ideal location for a static line. There are other water inlet options available on this engine and may provide an additional static line location. If a static line connection is installed in the customer piping it must be right at the inlet connection to the engine.

AUXILIARY WATER STATIC INLET CONNECTION

12-Cylinder Aux Static Line Connection

The static pressure line should be connected at the inlet of the Auxiliary Water pump in the piping between the pump and thermostat as shown in “Figure 9-4: Auxiliary Water static inlet connection with Waukesha thermostat”.

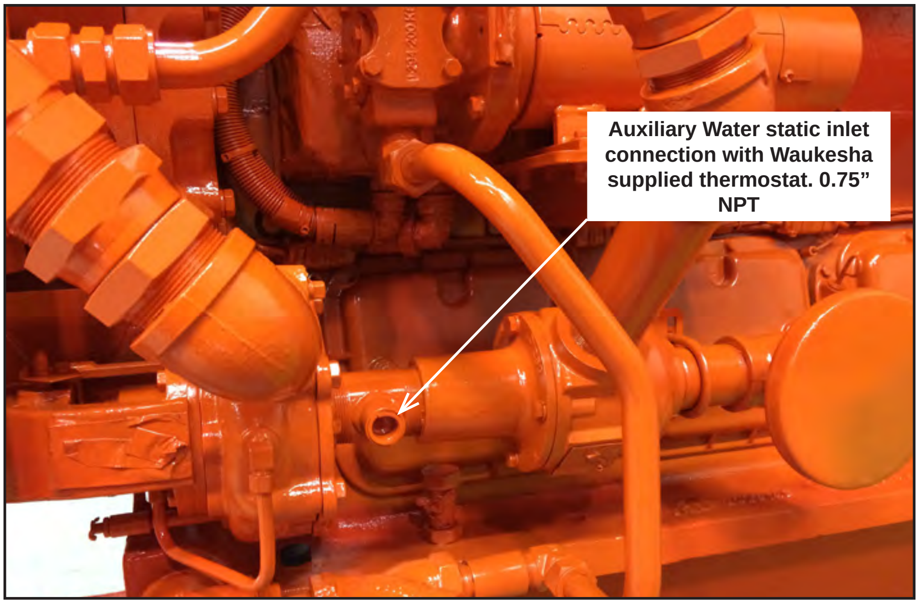


Figure 9-4: Auxiliary Water static inlet connection with Waukesha thermostat

VENT LINE CONNECTIONS

Vent lines are required to be installed at the high points in the cooling system. These vent lines allow trapped air in the cooling system to be vented up to the expansion tank. The vent lines should slope continuously upwards, so they do not create another air trap, and enter the expansion tank below the level of the coolant and away from the static line locations. Vent lines should be 1/4" in diameter on systems with vent lines less than 10 feet (3 meters) long, or 1/2" diameter with a 1/4" orifice on systems with vent lines more than 10 feet (3 m) long. Multiple vent lines can be combined provided they use a 1/4" orifice and combine into a 1/2" line.

All vent lines must have flex connections, or other provisions, to prevent stress on the lines due to engine vibration. The vent lines must also be properly supported so their weight is not being supported by the flexible connection. Failure to properly relieve these stresses may result in a broken vent line which could cause a glycol fire.

12-Cylinder Vent Lines

The 12-Cylinder engines have the following venting locations (see outline drawing for further detail):

Jacket water circuit:

- JW air bleed – 0.375"-18 NPT (2 places)

Auxiliary water circuit:

- Top intercooler piping – 0.25"-18 NPT (2 places)

COMPRESSOR COOLING CIRCUIT

It is common to use the engine auxiliary water circuit to also cool the compressor oil cooler and compressor packing. A provision on the engine has been provided to obtain some of the coolant immediately after the auxiliary water pump at the low temperature of 130°F (54°C) to be used for cooling the compressor. The compressor coolant is then returned to the circuit at the outlet of the engine. When designing a compressor cooling circuit the pump capacity must be considered since using some of the coolant for the compressor reduces the allowable external restriction or pressure drop. If the system restriction exceeds the pump capacity, the system must be redesigned to reduce the restriction, such as larger diameter piping or fewer elbows, or an additional booster pump must be installed to increase the capacity of the circuit.

WATER HEATER

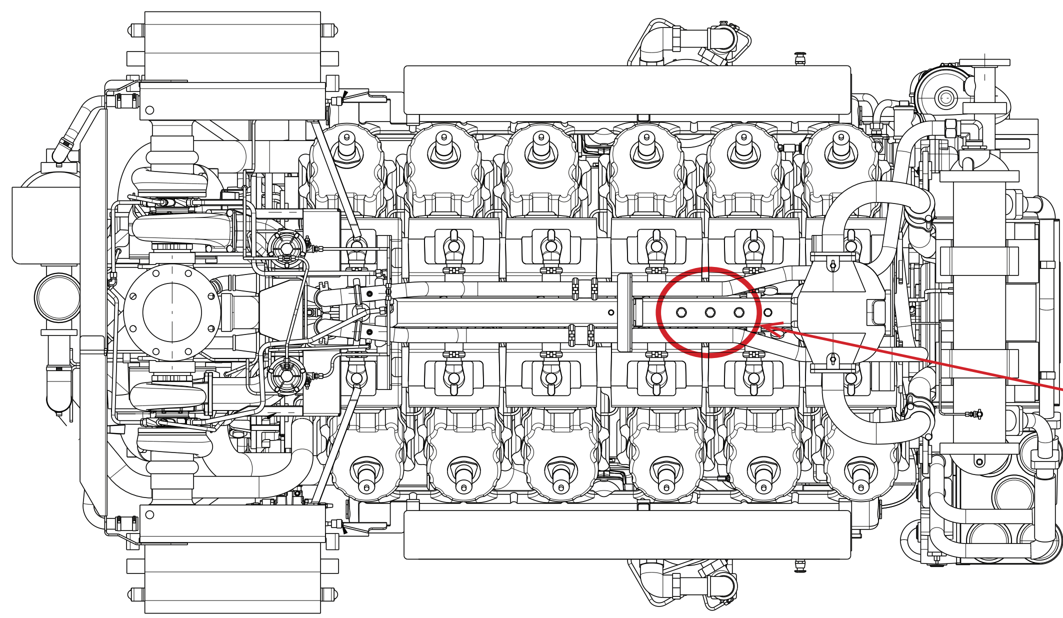
Starting an engine in cold conditions may require preheating of cooling and lubrication circuits. Waukesha requires jacket water and lube oil preheating for starting in temperatures below 50°F (10°C). Heaters should be sized to maintain 70°F (21°C) in these conditions. Once started, the engine should be allowed to warm up under a light load until water and oil temperatures exceed 100°F (38°C). Emergency standby engines which are required to start and accept load immediately must be preheated to 100°F (38°C) to 120°F (49°C). The size of the jacket water heater will depend on the ambient temperature, and the heater supplier should be consulted for sizing.

12-Cylinder JW Heater Connections

The jacket water heater inlet connections to the engine typically will use the water drains on each side of the crankcase. A tee can be installed to still allow draining of the coolant from the engine. Since the cooling system on the engine is split between the two banks, the water heater inlet will need to be connected to both sides of the crankcase for effective heating. The water heater outlet connection can be in the water manifold on the top of the engine. The other option is to not use the top connection and just use two side drains, however they must be on opposite sides and ends (diagonally) from each other (connections C on the outline drawing)

Figure 9-5: 12-Cylinder water heater outlet connection

Figure 9-6: 12-Cylinder water heater inlet connection



ENGINE THERMAL SHOCK AT SHUTDOWN DUE TO THERMOSIPHONING

Thermosiphoning is a process where coolant will circulate in a cooling loop without any assistance from a water pump. As coolant is heated, its density decreases, causing it to rise. As the coolant is cooled, it drops below warmer coolant. These actions create flow in a circuit. A greater difference between engine coolant temperature and radiator coolant temperature will cause a greater flow. A radiator at a higher elevation than the engine will have a greater thermosiphoning flow than one mounted in front of the engine. Thermosiphoning can cause engine damage due to thermal shock when a hot engine is shutdown and effective cooling of the engine stops. There are several methods to design the cooling system to prevent thermosiphoning which are detailed in Application Note app9_92 in Technical Data on *www.ge-distributedpower.com.*

CAUTION Restarting shortly after shutdown should be avoided. Restarting can cause a cold slug of coolant from the radiator to enter the engine because the thermostat may still be fully opened.

FAN DRIVE

The VHP engines are available with an optional stub shaft or pulley typically used for driving the cooler fan. In a direct drive application, a drive shaft directly coupled to the front stub shaft is used to drive the cooler fan. The drive shaft must be properly supported with a minimum of 2 bearing jackshafts, and a coupling must be used between the engine stub shaft and the drive shaft. No side loads should be applied to engine stub shaft when used in a direct drive application. A torsional analysis should also be performed to analyze the front drive system.

Power can also be transmitted from the engine front stub shaft or pulley with a belt drive application. In a pulley arrangement, a side load is applied to a front stub shaft which adds additional downward forces on the front crankshaft main bearing. If the forces on the front stub shaft are high, the front main bearing may experience premature wear and cause engine failure. Limitations for the maximum load applied are listed in the technical data sheet (S-4052-13) for the VHP engines.

12-Cylinder Front Drive

- Maximum front drive power with downward force: 61 BHP (45 kWb)
- Maximum front drive power with upward force: 95 BHP (71 kWb)

MAINTENANCE CONSIDERATIONS

After installation of the engine and cooling system piping, the piping should be cleaned before commissioning the engine. It is recommended to use a coarse screen or filter to capture any installation debris from the system.

Coolant for the engine is filled from the bottom of the engine to the top which allows air in the system to escape through the vent lines. When filling the engine, any component with a vent should be opened during the initial fill until coolant reaches that level of the engine during filling.

Periodically the coolant in the engine will need to be replaced (as needed by analysis or onsite maintenance schedule). Drain locations on the engine (as indicated on the engine outline drawing) should be easily accessible.

CHAPTER 10 - LUBRICATION SYSTEM

SYSTEM REQUIREMENTS

Lube Oil Recommendations

- The lube oil chosen to run in the engine must be classified to be run in natural gas engines.
- The oil must meet Waukesha lube oil requirements for the particular engine as listed in latest edition of S1015-30 or SB 12-1880.
- A lube oil analysis should be set-up for the engine.
- Engine requires SAE 40 oil with a minimum of 0.45% sulfated ash by weight with both metallic and ashless additive systems. A maximum of 0.50% sulfated ash is allowed when using an emPact emissions control system.
- A maximum of 0.10% zinc is recommended.

Engine Pre/Post Lubrication System

- Prelube system has been set to run for a minimum of the following times:
  - 12-Cylinder, DC or air/gas - 30 seconds
  - 12-Cylinder, AC motor - 3 minutes
- An automatic post lube system set to run after the gas valve has closed:
  - 12-Cylinder - 60 seconds minimum
- Solenoid valve exhausts piped to safe location if combustible gas is used.

Engine Oil Heaters

- Lube oil heaters must be used if the engine will be operating at ambient temperatures below 50° F (10° C).

Note: If an electric prelube pump is used oil heaters are required below 65° F (18.3° C).

- For a standby application in which the engine is required to pull load immediately upon start-up, the oil must be heated to a minimum of 100° F (38° C).
- Use a circulating type heater that circulates the oil in the engine sump. Refer to heater manufacturer for sizing requirements based on site conditions and engine size.

Angular Operating Limits

- Ensure the angular operating limits are within the defined limits for the engine model being used to assure constant supply of oil to the oil pick up screen.

STANDARD EQUIPMENT

The lubrication system consists of the following components:

- Oil pan and suction line
- Gear driven, externally mounted oil pump
- Adjustable pressure regulating valve

- Oil pump relief valve
- Full-flow oil filters
- Centrifugal oil bypass filtration
- Filter relief valves
- Lube oil temperature control valves
- Engine mounted, tube and baffle oil cooler
- Engine mounted pre-lube pump and inline lubricator
- Pilot operated prelube valve
- External piping

OPTIONAL EQUIPMENT

Standard Engine

Option code 5005 (12-cylinder only) is for the base style oil pan. This replaces the deep sump oil pan and reduces the oil capacity to 90 gal. (340L) and includes pan, filters, cooler and volume vessel. The lube oil volume vessel is shipped loose. With this option code the single fuel inlet is not available with this option code. This option is typically only ordered when replacing an old VHP engine so that the existing base can be used again.

Option code 5022 (12-cylinder) supplies the engine with a mounted, Kenco LCE oil level regulator.

Waukesha offers the following option codes to supply electric prelube pump motors:

12-Cylinder Electric Options:

- 5229B - 115V AC, 60Hz, single phase
- 5229D – 208-230V AC, 50/60 Hz, single phase
- 5229E – 24V DC

GC-Spec

The Gas Compression (GC) Spec uses the air/gas prelube motor and does not have an option to remove or change this.

CUSTOMER SUPPLIED EQUIPMENT

If option code 5235 is selected, customer must supply a motor to operate the prelube pump. The pump accepts common air or electric motor drives with a NEMA 56C frame ,¾ hp, 950-1200 rpm operation, and needs to be properly supported by the customer.

The supply air/gas is required to be delivered at 70-150psi (482 - 1030 kPa) when the Waukesha air/gas motor is used. If the air/gas starter is installed on the engine then the air/gas supply for the pre/postlube is routed from the starter inlet from the factory.

Customer must supply final air/gas piping for pre/postlube system for the motor exhaust. If combustible gas is used and the engine is installed in a hazardous area the solenoid valve exhausts must also be piped to a safe location per local codes.

Customer must supply a lube oil heater, if required, which heats and circulates the oil in the sump. Refer to heater manufacturer for sizing requirements based on site conditions and engine size.

Customer to supply a lube oil level regulator (if option code 5022/5022B is not selected) and oil make up tank, if desired. If Waukesha option code 5022/5022B is ordered the customer supplied make up tank must be at least 2' (0.6 m), and a maximum of 25' (7.6 m), above the inlet to the Kenco controller. The oil lines must be steel and should be ½" I.D., the controller has a ½" NPT connection. A flexible connection must be used to isolate the oil makeup piping from engine vibrations. A fire safe valve should be installed in the oil line as close to the controller as possible; this is included with option code 5022/5022B.

REFERENCE DOCUMENTS

S-1015-30	Lube Oil Recommendations
S-3549-J	Allowable Engine Angles
S-7382-56	Prelube & Postlube Requirements
S-7521-4	VHP 12-cylinder, GSI Oil Pump Performance
L-08041-302	VHP 12-cylinder Lube Oil Level Regulator, code 5022, Outline Drawing
S-05613-309	Lube Oil Level Regulator, code 5022, Piping Schematic
FORM 10063-1	VHP Series Five 12-cylinder with ESM2 O&M

SYSTEM DESCRIPTION

By circulating properly selected oil throughout the engine, the lubrication system performs three main functions: lubrication, cooling and cleaning.

Lubrication systems provide a cushion of oil preventing direct metal to metal contact be- tween engine components. Without a properly functioning lubrication system, moving metal surfaces would come into direct contact with each other. This will create wear and heat, leading to engine failure. If oil does not reach the cylinder sleeves and rings, piston and piston ring scuffing will occur, leading to a loss of ring seal. Excessive blow-by and decreased power would result, ultimately leading to engine seizure/failure.

Oil absorbs heat as it flows through the engine. The combustion chamber is cooled by the jacket water in the cylinder head and around the sleeve and by lube oil on the piston. The heat is then transferred from the lube oil to the auxiliary or jacket water system by the lube oil cooler.

The lube oil contains many additives which enhance specific performance characteristics. Among these additives are dispersants and detergents which suspend dirt and water particles in the oil allowing for removal by the oil filter system. This cleansing action is important for component longevity.

OIL SUMP AND SUCTION LINE (PICKUP/SUPPLY)

The bottom of the crankcase is enclosed by an oil sump of cast steel. Perforated plates separate the oil sump from the crankcase to prevent foreign matter from getting into the lubricant. A suction pipe draws the oil from the lowest point in the sump.

Sump capacity including filters and coolers:

- 190 gal (719L) for the VHP 12-cylinder with deep sump oil pan
- 90 gal (340L) for the VHP 12-cylinder with shallow sump oil pan (option code 5005)

OIL PUMP

The gear-driven oil pump is externally mounted. On VHP 12-cylinder Series Four engines, the oil pump is located on the front of the engine, below the crankshaft. This oil pump contains an integral spool-type pressure relief valve and an adjustable oil pressure regulating valve that will maintain oil pressure regardless of engine speed or oil temperature.

PRESSURE REGULATING VALVE

The pressure regulating valve is used to maintain the engine oil pressure within the proper operating range. The valve is located in the front gear housing (see “Figure 10-1: 12-cylinder front gear housing - pressure regulating valve”) and is preset at the factory. When the engine is at operating temperature there should be 50-60 psi (345 – 415 kPa) in the oil header.

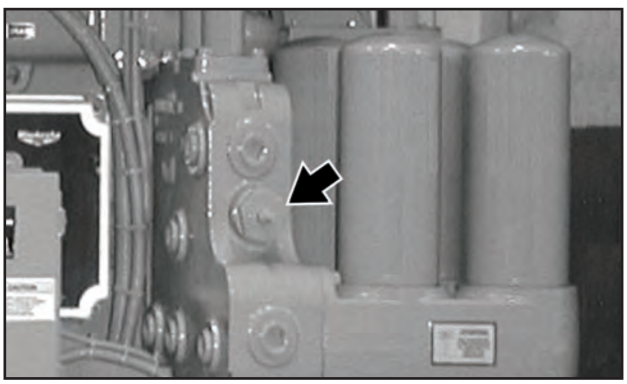


Figure 10-1: 12-cylinder front gear housing - pressure regulating valve

FULL-FLOW OIL FILTERS

The VHP engines use an oil filter system consisting of five replaceable filter cartridges mounted to a filter housing located on the front end of the engine for the 12-cylinder models. The oil filters are full-flow type. Each filter cartridge contains a bypass valve that prevents the loss of oil circulation due to a dirty filter.

The sight glass allows for inspection to ensure that the filters and base have been drained during filter changes (see “Figure 10-2: 12-cylinder Oil filters and housing”).

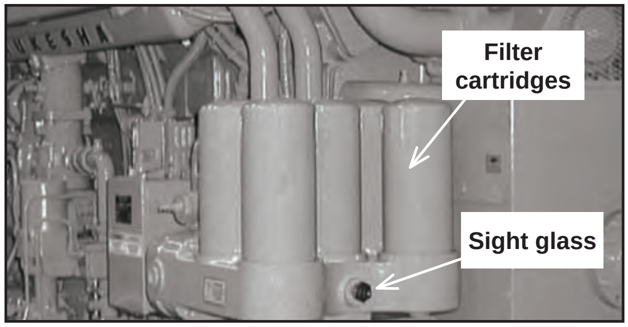


Figure 10-2: 12-cylinder Oil filters and housing

OIL TEMPERATURE CONTROL VALVE

The oil inlet temperature as measured at the oil header typically is 172°F (78C) (see “Table 10-1: Oil inlet temperature” and “Table 10-2: Oil inlet pressure”). The thermostatic valves are enclosed in the oil filter base on the 12-cylinder.

Table 10-1: Oil inlet temperature

OIL INLET TEMPERATURE AT THE OIL HEADER		
Normal	Alarm	Shutdown
180°F (82°C)	190°F (88°C)	200°F (93°C)

Table 10-2: Oil inlet pressure

OIL HEADER PRESSURE		
Normal	**Alarm**	**Shutdown**
50 - 60 psi (345 - 415 kPa)	35 psi (241 kPa)	30 psi (207 kPa)

OIL COOLER

The 12-cylinder oil cooler (see “Figure 10-3: 12-cylinder oil cooler”) is a tube and baffle type assembly. The auxiliary water pump circulates coolant through the oil cooler tube bundle. The oil circulates around the tube bundle. Heat from the oil passes through the tubes to the coolant, which then carries it to a heat transfer device for dissipation.

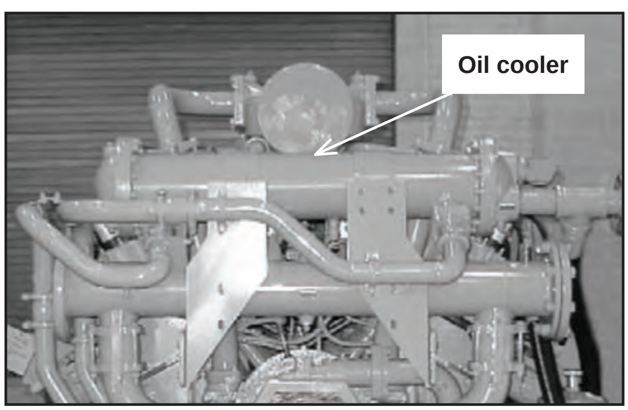


Figure 10-3: 12-cylinder oil cooler

CENTRIFUGE CLEANABLE OIL FILTERING SYSTEM

The centrifuge oil filtering system consists of a centrifuge, using a removable paper insert (see “Figure 10-4: Microspin centrifuge assembly”). The centrifuge is installed as a bypass system, working in conjunction with the full-flow filter. The centrifuge is driven by the engine’s oil pressure. The spinning action of the centrifuge’s internal turbine assembly develops a force that exceeds 2,000 Gs, which compacts the contaminants against the turbine’s housing. The centrifuge will remove oil-contaminating particles as small as 0.5 microns. The full-flow filter elements remove remaining particles as small as 25 microns absolute.

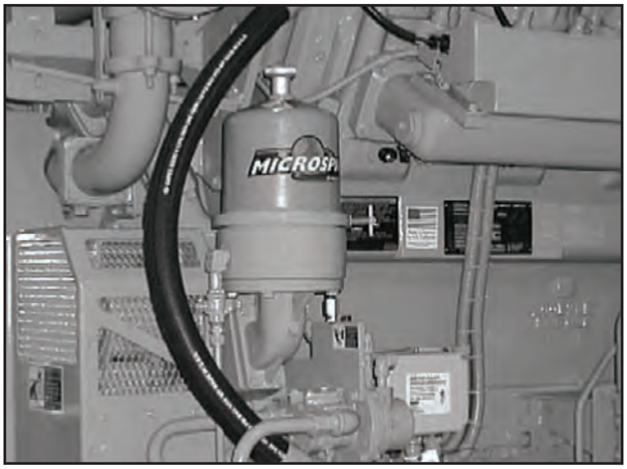


Figure 10-4: Microspin centrifuge assembly

ALLOWABLE ENGINE ANGLE LIMITS

Angular operating limits must be complied with to assure a constant supply of oil to the oil pump pickup screen. Due to its fluid nature, oil in the sump always flows to the lowest possi- ble point. If the engine is not level, it is possible that the oil pickup screen/tube would not be able to pick up the lubricant.

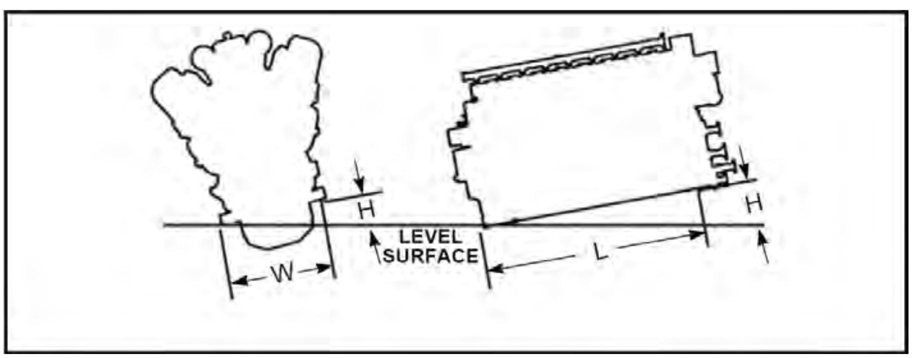


Figure 10-5: Angular measurement locale

This would mean a loss of lubrication at the bearings and other vital engine parts. Wauke- sha strongly recommends mounting the engine on a level surface. However, Waukesha has estab- lished permissible angles at which the engine can operate without loss of oil to the oil pickup screen (see “Table 10-3: Engine angular limits”).

Table 10-3: Engine angular limits

MODEL	FRONT DOWN DEGREES	REAR DOWN DEGREES	LEFT DOWN DEGREES	RIGHT DOWN DEGREES
VHP 12 Cylinder	2	2	7	7

1. Tabulated angle operation values are based on unidirectional tilt. For bi-directional tilt or allowable intermittent tilt consult Waukesha's Application Engineering Department.

2. Left and right are as viewed when facing the flywheel.

3. These values represent bare engine with oil leveler mounted in standard location.

LUBE OIL HEATER

Lube oil heaters are required for engines operating at ambient temperatures below 50° F (10° C), but if an electric prelube pump is used oil heaters are required below 65° F (18.3° C). Oil must be heated to ensure proper oil flow to ease start-ability and load application. For engines required to pull load immediately upon startup (standby applications), the oil should be heated to a minimum of 100° F (38° C). For engines that operate continuously other than planned service shutdowns, the oil should be heated to 70 – 100° F (21 – 38° C). Cold oil will not flow through the cooler and filter and still provide adequate supply pressure to the engine.

Waukesha requires circulating type oil heaters to be used. This prevents the burning or oil coking that can occur with immersion style heaters.

When piping for engine oil pre/post lubrication and oil heating, refer to the installation draw- ing for connection points and sizes. Oil is drawn directly from the engine oil sump drain, and piped to the inlet of the pump/heater. From the heater, the oil flow should be piped back to the engine oil sump.

Size the system following the heater manufacturer's recommendations based on system volume and ambient conditions.

PRELUBE PUMP/MOTOR

The function of the prelube pump/motor is to purge the lubrication system of air and to ensure that all moving parts are properly lubricated before the engine is started (see "Figure 10-6: Prelube motor/pump assembly (12-cylinder)" for the standard air/gas configuration). It is also used to ensure that sufficient heat is removed from the engine after shutdown.

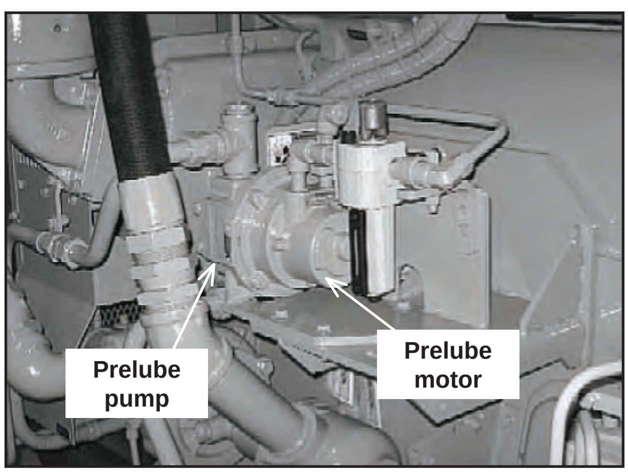


Figure 10-6: Prelube motor/pump assembly (12-cylinder)

The standard Waukesha air/gas prelube system will be controlled by the ESM system and wired from the factory. If combustible gas is used and the engine is installed in a hazardous area the solenoid valve exhausts must also be piped to a safe location per local codes.

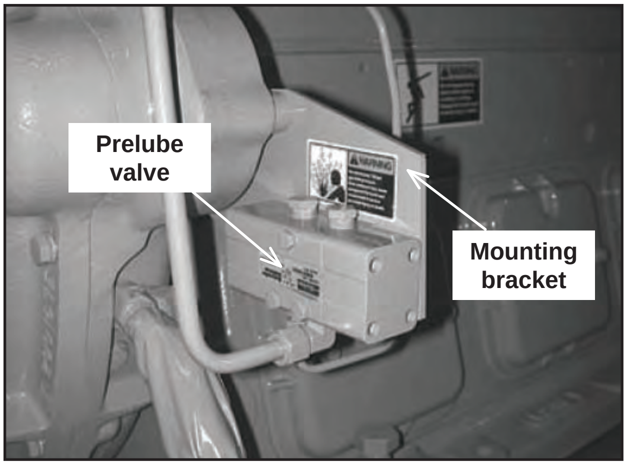


Figure 10-7: Prelube valve mounting bracket (12-cylinder)

PRELUBRICATION

Engine prelube extends engine life by filling the lube oil cooler and filter prior to the engine starting. This prevents the engine from being starved from the lack of lubricating oil upon immediate startup. Engine prelube also purges the lubrication system of air and ensures all moving parts subjected to friction are properly lubricated before the engine is started.

Prelubing is required on all VHP engine models. For continuous duty applications, the engine should run the prelube prior to each start. See the table below for prelube time, pressure, and flow rate. For standby applications, the engine should prelube for 5 minutes every hour to ensure the engine will be ready when it is required to start.

Pressures may drop in half with hot oil, flow is the determining factor.

The engine prelube is controlled by the ESM2. The duration can be changed in the Prelube Time field located on the [F3] Start-Stop panel in ESP.

Prelube specifications

ENGINE MODEL	PRELUBE TIME DURATION	PRESSURE (IN HEADER)	OIL FLOW RATE
VHP 12-cylinder	120 seconds before starting	1 - 4.5 psi[1] (7 - 31 kPa)	7 gpm[1] (26 lpm)

1. Based on 50°F oil
2. Based on 900 rpm pump speed

Table 10-4: Standard air/gas prelube motor specifications

ENGINE MODEL	AIR PRESSURE	MAX POWER	AIR CONSUMPTION
VHP 12-cylinder	70- 150 psig (482 - 1030 kPa)	1.9 hp (1.4 kW)	75 SCFM (127 m3/hr)

NOTICE **Excessive postlube may flood turbochargers.**

POST LUBRICATION

Waukesha recommends post lubrication for all VHP models. Post lubrication ensures that sufficient heat is removed from the engine after shutdown by providing cooling to the turbocharger bearings and preventing carbon coking of the oil which extends turbocharger life. Post lube should be performed automatically upon main gas valve closure for a minimum of 60 seconds after every engine shutdown. Excessive postlube may flood turbocharger.

WARNING

There must be NO postlube with any engine emergency shutdown.

LUBE OIL LEVEL REGULATOR

It is highly recommended to add a lube oil level regulator to the engine package if the option code for Waukesha to supply one is not ordered. ½” NPT connection is provided for venting line at the oil pan door. ½” NPT connection for the oil outlet is provided between 2L oil door pan and 1L oil door pan for deep sump oil pan and on the oil fill manifold for shallow oil sump. Lube oil level controllers are designed to maintain the running oil level in the crankcase of stationary engines. The oil controller works in conjunction with an overhead oil supply system which feeds the oil level controller. As the oil is consumed, the oil controller supplies the required amount of oil to maintain a proper level in the crankcase. The oil controller maintains the proper amount of oil in the crankcase using a float controlled valve. The valve opens and closes as oil is needed in the crankcase to provide a constant oil level. There are optional oil level switches that can be added to trip an alarm if the oil level is too high or too low.

The oil level controller can be mounted onto the engine oil pan or skid, and has a sight glass to visually show engine lube oil level. For engine oil level, reference Oil Level section below.

The Waukesha supplied (option code 5022) lube oil regulator comes mounted on the oil pan and replaces one of the oil pan doors. The customer supplied make up tank must be at least 2’ (0.6 m), and a maximum of 25’ (7.6 m), above the inlet to the Kenco controller. The oil lines must be steel and should be ½” I.D.; the controller has a ½” NPT connection. The shipped loose fire safe valve should be installed in the oil line as close to the controller as possible.

When regulators are customer-supplied, it is important to follow the regulator manufacturer’s installation instructions. This includes properly routing a vent line to the crankcase (above the oil level) to reference the correct pressure. The vent line should have a continuous downward pitch, and be sized per the manufacturer’s recommendations (e.g. for the Waukesha supplied models, minimum size is 3/8” I.D.). Additionally, for VHP engines, oil level regulators should be installed on the left side of the engine. For the VHP 12 cylinder models, the recommendation is to install on the crankcase door, left side, 3rd door from the rear. Due to effects of rotation of the crankshaft within the crankcase, installing a regulator in different locations could result in issues maintaining the proper oil level.

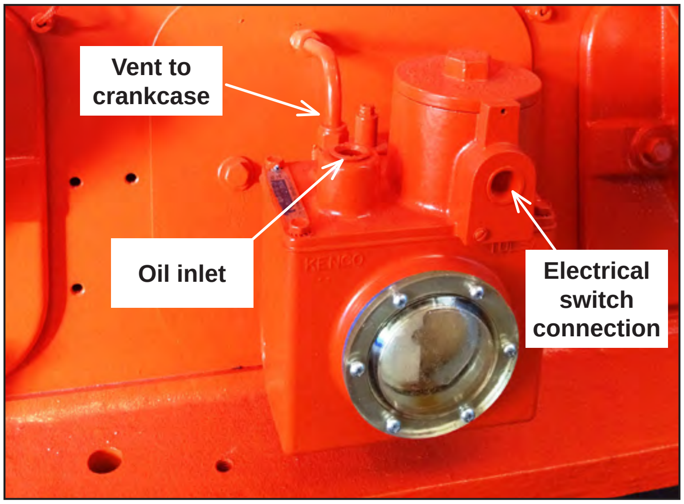


Figure 10-8: Optional Waukesha supplied oil level regulator

TYPICAL OIL CONSUMPTION

Typical lube oil consumption for a new Series Five engine running 1200 rpm at full load will be about 0.0003 lb.bhp-hr Waukesha recommends sizing make-up tanks to accommodate oil consumption of 0.0005 to account for variability in engine operation and age. See “Table 10-5: VHP Oil Consumption”:

Table 10-5: VHP Oil Consumption

ENGINE MODEL	Power		Oil Consumption	
	(hp)	(kW)	(gal/day	(L.day)
L7042GSI S5	1500	1104	1.5	6.8
L7044GSI S5	1900	1253	1.9	8.6

Oil consumption will vary depending on site conditions, engine load, engine speed, and the age of the engine. Excessive oil consumption is a sign that the engine may need service. When sizing an oil makeup tank double the values above to plan for oil consumption increase as the engine ages.

MAINTENANCE CONSIDERATIONS

OIL CHANGE

WARNING

Hot oil can cause severe burns. Allow oil to cool prior to working an oil system components. Wear protective equipment and use caution while working on oil system components.

WARNING

Always consider the weight of the item being lifted and use only properly rated lifting equipment and approved lifting methods.

WARNING

Allow the engine to cool to room temperature before cleaning, servicing or repairing the unit.

Always stop the unit before cleaning, servicing or repairing the unit or any driven equipment.

Always place all controls in the OFF position and disconnect or lock out starters to prevent accidental restarting. If possible, lock all controls in the OFF position and take the key. Put a sign on the control panel warning that the unit is being serviced.

Always close all manual control valves, and disconnect and lock out all energy sources to the unit, including all fuel, electric, hydraulic, and pneumatic connections.

Always disconnect or lock out driven euipment to prevent the possibilty of the driven equipment rotating the disabled engine.

CAUTION **Do not put the filter or cooler near the exhaust outlet or other places where the temperature could become excessively warm. Excessive heat will speed oil deterioration. It will also create a fire hazard in the event in the event of an oil spill or line rupture.**

Change the oil, including the oil filters, every 4,000 running hours or as determined by oil anal- ysis. Oil change intervals should never be extended beyond this recommendation because of additive depletion and changes in the physical properties of the oil. A sample of the used oil should be submitted for analysis after every 500 running hours at first , then can potentially be extended based on the analysis results.

When operating on a fuel that contains hydrogen sulfide (H_2S), the oil should be changed every 500 hours or sooner as determined by the lube oil analysis. Samples should be taken every 100 hours to ensure the oil is within the condemning limits given in S-1015-30.

Based on environmental and engine operating conditions, the lubrication oil may require changes that are much more frequent than those recommended by Waukesha. Many vari- ables are involved in determining the proper time between oil changes. The oil type, the se- verity of the environment and the internal condition of the engine are only a few of many variables that have a direct effect on the frequency at which the oil must be changed.

Using an incorrect oil or extending the time between oil changes may cause varnish deposits, oil oxidation/nitration, sludge or any number of problems to appear.

The paragraphs below highlight the basic procedure for completing an oil change. More detailed instructions can be found in the VHP Series Five O&M, FORM 10063-1

OIL FILL – INITIAL PROCEDURE

Fill the engine oil through the filler pipe located at the lower rear left side of the engine (see “Figure 10-9: Oil fill location”). Add oil until the level reaches the FULL mark on the dipstick. Then, run the prelube pump to fill the oil lines, cooler and filters. Recheck the oil level and fill until the oil level is back at the FULL mark. Install oil filler cap, start engine and allow oil to warmup to its normal operating temperature. Shut engine down and allow oil to drain back into pan. Check the dipstick and add oil to oil pan until level returns to FULL mark.

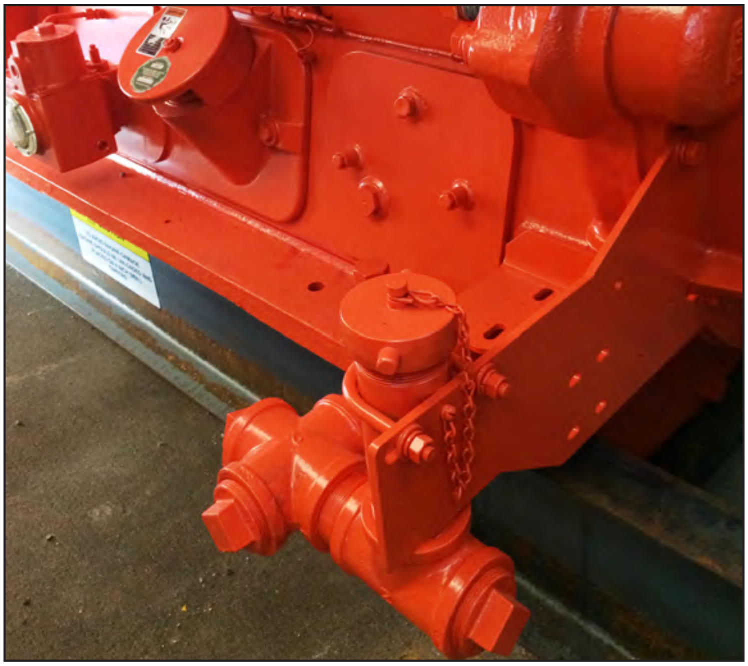


Figure 10-9: Oil fill location

OIL DRAIN

NOTE: *Drain oil warm for best results*

Oil Cooler: Remove the drain plug at bottom of oil cooler shell midway between inlet and rear bonnets. Install drain plug after oil has drained. Open the drain petcocks in oil cooler tubing. Close the petcocks after oil has drained.

Oil Filters: Open drain valve under filter housing to allow oil to drain back into the oil pan. Use sight glass in filter base to verify that the filter base has drained. Remove filter elements from housing.

Oil Pan: Remove 2 in. square-head drain plug. For convenience, two drain plugs are provided, one at each end of the oil pan. Retain an oil sample for oil analysis. Install drain plugs after oil has drained. Installation of a customer-supplied ball valve and pump facilitates draining of the oil pan.

The level of the oil in the crankcase should be checked each day while the engine is running and should always maintain the oil level at the upper notch. Since there is no static line on the dipstick, it does not indicate where the level of the oil in the sump should be when the engine is shut down. The difference between “Full” mark and “Low” mark on the oil pan dipstick, for VHP 12 cylinder deep sump oil pan is 22 gallons.

Whenever the oil level is checked, carefully examine the condition of the oil on the dipstick. Replace the oil any time it appears diluted, thickened by sludge or otherwise deteriorated.

OIL PRESSURE ADJUSTMENT

NOTE: *Before adjusting the oil pressure, always check the condition of the oil filters and replace if necessary. A dirty filter will cause the engine oil pressure to drop.*

The pressure regulating valve is adjusted on the outside of the engine through the use of an adjustment screw (see “Figure 10-10: Oil pressure control valve on 12-cylinder models”). Before adjustment of the oil pressure, the oil temperature must be at normal operating temperature with the engine operating at rated speed. Adjust the oil pressure to maintain 55 psi (380 kPa) at the maximum rated speed. Turn the screw in to increase the oil pressure and out to decrease the oil pressure.

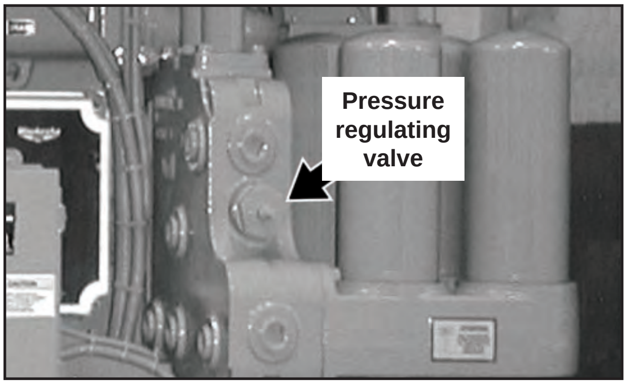


Figure 10-10: Oil pressure control valve on 12-cylinder models

OIL SAMPLING

An oil sampling port is located under the oil filter base on the engines. This is provided to allow lube oil samples to be easily taken for regular oil analyses.

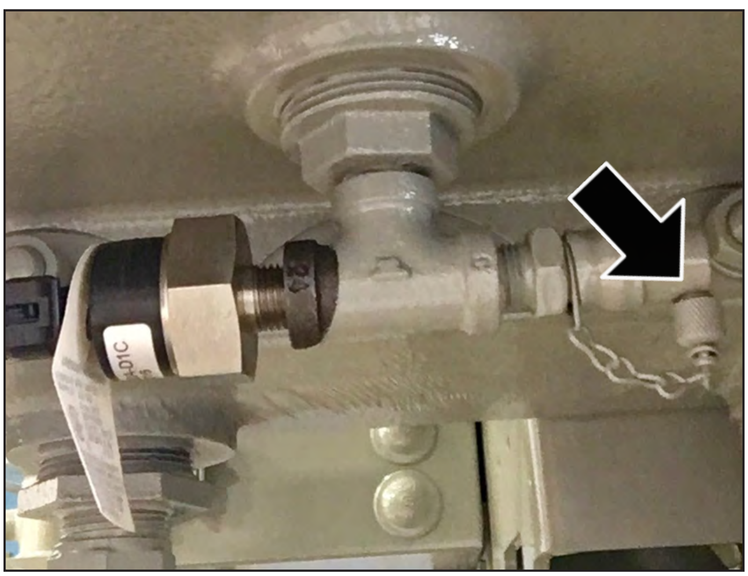


Figure 10-11: Oil Sampling Port - Bottom of oil filter base

CHAPTER 11 - CRANKCASE BREATHER SYSTEM

CRANKCASE BREATHER SYSTEM COMPONENT DESCRIPTION

The purpose of the crankcase breather system is to maintain a slight negative pressure in the crankcase. The negative pressure rids the crankcase of harmful water vapors and combustion gases, and helps to prevent sludge buildup and oil contamination. Maintaining a negative crankcase pressure is important to prevent oil leaks and vacate harmful vapors, but too much vacuum pulls in environmental dust and dirt. Vacuum lines from both turbocharger compressors create the draw past engine seals that pulls the gases from the crankcase. The gases go through a pre-separator and main (coalescing) separator to remove oil vapor from the gases prior to being drawn into the engine. The separated oil is returned to the crankcase through a return tube which contains a one-way check valve that prevents backflow of oil and/or vapor back into the separator. The crankcase pressure is regulated by the pressure regulator valve so the specified negative pressure in the crankcase is maintained. The crankcase breather system has the following benefits:

- Reduction of oil blow-by with use of new breather separator assembly
- Connection of breather system to both turbocharger banks reduces risk of coking the turbo and intake system
- Maintains crankcase vacuum across speed/load changes for improved sealing
- Extended service intervals (estimated at 8,000 hours depending on operating conditions)

NOTE: This breather system is not available on engines using a low pressure (draw-thru) fuel system.

The crankcase breather system consists of the following components:

- Breather pre-separator
- Crankcase pressure regulator valve
- Breather separator assembly
  - 12- Cylinder: Qty 1
- Breather check valve
- Breather insulation blanket
- Breather system tubing

BREATHER PRE-SEPARATOR

The breather pre-separator is located on the crankcase at the inlet breather tube connection.

The pre-separator allows vapors to be vented from the crankcase. It also serves to stop a portion of the oil carried by these vapors from reaching the oil separator. As the oil mist and vapors pass out of the crankcase, the expanded metal elements in the pre-separator restrict the flow of much of the oil, dropping the surplus back into the oil pan.

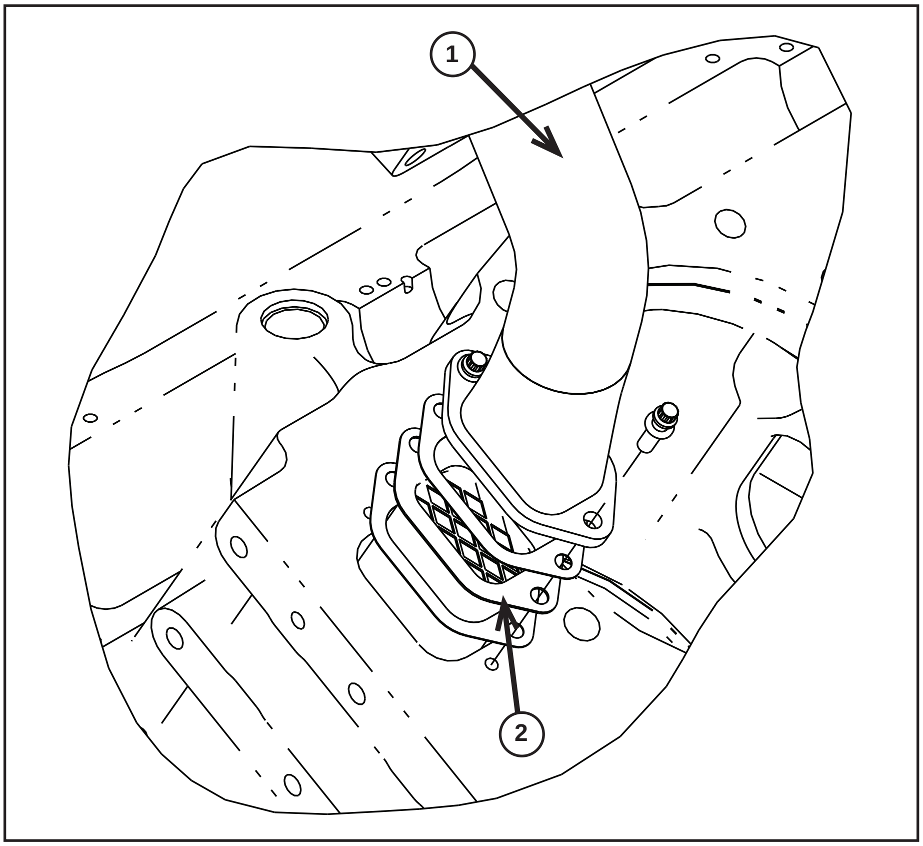


Figure 11-1: Breather pre-separator schematic

1. Breather inlet tube to crankcase pressure regulator valve
2. Breather pre-separator

CRANKCASE PRESSURE REGULATOR VALVE

The crankcase pressure regulator valve is connected to the oil separator inlet piping. The crankcase pressure regulating valve automatically adjusts to compensate for variations in crankcase pressure due to changes in engine speed and load to maintain crankcase pressure to specified levels. The valve assembly within the crankcase pressure control valve is calibrated to move up and down in response to turbocharger source vacuum. This movement opens or closes the through passage in the valve regulating the volume of air drawn from the crankcase.

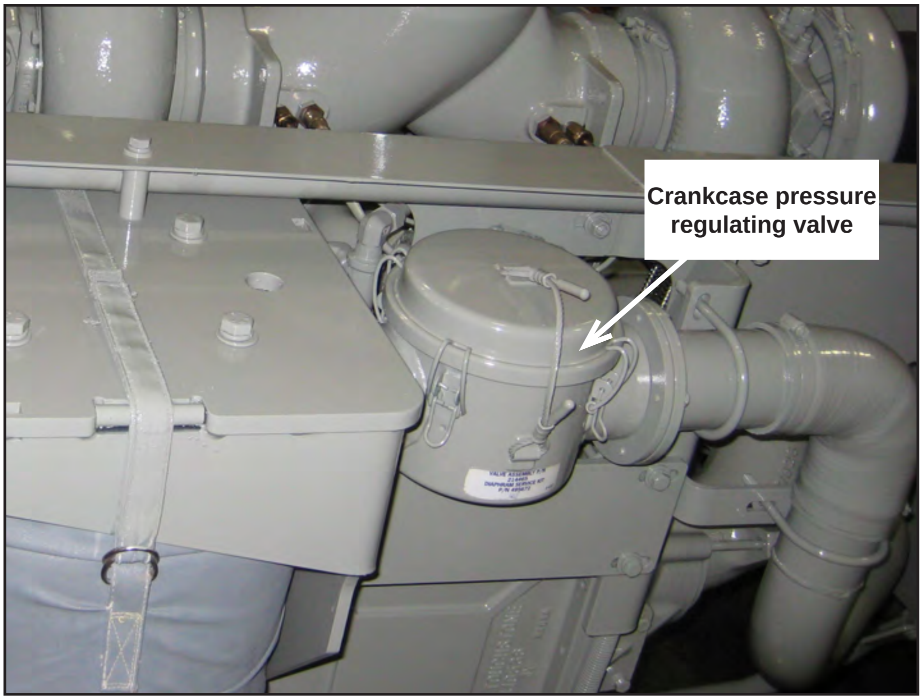


Figure 11-2: Crankcase pressure regulating valve

CRANKCASE PRESSURE REGULATOR VALVE OPERATION

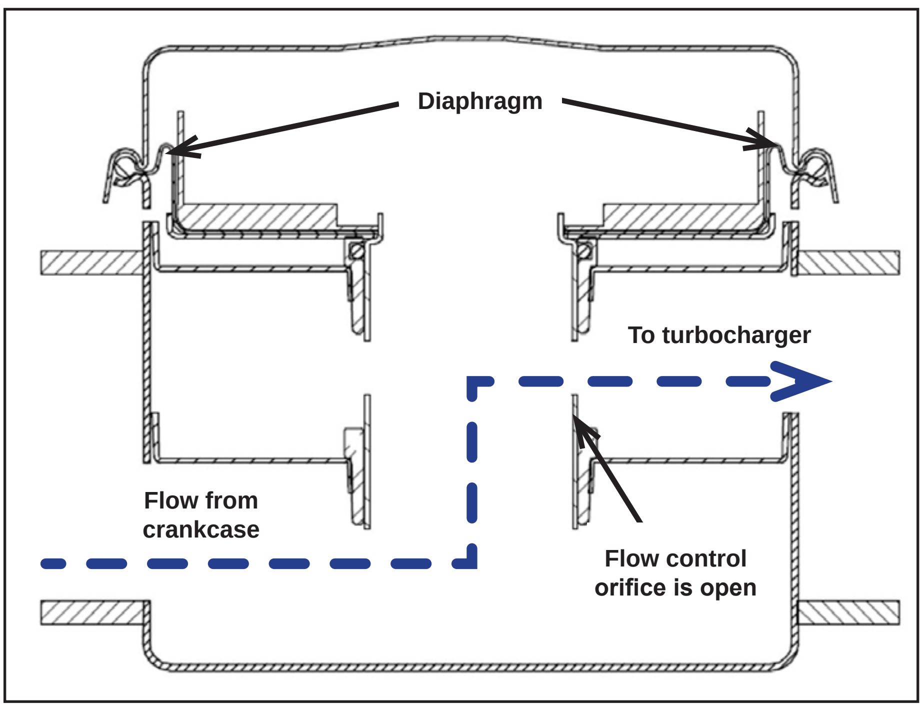


Figure 11-3: Cutaway of crankcase pressure regulating valve under low loads

Low load:

Under low load with minimal vacuum from the turbocharger, the diaphragm lowers to allow higher flow of crankcase vapors (See “Figure 11-3: Cutaway of crankcase pressure regulating valve under low loads”).

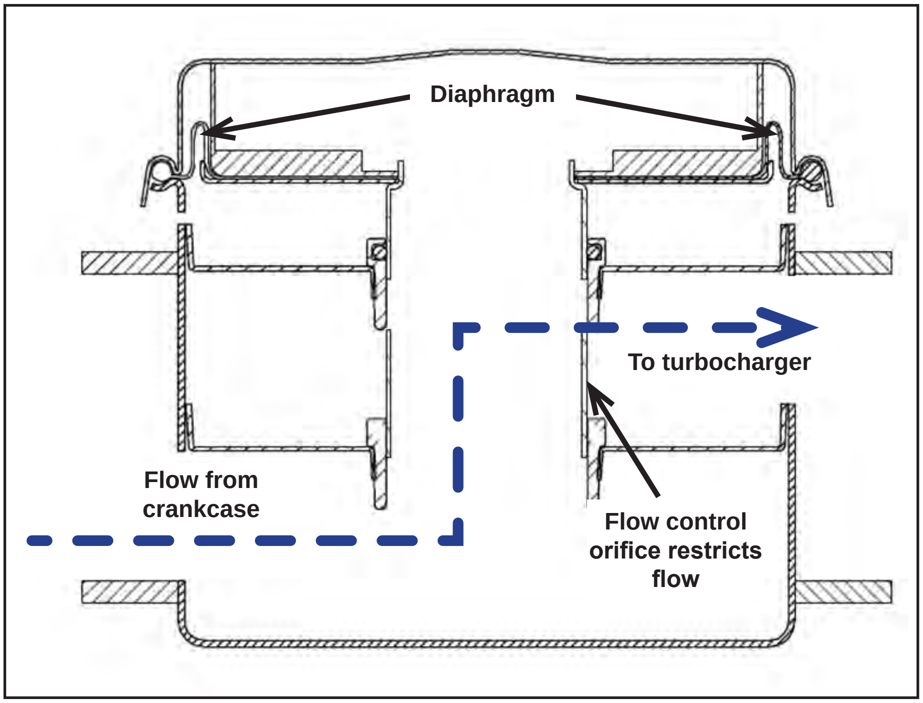


Figure 11-4: Cutaway of crankcase pressure regulating valve under full load

Full load:

Under higher loads with greater vacuum from the turbocharger, the diaphragm raises to restrict the flow of crankcase vapors. (See "Figure 11-4: Cutaway of crankcase pressure regulating valve under full load")

BREATHER SEPARATOR ASSEMBLY

The breather separator assembly is a canister with a replaceable coalescing element that condenses oil vapor into liquid form so it can be transferred back to the crankcase. The crankcase vapors are drawn from the breather by the turbocharger compressor into the air induction system and are burned in engine combustion.

The breather separator is wrapped with an insulation blanket. This blanket prevents any moisture from the crankcase vapor from freezing. It also improves blow-by gas entrained oil separation efficiency. This blanket must remain installed on the breather separator.

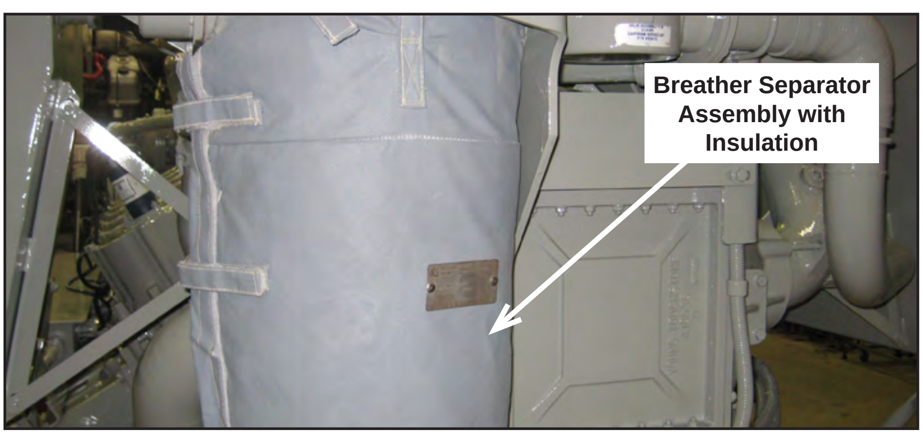


Figure 11-5: Breather separator assembly

BREATHER CHECK VALVE

The check valve is located at the base of the drain tube. It allows oil to return to the engine from the separator but prevents backflow of oil or vapor. The breather system components and routing have been specifically designed for the engine and should not be modified. The breather separator oil drain but exit below the oil pan oil level. The oil pan oil level must be kept at the FULL mark at all times for proper breather system operation.

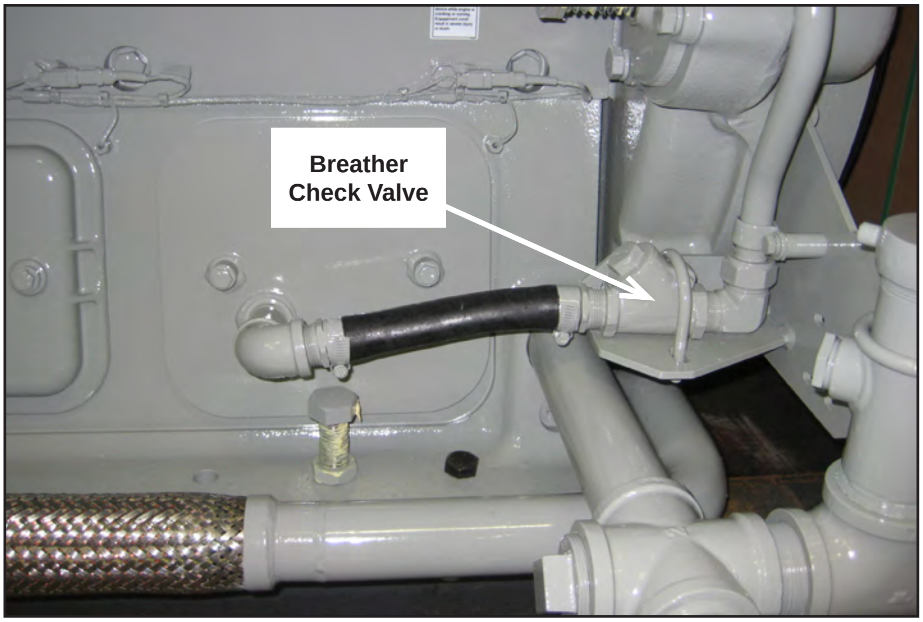


Figure 11-6: Breather check valve

MAINTENANCE

The following maintenance schedule should be followed for proper operation of the crankcase breather system.

COMPONENT	SERVICE INTERVAL	MAINTENANCE
Breather separator element	8,000 hours	Replace element
Return line check valve	8,000 hours	Inspect, replace if needed
Pressure regulator valve	12,000 hours	Clean/inspect, replace diaphragm if needed
Pre-separator screen	40,000 hours	Clean/inspect

CHAPTER 12 - CRANKCASE PRESSURE RELIEF VALVES

OPTIONAL EQUIPMENT

WARNING

The number of crankcase pressure relief valves used on the engine depends on the volume of the crankcase. Never operate the engine without all necessary valves on the engine working properly. The ability of the system to function is dependent upon the proper number of relief valves. Do not operate without the proper type and number of relief valves, or without the relief being properly maintained. Operating the engine without the proper type and number of relief valves may result in fire and explosion.

- Bicera crankcase pressure relief valves.
- Crankcase differential pressure switch.

CUSTOMER SUPPLIED EQUIPMENT

- Crankcase pressure relief valves (when not using Waukesha option)
- Crankcase differential pressure switch (when not using Waukesha option)

DESCRIPTION

The VHP engines have been designed with optional crankcase pressure relief valves on the crankcase doors. The number of relief valves are sized based on a ratio of 1.5 square inches of relief area per cubic foot of crankcase volume. As a safety precaution, crankcase pressure relief valves are available (see “Figure 12-1: Crankcase Pressure Relieve Valves”). The valves open fully when the pressure in the crankcase exceeds 6.9kPa (1psi) and close tightly and quickly to prevent the inflow of air after the internal pressure has been relieved. In this way, the possibility of a secondary explosion is greatly reduced. The valves do not prevent crankcase combustion, but only reduce the peak pressures during combustion, thereby minimizing damage.

Since there are always flames present in any explosion, the valve incorporates an internal flame trap to retard the emission of flame while the valve is venting. The flame trap is of an oil-wetted wire gauze design. The cooling capacity of the gauze is doubled when it is oil-wetted, a condition affected by the oil mist that normally exists in the crankcase or by an oil spray from the connecting rod bearings. The valve incorporates the flame trap as a single unit and the O-ring construction eliminates oil leakage.

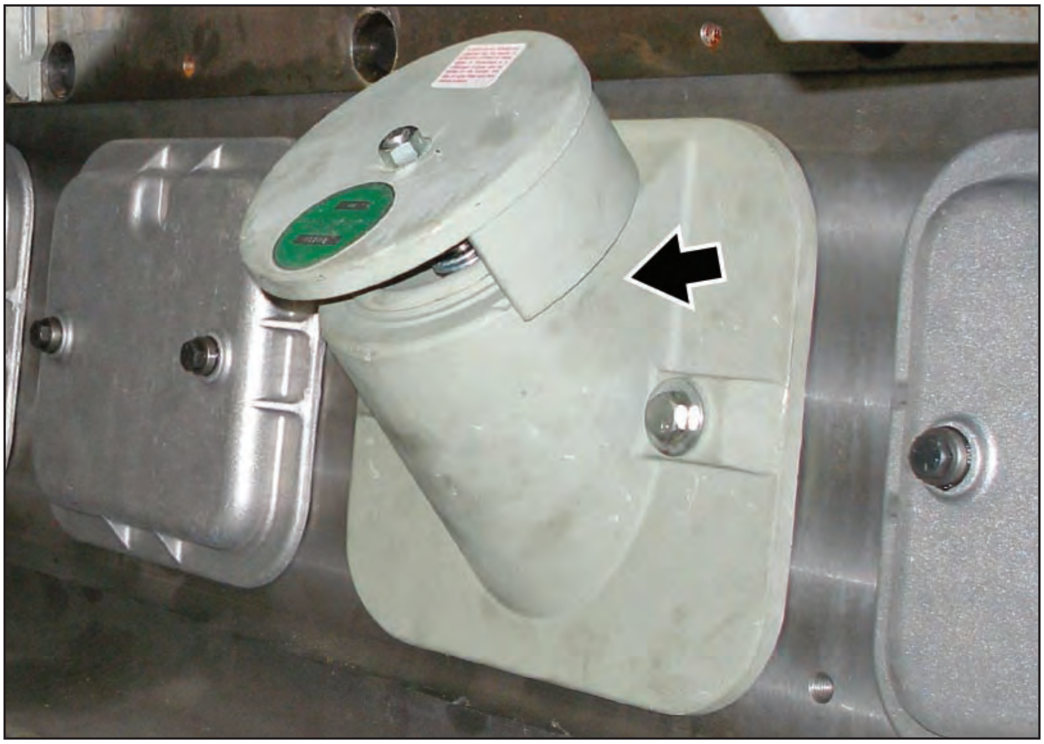


Figure 12-1: Crankcase Pressure Relieve Valves

The engine should not be allowed to operate with positive crankcase pressure due to the potential for a crankcase explosion. An engine safety pressure switch should be installed to detect positive crankcase pressure. An optional crankcase differential pressure switch is available which requires customer supplied alarm or shutdown logic in the event of a positive pressure. Also the crankcase pressure is a good indication on the engine condition (i.e. in event of catastrophic failure excessive blowby occurs resulting in high crankcase pressure).

MAINTENANCE CONSIDERATIONS

The seals in the explosion relief valves are intended to last for 16,000 hours before replacement is necessary, depending on the operating temperatures, engine vibration, etc. If the seals have gone over the seal life expectancy of 16,000 hours, they should be replaced to prevent oil leakage.

Exercise and inspect the crankcase pressure relief valves annually to ensure that they are in proper working condition.

CHAPTER 13 - COMBUSTION AIR INTAKE SYSTEM

INTAKE AIR REQUIREMENTS

- Air filter assemblies installed in a clean, dry location with minimal temperature variations
- Air filter assemblies installed with easy access to perform frequent air filter maintenance
- Intake air piping sized with minimal restriction
  - Total air induction system restriction (including air filter when dirty) less than 15 inches (381 mm) H_2O
- Intake air temperature less than 50°F (10°C) typically requires additional heating for effective engine starting
- Intake air temperature less than 0°F (-17.8°C) typically requires additional heating for effective engine operation
- Intake air temperature greater than 100°F (38°C) requires engine power reduction, refer to EngCalc site specific power ratings
- Intake air system designed to minimize temperature variation from hot and cold sources
- Intake air filter protective panels removed before engine commissioning
- Turbocharger air inlet silencers are not available from Waukesha

STANDARD EQUIPMENT – 12 CYLINDER (GSI)

- Engine mounted air cleaners with rain shield (one per bank).
- One 3in (76mm) thick, dry type filter element (one per bank).
- A service indicator mounted in the air cleaner housing (one per bank).

OPTIONAL EQUIPMENT – 12 CYLINDER (GSI)

- 2320B - Heavy duty inertia separator precleaners

NOTE: This replaces the standard rain shield, so rain protection will be needed.

- 2350 - Air cleaner housing modification for remote air intakes

CUSTOMER SUPPLIED EQUIPMENT

- Maintenance walkways for frequent changing of air filter elements (if necessary)
- Intake air heater for effective starting when combustion air inlet temperature will be less than 50°F (10°C) or if ambient temperature is below 0°F (-17.8°C) for continuous operation.

SUPPORTING DOCUMENTS

L-08088-30	VHP Series Five 12-Cylinder outline drawing
L-08088-29	VHP Series Five 12-Cylinder GC Spec outline drawing
L-08041-316	12 Cylinder Heavy duty precleaner drawing
L-0 8041-342	12 Cylinder Air cleaner housing modification for remote air intakes drawing
EngCalc	Engine data program for site specific combustion air flow rate

INTAKE AIR FILTRATION

The air intake filters used for VHP 12-cylinder engines are side-mounted on the rear of the engine standard (one for each engine bank). Each air filter assembly consists of one dry main air filter element and air restriction service indicator. The air filter assembly housings consist of a standard hinged rain shield to easily replace the air filter element.

Outline drawings of the air filter assembly housings can be found in Waukesha's standard engine outline drawings on www.ge-distributedpower.com.

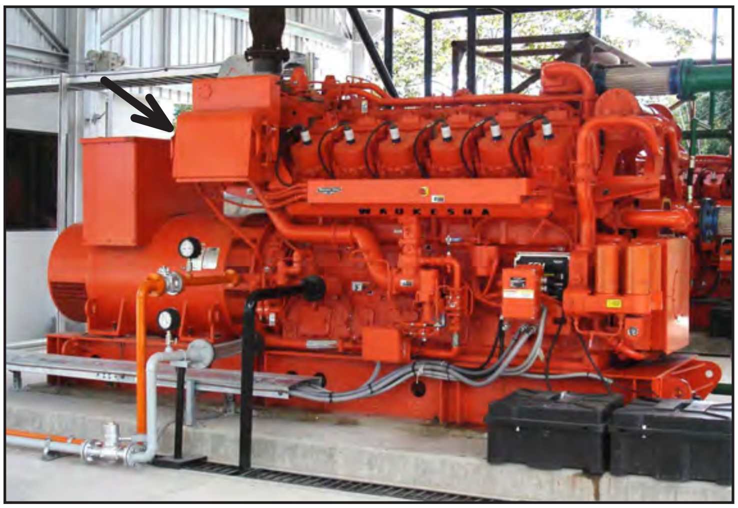


Figure 13-1: Standard air cleaner assembly mounted on a 12-Cylinder VHP

For extremely dusty air conditions, heavy duty air filter housings are available which utilizes inertial forces to remove a portion of the dust prior to reaching the main filter element. This inertial type precleaner can be ordered from Waukesha and replaces the standard rain shield on the air cleaner housing. It effectively filters out 70 – 90% of the large dirt particles in the first stage, thereby reducing the dust load passed onto the second stage of the filter. The precleaner is made up of various cyclone tubes. Large dirt particles are spun out of the air as it is drawn through the cyclone tubes and fall into a dust bin located at the bottom of the panel. These inertial type precleaners require the large dirt particles to be frequently emptied (based on site conditions) from the dust bin using an included discharge valve at the bottom of the dust bin. Each filter requires the customer to provide a cover to protect rain intrusion when installed outdoors.

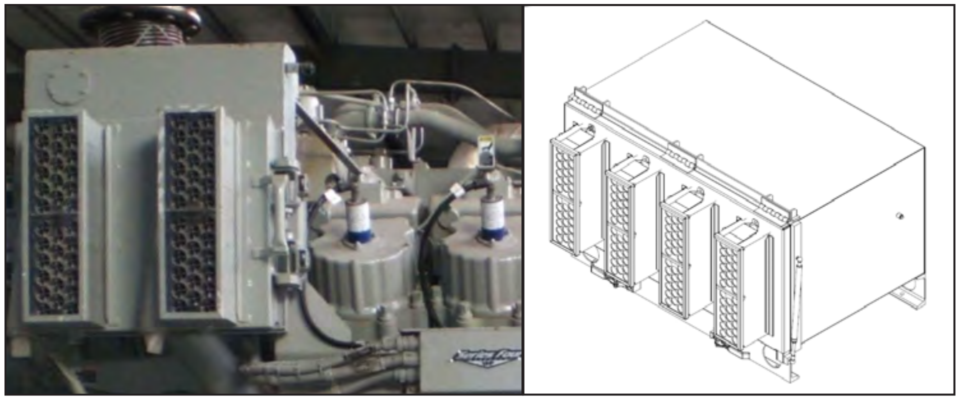


Figure 13-2: Optional inertia precleaners (12 cyl, engine mounted)

WARNING

Air inlets must be located away from fuel tanks, flammable vapors, tank vents, chemicals, industrial wastes or any other material of explosive nature. An engine backfire could ignite such material causing a dangerous explosion. Also, these volatile fumes could be drawn into the engine. Disregarding this information could result in severe personal injury or death.

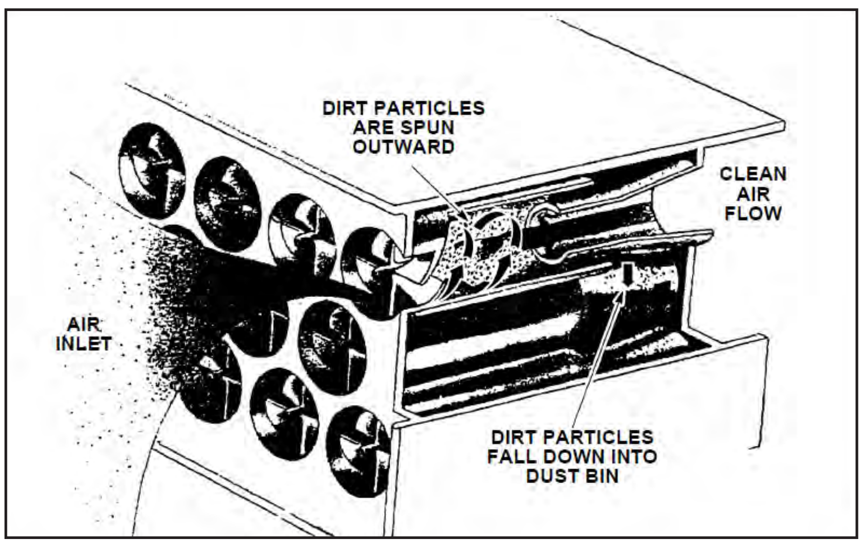


Figure 13-3: Schematic of air filter inertia separators

If intake air is desired to be taken from outside the engine room/enclosure for 12-cylinder models, the option code to modify the air cleaner housing should be selected. This modification allows for the breather system to operate properly when using remote air intakes by leaving the air filter housings on the engine. The modification provides a 5.5in (139.7mm) outside diameter connection on the top of the filter housing which should be connected to a customer supplied flexible hose to allow servicing of the air filter element without disconnecting the customer piping. When designing the piping for remote air intake, the maximum restriction of the air intake system must not be exceeded.

CAUTION

All pipes and fittings used to bring air into the system must be absolutely free of dirt, scale and slag. Otherwise this material may be drawn into the engine upon startup and will damage engine components.

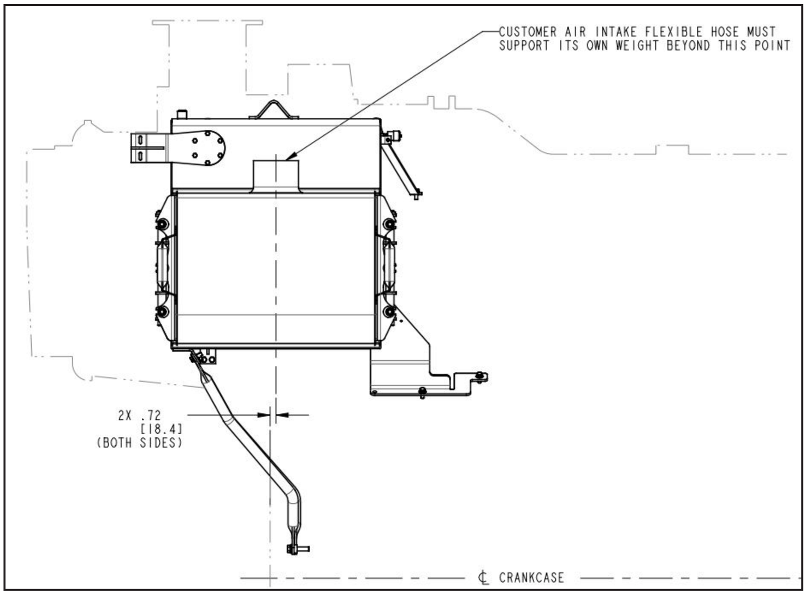


Figure 13-4: Air Cleaner Housing Modification for Remote Air Intakes

A total of 15” H2O restriction is allowed for the intake system. When the filter is mounted on the engine that means the air filter can absorb 15” of restriction before the filter needs to be changed. If the filter is mounted remotely and the piping adds an additional 5” H2O restriction it means that the air filter must be changed once its restriction reaches 10” across the filter.

Waukesha supplied air filter assembly specifications with clean air filter elements (per each assembly):

Restriction is based on standard conditions when running at full rated load. Restriction is based on clean air filters and the restriction will increase as the filter element becomes dirty. A reserve in restriction should be included to account for dirty air filter elements. The air restriction indicator will show “red” if the air intake restriction is 15 in. (381mm) of water. This indicates a clogged or dirty main air filter element.

Table 13-1: Inlet Air Restriction

Engine Model	Air Flow Rate (scfm)	Standard Air Filter Restriction (in w.c.)	Inertia Precleaner + Standard Air Filter Restriction (in w.c.)
L7044GSI S5	2536	1.5	3.5
L7042GSI S5	2224	1.3	2.9

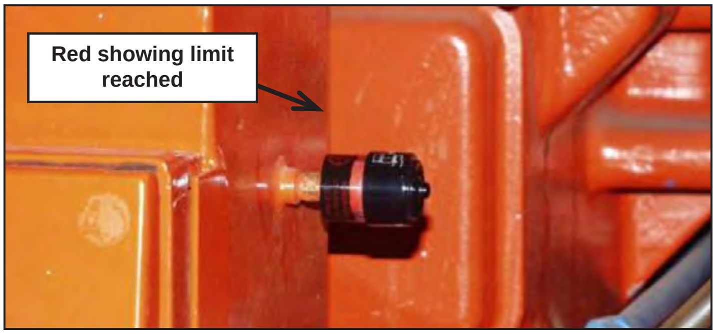


Figure 13-5: 12-cylinder Service Indicator

AIR TEMPERATURE

The temperature of the combustion air will vary depending on site conditions. It is preferred to design the air intake system in a method that will reduce the amount of temperature variation as much as possible. High temperature air is less dense and has fewer molecules per unit volume which reduces engine power output. The heat rejection to the intercooler can increase significantly, resulting in an increase in the radiator or heat exchanger size also. Refer to the Technical Data for engine specific derate information, or the latest EngCalc program for power ratings at elevated ambient air temperatures.

Cold intake air can also adversely affect engine operation affecting turbocharger performance and engine stability. Cold intake air creates a cold combustion chamber which can cause turbocharger surge, delay ignition and create a cold combustion chamber which can makestarting the engine difficult. In cold ambient temperatures, below 50°F (10°C), intake air heating is typically required for effective engine starting, and below 0°F (-17.8°C) will require heating for normal operation of the engine. Ducting air from the warm side of the radiator, utilizing engine jacket water heat to warm ducted air through the use of a packager supplied heat exchanger, or using warm engine room air are common methods of providing warm air in cold climates. Water heaters for the intercooler circuit are not an effective form of heating the combustion air because it does not heat the air up-stream of the turbocharger which is required to prevent turbo surge.

TRI-SENSOR

A Tri-Sensor, mounted in the right bank air cleaner housing, provides temperature, humidity, and barometric pressure display on the HMI.

Figure 13-6: Inlet Air Temp./Pressure/Humidity Sensor (12-cylinder)

CHAPTER 14 - EXHAUST SYSTEM

EXHAUST SYSTEM REQUIREMENTS

- Exhaust system must be properly supported with no forces applied to engine exhaust connection
- Proper selection and placement of flexible connections, to account for thermal expansion in both horizontal and vertical directions
- Adequate materials to be used, of sufficient strength and temperature capabilities. Recommended are listed below for guidance:
  - ANSI schedule 10 stainless steel pipe
  - ANSI schedule 20 carbon steel pipe
- Carbon steel piping should not be insulated. The higher temperatures and ability to trap moisture can lead to the deterioration of the piping. Waukesha recommends using stainless steel piping when insulating piping.
- Exhaust piping and components sized with minimal restriction
  - Total exhaust system restriction less than 20 inches (508mm) H_2O, at full load and 1200 RPM
  - Refer to S-7567-3 Ensure any exhaust transition sections are smooth (no abrupt transitions)
  - Exhaust elbow sections should be of the long radius type
- Piping should be sized to keep exhaust velocity less than 12,000 ft/min (60 m/sec). This will keep exhaust restriction and exit noise low
- Explosion relief valves, if installed, should be located in the exhaust piping near the engine to protect exhaust components from a damaging exhaust explosion. Explosion relief valves must be vented to a safe location to prevent fires or personal injury.
- Silencer(s) should be sized using the proper exhaust flow rate, temperature, and to achieve local/site sound attenuation requirements
- Moisture traps and drains - during startup of a cold system, water can condense and collect in low spots of exhaust piping. Moisture traps and drains in the low spots provide a way to remove this water. Many silencer manufacturers include drains in their equipment. Piping should be sloped away from engine.
- Common Exhaust Systems – the use of a single exhaust system fed by multiple engines is not allowed.
  - If an engine is not in operation, exhaust gas from other engines (s) can condense water in the non-operating engine and result in damage.
  - The engine which is not in operation can also be a path for exhaust gas to leak.
- Maintenance considerations
  - Access to drain points
  - Access to allow for catalyst replacement, if applicable
  - Access for emissions port sampling, if applicable

– Clearance between exhaust system components and building cranes or other site equipment

- Layout considerations

  – Exhaust outlet location and orientation should not be in the vicinity of the engine air intake or radiators/coolers. Prevailing winds should be considered.

  – The exhaust outlet should be designed to keep out rain, dirt, and other debris. This can be accomplished with a rain cap.

- Emissions – local requirements may require exhaust aftertreatment to attain specific emissions levels. If required, such equipment should be appropriately sized considering exhaust flow, temperature, and emissions produced by the bare engine.

- Exhaust purging - To prevent explosions and personal injury the engine and the exhaust system are purged by cranking the engine for several seconds before the ignition is turned on and the fuel valves are opened. The purge volume of the engine is approximately its displacement for every two revolutions. Additional purge time can be added in ESM2 via a user-programmable field. Up to 30 seconds can be added while still allowing the engine to start.

- Thermocouples are read and controlled by ESM2.

WARNING

Use high temperature gasket materials and proper room ventilation. Inadequate gaskets can break down allowing poisonous exhaust gas to leak. These fumes can cause personal injury or death.

CAUTION

Never discharge engine exhaust into a brick, tile, or cement block chimney, or a similar structure. Exhaust pulsations could cause severe structural damage.

STANDARD EQUIPMENT

Standard Engine (non-GC Spec)

The exhaust system consists of the following components:

- Water cooled exhaust manifold segments (one per cylinder)
- Stainless steel flexible bellow to account for engine thermal growth and vibration

GC-Spec

The exhaust system consists of the following components:

- Water cooled exhaust manifold segments
- Stainless steel flexible bellow to account for engine thermal growth and vibration

OPTIONAL EQUIPMENT

- emPact Emissions Control System with catalyst sized for 0.50g/bhp-hr NOx and 1.0g/bhp-hr CO
- emPact Emissions Control System with catalyst sized for 0.15g/bhp-hr NOx and 0.3g/bhp-hr CO

CUSTOMER SUPPLIED EQUIPMENT

- Exhaust Piping, supports
- Flex connections
- Silencer(s)
- Explosion relief valve(s) (if required)
- Emissions treatment equipment (if required)
- Mounting hardware between customer piping and Waukesha connection flange(s)
- Gasket between Waukesha connection and customer exhaust piping

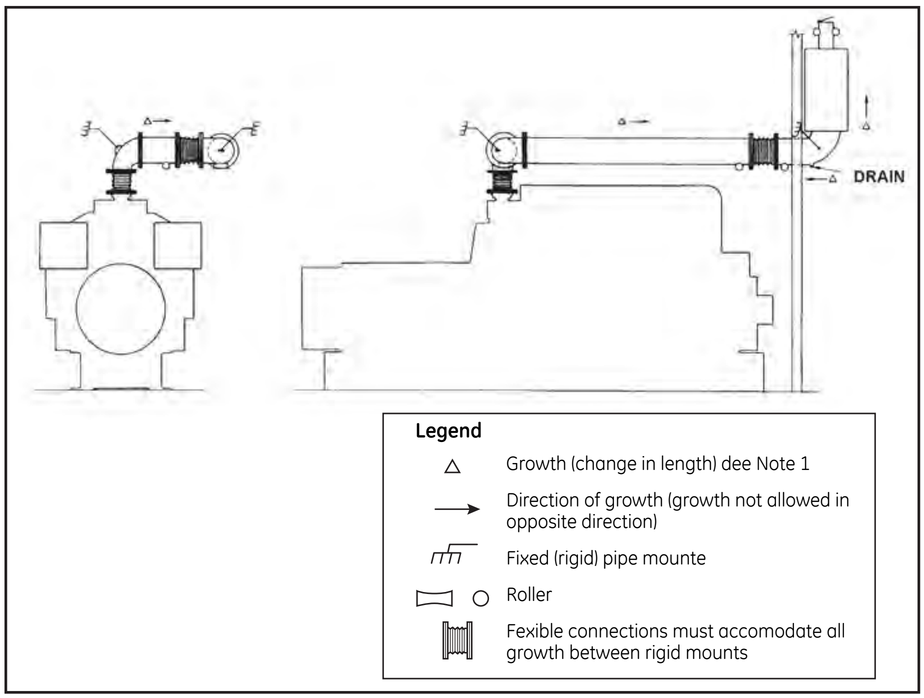


Figure 14-1: Example sketch of exhaust system layout

SUPPORTING DOCUMENTS

L-08088-30	L7042GSI S5/ L7044GSI S5 outline drawing
L-08088-29	L7042GSI S5/ L7044GSI S5-GC Spec outline drawing
App11_15	VHP 12-Cylinder Customer Exhaust System Support

SPECIFICATIONS

Table 14-1: Specifications

Engine model	**Maximum allowable backpressure** @ 100% load)	**Typical Temperature Range** (post-turbo)	**Connection Sizes** At bellow outlet (standard)
L7042GSI S5 L7044GSI S5	20 in. H_2O	900 - 1200F (480 - 650C)	8” ANSI 125# flat faced flange

BACKPRESSURE

The total exhaust system restriction must be less than 20 inches (508mm) H2O, at full load and 1200 RPM.

EXHAUST MANIFOLD SEGMENTS

12-Cylinder Exhaust Manifolds

The 12-cylinder VHP exhaust manifold consists of six individual cast-iron segments on each bank, one exhaust manifold segment per cylinder. Each of these segments are water cooled, but the connection pieces between the segments are not water cooled.

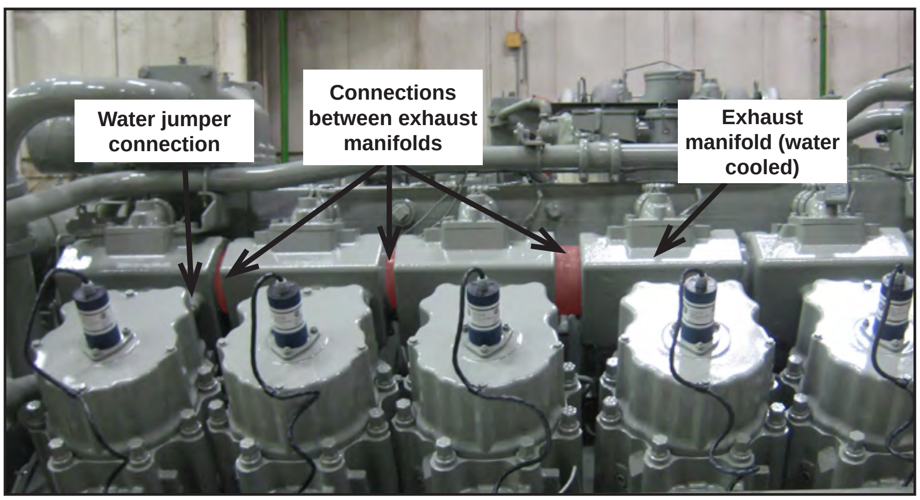


Figure 14-2: Exhaust Manifold Sections

EXHAUST THERMOCOUPLES

Thermocouples are used to monitor engine exhaust temperatures. The 12-cylinder VHP engines have 14 thermocouples. One thermocouple is provided for each of the cylinders and measures the exhaust temperatures within the respective cylinder head exhaust port. There is also one pre-turbine thermocouple for each turbocharger which is only intended to be used as a general indication of the relative exhaust temperature. These individual cylinder exhaust thermocouples and pre-turbine thermocouples are monitored by ESM2, and there is an auto shutdown features that can be set by the user. One exhaust stack temperature sensor (post-turbine, pre-catalyst) on each turbo charger is standard with the AFR2 system. These sensors are monitored by the ESM2 system with an alarm and shutdown fault if the temperature is too high.

Monitoring of exhaust temperatures can be useful for troubleshooting, for example aiding to detect a cylinder which is not firing properly (this would be indicated by a temperature significantly lower than other cylinders).

Figure 14-3: Exhaust Temperature Visualization Screen

EXHAUST CONNECTION

12-Cylinder Exhaust Connection

Standard exhaust connection point is a single 8.00” ANSI flat face flange on the rear of the engine. A flexible stainless steel connection is provided to account for the engine vibration and thermal growth. This flexible connection is shipped loose to be installed by the packager with supplied hardware. Gasket and hardware for connection to customer piping are not included. The exhaust system must be supported beyond this point so no forces are directed onto the engine.

The flexible connection that comes with the engine has the following characteristics:

- Axial extension: 0.23in (5.8mm)
- Axial compression: 0.23in (5.8mm)
- Lateral movement: 0.07in (1.8mm)
- Angular movement: 2.1°
- Approximate spring rate: 210lbs/in (76N/m)

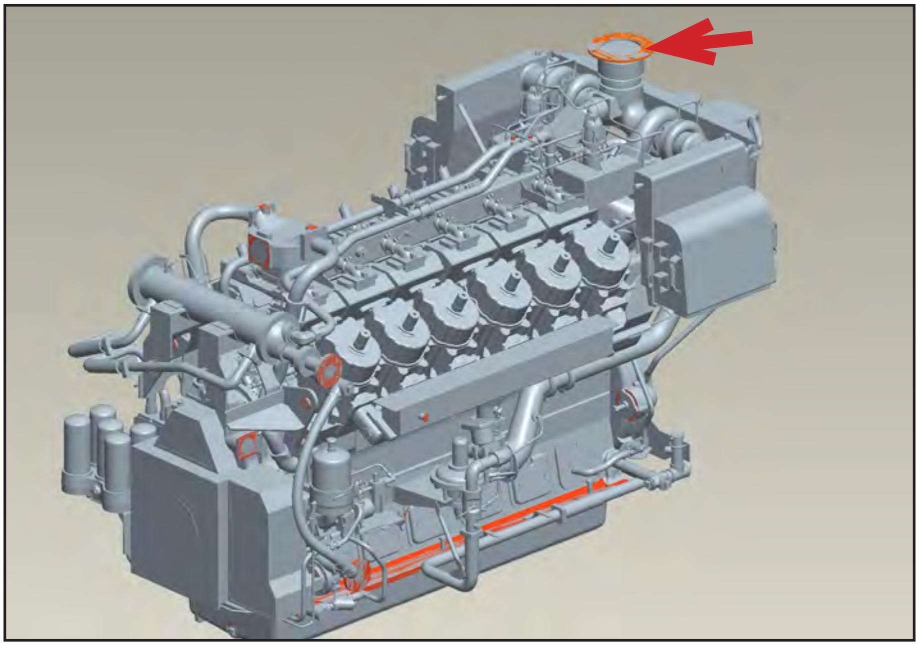


Figure 14-4: 12-Cylinder Exhaust Connection

12-Cylinder Exhaust Support

The preferred exhaust mounting method is mounting the exhaust supports to the engine foundation or engine enclosure. However, in instances that this might not be possible Waukesha has determined an alternate mounting method. There are 6 available locations on the engine to mount brackets to support the exhaust, but attention to Waukesha instructions is critical in order to prevent engine damage. Waukesha is not responsible for any damage incurred through improper mounting. The figure below illustrates the 6 locations on the engine that brackets can be mounted. There is a limit to the amount of force that can be applied to the mounting locations and critical torque values that must be followed. Full details of the mounting instructions can be found in the Application Note app11_15.

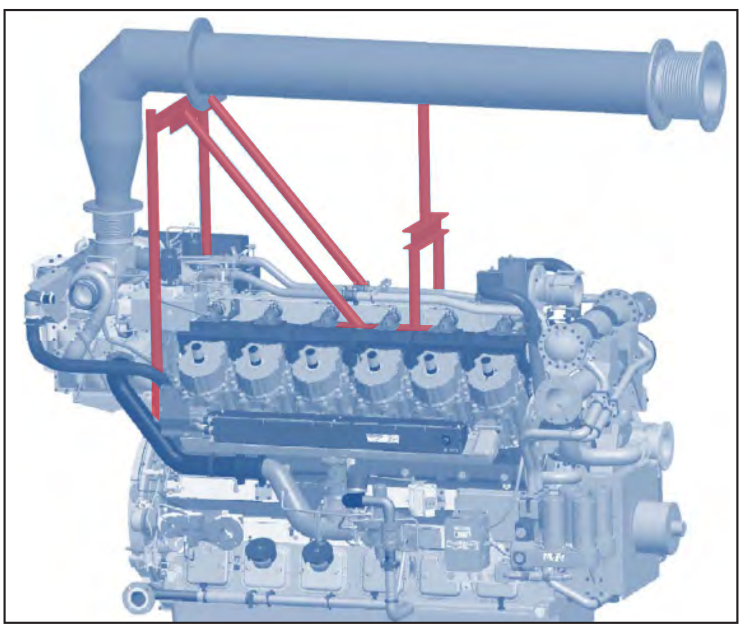


Figure 14-5: 12-Cylinder Exhaust Supports

THERMAL EXPANSION AND EXHAUST FLEXIBLE JOINTS

Allow for thermal expansion of the exhaust pipe beyond the Waukesha connection. The Waukesha exhaust flex will accommodate engine thermal expansion but cannot tolerate movement imposed by external thermal growth. Insulated pipes will run hotter and consequently expand more.

- Remember that a flex connection has “spring constants” (lateral, axial, radial, torsional) that should be considered when engineering the exhaust system. Transmission of forces to the engine exhaust system (engine exhaust flange) must be nil.

- The exhaust flex connection should be designed to allow for flexing caused by engine operation, acceleration, deceleration, starting and stopping. The Waukesha exhaust flex will accommodate engine vibrations with a solidly mounted unit, but cannot tolerate the additional forces/displacement imposed by mounting on spring isolators. Additional flex capabilities will be required when the unit is mounted on isolators.

- Consider expected life. Cyclic flexing can lead to premature failure by causing fatigue breakage.

- Reference document app10_91 available in Waukesha technical data.

CHAPTER 15 - emPact EMISSION CONTROL

emPact REQUIREMENTS

- Mounting of emPact catalyst within 25 linear pipe feet of 14 in. diameter piping from the exhaust outlet
- Designed so inlet temperatures to the catalyst are 900°F - 1300°F (482°C – 704°C)
- Assemble shipped loose catalyst components as shown in S7232-374
- Install supplied expansion joint between the engine and catalyst
- Expansion joints in the exhaust system to allow for thermal expansion
- Setup of air/fuel ratio control during engine commissioning
- The engine's fuel gas must meet Waukesha's fuel spec S-7884-7

SUPPORTING DOCUMENTS

Form 10063-1	VHP Series Five 12-cylinder engine with ESM2 operation & maintenance manual
S7232-374	emPact Emission Control System Installation Instructions
L8041-333	VHP 12-cylinder emPact Emission Control System outline drawing for 0.15 g/bhp-hr NOx
S7884-7	Gaseous Fuel Specification

EMPACT OVERVIEW

The purpose of the emPact emission control system is to provide a complete Waukesha solution that is capable of achieving the latest air quality regulations. Two option codes are available to meet varying levels of emissions requirements.

Option Code	Outline Drawing	NOx [g/bhp-hr]	CO [g/bhp-hr]
1004 (12-CYL.)	L8041-335 **(12-CYL.)**	0.5	1.0
1005 (12-CYL.)	L8041-333 **(12-CYL.)**	0.15	0.3

These levels are achievable by using Waukesha's AFR2 fuel control system, properly sized catalyst elements and pre-/post-O2 sensors. The following components comprise the emPact emission system:

- Catalytic converter (stainless steel housing with 2 or 3 removable elements)
- HMI (Human Machine Interface)*
- Pre-catalyst temperature RTD sensor
- Post-catalyst temperature RTD sensor
- Pre-catalyst pressure sensor
- Post-catalyst pressure sensor

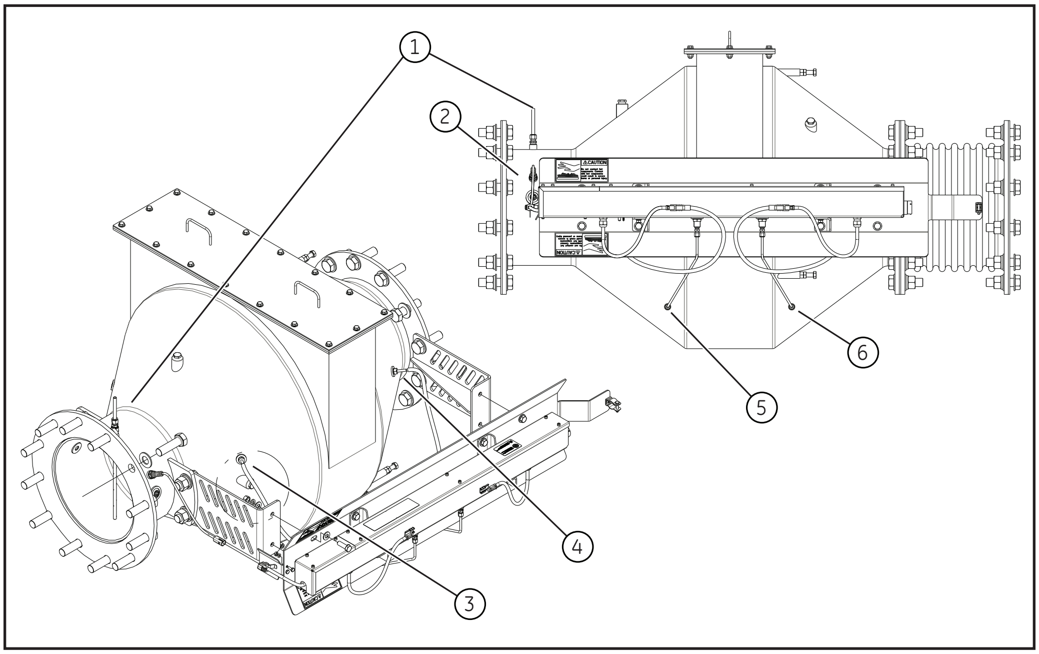
- Pre-catalyst O2 and RTD sensors (left and right bank)*
- Post-catalyst O2 sensor

** Supplied with or without emPact emission control system, all others specific to emPact*

The fuel control system also plays a vital role in producing a complete package that can achieve low emissions. A very specific air/fuel ratio must be maintained in order for the catalyst to operate at a high efficiency. This is achieved using Waukesha AFR2 system; more information can be found in the AFR2 air/fuel ratio control section.

CATALYTIC CONVERTER

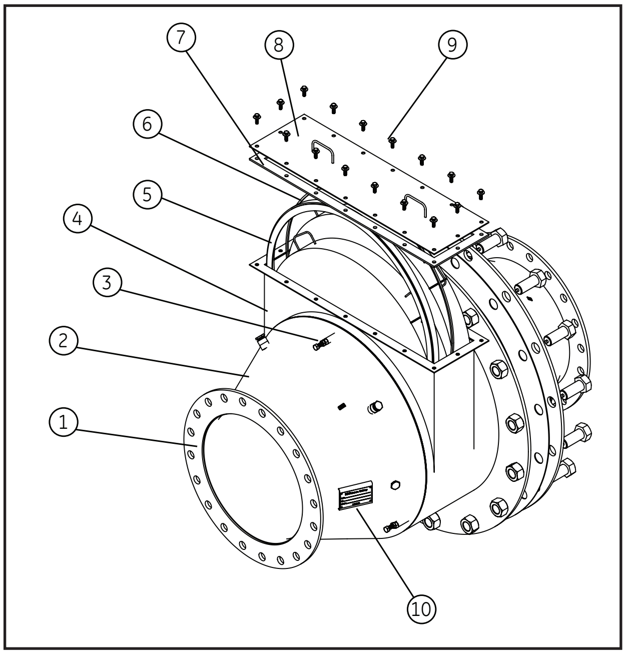
The converter housing is a large chamber made of stainless steel. The catalyst elements are positioned in the center of the housing and held in place by clamp rings. The elements are accessible through a bolted hatch. At each end of the housing are pipe flanges for attaching the converter to the exhaust system. There are ports for the O2, RTD and pressure sensors. Also, there is a post-catalyst exhaust sample port (0.375" – 18 NPT) for verifying emission levels.



1 Exhaust Sample Probe	4 Pre-Catalyst Temperature RTD Sensor
2 Post-Catalyst O2 Sensor	5 Post-Catalyst Pressure Sensor
3 Post-Catalyst Temperature RTD Sensor	6 Pre-Catalyst Pressure Sensor

Figure 15-1: emPact Emission System Sensors (12-cylinder)

The removable element resembles a large honeycomb disc which consists of a finely wound ferric steel metal foil corrugated substrate material that is coated with precious metals. The entire element is banded into a large disc for easy replacement and inspection. The catalyst is classified as a (NSCR) Non Selective Catalytic Reduction or 3-way catalyst. This type of catalyst is suitable for rich burn engines and is similar to automotive catalysts as it reduces NOx, CO and HC simultaneously.



1 Inlet Flange	6 Catalyst Spacerr
2 Inlet Cone + Center body Assembly	7 Flat Hatch Gasket
3 Catalyst Lockbolts (3)	8 Flat Hatch Cover
4 Catalyst (2)	9 Flat Hatch Cover Bolts
5 Catalyst Retainer Ring	10 Name Plate

NOTE:Flat and spring washers removed for clarity.

Figure 15-2: Non-Silenced Housing Option Shown (12-cylinder)

HMI

The HMI provides the interface to the fuel system. It displays status, settings, alarms and history. Commands are performed directly on the HMI's screen. The HMI interfaces with the ECU through CAN communication for displayed values, faults and calibrations. The temperature rating for the HMI panel is -40° to 140°F (-40° to 60°C).

PRE-CATALYST O2 SENSOR

Each bank has one wideband pre-catalyst O2 RTD sensor. The wideband sensor allows for stable operation at nearly any setpoint. This optimizes performance for gaseous fuel and minimizes change in oxygen during fuel swings for steadier emissions with varying fuel.

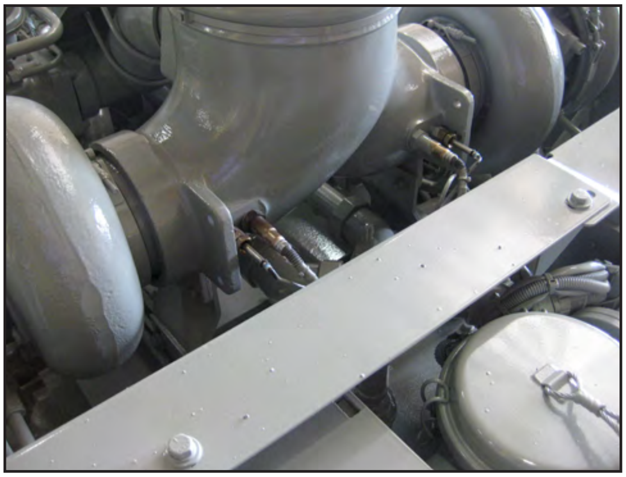


Figure 15-3: Pre-Catalyst O2 RTD Sensors (12-cylinder)

POST-CATALYST O2 SENSOR – EMPACT EMISSION SYSTEM ONLY

A narrowband post-catalyst O2 RTD sensor is located in the catalyst. The narrowband sensor provides quicker response to variation. It also minimizes ammonia interference, providing a more accurate reading.

CATALYST HEALTH MONITORING SENSORS – EMPACT EMISSION SYSTEM ONLY

Two RTD sensors (one pre- and one post-catalyst) monitor catalyst temperatures. These values along with the calculated differential are displayed on the HMI. All three values have user-adjustable alarm and shutdown setpoints. Two pressure sensors (one pre- and one post-catalyst) monitor catalyst pressure. These values along with the calculated differential are displayed on the HMI. All three values have user-adjustable alarm and shutdown setpoints.

SETUP FOR CATALYST CONTROL

The target setting is chosen to optimize engine out emissions for a three-way catalyst input. Three-way catalysts are used to oxidize carbon monoxide (CO) and hydrocarbons (HC), and to reduce oxides of nitrogen (NOx) on rich burn applications. These processes require high temperature and precise air/fuel ratio control. Best performance for emissions reduction is achieved when operating slightly rich of the stoichiometric air/fuel ratio.

The stoichiometric air/fuel ratio is the theoretical balance where exactly the required amount of air (O2) is present to completely burn all of the fuel with no excess air. In an ideal case, the only products of this combustion would be water (H2O) and carbon dioxide (CO2). However, because engine combustion is not perfect, typical emission by-products include O2, HC, NOx and CO. The catalyst then converts most of these to H2O, CO2 and nitrogen (N2).

The wideband oxygen sensor in the exhaust stream provides feedback to the ECM. The signal provides a means of controlling air/fuel ratio slightly rich of stoichiometry.

CONTROL ROUTINE WITH EMPACT EMISSION CONTROL UNIT

The emPact Emission Control System ECU controls the engine air/fuel ratio by regulating the quantity of oxygen in the stream. In the FULL AUTO mode, if the actual post-catalyst

sensor voltage is different from the sensor’s voltage setpoint (determined by the user), the value of the precatalyst sensor setpoint will be adjusted by the ECU. The ECU will communicate with the FCVs to adjust until the new desired pre-catalyst setpoint is achieved.

EMPACT DESIGN CONSIDERATIONS

Exhaust system design considerations specific to the emPact catalyst system are listed below. All other Waukesha recommendations for general exhaust system installations from “Chapter 14: Exhuast System” should also be followed.

- It is required to mount the converter no more than 25 linear feet (7.6 m) of 14 in. (35.6 cm) diameter piping away from the transition mounted to the engine exhaust flex flange and upstream of an exhaust silencer if so equipped
- Install supplied expansion joints between the engine exhaust flange and the converter inlet flange. This will isolate the converter and other downstream components from engine vibration and thermal expansion.
- Ensure exhaust temperatures to the catalyst are between 900°F and 1300°F for all engine operating conditions.
- Do not lift the converter from the center body area; only lift it from the flange ends
- Only use supplied fasteners. Do not substitute with unknown grade fasteners. Contact Waukesha Parts for replacement parts. High temp anti-seize should be used on the fasteners.
- The converter must be structurally supported from beneath the converter center body and mounted horizontally. This structural support needs to allow for expansion of the housing due to thermal loads. Do not support the converter by the flanges.
- The exhaust system must remain air tight at all times for proper operation of the converter. Pressure relief valves, flexible connections, flanges, water traps/drains and piping may leak over time and may require repair or replacement to maintain an air tight exhaust system.

- A burst disk located in the exhaust piping near the engine can protect exhaust components from a damaging exhaust explosion. Burst disks must be vented to a safe location to prevent fires or personal injury. These devices will become damaged or leak after an exhaust explosion occurs which will require replacement or repair. These devices must be air-tight.
- Sufficient clearance must be allowed for the converter hatch to open and for element replacement. Options are available to remove the catalyst elements vertically or horizontally. See “Table 15-2:” for element weights.

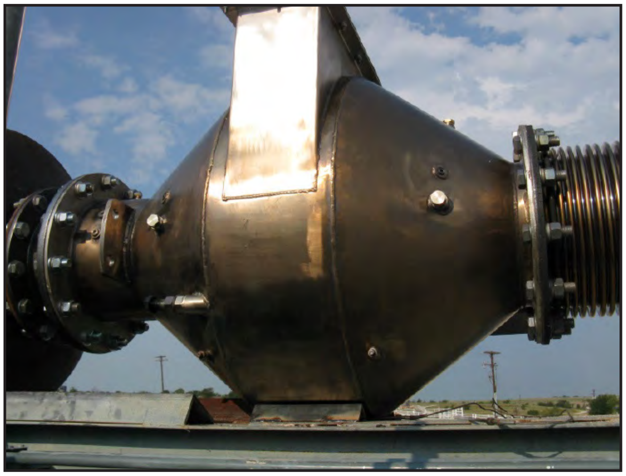


Figure 15-4: emPact catalyst installed

Exhaust system restriction must be taken into account while designing the exhaust system. See “Table 15-1:” for exhaust pressure drop across the catalyst. This data is given at 158 psi BMEP, 1200 RPM and adds 2 inches water column to account for ash/soot accumulation on the catalyst. If pressure drop across the catalyst exceeds the values listed in the table below it may indicate a need for catalyst washing.

Table 15-1:

Engine Model	Option Code	Catalyst Size	Backpressure [inches of H2O]
L7044GSI S5	1004	0.5 g NOx	5.5
L7044GSI S5	1005	0.15 g NOx	5.0

CATALYTIC CONVERTER INSTALLATION

Do not lift the converter from the center body area or catalyst cover handles; only lift it from the flange ends.

WARNING

The catalytic converter weighs approximately 550 lb (249 kg) for 0.5 g NOx converter, 645 lb (293 kg) for 0.15 g NOx converter. Always use suitable rigging and lifting equipment.

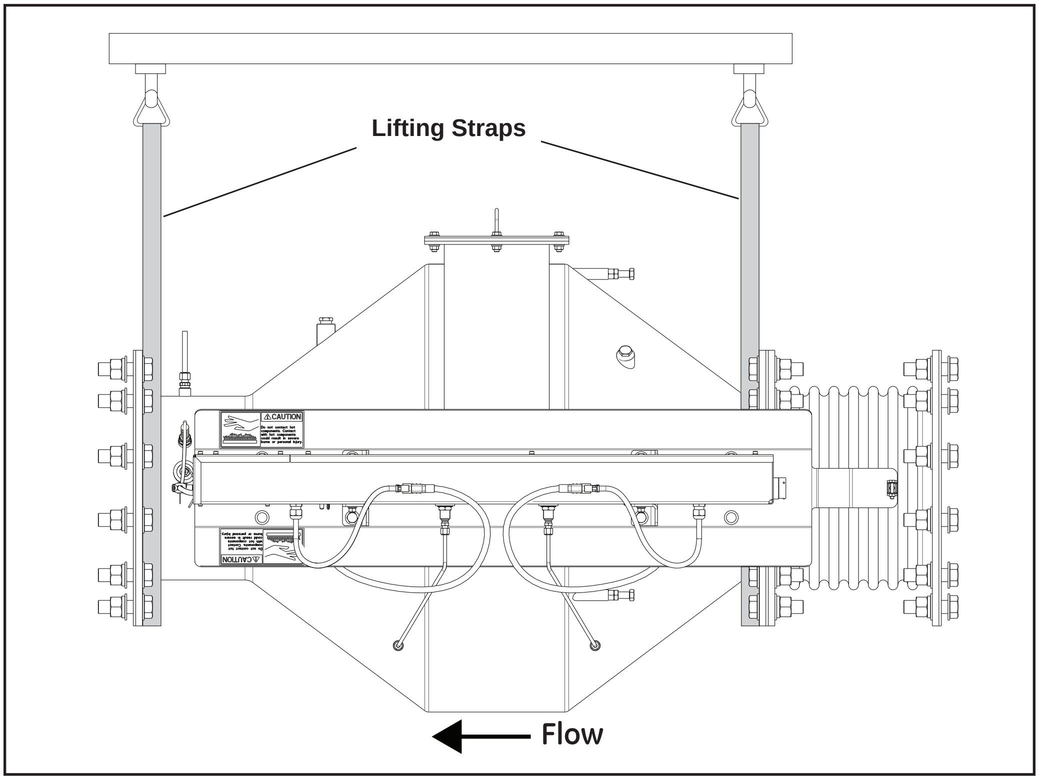


Figure 15-5: emPact lifting points

Most of this assembly should be done prior to lifting into place. This will save time and avoid working several feet above the ground. A detailed assembly drawing is available on S7232-374.

Table 15-2:

Engine	Option Code	Outline Drawing	NOx [g/bhp-hr]	Catalyst Assembly	Catalyst element (each)	Number of elements
12-Cylinder	1005	L8041-333	0.15	645 lbs (293kg)	70 lbs (32kg)	2

NOTE: It is recommended that the catalyst be supported from the bottom. A suitable support needs to be added under the bottom of the catalyst. Catalyst assembly weight includes about 200 lbs (91 kg) for the wireway, heat shield and brackets.

1. Install heat shield onto catalyst housing.
2. Install wireway onto catalyst housing.
3. Install the thermocouples, pre and post into the catalyst and plug into the harnesses.
4. Install the pressure sensors tubing, pre- and post-,into the catalyst and the wireway.

NOTICE **Be careful during the lifting process to not damage the pressure tubes or the sensors.**

5. Support the converter housing flange ends, using a suitable lifting device, and lift the converter housing into position.

6. Catalyst housing center body must be mounted on structural saddle supports when mounted horizontally. This structural saddle support should allow for expansion of the housing due to thermal loads. Do not support the housing by the flanges when mounted horizontally.

7. Align the inlet and outlet flanges with their connecting flanges and insert supplied gaskets as required.

NOTICE **Make sure the catalyst flow direction is correct. The directional arrow on the converter housing must match the flow direction of exhaust gas.**

8. Install all supplied mounting fasteners loosely, allowing for movement until final tightening.

9. Check alignment of flanges to make sure flanges are squarely aligned and no binding is evident.

10. Torque all flange fasteners.

11. Make sure that the exhaust system after the converter is independently supported.

NOTICE **Do not weld to the converter housing.**

HMI INSTALLATION

See HMI Installation section in Chapter 16: Fuel Systems for installation instructions.

The HMI provides the interface to the fuel system. It displays status, settings, alarms and history. Commands are performed directly on the HMI's screen.

Figure 15-6: HMI interface for AFR2/emPact

EMPACT, AFR2 SETUP

The emPact control system is configured through the provided HMI panel. This easy to use, step-by-step process significantly minimizes the time to set the engine up for catalyst control. All of the instructions are displayed on the screen and the entire setup process takes less than one hour.

For more detailed information and step-by-step instructions see Chapter 20: Engine Commissioning.

Prior to start-up it is recommended that the process run, before installing the catalyst elements, for a sufficient period of time to clear all debris in the flow path upstream from the catalyst. This protects the catalyst from experiencing any adverse conditions such as over temperature or contamination during initial engine set-up. Catalyst elements can be permanently damaged when exposed to continuous misfires and when engine start-up procedures have been ignored.

EMPACT MAINTENANCE

During normal operation accumulation of soot, ash or other by-products of combustion will reduce the effectiveness of catalyst elements. Although, there are some non-standard operating conditions which can result in premature loss of catalyst activity. Therefore, a periodic [annual] inspection and maintenance program will assure the catalyst retains its full activity.

To inspect the catalyst unit, remove the element and visually examine the catalyst for any physical damage or obstructed passages, especially on the inlet face. Excessive cell blockage must be cleared by cleaning the catalyst. More information on the catalyst condition and cleaning process can be found in the O&M Manual, Form 10063-1.

CHAPTER 16 - FUEL SYSTEM

AFR2 AIR/FUEL RATIO CONTROL

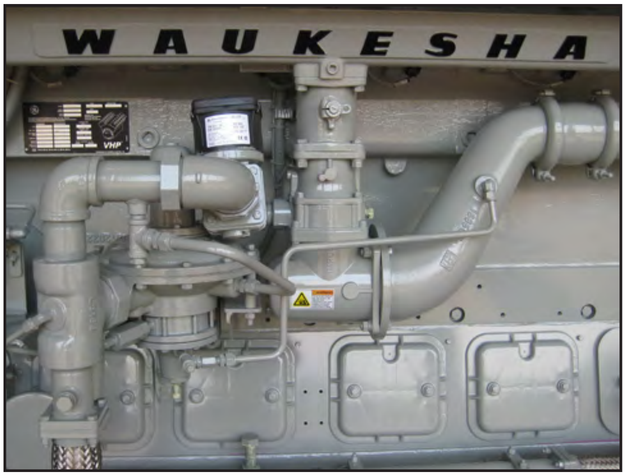
FUEL SYSTEM / AFR2 REQUIREMENTS

- Setup of air/fuel ratio control during engine commissioning
- Fuel pressure at inlet flange of engine mounted fuel valve between 40 – 60 psig (267 – 414 kPa) and 43 – 60 psig (296 – 414 kPa) if > 5000ft (1524 m) elevation
- Fuel piping sized for maximum fuel flow with minimal piping restriction
- Coalescing fuel filter installed as close to the engine inlet as possible when fuel contains water vapor or heavy hydrocarbons
- Fuel meets Waukesha's latest fuel specification S-7884-7 in technical data
- Additional pressure regulators installed upstream of engine if fuel pressure at engine exceeds 60 psig.
  - For fuels containing water vapor or heavy hydrocarbons, a coalescing fuel filter and possibly fuel heater is installed between the high pressure regulator and engine con- nection to remove liquids from the fuel at the engine inlet pressure.
- Fuel LHV variation within ± 150 BTU. Fuel variation greater than ± 150 BTU requires engine adjustment.
- Customer supplied fuel shut-off valve wired to the ESM2 with supplied harness. A surge suppression diode must also be installed. Waukesha requires a "freewheeling" diode (1N4002 or equivalent rated for 100V and 1A) be added across the coils of relays and solenoids to suppress high induced voltages that may occur when equipment is turned off.

STANDARD EQUIPMENT

Single 3" ANSI flange fuel inlet connection. Two natural gas, 4" (102 mm) updraft carburetors and two mounted Fisher 99, 2" (51 mm) gas regulators, 40-60 psi (267-414 kPa) fuel inlet pressure required or 43-60 psi (296 – 414 kPa) if >5000ft (1524m) elevation. 10 foot (3 m) harness provided for ESM2 control of customer supplied fuel shutoff valve. The AFR2 fuel control valve is located between regulator and carburetor.

OPTIONAL EQUIPMENT



The standard fuel system for the VHP 12-cylinders are capable of operating on fuels that have an LHV of 850 - 2400 BTU/ft3 (33.4 - 94.4 MJ/nm3).

CUSTOMER SUPPLIED EQUIPMENT

- Fuel piping connections to engine
- Flexible connection to engine
- Fuel filter
- Fuel coalescing filter
- Fuel treatment system (when needed)
- Customer supplied fuel shut-off valve wired to the ESM2 with supplied harness. A surge suppression diode must also be installed. Waukesha requires a “freewheeling” diode (1N4002 or equivalent rated for 100V and 1A) be added across the coils of relays and solenoids to suppress high induced voltages that may occur when equipment is turned off.

REFERENCE DOCUMENTS

Form 10062-1	ESM2 Packaging guide
Form 10063-1	VHP Series Five 12-Cylinder with ESM2 operation & maintenance manual
S-8685-17	ESM2 system schematic

FUEL SYSTEM / AFR2 OVERVIEW

The function of the fuel system is to maintain a constant air/fuel ratio throughout the load range of the engine and to deliver the air/fuel mixture in the proper quantities. The following components comprise the engine fuel system:

- Main Fuel Pressure Regulators (left and right side)
- Carburetors (left and right side)
- Fuel Control Valves (left and right side)
- Engine Control Unit (ECU)
- Emission Control Sensors

PRE-CATALYST O2 SENSOR

Each bank has one wideband pre-catalyst O2 RTD sensor. The wideband sensor allows for stable operation at nearly any setpoint. This optimizes performance for gaseous fuel and minimizes change in oxygen during fuel swings for steadier emissions with varying fuel.

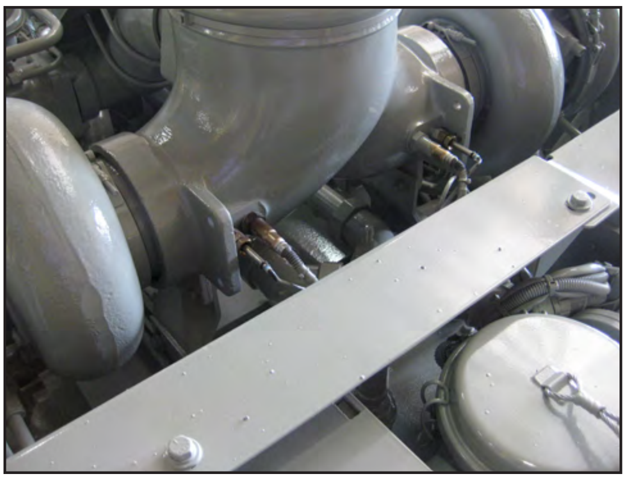


Figure 16-1: Pre-Catalyst O2 RTD Sensors (12-cylinder)

POST-CATALYST O2 SENSOR – EMPACT EMISSION SYSTEM ONLY

A narrowband post-catalyst O2 RTD sensor is located in the catalyst. The narrowband sensor provides quicker response to variation. It also minimizes ammonia interference, providing a more accurate reading.

FUEL CONTROL VALVES

A Fuel Control Valve (FCV) is located on each engine bank. The FCV is an electronically controlled valve used to adjust fuel flow into each carburetor. The FCV is controlled by input from the ECU. The minimum percent and maximum percent for the open position of the FCVs are adjusted through the HMI.

Figure 16-2: Fuel Control Valve

CARBURETORS

One carburetor is mounted on each bank just below the center of each intake manifold. The carburetor produces a combustible mixture by automatically mixing fuel from the FCV and air from the turbocharger.

AFR2/EMPACT CONTROL

The engine's Air/Fuel Ratio (AFR) is controlled by the ESM2. An engine's air/fuel ratio is the amount of air measured by mass in relation to the mass of fuel supplied to an engine for combustion. By controlling an engine's air/fuel ratio with ESM2 control, exhaust emissions are minimized while maintaining peak engine performance. The AFR control regulates the engine's air/fuel ratio even with changes in engine load, fuel pressure, fuel quality and environmental conditions.

THEORY OF OPERATION

Control Routine Without Factory Supplied Catalyst

The ECU AFR routine controls engine air/fuel ratio by regulating the quantity of oxygen present in the exhaust stream. If the actual O2 sensor voltage is different from the O2 sensor voltage setpoint, the ECU AFR routine directs the FCV to adjust the gas flow to the carburetor. The FCV adjusts in position, within programmed limits, increasing or decreasing the fuel flow to the carburetor.

SETUP FOR CATALYST CONTROL

The target setting is chosen to optimize engine out emissions for a three-way catalyst input. Three-way catalysts are used to oxidize carbon monoxide (CO) and hydrocarbons (HC), and to reduce oxides of nitrogen (NOx) on rich burn applications. These processes require high temperature and precise air/fuel ratio control. Best performance for emissions reduction is achieved when operating slightly rich of the stoichiometric air/fuel ratio.

The stoichiometric air/fuel ratio is the theoretical balance where exactly the required amount of air (O_2) is present to completely burn all of the fuel with no excess air. In an ideal case, the only products of this combustion would be water (H_2O) and carbon dioxide (CO_2). However, because engine combustion is not perfect, typical emission by-products include O_2, HC, NO_x and CO. The catalyst then converts most of these to H_2O, CO_2 and nitrogen (N_2).

The wideband oxygen sensor in the exhaust stream provides feedback to the ESM2. The signal provides a means of controlling air/fuel ratio slightly rich of stoichiometry.

CONTROL ROUTINE WITH EMPACT EMISSION CONTROL UNIT

The ESM2 controls the engine air/fuel ratio by regulating the quantity of oxygen in the exhaust stream. In the FULL AUTO mode, if the actual post-catalyst sensor voltage is different from the sensor's voltage setpoint (determined by the user), the value of the precatalyst sensor setpoint will be adjusted by the ECU. The ECU will communicate with the FCVs to adjust until the new desired pre-catalyst setpoint is achieved.

MAINTENANCE CONSIDERATIONS

The filter of the main fuel gas pressure regulators should be cleaned or replaced regularly. If clogging is suspected in the upstream regulator passages, more frequent cleaning may be required. Operation of the fuel system and AFR2 system components should be inspected periodically to maintain proper engine operation and maintain emissions compliance. This may include periodic verification of engine emissions and exhaust O2 settings. Adjustments should be made as needed by following the AFR2 setup on the HMI, refer to the latest version of the engine Operation & Maintenance manual (Form 10063-1) for more details.

CHAPTER 17 - STARTING SYSTEM

STARTING SYSTEM REQUIREMENTS

- Adequately sized starter for turning over the engine and driven equipment
- High pressure air or gas supply (for pneumatic starter options): 90-150 psig (620 – 1030 kPa) for high pressure, 60-90 psig (415 – 620 kPa) for low pressure
- Piping to and from the starter, sized to reduce restriction and supply appropriate pressure
- Flex connections used at starter inlets and outlets (for pneumatic starter options)
- Starter and solenoid valve exhausts piped to safe location if combustible gas is used (for pneumatic starter options)
- Power wiring (24VDC) to starters (for electric starter option)
- Refer to S-7447-08 for properly sizing the air starter requirements

STANDARD EQUIPMENT

Standard Engines:

- Customer-supplied starter
- ESM2 control of the starter motor
- Starter motor pad for SAE number 3 motor mounting flange

Gas Compression (GC) - spec Engines

- High pressure, turbine-type, inertia engaged, pneumatic starter mounted with stainer and valve
- Electronically controlled through a normally closed, CSA Class I Div II, 24VDC solenoid valve which is actuated when it receives a signal from ESM2

OPTIONAL EQUIPMENT

Standard Engines:

- High or low pressure pneumatic starter - turbine-type, inertia engaged, mounted with strainer and valve.
- Two 24VDC electric starters (for use in non-hazardous areas) - 24VDC, positive engagement, 9.0 kW maximum output (per starter), with 11 tooth pinion.
- Dual pneumatic high pressure starters, pre-engaged, mounted with strainer and valve.

GC - spec Engines:

- Low pressure pneumatic starter, in place of the standard high pressure starter.
- Dual pneumatic high pressure starters, in place of the standard high pressure starter.

CUSTOMER CONNECTION

- Waukesha-supplied high or low pressure pneumatic starter:
  - Starter Inlet - 1.5” ANSI 150# raised face flange (each starter)
  - Starter Outlet - 3” ANSI 150# raised face flange (each starter)
  - Starter valve solenoid outlet/exhaust with removable mufflers
    - 12-cylinder: (qty 2) 0.25” NPT
- Waukesha-supplied electric starter:
  - Electric power supply
- Customer-supplied pneumatic starter:
  - Starting motor pad, for motors with SAE number 3 mounting flange
  - Pneumatic supply to starter valve solenoid: 0.25” – 18 NPT
  - Pneumatic connection from starter valve solenoid to air/gas starter relay: 0.25” – 18 NPT
  - Starter valve solenoid outlet/exhaust with removable mufflers
    - 12-cylinder: (qty 2) 0.25” NPT
- Customer-supplied electric starter:
  - Starting motor pad, for motors with SAE number 3 mounting flange
  - Electric power supply
  - “Freewheeling” diode across starter relay/solenoid
  - Wiring to ESM2 control
- See S-7232-422 for battery sizing

NOTICE

Disconnect all engine harnesses and electronically controlled devices before welding on or near an engine. Failure to comply will void product warranty.

The electrical interference from solenoids and other electrical switches will not be cyclic and can be as high as several hundred volts. This could cause faults within the ESM system that may or may not be indicated with diagnostics. Waukesha requires a “freewheeling” diode (1N4002 or equivalent rated for 100V and 1A) be added across the coils of relays and solenoids to suppress high induced voltages that may occur when equipment is turned off. Failure to comply will void product warranty.

WARNING

Do not disconnect equipment unless power has been switched off or the area is known to be non-hazardous.

Do not install, set up, maintain or operate any electrical components unless you are a technically qualified individual who is familiar with the electrical elements involved.

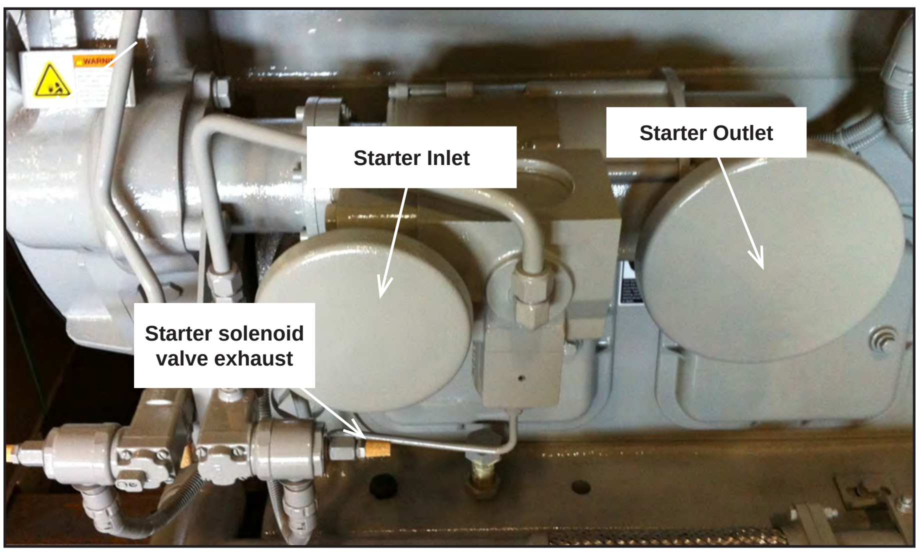
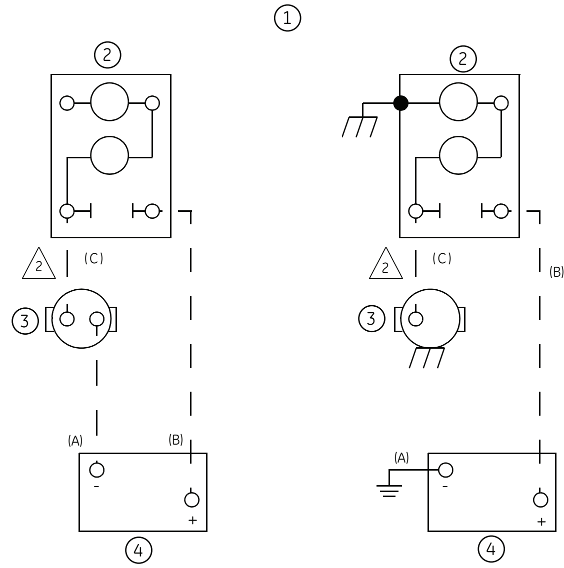


Figure 17-1: Connection points for Waukesha-supplied pneumatic starter (12-cylinder)

NOTICE

Always turn the battery charger off first, before disconnecting the batteries. Then disconnect the battery negative (-) cable before beginning any repair work.

Table 17-1: Battery Cable Lengths for 24VDC Starting Motor Circuits



1 - Typical Starting Motor Circuits
2 - Starting Motor Contactor
3 - Starting Motor
4 - Battery

SELECT SIZE OF CABLE FROM LISTING BELOW USING FIGURE POINTS A, B AND C ABOVE:

TOTAL CABLE LENGTH (A + B + C)	USE SIZE OF CABLE
Less than 16 ft (4.9 m)	#0
16 – 20 ft (4.9 – 6.1 m)	#00
20 – 25 ft (6.1 – 7.6 m)	#000
25 – 32 ft (7.6 – 9.8 m)	#0000 or (2) #0
32 – 39 ft (9.8 – 11.9 m)	(2) #00
39 – 50 ft (11.9 – 15.2 m)	(2) #000
50 – 64 ft (15.2 – 19.5 m)	(2) #0000

NOTE: Information based on 0.002 ohm total cable resistance for 24- or 32-volt systems. Consult factory if ambient temperature is below 50°F (10°C) or above 120°F (49°C).
NOTE: When contactor is an integral part of starting motor, a bus connection is used. (A) + (B) will then be total cable length.

SUPPORTING DOCUMENTS

L-08088-30	VHP Series Five 12-cylinder standard outline drawing
L-08088-29	VHP Series Five 12-cylinder GC-spec outline drawing
L-08041-331	Accessory Drawing, 12-cylinder Air/Gas Starter
S-7447-08	Air volume and pressure guidelines for air starter
S-7232-422	Battery Specification

SYSTEM DESIGN

The starter(s) for the engine must be sized so that they are capable of rotating the engine and driven equipment; different options and pressure ranges are available. The pneumatic starters are integral designs which include a relay valve and strainer. In Gas Compression applications, compressor bypass valves are typically used to unload compressors and make the package easier to start. Documents for sizing the starter, torque output and air/gas consumption are available in S-7447-08. This documents also contain information and equations for sizing the air receiver if compressed air is being used.

Compressed air or high pressure gas can be used to spin the pneumatic starters. If a combustible gas is used then the starter exhaust and solenoid exhaust/vent must be plumbed to a safe location per applicable local codes and regulations. If compressed air is used and the exhaust is not routed away from the engine, it should be directed to prevent personal injury.

Piping must be sized to provide the appropriate flow and pressure to the starters. Pressure loss through the piping to the starters and restriction from the exhaust piping must be taken into consideration. It is common to see up to a 30% pressure loss due to piping restriction. Using transition pieces and piping larger than the starter flange sizes can help reduce restriction in the system for longer piping runs. Flex connections should be used at the inlet and outlet of any engine connections.

AIR/GAS QUALITY

The starter does not require lubrication of the drive air/gas supply. The starters incorporate sealed, greased packed lubrication of the gearbox and bearings, designed to be maintenance free for the life of the starter. It is recommended to use a coarse (40 mesh [420 micron]) filter in the supply stream of the air/gas in applications where larger particulate is abundant. The most common damaging solid contaminants found in unfiltered air/gas supply are weld slag or steel pipe shavings generally found in new installations or when piping has been modified. The starter includes an internal piping screen to remove some debris; however this should not be used for gross debris removal and an additional screen should be used to clean the piping before commissioning. These starter motors will operate reliably on field quality (wellhead) gas and “sour natural gas” (including gas that has H_2S content as high as 6000 PPM). Liquids in the supply stream will not damage the starter motors. The only detriment to operating on air/gas supplies with high concentrations of liquids is freeze-up. Liquids which “pool” and then freeze around rotating elements (turbine rotors) may restrict motor rotation until the liquids are thawed.

CHAPTER 18 - ESM2 PACKAGING

ESM SYSTEM REQUIREMENTS

- 24VDC power connection to power distribution box (PDB) – provides source of power for all engine-mounted components and ignition system
- Customer interface harness connection – connection from engine bulkhead to customer control panel. Includes CAN wires, which connect to the Waukesha HMI, and additional wires which connect to the customer control panel. HMI includes a connector with 6' (1.8m) flying leads for the CAN connection
- 24VDC power for HMI – since the HMI is mounted in the customer control panel, typically the power source would come from within the panel. To simplify things, the HMI includes a connector with 6' (1.8m) flying leads

STANDARD EQUIPMENT

Standard engine

- ESM2 with AFR2
- HMI display panel
- 50ft harnesses

OPTIONAL EQUIPMENT

Standard engine

- 25ft, 100ft or 200ft harness lengths

GC-Spec

- N/A

CUSTOMER SUPPLIED EQUIPMENT

- 24VDC power source (battery preferred)
- Earth ground

SUPPORTING DOCUMENTS

Form 10063-1	VHP Series Five 12-Cylinder wth ESM2 Operation & Maintenance Manual
Form 10062-1	ESM2 Packaging Guide
S-07232-422	Battery Specifications

SYSTEM DESCRIPTION

The Waukesha ESM2 is a system designed to optimize engine performance and maximize up-time. The ESM2 integrates spark timing cotrolcontrol, speed governing, knock detection, start-stop control, air-fuel ratio control, diagnostic tools, continuous data logging and engine protectionfault logging and engine safeties. In addition, the ESM2 system has safety shutdowns such as low oil pressure, engine overspeed, high IMAT, high coolant outlet temperature and uncontrolled knock.

The Engine Control Unit (ECU) is the central brain of the control system and main customer interface. Interface with ESM2 is through 50 foot (15.2 m) harness to local panel, through MODBUS RTU slave connection RS-485 multidrop hardware, and through the Electronic Service Program (ESP). ESM2 meets Canadian Standards Association Class I, Division 2, A, B, C & D (Canada & US) hazardous location requirements

See "Figure 18-1: ESM2 schematic" for a general overview of the ESM2 system inputs and outputs.

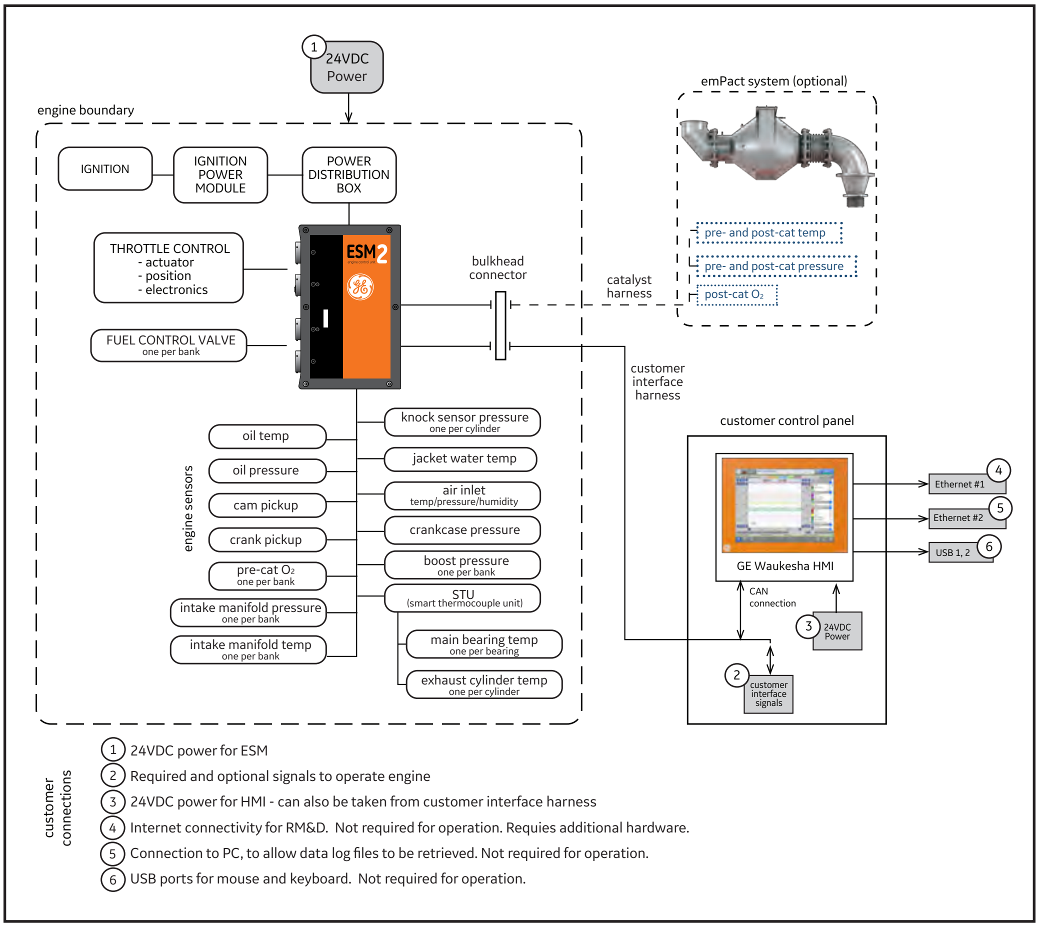


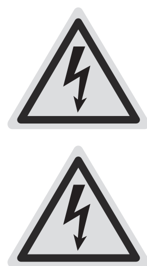
Figure 18-1: ESM2 schematic

REQUIRED CONNECTIONS

POWER SUPPLY

The ESM2 system requires a connection to a steady power source; 18 – 32 VDC and a peak-to-peak voltage ripple of less than 2 volts. Batteries are the preferred method of supplying the ESM2 system with clean, stable power. In addition, batteries have the advantage of continued engine operation if there is a disruption in the source of electric power. See “Figure 18-2: Power supplied by batteries” for a wiring schematic.

WARNING



Do not install, set up, maintain or operate any electrical components unless you are a technically qualified individual who is familiar with the electrical elements involved.

Disconnect all electrical power supplies before making any connections or servicing any part of the electrical system.

NOTICE

Disconnect all engine harnesses and electronically controlled devices before welding on or near an engine. Failure to disconnect all engine harnesses and electronically controlled devices will cause damage to electronic components and void warranty.

WARNING

Comply with the battery manufacturer’s recommendations for procedures concerning proper battery use and maintenance.

Batteries contain sulfuric acid and generate explosive mixtures of hydrogen and oxygen gases. Keep any device that may cause sparks or flames away from the battery to prevent explosion.

Always wear protective glasses or goggles and protective clothing when working with batteries. You must follow the battery manufacturer’s instructions on safety, maintenance and installation procedures.

NOTICE

Always turn the battery charger off first, before disconnecting the batteries. Then disconnect the battery negative (-) cable before beginning any repair work. Failure to turn battery charger off before disconnecting the batteries may cause electronic component damage and void warranty.

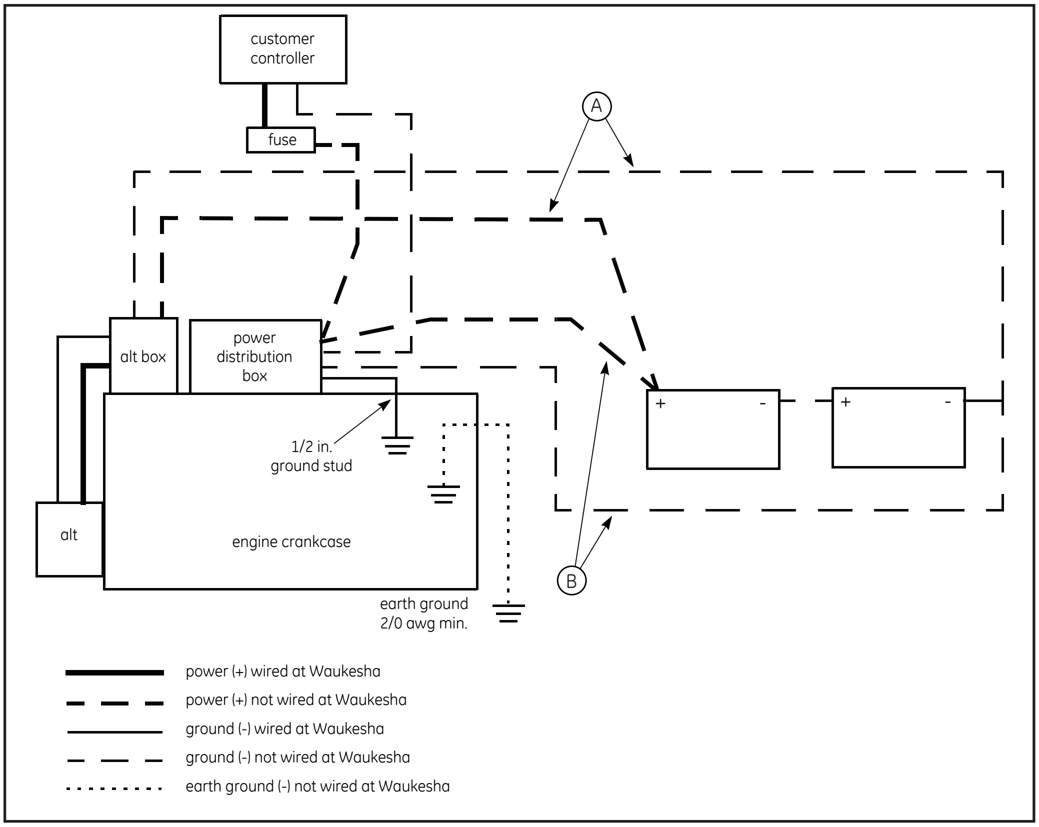


Figure 18-2: Power supplied by batteries

Minimum of #6 copper wire is recommended for the power feed to the power distribution box from either batteries or the power supply. VHP engine equipped with ESM2 controls have a maximum current draw of 25 amps. This includes the 5 amp optional user power “24V for U”. The batteries should be wired directly to the 3/8 inch stud located in the Power Distribution Junction Box

The ESM2 system will have a power draw even when the engine is not running. For engines that do not have a constant power supply to the batteries, it is recommended that a battery disconnect be installed to prevent the batteries from becoming fully discharged when the engine is not running. An electronically controlled disconnect is recommended. This will allow the batteries to disconnect if there is an unintended shutdown.

WARNING

Disconnect all electrical power supplies and batteries before making any connections or servicing any part of the electrical system.

Do not install, set up, maintain or operate any electrical components unless you are a technically qualified individual who is familiar with the electrical elements involved.

Equipment must be grounded by qualified personnel in accordance with IEC (International Electric Code) and local electrical codes.

The customer-supplied earth ground should be connected to the right side of the engine. There is a ½"-13UNC-2B ground stud located just below the carburetor (12-cylinder) and is readily accessible for this requirement. See "Figure 18-3: Earth ground location (12-cylinder)"

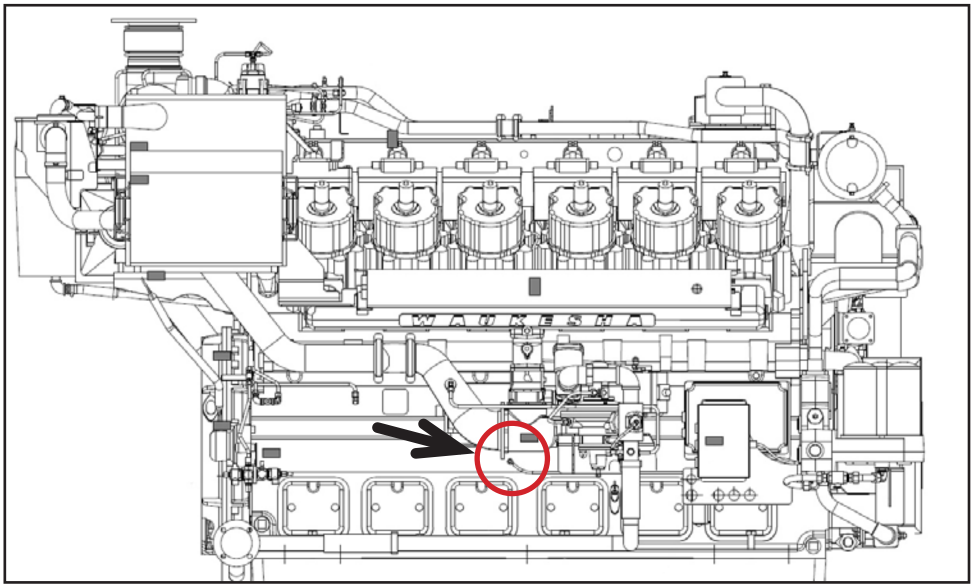


Figure 18-3: Earth ground location (12-cylinder)

POWER DISTRIBUTION BOX

The Power Distribution Box (PDB) is used to protect a distribute 24VDC power to all the components on the engine that require power such as ECU, IPM-D and throttle actuator. No other power connections are necessary. It also triggers controlled devised such as the prelube motor and fuel valve. The PDB contains circuitry to limit input voltage to a safe level before distribution. It disables individual output circuits from high circuit events such as short circuit.

1" and ½" conduit holes are provided for customer connections or other electrical options. #8 are used for the terminal strip.

CUSTOMER INTERFACE HARNESS

NOTICE

The electrical interference from solenoids and other electrical switches will not be cyclic and can be as high as several hundred volts. This could cause faults within the ESM2 that may or may not be indicated with diagnostics. Waukesha requires a "freewheeling" diode be added across the coils of relays and solenoids to suppress high induced voltages that may occur when equipment is turned off. Failure to comply will void product warranty.

Customer electrical connections to the ECU are made through the Customer Interface Harness. A 1.25 inch diameter harness will be shipped loose with the engine which will have unterminated wire ends for connecting inside the customer panel. This Customer Interface harness has a Deutsch connector for connecting to the on engine harness. On the customer connection side there is a 1.25" sealing ring and gland for connection to the customer control panel and this harness has a maximum bend radius of 7". The Customer Interface Harness must be properly grounded to maintain CE compliance.

Table 18-1: Harness construction

Harness	Diameter	Engine Side	Customer Side	Maximum bend radius
Customer Interface	1.25"	Deutsch connector	Loose wires, 1.25" sealing gland	7"

Some connections of the Customer Interface Harness are required for ESM2 operation: Start Engine, Normal Shutdown, Emergency Shutdown and 3 wires for speed controls. Refer to "Table 18-2: Required connections" below for the required connections. For a full list of customer interface harness connections, see "Appendix D: Customer Interface Connections".

Table 18-2: Required connections

FUNCTION	SIGNAL TYPE	WIRE NUMBER WIRE DESCRIPTION	DESCRIPTION
Start Engine	Momentary digital input (24V)	1609 START	Momentary (>1/2 second and <60 seconds) digital signal input to ECU to begin the starting process, must momentarily be connected to +24 VDC nominal (8.6 – 32 volts) for the ECU to start the engine.
Run / Stop	Digital input (24V)	1611 RUN/STOP	• +24 VDC nominal for the engine to run.If goes open circuit, the engine performs a normal shutdown.
Emergency shutdown	Digital input (24V)	1606 ESD	• +24 VDC nominal for the engine to run.If ESD goes open circuit, the engine performs an emergency shutdown.
CAN communication high	CAN	1300 CAN	CAN communication between the ECU and HMI
CAN communication low	CAN	1301 CAN	CAN communication between the ECU and HMI
CAN c ommunication shield	CAN	1302 CAN	CAN communication between the ECU and HMI
ADDITIONAL CONNECTIONS FOR RATED/IDLE SPEED CONTROL			
Rated Speed/ Idle Speed (Fixed Speed Application)	Digital input (24V)	1616 GOVHL IDL	• +24V DC nominal (8.6 – 32 volts) for rated speed Open circuit for idle speed and remote speed wire 1608 (GOVREMSEL) must be open circuit.
ADDITIONAL CONNECTIONS FOR REMOTE VARIABLE SPEED CONTROL			
Customer reference ground	Ground	1111 LOGIC GND	Used as the negative connection point for signal inputs (voltage and current) (4 – 20 mA and 0 – 5 volt).
Remote speed setting enable (variable speed application)	Digital input (24V)	1608 GOVREMSEL	24 VDC nominal to enable remote speed/load setting
Remote speed Setting (using voltage input)	0.5 – 4.5 volt	1618 GOV 40	0.5 – 4.5 VDC signal +
Remote speed setting (using current input)	4 – 20 mA	1614 GOVREMSP+ 1613 GOVREMSP	1614 + signal 1613 – signal NOTE: Inputs below 2 mA and above 22 mA are invalid. See Figure 2.501 for an example showing the user 4 – 20 mA analog inputs.

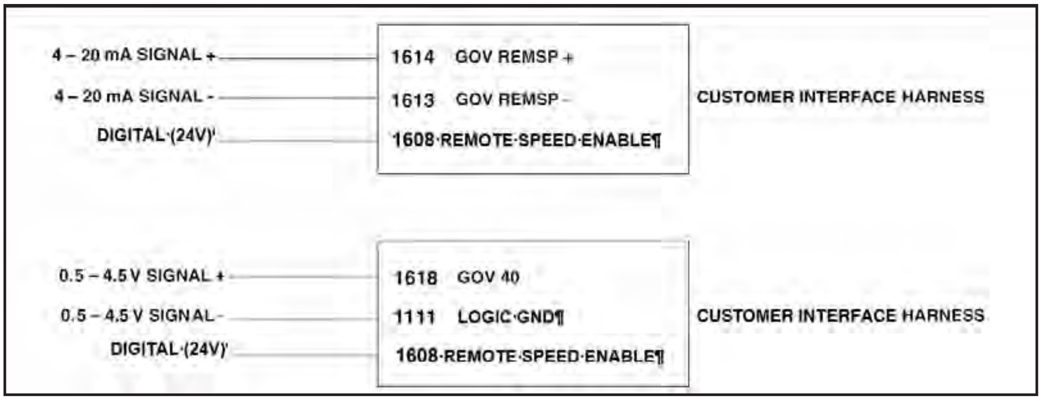
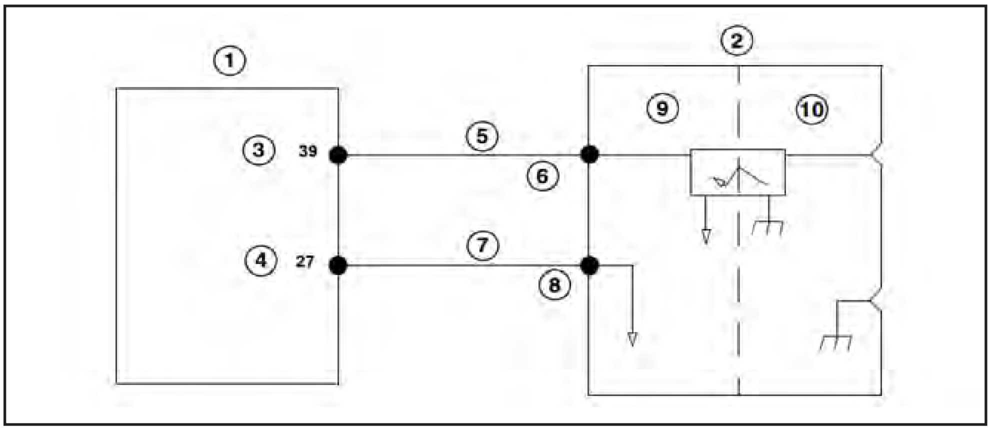


Figure 18-4: Connection options for variable speed setting input



1 - Customer Interface Harness	6 - Positive
2 - Typical PLC	7 - 4-20 mA Signal -
3 - GOVREMSP+	8 - Negative
4 - GOVREMSP-	9 - Isolated Current Output Card
5 - 4-20 mA Signal +	10 - Main

Figure 18-5: Example connecting user 4-20 mA analog input to PLC

OPTIONAL CONNECTIONS

There are many optional connections available in the customer interface harness. “Table 18-3: Optional connection descriptions - Customer interface harness” provides a description of these different optional connections.

Table 18-3: Optional connection descriptions - Customer interface harness

DESCRIPTION	PHYSICAL CONNECTION
Analog Outputs	4 – 20 mA analog outputs from the ECU that can be used to read engine parameters such as oil pressure, coolant outlet temperature, engine speed and intake manifold pressure (see Table 2.507). PROG OP 1 through PROG OP 3
MODBUS	The ECU is a MODBUS RTU slave on “two wire” RS485 hardware. Current operating values such as oil pressure and fault information are available. Baud rate and slave ID are programmed via the HMI. See MODBUS COMMUNICATIONS on page 2.551. RS485A and RS485B+
Engine OK / Emergency Shutdown	Digital signal output from ECU goes from open circuit to +24 VDC nominal (battery voltage – 1 volt) when ECU performs an emergency shutdown. ENG ESD

DESCRIPTION	PHYSICAL CONNECTION
Engine Alarm	Digital signal output from ECU goes from open circuit to +24 VDC nominal (battery voltage – 1 volt) when ECU detects engine problem. Output remains +24 VDC nominal while an alarm is active. As soon as alarm condition is resolved, digital signal returns to open circuit. ENG ALM
WKI Value	A 4 – 20 mA input to the ECU that allows the customer to change the input fuel quality (WKI) in real time. (4 mA = 20 WKI; 20 mA = 135 WKI) WKI+ and WKI
Uncontrolled Knock	Digital signal output from ECU goes from open circuit to +24 VDC nominal (battery voltage – 1 volt) when ECU cannot control engine knock. Allows customer knock control strategy such as load reduction instead of the ECU shutting down the engine. KNK ALM
Aux Speed Input	A 5 volt input to the ECU used for compatibility to generator control products (or other comparable control products). GOVAUXSIG+ and GOVAUXGND
Synchronizer Mode/Alternate Governor Dynamics	Digital signal input to the ECU when +24 VDC nominal (8.6 – 32 volts) allows synchronizer mode/alternate governor dynamics. User can adjust a small speed offset to aid in synchronization. GOVALTSYN
Load Coming	Digital signal input to the ECU when +24 VDC nominal (8.6 – 32 volts) is applied, signals the ECU that a large load will be applied to the engine. This input can be used to aid in engine load acceptance. User can adjust delay time from receipt of digital signal to action by the ECU and amount of throttle movement action. LRG LOAD
Two Digital Inputs	Two digital signal inputs to the ECU when +24 VDC nominal (8.6 – 32 volts) is applied allows user to wire alarm and/or shut down digital outputs of the local control into ESM2. The purpose of these two digital inputs to the ECU is to aid in troubleshooting problems with the driven equipment. USER DIP 1 and USER DIP 2
Engine Running	A digital output from the ECU that indicates that the engine is running. ENG RUN
User Power	Power (24V DC, 5 amps maximum) available for items such as a local control panel and panel meters +24VFOR U
User Ground	User ground GND 4 U
Emergency Stop Switch, Normally Open	Emergency Stop Switch, Normally Open ESTOP SW
Customer Prelube Control Request	Customer PreLube Control Request PREL CTRL
Compatible loadsharing input	Used for compatible loadsharing input LSMI+ and LSMI
***NOTE**: BOLD letters in table match wire label names.*	

LOCAL DISPLAYS

The ESM 2 system has three 4-20mA analog outputs that can be either read into a PLC or read with a local display. Each analog output can be configured to one of 11 different vales. See "Table 18-4: Adjustment of analog outputs"for the PROG OP wire description in the customer interface harness and for the output and scale values.

Table 18-4: Adjustment of analog outputs

WIRE LABEL	DESCRIPTION	SIGNAL NAME	SIGNAL TYPE	WIRE COLOR	FROM PIN	WIRE SIZE	SOCKET SIZE	WIRE#
PROG OP 1+	A 4 – 20 mA output from the ECU that represents an engine operating parameter. See Table 2.508 Available Analog Outputs on page 2.5011 for listing of parameters, scaling and other information.	Customer selected see Table 2.508Available Analog Outputs on page 2.5011	4 – 20 mA O/P+	Dark Green	21	18	20	1601
PROG OP 1	NEG for 4 – 20 mA PROG OP 1	NEG	4 – 20 mA O/P	Black	26	18	20	1648

WIRE LABEL	DESCRIPTION	SIGNAL NAME	SIGNAL TYPE	WIRE COLOR	FROM PIN	WIRE SIZE	SOCKET SIZE	WIRE#
PROG OP 2+	A 4 – 20 mA output from the ECU that represents an engine operating parameter. See Table 2.508 Available Analog Outputs on page 2.5011 for listing of parameters, scaling and other information.	Customer selected see Table 2.508Available Analog Outputs on page 2.5011	4 – 20 mA O/P+	Dark Green	3	18	20	1602
PROG OP 2	NEG for 4 – 20 mA PROG OP 2	NEG	4 – 20 mA O/P	Black	18	18	20	1649
PROG OP 3+	A 4 – 20 mA output from the ECU that represents an engine operating parameter. See Table 2.508 Available Analog Outputs on page 2.5011 for listing of parameters, scaling and other information.	Customer selected see Table 2.508Available Analog Outputs on page 2.5011	4 – 20 mA O/P+	Dark Green	11	18	20	1603
PROG OP 3	NEG for 4 – 20 mA PROG OP 3	NEG	4 – 20 mA O/P	Black	13	18	20	1650

Table 18-5: Available analog outputs

USER SELECTION	OUTPUT	SCALE LOW (4 mA)	SCALE HIGH (20 mA)
1	Engine Load in percent	0%	125%
2	Engine Power in kW	0	4000
3	Engine RPM	0	2200
4	Throttle Position in Percent	0	100
5	Intake Manifold Press in kPa	0	517
6	Engine Oil Pressure in kPa	0	1034
7	Intake Manifold Temp C	40	150
8	Exhaust Temp LB C	80	1100
9	Exhaust Temp RB C	80	1100
10	Engine Coolant Temp C	40	150
11	Engine Oil Temp C	40	150
12	Future Spare	NA	NA
13	Future Spare	NA	NA
14	Future Spare	NA	NA
15	Future Spare	NA	NA
16	Future Spare	NA	NA

+24V FOR U AND GND FOR U

NOTICE

Never attempt to power the engine using the +24VFOR U wire. The +24VFOR U wire is for customer use to provide 24 VDC power to other equipment.

Never attempt to power the engine using the +24VFOR U wire in the ustomer interface option harness. The +24VFOR U wire is for customer use to provide 24 VDC power to other equipment.

Power (24 VDC, 5 amps maximum) is available for items such as a local control panel and panel meters. The 24 VDC wires are labeled +24VFOR U and GND FOR U. DO NOT POWER THE ENGINE THROUGH THIS CONNECTOR!

MODBUS

MODBUS is an industrial communication network that uses the master-slave topology. Through this connection nearly every parameter that ESM is monitoring can be read by the customer's PLC. This includes temperatures, pressures, timing, engine speed, error codes etc. See the O&M manual for more information.

Modbus RS-485 output is available through the customer interface harness as two wires labeled RS 485A- and RS 485B+ (green and yellow, respectively).

ALARM AND SHUTDOWNS

ESM2 has alarm and shutdown setpoints built into its logic to help prevent engine damage or unsafe operation. User signals can also be sent to ESM to perform a shutdown; Waukesha recommends monitoring the main bearing and exhaust thermocouples to program alarm and shutdowns.

"Table 18-6: Alarm and shutdown parameters" lists some of the normal operating parameters as well as the respective alarm and shutdown setpoints.

Table 18-6: Alarm and shutdown parameters

Parameter	Normal	Alarm	Shutdown
Jacket Water	180°F	190°F	200°F
Lube Oil Header Temp	180°F	190°F	200°F
Lube Oil Header Pressure	50-60 psi	35 psi	30 psi
Intake Manifold Temperature	up to 140°F	155°F	160°F
Main Bearing Temperature*			250°F
Exhaust Temperature*		1450°F	1475°F
Overspeed	1200 rpm max		10% overspeed
Fuel Pressure*	40-60 psi	30 psi	25 psi

*logic supplied by customer

Other shutdowns programed into ESM2 include the following:

- E-Stop buttons on each side of the engine
- Low oil pressure
- Engine overspeed
  - 10% overspeed instantaneous
  - Waukesha-calibrated to run no more than rated speed
  - User-calibrated driven equipment overspeed
- Customer-initiated emergency shutdown
- Engine overload (based on percentage of engine torque)
- Uncontrollable knock
- Overcrank
- Engine stall
- Failure of magnetic pickup

- Catalyst temperature or pressure limit exceeded
- High coolant temperature
- High intake manifold temperature
- High oil temperature
- High exhaust temperature
- High crankcase pressure
- High main bearing temperature
- ECU internal faults
- Security violation

HMI INSTALLATION

The HMI is installed in the cutout using retaining clips. The number of retaining clips depends on the display unit.

The thickness of the wall or cabinet plate must be between 1 mm and 6 mm.

A 2.5 mm hex socket screwdriver is needed to tighten and loosen the screws on the retaining clips. The maximum tightening torque for the retaining clips is 1 Nm.

Devices must be installed on a flat, clean and burr-free surface; uneven areas can cause damage to the display when the screws are tightened or the intrusion of dust and water.

Procedure

1. Check whether the included mounting screws are screwed into the retaining clips. If not, then the mounting screws must be screwed into the retaining clips with a 2.5 mm hex key screw-driver. The mounting screws only need to be screwed in far enough that they no longer protrude above the retaining clip.

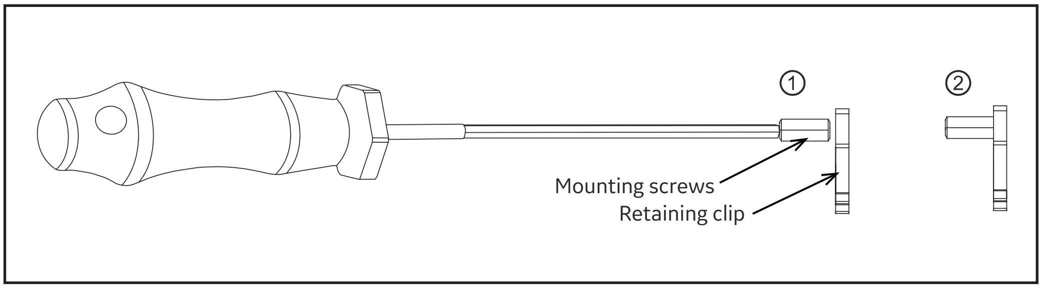


Figure 18-6: Preparing the retaining clips

2. Insert the device into the front side of the smooth, flat installation cutout. The cutout dimensions can be found in figure A-1.

3. Install the retaining clips on the device. This is done by inserting the clips into the openings on the sides of the device (indicated by the orange circles). The number of retaining clips depends on the display size (refer to table A-1).

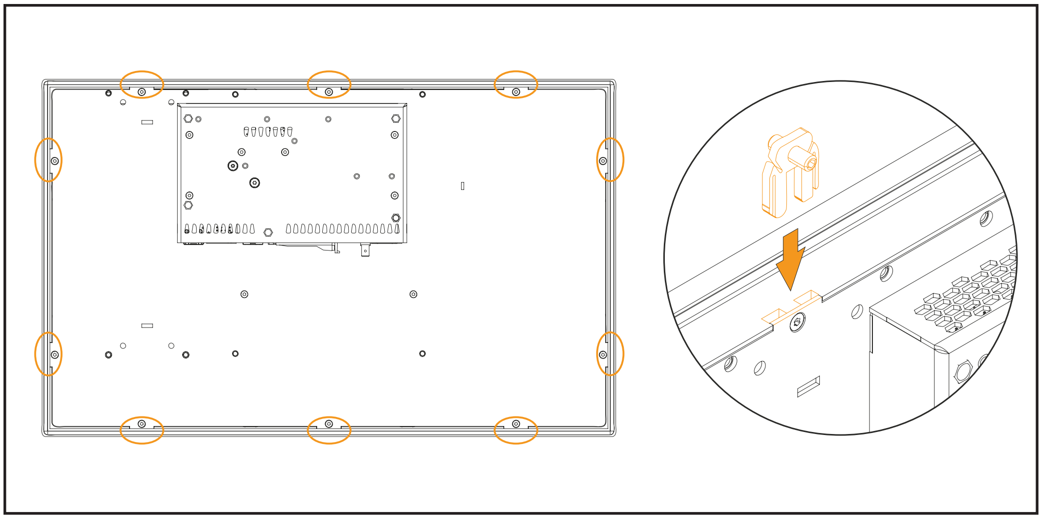


Figure 18-7: Inserting the retaining clips

4. Fasten the retaining clips to the wall or control cabinet by alternately tightening the screws with a 2.5mm hex key screwdriver. The tightening torque should be max. 9 in-lb (1 N-m) to provide an optimal seal.

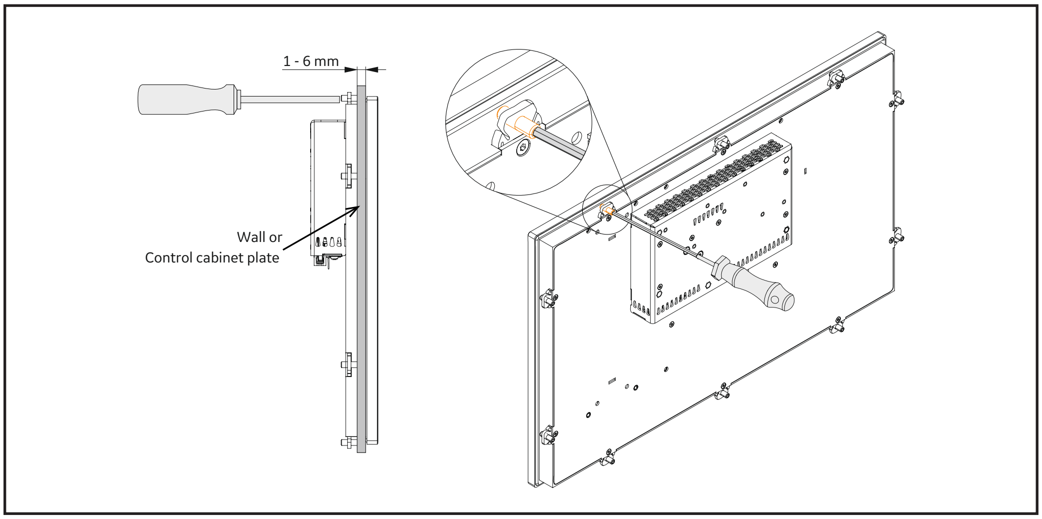


Figure 18-8: Fastening the retaining clips

HMI CONNECTION OVERVIEW

Figure 18-9: Back of HMI

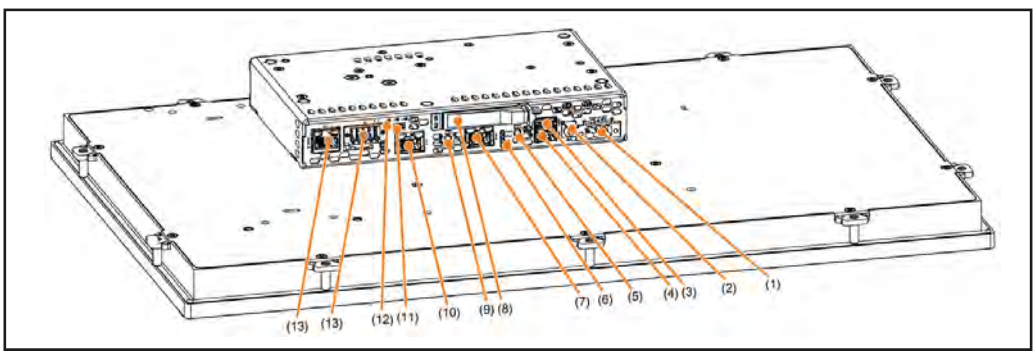
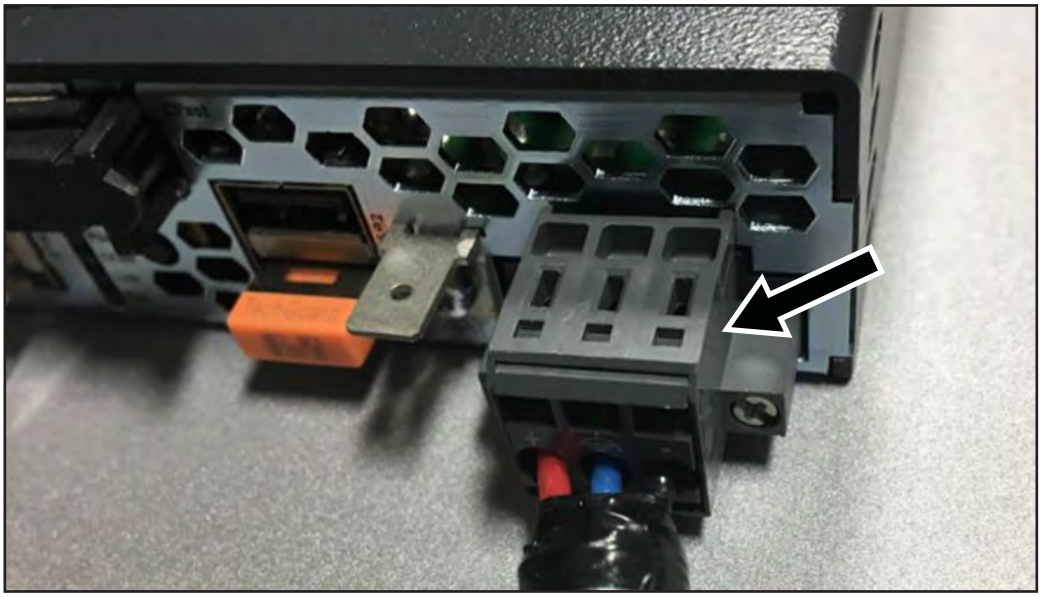


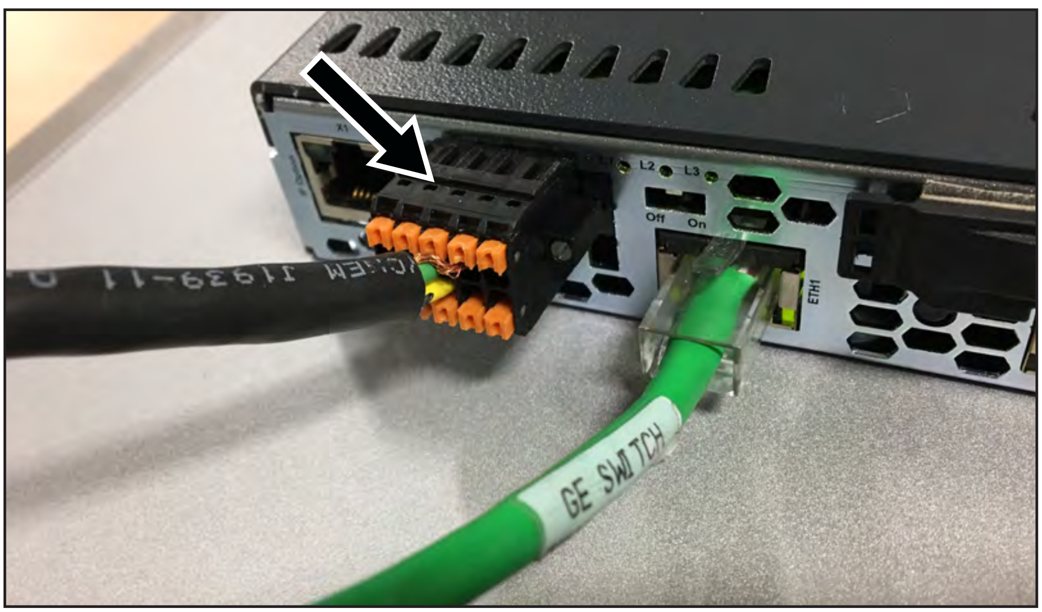
Figure 18-10: HMI Connection Overview

1 24 VDC Power	8 CFAST
2 Functional Ground Connection	9 Reset Button
3 USB2	10 ETH1
4 USB1	11 On/Off (NOTE: Set to ON for active resistance)
5 Power Button	12 L1, L2, L3
6 Power, CFast, Link, Run	13 X1, X2 IF Option
7 ETH2	



HMI Power Connector Wiring Details				
Wire Label	From (A)	To (B)	Wire Color	GA
+24V	HMI Power (+)	Customer Panel +24V	Red	16
-24V	HMI Power (-)	Customer Panel -24V	Black	16
GND	HMI Power (Ground)	Customer Panel Ground	Blue	16

Figure 18-11: Power connector – included with 6' length pigtails, for connection to 24VDC power source



HMI CAN Connector Wiring Details				
Wire Label	From (A)	To (B)	Wire Color	GA
CAN HI	HMI CAN-5	Customer Interface Harness Wire # 1300 (CAN HI)	Yellow	20
CAN LO	HMI CAN-6	Customer Interface Harness Wire # 1301 (CAN LO)	Green	20
CAN GND	HMI CAN-7	Customer Interface Harness Wire # 1302 (CAN GND)	Drain	20

Figure 18-12: CAN connector – included with 6' length pigtails, for connection to Customer Interface Harness

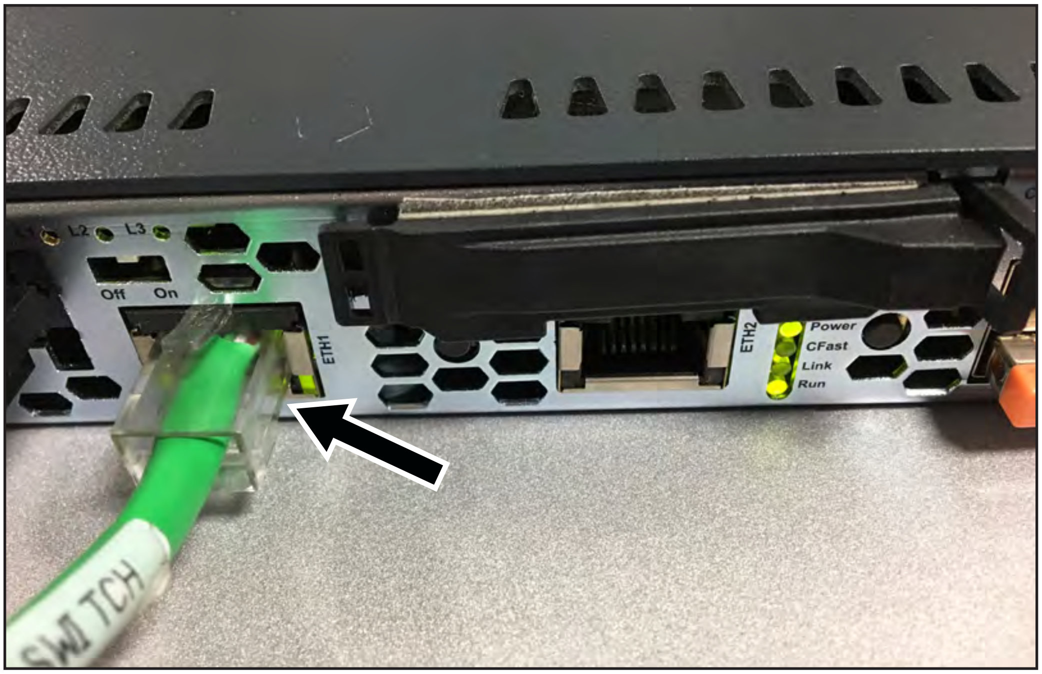


Figure 18-13: Ethernet connection for APM

NOTE: The ambient temperature rating for the HMI is -4° – 140°F (-20° – 60°C).

NOTICE

When installing the HMI, be sure to leave sufficient spacing for air circulation as well as additional space for operation and maintenance of the device.

In order to guarantee sufficient air circulation, the specified amount of space above, below, to the side and behind the device must be provided. The minimum specified spacing is indicated in "Figure 18-14: Spacing for Air Circulation".

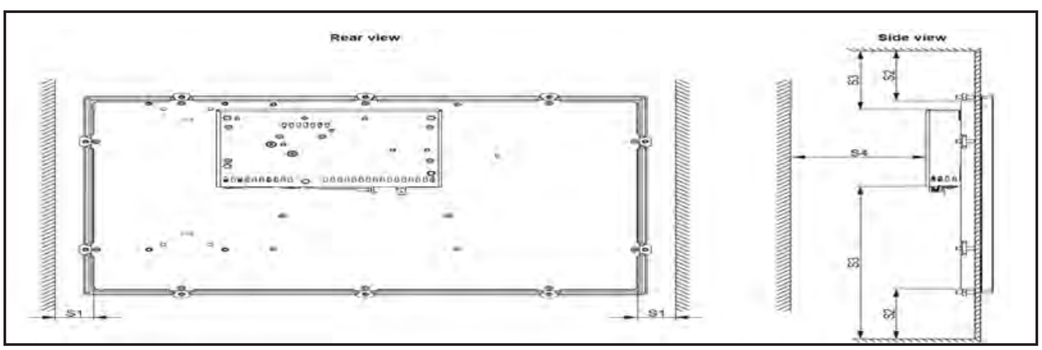


Figure 18-14: Spacing for Air Circulation

S1	S2	S3	S4
0.80 in. (20 mm) minimum	1.96 in. (50 mm) minimum	3.94 in. (100 mm) minimum	1.96 in. (50 mm) minimum

NOTICE

The spacing specifications for air circulation are based on the worstcase scenario for operation at the maximum specified ambient temperatures. The maximum specified ambient temperature must not be exceeded..

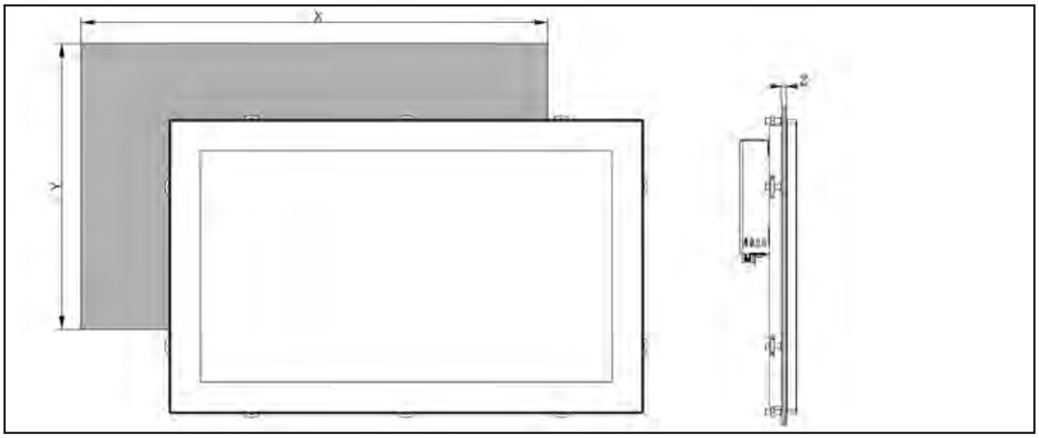


Figure 18-15: Installation Diagram

X	Y	Z (Minimum – Maximum)	Number of Clips
12 in. (304 mm)	8.97 in. (228 mm)	0.04 – 0.24 in. (1 – 6 mm)	10 pieces
15 in. (359 mm)	11 in. (277 mm)	0.04 – 0.24 in. (1 – 6 mm)	10 pieces
19 in. (429 mm)	13.7 in. (347 mm)	0.04 – 0.24 in. (1 – 6 mm)	12 pieces

A hexhead screwdriver is needed to tighten and loosen the screws on the retaining clips. The maximum tightening torque for the retaining clips is 9 in.lb (1 N·m).

INITIAL SETUP

During the initial setup, several steps are required before operating the engine. This section will show some of the essential steps required, but refer to the operation & maintenance manual, Form 10063-1, for more in depth information.

LOGIN TO THE HMI

Guest access (not logged in) does not have the ability to change any parameters on the engine. This access level will be able to view the VISUALIZATION, GRAPH, and SYSTEM tabs only.

Figure 18-16: Guest login

With a customer login, the user now has the ability to change any of the parameters on the PARAMETERS tab which is not available with guest access.

Figure 18-17: Customer login

To change the user profile, select the desired profile and a keypad will appear.

Figure 18-18: Keypad

Enter the appropriate 6-digit password and the corresponding access level of that profile will be active.

NOTE: A unique password is generated at the factory and is provided with the HMI.

To add a user, you must be connected with a computer. An Ethernet cable must be used between the computer and the ETH2 port of the HMI.

Each user profile can set their own specific settings to display their preferred units and format.

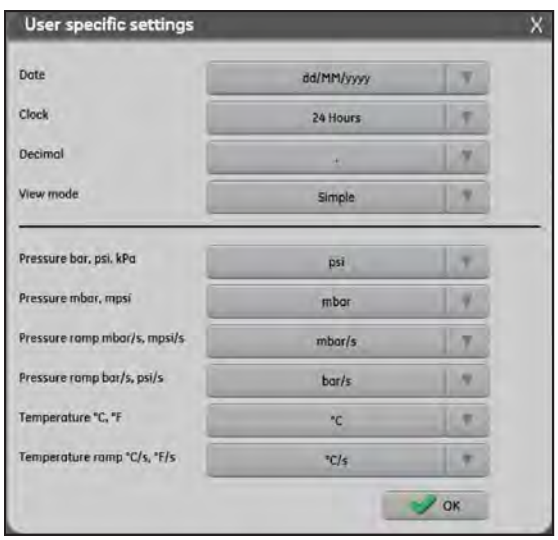


Figure 18-19: User-specific settings

Selecting the SYSTEM tab brings up a new set of icons on the bottom of the screen (see “Figure 18-20: SYSTEM Tab”).

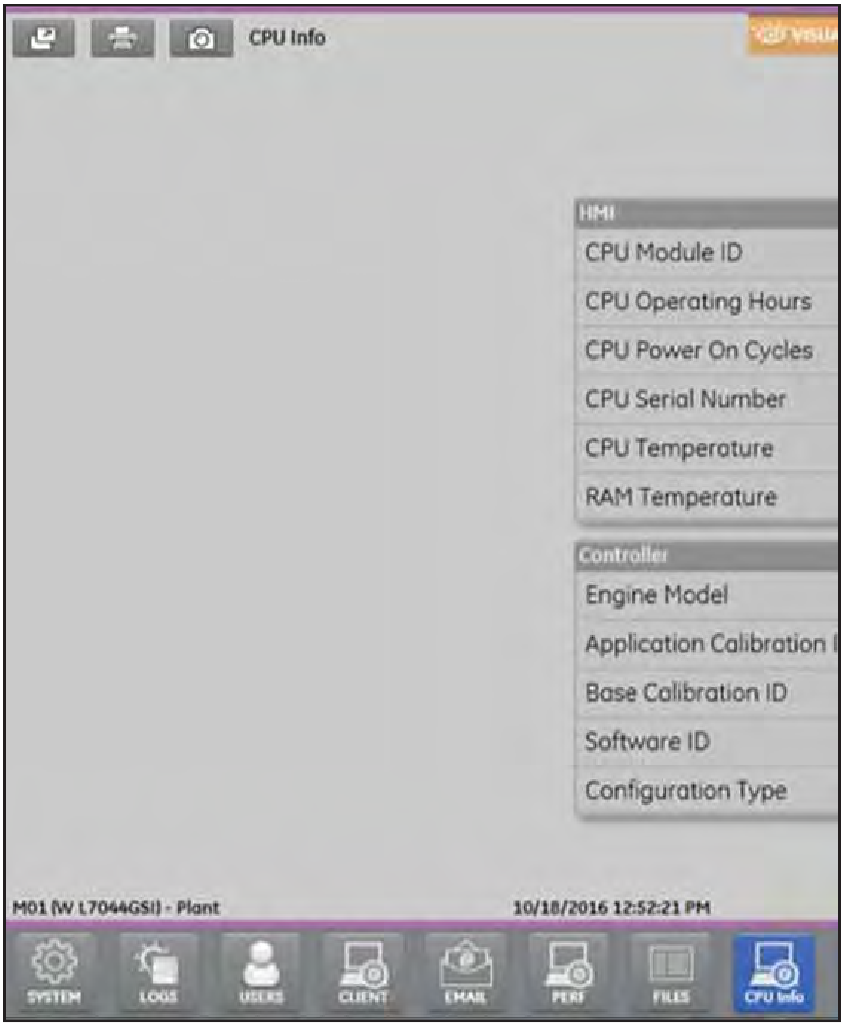


Figure 18-20: SYSTEM Tab

SYSTEM > Time brings up the time screen (see “Figure 18-21: System > Time Screen”), which allows you to connect to a time server or to change date/time.

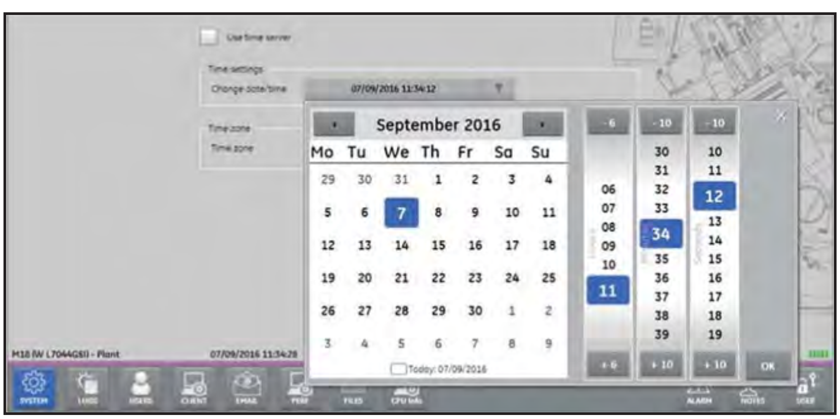


Figure 18-21: System > Time Screen

ENTER THE WKI VALUE

The "WKI" (Waukesha Knock Index) must be entered by the user for proper engine operation. The WKI value can be determined using the EngCalc application program. The program will calculate the WKI value from a customer's gas analysis breakdown. The WKI value must be based on the composition of a fuel sample taken from the engine site and analyzed using the EngCalc program.

NOTICE **Ensure an accurate WKI value is entered. Failure to enter the WKI value correctly could lead to poor engine performance and the potential for engine detonation.**

To enter the WKI value, go to the Ignition Parameters screen.

Figure 18-22: Ignition parameters screen

Select the "WKI" field, and a keypad will appear.

Figure 18-23: WKI keypad

Enter the WKI value of the fuel, and select the return tab on the keypad. The "Change: WKI" confirmation popup will appear, and select "Yes" to change the WKI value.

Figure 18-24: WKI confirmation pop-up

INPUT LOAD INERTIA VALUE

NOTICE

Make sure the correct rotating moment of iniertia (load inertia) is entered for the engine's driven equipment. Failure to enter the moment of inertia for the driven equipment on the engine will lead to poor steady-state and transient speed stability.

The "Load Inertia" field must be entered by the operator for proper engine operation, and should be entered when the engine is not running.

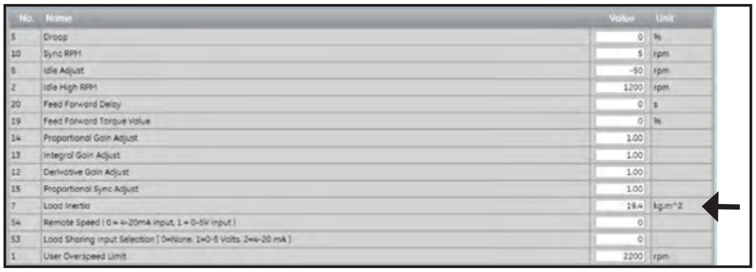
Adjusting the load inertia, or the rotating moment of inertia of the driven equipment, results in the governor gain being preset correctly which aids in rapid start-up of the engine.

The rotating moments of inertia must be known for each piece of driven equipment and then added together. Rotating moment of inertia is needed for all driven equipment. Rotating moment of inertia is not the weight or mass of the driven equipment.

NOTE: The rotating moment of inertia of driven equipment is an inherent property of the driven equipment and does not change with engine speed or load. Contact the coupling or driven equipment manufacturer for the moment of inertia value.

To determine the rotating moment of inertia for ALL driven equipment, determine the rotating moment of inertia for each piece of driven equipment (being consistent with U.S./English and metric units). Once you have the value for each piece of driven equipment, sum all the values. The summed value is what is adjusted on the Engine > Governor Parameters screen.

Figure 18-25: Figure 2: Engine > Governor Screen



No.	Name	Value	Unit
5	Droop	0	%
10	Sync RPM	5	rpm
8	Idle Adjust	-50	rpm
2	Idle High RPM	1200	rpm
20	Feed Forward Delay	0	s
19	Feed Forward Torque Value	0	%
14	Proportional Gain Adjust	1.00	
13	Integral Gain Adjust	1.00	
12	Derivative Gain Adjust	1.00	
15	Proportional Sync Adjust	1.00	
7	Load Inertia	19.4	kg.m^2
54	Remote Speed (0 = 4-20mA input, 1 = 0-5V input)	0	
53	Load Sharing Input Selection (0=None, 1=0-5 Volts, 2=4-20 mA)	0	
1	User Overspeed Limit	2200	rpm

Figure 18-26: Governor parameter screen

Select the “Load Inertia” field, and a keypad will appear for you to enter the sum of all the moment of inertia values for all driven equipment.

Figure 18-27: Load inertia keypad

NOTE: The units for load inertia are set on the HMI via the user settings discussed earlier.

Select the return tab on the keypad, and the load inertia acknowledgement popup will appear.

Figure 18-28: Load inertia acknowledgement pop-up

Select “Yes” to change the load inertia.

SETTING UP THE AFR2 FUEL CONTROL MODE

The AFR2 setup procedure will set the fuel pressure regulator and carburetor screws as well as synchronize and center the right and left bank fuel control valves at a low speed/load setting and a high speed/load setting. This will account for the fuel being used and ensure the FCVs are in the optimum position throughout the operating range. Adjust the fuel system using the AFR Visualization screen and should be done when commissioning the engine on site.

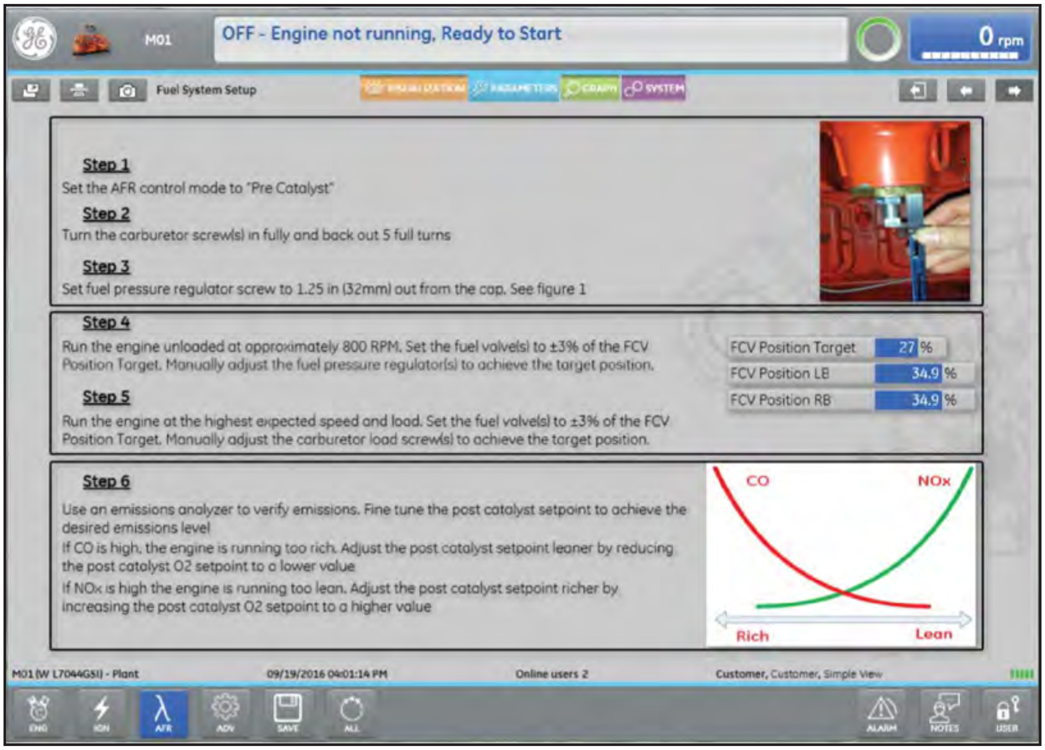


Figure 18-29: Fuel system setup screen

For more details on the setup process, refer to section 2.70 in the Operations & Maintenance manual, Form 10002-1 (or most current version).

There are 3 different control modes available in the AFR2 system.

1. MAN (Manual) – will indicate the system is operating in manual mode

2. PRE (Pre-catalyst) – will indicate the system is operating in pre-catalyst mode

3. POST (Post-catalyst) – will indicate the system is operating in post-catalyst mode (only available when emPact emissions control system is being used)

CHAPTER 19 - ASSET PERFORMANCE MANAGEMENT (APM)

APM REQUIREMENTS

- Cellular network or internet connection on site to transmit data
- Access to myPlant to allow user to view APM data from laptop or smartphone
- APM Module must be located at least 3ft (1m) from the engine to reduce vibration, avoid electro-magnetic interference, and must be installed in an enclosure to keep safe from the environment (rain, sunlight, dust, etc.)
- Requires 24VDC power source for APM module and optional cell router. 120VAC power required for optional cell booster

OPTIONAL EQUIPMENT

All VHP engines with ESM2 will come with the parts shown in Kit 1 shipped loose as an option without any additional cost. Note that these are sensitive electrical components and care should be taken to not allow the shipped loose parts box to be exposed to the elements.

Table 19-1: Kit 1 Components

Item	Description	Quantity	Part Number
APM Module	Data Collector	1	741335
APM Installation and Operation Instructions	Manual	1	FORM 10000-3

The data that is collected with the APM Module needs to be transmitted to GE's secure data storage. To do this GE offers different option codes depending on the location, which provides a cell router, SIM card, and antenna. This kit is meant to connect the APM Module to the internet via a cellular connection to allow data transmissions to the APM user interface. Check with application engineering to ensure suitability of the cell router in the specific country that the package will be located.

This option is not needed if the site has an internet connection or an existing cellular network is being used, refer to S-09209-1 for router performance requirements. A local area network connection could also be used to transmit the data, but one of these options is required for the system to function.

Table 19-2: Kit 2 Components

Item	Quantity
Cell Router	1
SIM Card	1
Cellular Antenna	1
Antenna Magnetic Base	1

There is an additional option (code 1022) for a cellular signal booster kit that is available for North American customers who have poor cellular coverage. This booster can be ordered for sites where APM Kit # 2 – cell router, does not provide adequate cell connection. The cell booster must be installed outside of a Class 1, Div. 2 area. The kit includes:

Table 19-3: Kit 3 Components

Item	Quantity	Part Number
Directional Antenna	1	741290
Cell Booster	1	741074
50ft Coax Cable	1	741312

CUSTOMER SUPPLIED EQUIPMENT

The customer must supply a suitable location to mount the APM hardware to keep it safe from exposure to the environment (rain, sunlight, dust, etc.). The APM Module and optional cell router kit should be installed at least 3ft (1m) away from the engine in either the local control panel or an additional junction box (NEMA 4/IP66 rated). Other miscellaneous hardware for installation will be required, which may include Ethernet and/or serial cable as well as power and ground wires for the devices as the lengths of these connections will be site specific.

REFERENCE DOCUMENTS

Form 10000-3 APM Installation and Operation Instructions

SYSTEM DESCRIPTION

The GE Waukesha Asset Performance Management Module (APM Module) is a data collector that allows collection of operational and site data from multiple sources. The collected data is transferred to GE's secure APM User Interface, called "myPlant", for further data trending and analysis. Collected data can be used to identify trends and fine tune maintenance actions to reduce plant operating costs and keep assets running at optimal performance and availability. The myPlant interface can be viewed from either a laptop or smartphone to allow users access to their data 24/7 from anywhere, and allows trending of historical data. myPlant also offers analytics to allow better planned maintenance or a close watch on any user defined parameter.

In addition to collecting operational data from the engine's ESM2, the APM Module can gather operational data from the driven equipment and site balance of plant (BoP) data from the site PLC. The APM system can aggregate data from multiple assets (compressor/generator, ESM, AFR2, or PLCs) at the same time, using a Modbus RTU or Modbus TCP network. Up to 6 packages (engine + compressor/generator) and all related PLCs or site BoP can be connected to one APM Module for stable data collection. One APM Module is needed for each duplicate Modbus network that requires data collection (up to 6 packages per network).

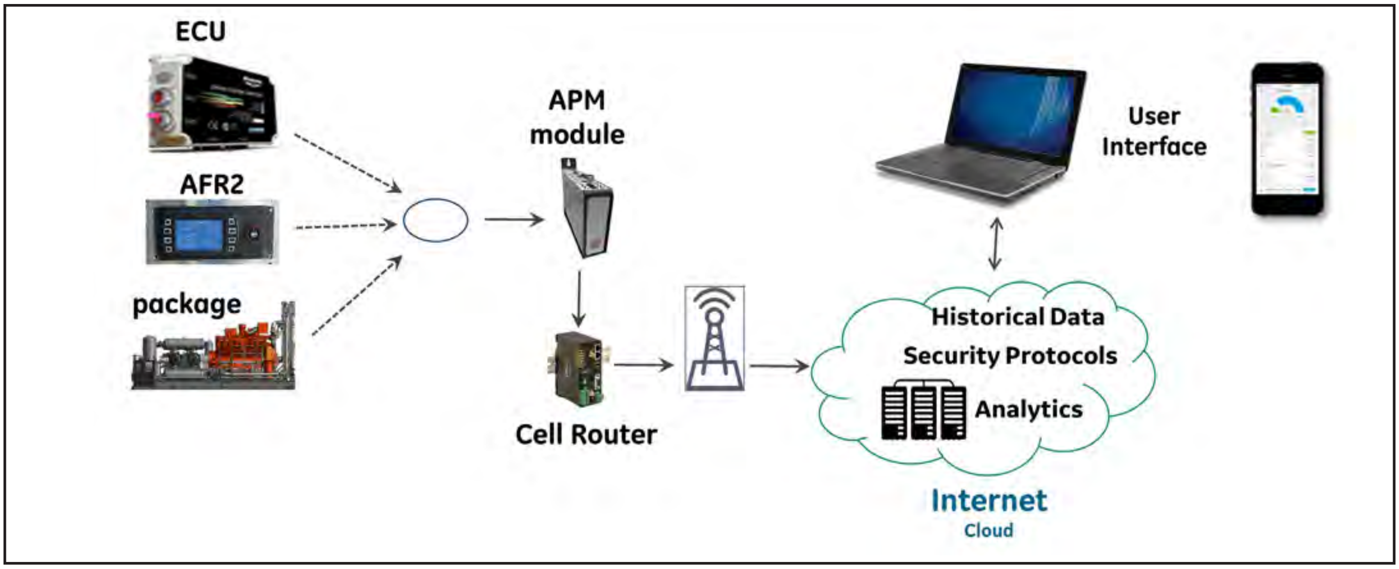


Figure 19-1: APM System Flow Diagram

The APM Module and optional cell router are CSA Class 1, Div. 2 rated for hazardous environments. The APM Module has an IP20 rating, and it, along with the optional cell router, must be mounted in an enclosure so they are not exposed to the environment (rain, sunlight, dust, etc.).

Refer to Form 10000-3 – APM System Installation and Operation Instructions manual for more information on mounting, installation, system configuration, and specific component details and schematics.

CHAPTER 20 - ENGINE OPERATION

LIGHT LOAD OPERATION

The following information gives recommendations for special operation and maintenance procedures when operating Waukesha natural gas engines at light loads or no loads for extended periods of time.

Light load operation is typically defined as power levels less than 50% of the maximum continuous power rating. Gas engines usually have unstable combustion at light loads because combustion chamber pressures are lower, which increases blow-by past the piston rings. This can lead to contamination of the engine oil including an increase in oil nitration rates and carboning of the piston ring grooves. Oil analysis is recommended to determine proper oil change intervals. See latest edition of Service Bulletin 12-1880 for Waukesha oil recommendations. Change intervals are usually not affected by periodic light loading.

If the engine is operated at less than 30% load for long periods (>300 hours), it is recommended that the engine be exercised at full load for 2 hours every 400 hours.

Engine oil and coolant temperatures should be maintained within the standard operating ranges.

Always check thermostats for proper operation.

For further information regarding light load operation, refer to service bulletin 16-2864.

ENGINE STARTING

The following section describes the routine start-up sequence and procedure. For initial commissioning and pre-start procedures, refer to the Commissioning section of this manual.

STARTING REQUIREMENTS:

- Engines that are required to start at ambient temperatures below 50°F (10°C) require Lube Oil and Jacket Water Heaters. Verify engine is warm enough before attempting to start. Lube oil temperature range is 70°F - 100°F (21°C - 38°C). Jacket water temperature range is 70°F - 125°F (21°C - 52°C)

- Intake air heater for effective starting when combustion air inlet temperature will be less than 50°F (10°C) or for continuous operation if ambient temperature is below 0°F (-17.8°C).

NOTE: The ESM2 is calibrated by Waukesha to both alarm and shut down on low oil pressure. However, low oil pressure alarm and shutdowns are inhibited for a period of time after engine start. Follow these instructions for normal start-up of the engine.

⚠ WARNING

Always purge the engine and the exhaust system by cranking the engine for several seconds before the ignition is turned on and the main gas shutoff valves are opened.

The volume that is purged is several times greater than the volume of the exhaust system. This purge volume is approximately the engine displacement for two revolutions.

In case the volume of the exhaust system is such that it will not be purged by the cranking of the engine, the customer has to use an alternative means to purge the exhaust system.

NOTICE **Only trained personnel should program the ESM.**

STARTING PROCEDURE:

1. Complete all prestart activities and checks.

2. Reset all engine protection switches and devices.

3. Set operating speed to 750 rpm.

4. Confirm engine coolant and lube oil are at least 10°C (50°F) for reliable starting.

5. Open the manual gas shutoff valve, if closed. This statement refers to a customer-supplied shutoff valve, located upstream of the engine. The ESM2 will automatically open the engine-mounted shutoff valve at the appropriate time.

6. Initiate pre-lube/start cycle by activating the digital Start Signal to the ESM2.

- Start Signal – a momentary "high" (8.6 – 36 volts; 24VDC nominal) input to the ECU indicating the engine should be started. The minimum duration of the signal is 1/2 second but should not exceed 1 minute. The wire is labeled "START" and is located in the Customer Interface Harness.
- The shutdown signals must both be "high" (8.6 – 36 volts; 24VDC nominal) in order to allow the engine to start and run. This includes the Normal Shutdown (Run/Stop) digital input (wire label "RUN/STOP") and Emergency Shutdown digital input (wire label "ESD"). Both of these wires are located in the Customer Interface Harness.

7. Engine should start in the first 7 – 8 seconds of cranking cycle. (A 5-second delay from crank initiation to main gas shutoff valve opening is programmed into the ESM to purge unburned fuel from previous start attempts from the engine and fuel system.)

When the engine is started, listen carefully for any unusual noises. If a problem is suspected, stop the engine immediately.

After the engine is started, verify that there are no gas, air, coolant or oil leaks. Pay special attention to the gas manifolds and piping.

NOTICE

If the oil pressure display does not indicate sufficient oil pressure within 15 seconds, shut the engine down immediately. Never operate the engine without the proper oil pressure indication.

If the engine has not reached the proper operating temperature of 76° – 82°C (170° – 180°F), the oil pressure could be as high as 758 kPa (110 psi). Once the engine has reached the proper operating temperature, the oil pressure should meet the above specifications.

WARNING

Never idle turbocharged engines for extended periods. Accumulated carbon may damage turbocharger. Instead of idling the engine, shut it down and restart when needed.

8. Warm engine by running with little or no load until oil pressure is 345 – 415 kPa (50 – 60 psi) and jacket water temperature exceeds 38°C (100°F). For standby units, jacket water heating to 43°C (110°F) is required.

9. Gradually apply load to avoid overloading engine. Refer to the following “Engine Loading” section for further details.

ESM2 START SEQUENCE:

See “Figure 20-1: Start Flow Diagram”.

During the start sequence, the ESM2 performs the following steps:

- Prelubes engine (programmable from 0 – 10,800 seconds from the Prelube Time field located on the Start-Stop visualization screen on the HMI)
- Engages starter motor (programmable rpm range using the HMI)
- Turns ignition on (after a user-calibrated purge time using the HMI)
- Turns main fuel on (programmable above a certain rpm and after a user-calibrated purge time using the HMI)

When the user initiates a start from the user panel, a signal is sent to the ECU to begin the start procedure. After receiving a start signal, and confirming the emergency stop and run/stop signals are high, the ECU prelubes the engine for a user-calibrated period of time.

Once the prelube is complete, the starter is activated. The ignition is energized after the engine has rotated through a minimum of two complete engine revolutions and a user-calibrated purge timer has expired. When the engine speed reaches an rpm determined by Waukesha, the main gas shutoff valve is energized. The engine then increases speed until it reaches its governed rpm.

Once the starter is activated, a timing circuit begins. If the engine does not reach a minimum rpm within a calibrated amount of time, the ECU will initiate a shutdown and de-energize the starter.

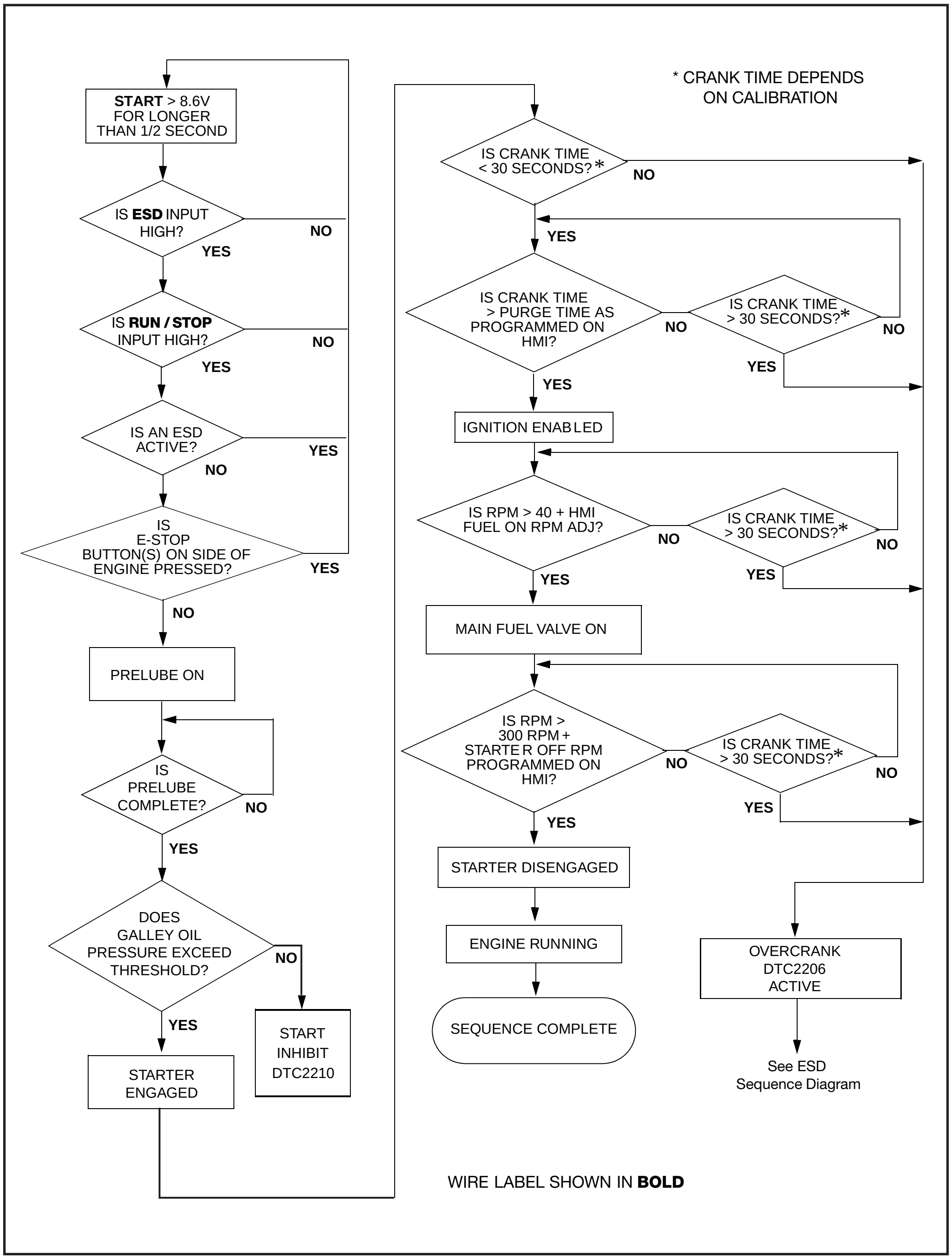


Figure 20-1: Start Flow Diagram

ENGINE LOADING

COMPRESSION APPLICATIONS

In compression applications, a compressor bypass is used to apply the load to the engine, which is designed to equalize the suction and discharge pressures on the compressor and can minimize the load required from the engine for startup and warm-up. The bypass valve must be completely open during engine startup and warm-up.

Loading of engine is accomplished by either ramping (timed) closure of bypass valve or opening of suction valve depending on operating protocol of end-user. In either manner the loading is continued over a period of time, while maintaining engine RPM within acceptable drop limits. Once the unit has warmed up, load should be applied at a controlled ramp rate. This rate is linear and should not exceed 20% of maximum rated load per minute (therefore 0-100% load can be achieved in 5 minutes).

The bypass line must be properly sized to minimize the compressor load during engine startup and warm-up. Typically a bypass line with a diameter equal to the discharge line is ideal because it can accommodate all the flow from the compressor. A bypass line with a smaller diameter will normally cause the engine to be started under a partial load. This will compromise the durability of the starting system and internal components of the engine.

While a completely open bypass line will reduce the load required from the engine, there may still be a small load applied to the engine if the compressor is not depressurized after shutdown. While using a completely open bypass line, starting the engine does not require depressurizing of the compressor unless otherwise required by the operating philosophy of the customer’s compressor site.

Engine speed ramp rate is limited by ESM2. The quickest speed change rate that ESM2 will allow is 10 rpm per second.

POWER GENERATION APPLICATIONS

In Power Generation applications, the units are started and can be warmed up at either low idle speed, or at synchronous speed (1000 or 1200rpm). With the circuit breaker open, there is no load applied during warmup.

For units operating in parallel with the utility grid, once the unit has warmed up, load should be applied at a controlled ramp rate. This rate is linear and should not exceed 20% of maximum rated load per minute (therefore 0-100% load can be achieved in 5 minutes).

For units in island mode operation (also known as stand-alone mode), the loading is determined by the sequencing/starting of individual site loads. In these cases, the maximum allowable load steps for the 12-cylinder rich-burn engines are typically 20-25% of rated load. Contact Waukesha Application Engineering for more details.

SHUTDOWN

The following section describes the routine and emergency shutdown procedures and sequences. A routine shutdown is the normal method use to stop the engine, whereas an emergency shutdown should be used to avoid imminent personal injury or property damage.

ROUTINE SHUTDOWN PROCEDURE:

WARNING

Allow engine to cool for at least 10 minutes after shutdown. Do not restart an overheated engine or an engine that has been shut down by the engine protection system until the cause has been determined and corrected.

WARNING

Always ensure that the fuel gas valve(s) are closed after engine shutdown.

NOTICE

If the engine is being shut down for an extended period of time, cap the exhaust pipe to prevent moisture or contaminants from entering the engine.

1. Gradually reduce engine load.

2. Operate engine at no load for 5 minutes to cool down engine temperatures.

3. Shut down engine using customer-supplied control panel.

4. Postlube engine for minimum of 60 seconds. ESM2 system is programmed to automatically postlube engine.

ROUTINE SHUTDOWN SEQUENCE

See “Figure 20-2: Routine Stop Flow Diagram”.

To initiate a routine shutdown, the engine should be stopped by causing the normal stop (or run/stop) input to go “low.” This turns off the fuel supply before ignition is halted, eliminating unburned fuel. It runs the postlube procedure supplying oil to vital engine components. The wire is found in the Customer Interface Harness and is labeled “RUN/STOP”. During this routine shutdown, the Emergency Shutdown input must remain active (high).

During the routine shutdown sequence, the ESM2 performs the following steps:

• Begins cooldown period (programmable using the HMI)

• Shuts off fuel (by closing the engine-mounted shutoff valve)

• Stops ignition when engine stops rotating.

• Postlubes engine (programmable from 0 – 10,800 seconds using the HMI)

When the run/stop digital input to the ECU goes low (less than 3.3 volts), and a user-calibrated cooldown period is met, the ECU stops the engine. This is accomplished by first de-energizing the main gas shutoff valve and prechamber main gas shutoff valve and then, when the engine speed drops to zero, de-energizing the ignition. If the engine fails to stop in a preprogrammed period of time (typically less than 1 minute) after the main gas shutoff valve has been de-energized, the ignition is de-energized, forcing a shutdown.

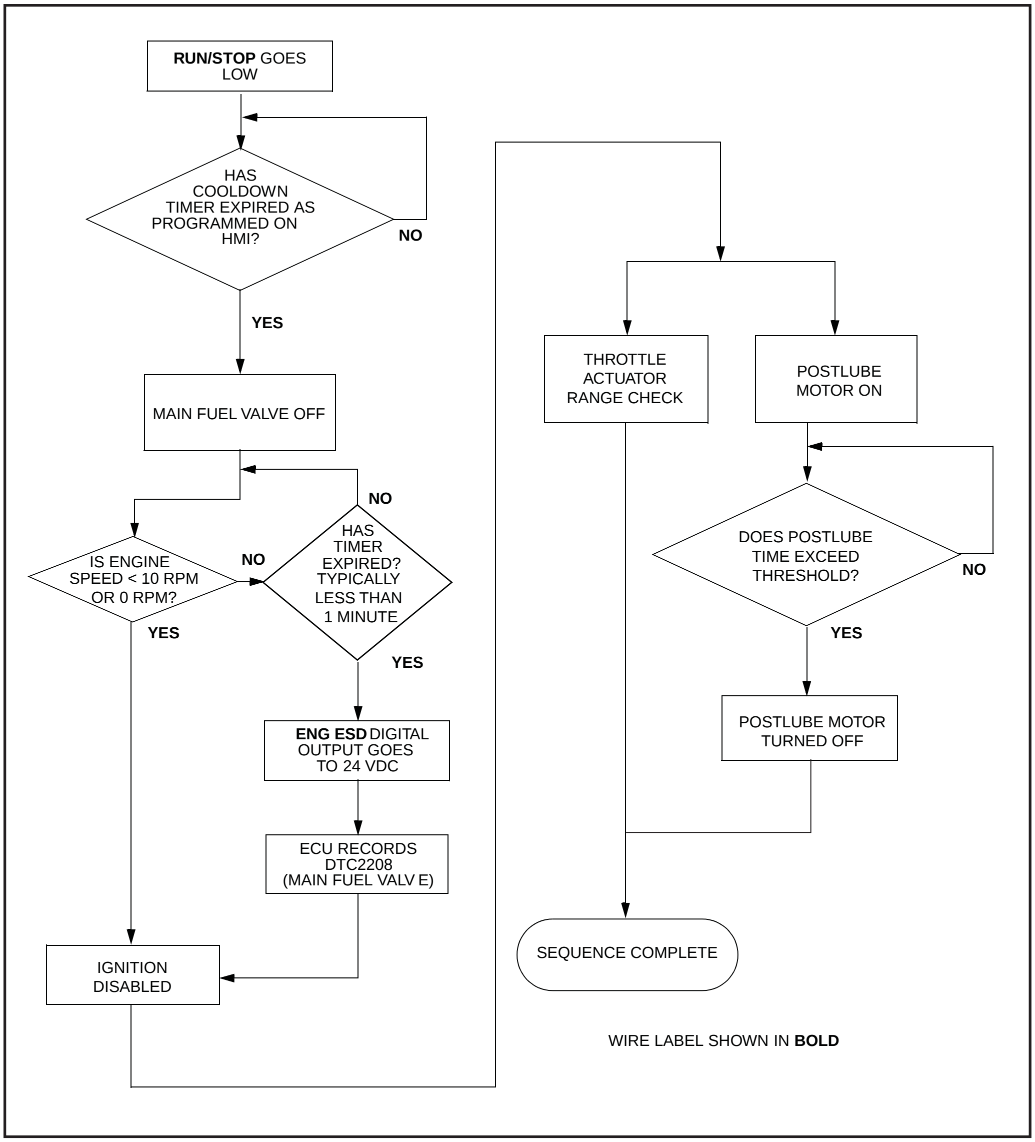


Figure 20-2: Routine Stop Flow Diagram

EMERGENCY SHUTDOWN SEQUENCE (ESD)

See “Figure 20-3: Emergency Stop Flow Diagram”.

WARNING

Use an emergency shutdown to stop the engine to avoid imminent personal injury or property damage. Never use an emergency shutdown to stop the engine under normal circumstances, as this may result in unburned fuel in the exhaust system which could ignite.

An Emergency shutdown can be initiated in three ways:

1. An engine-mounted emergency pushbutton is activated

2. Activating the ESD digital input signal:

- A digital signal input to the ECU that must be connected to +24 VDC nominal (8.6 – 36 volts) for the engine to run. If ESD goes open circuit, the engine performs an emergency shutdown. The ESD wire connection can be found in the Customer Interface Harness.

NOTE: Do not use this input for routine stopping of the engine. After an emergency shutdown and rpm is zero, ESD input should be raised to high to reset the ESM2. If ESD input remains low, ESM2 reset will be delayed and engine may not start for up to 1 minute.

3. The engine will perform an ESD if one of the ESM2 safety shutdowns are activated (overspeed condition, low oil pressure, etc.).

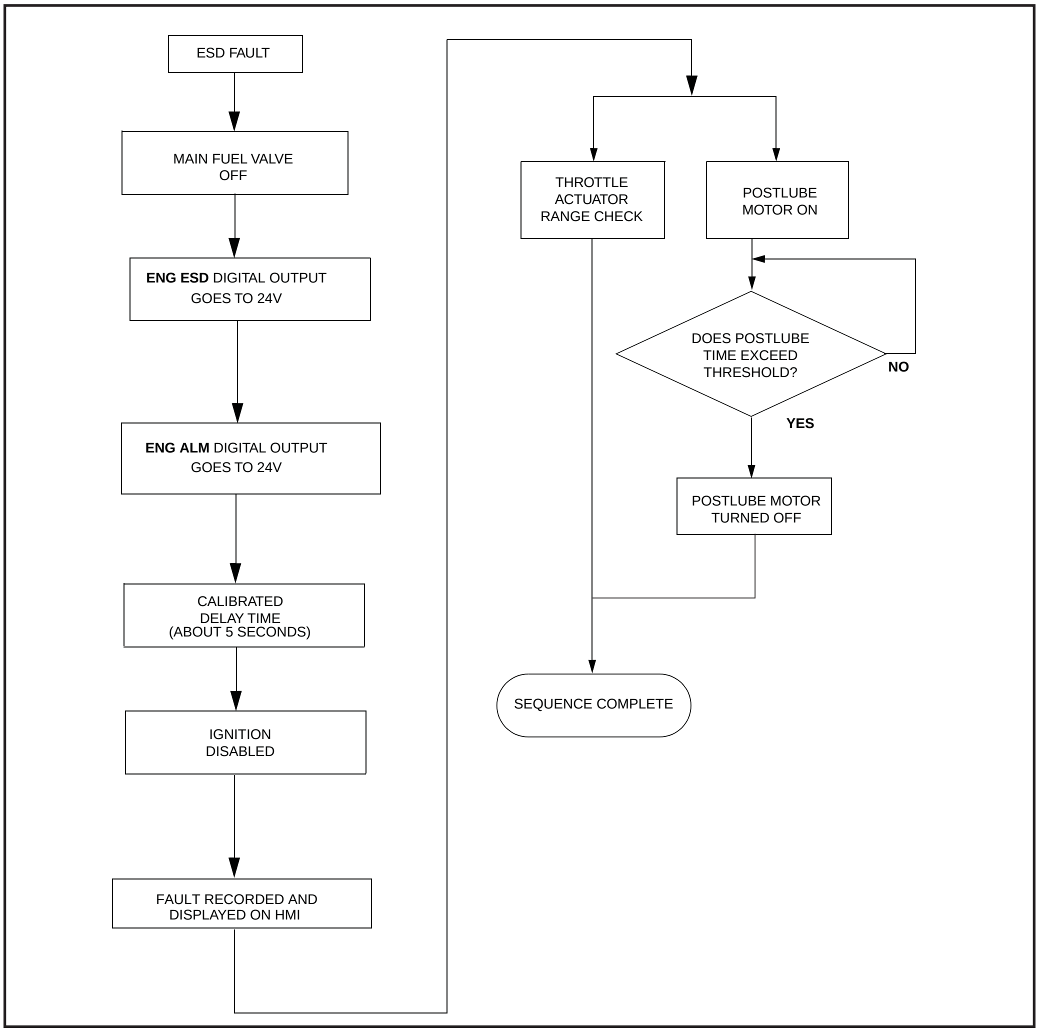


Figure 20-3: Emergency Stop Flow Diagram

CRITICAL EMERGENCY SHUTDOWN SEQUENCE

See Figure 2.254 for critical shutdown sequence diagram. Certain faults require that the engine come to a stop as quickly as possible to reduce the risk of major engine damage or personal injury or death. These faults are cESD faults. The shutdown sequence for cESD faults disables the fuel and ignition simultaneously to ensure the engine comes to a complete stop as quickly as possible. In some cases, the postshutdown sequence is disabled, as well.

During a critical emergency shutdown sequence, the ESM2 system performs the following steps:

1. Engine running

2. cESD conditions identified by the controller

3. Fuel and ignition are disabled immediately

4. Engine rpm reaches zero

5. Postshutdown sequence triggered

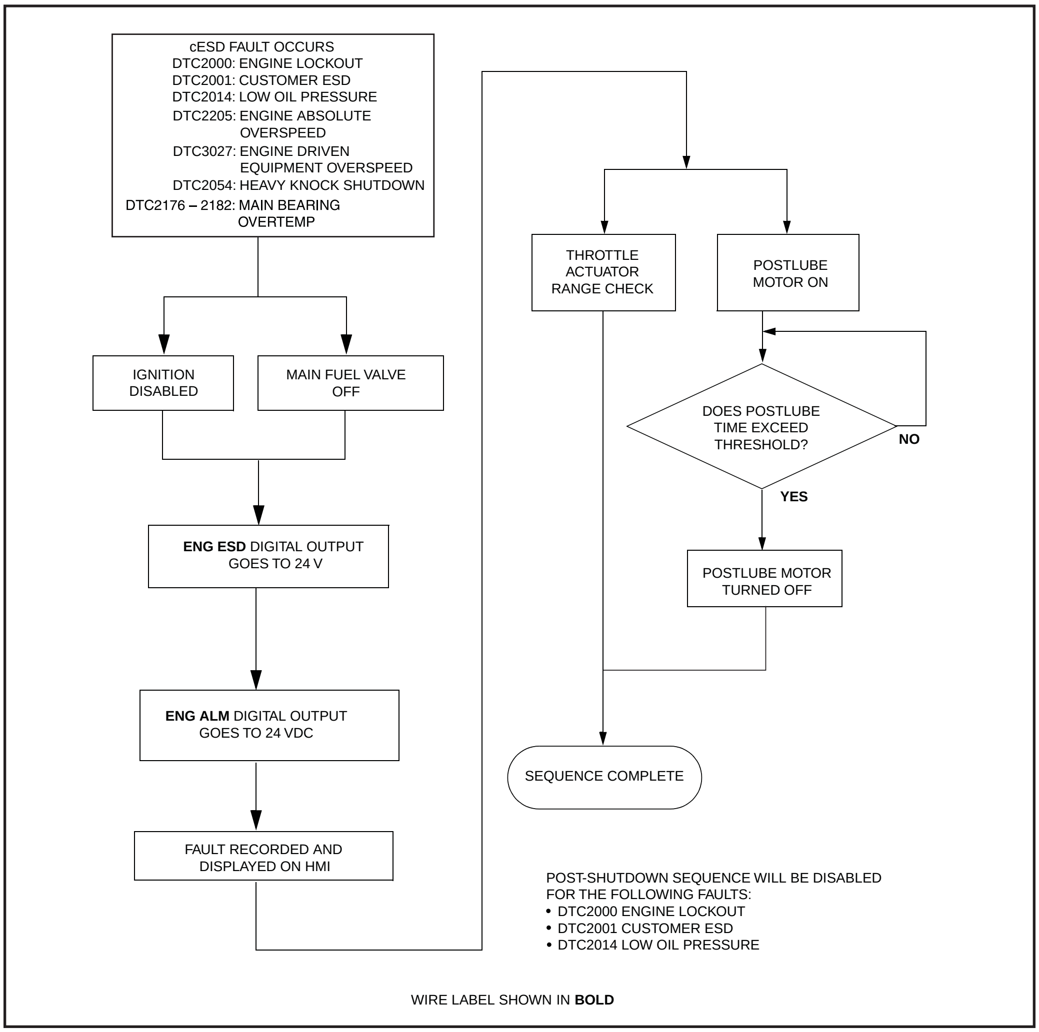


Figure 20-4: cESD Sequence Diagram

CHAPTER 21 - ENGINE COMMISSIONING

Initial commissioning of the engine may take place at the project site or at the packager's facility. Prior to engine startup, there are checks, procedures, and initial setups which must be performed to ensure the engine ready for startup.

This includes:

- checks of various mechanical and electrical components for proper operation
- initial fuel system adjustments
- ESM2 setup, using he HMI

Once the engine is initially started, there are additional items to perform including:

- Check for proper lube oil pressure and engine temperatures
- Verify engine status and parameters using the HMI
- Listen for any potential problems
- Visually examine lines and components for signs of leaks, damage, or corrosion
- Continue with fuel system setup

The above information is intended to serve as reference. For further details and for actual commissioning and startup of the engine, refer to the Operation Manual. Startup, testing, and commissioning of engines should be performed only by qualified individuals.

CHAPTER 22 - STORAGE

STANDARD PRESERVATION

All Waukesha engines leave the factory with preservative oil which allows the engine to be stored up to one year after shipment from the Waukesha factory with the capability of being re-preserved to extend the preservation period. If the engine is stored outside or in harsh or humid conditions, it may need to be preserved more frequently. Consider the following factors before deciding how much preservation is required:

- Whether the engine was used, the length of service since the last oil change
- The period of time the engine is likely to be idle or inoperative
- The atmospheric conditions at the time and place of storage. For example, the storage problems encountered in a tidewater warehouse will differ greatly from those that may be experienced in a dry and dusty location.

If caps from the engine connections have been removed for packaging or the engine has been run for testing purposes then the engine must be re-preserved according to Waukesha standards outlined in the latest revision of Service Bulletin 16-1855J.

NOTICE

Waukesha engines should be purged of all preservative oil from the cylinder head area prior to start-up. Failure to comply with this message may result in engine damage.

NOTICE

Engines stored outdoors or in humid environments may require more frequent preservations and inspections.

WARNING

Do not heat preservative compounds to temperatures that exceed 93°C (200°F).

EXTENDED PRESERVATION FOR NEW ENGINES

The purpose of the deferred engine start-up is to maintain Waukesha's Express Limited Warranty on an engine which will be stored longer than 12 months from the factory shipment date. The engine may be preserved beyond the one year period by contacting an authorized Waukesha Distributor. Waukesha gas engines will allow two (2) deferred start-up requests: the first after one (1) year from the factory ship date and the second two (2) years after the factory ship date. Only an authorized Waukesha Distributor can perform the deferred start-up process. Deferred start-up inspection and preservation instructions can be found in the most current version of Service Bulletin 16-1855.

PRESERVATIVE OIL

Waukesha Preservative Oil offers a practical and economical solution to the problems previously mentioned. While similar in appearance to SAE 10 lubricating oil, it contains corrosion-inhibiting chemicals. These chemicals vaporize slowly and diffuse throughout an enclosed area, forming an invisible protective layer on the exposed surfaces. All engine outlets must be sealed to block the escape of the vaporized corrosion-inhibiting chemicals.

Waukesha preservative oil will protect the engine during storage for up to one year when applied correctly; refer to the current version of Service Bulletin 16-1855.

When an engine is ready to be taken out of storage and put into operation or tested the spark plugs must be removed and the engine cranked over to evacuate the combustion chambers of any preservative oil.

HMI STORAGE

The HMI panel should be stored in a proper ambient temperature and humidity. The temperature for storage is ranging from -25° C to 80° C. The humidity for storage is ranging from 5% to 90%.

CHAPTER 23 - MAINTENANCE CONSIDERATIONS

WORK PLATFORMS

Work platforms should be installed on both sides of the engine to allow access to components on the top of the engine. The platforms should be made large enough to allow an individual to easily perform any required maintenance. Follow local codes and regulations for the use of work platforms, railings, and ladders.

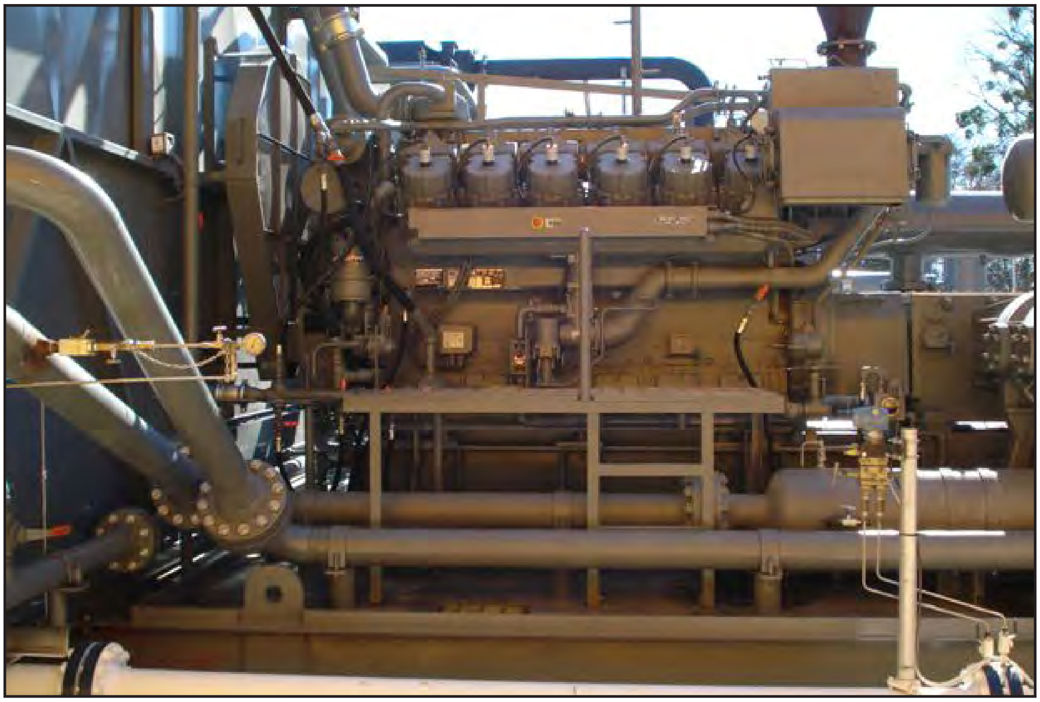


Figure 23-1: Engine Work Platform

Work platforms and ladders can also be installed to allow easy access to the catalyst elements to provide service.

Figure 23-2: Engine Work Platform and Ladder for Access to Catalyst Element in Exhaust

COMPONENT WEIGHTS

Refer to Component Weights for approximate weights of engine components. Use this table to determine the size of the overhead crane required to do maintenance on site. The heaviest engine part that needs to be removed for a top end overhaul is the cylinder head which weighs approximately 195 lb. (89 kg). For other routine maintenance, there are heavier components. Refer to "Table 23-1: Component Weights".

Table 23-1: Component Weights

ITEM DESCRIPTION	APPROXIMATE WEIGHT	
	12-Cylinder	
	lb	kg
Air/Gas Starter	64	30
Air Duct	53	24
Camshaft Cover	198	90
Camshaft Gear	32	15
Camshaft	114	52
Carburetor	24	11
Cover, Gear	161	73
Connecting Rod Assembly	62	28
Crankcase w/Main Bearing Caps/Studs/Nuts, Machined	4,965	2,252
Crankshaft Assembly	1,828	829
Cylinder Head	195	89
Cylinder Liner (Sleeve)	63	28
Damper	303	137
Housing, Gear	263	119
Housing, Flywheel, Front Section	202.67	100.1
Housing, Flywheel, Rear Section	113.97	51.7
Flywheel w/Ring Gear	878	398
Gear Housing Assembly	274	124
Idler Gear	27	12
Intercooler, without Bracket or Piping	558.8	253.5
Manifold, Exhaust	92	42
Manifold, Intake	86	39
Manifold, Water	102	46
Oil Cooler	225	106
Oil Cooler w/ Support Brackets	350	156
Oil Filter	29	13
Oil Filter Base	124	56
Oil Pump	123	56
Oil Pan, Deep Sump	2,474	1,122
Piston	41.17	15
Piston Pin	12	6
Pulley, Rear Crankshaft	81	37
Regulator, Gas (Fisher)	115	52
Shipping Skid	466	211
Turbocharger	65	30
Water Pump, Jacket Water	101	46
Water Pump, Auxiliary Water	61	28

MAINTENANCE CLEARANCES

The recommended minimum spacing between engines is 36 in. (914 mm) and between an engine and a building wall is 36 in. (914 mm). This distance allows a worker to perform required maintenance on the engines when given the required spacing between engines and from a building wall. When performing maintenance, allowing adequate space between engines and walls is encouraged to ease maintenance procedures.

The recommended minimum overhead clearance is 60 in. (1524 mm). This measurement is the distance from the crankshaft centerline required to remove the power cylinder parts (cylinder head, piston, connecting rod, and cylinder liner). Additional clearance is then required for the lifting device and any tools or straps for connecting the crane hood to the engine component being removed. This additional clearance will vary per the equipment being used.

PACKAGE DESIGN

Placing the engine and driven equipment underneath a roof or inside a building can help protect the engine from the environment and give maintenance personnel a more suitable environment for working. Buildings or walls can also be used for sound attainment if local regulations impose limits on sound levels. Any structure erected around the engine should be designed with consideration given to maintenance and operation tasks.

Whether a building will be constructed around the engine or the engine will be installed into an existing building there should be easy access to remove the engine and driven equipment for maintenance purposes and major overhauls. Having a large enough door or removable wall will help facilitate removal of the equipment. If a removable wall design is used the amount of piping or equipment running through, or connected to, the wall should be minimized to make this process easier.

Building ventilation is required to maintain a suitable temperature inside the building and provide enough air to the intake filters if they are mounted inside. Wherever they are mounted there should be easy access to the filters for maintenance purposes. The engine room temperature should not exceed 65°C and the temperature to the intake filters should be below 38°C or the maximum engine output will be reduced. For these situations it is usually beneficial to remotely mount the filters or duct air from outside the building. Precautions must be taken so that warm air is not recirculated into the intake. Common heat sources are from engine exhaust, radiators or coolers, building ventilation and heat from generator fans.

Exhaust silencers are often mounted on top of coolers, buildings or support structures. The building should be designed to support any auxiliary equipment that will be mounted on it. Exhaust systems should be configured so prevailing winds do not recirculate exhaust gases back towards the engine and so the sound level and exhaust stack emissions meet local regulations.

TYPICAL MAINTENANCE SCHEDULE

Table 23-2: Typical Service Schedule

Engine Model	Top End Overhaul Hours	Bottom End Overhaul Hours
L7042GSI S5	32,000	64,000
L7044GSI S5	22,000	44,000

Table 23-3: Typical Maintenance Schedule

ITEM	SERVICE	Daily (or as required)	4000 Hours	8000 Hours	16000 Hours	Top End Overhaul	Bottom End Overhaul
Air Cleaner Filter Element	Check/Clean or Replace	●					
Pre-Lube Motor Lubricator (if equipped)	Check/Fill	●					
Cooling Systems Fluid Level (Jacket and Auxiliary)	Check/Fill	●					
Crankcase Oil Level	Check/Fill	●					
ESP Fault History (If active alarms)	Review (Monthly)	●					
Spark Plug	Replace		●				
Main Air Filter	Replace		●				
Oxygen Sensors	Replace		●				
Oil Centrifuge Paper Liner	Replace		●				
Lube Oil	Replace		●				
Oil Filter	Replace		●				
Breather Filter Element	Replace			●			
Carburetors	Replace			●			
Gas Regulator Filter	Replace			●			
Belts (Aux Water Pump, Jacket Water Pump, V-belts)	Replace			●			
Air Filter Pre-cleaner Elements	Replace			●			
Oil Centrifuge Element and O-ring	Replace			●			
Spark Plug Extensions	Replace				●		
Ignition Coils	Replace				●		
Gas Regulator	Replace				●		
Starter	Replace				●		
Crankcase Breather	Overhaul				●		
Starter	Inspect / Repair				●		
Rocker Arms	Inspect / Repair					●	
Cylinder Heads	Replace / Rebuild					●	
Jacket Water Pump	Replace / Rebuild					●	
Auxiliary Water Pump	Replace / Rebuild					●	
All Thermostats	Replace					●	
Pulleys	Replace					●	
Hoses and Dresser Couplings	Replace					●	
Turbocharger	Replace / Rebuild					●	
Exhaust RTDs	Replace					●	
Wastegate	Replace / Rebuild					●	
Turbo exhaust component and piping	Replace					●	

ITEM	SERVICE	Daily (or as required)	4000 Hours	8000 Hours	16000 Hours	Top End Overhaul	Bottom End Overhaul
Oil Pump	Replace / Rebuild					●	●
Control Harnesses	Inspect / Replace						●
IPMD2	Inspect / Replace						●
Actuator	Inspect / Replace						●
Connecting Rods	Replace						●
Camshaft	Replace / Refurbish						●
Crankshaft	Replace / Refurbish						●
Carburetors	Inspect / Repair						●
Regulators	Inspect / Repair						●
Governor Linkage	Inspect / Repair						●
Cam Shafts	Inspect / Repair						●
Crank Shaft	Inspect / Repair						●
Connecting Rods	Inspect / Repair						●
Main Bearings	Replace						●
Cam Bearings	Replace						●
Connecting Rod Busing	Replace						●
Connecting Rod Bearings	Replace						●
Power Cylinder	Replace						●
Tappets	Replace						●
Push Rods	Replace						●
Damper	Replace						●
Sensors	Replace						●

** Because of ongoing evaluation and continual updates to Waukesha's oil recommendations, see the latest edition of Waukesha Lube Oil Recommendations S1015-30 in Technical Data*

*** Local regulations may require more frequent maintenance*

EMERGENCY SPARES

An emergency spares list is available upon request. Please contact application engineering or local sales representative.

SPECIAL TOOLS

Waukesha has developed various special tools which have been designed to simplify performing maintenance on a VHP engine.

Table 23-4: Special Tools for VHP

L7042GSI S5	L7044GSI S5	PART NUMBER	DESCRIPTION
X	X	494217	COMPRESSION TESTER/ADAPTER
X	X	494287	VALVE ADJUSTING WRENCH
X	X	494385	SEAL REMOVER TOOL
X	X	474034	VALVE SPRING COMPRESSOR
X	X	474038	VALVE SEAT EXTRACTOR
X	X	474040	VALVE BRIDGE GUIDE TOOL
X	X	474046	VALVE GUIDE REAMER
X	X	495327	VALVE STEM SEAL INSTALLER
X	X	495328	INTAKE VALVE SEAT INSTALLER
X	X	495329	EXHAUST VALVE SEAT DRIVER
X	X	495330	BRIDGE GUIDE PIN DRIVER
X	X	474044	VALVE GUIDE STRAIGHTNESS GAUGE
X	X	474000	CAMSHAFT DUMMY GEAR
X	X	474005	STOP SLEEVE
X	X	474013	WATER PUMP KIT
X	X	474025	CAM BEARING ROLLOUT TOOL
X	X	474041	9-3/8 IN. PISTON RING EXPANDER
X	X	494206	9-3/8 IN. BORE RING COMPRESSOR
X	X	494286	9-3/8 IN. SLEEVE PLATE
X	X	494366	MAIN BEARING ROLL-OUT TOOL (T-DRILLED)
X	X	499233	CYLINDER SLEEVE REMOVAL KIT
X	X	495350	SPARK PLUG SLEEVE SEAT RESURFACER
X	X	474018	VHP GAS PISTON PULLER – 9-3/8 IN. BORE

NOTE: Hand Tool Kit 494261 is recommended as the best method to obtain the needed hand tools and torque wrenches.

APPENDICES

APPENDIX A

CALCULATIONS FOR COOLANT PIPING RESTRICTION

1. Calculate coolant velocity (V) in pipe.

Equation 2

$$V\,(FPM) = \frac{Flow(ft^3/min)}{Pipe\ inside\ area(ft^2)} \quad or \quad V(m/sec) = \frac{1000x\,Flow(L/sec)}{Pipe\ inside\ area(mm^2)}$$

$$Flow\,(ft^3/min) = Flow(GPM) * 0.1247(ft^3/gallon) \quad or$$

$$Flow\,(L/sec) = Flow\,\frac{m^3/hr}{3.6}$$

$$Pipe\ Area\,(ft^2) = \{Diameter\,(inch)\}^2 * \pi/4 * 0.00694\,ft^2/inch^2$$

$$Pipe\ Area\,(mm^2) = \pi/4 * \{Diameter(mm)\}^2$$

Table A-1: Pipe areas for standard pipe

PIPE SIZE (inch)	ID (inch)	ID (mm)	AREA (inch^2)	AREA (mm^2)	AREA (ft^2)
1.5	1.61	40.894	2.04	1312.77	0.0142
2	2.067	52.502	3.36	2163.80	0.0233
2.5	2.344	59.538	4.32	2782.61	0.030
3	3.068	77.927	7.39	4767.03	0.0513
4	4.026	102.260	12.73	8208.89	0.0884
5	5.047	128.194	20.01	12900.42	0.139
6	6.065	154.051	28.89	18629.39	0.201
8	7.981	202.717	50.03	32259.06	0.347

2. Determine pressure loss (P_L) per 100 ft. or meter of pipe for the velocity and pipe size from "Figure A-1: Piping Restriction Chart".

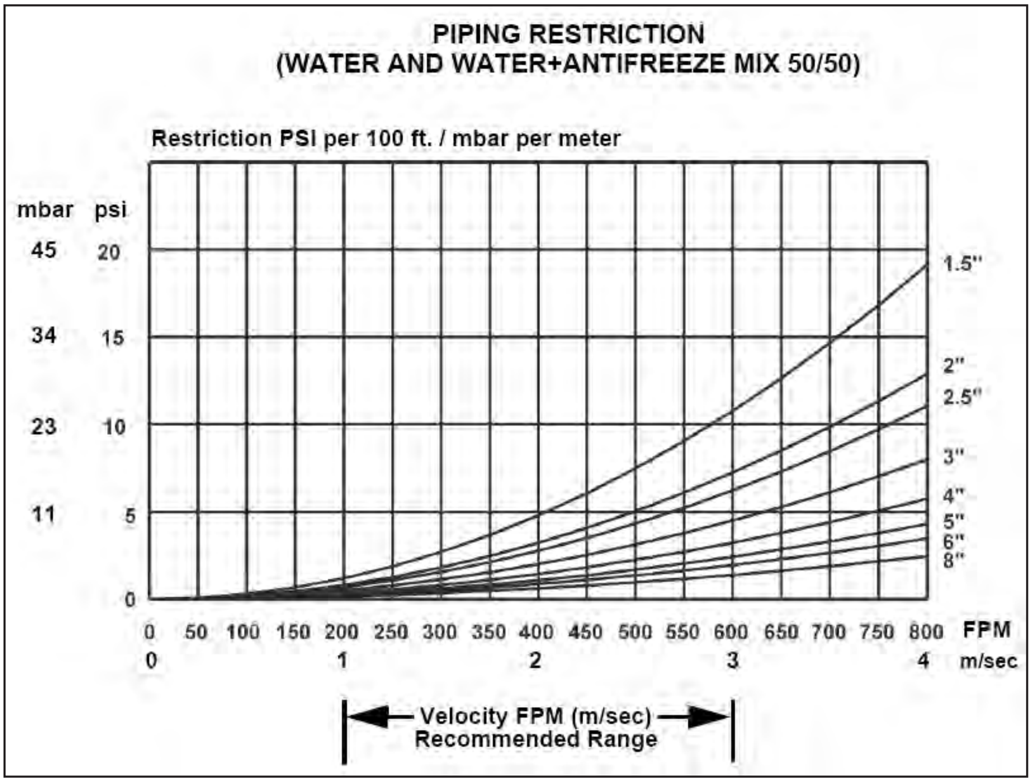


Figure A-1: Piping Restriction Chart

3. Determine the equivalent pipe length (EPL) for all fittings:

"Figure A-2: Equivalent pipe length of fittings" gives equivalent pipe length in feet or meters for various pipe fittings. Sum the EPL's and add them to the total length of straight pipe to find the total EPL.

4. Calculate the total piping restriction (R_P):

Equation 3

$$R_P = \frac{P_L\,(\text{psi})}{100\text{ft}} \times \text{EPL(ft)} \text{ or } \frac{P_L\,(\text{mbar})}{\text{m}} \times \text{EPL(m)}$$

5. Calculate the total cooling circuit restriction:

Equation 4

$$R_T = R_P + R_E + R_R$$

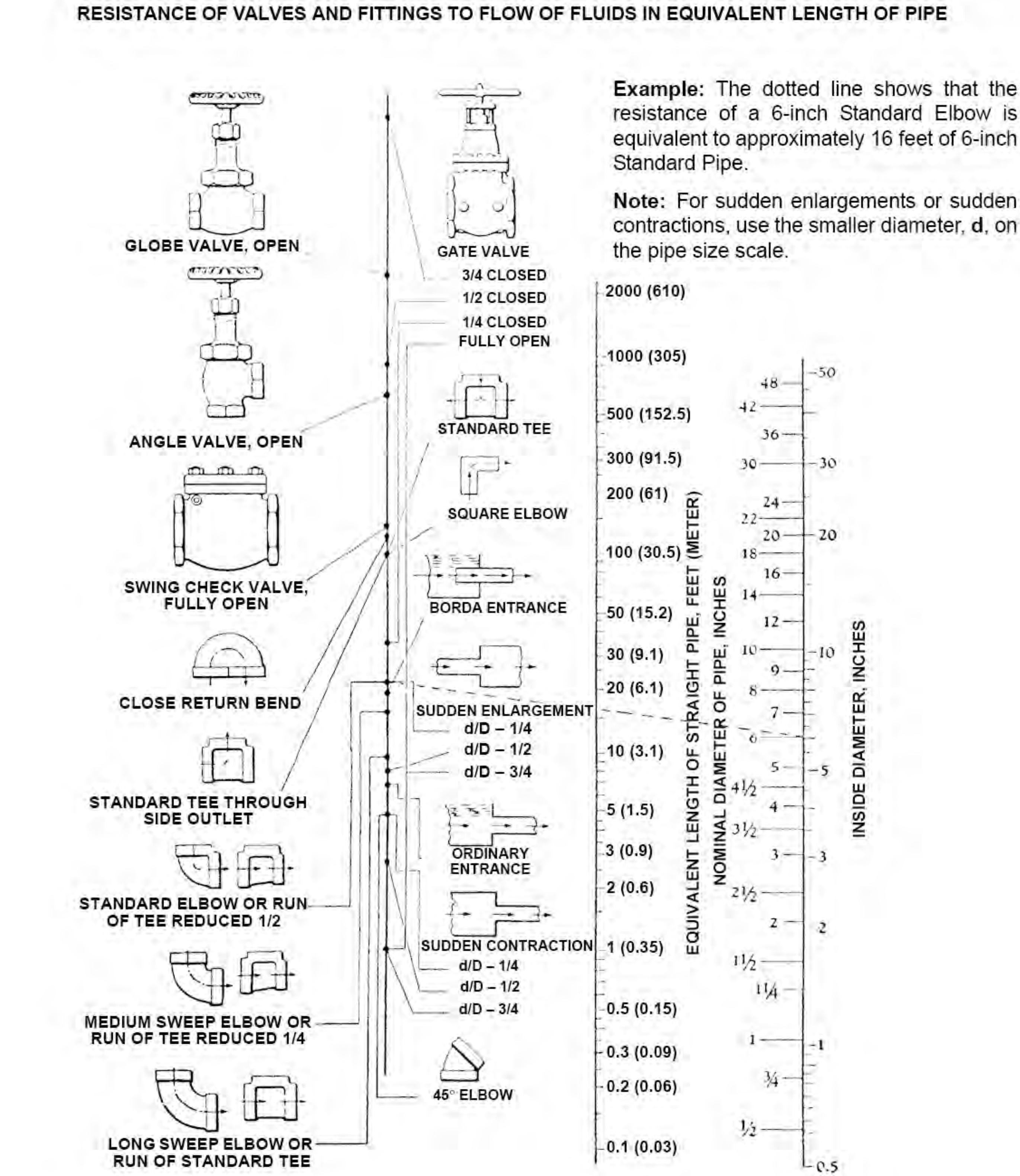
Where

R_T = total restriction (psi)

R_P = piping restriction (psi)

R_E = engine restriction (psi)

R_R = radiator/heat exchanger restriction (psi)



From Crane Co. Technical Paper No. 409. Data based on the above chart are satisfactory for most applications.
REPRINTED WITH PERMISSION OF CRANE VALVE GROUP.

Figure A-2: Equivalent pipe length of fittings

CALCULATIONS FOR FUEL PIPING RESTRICTION

1. Determine fuel consumption (Btu/hr or kW) for the highest speed and load condition expected. This information is available in the Ratings and Standards section or Heat Rejection section of the Waukesha Tech Data Manual. If working with the Brake Specific Fuel Consumption “BSFC” (Btu/hp-hr) then multiply this figure by the maximum horsepower to get fuel consumption in Btu/hr.

Equation 1

$$\text{Fuel Consumption (Btu/hr)} = \text{BSFC (Btu/hp-hr)} \times \text{BHP}$$

or

$$\text{Fuel Consumption (kW)} = \frac{\text{KJ}}{\text{kW/hr}} \times \frac{\text{kW}}{3600}$$

2. Determine the flow volume at standard temperature (60° F) and pressure (29.92” HG) with the following formula:

Equation 2

$$\text{Standard Flow (ft}^3\text{ / min)} = \frac{\text{Fuel consumption (Btu/hr)}}{\text{Fuel SLHV (Btu/SCF SLHV)}} \div 60$$

or

$$\text{Standard Flow (nm}^3\text{/hr)} = \frac{\text{Fuel consumption (kW)}}{\text{Fuel SLHV (KJ/nm}^3\text{)}}$$

3. Determine the flow volume at the site supply temperature and pressure:

Equation 3

$$F_{sup} = F_{std} \times \frac{14.7\,[\text{psia}] \times (460^o\,[\text{R}] + T_{sup})}{(14.7\,[\text{psia}] + P_{sup}) \times 520^o\,[\text{R}]}$$

or

$$\text{ACTUAL FLOW (m}^3\text{/s)} = \frac{101.3\,\text{kPa} \times (273 + T_{sup})}{(101.3\,\text{kPa} + P_{sup}) \times 273}$$

Table A-2: Pipe areas for schedule 40 pipe

PIPE SIZE (inch)	ID (inch)	ID (mm)	AREA (inch²)	AREA (mm²)	AREA (ft²)
1”	1.049	26.644	0.864	557.42	0.00600
1.25”	1.380	35.53	1.496	965.16	0.01039
1.5”	1.610	40.894	2.04	1312.77	0.0142
2”	2.067	52.502	3.36	2163.80	0.0233
2.5”	2.344	59.538	4.32	2782.61	0.030
3”	3.068	77.927	7.39	4767.03	0.0513
4”	4.026	102.260	12.73	8208.89	0.0884
5”	5.047	128.194	20.01	12900.42	0.139
6”	6.065	154.051	28.89	18629.39	0.201

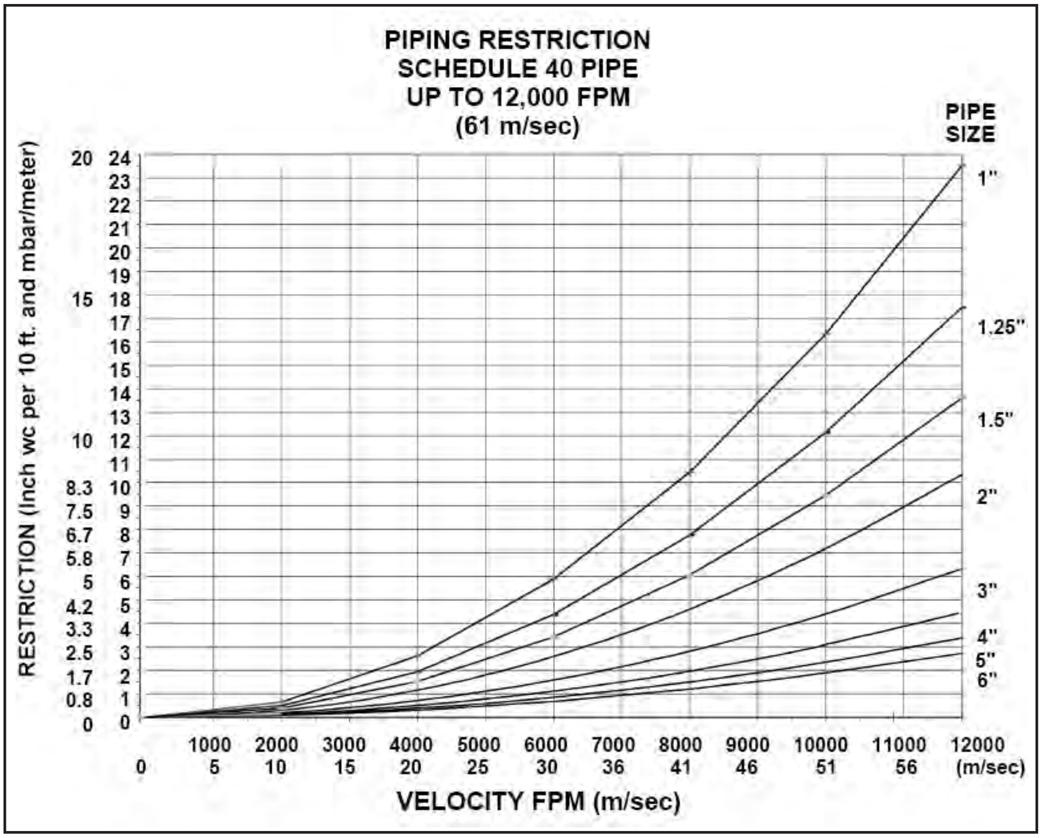


Figure A-3: Restriction Vs. Velocity for pipe diameters up to 6 inches.

Where

F_{std} = Flow at standard conditions (ft^3/min or Nm^3/sec)

F_{sup} = Flow at supply conditions (ft^3/min or Nm^3/sec)

T_{sup} = supply temperature (^oF or ^oC)

P_{sup} = supply pressure (psig or kPa)

4. Calculate fuel velocity (V) based on the supply flow Fsup for each pipe size used:

Equation 4

$$V\,(FPM) = \frac{F_{sup}\,(ft^3/min)}{\text{Pipe inside area}\,(ft^2)} \quad \text{or}$$

$$V\,(m/sec) = \frac{F_{sup}\,(m^3/sec) \times 1{,}000{,}000}{\text{Pipe inside area}\,(mm^2)}$$

$$\text{Pipe Area}\,(ft^2) = [\text{Diameter (inch)}]^2 \times \pi/4 \times 0.00694\,ft^2/inch^2$$

Inside diameter and area for common pipe sizes are given in “Table A-2: Pipe areas for schedule 40 pipe”.

As a general rule gas velocities over 12,000 FPM (60 m/s) are unacceptable because of the high resulting restriction.

5. Determine pressure loss PL per 10 ft or 1 meter of pipe for each velocity and pipe size from “Figure A-3: Restriction Vs. Velocity for pipe diameters up to 6 inches.”

6. Determine the equivalent pipe length (EPL) for all fittings of each pipe size.

"Figure A-2: Equivalent pipe length of fittings" gives equivalent pipe length in feet for various pipe fittings. For each pipe size, sum the EPLs and add them to the total length of straight pipe of that size to find the total of each pipe size.

7. Calculate the fuel gas corrected specific gravity:

Equation 5

$$SG_C = SG \times \frac{(14.7\,[psia] + P_{sup}) \times 520^{\circ}\,[R]}{14.7\,[psia] \times (460^{\circ}\,[R] + T_{sup})} \quad \text{or}$$

$$SG_C = SG \times \frac{(101.3\,[kPa] + P_{sup}) \times (273)}{(101.3 \times (273 + T_{sup}))}$$

Where

SGc = specific gravity corrected for pressure and temperature

SG = fuel specific gravity

Natural Gas	SG ≈ 0.6
600 Btu Digester Gas	SG ≈ 0.9
400 Btu Landfill Gas	SG ≈ 1.1
Field Gas	SG ≈ 0.6 to 1.0
HD-5 Propane	SG ≈ 1.5

T_{sup} = supply temperature (°F or °C)

P_{sup} = supply pressure (psig or kPa)

8. Calculate the total piping restriction RP for each pipe size:

Equation 6

$$R_{P1} = P_{L1}\ (\text{" wc /10 ft}) \times SG_C \times EPL(ft) \text{ or } P_{L1}\,(mbar/m) \times SG_C \times EPL\,(m)$$

9. Calculate the total fuel piping restriction:

Equation 7

$$R_T = R_{P1} + R_{P2} + R_{P3} + R_A$$

Where

RT = total restriction (" wc or mbar)

RP1,2,3 = piping restriction for various pipe sizes (" wc or mbar)

RA = accessories (filters, solenoid valves, etc.) restriction (" wc or mbar)

CALCULATIONS FOR INDUCTION AIR PIPING RESTRICTION

Determine maximum engine inlet airflow at site conditions:

Actual airflow = SCFM x (T_{site} + 460 / T_{std} + 460)

Determine the equivalent pressure loss using “Figure A-4: Presssure loss vs. airflow”, “Figure A-5: Presssure loss vs. airflow”, and “Figure A-6: Presssure loss vs. airflow”.

Determine the Equivalent Duct Length (EDL) from “Table A-4: Equivalent Pipe Length Of Fittings In Feet (Meter)” and Table A-5 for each applicable component from step 2.

Calculate the pressure loss (P_L) for each applicable components in the air induction system from step 2 and 3.

$P_L = P_L/L * EDL$

Determine the total pressure loss for miscellaneous components such as piping bellows, air cleaners, etc.

Calculate the total air induction system restriction by adding the P_L for each component and miscellaneous components

Verify that the total restriction does not exceed the maximum permissible restriction, including a 30% reserve. If the restriction is too high, redesign the system to reduce the restriction such as using larger diameter piping, or reducing the amount of flow reducing components such as elbows.

Table A-3: ANSI schedule 40 pipe dimensions

ANSI PIPE DIAMETER	ID (inch)	ID (mm)	AREA (inch^2)	AREA (mm^2)	AREA (ft^2)
1.5”	1.61	40.894	2.04	1312.77	0.0142
2”	2.067	52.502	3.36	2163.80	0.0233
2.5”	2.344	59.538	4.32	2782.61	0.030
3”	3.068	77.927	7.39	4767.03	0.0513
4”	4.026	102.260	12.73	8208.89	0.0884
5”	5.047	128.194	20.01	12900.42	0.139
6”	6.065	154.051	28.89	18629.39	0.201
8”	7.981	202.717	50.03	32259.06	0.347
10”	10.02	254.508	78.85	50847.84	0.5476
12”	12	304.800	113.1	72928.89	0.7854
14”	13.25	336.550	137.9	88913.73	0.9575
16”	15.25	387.350	182.7	117781.42	1.268
18”	16.88	428.752	223.7	144305.20	1.553
20”	18.81	477.774	278.0	179190.38	1.931
22”	21.00	533.400	346.4	223344.71	2.405
24”	22.60	574.040	401.2	258674.71	2.786

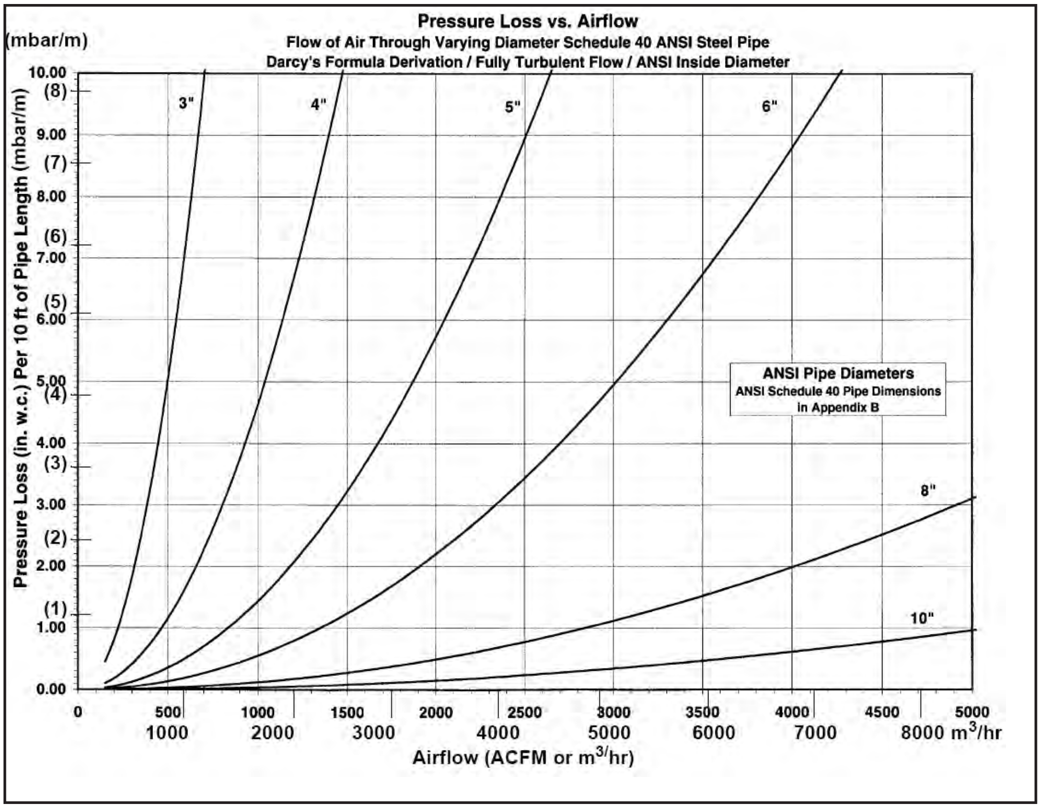


Figure A-4: Presssure loss vs. airflow

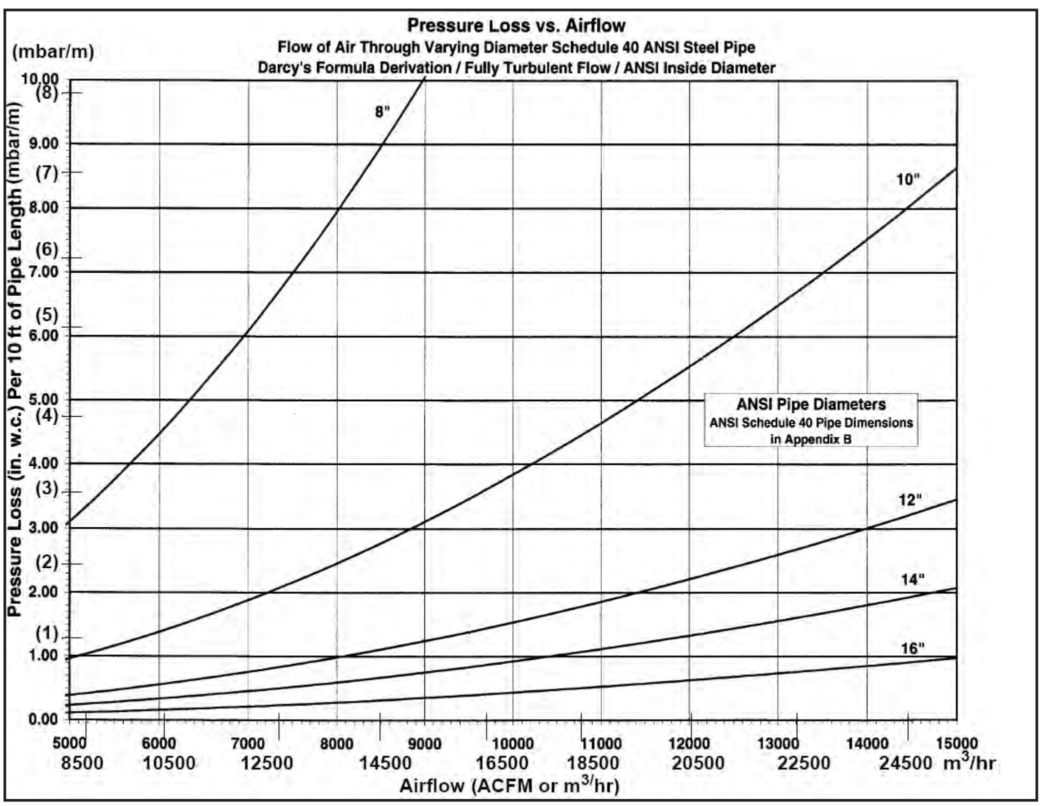


Figure A-5: Presssure loss vs. airflow

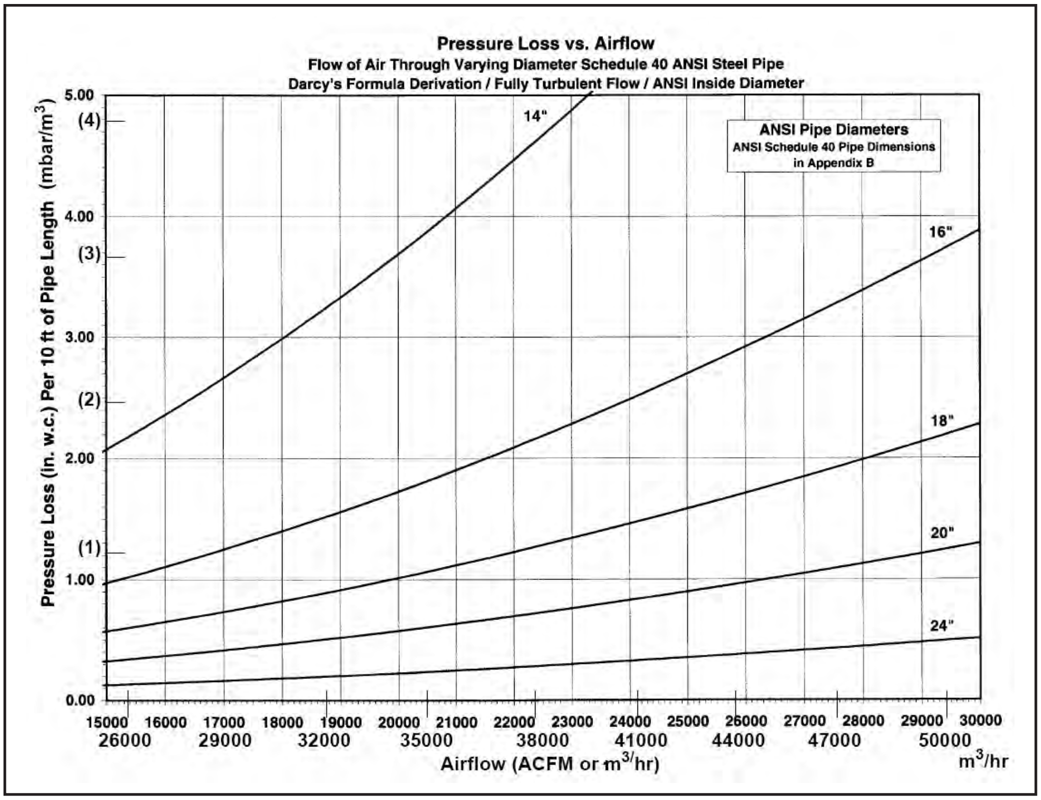
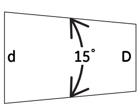
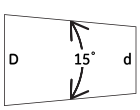


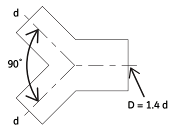
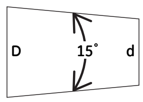
Figure A-6: Presssure loss vs. airflow

Table A-4: Equivalent Pipe Length Of Fittings In Feet (Meter)

FITTINGS		ROUND PIPE DIAMETER											
		3”	4”	5”	6”	8”	10”	12”	14”	16”	18”	20”	24”
 15° Diffuser* EPL based on flow at “d”	d/D=1/4 Flanged	3.5 (1)	4.9 (1.5)	6.3 (1.9)	7.9 (2.4)	11.2 (3.4)	14.5 (4.4)	18.3 (5.6)	20.6 (6.3)	24.3 (7.4)	29.7 (9.1)	31.9 (9.7)	39 (11.9)
	d/D=1/2 Flanged	2.4 (0.7)	3.3 (1)	4.3 (1.3)	5.4 (1.6)	7.6 (2.3)	9.9 (3)	12.5 (3.8)	14.0 (4.3)	16.5 (5)	20.3 (6.2)	21.7 (6.6)	27 (8.2)
	d/D=3/4 Flanged	1.1 (0.3)	1.6 (0.5)	2.0 (0.6)	2.5 (0.8)	3.6 (1.1)	4.6 (1.4)	5.8 (1.8)	6.6 (2)	7.8 (2.4)	9.5 (2.9)	10.2 (3.1)	13 (4)
 15° Diffuser* EPL based on flow at “D”	d/D=1/4 Flanged	1.3 (0.4)	1.8 (0.5)	2.4 (0.7)	3.1 (0.9)	4.3 (1.3)	5.5 (1.7)	7.0 (2.1)	7.7 (2.3)	8.8 (2.7)	10.7 (3.3)	11.9 (3.6)	14.4 (4.4)
	d/D=1/2 Flanged	1.0 (0.3)	1.4 (0.4)	1.9 (0.6)	2.5 (0.8)	3.5 (1.1)	4.4 (1.3)	5.6 (1.7)	6.2 (1.9)	7.0 (2.1)	8.6 (2.6)	9.6 (2.9)	11.5 (3.5)
	d/D=3/4 Flanged	0.6 (0.2)	0.8 (0.2)	1.1 (0.3)	1.4 (0.4)	2.0 (0.6)	2.5 (0.8)	3.3 (1)	3.6 (1.1)	4.1 (1.2)	5.0 (1.5)	5.6 (1.7)	6.7 (2)

(Calculated using NTIS Handbook Of Hydraulic Assistance, Form AEC-TR-6630)

Table A-5: Equivalent Pipe Length Of Fittings In Feet (Meter)

FITTINGS		ROUND PIPE DIAMETER											
		3”	4”	5”	6”	8”	10”	12”	14”	16”	18”	20”	24”
 **Y-Connection based on flow at “d”**	**Flanged**	—	—	—	—	—	34.7 (10.6)	43.7 (13.3)	49.1 (15)	58.1 (17.7)	—	—	—
 **15° Diffuser* EPL based on flow at “D”**	**Bell mouth inlet**	0.7 (0.2)	1.0 (0.3)	1.3 (0.4)	1.6 (0.5)	2.3 (0.7)	2.9 (0.9)	3.5 (1.1)	4.0 (1.2)	4.7 (1.4)	5.3 (1.6)	6.1 (1.9)	7.6 (2.3)
	**Square mouth inlet**	6.7 (2)	9.5 (2.9)	13.0 (4)	16.0 (4.9)	23.0 (7)	29.0 (8.8)	35.0 (10.7)	40.0 (12.2)	47.0 (14.3)	53.0 (16.2)	61.0 (18.6)	76.0 (23)

* Minimum restriction is with a 6° diffuser. EPL with a 6° diffuser is approximately 1/2 the EPL of a 15° diffuser.

EXHAUST PIPING THERMAL GROWTH CALCULATION

NOTES:

1. Allow for thermal expansion of the exhaust pipe beyond the engine exhaust flex connection. The Waukesha exhaust flex (when supplied) will accommodate engine thermal expansion but cannot tolerate movement imposed by external thermal growth. Insulated pipes will run hotter and consequently expand more.

COEFFICIENT OF EXPANSION Ce

$$\text{Steel } 6.5 \times 10^{-6} \frac{\text{in}}{\text{in } ^\circ\text{F}} \left(1.17 \times 10^{-5} \frac{\text{mm}}{\text{mm } ^\circ\text{C}}\right)$$

$$\text{Stainless Steel } 9.9 \times 10^{-6} \frac{\text{in}}{\text{in } ^\circ\text{F}} \left(1.7 \times 10^{-5} \frac{\text{mm}}{\text{mm } ^\circ\text{C}}\right)$$

Thermal expansion can be calculated with the following formula:

Equation 1

$$L_e = C_e * L * (T_{exh} - T_{stnd})/100$$

WHERE:

L_e = Length of pipe expansion (inches or meters)

C_e = Coefficient of expansion for the material (in/in/ °F or mm/mm°C)

L = Piping length at standard conditions (inches or meters)

T_{exh} = Exhaust Temperature (°F or °C)

T_{stnd} = Standard Temperature (°F or °C)

EXHAUST PIPING RESTRICTION CALCULATION

1. Determine exhaust volume flow rate (ft^3/min or m^3/hr) for the specific engine model from the heat rejection sections in the Technical Data Manual. If exhaust flow is given in terms of mass flow, a conversion is available in the notes section of the heat balance.

2. Calculate exhaust velocity (V) for each pipe size used:

Equation 2

$$V\,(FPM) = \frac{Flow\,(ft^3/min)}{Pipe\,inside\,area\,(ft^2)}$$

or

$$V\,(m/sec) = 277.8 \times \frac{Flow\,(m^3/hr)}{Pipe\,inside\,area\,(mm^2)}$$

$$Pipe\ Area\,(ft^2) = [Diameter\,(inch)]^2 \times \pi/4 \times 0.00694\,ft^2/inch^2$$

Inside diameter and area for common pipe sizes are given in “Table A-6: ANSI schedule 40 pipe dimensions”.

Table A-6: ANSI schedule 40 pipe dimensions

ANSI PIPE DIAMETER	ID (inch)	ID (mm)	AREA ($inch^2$)	AREA (mm^2)	AREA (ft^2)
1.5”	1.61	40.894	2.04	1312.77	0.0142
2”	2.067	52.502	3.36	2163.80	0.0233
2.5”	2.344	59.538	4.32	2782.61	0.030
3”	3.068	77.927	7.39	4767.03	0.0513
4”	4.026	102.260	12.73	8208.89	0.0884
5”	5.047	128.194	20.01	12900.42	0.139
6”	6.065	154.051	28.89	18629.39	0.201
8”	7.981	202.717	50.03	32259.06	0.347
10”	10.02	254.508	78.85	50847.84	0.5476
12”	12	304.800	113.1	72928.89	0.7854
14”	13.25	336.550	137.9	88913.73	0.9575
16”	15.25	387.350	182.7	117781.42	1.268
18”	16.88	428.752	223.7	144305.20	1.553
20”	18.81	477.774	278.0	179190.38	1.931
22”	21.00	533.400	346.4	223344.71	2.405
24”	22.60	574.040	401.2	258674.71	2.786

3. Determine pressure loss (P_L) per 10 ft (3m) of pipe for each velocity and pipe size from “Figure A-8: Restriction vs. velocity for pipe diameter up to 8” (high speed)”, and “Figure A-9: Restriction vs. velocity for pipe diameter up to 24””.

4. Determine the equivalent pipe length (EPL) for all fittings of each pipe size:

“Table A-7: Equivalent Pipe Length Of Fittings In Feet (Meter)” give equivalent pipe length in feet for various pipe fittings. For each pipe size sum the EPLs and add them to the total length of straight pipe of that size to find the total of each pipe size. Exit loss does not need to be considered in these calculations.

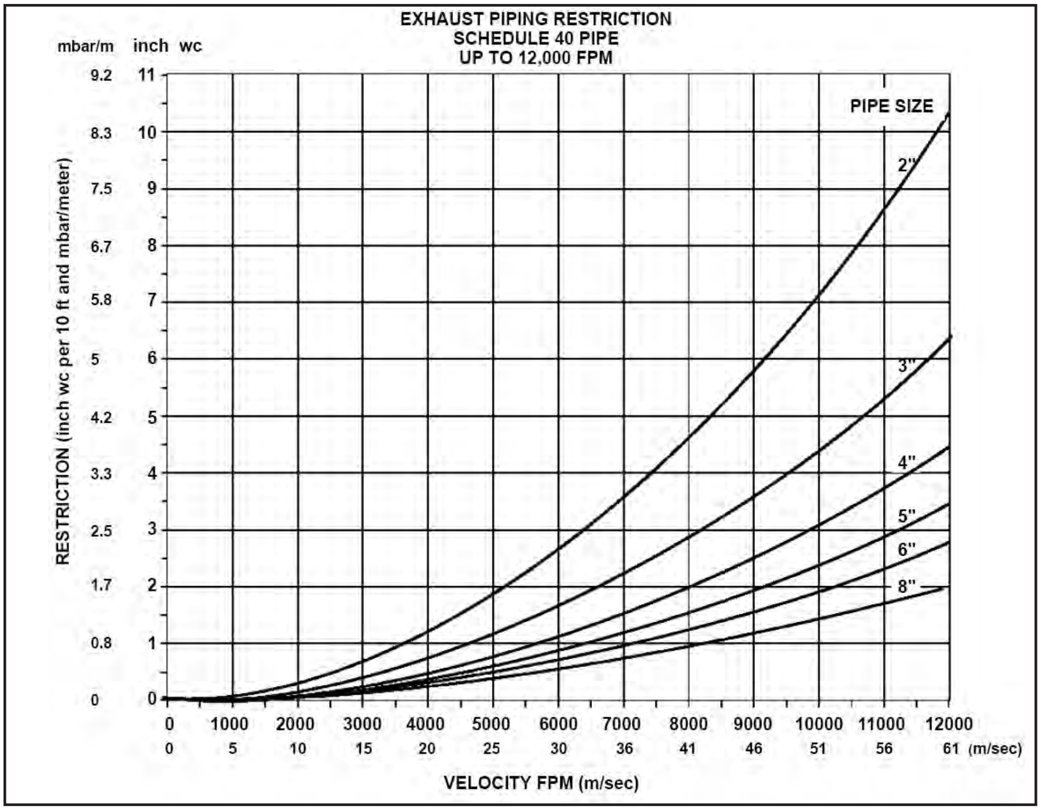


Figure A-7: Restriction vs. velocity for pipe diameter up to 8”

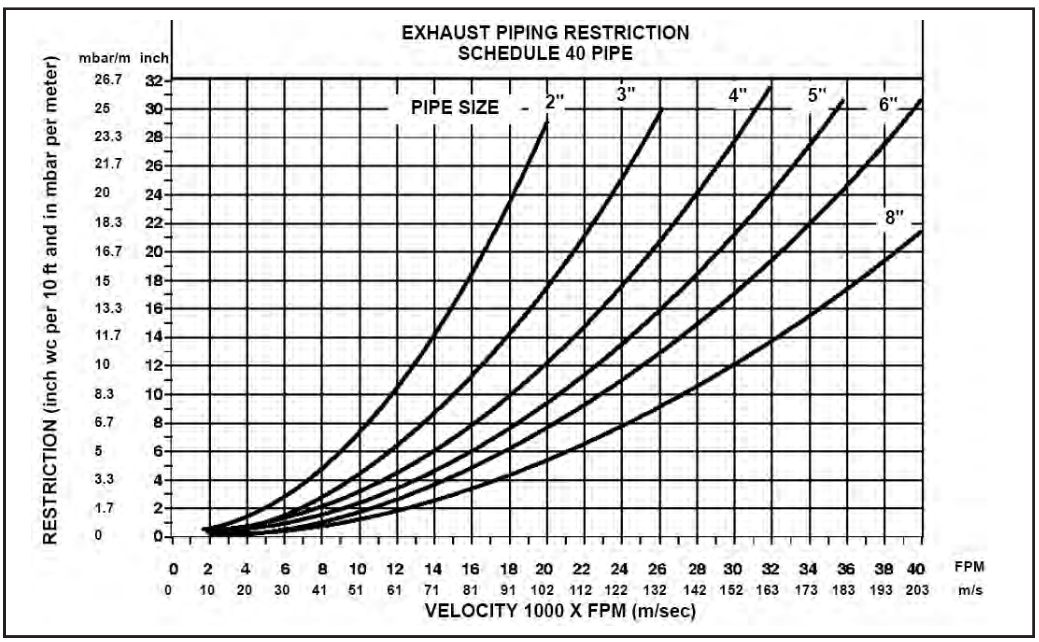


Figure A-8: Restriction vs. velocity for pipe diameter up to 8” (high speed)

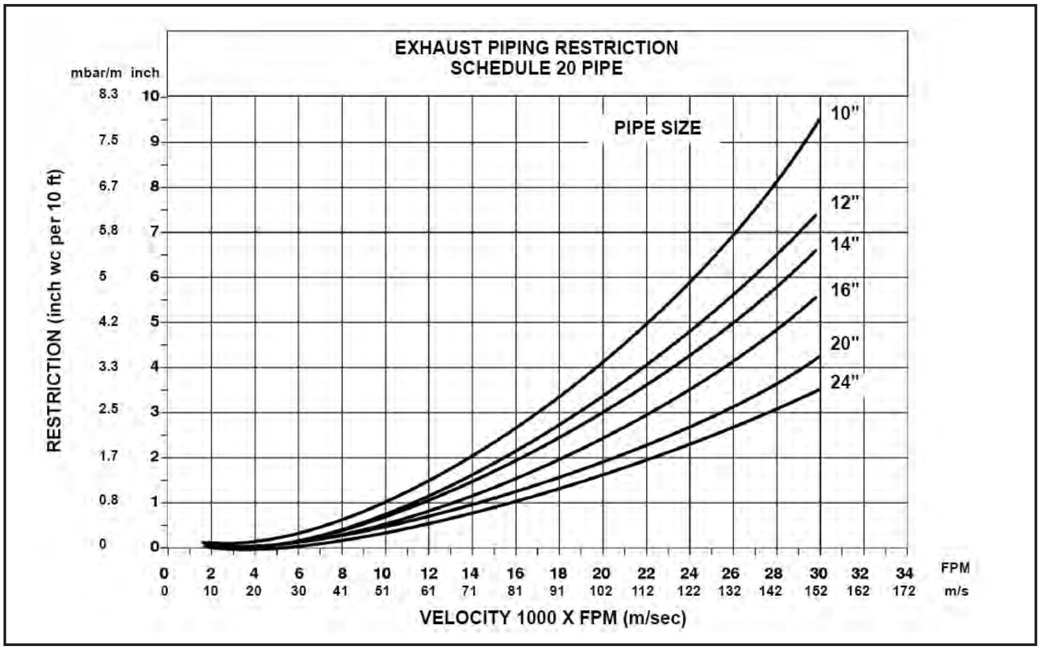
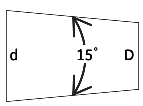
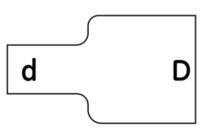
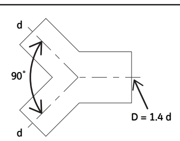


Figure A-9: Restriction vs. velocity for pipe diameter up to 24”

Table A-7: Equivalent Pipe Length Of Fittings In Feet (Meter)
(Calculated using NTIS Handbook Of Hydraulic Assistance, Form AEC-TR-6630)

FITTINGS		ROUND PIPE DIAMETER 3”	4”	5”	6”	8”	10”	12”	14”	16”	18”	20”	24”
 **15° Diffuser* EPL based on flow at “d”**	**d/D=1/4 Flanged**	3.5 (1)	4.9 (1.5)	6.3 (1.9)	7.9 (2.4)	11.2 (3.4)	14.5 (4.4)	18.3 (5.6)	20.6 (6.3)	24.3 (7.4)	29.7 (9.1)	31.9 (9.7)	39
	d/D=1/2 Flanged	2.4 (0.7)	3.3 (1)	4.3 (1.3)	5.4 (1.6)	7.6 (2.3)	9.9 (3)	12.5 (3.8)	14.0 (4.3)	16.5 (5)	20.3 (6.2)	21.7 (6.6)	27 (8.2)
	d/D=3/4 Flanged	1.1 (0.3)	1.6 (0.5)	2.0 (0.6)	2.5 (0.8)	3.6 (1.1)	4.6 (1.4)	5.8 (1.8)	6.6 (2)	7.8 (2.4)	9.5 (2.9)	10.2 (3.1)	13 (4)
 **Sudden expansion based on flow at “d”**	**d/D=1/4 Flanged**	13.2 (4)	18.7 (5.7)	24.3 (7.4)	30.1 (9.2)	42.7 (13)	56	70	79 (24)	93 (28)	114 (35)	122 (37)	151 (46)
	d/D=1/2 Flanged	8.5 (2.6)	12.1 (3.7)	15.7 (4.8)	19.5 (5.9)	27.6 (8.5)	35.9 (11)	45.4 (14)	51	60 (18)	74 (23)	79 (24)	97 (30)
	d/D=3/4 Flanged	2.9 (0.9)	4.2 (1.3)	5.4 (1.6)	6.7 (2.0)	9.5 (2.9)	12.3 (3.7)	15.5 (4.7)	17.6 (5.4)	20.8 (6.3)	25.4 (7.7)	27.2 (8.3)	34
 **Y-Connection based on flow at “d”**	**Flanged**	—	—	—	—	—	34.7	43.7	49.1 (15)	58.1	—	—	—

5. Calculate the exhaust gas density correction:

Equation 3

$D_C = L_C * 520 / (460 + T_{exh})$ or $D_C = L_C * 273 / (273 + T_{exh}\ °C)$

WHERE:

D_C = density correction

L_C = lambda correction,

for Lambda = 0.97 to 1.06, L_C = 0.95 (rich burn)

for Lambda = 1.53 to 2.0, L_C = 0.97 (lean burn)

T_{exh} = exhaust temperature ° F (° C)

6. Calculate the total piping restriction RP for each pipe size:

Equation 4

$$R_{P1} = \frac{P_{L1}(psi)}{10\,ft.} \times D_C \times EPL\,(ft) \quad \text{or} \quad R_{P1} = \frac{P_{L1}(mbar)}{m} \times D_C \times EPL\,(m)$$

7. Calculate the total exhaust system restriction:

Equation 5

$R_T = R_{P1} + R_{P2} + R_{P3} + R_S + R_A$

WHERE:

R_T = total restriction (psi or mbar)

$R_{P1,2,3}$ = piping restriction for various pipe sizes (psi or mbar)

R_S = silencer restriction (psi or mbar)

R_A = accessories (catalyst, boiler, etc.) restriction (psi or mbar)

APPENDIX B

SOIL BEARING LOAD

The necessary soil bearing load (S.B.L.) can be determined with the following formula:

$$S.B.L. = \frac{(2.5)(M+F)}{(W)(L)}$$

2.5 = Safety constant

M = Weight of engine

W = Width of inertia block or pad

L = Length of inertia block or pad

F = Weight of engine and equipment (see Note 1)

The weight of the inertia block or pad (F) must first be determined.

The weight is determined by the following formula:

Weight of inertia block or pad = W x L x H x density of the concrete

NOTE1: The above example only takes into account the weight and size of the engine. An actual installation would have to include the weight of the engine and the driven equipment, and the weight of a common mounting skid large enough to support both the engine and driven equipment.

Example: F3524GSI

F = 4.5 x 9.3 x 3.75 x 135 lb/ft3

F = 21187 lb.

F=1.37 m x 2.84 m x 1.13 m x 2162kg/mr3

F = 9505 kg.

Now that "F" is known, the required soil bearing load can be determined using the given formula.

$$S.B.L. = \frac{(2.5)(M+F)}{(W)(L)}$$

$$S.B.L. = \frac{(2.5)(15{,}000+21{,}187)}{(4.5)(9.3)}$$

Required S.B.L. = 2161.7lbs/sq.ft.

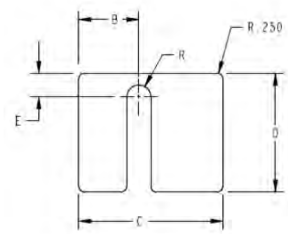
NOTE 1: The above example only takes into account the weight and size of the engine. An actual installation would have to include the weight of the engine and the driven equipment, and the weight of a common mounting skid large enough to support both the engine and driven equipment.

APPENDIX C

VHP STAINLESS STEEL SPACERS AND SHIMS

Shims can be made locally (see “Table A-8: Shim dimensions”), preferably of stainless steel in a size that adequately covers the engine base mounting pad. They should be sized in thickness so that no more than four of one size are necessary to equal, or surpass, the next larger size.

Table A-8: Shim dimensions



Part Number	A	B	C	D	E	R
P310316	0.002	2.500	6.000	5.000	1.000	0.500
P310121	0.005	2.500	6.000	5.000	1.000	0.500
P310122	0.010	2.500	6.000	5.000	1.000	0.500
P310123	0.030	2.500	6.000	5.000	1.000	0.500

Stainless steel shims are shipped loose with Waukesha Generator Sets in thicknesses listed in the table. Shims and spacers are available as listed in the table below. Waukesha recommends ordering the quantities listed below for each engine.

Table A-9: Engine spacers

Item	Description	Recommended order quantity
P316795	Front Spacer	2
P316794	Middle Spacer	2
P316793	Rear Spacer	2
P310316	Shim 0.002 in. thick	10
P310121	Shim 0.005 in. thick	20
P310122	Shim 0.010 in. thick	20
P310123	Shim 0.030 in. thick	10

APPENDIX D

CUSTOMER INTERFACE CONNECTIONS

Table A-10: Customer Interface Harness Loose Wire Identification

WIRE LABEL	DESCRIPTION	SIGNAL NAME	SIGNAL TYPE	WIRE COLOR	FROM PIN	WIRE SIZE	SOCKET SIZE	Wire#
ESD	A digital input to the ECU from the local control that must be high for the engine to run. If ESD goes low, the engine performs an emergency shutdown.	Emergency Engine Shutdown	Digital I/P	Yellow	15	18	20	1606
RUN/ STOP	A digital input to the ECU from the local control that must be high for the engine to run. If RUN/ STOP goes low, the engine performs a normal shutdown.	High = OK to Run Low = Normal Shutdown	Digital I/P	Yellow	25	18	20	1611
START	Momentary (>1/2 second and <60 seconds) digital signal input to ECU to begin the starting process, must momentarily be connected to +24 VDC nominal (8.6 – 32 volts) for the ECU to start the engine.	Start Engine	Digital I/P	Yellow	24	18	20	1609
CAN HI	CAN Communication High	CAN	CAN	Yellow	1	20	20	1300
CAN LO	CAN Communication Low	CAN	CAN	Green	5	20	20	1301
CAN GND	CAN Communication Shield	SHIELD	CAN	Drain	6	20	20	1302
GOVHL IDL	Digital input to the ECU that changes the operating rpm of the engine from low idle to high idle. Used for fixed speed applications only. The desired speed is set on the HMI.• +24 VDC nominal (8.6 – 32 volts) for rated speedOpen circuit for idlespeed	Rated Speed/ Idle Speed select	Digital I/P	Yellow	37	18	20	1616
GOV 40	Used for remote speed setting using a voltage input for control (0.5 – 4.5V signal).	Remote Speed Setting Mode Select	0.5 – 4.5 V DC I/P	Tan	40	18	20	1618
GOV-REMSP+	Used for remote speed setting using a current input for control (4 – 20 mA signal). See Figure 2.501 for an example showing the user 4 – 20 mA analog inputs.	Remote Speed Setting 4 – 20 mA-Signal +	4 – 20 mA I/P+	Light Green	39	18	20	1614
GOV-REMSP	Used for remote speed setting using a current input for control (4 – 20 mA signal). See Figure 2.501 for an example showing the user 4 – 20 mA analog inputs.	Remote Speed Setting 4 – 20 mASignal	4 – 20 mA I/P	Light Blue	27	18	20	1613
GOV-REMSEL	Digital input to the ECU that switches between either remote speed setting input or high/low idle input. Must be used to enable remote speed input. Not typically used for power generation.	Remote Speed select	Digital I/P	Yellow	22	18	20	1608

WIRE LABEL	DESCRIPTION	SIGNAL NAME	SIGNAL TYPE	WIRE COLOR	FROM PIN	WIRE SIZE	SOCKET SIZE	Wire#
LOGIC GND	Used as the negative connection point for signal inputs (voltage and current) (4 – 20mA and 0 – 5 volt).	Customer Reference Ground	Ground	Black	4	16	16	1111
ENG ALM	A digital output from the ECU that indicates that the ECU is in either alarm or shutdown mode.	Engine Alarm	Digital HSD O/P	White	14	18	20	1604
KNK ALM	A digital output from the ECU that indicates the engine is knocking and will shut down unless some action is taken to bring the engine out of knock.	Engine Knocking	Digital HSD O/P	White	47	18	20	1617
ENG ESD	A digital output from the ECU that indicates that the ECU is in shutdown mode. Output is NOT latched.	Emergency Shut-down	Digital HSD O/P	White	42	18	20	1607
WKI+	A 4 – 20 mA analog input to the ECU that represents the real time WKI rating of the fuel. Use not necessary for most applications. Table 2.509 Changing Fuel/WKI Inputs on page 2.5014 for scaling information.	Fuel Quality (WKI) Signal +	4 – 20 mA I/P+	Light Green	30	18	20	1623
WKI	A 4 – 20 mA analog input to the ECU that represents the real time WKI rating of the fuel. Use not necessary for most applications. Table 2.509 Changing Fuel/WKI Inputs on page 2.5014 for scaling information.	Fuel Quality (WKI) Signal	4 – 20 mA I/P	Light Blue	31	18	20	1622
PROG OP 1+	A 4 – 20 mA output from the ECU that represents an engine operating parameter. See Table2.508 Available Analog Outputs on page 2.5011 for listing of parameters, scaling and other-information.	Analog Output 1+	4 – 20 mA O/P+	Dark Green	21	18	20	1600
PROG OP 1	NEG for 4 – 20 mAPROG OP 1	Analog Output 1–	4 – 20 mA O/P	Black	26	18	20	1647
PROG OP 2+	A 4 – 20 mA output from the ECU that represents an engine operating parameter. See Table2.508 Available Analog Outputs on page 2.5011 for listing of parameters, scaling and other-information.	Analog Output 2+	4 – 20 mA O/P+	Dark Green	3	18	20	1601
PROG OP 2	NEG for 4 – 20 mAPROG OP 2	Analog Output 2–	4 – 20 mA O/P	Black	18	18	20	1648
PROG OP 3+	A 4 – 20 mA output from the ECU that represents an engine operating parameter. See Table2.508 Available Analog Outputs on page 2.5011 for listing of parameters, scaling and other-information.	Analog Output 3+	4 – 20 mA O/P+	Dark Green	11	18	20	1602

WIRE LABEL	DESCRIPTION	SIGNAL NAME	SIGNAL TYPE	WIRE COLOR	FROM PIN	WIRE SIZE	SOCKET SIZE	Wire#
PROG OP 3	NEG for 4 – 20 mAPROG OP 3	Analog Output 3–	4 – 20 mA O/P	Black	13	18	20	1649
RS 485A	RS485 MODBUS,see MODBUS COMMUNICATIONSon page 2.551 for additionalinformation.	RS485 A	Comms	Green	2	18	20	1305
RS 485B+	RS485 MODBUS,see MODBUS COMMUNICATIONSon page 2.551 for additionalinformation.	RS485 B+	Comms	Yellow	23	18	20	1306
USER DIP 1	A digital input to the ECU that can be used to indicate a customer alarm. See Figure 2.503 for additional information.	User Defined Digital Input 1	Digital I/P	Yellow	16	18	20	1627
USER DIP 2	A digital input to the ECU that can be used to indicate a customer alarm. See Figure 2.503 for additional information.	User Defined Digital Input 2	Digital I/P	Yellow	17	18	20	1628
FUTURE	Spare	Spare		Red	7	20	20	1636
FUTURE	Spare	Spare		Black	8	20	20	1637
ENG RUN	A digital output from the ECU that indicates that the engine is running.	Engine Running	Digital O/P	White	12	18	20	1646
	Power (24V DC, 5 amps maximum) available for items such as a local control panel and panel meters	User Power	+24 VDCnominal	Red	32	18	16	1020
GND FOR U	User Ground	User Ground	Ground	Black	33	18	16	1120
ESTOP SW	Emergency Stop Switch, Normally Open	Emergency Stop Switch, Normally Open	Customer supplied	Tan	44	18	16	1802
ESTOP SW	Emergency Stop Switch, Normally Open	Emergency Stop Switch, Normally Open	Customer supplied	Tan	45	20	16	1804
PREL CTRL	Customer PreLube Control Request	Customer Pre Lube Control	+24 VDCdigital I/P	Brown	34	20	16	1679
FUTURE	Spare	Spare		Black	46	18	20	1640
GOV-AUX-SIG+	Used for compatible loadsharing input.	Aux. Input Signal	0.5 – 4.5V I/P+	Red	28	20	20	1615
GOV-AUX-GND	Used for compatible loadsharing input.	Aux. Input Signal	0.5 – 4.5V I/ Preferenced to logic ground pin 4 / wire 1111	Black	29	20	20	1110
GOV-AUXSHD	Used as a shield for compatible load sharing input.	Aux. Input Shield	Shield	Drain	43	22	20	1137
GOVALT-SYN	Alternate governor dynamics. Used for power generation applications only to obtain a smooth idle for fast paralleling to the grid.	Alternate Governor Dynamics	Digital I/P	Yellow	10	18	20	1620

WIRE LABEL	DESCRIPTION	SIGNAL NAME	SIGNAL TYPE	WIRE COLOR	FROM PIN	WIRE SIZE	SOCKET SIZE	Wire#
LRG LOAD	Digital input to the ECU that “kicks” the governor to help the engine accept large load additions. Mainly useful for standalone power generation applications.	Load Coming	Digital I/P	Yellow	20	18	20	1631
LSMI+	Used for compatible loadsharing input.	4 – 20 mASignal +	4 – 20 mA I/P+	Red	35	20	20	1651
LSMI	Used for compatible loadsharing input.	4 – 20 mASignal –	4 – 20 mA I/P	Black	36	20	20	1652

Use LOGIC GND “Customer Reference Ground” as the negative connection point for these 4 – 20 mA signals. Self-regulating solid state logic can become high impedance during an overcurrent event. The overcurrent logic is rated for 1.1 A.

Table A-11: Required Connection Descriptions

DESCRIPTION	WIRE LABEL	PHYSICAL CONNECTION
Start Engine	**START**	Momentary (>1/2 second and <60 seconds) digital signal input to ECU to begin the starting process, must momentarily be connected to +24 VDC nominal (8.6 – 36 volts) for the ECU to start the engine.
Normal Shutdown (Run / Stop)	**RUN/STOP**	A digital signal input to the ECU that must be connected to +24 VDC nominal (8.6 – 36 volts) for the engine to run. If RUN/STOP goes open circuit, the engine performs a normal shutdown.
Emergency Shutdown	**ESD**	A digital signal input to the ECU that must be connected to +24 VDC nominal (8.6 – 36 volts) for the engine to run. If ESD goes open circuit, the engine performs an emergency shutdown. NOTE: Do not use this input for routine stopping of the engine. After an emergency shutdown and rpm is zero, ESD input should be raised to high to reset the ESM. If ESD input remains low, ESM reset will be delayed and engine may not start for up to 1 minute.
Rated Speed/Idle Speed (Fixed Speed Application)	**GOVHL IDL**	Digital signal input to ECU must be connected to +24 VDC nominal (8.6 – 36 volts) for rated speed, idle speed and remote speed setting enable (GOVREMSEL) must be open circuit. When using the Remote Speed/Load Setting, GOVHL IDL should be set to a safe mode. “Safe mode” means that if the wire that enables remote rpm operation (GOVREMSEL) fails, the speed setpoint will default to the GOVHL IDL idle value. Consider all process/driven equipment requirements when programming idle requirements.
Remote Speed/Load Setting (Variable Speed Application)	**GOVREMSP-** **GOVREMSP+**	Either 4 – 20 milliamp or 0.875 – 4.0 volt input to ECU. Inputs below 2 milliamps (0.45 volts) and above 22 milliamps (4.3 volts) are invalid. Input type can be changed by fitting a jumper across pins 40 and 41 to enable the 4 – 20 milliamp option. GOVREMSP- and GOVREMSP+ are used for the 4 – 20 milliamp input. For voltage, input pin 40 is the + voltage input and pin 41 is the - voltage input. See Figure 5.00-5 for an example showing the user 4 – 20 mA analog inputs.
Remote Speed Setting Enable (Variable Speed Application)	**GOVREMSEL**	Digital signal input to ECU must be connected to +24 VDC nominal (8.6 – 36 volts) to enable remote speed/load setting. NOTE: When programming Rated Speed/Idle Speed, GOVHL IDL must be set to safe mode.

Table A-12: Optional Connection Descriptions – Customer Interface Harness

DESCRIPTION	WIRE LABEL	PHYSICAL CONNECTION
Current Operating Torque	**ACT LOAD%**	A 4 – 20 milliamp output from the ECU that represents the current engine torque output on a 0 – 125% of rated engine torque scale.
Desired Operating Torque	**AVL LOAD%**	A 4 – 20 milliamp output from the ECU that represents the desired operating torque of the engine. Always indicates 100% of rated engine torque unless there is an engine fault such as uncontrollable knock.
Engine Alarm	**ENG ALM**	Digital signal output from ECU goes from open circuit to +24 VDC nominal (battery voltage – 1 volt) when ECU detects engine problem. Output remains +24 VDC nominal while an alarm is active. As soon as alarm condition is resolved, digital signal returns to open circuit.
Engine OK/Emergency Shutdown	**ENG ESD**	Digital signal output from ECU goes from open circuit to +24 VDC nominal (battery voltage – 1 volt) when ECU performs an emergency shutdown.
Synchronizer Mode/ Alternate Governor Dynamics	**GOVALTSYN**	Digital signal input to the ECU when +24 VDC nominal (8.6 – 36 volts) allows synchronizer mode/ alternate governor dynamics. User can program a small speed offset to aid in synchronization.
Aux. Speed Input	**GOVAUXSIG** **GOVAUXGND** **GOVAUXSHD**	A ±2.5 volt input to the ECU used for compatibility to Woodward™ generator control products (or other comparable control products).
Uncontrolled Knock	**KNK ALM**	Digital signal output from ECU goes from open circuit to +24 VDC nominal (battery voltage – 1 volt) when ECU cannot control engine knock. Allows customer knock control strategy such as load reduction instead of the ECU shutting down the engine.
Load Coming	**LRG LOAD**	Digital signal input to the ECU when +24 VDC nominal (8.6 – 36 volts) is applied, signals the ECU that a large load will be applied to the engine. This input can be used to aid in engine load acceptance. User can program delay time from receipt of digital signal to action by the ECU.
Four Analog Outputs	**PROG OP 1 through PROG OP 4**	4 – 20 milliamp analog outputs from the ECU that can be used to read engine parameters such as oil pressure, coolant outlet temperature, engine speed and intake manifold pressure.
MODBUS	**RS 485A–** **RS 485B+** **RS485SHD**	The ECU is a MODBUS RTU slave operating from 1200 to 19,200 baud on “two-wire” RS-485 hardware. Current operating values such as oil pressure and fault information are available.
Four Digital Inputs	**USER DIP 1 through USER DIP 4**	Four digital signal inputs to the ECU when +24 VDC nominal (8.6 – 36 volts) is applied allows user to wire alarm and/or shutdown digital outputs of the local control into ESM. The purpose of these four digital inputs to the ECU is to aid in troubleshooting problems with the driven equipment.
WKI Value	**WKI+** **WKI-**	A 4 – 20 milliamp input to the ECU that allows the customer to change the input fuel quality (WKI) in real time (4 mA = 20 WKI; 20 mA = 135 WKI).

APPENDIX E

SCOPE OF SUPPLY

Gas Compression (GC) Spec Engines:

GC spec engines are engine configurations which already include the most common options typically found in gas compression applications.

Table A-15 lists all the option codes that come standard on the GC spec engines. Table A-16 lists all the option codes that would be available to add to a GC spec engine. In all cases, the Price Book should be referred to for the most current options and complete descriptions.

GC-Spec equipment for VHP 12-cylinder GSI:

Table A-13: Standard on 7042GSI S5/7044GSI S5

Code 12-Cyl.	Description
1161C	Flywheel - Machined to accept two drive adapters: 22.5" (572 mm) pilot bore, 20.5" (521 mm) bolt circle, (8) 1.00""-8 tapped holes; or 28.88" (734 mm) pilot bore, 27.25" (692 mm) bolt circle, (12) 0.75"-10 tapped holes
3433E	Alternator – Denso, 24V DC, 50A. Meets CSA Class 1, Div 2, Group A, B, C & D hazardous location requirements
4293	Inlet Water Header; Side Inlet
4342	Water Outlet; Dresser Coupling
Optional	BICERA Valve – Six (6) crankcase explosion relief valves.
6020	Main Bearing Temp Sensors; 12-cylinder: 7 K-Type
6526A	Exhaust Thermocouples; 12-cylinder: 14 K-Type. One for each cylinder exhaust and pre-turbine.
6650B	50' (15.2m) Exhaust Thermocouple harness; replaces 25' (7.6m)
6650C	50' (15.2m) Main Bearing Thermocouple Harness; replaces 25' (7.6m)
6650D	50' (15.2m) ESM Customer Interface & Option Harnesses; replaces 25' (7.6m)
8006	Front Stub Shaft
9208	High Pressure Air/Gas Starter (TDI T109)

Table A-14: Available Options on 5794GSI/7042GSI/L7042GSI S4/7044GSI/9394GSI GC Spec

Code 12-Cyl.	Add or Omit	Description
1004	Add:	emPact Emission Control System — Catalyst w/access door on top of housing for 0.50 g/bhp-hr NOx and 1.0 g/bhp-hr CO
1004S	Add:	emPact Emission Control System — Catalyst w/access door on side of housing for 0.50 g/bhp-hr NOx & 1.0 g/bhp-hr CO
1005	Add:	emPact Emission Control System — Catalyst w/access door on top of housing for 0.15 g/bhp-hr NOx and 0.3 g/bhp-hr CO
1005S	Add:	emPact Emission Control System — Catalyst w/access door on side of housing for 0.15 g/bhp-hr NOx & 0.3 g/bhp-hr CO
–	Add:	Omit Front End Drive Assembly: front shaft drive/pulley assembly, pillow block and coupling
1140A	Add:	Front Crankshaft Pulley - "C" grooves
	Omit:	Code 8006 - Front Stub Shaft
1140B	Add:	Front Crank Pulley - "V" grooves

Code 12-Cyl.	Add or Omit	Description
	Omit:	Code 8006 - Front Stub Shaft
1141	Add:	Pulley Spacer - 1" (Requires Code 1140A or 1140B)
—	Add:	Shipped-loose, off-engine mounting of air cleaner. Includes heavy duty inertia precleaner
—	Add:	Shipped-loose, off-engine mounting of air cleaner. Includes rain shield
—	Add:	Standard air cleaners shipped-loose for on-engine mounting
—	Add:	Shipped-loose weather louves for standard, on-engine air filters
2320B	Add:	Precleaner - Heavy Duty Inertia Separator
2350	Add:	Air Cleaner Housing Modification for Remote Air Intakes
3441	Add:	Delete Standard ESM Battery Box and Cable
4292	Add:	Inlet Water Header; Center Inlet
	Omit:	Code 4293 - Inlet Water Header; Side Inlet
4341	Add:	Water Outlet; 6" flange
	Omit:	Code 4342 - Water Outlet; Dresser Coupling
—	Add:	Regulator – Lubricating oil level. Kenco model LCE
6012	Add:	Four (4) Bicera Crankcase Relief Valves
6015	Add:	Crankcase Differential Pressure Switch
6190F	Add:	Magnetic Pickup -- Meets CSA Class 1, Div 2, Group A, B, C & D hazardous location requirements
6650CC	Add:	Omit Main Bearing Temperature Sensor Harness
9208A	Add:	Low Pressure Air/Gas Starter (12cyl: TDI T115) (16cyl: TDI 121)
	Omit:	Code 9208(B) - High Pressure Air/Gas Starter
9308	Add:	Dual High Pressure Pre-Engaged Air/Gas Starters (TDI T112); includes 2 starters
	Omit:	Code 9208(B) - High Pressure Air/Gas Starter
—	Add:	Dual Low Pressure Pre-Engaged Air/Gas Starters (TDI T121); includes 2 starters
	Omit:	Code 9208B - High Pressure Pre-Engaged Air/Gas Starter (TDI T112)
	Add:	Shipping Skid - For Overseas Container

Scope of supply is meant only as a guide. Always refer to the latest version of the Waukesha gas engine price book for available equipment.

Table A-15: Scope of Supply (12-Cylinder)

12-Cylinder	Qty.	Standard	Optional	Customer supplied	Mounted/Shipped Loose
STARTING SYSTEM					
Air/gas starters (high pressure)	1		9208		Mounted
Air/gas starters (low pressure)	1		9208A		Mounted
Dual air/gas starters (high pressure)	2		9308		Mounted
Inlet flexible connection	1			✓	
Outlet flexible connection	1			✓	
Solenoid valve	1	✓			Mounted
Solenoid valve wiring to ESM (and to starter, if supplied)	1	✓			Mounted
External piping to each starter	1			✓	
Air/gas supply to each starter	1			✓	
Electric starting motors, 24VDC	2		9000		Mounted
COOLING SYSTEM					
AUXILIARY CIRCUIT					
Water pump	1	✓			Mounted
Thermostat	1	✓			Mounted
Thermostat bypass	1	✓			Mounted
Radiator / heat exchanger	1			✓	
External piping				✓	
Inlet flexible connection	1			✓	
Outlet flexible connection	1			✓	
Expansion tank	1			✓	
Circuit vent lines to expansion tank				✓	
Static pressure line to pump inlet	1			✓	
Radiator fan drive				✓	
JACKET CIRCUIT					
Water pump	1	✓			Mounted
Thermostat	1	✓			Mounted
Thermostat bypass	1	✓			Mounted
Jacket water circuit heater, 2500W 240VAC	2		4282		Mounted
Jacket water circuit heater, 4500W 240VAC	2		4282A		Mounted
Jacket water heater canister, for packager-supplied heating element	2		4285		Mounted
Inlet water header - single 6" center inlet	1		4292		Mounted
Inlet water header - single 6" side inlet	1		4293		Mounted
Outlet water connection, single 6" flange			4341		Mounted
Outlet water connection, single 6" Dresser coupling			4342		Mounted
Radiator	1			✓	
External piping				✓	
Inlet flexible connection	1			✓	
Outlet flexible connection	1			✓	
Expansion tank	1			✓	
Circuit vent lines to expansion tank				✓	

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12-Cylinder	Qty.	Standard	Optional	Customer supplied	Mounted/Shipped Loose
Static pressure line to pump inlet	1			✓	
Radiator fan drive				✓	
FUEL SYSTEM					
850 - 2300 BTU/scf (33.4 – 90.5 MJ/nm3) fuel system range	1	✓			Mounted
Carburetors	2	✓			Mounted
Main gas regulators	2	✓			Mounted
Main fuel valve	1			✓	
Fuel valve wiring and surge suppression diode	1			✓	
Fuel valve open/close ESM2 control	1	✓			
Fuel valve vent piping (if required)				✓	
Particulate fuel filter	1			✓	
Coalescing fuel filter	1			✓	
Additional fuel treatment (if required)				✓	
Fuel inlet flexible connection	1			✓	
LUBRICATION SYSTEM					
Oil pump	1	✓			Mounted
Oil filter (set of spin-on filters)	1	✓			Mounted
Oil cooler and thermostats	1	✓			Mounted
Centrifugal oil filter	1	✓			Mounted
Oil pressure regulator	1	✓			Mounted
Prelube pump	1	✓			Mounted
Prelube pump oil piping	1	✓			Mounted
Prelube pump air/gas motor	1	✓			Mounted
Prelube pump solenoid valve, wiring and control by ESM2	1	✓			Mounted
Prelube pump air/gas supply	1			✓	
Prelube pump air/gas piping - include w/ air/gas starter	1		✓		Mounted
Oil level regulator	1		5022		
Oil sump heater (if required)	1			✓	
Base style oil pan (replaces deep sump, inc. ship-loose volume vessel)	1		5005		
Electric prelube pump w/ 115VAC 60Hz motor	1		5229B		Mounted
Electric prelube pump w/ 208-230VAC 50/60Hz motor	1		5229D		Mounted
Electric prelube pump w/ 24VDC motor	1		5229E		Mounted
Prelube pump, for electric drive (motor by others)	1		5235		Mounted
BICERA crankcase explosion relief valves	4		6012		Mounted
Crankcase differential pressure switch	1		6015		Mounted
EXHAUST SYSTEM					
Exhaust engine flexible connection	1	✓			Shipped Loose
Exhaust silencer	1			✓	
3-way catalyst sized for 0.5 g/bhp-hr NOx and 1.0 g/bhp-hr CO, including pressure & temperature sensors and post-catalyst O2 sensor			1004		Shipped Loose

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12-Cylinder	Qty.	Standard	Optional	Customer supplied	Mounted/Shipped Loose
3-way catalyst sized for 0.15 g/bhp-hr NOx and 0.3 g/bhp-hr CO, including pressure & temperature sensors and post-catalyst O2 sensor			1005		Shipped Loose
Exhaust piping flexible connections				✓	
Exhaust system support				✓	
CRANKCASE VENTILATION SYSTEM					
Self-regulating, closed breather system	1	✓			Mounted
AIR INDUCTION SYSTEM					
Air filters - 3" dry type w/ rain shield and service indicator	2	✓			Mounted
Air cleaner housing for remote air intakes	2		2350		Mounted
Heavy duty inertia separators, for std. air cleaner	2		2320B		Mounted
FLYWHEEL					
Flywheel Housing, No. 00 SAE	1	✓			Mounted
Flywheel, 30.25" 12-hole and 27.25" 12-hole bolt circles	1	✓			Mounted
Flywheel, 16.75" 12-hole and 27.25" 12-hole bolt circles	1		1161A		Mounted
Flywheel, 20.5" 8-hole and 27.25" 12-hole bolt circles	1		1161C		Mounted
Flywheel, for TD-321 clutch, 25.25" 12-hole bolt circle	1		1163		Mounted
Flywheel, machined for 24" SAE#24 generator coupling	1		1164		Mounted
Coupling	1			✓	
Driven Equipment	1			✓	
POWER TAKE-OFF					
Rear Stub Shaft, for attachment to standard PTO flywheel	1		8000A		Mounted
Front Stub Shaft	1		8006		Mounted
Front Crankshaft Pulley - Six C section grooves, 9.60in. Pitch diameter	1		1140A		Mounted
Front Crankshaft Pulley - Five C section grooves, 9.60in. Pitch diameter	1		1140B		Mounted
Front Pulley Spacer, 1 inch- requries 1140A or 1140B	1		1141		Mounted
ENGINE MOUNTING					
Shims for engine alignment				✓	
Engine jacking bolts		✓			Mounted
Engine mounting bolts				✓	
Skid/baseplate, for engine and driven equipment				✓	
ENGINE CONTROL & ELECTRICAL					
ESM2	1	✓			Mounted
50’ (15m) Harnesses for ESM2 customer interface	1	✓			Shipped Loose
25’ (7.6m) harnesses for items above	1		6690A		Shipped Loose
100’ (30.4m) harnesses for items above	1		6690B		Shipped Loose
200’ (60m) harnesses for items above	1		6690C		Shipped Loose
HMI Display Panel (connects via customer interface harness, for mounting in customer panel)	1	✓			Shipped Loose

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12-Cylinder	Qty.	Standard	Optional	Customer supplied	Mounted/Shipped Loose
15" HMI Harness	1		6680		Shipped Loose
19" HMI Harness	1		6680A		Shipped Loose
Cylinder exhaust thermocouples monitoring	14	✓			Mounted
Main bearing thermocouples monitoring	7	✓			Mounted
Magnetic Pickup - for customer use			6190F		Mounted
Alternator - Denso, 24VDC, 50A	1		3433E		Mounted
AC/DC Power Supply, Lambda model LZS-1000-3	1		3436		Shipped Loose
ESM battery box and cable	1	✓			Shipped Loose
Delete ESM2 battery box and cable	1		3441		
ESM2 control batteries				✓	
ESM2 control battery charger				✓	
PAINTING					
Oilfield orange or gray topcoat		✓			
SHIPPING SKID					
For domestic truck or rail	1	✓			Mounted
For overseas container	1		9998A		Mounted
ENGINE LIFTING DEVICE					
Lifting device (engine includes lifting eyes)				✓	
SERVICE ITEMS					
Engine Test Log			9900		
Torsional analysis			9965/A/B		
Mass Elastic System Data (MESD)			9981		
Static and modal anaylsis of genset skid or engine/ compressor skid				✓	
Specification Package			9972		
Engine that is Customs Union compliant			9974Q		
Engine that is CE Mark compliant			9974R		
Engine that is CE Mark compliant - includes 9974R, plus one Operator's manual in European Union language of choice			9974T		

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