CATERPILLAR®

3600 Marine Engine Application and Installation Guide

● **Controls**

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Controls

Control system types and sophistication levels are varied. This section covers common Caterpillar 3600 engine control arrangements and governor features.

The two basic control systems used are electric and pneumatic. A number of variations can be developed from these, but only the more common will be discussed herein.

Pneumatic Control System

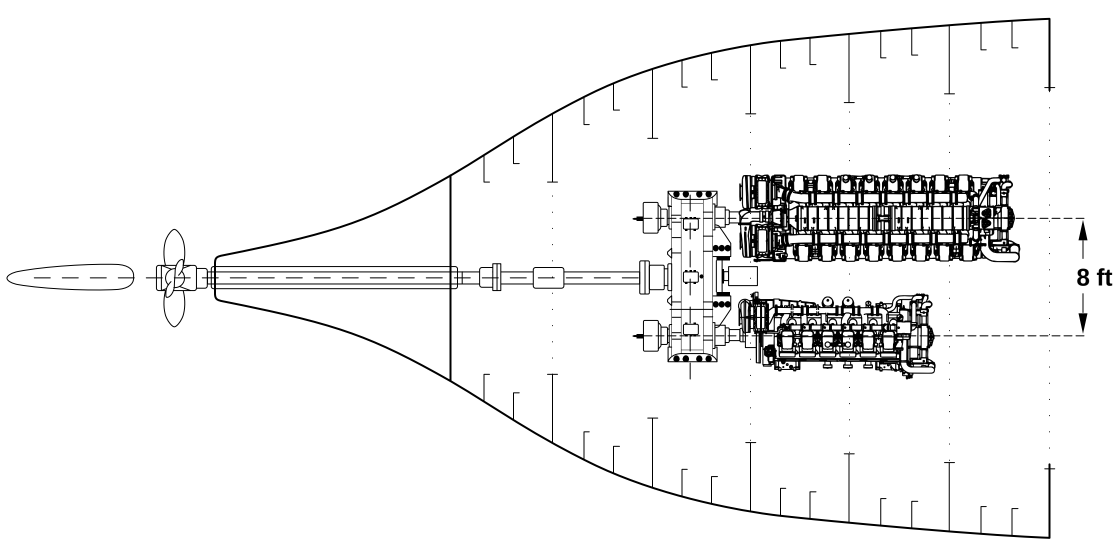
Pneumatic engine control is the most common method of speed setting 3600 marine engines. Control pressures range from 69 to 690 kPa (10 to 100 psi) and 69 to 414 kPa (10 to 60 psi). Valves, switches, and relays are commercially available to allow for multiple station operation. While pneumatic systems allow for installation over longer distances, they are prone to delays in the control signal between the bridge and the engine room. Routine maintenance is required to keep the system leak-free and prevent water and oil contamination. The pneumatic signal can be connected directly to the Woodward 3161 governor with pneumatic speed control. Examples are illustrated in Figures 1 through 3 on pages 27 through 29.

Electronic engine controls with pneumatic ship controls require a pressure-to-current or pressure-to-voltage transducer to convert the pneumatic speed signal to a usable electrical signal.

Electronic Controls

Electronic propulsion controls are becoming more popular. This type of system is typically used for:

- Multiple engines driving a common controllable pitch propeller requiring precise load sharing between engines operated under different conditions. See Figure 6 in the *Drawings* section of this guide.
- Single main engines driving a controllable pitch propeller and a number of different power takeoffs (PTOs). See Figure 6 in the *Other Applications* section of this guide. The PTOs could consist of ship service generators, pumps, and/or compressors.
- Multiple engines of different power ratings driving a controllable pitch propeller (*Father-Son* engine configuration). This arrangement requires load sharing over the operating range of the propulsion system (see Figure 4).



Twin Engine - Single Screw (CPP)
Father - Son Configuration

Figure 4

Engine Governors

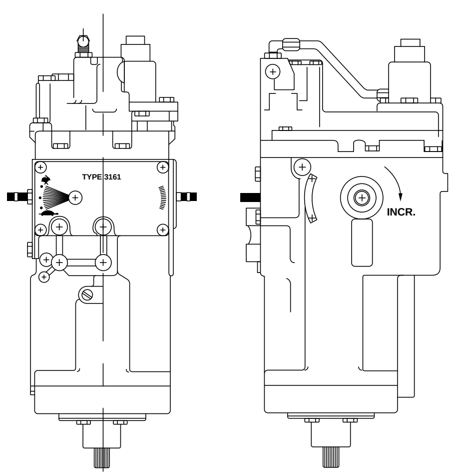
There are a few different governors available for 3600 marine engines for use in either pneumatic or electronic control systems.

- Woodward 3161 hydra-mechanical governor with pneumatic speed control (Figure 5)
- Heinzmann E30 electronic governor system (Figure 6)
- Woodward 721 digital electronic governor system

The Woodward 3161 governor is most commonly used with a pneumatic control system, the Heinzmann E30 governor can be used with either a pneumatic or electronic control system, and the Woodward 721 governor is most commonly used with an electronic control system. The Woodward 3161 is a stand-alone governor without the need for a separate fuel rack actuator. The electronic governors require a separate fuel rack actuator.

Governor Descriptions
Hydra-mechanical:
Woodward 3161
(Proportional and integral governor)

- Pneumatic speed control, 60-413 kPa (10-60 psi) or 69-690 kPa, (10-100 psi)
- Smoke limiter (standard)
- Drive speed = 1.5 x engine speed
- Manual and electric shutoff standard, pneumatic shutoff optional (Electric shutdown solenoid is required with Caterpillar safety shutoff system). The options are ETR or ETS.
- Self-contained oil supply
- Droop available: 0-5% factory set, non-adjustable
- Low idle offset (LIO) to prevent stalling from full load to no load
- Reference SENR3028, 3161 Governor Service Manual



Outline of 3161 Governor with Pneumatic Speed Setting Device

Figure 5

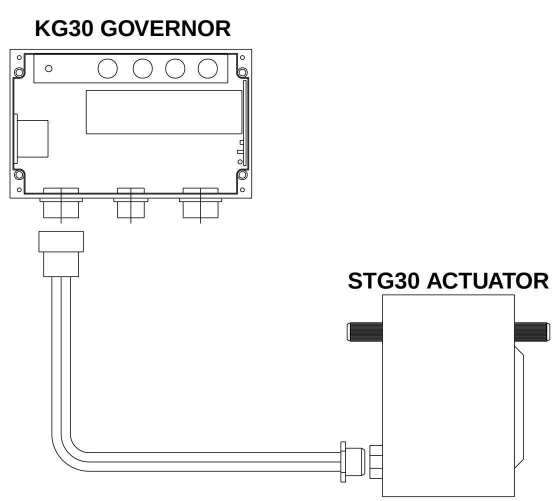


Figure 6

Electronic:
Heinzmann KG30 governor with STG30 Actuator
(Proportional, integral, and derivative governor)

- Remote speed setting potentiometer standard, optional mA or VDC speed setting transducer or pneumatic speed setting with pressure transducer
- Optional smoke limiter with pressure transducer
- Actuator is all electric without ballhead backup, no oil required
- 0-8% adjustable droop
- Actuator is spring loaded to shutoff and is energized-to-run (ETR)
- Requires 20-35 VDC (24 VDC nominal) @ 8 amps, optional power supply/battery backup available
- Equal rack load sharing available for multiple engine applications
- Setup/trouble shooting hand tool provided
- Reference SENR4661, Heinzmann Marine Governor Service Manual

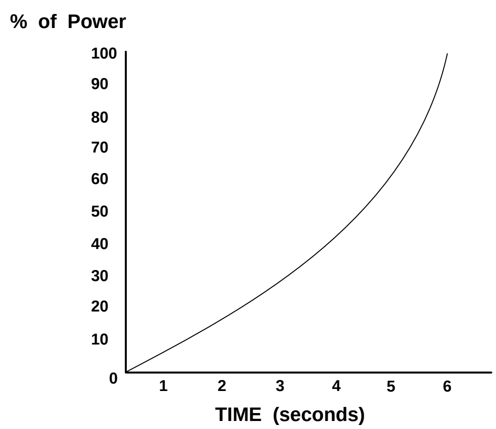
Electronic:
Woodward 721 digital governor
(Proportional, integral, and derivative governor)

- Remote and local electronic speed inputs
- Fuel limiting feature available for boost pressure, speed, and starting
- Fuel indexing control
- Torsional filtering and alarm (requires additional magnetic pickup)
- Multiple ramp rates
- Gain slope and gain windows
- Choice of actuators: UG-18 with no ballhead backup, EGB-13P (in-line) or EGB29P (vee) with ballhead backup, or PGA-EG with tracking ballhead, all require oil
- UG actuator is forward acting and ETR only, forward/reverse acting and ETR/ETS combination available with EGB and PGA-EG actuators
- Isochronous or adjustable droop operation
- Requires 18-40 VDC (24 VDC nominal) power supply
- Equal rack load sharing available for multiple engine applications
- 8 discrete inputs, 4 analog inputs, 3 relays, and 3 analog outputs
- Rough sea mode
- Clutch inputs and clutching logic
- Soft loading and unloading
- Parameters set by hand-held programmer

Clutches

Selection of marine gear clutches is important to propulsion system operation. Clutch characteristics directly affect how rapidly the propulsion system can respond to maneuvering demands of the vessel.

The 3600 Family of Engines' low load torque rise characteristics exceed most similar engines (including two stroke design). Their ability to develop low rpm power depends on how quickly the exhaust gas turbocharger can increase the combustion air mass flow rate. This is inherent in all high bmep four stroke diesel engines. It becomes more important when the main engine is operating at a low load/idle rpm condition and a high torque demand is placed on the engine. Figure 7 illustrates the time required for an unloaded/idled engine to achieve rated horsepower at a specific rpm. The reduction gear clutches must be capable of providing a smooth transition from a no load to high load condition. This is directly related to clutch slip capability.



Approximate Time Required For Turbocharger Acceleration

Figure 7

The duration of clutch slip is limited by the heat rise (thermal horsepower) the clutch materials can withstand. The heat generated during slip is a function of instantaneous driveline torques, driveline inertia, and the difference in velocity of the clutch's driven and driving elements. Matching a clutch's slip ability to the engine's torque rise characteristics is an iterative process. The engine may stall if the slip duration is too brief. If the slip duration is too great, the resulting frictional heat load will exceed the thermal capacity of the clutch, resulting in clutch failure. The clutch manufacturer must be consulted in the early project stages.

The control system must precisely time and sequence ahead and astern clutch engagement during *all* maneuvering conditions.

Shaft Brake

A propeller shaft brake is beneficial in applications where frequent maneuvering is required, or if full speed reversals may be encountered. A properly controlled shaft brake will stop the rotation of the propeller when the reduction gear clutches are disengaged. This action reduces the heat loading of the clutches and the amount of torque required from the engine/clutch to complete a shaft directional change.

Several advantages are gained with the use of shaft brakes:

- Reduce vessel maneuvering time. Vessel speed is reduced quickly due to increased drag of a stopped propeller versus a windmilling propeller. The propeller back torque is also reduced as vessel speed diminishes.
- The shaft brake brings the propeller to a stop with the propeller back torque and driveline momentum transmitted directly into the hull. The main engine is only required to develop the torque associated with a stopped propeller shaft rather than a windmilling propeller. Because thermal loading on the engaging clutch is greatly reduced, clutch life is extended.
- The propeller shaft brake will reduce the chance of engine stall when attempting crash stops, or when attempting high vessel speed shaft reversals.

Consider a propeller shaft brake on any fixed pitch marine propulsion system where repetitive high speed maneuvering is a requirement.

Both disc and drum type brakes are available. The brake and structural supports must be sized for full rated shaft torque, and should stop the shaft quickly during all maneuvering scenarios. Shaft brake size requirements will vary with the propeller type, driveline inertia, vessel speed, and vessel application.

Consult the clutch manufacturer for sizing and application guidelines.

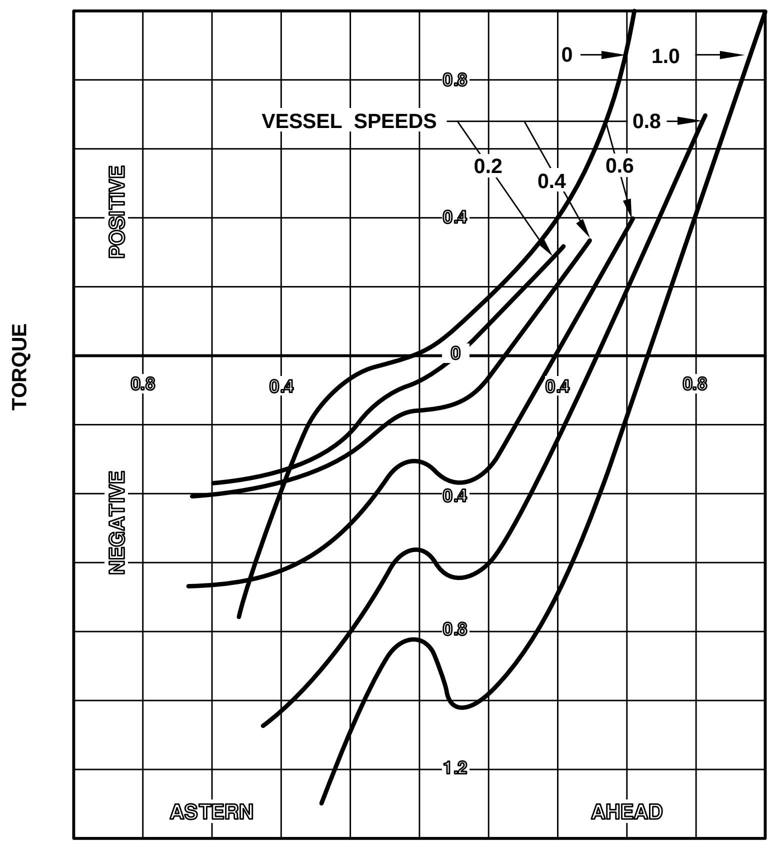
Fixed Pitch Propeller Systems

Pneumatic or electronic control systems require proper sequencing of shaft brake engagement, clutch engagement, and engine speed to ensure safe vessel operation and driveline component protection.

Sufficient engine torque must be available at engagement engine speed when shifting from forward to reverse, or vice versa, to overcome driveline inertia and propeller back torque. The engine will stall or operate in reverse if sufficient torque is not available.

It is important to review the propeller characteristics during the preliminary design phase of the vessel. This includes propeller torque during deceleration and reversing. These values are graphically represented on a Robinson Diagram, Figure 8.

Propeller back torque is generated by a free-wheeling propeller being turned by water flowing past the hull.
Engine stalling and reversal problems can be predicted with a Robinson diagram of the propeller. Inform the propeller designer of the ship's intended maneuvering characteristics.



Shaft rpm
Robinson Diagram
Figure 8 Propeller Torque During Deceleration and Reversing

Recommended Control System

A control system with flexible sequencing and timing of engine speed and signals for clutch and shaft brake engagement is the optimum in maneuvering capability as well as protection of driveline machinery.

Proper sequencing and timing of the controls is necessary to:

- Reduce vessel maneuvering time
- Prevent excessively low engine speed
- Prevent excessive loading of driveline components
- Reduce the possibility of engine stalling

One or more of the following features may be required to minimize the possibility of engine stall during normal and emergency maneuvers:

- Raised low idle speed setting
- Engine throttle boost control
- Shaft brake
- Flexible control system timing

Raised Low Idle Speed Setting

To increase the engine's low speed torque, the low idle setting may be increased providing the vessel's low speed maneuvering is not jeopardized. This will help prevent the engine from stalling or being reversed during maneuvering. *The setting should only be changed by an authorized Caterpillar Dealer. Low speed engine torsionals must be considered.* Excessive shock loading and transmission clutch wear can occur if the engine low idle speed is too high.

Engine Throttle Boost

Throttle boost momentarily raises the idling speed setting of the engine. The engine speed increase should occur just prior to engagement of the clutch. The momentary speed increase occurs only during maneuvering; the engine's normal idle speed is unaffected. Keep throttle boost as low as possible because it tends to increase the load on clutches during maneuvering. With air clutches, increased throttle boost will increase centrifugal forces on the clutch pads, causing very rapid clutch lockup. The control system should permit adjustment of the amount, duration, and rate of throttle boost. As a safety feature, some application controls will not allow throttle boost to be applied until marine gear oil pressure reaches a preset level.

Shaft Brake

Proper control and sequencing of the shaft brake is extremely important. Improper adjustment of the brake and clutch sequencing will manifest itself in two ways - clutch/brake overlap or underlap. Overlap can occur if the clutch engages before the brake is released. This would be realized as an additional load on the engine imposed by the engaged brake. Conversely, underlap represents releasing the brake prior to clutch engagement. In this case, the propeller will quickly begin to windmill, and much of the advantage of the brake is lost.

Overlap is desired in some applications to allow the engine torque to rise prior to brake release.

Flexible Control System Timing

The sequencing and timing of the engine governor, clutches, and shaft brake are critical. Consider only control systems with the following capabilities:

Event Sequences (Adjustable)

1. Governor move to low idle

1a. Engine used as a dynamic brake, (coast down with engine absorbing propeller torque)

2. Clutch disengaged
3. Shaft brake applied, propeller shaft stops
4. Shaft brake released

5a. Throttle boost applied

5b. Clutch fill

5c. Clutch contact*

5d. Clutch lockup*

6. Throttle boost off, governor to full fuel position

* The time between contact and lockup represents clutch slip.

The timing sequence from shaft brake off to clutch lockup should result in only one quarter revolution of the propeller shaft. This ensures no overlap between brake release and clutch engagement. With the above sequencing and timing, the shaft brake will engage any time the pilot house control lever is in the neutral position. Throttle boost will activate each time the pilot house control lever is shifted from neutral to a clutch-engaged position. The boost timing must be precise in multiple engine installations to prevent one engine from attempting to provide required power before the others become active.

Without a propeller shaft brake, a longer pause in neutral in place of Steps 3 and 4 will normally be required to allow vessel speed to diminish.

A proportional neutral delay-type control system is highly recommended to allow a variable time delay between steps 3 and 4 when the shaft brake is applied. This delay is proportional to the last-called-for engine speed signal (indirectly related to vessel speed at the time of maneuver). A crash reversal from full speed causes the brake to be applied longer than when slow speed maneuvering. In full speed reversal, adjust the neutral delay to be just long enough to slow the vessel speed, so propeller back torque won't reduce engine speed 100 rpm below low idle setting when engaging the astern clutch.

For adequate lubrication and to prevent engine stall during vessel maneuvers, it is imperative that engine speed not drop 100 rpm below the low idle rpm. Engines equipped with the Woodward 3161 governor will shut off fuel if subjected to engine reversal. Engines equipped with electronic speed governors need extra protection to prevent the engine from firing and starting in reverse.

Set the control system timing as fast as the propulsion system can safely be operated. Set and permanently lock-wire the timing adjustments after the completion of sea trials. Record the sequence timing and adjustment settings in the control box for future reference.

Suggested Initial Timing Sequence:

- 50 to 75 rpm throttle boost
- Less than one second initial pressure to clutch touch point
- Six seconds from clutch touch to full lock
- One second hard fill time
- Proportional delay of one second per each 100 engine rpm

Typical Pneumatic Control System

The Rexroth Logicmaster Pneumatic Control System is an example of a flexible sequencing propulsion control system. *Other manufacturers may also provide similar suitable systems.*
The system provides interlocked and sequenced operation of proportional timing in ahead and astern clutch engagement and engine speed control. This ensures proper operation of the propulsion machinery as the operator manipulates the remotely mounted control lever. The control system incorporates the following interlocks and the optional features:

- Positive cross engagement interlocks ensure that one clutch is vented before the opposite clutch can be engaged.
- The clutch engagement system incorporates a three stage clutch fill as shown in Figure 9.

1. An initial quick-fill to bring the clutch pads into contact with the drum, (or hydraulic clutch plate initial movement).
2. A controlled (adjustable) rate of fill of approximately 6 seconds.
3. Hard fill inflation at a maximum rate up to supply pressure.

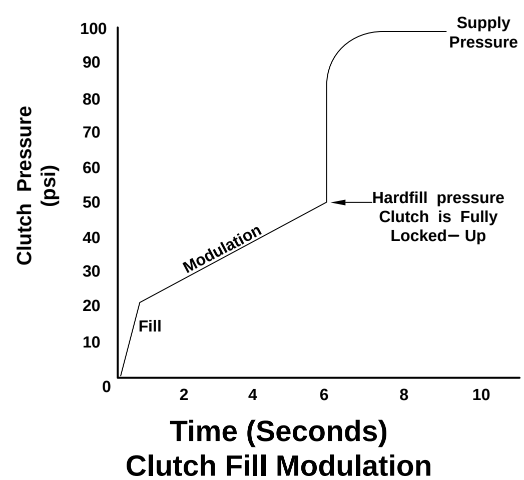


Figure 9

The *initial* quick-fill assures the clutch will move just to the point of contact as soon as possible to reduce the overall clutch engagement times.

Note: For dry type drum clutches, the higher the throttle boost the faster the clutch spins and the greater the centrifugal force exerted on the clutch pads. High engine rpm with the clutch disengaged will result in the pads engaging too fast. As a result, centrifugal force will tend to hold the clutch pads away from the hub until the air pressure overcomes the centrifugal forces. If the throttle boost is too high the actual clutch lock-up times can be cut to less than 1/4 the *clutch fill* times because of the influence of centrifugal forces.

- Governor speed boost is applied during initial clutch engagement to prevent engine stalling. This boost is adjustable in magnitude, duration, and rate.
- A clutch-pressure-engine speed signal interlock is used to ensure the clutch is inflated to lockup pressure prior to an engine speed increase.
- Proportional neutral time delay occurs in both ahead and astern directions. The delay is adjustable and provides a neutral time proportional to vessel speed. Normal low speed maneuvers are accomplished with a minimum delay.
- The ahead clutch hold-in function shortens the reversing time by holding the ahead clutch while the vessel coasts down in speed. This procedure uses the engine's compression to absorb torque from the propeller.
- A shaft brake signal (optional) is provided to actuate a shaft brake in synchronization with the clutch engage/disengage control system. The brake is released when clutch engagement is initiated and is applied when both clutches are disengaged. When a brake is used, the *interlocks* provide a neutral hold to permit the brake to be applied and the shaft stopped before reversal is initiated.

Controllable Pitch Propeller Systems

Controllable pitch propellers have blades separately mounted on the hub. The pitch can be changed or reversed to suit vessel operating conditions. The two basic propulsion systems are:

- Single or multiple main engines with auxiliary power takeoffs (PTOs) requiring main engine load control.
- Multiple main engines with power takeoffs (PTOs) requiring main engine load control and load sharing.

Single Engine

With a single main engine the engine controls are required to:

- Interface with the controllable pitch propeller (CPP) system's engine speed demand signal. This component typically converts the CPP system speed demand signal to a signal that is usable by the engine speed governor.
- Generate a signal representative of the engine's power output to the CPP control system. This component's output is electrical in nature. It is utilized by the CPP control system to protect the engine from overload. If an overload condition is detected, the propeller pitch is reduced until the engine is no longer overloaded.

The Woodward 3161 can be used in this application. An additional interface device is required to convert a voltage or current speed signal to a pneumatic speed signal acceptable to the governor. A rack position indicator is required for an electrical engine load signal.

The Heinzmann E30 electronic governor system is capable of interfacing directly with CPP control systems. An SG02 rack position indicator is required to provide an electrical engine load signal (either 4-20 mA, 1-5 VDC or 1-10 VDC) to the CPP control system. It is mechanically connected to the fuel system linkage and outputs a signal directly to the CPP control system.

A speed setting potentiometer is provided standard with the Heinzmann E30 governor system, but the governor can receive a remote electrical or pneumatic speed signal from the CPP control system with the addition of a SW09 speed setting transmitter or BG03 pressure converter. The SW09 speed setting transmitter receives a 1-5 VDC or 4-20 mA signal from the CPP control system and sends a signal to the governor to match speed demand. The BG03 pressure converter receives either a 1-5 bar or 1-10 bar pneumatic pressure signal from the CPP control system and converts it to an electrical signal that is sent to the governor for speed demand.

Caterpillar provides a Heinzmann control panel that encloses the governor, rack position amplifier, speed setting potentiometer and remote speed setting transmitter all pre-wired and ready for customer installation. A local/remote switch is mounted on the front of the panel for choosing governor control from the local speed setting potentiometer or from the remote speed setting signal. An optional power supply/battery backup box is also available since the governor does not have a ballhead backup. See Figure 10, on page 30, for a typical wiring schematic of the Heinzmann E30 governor system.

The Woodward 721 governor is also capable of interfacing directly with CPP control systems. As with the other two governors previously discussed, a rack position signal is required from the governor to the CPP control system to indicate engine load. An electrical engine speed demand signal is required from the CPP control system to the 721 governor.

Multiple Engines

With several main engines driving a single propeller the controls are required to:

- Interface with the controllable pitch propeller (CPP) control system's engine speed demand signal. This component typically converts the CPP system speed demand signal to a signal usable by the engines' speed governors.
- Generate an electrical signal representative of the engines' power output to the CPP control system. It is utilized by the CPP system to protect the engines from overload. It provides a reference for a proper diversion of load during load sharing operation.

Either the Heinzmann E30 or Woodward 721 electronic governor can be used for multiple engine loadsharing applications. The Heinzmann system uses an SW50 marine control unit for each engine, along with the STG30 actuator, KG30 governor and SG02 rack position indicator, that provides the following features (see Figure 11 on page 31):

- Equal fuel rack load sharing
- Direct interface capability for volts or milliamps speed setting (SW09 not needed)
- Adjustable speed ramping between idle and rated speed
- Fuel limiting proportional to boost pressure
- Smoke limiting (requires an optional pressure transducer)
- Power supply and battery backup provided as standard

The Woodward 721 governor also provides equal fuel rack loadsharing between multiple engines. A rack position indicator is required for each engine along with a choice of fuel rack actuators previously discussed.

Instrumentation and Monitoring Systems

Wiring Routing - Preferred Practices

Wiring for D.C. circuits, magnetic pickups, thermocouples, and resistance temperature detectors (RTDs) can be routed in common conduits. They must not be in the same conduit with A.C. circuits. Separate A.C. circuits greater than 600 Volts from A.C. circuits less than 600 Volts.

Always use 100% shielded wire for magnetic pickups as well as wiring for the electronic governor actuator.

The RTDs supplied by the factory are 100 Ohm platinum, and all factory supplied thermocouples are type K with chromel alumel material. *Care must be taken when attaching additional wiring at the job site. The wrong material, incorrect fastening, or different lengths can result in erroneous temperature readings.*

Instruments (also see Alarm/Shutdown section)

The Caterpillar supplied engine protection, alarms, and instrumentation systems are strongly recommended. Installations not using recommended systems must have factory approval.

The functions below are listed in their order of desirability for operator station instrument panel placement.

A = Highly Desirable Instrumentation (Caterpillar, Caterpillar dealer, installer, or user supplied)

B = Desirable Instrumentation

C = Useful Instrumentation

A **Engine Speed (rpm)**
Observing the relationship between engine speed and governor (or rack) can allow the operator to make engine operation and maintenance judgments. Manual shutdown for an overspeed fault is not possible as an engine will overspeed too quickly for operator reaction.

A **Lube Oil Pressure**
Loss of oil pressure is likely to result in severe engine damage. Quick action in reducing engine speed and load or stopping the engine can minimize damage. Engine oil pressure must be continuously monitored and recorded, either manually or automatically.

A **Lube Oil Temperature**
Much like all modern diesel engines, 3600 Engines rely on piston cooling with lubricating oil. Oil temperature is a good indicator of cooling system operation as well as oil cooler condition.

A **Jacket Water Temperature**
Jacket water temperature increase is almost as serious as loss of lube oil pressure and is more likely to occur. Similar quick action can minimize engine damage.

A **Intake Manifold Air Temperature**
High technology diesel engines rely on efficient turbocharger and aftercooler operation to produce the required output within safe operating limits. Air inlet temperature is a good indication of the turbocharger and air inlet system operation.

A **Exhaust Manifold Temperature**
Changes from normal exhaust manifold temperatures give useful information concerning air filter restriction, aftercooler restriction, valve problems, turbocharger fouling, and engine speed and load.

A **Clock Hour Meter**
Operating hours are essential for determining required maintenance intervals.

A **Fuel Pressure**
Low fuel manifold pressure to the unit injectors can result in poor performance, reduced power, poor starting characteristics, and misfire.

B **Differential Pressure Gauges**
Oil, fuel, and air filter condition can be accurately monitored with the differential pressure gauges. The instrumentation is helpful in determining service periods.

B **Crankcase Pressure (or vacuum)**
High crankcase pressure can indicate crankcase breather malfunctions or problems in the piston and piston ring belt areas. Changing trends in crankcase pressure will normally detect impending problems. Continued operation of an engine with severe problems can result in significant damage to the engine. In these rare instances, the damage occurs much too rapidly to detect by normal gauge observation. Automatic engine shutdown for high crankcase pressure is essential. See *Alarm / Shutdown* section.

B **Inlet Manifold Air Pressure**
This measurement is helpful in determining the condition of the turbocharger, aftercooler, and air intake system as well as being an indicator of engine load.

B **Oil Scavenge Pump Outlet Pressure**
Large engines can be applied in installations requiring very large external oil sumps in addition to the engine oil pan (dry sump configuration). In those instances the oil pressure measured at the scavenge pump outlet can detect oil system problems prior to low pressure detection in the main engine lube oil supply.

B **Air Start Pressure**
Low air tank pressure can prevent engine starting until tank pressure is raised to the required level.

C **Individual Cylinder Exhaust Temperature**
While these instruments will give warning of individual injector failure, the inevitable wide tolerance on the standard temperature (± 42°C (75°F)) often causes undue operator concern. Advantages gained can be overshadowed by cost (thermocouples need annual replacement) and need for special operator training.

C **Sea Water Pressure**
Particularly when using an engine driven sea water pump, it is important to insure that sufficient sea water pressure is delivered to the engine cooler. Engine overheating may result from loss of sea water pressure. In many single engine applications, an electric emergency sea water pump will be used to automatically start upon loss of engine driven pump pressure.

C **Jacket Water Pressure**
It is important to maintain jacket water pressure to the engine to prevent overheating. Single engine applications may use an electric emergency jacket water pump to automatically start upon loss of engine driven pump pressure.

C **AC/OC Water Pressure**
Loss of AC/OC water pressure will result in high inlet manifold air temperature and lube oil temperature, which can quickly cause engine damage. An electric emergency AC/OC water pump may be installed to automatically start upon loss of engine driven pump pressure.

C **AC/OC Water Temperature**
It is beneficial to monitor AC/OC water temperature to help determine operating efficiencies of the aftercooler and oil cooler. Impending problems with the inlet regulator may be detected with a gradual rise in water temperature.

C **Fuel Temperature**
The temperature of the fuel delivered to the engine may be useful for determining the fuel viscosity and power limitations of the engine. Fuel at higher temperatures causes a reduction in maximum available engine power and lower fuel viscosity which may lead to seized injectors.

Alarms and Shutdowns

A wide variety of preset contactors (switches), transducers, and RTD's are available to activate a specified alarm, light, or engine shutdown. Any equipment operating function can be monitored depending on individual installation requirements.

Alarm switches available from Caterpillar operate at various voltages (refer to Form No. LEBQ5043, 3600 Engine and Attachment Selection Guide). They are single-pole, double-throw type.

Minimum engine protection includes automatic shutdowns for overspeed, low lubricating oil pressure (at both low and high engine speeds), and high crankcase pressure. Additional shutdowns are available for cooling water loss, high lubricating oil temperature, high jacket water temperature, and oil mist detection.

A = *Mandatory* (Caterpillar supplied). Exceptions to this requirement will only be allowed by agreement from Caterpillar.

B = Highly desirable

C = Useful

A **Overspeed Shutdown**

Overspeed faults occur when some part of the engine fails, causing the fuel control mechanism to lock in a high fuel flow condition. When the engine load goes to a low level the engine will continue to receive a high fuel flow. Without the load, the engine speed increases rapidly to a dangerously high level. Generally, the engine's air and fuel supply must be cut off to stop the engine. The air shutoff requires a 552 kPa (80 psi) minimum air supply pressure for activation force. Overspeed contactors are set 13% nominally over rated engine speed to avoid nuisance engine shutdowns during sudden reductions in engine load.

A **Low Lube Oil Pressure Alarm And Shutdown**

Two operating conditions require alarms and shutdowns: low oil pressure at low engine speed (idle conditions) and low pressure at high engine speed and/or load. A safe oil pressure while operating at very low loads and/or speeds is too low at full load/speed conditions. The system includes two pressure-sensitive contactors for alarm, two for shutdown and one speed (rpm) switch to decide which pressure switch has the authority to initiate the alarm or shutdown for the engine.

A **High Crankcase Pressure Shutdown**

High crankcase pressure indicates problems occurring in the piston and piston ring belt areas. Continued operation of an engine with severe problems can result in significant damage.

A **Oil Mist Detector Shutdown**

An oil mist detector may be required by marine societies on engines with a rating of 2250 bkW and higher. Oil mist can be an immediate indication of an impending bearing failure, and the engine should be shutdown for inspection.

A **High Oil Temperature Alarm**

Oil temperature measured near the supply to the engine oil manifolds and piston cooling jets indicates the lube oil cooling system's condition. Higher than normal oil temperatures can result in bearing and/or piston problems.

A **Cooling Water Loss Alarm**

Warning of coolant loss can allow the operator to save an engine which would otherwise be lost to overheat failure. If the high water temperature sensors discussed below are not immersed in water they will not activate. This coolant detection switch is installed on the engine at the highest location in the jacket water system.

A **High Jacket Water Temperature Alarm**
Set the high coolant temperature contactors to activate within 2.8°C (5°F) of the highest normal engine temperature at the time of installation.

A **Intake Manifold Air Temperature Alarm**
Excessive intake air temperature indicates problems in the turbo/aftercooler/air intake system.

A **Exhaust Manifold Temperature Alarm**
Excessive temperatures indicate a variety of impending engine problems, see the previous section on *Instruments*.

B **Fuel Temperature Alarm**
High fuel temperature can present performance, power loss, and injector durability problems. This is even more significant when operating on heavy fuel.

B **Oil Level Alarm**
Oil temperatures and pressures are not the complete picture of an engine's lubrication system condition. An alarm to signal low oil level in the sump can also warn of impending danger.

B **Low Fuel Pressure Alarm**
Low fuel pressure in the fuel manifold supplying the unit injectors can result in poor performance, reduced power, poor starting characteristics, and misfire.

B **High Injector Coolant Temperature Alarm**
For use with heavy fuel.

B **Expansion Tank Level Alarm**
While coolant temperatures and pressures are important indicators of cooling system operation, an expansion tank level alarm can indicate loss of system coolant.

C **Low Starting Air Pressure Alarm**
Time saving feature to alert the operator of impending starting problems prior to attempting to start the engine.

C **Low Injector Coolant Pressure Alarm**
Lack of adequate injector tip cooling can result in injector problems when using heavy fuel.

C **Low Sea Water Pressure Alarm**
Can warn of impending problems with an engine mounted sea water pump.

C **Low Jacket Water Pressure Alarm**
Can warn of impending problems with an engine mounted jacket water pump.

C **Low AC/OC Water Pressure Alarm**
Can warn of impending problems with an engine mounted AC/OC water pump.

C **Low AC/OC Water Temperature Alarm**
Set the AC/OC water temperature alarm at 65°C (149°F) for distillate fuel engines and 38°C (100°F) for heavy fuel engines.

- **Differential Pressure Alarms**
  Oil and fuel filter condition should be monitored with differential pressure alarms to prevent low oil and fuel pressure delivery to the engine.
- **Exhaust Temperature Deviation Alarm**
  An individual injector failure may be detected with an exhaust port temperature deviation alarm.

Protection System Settings

The chart below lists required protection system settings. See the chart below for alarm function settings. The settings should be used for the protection and monitoring system, regardless of source (attachment, special order, or customer provided).

Function	Protection System Alarm System Settings		Shutdown	
	Metric	U.S.	Metric	U.S.
Engine Overspeed (% Rated)	—	—	113%	
Maximum Speed (Before Shutdown)	—	—	120%	
Jacket Water Temperature	103°C	217°F	109°C	228°F
Coolant Loss Detector	Non-adjustable Coolant Level Sensor			
Oil Temperature To Bearings and Cooling Jets	92°C	198°F	98°C	208°F
Oil Pressure 650-1000 rpm	320 kPa	46 psi	260 kPa	38 psi
Oil Pressure 0-650 rpm	120 kPa	17 psi	105 kPa	15 psi
Crankcase Pressure	–	–	101.6 mm H_20	4.0 in. H_20
Fuel Temperature	Fuel Viscosity Dependent			

Note: *Low sea water pump pressure, low JW pump pressure, and low aftercooler pump pressure alarms are normally connected to the 650 rpm speed switch contacts. Pump pressures below 650 rpm will not result in an alarm. The alarm contactor can therefore be set at 140 kPa to protect the engine at high speeds and loads without getting nuisance alarms at low engine speeds.*

Alarm Settings

The chart below lists alarm system settings. Fuel temperature and injector coolant temperature alarm settings are dependent on fuel viscosity and the fuel conditioning requirements to maintain the viscosity at the unit injector between 15 and 20 cSt.

Function	Alarm System Settings	
	Metric	U.S.
Exhaust Manifold Gas Temperature		
(Distillate Fuel)	630°C	1166°F
(Heavy Fuel)	550°C	1025°F
Low Water Level	Variable- dependent on expansion tank volume	
Low Oil Level (Vertical distance above oil suction inlet while operating)	50 mm	2 in.
Low Fuel Pressure	260 kPa	38 psi
Low Sea Water Pump Pressure	35 kPa +static head	5 psi +static head
Low Starting Air Pressure (Vane starter)	750 kPa	110 psi
Low Injector Coolant Pressure	35 kPa	5 psi
High Air Manifold Temperature		
(Diesel Fuel)	92°C	198°F
(Heavy Fuel)	72°C	162°F
High Injector Coolant Temperature	Fuel Viscosity Dependent	
Low Fuel Temperature	Fuel Viscosity Dependent	
High Fuel Temperature	Fuel Viscosity Dependent	

Note: *Low sea water pump pressure, low JW pump pressure, and low aftercooler pump pressure alarms are normally connected to the 650 rpm speed switch contacts. Pump pressures below 650 rpm will not result in an alarm. The alarm contactor can therefore be set at 140 kPa to protect the engine at high speeds and loads without getting nuisance alarms at low engine speeds.*

Alarm and Protection Probe Location	
Function	**Location**
Engine Overspeed	Flywheel Ring Gear
Jacket Water Temperature	Water Manifold Outlet
Oil Temperature to bearings	Oil Temperature Regulator Outlet
Oil Pressure to bearings 650-1000 rpm	Priority Valve
Oil Pressure to bearings 0-650 rpm	Priority Valve
Crankcase Pressure	Side Cover With Oil Filter Neck
Exhaust Manifold Gas Temperature	Exhaust Manifold
Low Water Level	Expansion Tank
Low Oil Level	Side Cover with Oil Filler Neck
Low Fuel Pressure	Fuel Filter Housing
Low Sea Water Pump Pressure	Sea Water Pump Outlet
Low Starting Air Pressure	Air Supply
Low Injector Coolant Pressure	Coolant Manifold
Low Jacket Water Pressure	Cylinder Block Inlet
High Air Manifold Temperature	Air Manifold
High Injector Coolant Temperature	Fuel Module Dependent
Low Fuel Temperature	Fuel Inlet to Engine
High Fuel Temperature	Fuel Inlet to Engine

Caterpillar Protection Systems

Caterpillar offers two types of engine protection systems, the Marine Monitoring System (MMS) and the standard relay based protection system.

Marine Monitoring System

The Caterpillar MMS is a microprocessor based engine control, protection and monitoring system designed specifically for marine applications. The control features of the system enable the operator to start and stop the engine locally from the MMS panel or remotely. The minimum protection features enable the system to shutdown the engine if overspeed, low oil pressure, crankcase pressure, or oil mist detector (if applicable) parameters exceed the set points. The monitoring features allow the operator to view current operating temperatures and pressures of various engine parameters. A 10" touch screen computer display screen displays the information, and shows when a parameter is in alarm condition.

The MMS utilizes all engine mounted sensors so there are no customer pressure connections or temperature capillary connections. All sensors are wired to an engine mounted terminal box. The entire system is enclosed in a single panel for ease of installation. The MMS can also communicate with other shipboard alarm systems via an industry standard data link connection. The system has been designed to meet ABS, Lloyd's and DNV unmanned engine room requirements. The MMS has some flexibility built in to allow customers to add additional monitoring and alarm parameters such as marine gear oil temperature and pressure, bilge level alarms, etc. See Figure 12 for one line drawing of the MMS system layout.

Standard Relay Based Protection System

Caterpillar also has a standard relay based protection system that uses separate panels for control, protection, and monitoring. A start/stop control panel provides these functions for the engine. A customer mounted junction box contains the relay protection logic and a separate contactor panel provides the required switches for alarm and shutdown parameters. Flexible hoses must be used to connect the pressure switches from the contactor panel to the engine and the temperature switch capillaries must also be connected to the engine. A separate relay based alarm annunciation panel is also available with this system.

Alarm Panel

Caterpillar recommends the following minimum features in alarm panels:

- Fault light lock-in circuitry keeps the fault light on when intermittent faults occur.
- Lockout of additional alarm lights prevents subsequent alarm lights from going on after the activated engine shutoff stops the engine. This aids in troubleshooting.
- Alarm silence allows the operator to acknowledge the alarm without the need to continually listen to the alarm horn. The alarm light is left on until the fault is corrected.
- If more than one engine is connected to an alarm panel, a fault in a second engine should activate the alarm even though the alarm horn may have been silenced after a fault on another engine.
- Circuit test provides for periodic checking of alarm panel functions.

Electrical Systems

Caterpillar Wiring Diagrams

The following are generic comments applicable to Caterpillar wiring diagrams:

- SR1 is used to activate the fuel shutoff for any fault reason. This relay can also be used to trip a circuit breaker.
- SR2 is used to activate the air shutoff due to an emergency or overspeed fault.
- The position of all switches are shown *at rest*.
- Crank termination (CT) comes on at 170 rpm and stays on for two seconds after the engine shuts down.
- The engine electrical system uses less than 1 amp during normal operation with no faults. About 40 milliamps are used when the engine is stopped. About 7 amps is used during an overspeed fault until the engine comes to a complete stop.
- The annunciator panel has its own power supply. Once a light is turned on it stays on (latched in) until the reset button is pressed.
- The water level low alarm switch (WLLA) and the oil level low alarm switch (OLLA) are shown in the no fluid condition.

Electrical Speed Switch

The Caterpillar *electrical engine speed switch* is located inside the MMS panel or junction box as applicable. The power supply to this switch can be 8-40 VDC, but is typically 24 VDC. It receives its speed input signal from a magnetic pickup which senses speed from the flywheel ring gear teeth. All contacts are single pole, double throw, “C” form. *The engine speed switch provides three functions:*

- **Overspeed:** Provides an adjustable overspeed setting. The overspeed recognition point is typically set at 113% of rated speed for engines rated at 720, 750, 900 and 1000 rpm. This gives a shutdown before 120% overspeed is reached. The switch trips using a latching contact on increasing speed. A manual reset button on the switch is used to clear the fault. The switch also has a 75% verify feature which provides an electrically simulated overspeed shutdown at 75% of the true overspeed setting (rpm).
- **Crank Termination:** Senses if engine is running. This contact becomes energized when engine speed reaches 170 rpm on increasing speed and stays energized for two seconds after the engine stops. It automatically disengages the starter and energizes the safeties after a 9 second delay on startup.
- **Oil Step:** Used to arm the high speed oil pressure alarm and shutdown contactors. It is preset to arm when engine speed reaches a preset function of rated engine speed. The unit has a 9 second delay on increasing speed and no time delay on decreasing speed. It allows time for pressure to develop to the alarm and shutdown contactors before checking for faults.
- **Miscellaneous:** *The air shutoff and governor fuel shutoff solenoids trip for overspeed or emergency shutdowns.* The air shutoff and speed switch must be manually reset for restarts. The air shutoff is connected as an energized to shutdown solenoid. Only the governor fuel shutoff solenoid trips in other shutoff modes. 24 VDC is standard for both the fuel and air shutoff solenoids.

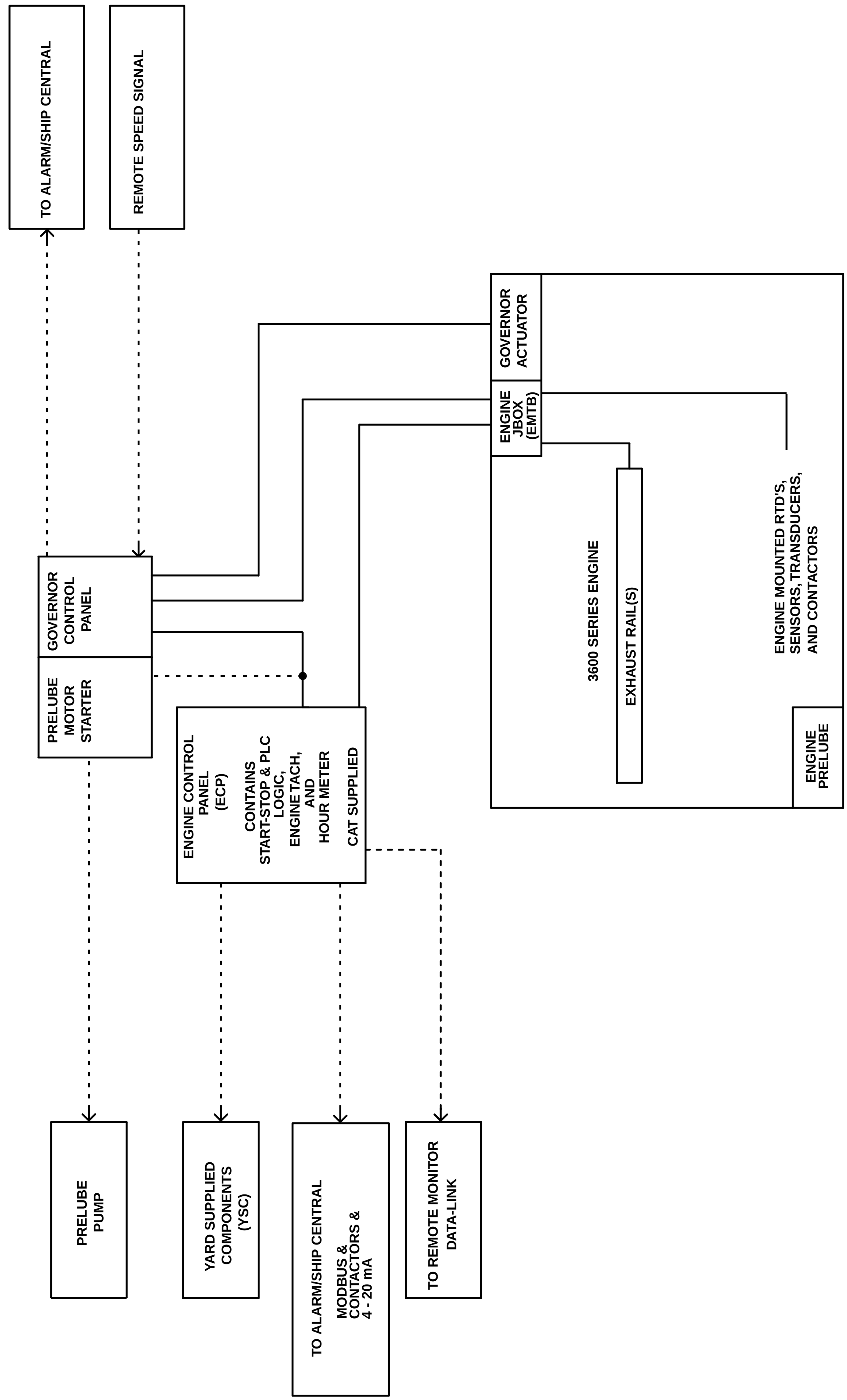

TO ALARM/SHIP CENTRAL
REMOTE SPEED SIGNAL
GOVERNOR CONTROL PANEL
PRELUBE MOTOR STARTER
ENGINE CONTROL PANEL (ECP)
CONTAINS START-STOP & PLC LOGIC, ENGINE TACH, AND HOUR METER
CAT SUPPLIED
GOVERNOR ACTUATOR
ENGINE JBOX (EMTB)
3600 SERIES ENGINE
EXHAUST RAIL(S)
ENGINE MOUNTED RTD'S, SENSORS, TRANSDUCERS, AND CONTACTORS
ENGINE PRELUBE
PRELUBE PUMP
YARD SUPPLIED COMPONENTS (YSC)
TO ALARM/SHIP CENTRAL
MODBUS & CONTACTORS & 4 - 20 mA
TO REMOTE MONITOR DATA-LINK

Figure 12

Commissioning

Recommended Instrumentation

Because of the need for precise sequencing of the control system, use an event logger during the commissioning of the propulsion system. The instrumentation points are:

Fixed Pitch

- Engine speed
- Shaft speed
- Shaft brake pneumatic signal
- Astern clutch pressure
- Engine pneumatic speed signal
- Ahead clutch pressure
- Engine fuel rack position
- Turbocharger boost pressure

Controllable Pitch

- Engine speed
- Shaft speed
- Engine pneumatic speed signal
- Propeller pitch position
- Engine fuel rack position
- Turbocharger boost pressure

3161 (LIO) Marine Governor Setup Recommendations

The seven areas of recommendations covered for the 3161 with air head control are:

A. Governor Installation and Engine Synchronization
B. Governor Angle Indicator Setting
C. Air Fuel Ratio Control Adjustment
D. Compensation Screw Adjustment
E. Idle Adjustment
F. Matching Ship's Controls
G. Clutch/Control adjustment

A. Governor Installation and Engine Synchronization Procedure

- Install governor with linkage to the rack control housing disconnected.

Note: *Use caution — the governor drive can fall inside the engine.*

- Rotate the allen head *rig pin* on the governor and move the governor output lever to fuel on. Hold the lever against the pin with a force of approximately 20 N•m (15 lb ft). The *governor* is now in the *sync* position (about 50% fuel).
- Install the engine *sync* bolt (without the washer) and rotate the racks in the fuel on direction. Hold the racks against the *sync* bolt with a force of approximately 20 N•m (15 lb ft). The *engine racks* are now in their *sync* position.
- Adjust the engine-to-governor rod until the bolts on the rack control housing and governor can be installed freely. Install the bolts, remove the tension from the governor and rack, remove the sync pin, and rotate the rig pin back to its normal position.

B. Governor Angle Indicator Setting

Note: *An angle indicator is available from Woodward to indicate engine rack travel.*

- With the engine off move the governor to full fuel (rack control touching the rack screw). Adjust the angle indicator to read a round number, approximately 30° for river boat engines.
- Return the governor to the fuel-off position and recheck governor angle. It should be approximately 0°.

The operator can use the angle indicator to get an approximate indication of fuel rack.

C. Air/Fuel Ratio Control Adjustment

- Start the engine and allow the governor oil to warm. A final adjustment may be required after the governor is at normal operating temperature. This can take up to 6 hours.
- From step B, note the angle position for idle and *dead* rack (fuel rack stop position) — typically 10° at idle and 30° at *dead* rack.
- Blip the throttle toward full fuel. Note where the air/fuel ratio control is holding the rack. Adjust the control to give about 50% (approximately 20°) of maximum fuel.

Note: *Speeds above approximately 450 rpm are not needed. Only a blip of the throttle is needed to find the air/fuel ratio control setting.*

Note: *Setting the air/fuel ratio control too much under 50% will cause the engine to accelerate slowly, particularly in flanking and crash maneuvers. Setting it to a higher (richer setting) will allow the engine to accelerate faster, but with pronounced smoke.*

D. Compensation Screw Adjustment

The LIO governor is isochronous above 450 rpm but has approximately 10% droop at idle (200 to 450 rpm). Therefore, the compensation screw can be turned out considerably when the engine is at 350 rpm, but can only be turned out about 1/2 turn above 450 rpm. More turns causes the engine to become unstable unless there is a load on the engine.

When the governor is warm and at idle, turn the compensation in until it softly seats. Then turn the screw out between 1/2 to one turn. More turns will increase engine response but the engine will surge if operated without load.

E. Idle Adjustment

- Move the governor speed handle from low idle to high idle. Check that both speeds are within specifications.

Note: *The low idle setting should be 350 rpm and the high idle setting is dependent upon the governor's droop setting. Both low and high idle settings are part of the engine's 2T specification and they are stamped on the engine nameplate. The following formula can be used to calculate the high idle speed based on the governor's droop setting:*

$$\text{rpm}_{\text{high idle}} = \text{rpm}_{\text{rated}} \left(1 + \frac{\%\ \text{Droop}}{100}\right)$$

- Make adjustments as necessary.

F. Matching Ships Controls

Note: *The governor operates with ship service air between 69 kPa (10 psi) at idle and 414 kPa (60 psi) at rated rpm.*

- Check the ship service air by plugging off the air clutches and moving the pilot house air controls from neutral to idle and then to full speed. Note the following pressures to the governor.

Neutral	0 kPa (0 psi)
Idle	69 kPa (10 psi)
Full speed	414 kPa (60 psi)

- After setting the ship controls to the 69-414 kPa (10-60 psi) signal, move the throttle lever to idle. Adjust the air head to obtain approximately 365 rpm and move the throttle to within 13 mm (1/2 in.) of full throttle. Rotate the bellows to get high idle rpm.
- Shut off the engine, reconnect the air lines to the clutches, and restart the engine. Move the throttle to idle and adjust the air head to 350 rpm with the prop turning. Some customers may want the idle rpm to be higher when the prop is engaged to prevent gear box noise. Adjustment on the air head can accommodate the customer's wishes. The in-gear rpm should not be below 350 rpm for engine oil pressure and engine response reasons.

Note: *Because of the high droop of the governor in the 200-450 rpm range, the load of the prop will affect the rpm of the engine. Water depth, rudder position, and water flow will affect the load on the engine and, therefore, will affect the rpm of the engine. This is a normal situation for the LIO governor.*

G. Clutch/Control Adjustment

Note: *Clutch fill occurs in three phases.*

- Initial filling of the cavities.
- Actual engagement and transfer of power from the engine to the gear.
- A hard clutch fill to maintain clutch engagement at higher rpm. The following recommendations reduce clutch abuse and provide acceptable engine response:

1. Clutch fill times/rates
   The first phase (initial fill) occurs between 0 kPa (0 psi) and 138 kPa (20 psi). This phase should occur as quickly as possible. The second phase (transfer of power) occurs between approximately 138 to 345 kPa (20 to 50 psi) and this should be set between 5 to 7 seconds. The third phase (hard fill and lock up) occurs at approximately 414 kPa (60 psi), and should occur as quickly as possible to fully hold the clutch in at the higher rpm.

2. Throttle boost
   Just before clutch engagement throttle boost should bring the engine to a speed acceptable to the marine gear manufacturer, typically 400 - 500 rpm. Excessive boost will cause the centrifugal forces of the clutch to hold the clutch away from the drum for a longer time. This causes the clutch to *grab* and either lock up too fast, thereby stalling the engine, or creating excessive heat in the clutch. The throttle boost should remain on until the clutch has fully engaged.

   If the boost is too low, reduced engine rpm, low engine oil pressure, and acceleration problems occur during normal vessel maneuvers. This can cause engine stalling and/or running in reverse during a crash reversal maneuver.

   Additional information of shaft brakes, proportional time delays, clutch *hold-in*, etc., is available from the air control manufacturer.

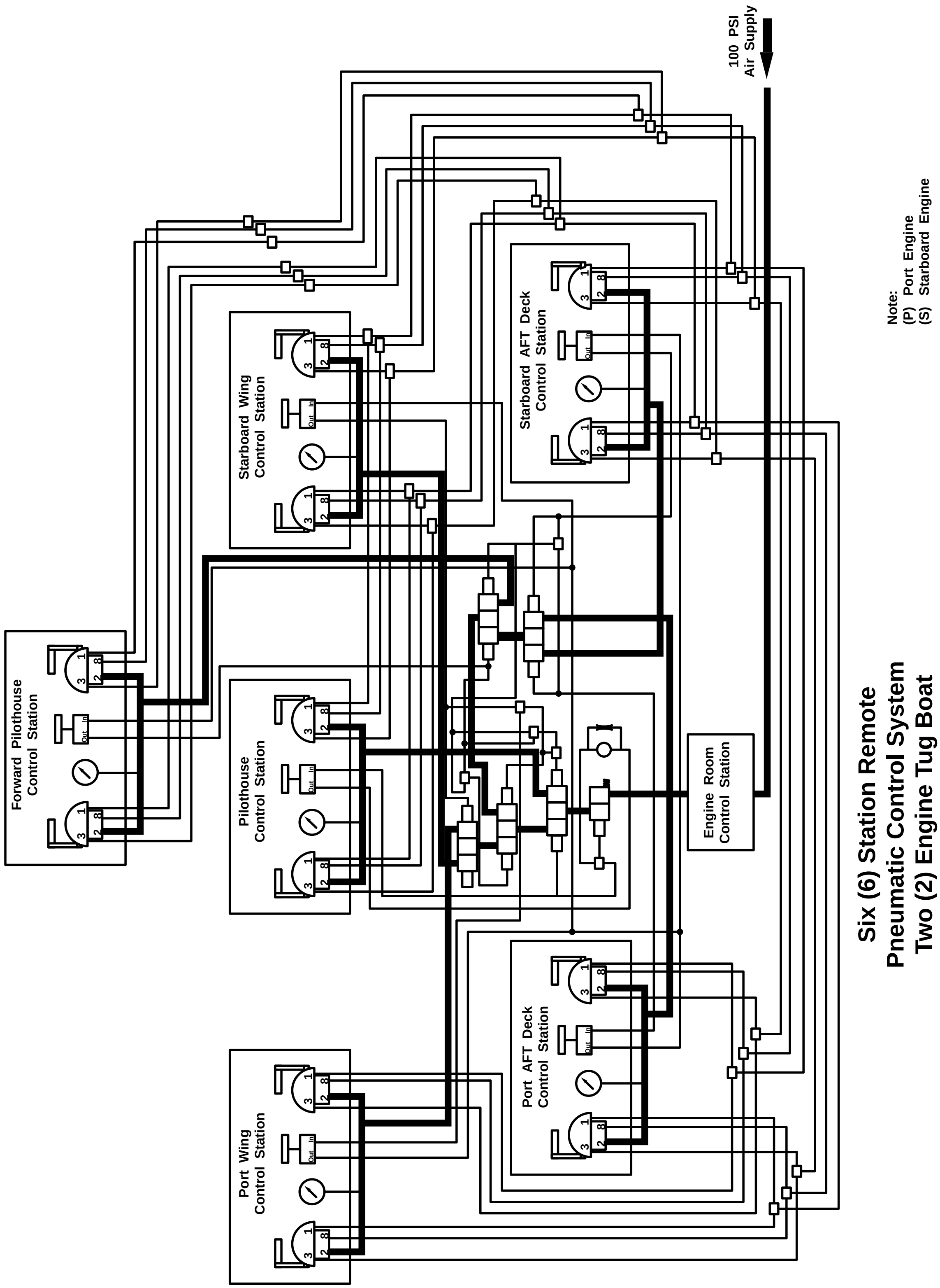
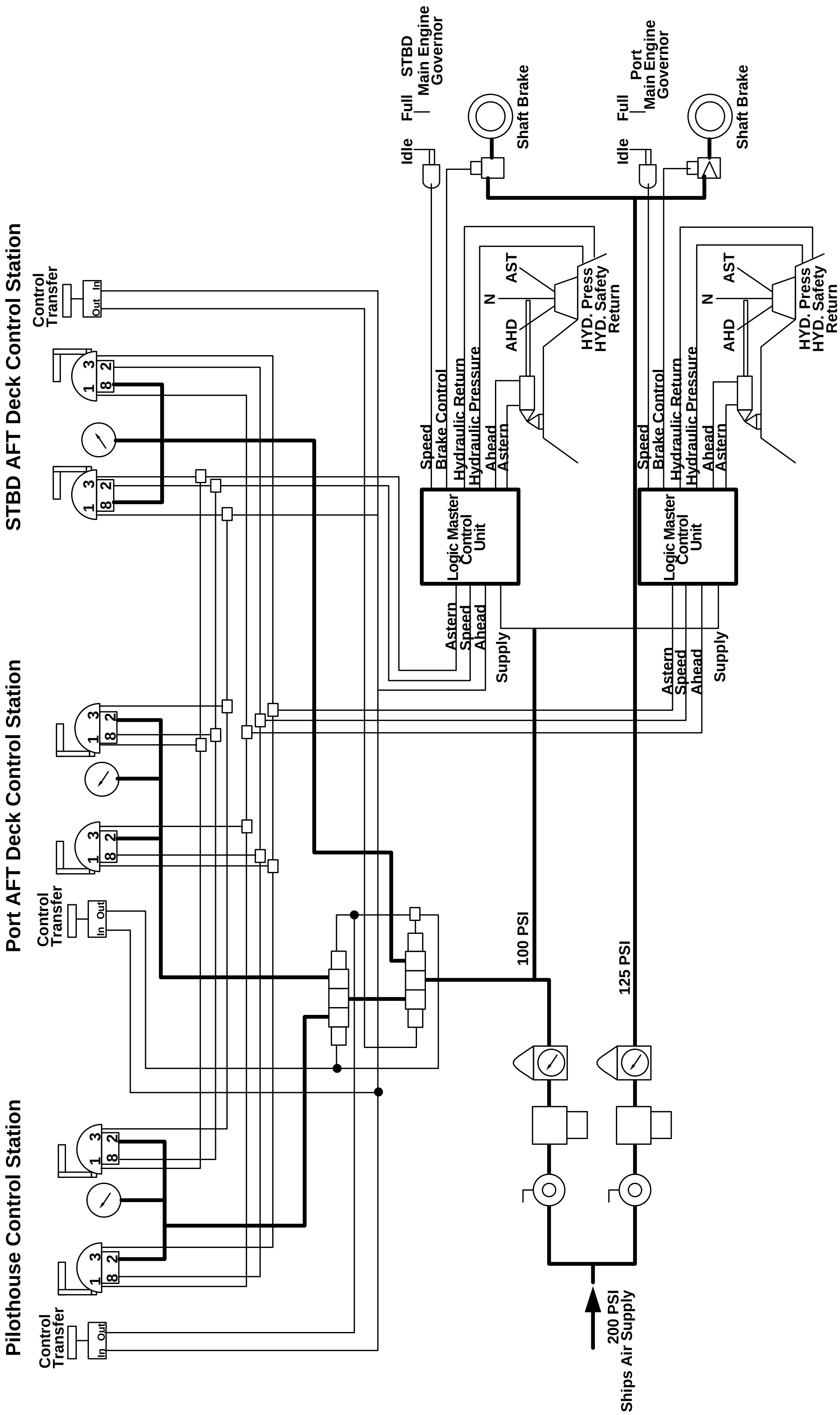
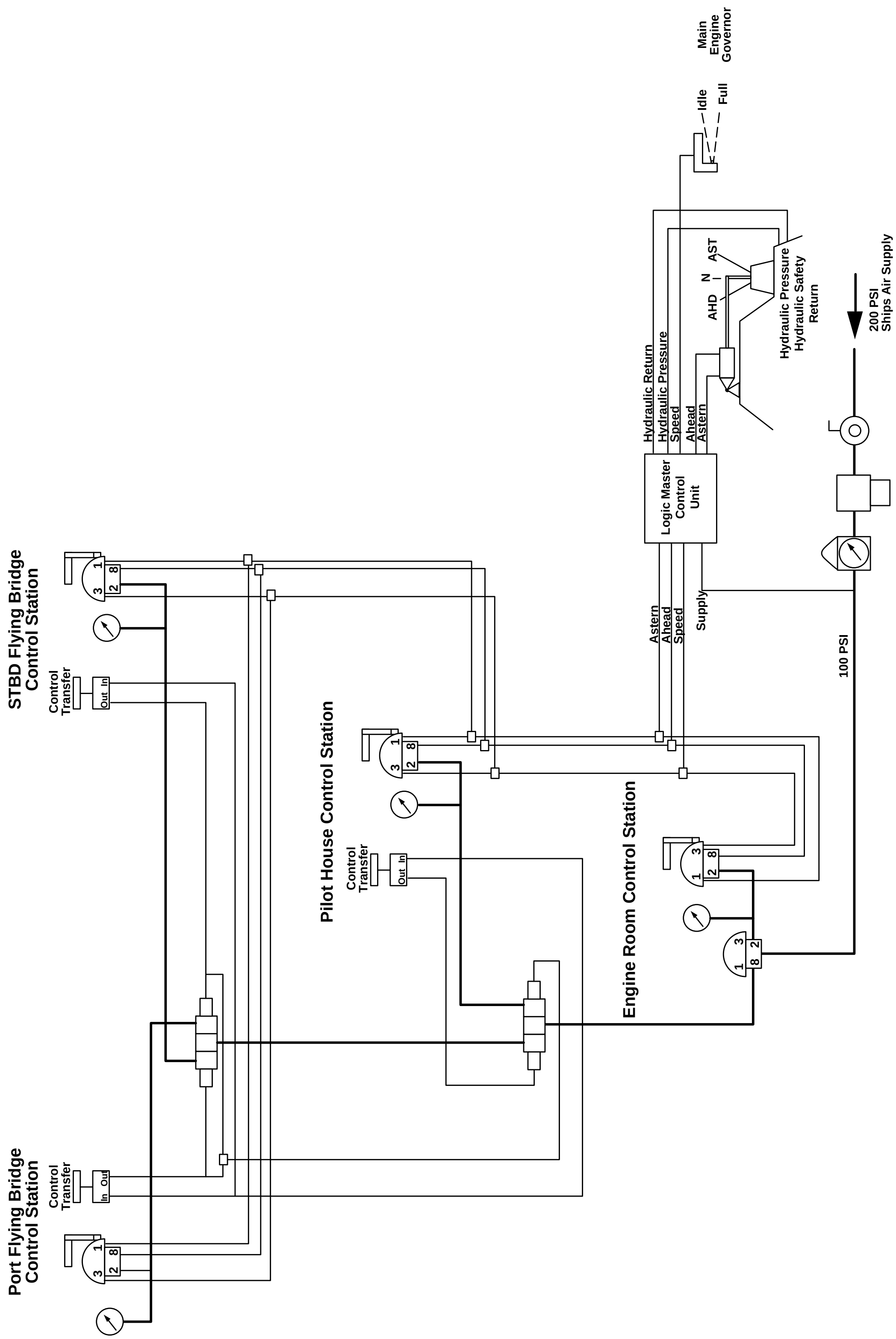

Six (6) Station Remote
Pneumatic Control System
Two (2) Engine Tug Boat
100 PSI
Air Supply
Note:
(P) Port Engine
(S) Starboard Engine
Forward Pilothouse
Control Station
Pilothouse
Control Station
Starboard Wing
Control Station
Starboard AFT Deck
Control Station
Port Wing
Control Station
Port AFT Deck
Control Station
Engine Room
Control Station

Figure 1



Three (3) Station Remote Pneumatic Control System Two (2) Engine Utility Vessel

Figure 2



Four (4) Station Remote
Pneumatic Control System
Single Main Engine Fishing Vessel

Figure 3

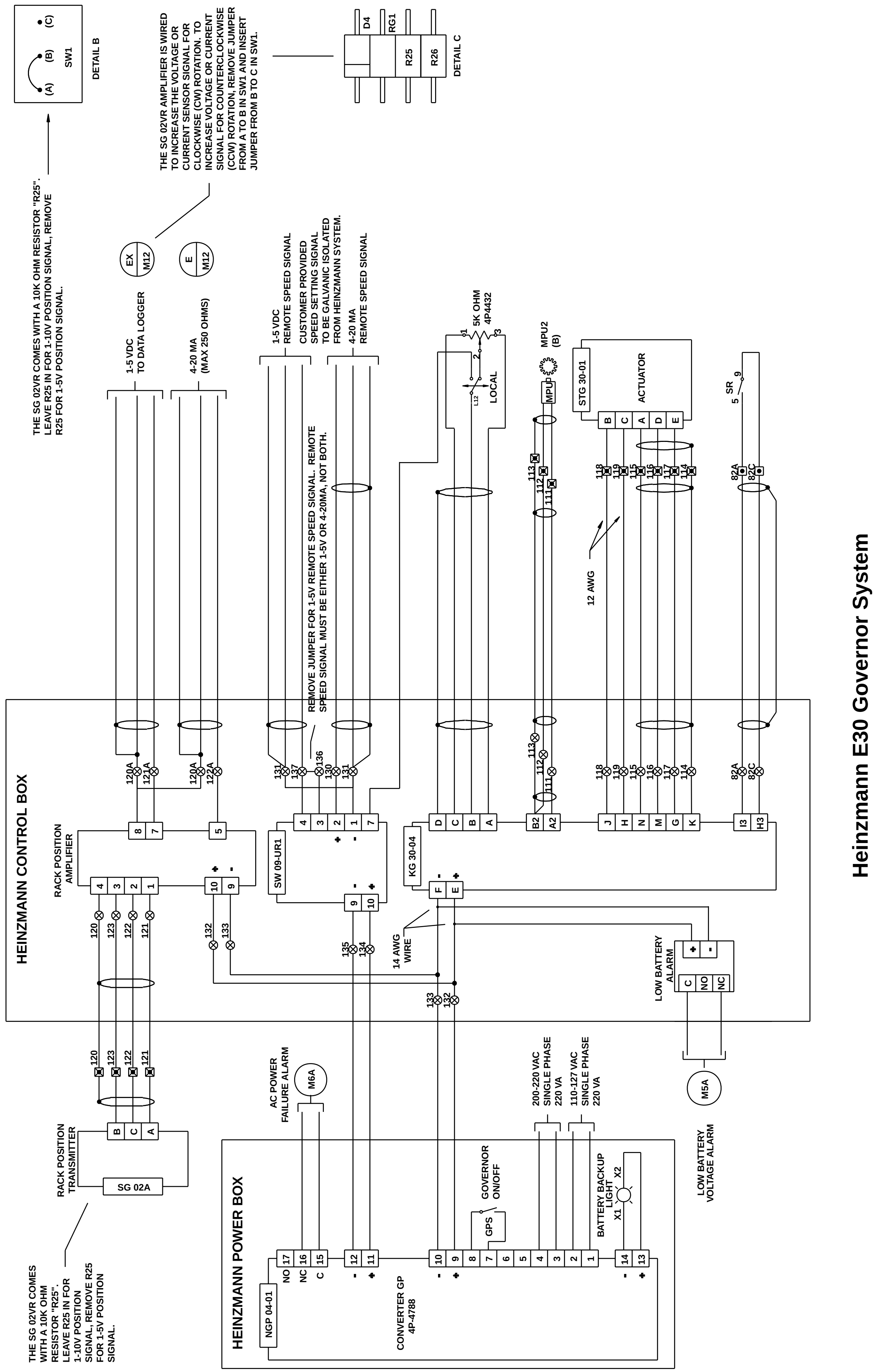

Heinzmann E30 Governor System
HEINZMANN CONTROL BOX
HEINZMANN POWER BOX
RACK POSITION AMPLIFIER
RACK POSITION TRANSMITTER
SG 02A
SW 09-UR1
KG 30-04
NGP 04-01
CONVERTER GP 4P-4788
LOW BATTERY ALARM
LOW BATTERY VOLTAGE ALARM
AC POWER FAILURE ALARM
M6A
M5A
GOVERNOR ON/OFF
GPS
BATTERY BACKUP LIGHT
200-220 VAC SINGLE PHASE 220 VA
110-127 VAC SINGLE PHASE 220 VA
14 AWG WIRE
12 AWG
ACTUATOR
STG 30-01
MPU2 (B)
MPU
LOCAL
5K OHM 4P4432
SR
1-5 VDC TO DATA LOGGER
4-20 MA (MAX 250 OHMS)
1-5 VDC REMOTE SPEED SIGNAL
CUSTOMER PROVIDED SPEED SETTING SIGNAL TO BE GALVANIC ISOLATED FROM HEINZMANN SYSTEM.
4-20 MA REMOTE SPEED SIGNAL
REMOVE JUMPER FOR 1-5V REMOTE SPEED SIGNAL. REMOTE SPEED SIGNAL MUST BE EITHER 1-5V OR 4-20MA, NOT BOTH.
EX M12
E M12
THE SG 02VR COMES WITH A 10K OHM RESISTOR "R25". LEAVE R25 IN FOR 1-10V POSITION SIGNAL, REMOVE R25 FOR 1-5V POSITION SIGNAL.
THE SG 02VR AMPLIFIER IS WIRED TO INCREASE THE VOLTAGE OR CURRENT SENSOR SIGNAL FOR CLOCKWISE (CW) ROTATION. TO INCREASE VOLTAGE OR CURRENT SIGNAL FOR COUNTERCLOCKWISE (CCW) ROTATION, REMOVE JUMPER FROM A TO B IN SW1 AND INSERT JUMPER FROM B TO C IN SW1.
DETAIL B
SW1
DETAIL C
D4
RG1
R25
R26
THE SG 02VR COMES WITH A 10K OHM RESISTOR "R25". LEAVE R25 IN FOR 1-10V POSITION SIGNAL, REMOVE R25 FOR 1-5V POSITION SIGNAL.

Figure 10

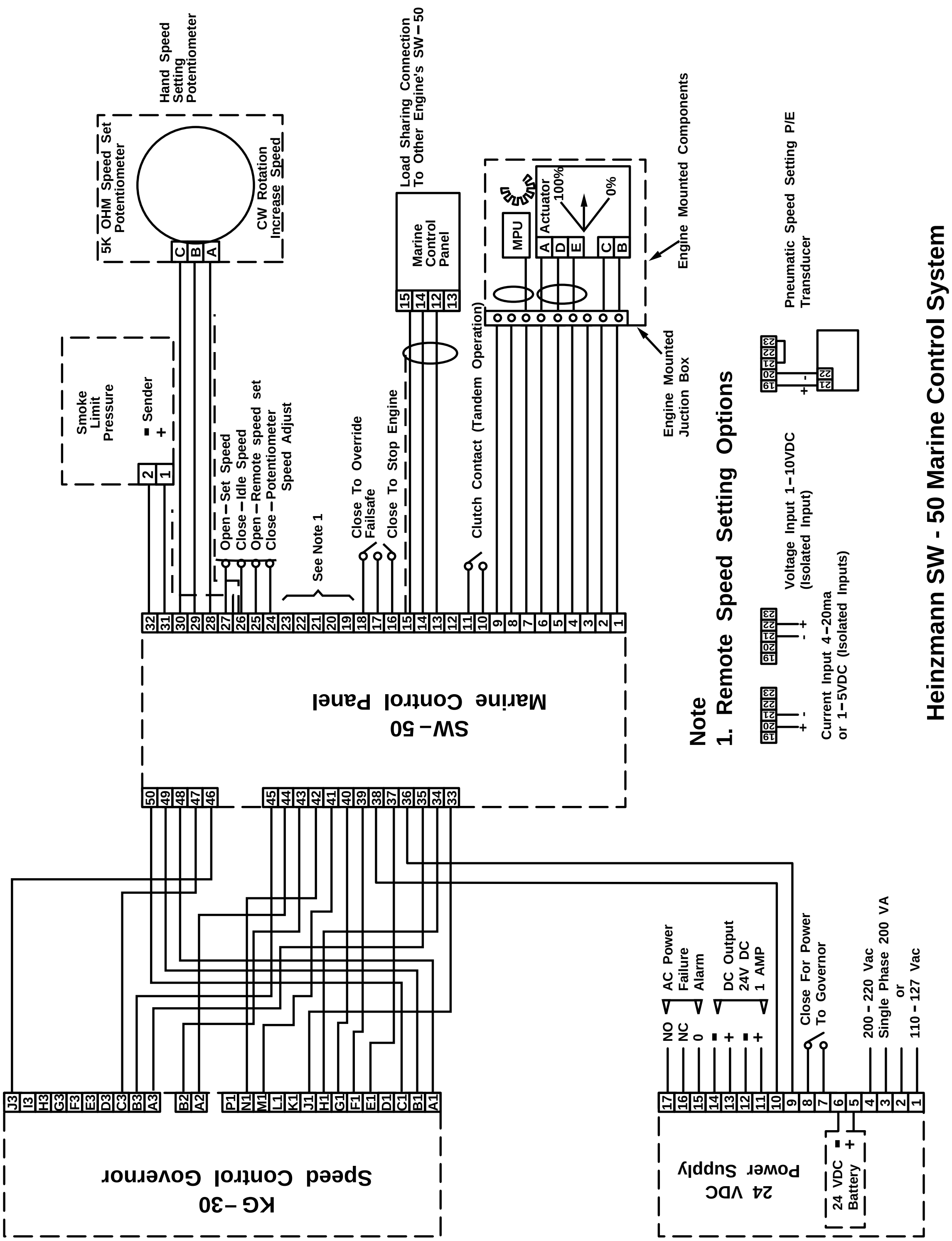

Heinzmann SW - 50 Marine Control System
Hand Speed Setting Potentiometer
5K OHM Speed Set Potentiometer
CW Rotation Increase Speed
Smoke Limit Pressure
Sender
Open – Set Speed
Close – Idle Speed
Open – Remote speed set
Close – Potentiometer
Speed Adjust
See Note 1
Close To Override Failsafe
Close To Stop Engine
Clutch Contact (Tandem Operation)
Load Sharing Connection To Other Engine's SW – 50
Marine Control Panel
Engine Mounted Components
MPU
Actuator
100%
0%
Engine Mounted Juction Box
SW – 50
Marine Control Panel
Note
1. Remote Speed Setting Options
Current Input 4 – 20ma or 1 – 5VDC (Isolated Inputs)
Voltage Input 1 – 10VDC (Isolated Input)
Pneumatic Speed Setting P/E Transducer
KG – 30
Speed Control Governor
24 VDC
Power Supply
24 VDC Battery
AC Power Failure Alarm
DC Output 24V DC 1 AMP
Close For Power To Governor
200 - 220 Vac Single Phase 200 VA
or
110 - 127 Vac

Figure 11

Materials and specifications are subject to change without notice.

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