ESD5400 SERIES SPEED CONTROL UNIT

PRODUCT TECHNICAL INFORMATION

PTI 1120

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INTRODUCTION

The ESD5400 Series speed control unit is an all electronic device designed to control engine speed with fast and precise response to transient load changes. This closed loop control, when connected to an electric actuator with position feedback and supplied with a magnetic speed sensor signal, will control a wide variety of engines in an isochronous or droop mode. It is designed for high reliability and built ruggedly to withstand the engine environment.

Simplicity of installation and adjustment was foremost in the design. Non-interacting performance controls allow near optimum response to be easily obtained.

Other features include; adjustable droop and idle operation, speed ramping, fuel limiting, inputs for accessories used in multi-engine or special applications, a single element speed switch, protection against reverse battery voltage and transient voltages, and fail-safe design in the event of loss of speed sensor signal, battery supply or actuator short circuit.

DESCRIPTION

Engine speed information for the speed control unit is usually received from a magnetic speed sensor. Any other signal generating device may be used provided the generated frequency is proportional to engine speed and meets the voltage input and frequency range specification. The speed sensor is typically mounted in close proximity to an engine driven ferrous gear, usually the engine ring gear. As the teeth of the gear pass the magnetic sensor, a signal is generated which is porportional to engine speed.

Signal strength must be within the range of the input amplifier. An amplitude of 0.5 to 120 volts RMS is required to allow the unit to function within its design specifications. The speed signal is applied to Terminals J and K of the speed control unit. Between these terminals there is an input impedance of over 33,000 ohms. Terminal K is internally connected to Terminal D, battery negative.

When a speed sensor signal is received by the controller, the signal is amplified and shaped by an internal circuit to provide an analog speed signal. If the speed sensor monitor does not detect a speed sensor signal, the output circuit of the speed control unit will turn off all current to the actuator.

A summing circuit receives the speed sensor signal along with the speed adjust set point input. The speed range has a ratio of 8:1 and is adjusted with a 25 turn potentiometer. The output from the summing circuit is the input to the dynamic control section of the speed control unit. The dynamic control circuit, of which the gain and stability adjustments are part, has a control function that will provide isochronous and stable performance for most engine types and fuel systems.

The speed control unit output circuit is influenced by the integral gain and stability performance adjustments. The governor system sensitivity is increased with clockwise rotation of the gain adjustment. The stability adjustment, when advanced clockwise, increases the time rate of response of the governor system to match the various time constants of a wide variety of engines. Since the speed control unit is a P I D device, the "D", derivative portion can be varied, when required with the internal DIP switches. (See Instability section).

During engine cranking, the actuator is fully energized and moves to the maximum fuel position. The actuator will remain in that state during engine cranking and acceleration. While the engine is at steady load, the actuator will be energized with sufficient current to maintain the governor speed set point.

The electric actuator circuit is a closed loop position control circuit. The summation point for position control includes the requested fuel position and the actual position as measured in the actuator by the internal position sensor. The control compares the two signals. Any error between the two requests results in the actuator current being changed appropriately to eliminate any error. This actuator control loop is fast and tends to eliminate the effects of friction in the control systems linkage.

The power output stage of the ESD5401 control that drives the actuator is a high frequency PWM with output capability up to 10 Amps.

In standard operation, the speed control unit performance is isochronous. Droop governing can be selected by connecting Terminals S and T and the percent of droop governing can be varied with the integral droop adjustment control.

The speed control unit has several performance and protection features which enhance the governor system. A speed anticipation circuit minimizes speed overshoot on engine start-up or when large increments of load are applied to the engine. Engine idle speed can be remotely selected and is adjustable. Accessory inputs to achieve variable speed operation and multi-engine control can be accepted by the speed control unit from GAC load sharing modules, automatic synchronizers, and other accessory engine control modules. Protection against reverse battery voltage and transient voltages is provided.

The ESD5400 Series includes a single element speed switch. It provides a convenient means of sensing an overspeed condition and activates an internal relay. This relay may be used to shut off the fuel or ignition to provide safe engine shut down. The speed switch feature includes a wide adjustment range, test and reset functions, and an LED status indicator.

The ESD5400 Series is compatible with GOVERNORS AMERICA CORP. electric actuator models 120F, 225F and 275F.

SPECIFICATIONS

PERFORMANCE

Isochronous Operation / Steady State Stability	± 0.25% or better
Speed Range/Governor	1.1K – 7.0K Hz. continuous
Speed Drift With Temperature (Governor and Speed Switch)	less than ± 1% maximum
Idle Adjust CW	Min. 300 Hz. Below set speed
Idle Adjust CCW	Min. 4100 Hz. Below set speed
Gain Range	30:1 non-linear
Droop Range	1 – 5% regulation*
Droop Adj. Max. (S-T Jumpered)	1500 Hz., ± 75 Hz. per 50% change
Droop Adj. Min.	6 Hz., ± 6 Hz. per 50% change
Speed Trim Range (5K pot between Terminals L and M)	± 200 Hz.
Remote Variable Speed Range	500 - 7.0K Hz. or any part thereof
Terminal Sensitivity	
M	100 Hz., ± 15 Hz / Volt @ 5.0 K impedance
T	735 Hz., ± 60 Hz / Volt @ 65 K impedance
U	148 Hz., ± 10 Hz / Volt @ 1 Meg. impedance
P (internal 10V supply)	10 VDC Supply @ 20 ma Max.
Speed Switch Adjustment Range	1000 - 10000 Hz.

ENVIRONMENTAL

Ambient Operating Temperature Range	−40° to +180°F (−40° to +85°C)
Relative Humidity	up to 95%
All Surface Finishes	Fungus proof & corrosion resistant

INPUT POWER

Supply	12 (ESD5401-12) or 24 VDC Battery Systems (transient & reverse voltage protected)**
Polarity	Negative ground (case isolated)
Power Consumption	50 ma continuous plus actuator current
Maximum Actuator Current at 25°C (77°F)	10 Amps continuous***
Speed Sensor Signal	0.5-120 Volts RMS
Speed Switch Relay Contacts (N.O. and N.C.)	10 Amps

RELIABILITY

Vibration	± 0.7 g up to 100 Hz.
Testing	100% Functionally tested.

PHYSICAL

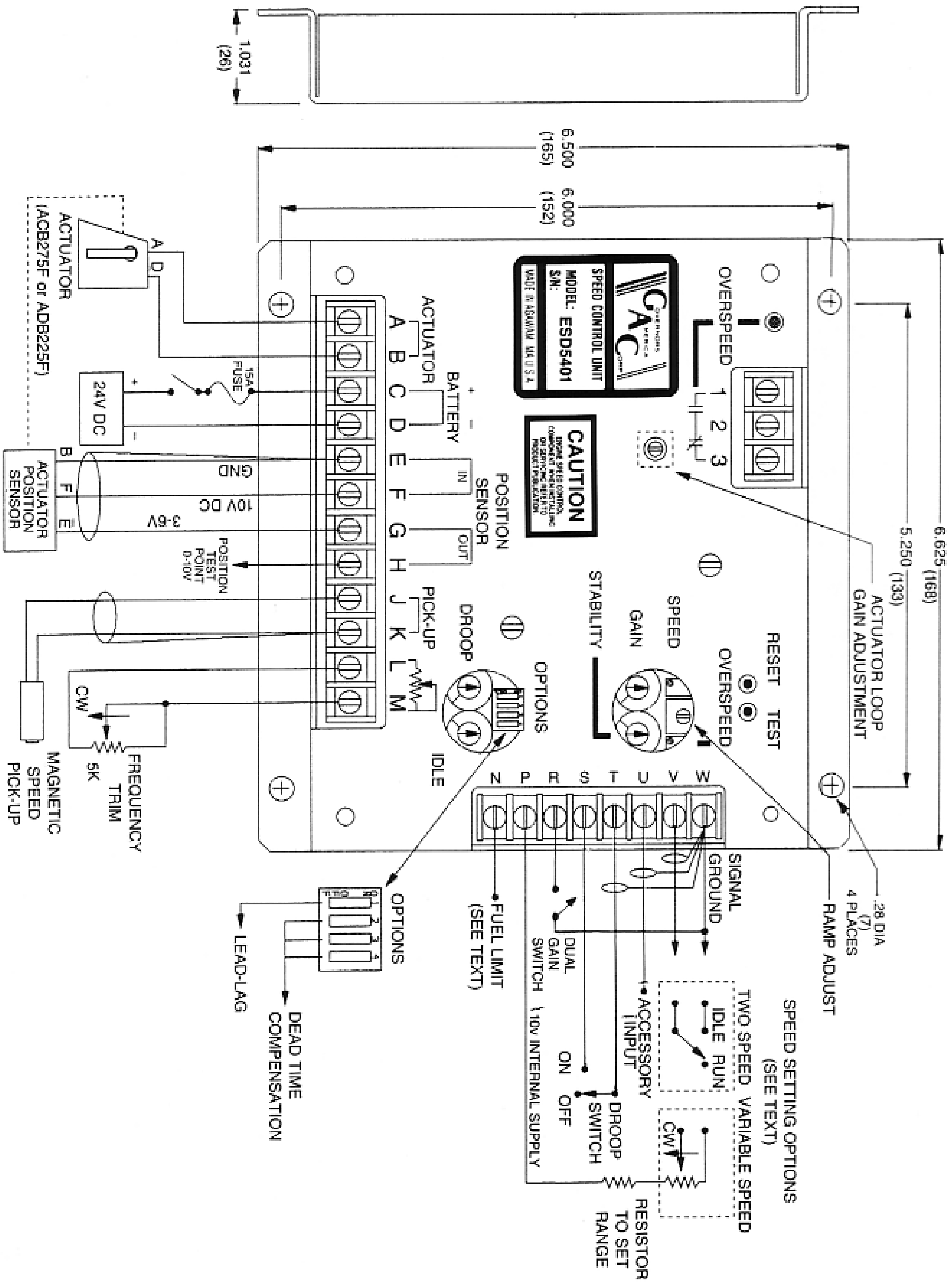
Dimensions	See outline (Diagram 1)
Weight	1.8 lbs. (820 grams)
Mounting	Any position, vertical preferred

*Droop is based on a speed sensor frequency of 4000 Hz. and an actuator position change of 50% from no load to full load. Applications with higher frequency speed sensor signals will experience less percentage of droop. Applications with more actuator current change will experience higher percentages of droop. See droop description for specific details on operation of droop ranges.

**Protected against reverse voltage by a series diode. A 15 amp fuse must be installed in the positive battery lead for maximum protection. For 32V systems, contact the factory.

***Protected against short circuit to actuator (shuts off current to actuator), unit automatically turns back on when short is removed.

DIAGRAM 1 **WIRING DIAGRAM AND OUTLINE**



APPLICATION AND INSTALLATION INFORMATION

The speed control unit is rugged enough to be placed in a control cabinet or engine mounted enclosure with other dedicated control equipment. If water, mist, or condensation may come in contact with the controller, it should be mounted vertically. This will allow the fluid to drain away from the speed control unit.

Extreme heat should be avoided.

> **WARNING**
> An overspeed shutdown device, independent of the governor system, should be provided to prevent loss of engine control which may cause personal injury or equipment damage. Do not rely exclusively on the governor system electric actuator to prevent overspeed. A secondary shut off device, such as a fuel solenoid, should be used.

WIRING

Basic electrical connections are illustrated in Diagram 1. Actuator and battery connections to Terminals A, B, C, and D must be #16 AWG (1.3 mm sq.) or larger. Long cables require an increased wire size to minimize voltage drops.

The cable to the actuator position sensor should be shielded. This connects Terminals B, F and E of the actuator to E, F and G of the controller. The ground shield should be connected to E of the controller only. (See Diagram 1)

The battery positive (+) input, Terminal F, should be fused for 15 amps as illustrated.

Magnetic speed sensor connections to Terminals C and D **MUST BE TWISTED OR SHIELDED** for their entire length. The speed sensor cable shield should only be connected to Terminal K. The shield should be insulated to insure no other part of the shield comes in contact with engine ground, otherwise stray speed signals may be introduced into the speed control unit.

ADJUSTMENTS

Before Starting Engine

Check to insure the SPEED, GAIN, STABILITY and **IDLE** adjustments, and if applied, the external **SPEED TRIM CONTROL** are set to mid position. Also check that the actuator loop gain adjustment is set to a 30% CW position.

> **CAUTION**
> Overspeed relay has not been set yet, to protect the engine.

Start Engine

The controller is factory set at approximately engine idle speed. (1000 Hz. speed sensor signal)

The speed switch is factory set at its maximum speed setting. (10000 Hz. speed sensor signal)

Crank the engine with D.C. battery power applied to the governor system. The actuator will energize fully to the maximum fuel position until the engine starts. The governor system should control the engine at low idle speed. If the engine is unstable after starting, turn the **GAIN** and **STABILITY** adjustments counterclockwise until the engine is stable.

Governor Speed Setting

The governed speed set point is increased by clockwise rotation of the **SPEED** adjustment control. Remote speed adjustment can be obtained with an optional Speed Trim Control. See Diagram 1.

Governor Performance

Once the engine is at the operating speed and at no load, the following governor performance adjustments can be made.

A. Rotate the **GAIN** adjustment clockwise until instability develops. Gradually move the adjustment counterclockwise until stability returns. Move the adjustment one division further counterclockwise to insure stable performance.

B. Rotate the **STABILITY** adjustment clockwise until instability develops. Gradually move the adjustment counterclockwise until stability returns. Move the adjustment one division further counterclockwise to insure stable performance.

C. Gain and stability adjustments may require minor changes after engine load is applied. Normally, adjustments made at no load achieve satisfactory performance. A strip chart recorder can be used to further optimize the adjustments.

The four position **OPTIONS** switch adjusts the derivative function of the ESD5401.

Position 1 controls the Lead / Lag circuit. Turn the switch ON if there is slow instability, OFF if there is fast instability.

Positions 2, 3 and 4 should be switched in combination based on the frequency of instability that results when the **GAIN** is turned too far **CW**.

POSITION

	2	3	4	
FAST ↓	OFF	OFF	OFF	↑
	ON	OFF	OFF	
	OFF	ON	OFF	
	ON	ON	OFF	
	OFF	ON	ON	SLOW
	ON	ON	ON	

If instability cannot be corrected or further performance improvements are required, refer to section on **SYSTEM TROUBLESHOOTING** for instructions on changing the Dead Time Compensation and/or Lead Lag DIP switches.

Idle Speed Setting

After the governor speed setting has been adjusted, place the optional external selector switch in the **IDLE** position. The idle speed set point is increased by clockwise rotation of the **IDLE** adjustment control. Note that the speed ramping function will be used in this operation. When the engine is at idle speed, the speed control unit applies droop to the governor system to insure stable operation.

Speed Droop Operation

Droop is typically used for the parelleling of engine driven generators.

Place the optional external selector switch in the **DROOP** position. Droop is increased by clockwise rotation of the **DROOP** adjustment control. When in droop operation, the engine speed will decrease as engine load increases. The percentage of droop is based on the actuator position change from engine no load to full load. A wide range of droop is available with the internal control.

If droop levels experienced are higher or lower than those required, contact the factory for assistance.

After the droop level has been adjusted, the rated engine speed setting may need to be reset. Check the engine speed and adjust the speed setting accordingly.

Accessory Input

The **AUX**iliary Terminal U accepts input signals from load sharing units, auto synchronizers, and other governor system accessories. GAC accessories are directly connected to this terminal. It is recommended that this connection from accessories be shielded as it is a sensitive input terminal.

If the auto synchronizer is used alone, not in conjunction with a load sharing module, a 3 M ohm resistor should be connected between Terminals U and P. This is required to match the voltage levels between the speed control unit and the synchronizer.

When an accessory is connected to Terminal U, the speed will decrease and the speed adjustment must be reset.

When operating in the upper end of the control unit frequency range, a jumper wire or frequency trim control may be required between Terminals G and J. This increases the frequency range of the speed control to over 7000 Hz.

Accessory Supply

The + 10 volt regulated supply, Terminal P, can be utilized to provide power to GAC governor system accessories. Up to 20 ma of current can be drawn from this supply. Ground reference is Terminal W.

Internal Speed Switch

When the engine is running at the desired speed, push and hold the **TEST** button. Rotate the **OVERSPEED** adjustment counter-clockwise until the LED lights and the relay energizes. Current to the actuator will be removed and the engine will shut off.

Release the **TEST** button. After the engine stops, press the **RESET** button or remove battery power. Restart the engine and it will return to the original speed setting.

The overspeed function is now set to approximately 10% above the requested speed. If a different value for overspeed is required, standard procedures for adjustment should be used.

Always use the relay contacts provided to shut down the system by a means other than the governor or actuator.

It is recommended that the overspeed protection system be tested and verified during scheduled service of the equipment.

Wide Range Variable Speed

Simple and effective remote variable speed can be obtained with the ESD5400 Series speed control unit.

A single remote speed adjustment potentiometer can be used to adjust the engine speed continuously over a specific speed range.

Actuator Loop Gain Adjustment

The actuator control loop sensitivity can be adjusted using the single turn adjustment located below the relay Terminals 2 and 3. The advancement of this control CW will stiffen the actuators response.

In applications such as carbureted systems or high friction systems advancement of the actuator loop gain setting will likely improve the governing. However, any advancement may require a reduction of the speed gain setting to balance the overall governor loop gain. It is therefore recommended that the two gain adjustments be changed in opposition. Then the overall governing should be evaluated to determine the best setting.

Caution must be exercised in the optimization process as the actuator loop can become unstable as well as or in addition to the speed loop. Reducing the actuator loop gain and increasing the speed loop gain will likely make the speed loop gain unstable. Reducing the speed loop gain to zero and increasing the actuator loop gain can make the actuator loop unstable especially if the actuator is disturbed.

Dual Gain Switch

The ESD5400 Series speed control units have a dual gain capability. When Terminal "R" is connected to Terminal "W" (ground) the governor will have a standard gain setting. In this condition the system has the highest performance and is typically set with the internal gain control.

If a situation arises where the gain is required to be lower such as when changing fuels to the engine (natural gas to bio gas), the connection between R-W can be opened to reduce the governors gain to 1/2 of the standard setting made by the gain control.

A resistor may be inserted in series with Terminal "R" to lessen the gain change if necessary.

Fuel Limiting

Terminal "N" of the ESD5401 can be used to externally limit the maximum position of the actuator. The range of voltages is between 1 and 5 Volts. With a voltage above 5 Volts applied to Terminal "N" with respect to Terminal "W" no fuel limiting will occur. As this voltage is reduced it will limit the maximum travel of the actuator. Since the position loop is stiff and accurate the limit is as hard as the electro magnetics and the internal spring can possess.

Continued reduction of the voltage at "N" will limit the travel to the point of zero actuator travel.

SYSTEM TROUBLESHOOTING

System Inoperative

If the engine governing system does not function, the fault may be determined by performing the voltage tests described in Steps 1, 2, 3, and 4, (+) and (−) refer to meter polarity. Should normal values be indicated as a result of following the troubleshooting steps, the fault may be with the actuator or the wiring to the actuator. See actuator publication for testing details.

Step	Terminals	Normal Reading	Probable Cause of Abnormal Reading
1	C(+) & D(−)	Battery Supply Voltage (12 or 24 VDC)	1. DC battery power not connected. Check for blown fuse. 2. Low battery voltage. 3. Wiring error.
2	J & K	1.0 VAC RMS min., while cranking	1. Gap between speed sensor and gear teeth too great. Check gap. 2. Improper or defective wiring to the speed sensor. Resistance between Terminals J and K should be 30 to 300 ohms. 3. Defective speed sensor.
3	P(+) & W(−)	10 VDC, Internal Supply	1. Short on Terminal P. 2. Defective speed control.
4	N(+) & W(−)	10 VDC	1. Low voltage applied at fuel limiting terminal.
5	H(+) & E(−)	Position sensing — 0.5-9.5 VDC, while manually moving the actuator through its stroke.	1. Wiring Error 2. Actuator Defective
6	C(+) & A(−)	1.0-2.0 VDC, while cranking	1. **SPEED** adjustment set too low. 2. Short / open in actuator wiring. 3. Defective speed control. 4. Defective actuator. See Actuator Troubleshooting.

Unsatisfactory Performance

If the governing system functions poorly, perform the following tests.

Symptom	Test	Probable Fault
Engine Overspeeds	1. Do Not Crank. Apply DC power to the governor system.	1. Actuator goes to full fuel. Then, Disconnect speed sensor at Terminals J & K. If actuator still at full fuel - speed control unit defective. If actuator at minimum fuel position - erroneous speed signal. Check speed sensor cable.
	1. Manually hold the engine at the desired runnning speed. Measure the DC voltage between Terminals A(−) & C(+) on the speed control unit.	1. If the voltage reading is 1.0 to 2.0 VDC, a) **SPEED** adjustment set above desired speed. b) Defective speed control unit. 2. If the voltage reading is above 2.0 VDC, a) Actuator or linkage binding. 3. If the voltage reading is below 1.0 VDC, a) Defective speed control unit. 4. Gain set too low. 5. Overspeed set point too low.
Overspeed shuts down engine after running speed is reached.		1. SPEED adjust set too high. Turn CCW to lower. 2. OVERSPEED set too close to running speed. See OVERSPEED adjustment section. 3. Actuator or linkage binding. 4. Speed control unit defective.
Overspeed shuts down engine before running speed is reached.	Check impedance between Terminals J & K. Should be 30 to 300 ohms.	1. OVERSPEED set too low. Adjust 5-6 turns CW. 2. Erroneous speed sensor signal. Check wiring.
Actuator does not energize fully	1. Measure the voltage at the battery while cranking.	1. If the voltage is less than 7V for a 12V system, or 14V for a 24V system, replace the battery if it is weak or undersized.
	2. Momentarily connect Terminals A and C. The actuator should move to the full fuel position.	1. Actuator or battery wiring in error. 2. Actuator of linkage binding. 3. Defective actuator. See actuator troubleshooting. 4. Fuse opens. Check for short in actuator or actuator wiring harness.
Engine remains below desired governed speed.	1. Measure the actuator output, Terminals A & B, while running under governor control.	1. If voltage measurement is within appriximately 2 volts of the battery supply voltage, then fuel control restricted from reaching full fuel position. Possibly due to interference from the mechanical governor, carburetor spring or linkage alignment. 2. Speed setting too low.

SYSTEM TROUBLESHOOTING

Insufficient Magnetic Speed Sensor Signal

A strong magnetic speed sensor signal will eliminate the possibility of missed or extra pulses. The speed control unit will govern well with 0.5 volts RMS speed sensor signal. A speed sensor signal of 3 volts RMS or greater at governed speed is recommended. Measurement of the signal is made at Terminals C and D.

The amplitude of the speed sensor signal can be raised by reducing the gap between the speed sensor tip and the engine ring gear. The gap should not be any smaller than 0.020 in. (0.45 mm). When the engine is stopped, back the speed sensor out by ¾ turn after touching the ring gear tooth to achieve a satisfactory air gap.

Electromagnetic Compatility (EMC)

EMI SUSCEPTIBILITY — The governor system can be adversely affected by large interfering signals that are conducted through the cabling or through direct radiation into the control circuits.

All GAC speed control units contain filters and shielding designed to protect the units sensitive circuits from moderate external interfering sources.

Although it is difficult to predict levels of interference, applications that include magnetos, solid state ignition systems, radio transmitters, voltage regulators or battery chargers; should be considered suspect as possible interfering sources.

If it is suspected that external fields either those that are radiated or conducted, are or will affect the governor systems operation; it is recommended to use shielded cable for all external connections. Be sure that only one end of the shields including the speed sensor shield, is connected to a single point on the case of the speed control unit. Mount the speed control unit to a grounded metal back plate or place it in a sealed metal box.

Radiation is when the interfering signal is radiated directly through space to the governing system. To isolate the governor system electronics from this type of interference source, a metal shield or a solid metal container is usually effective.

Conduction is when the interfering signal is conducted through the interconnecting wiring to the governor system electronics. Shielded cables and installing filters are common remedies.

As an aid to help reduce the levels of EMI of a conductive nature, a battery line filter and shielded cables is conveniently supplied by GAC in KT310. To reduce the levels of EMI of a radiated nature, a shielded container P/N CA114 can be sourced from GAC and its distributors.

In severe high energy interference locations such as when the governor system is directly in the field of a powerful transmitting source, the shielding may require to be a special EMI class shielding. For these conditions, contact GAC application engineering for specific recommendations.

Instability

Instability in a closed loop speed control system can be categorized into two general types. **PERIODIC** appears to be sinusoidal and at a regular rate. **NON-PERIODIC** is a random wandering or an occasional deviation from a steady state band for no apparent reason.

The **PERIODIC** type can be further classified as a fast or slow instability. Fast instability is a 3 Hz. or faster irregularity of the speed and is usually a jitter. Slow periodic instability is below 3 Hz., can be very slow, and is sometimes violent.

If fast instability occurs, this is typically the governor responding to engine firings. Raising the engine speed increases the frequency of instability and vice versa. If this is the case, setting the **LEAD** switch (SW1) nearest the **SPEED** adjustment to "OFF" will reduce this tendency. In extreme cases, this may not take all the jitter out of the system. In this case, turn the additional **DTC** switches to "OFF", to further stabilize the system. Switch locations are illustrated in Diagram 1.

To resolve instability, DIP switches 2, 3, and 4 should be switched in combination based on the frequency of instability that results when the **GAIN** is turned too far CW.

	POSITION 2	POSITION 3	POSITION 4	
FAST ↓	OFF	OFF	OFF	↑
	ON	OFF	OFF	
	OFF	ON	OFF	
	ON	ON	OFF	
	OFF	ON	ON	SLOW
	ON	ON	ON	

Readjust the **GAIN** and **STABILITY**, after each change of the DIP switch position. The control system can also be optimized for best performance by following this procedure.

If slow instability is unaffected by this procedure, evaluate the fuel system and engine performance. Check the fuel system linkage for binding, high friction, or poor linkage. Be sure to check linkage during engine operation. Also look at the engine fuel system. Irregularities with carbuereted or fuel injection systems can change engine power even with a constant throttle setting. This can result in speed deviations beyond the control of the governor system. Adding a small amount of droop can help stabilize the system for troubleshooting.

Interference from powerful electrical signals can also be the cause. Turn off the battery chargers or other electrical equipment to see if the symptom disappears.

NON-PERIODIC instability should respond to the **GAIN** control. If increasing the gain reduces the instability, then the problem is probably with the engine. Higher gain allows the governor to respond faster and correct for the disturbance. Look for engine misfirings, an erratic fuel system, or load changes on the engine generator set voltage regulator. If the throttle is slightly erratic, but performance is fast, setting the left side switch (SW1) to "OFF" will tend to steady the system.

If unsuccessful in solving instability, contact the factory for assistance.

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