APPLICATION AND INSTALLATION GUIDE

GOVERNORS – GAS & DIESEL

CATERPILLAR®

Contents

Foreword

This section of the Application and Installation Guide generally describes Governors for Caterpillar® gas and diesel engines listed on the cover of this section. Additional engine systems, components and dynamics are addressed in other sections of this Application and Installation Guide.

Engine-specific information and data is available from a variety of sources. Refer to the Introduction section of this guide for additional references.

Systems and components described in this guide may not be available or applicable for every engine.

Governors – Gas & Diesel

While many Caterpillar engines utilize advanced electronic control systems, with integrated engine speed governing capabilities, there are many Caterpillar engines, both gas and diesel, that require the use of separate engine speed governing systems. This section of the Application and Installation Guide discusses governor basics, various governor types and governor features.

Engine speed governing systems associated with the advanced electronic control systems are addressed in the Diesel Engine Control Systems and Gas Engine Control and Ignition Systems sections of the Application & Installation Guide.

SECTION CONTENTS

Governor Basics

The engine governor in its simplest form controls engine speed. To select the correct governor for a particular application, governor capabilities must be understood. The following terms are commonly encountered when describing governors.

Droop

Droop describes the relationship of engine speed change from no load (high idle) to full load (rated) in steady state operation. It is the rpm loss experienced when a load is applied to an engine operating at a fixed throttle position.

Expressed as a percentage, droop is calculated as follows.

$$\% \text{ Droop} = \frac{(\text{No-load speed} - \text{Full-load speed}) \times 100}{\text{Full-load speed}}$$

Figure 1 and **Figure 2** describe various degrees of droop for both generator and industrial applications.

The percent droop remains constant and independent of operator speed change. Percent droop will not change if the operator moves the throttle position because the change affects the full load speed. Although the full-load rpm will change, the relationship (% droop) between full-load and no-load will not change.

Many applications can easily accept some speed droop. This allows the use of a less costly and less complex governor and still allows, in generator sets, the capability of paralleling with other units.

Generator Applications

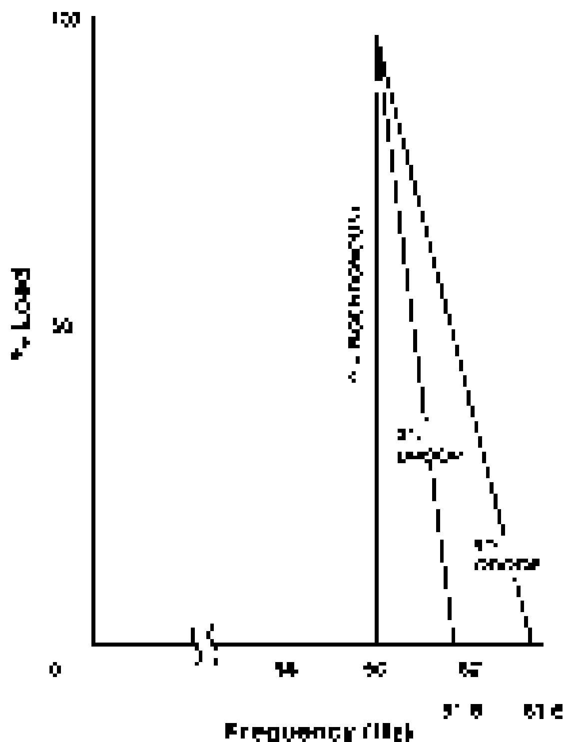

Figure 1

Industrial Applications

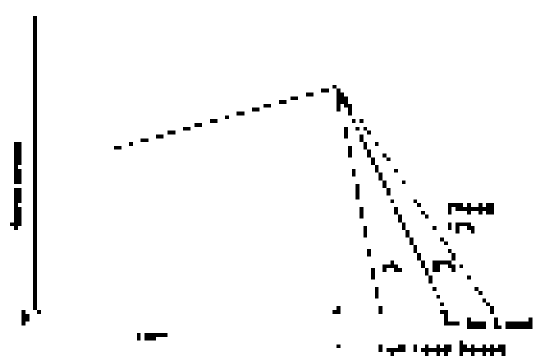

Figure 2

Isochronous

Isochronous is a term that describes 0% droop; the engine rpm remains constant as load is applied from no load to full load. This capability is often required on generator sets with certain loads demanding precise frequency control such as communications equipment, computers, movie lighting and clocks. Isochronous speed capability is also required for automatic paralleling.

Compensation

Compensation is a governor feedback adjustment feature that allows the governor to be tuned to the application. Compensation increases engine stability. This feature may be hydraulic or electrical and increases the cost of the governor.

Speed Band

Speed Band is a tolerance on speed at any steady load. Refer to **Figure 3**.

For example, the Woodward 3161 governor has a speed tolerance of ±0.33% while the Woodward 2301A and Heinzmann electronic governors offer ±0.25%.

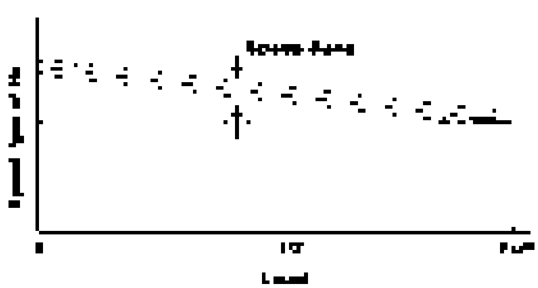

Figure 3

Transient Response

Transient Response is characterized by a speed dip or rise; it is the time interval required for the engine speed to recover from a sudden load change.

Dip is the maximum momentary decrease in speed (frequency) upon sudden load increase.

Overshoot is the maximum momentary increase in speed (frequency) upon sudden load removal.

Figure 4 shows an example of how an engine reacts to sudden load changes. The illustration labels overshoot at load application, but not at load removal.

Governors are only one factor affecting transient response. The size of the engine load, engine configuration, type of generator, voltage regulator and rotating inertia of engine & generator are significant influences on an engine's recovery capabilities.

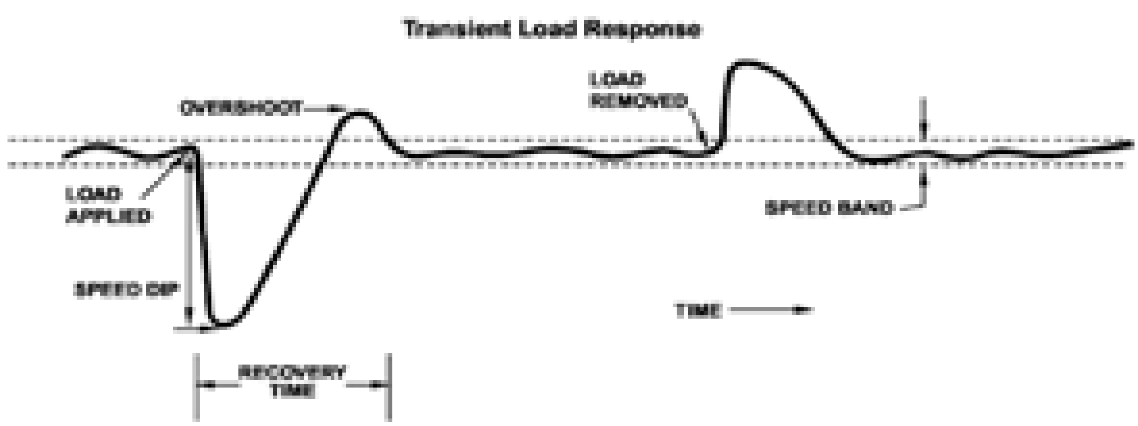

Figure 4

Types of Governors

Application requirements for governors can range from simple to complex. Just as there are a wide variety of applications, Caterpillar offers a wide variety of governors to meet customer needs.

Hydra-mechanical Governor

The Caterpillar hydra-mechanical governors sense engine speed mechanically, and use the engine's oil pressure to hydraulically move the actuator. This governor has a fixed droop, generally 2-15%. Caterpillar hydra-mechanical governors are available for both gas and diesel engine applications.

Vernier and Positive Lock Governor Control

Vernier and Positive Lock Governor Control is a mechanical device used with the hydra-mechanical governor to manually adjust the engine rated speed set point.

Governor Control Motor

The Governor Control Motor is an optional 24 VDC motor, available for use with the hydra-mechanical governor, which replaces the Vernier and Positive Lock Governor Control and allows for engine speed control from a remote location through a governor raise/lower toggle switch. This governor control switch is used with the optional EMCP II.

Woodward PSG Governor

The PSG, shown in **Figure 5**, is a hydra-mechanical speed control governor used for controlling speed and load sharing. The PSG governor can be used in the droop mode or in isochronous operation, depending on the application. The industrial engines come standard with a positive locking manual speed control. The generator sets come standard with a 24 VDC motor that can provide remote speed adjustment. Even though the PSG has its own oil pump, it uses oil from the engine and must use straight weight oil for proper governor operation.

Figure 5

Woodward 3161 Governor

The 3161, shown in **Figure 6**, is a hydra-mechanical governor capable of isochronous operation. In addition to isochronous operation, the 3161 can be externally adjusted for 0% (isochronous) to 8% droop. The 3161 comes with either manual, pneumatic (3-15 psi), or electric (24 VDC) remote speed control. A compensation needle valve is provided that allows adjustment of stability and response.

Figure 6

Caterpillar Programmable Electronic Engine Control (PEEC)

The Caterpillar Programmable Electronic Engine Control (PEEC) utilizes an Electronic Control Module (ECM) that drives a Brushless Torque Motor (BTM). This system controls the rack position and drives a fuel shutoff valve for absolute control of fuel to the engine. Desired engine speed and droop are received by the ECM through Pulse Width Modulated (PWM) inputs and are held within tolerances for isochronous and droop mode. The proper amount of fuel is delivered through the fuel system based on these calculations. For isochronous load sharing, an additional (optional) module is available. Communication from PEEC to the EMCP is via a PWM converter.

Woodward Flo-Tech 68 Governing System

The combination of the Flo-Tech speed control and the Flo-Tech 68 actuator with integral throttle, shown in **Figure 7**, offers improved stability and response over the former actuator and control. Flo-Tech offers flow-shaping which optimizes the flow of the fuel mixture into the cylinders. This enhancement addresses the flow variability of the standard throttle body.

The Flo-Tech 68 governing system is designed to provide basic isochronous speed control for gas engines. Engines with mechanical loads and generator loads are handled equally well. This governing system is standard on all G3406 engines used for electric power generation.

Figure 7

Woodward 8290/524 and 8290/1724 Governors

The Woodward 8290/524 and 8290/1724, shown in **Figure 8**, are completely electronic add-on governing systems. The 8290 identifies the control module. The 524 and 1724 identify the electric actuator assembly. The 8290 is an isochronous electronic control. In order to provide load share capability, an add-on load share module is offered as an attachment.

Figure 8

Woodward 2301A Speed Control Governor

The 2301A Speed Control Governor is an electric isochronous governor with droop adjustment. It is used to control EG3P gas and diesel engines or EG6PC diesel engines and an engine-driven hydraulic actuator. The hydraulic actuator is operated by straight weight engine oil.

An EG3P gas engine actuator is shown in **Figure 9**. The 2301A Speed Control Governor is used mainly for stand alone applications. If operated parallel to a utility, the governor can only control in droop mode. In the isochronous mode, it cannot load share with another unit or the utility without a Woodward load share module.

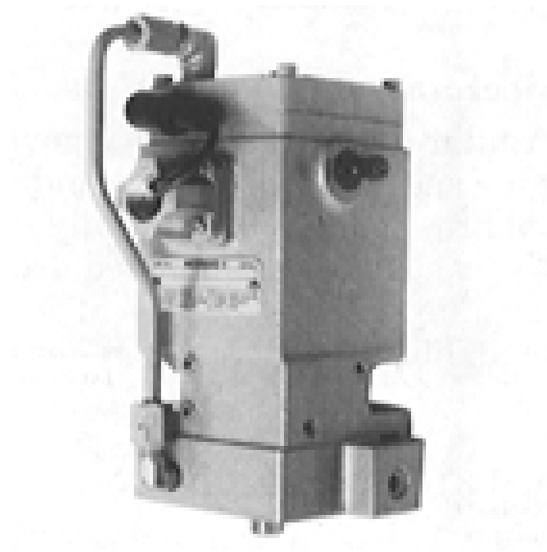

Figure 9

Woodward 2301A Load Sharing Governor

The 2301A Load Sharing governor, shown in **Figure 10**, is a 2301A Speed Control with a built-in load share module. It also uses the EG3P actuator for gas engine applications, but has several available options for diesel engine applications.

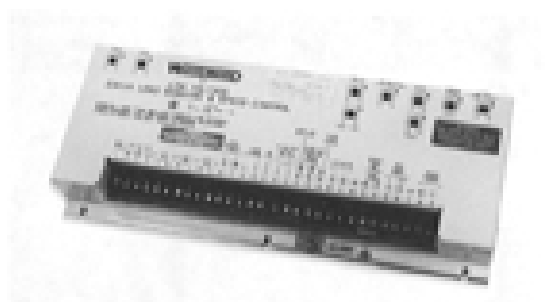

Figure 10

A UG hydra-electric actuator is standard supply for diesel engines, but EGB-29P and EGB-13P actuators are available options. The EGB actuators include shut-off solenoids and mechanical ballhead backups, in forward or reverse acting configurations. The ballhead backup allows for engine control when the electrical governor control signal is lost at the actuator; when in ballhead back-up mode, the governor is less responsive to load changes. The forward and reverse acting configurations are described below.

Forward Acting

When the control signal is lost at the actuator, the EGB actuator goes to the fuel shut-off position. A pneumatic start assist puts the actuator under ballhead control when supplied with 690 to 1655 kPa (100 to 240 psi) control air.

Reverse Acting

When the control signal is lost at the actuator, the engine speed increases to approximately 25 rpm above rated, no-load speed and the ballhead mode switch closes electrical contacts when the ballhead back-up is controlling the engine.

CAUTION: Setting the ballhead speed affects the amount of load the engine carries during ballhead operation.

Energized-To-Shutdown (ETS) and Energized-To-Run (ETR) fuel shut-off systems, in conjunction with forward and reverse acting actuator options, allow a wide variety of shut down actions to occur in the event of various signal losses.

When an ETS system loses control voltage, the governor shutoff solenoid will allow the engine to continue to run under the control of the 2301A. The emergency-stop button must be used to shut the engine down. A reverse acting and a direct acting actuator will behave the same with an ETS system.

Use of the ETR system introduces the possibility of a brownout or blackout; this is not present using the ETS system.

Table 1 and **Table 2** show a summary of actions resulting from different signal losses while the engine is running. Also listed, are cases where the engine cannot be started without further action or options.

Reverse Acting		
Loss of:	**Results In:**	
	ETS	**ETR**
Solenoid voltage (at solenoid)	No shutoff (a)	Shutdown (b)
Control voltage (to 2301A)	Ballhead	Ballhead
Actuator signal (from 2301A)	Ballhead	Ballhead
Speed signal from magnetic pickup	Shutdown	Shutdown

(a) Must use air shutoff to shutdown engine.

(b) Cannot start engine until problem is corrected.

Table 1

If it is desired to go to the ballhead backup governor upon loss of speed pickup signal, the following steps must be performed before starting the engine.

- Turn the start fuel limit potentiometer fully clockwise (CW).
- Put a jumper wire across the failsafe override terminals
  - Terminals 16 and 18 on 24 VDC, model 4P1570.
  - Terminals 0 and 18 on high voltage, model 4P1561.

If the fail-safe override is not in place, the actuator will go to minimum fuel (shutoff) with loss of speed pickup signal.

If the failsafe override is wired correctly, but the start fuel limit is in effect (potentiometer not fully clockwise), the actuator will go to the start fuel limit position upon loss of speed pickup signal.

Forward Acting

Loss of:	**Results In:**	
	ETS	**ETR**
Solenoid voltage (at solenoid)	No shutoff (a)	Shutdown (b)
Control voltage (to 2301A)	Shutdown (c)	Shutdown (c)
Actuator signal (from 2301A)	Shutdown (c)	Shutdown (c)
Speed signal from magnetic pickup	Shutdown (b)	Shutdown (b)

(a) Must use air shutoff to shutdown engine.

(b) Cannot start engine until problem is corrected.

(c) Cannot start engine without pneumatic or manual ballhead changeover option.

Table 2

When an application requires load sharing between paralleled AC generators or the utility, the 2301A Load Sharing Governor is more economical than the 2301A combination with a load control module. This governor is isochronous (with droop adjustment) and is specifically designed to provide automatic and proportional load division between paralleled AC generators and still maintain isochronous speed. This governor is satisfactory for single and multiple-unit power applications, or when used individually in the standby mode.

Woodward 701A and 723PLUS Digital Speed Control

The 701A and 723PLUS governors, shown in **Figure 11**, are microprocessor controlled with programmable memory to vary governor dynamics. These governors have provisions for multiple gain settings which allow optimizing of the governor adjustments and engine performance for the various modes of operation. An increasing number of units are being installed in complex power projects where the governor must be integrated with process controllers that combine operation with auto parallel devices, auto loading devices, and export/import controllers. For satisfactory performance, different governor gains are required for each mode of operation. For those installations requiring multiple governor gains, Caterpillar recommends the Woodward 701A or 723PLUS digital governor. The 701A and 723PLUS governors have speed control functions only. Load share ability is provided by an additional module. The 701A and 723PLUS governor load share module is the same add-on module as for the 8290/1724. The 701A governor also uses the EG3P hydraulic actuator and requires straight weight oil. The 723PLUS governor uses the UG hydra-electric, EGB-29P or EGB-13P actuators as previously described.

Figure 11

When the following two conditions occur concurrently, the Woodward 701A or 723PLUS governor is recommended for use in place of the 2301A:

- When installation involves an automatic paralleling device.
- When the unit is paralleled to a utility grid even briefly during load transfer.

Woodward ProAct

The ProAct governor, shown in **Figure 12**, is a digital control system with an electrically powered governor actuator. The actuator in **Figure 13** is directly coupled to the engine throttle and it provides 75 degrees of rotation. The control has two complete sets of dynamic adjustments to aid when operating with such conditions as two different fuels, or in parallel/stand-alone electrical generation. A four-point gain schedule is available in each set of dynamics. The control can operate in isochronous or droop.

Figure 12

Figure 13

Heinzmann E30 Electronic Governor

The Heinzmann E30 provides engine speed governing with high and low idle adjustment and a remote speed setting potentiometer. Speed droop is adjustable between isochronous and 8%. The governor system includes an electrically driven actuator, engine-mounted at right rear, with an engine-mounted speed pickup. The controller is shipped loose for remote mounting and includes all electrical connectors required for wiring.

The governor operates on 20-35 VDC @ 8 amps. A shipped-loose power supply can be provided for certain governor system selections. This supply converts 110/115 VAC or 220/230 VAC, 50/60 Hz single phase into 24 VDC. It can also be used with 190/230/380/460 VAC 3 phase.

The actuator does not have ballhead backup capability. Battery backup can be provided as an optional attachment.

Additional control functions including load share interfacing with Woodward governors, ramp loading, and torque limiting are available as a special order.

Generator Set Stability and Response

The transient response and steady-state stability of generator set engines can vary with a number of the following factors.

- Engine model
- Engine speed
- Aspiration
- Power factor
- Governor
- Gas pressure
- Presence of an idle circuit

Diesel engines have a short mechanical path between the governor actuator and the fuel delivery system to the combustion chamber. This results in a very responsive system that responds quickly to load change requests from the governor.

On gas engines, the governor controls a throttle plate that adjusts the intake manifold pressure to control power. The intake manifold pressure will determine the amount of air-fuel mixture in the combustion chamber, hence the engine power. The physical volume of the intake manifold and the flow dynamics of the air/fuel mixture add time constants into the governor control system. The result is a less responsive system than the diesel.

ISO 8528, Class 1 and 2 are international standards for generator set response criteria. ISO has recognized the response differences between diesel and gas engines and has two different sets of performance requirements. ISO requirements for gas engines are not as stringent as they are for diesel engines. The frequency deviation and recovery times for gas engines are approximately double that of diesel. The two different ISO classes refer to the performance level or specifications. Class 2 has more demanding performance specifications than Class 1. **Table 3** and **Table 4** reflect the current ISO standards for Class 1 and Class 2 engines as they apply to Caterpillar gas engines.

Transient Response		
	Class 1	Class 2
Frequency Recovery Time	10 sec	5 sec
Frequency Deviation		
Stepped Load Increase	-25%	-20%
100% Load Decrease	+18%	+12%
Tolerance for Recovery	±1.75%	±1.0%
Voltage Recovery Time	10 sec	6 sec
Voltage Deviation		
Stepped Load Decrease	+35%	+25%

This criteria is based on adding load in two steps:
Step 1: 800 kPa (116 psi) bmep or approximately 64% of rated load on most TA engines.
Step 2: Remainder of load.
Full load pickup for engines rated above 800 kPa (116 psi) bmep, is not a requirement under the ISO classification. For dropping a load, 100% is used.
Note: Above 116 psi (800 kPa), the ISO guideline is actually a sliding scale. Only at a 180 psi (1240 kPa) rating is the recommended first load step 64%. Then, for example, as the rating increases above 196 psi (1350 kPa) the first step is only 60% and a third load step is recommended to achieve 100% loading.

Table 3

Steady-State Stability		
	Class 1	Class 2
Frequency	± 1.25%	± 0.75%
Voltage	±5.0%	±2.5%

The generator set stability required for auto-paralleling is ±0.25%. (Note: this is a Caterpillar requirement, not an ISO requirement.)

Table 4

Governor Selection

Table 5 and **Table 6** summarize the various governor configurations offered in the price list.

Governor Availability and Recommended Usage	Hydra-mechanical	3161 Positive Lock	3161 Pneumatic	3161 24 VDC Motor	PSG Positive Lock	PSG 24 VDC Motor	8290 / 524	8290 / 1724	2301	2301A Speed Control	2301A Load Sharing	701A	723Plus	Flo-Tech 68 Governing System	Heinzmann E30	Caterpillar PEEC
G3500 Ind			S	A	A					A						
G3500 Gen*										S	A	A				
G3412 Ind					S	A				A						
G3412 Gen						A			A	S	A					
G3408 Ind					S	A				A						
G3408 Gen						A			A	S	A					
G3406 Ind					S	A								A		
G3406 Gen														S		
G3306 Ind	S					A										
G3306 Gen						S										
G3304 Ind	S															
3600 MUI											A		A		A	
3500 MUI										S	A					
3400 MUI	S				A	A		A		A	A					A
3300 MUI	S							A								

S = Standard Equipment

A = Attachment, Obtained Separately

* Some models offering Woodward ProAct as standard. Consult price list for details.

Table 5

Governor Features	Hydra-mechanical	3161 Positive Lock	3161 Pneumatic	3161 24V DC Motor	PSG Positive Lock	PSG 24V DC Motor	8290 / 524	8290 / 1724	2301A Speed Control	2301A Load Sharing	701A	723Plus	Flo-Tech 68 Governing System	Heinzmann E30	Caterpillar PEEC
Speed Droop	X	X	X	X	X	X	X		X	X	X				X
Isochronous				X		X	X		X	X	X		X		X
Load Sharing At Isochronous Speed							X*		X*	X	X*		X**		X
Rheostat Speed Adjustment							X		X	X	X		X		
Electric Motor Speed Adjustment				X		X									
Pneumatic Speed Adjustment			X												
Manual Speed Adjustment	X	X			X										
Adjustable Feedback Comp.		X	X	X	X	X	X		X	X	X				
Dual Dynamics											X		X		
Manual Paralleling				X		X	X		X	X	X		X**		
Automatic Paralleling							X*		X*	X	X*		X**		
High Idle Low Idle Contact									X	X	X		X		X

* Load sharing is provided by an optional load share module.
** Additional accessories required.

Table 6

Wiring Methods and Considerations

Control devices are especially sensitive to wiring methods and practices. Proper wiring, grounding and shielding can greatly reduce improper governor operation and avoid equipment damage.

Wire Size and Shielding

Wire Size

It is imperative to size the wire according to the maximum amperage the wire will carry. Improper sizing can result in excessive voltage drop of the signal or supply and heat dissipation in the wire. Wire size needs to be considered from battery or power supply to low voltage signal wiring. Refer to the NFPA, National Electric Code or similar for wire sizing tables.

Shielding

Generally, use shielded wire for magnetic pickups as well as wiring for the electronic governor actuator. The shield should be grounded on one end only to prevent current flow from creating a potential noise source in the shield. Shield breakouts should not exceed 51 mm (2 in) in length.

Wire Insulation

Consideration of wire insulation will allow proper usage to protect the current conductors from environmental conditions and abrasion. It will also contribute to the ampacity of the wire. Ampacity is a measured amount of amperage a conductor can carry without exceeding its temperature limits.

Connectors

It is imperative that connectors be applied that are acceptable to the specific application. Sealing and vibration capabilities need to be considered for reliability. A minimum sealing capability of 35 kPa (5 psi) and vibration capability of 30 G's rms (100 to 2000 Hz) should be considered in engine applications.

Moisture ingression, of the connector, will allow the formation of corrosion and create a conductive path between conductors. Excessive vibration will allow the wearing away of the metal at the contact points of the connector, also called pin fretting. Corrosion and pin fretting may cause intermittent or complete failure of the connector.

Routing, Support & Protection of Harnesses

Routing

Harnesses should be installed and routed to prevent accidental contact by personnel or components that may wear into the conductors. Unavoidable contact with vibrating components requires protection to prevent wear into the harness.

Route harnesses and wires away from hot exhaust manifolds and turbochargers, unless special insulation is provided. Route so wiring is protected from abrasive wear (such as grommets). Avoid sharp harness radii to reduce unnecessary wire connection strain. Route harnesses such that someone standing on equipment does not strain wiring.

Conduit

Metal conduit will help reduce electrical noise, therefore, it's preferred to plastic conduit.

Support

Depending on method of harnessing, either bundled wires in a flexible sleeve or in rigid conduit, the harnesses should be supported as needed to prevent sagging or strain on the conductors. Provide support between 150 to 300 mm (6 to 12 in) on either side of the connectors. This support distance prevents vibrations from being induced into the connector and prevents undue strain of the connector's weight on the conductors.

Separating AC & DC Circuits

Wiring for DC circuits, magnetic pickups, thermocouples and RTD's can be routed in common conduits. However, they must not be in the same conduit with AC circuits. In addition, AC circuits greater than 600 volts should be separated from AC circuits less than 600 volts.

Grounding

Ground loops should be avoided. Ground points should not be painted. Electrical codes and service publications or instructions may provide additional requirements.

IEEE Standard 142 (Recommended Practice for Grounding of Industrial and Commercial Power Systems), IEEE Standard 1100 (Recommended Practice for Powering and Grounding Sensitive Electronic Equipment) may also provide additional assistance.

Noise & Electromagnetic Interference

To avoid potential noise, signal wiring should not exceed 30 m (98 ft) in length.

Avoid coiling extra wire length as it can create an electromagnetic compatibility (EMC) issue. Extra wire length should be cut off.

Installations with severe electromagnetic interference (EMI) may require shielded wire run in conduit, double shielded wire, or other precautions.

Reference Material

Media List

The following information is provided as an additional reference to subjects discussed in this manual.

SENR3028: Systems Operation – Caterpillar 3161 Governor

SENR3585: Systems Operation - 2301A Electric Governors (Load Sharing) for Generator Set

RENR2228: Systems Operation - 723PLUS Digital Speed Control

SENR4661: General Service Information - Heinzmann Governor (3600 Marine Application)

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