U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

Chapter 8

DIESEL ENGINE CONTROLS AND GOVERNING

HRTD
Human Resources
Training & Development

Learning Objectives

As a result of this chapter, you will be able to:

1. Describe the functional relationship between the engine control governor and the fuel injection system.
2. Explain how the engine control governor senses changes in generator load and compensates by regulating fuel delivery to the injectors.
3. Describe primary components of governing systems, their features and functions.
4. Explain how the terms "isochronous" and "droop" apply to EDG engines.

Learning Objectives (continued)

5. Describe how the EDG is synchronized with the grid for periodic test loading.
6. Explain rack boost and how it provides for faster starts.
7. Describe the overspeed trip, how it functions to shut down the EDG even during emergency loading, and its manual reset.
8. Understand advantages and disadvantages of digital systems.

Purpose of Governor:

To control fuel to engine cylinders so as to control speed of the unit, holding a constant speed (RPM) for all load conditions imposed on the generator being driven by the engine.

In order to maintain the output frequency of the generator (60 Hz), engine speed must be held constant.

Purpose of Governor (continued)

The relationship between generator frequency and the engine speed is expressed by the formula:

$$F = N * \frac{P}{120}$$

Where F is frequency (Hz), N the engine speed (RPM), and P is the number of poles on the generator.

For F = 60 Hz $\Longrightarrow$ N = 7200/P or P = 7200/N

$\therefore$ At 900 RPM, 60Hz requires 7200/900 = 8-pole generator

Basic Governor Elements

Every engine governing system, whether the simple mechanical type or electrical/electronic, must contain these basic elements:

- A speed sensing element (the flyweights)
- A speed setting "reference" element (the speeder spring)
- An error sensing/correcting element (the valve or fuel rod)
- A power element sufficient to manage engine fuel controls (the power piston)
- A compensation/resetting/stabilizing element
- A means of determining the method of operation, meaning droop or isochronous mode (operating in parallel or alone)

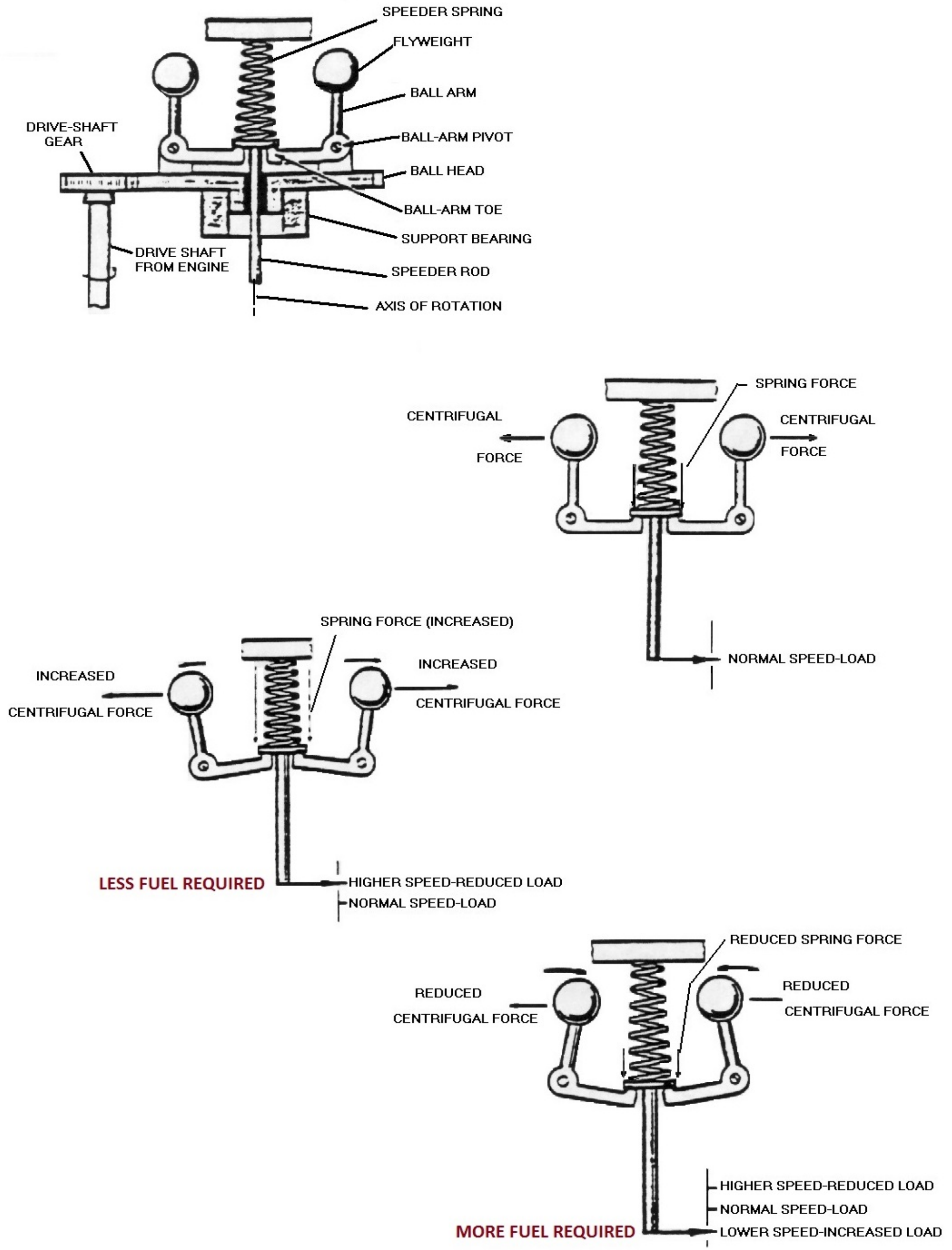


Figure 8-2

Basic Mechanical Governor

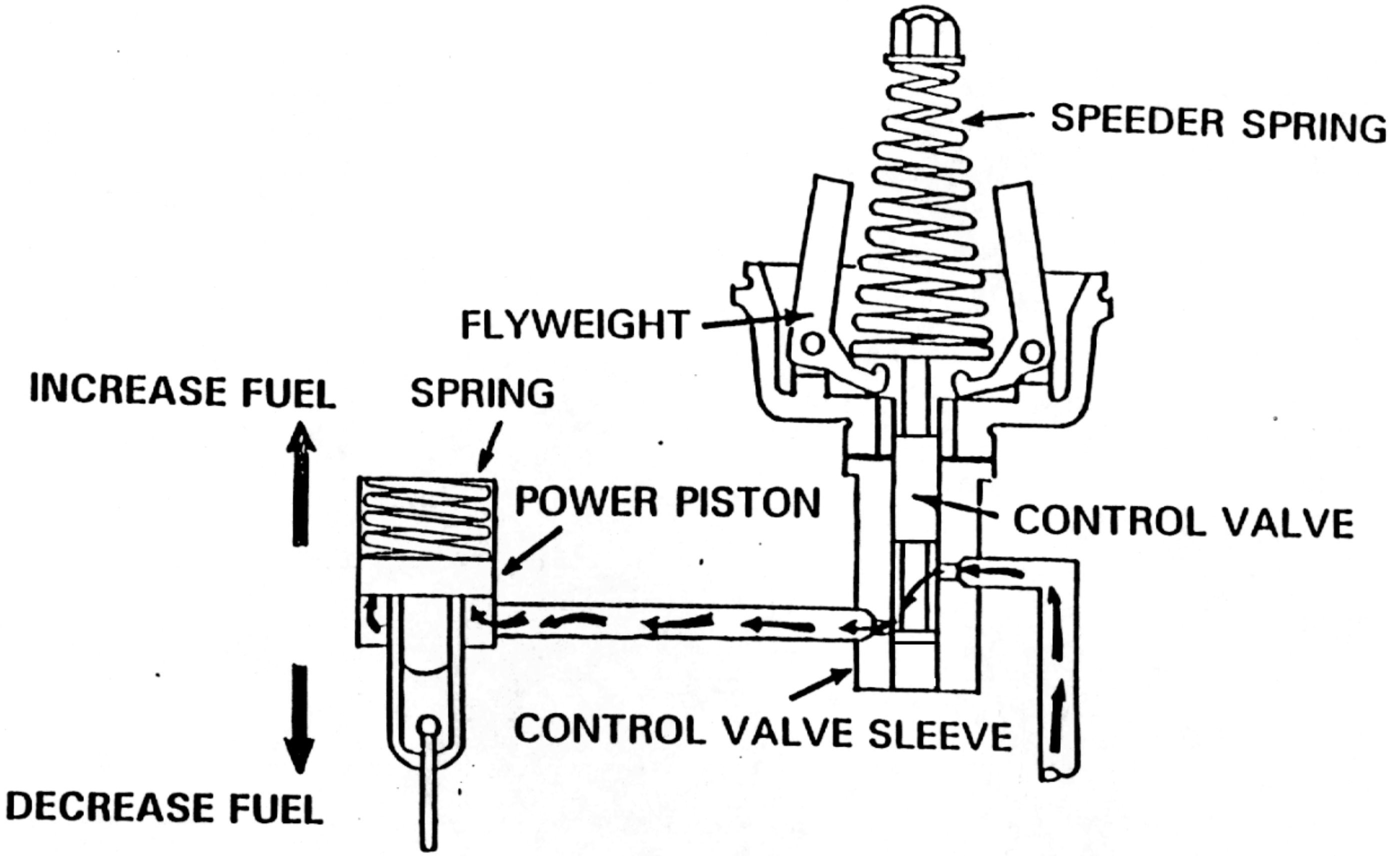


Figure 8-3 Basic Governor with Hydraulic Power Piston

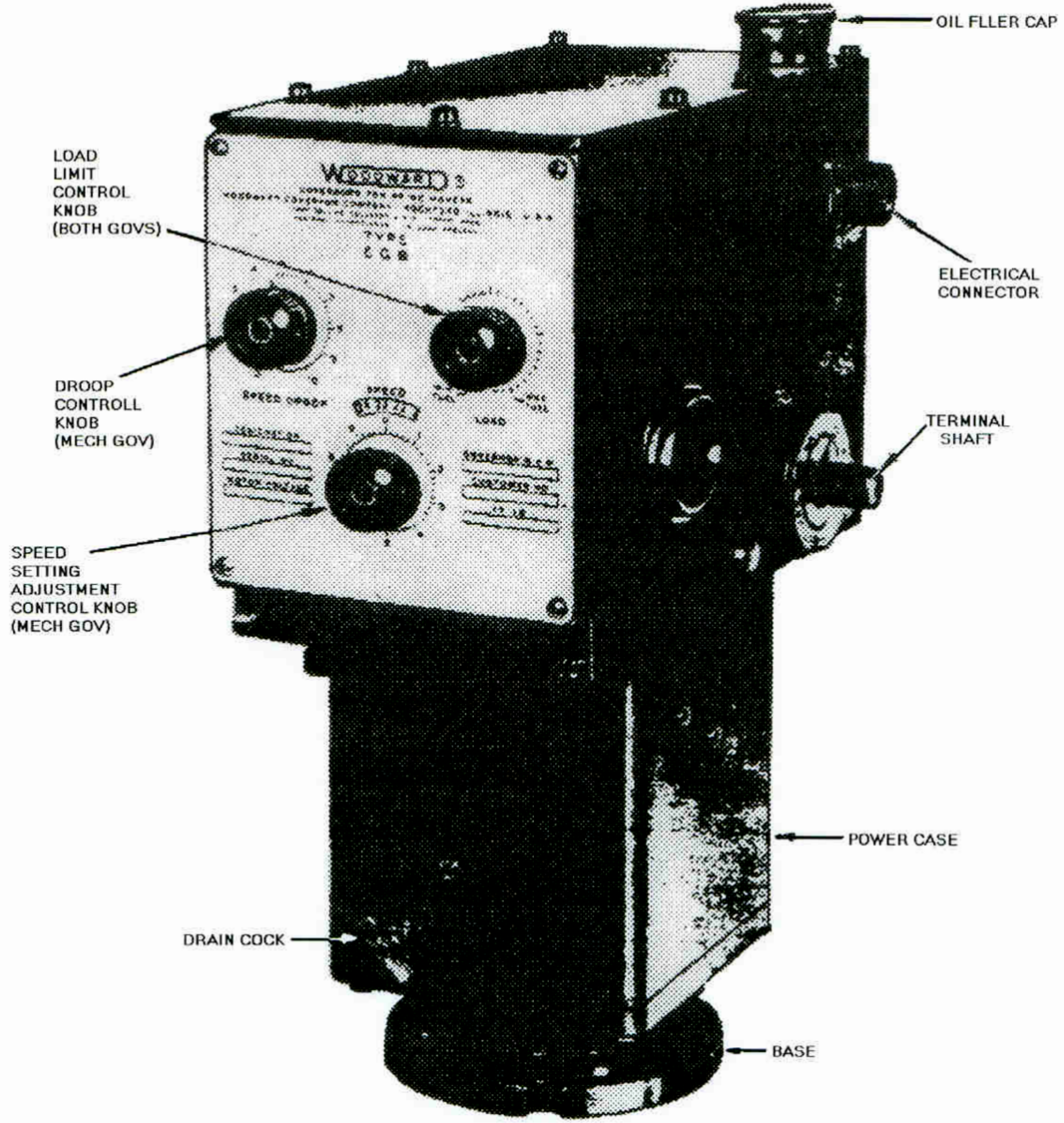


Figure 8-4

Electrical Governor Hydraulic Actuator

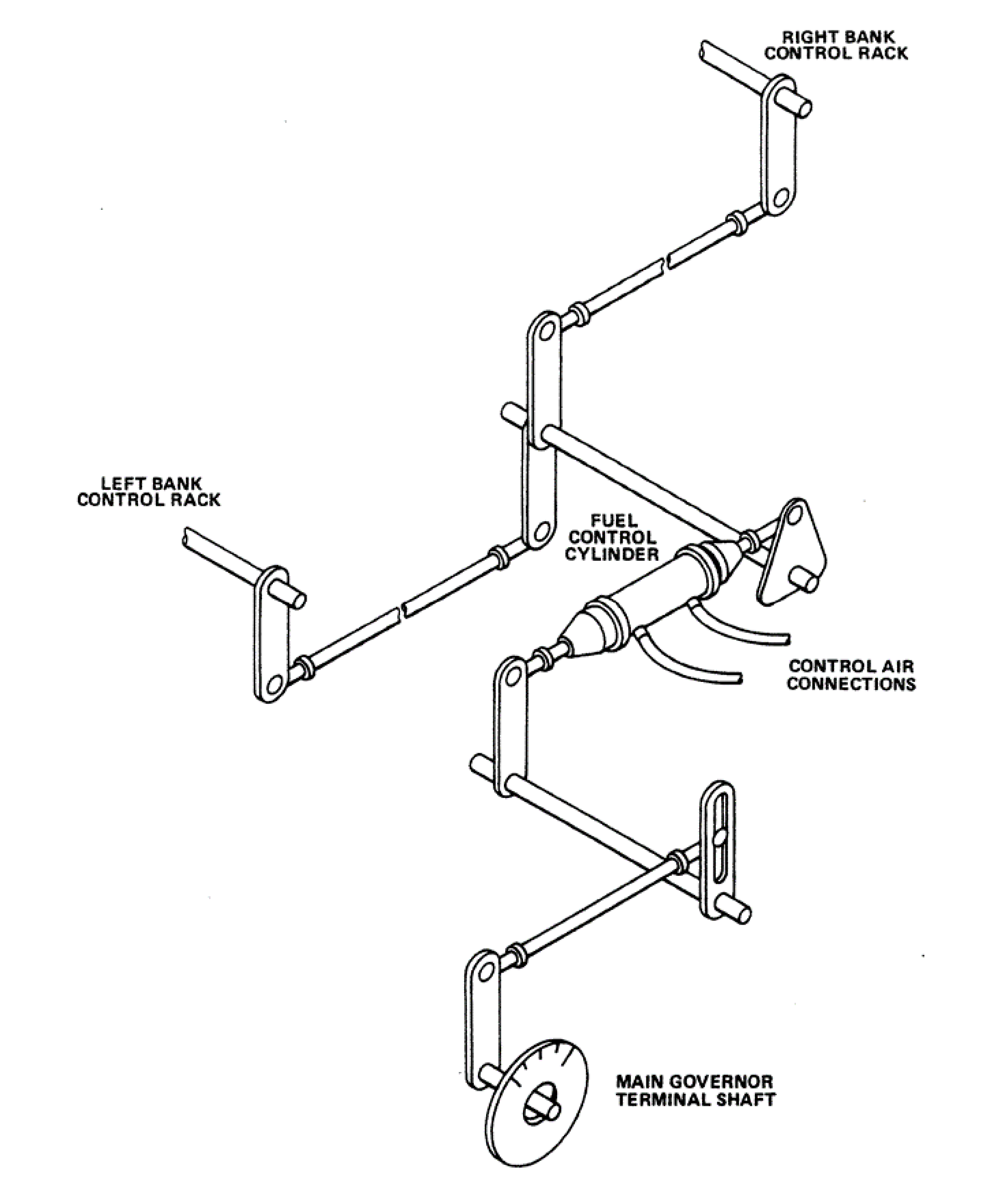


Figure 8-5

Governor Fuel Control Linkage

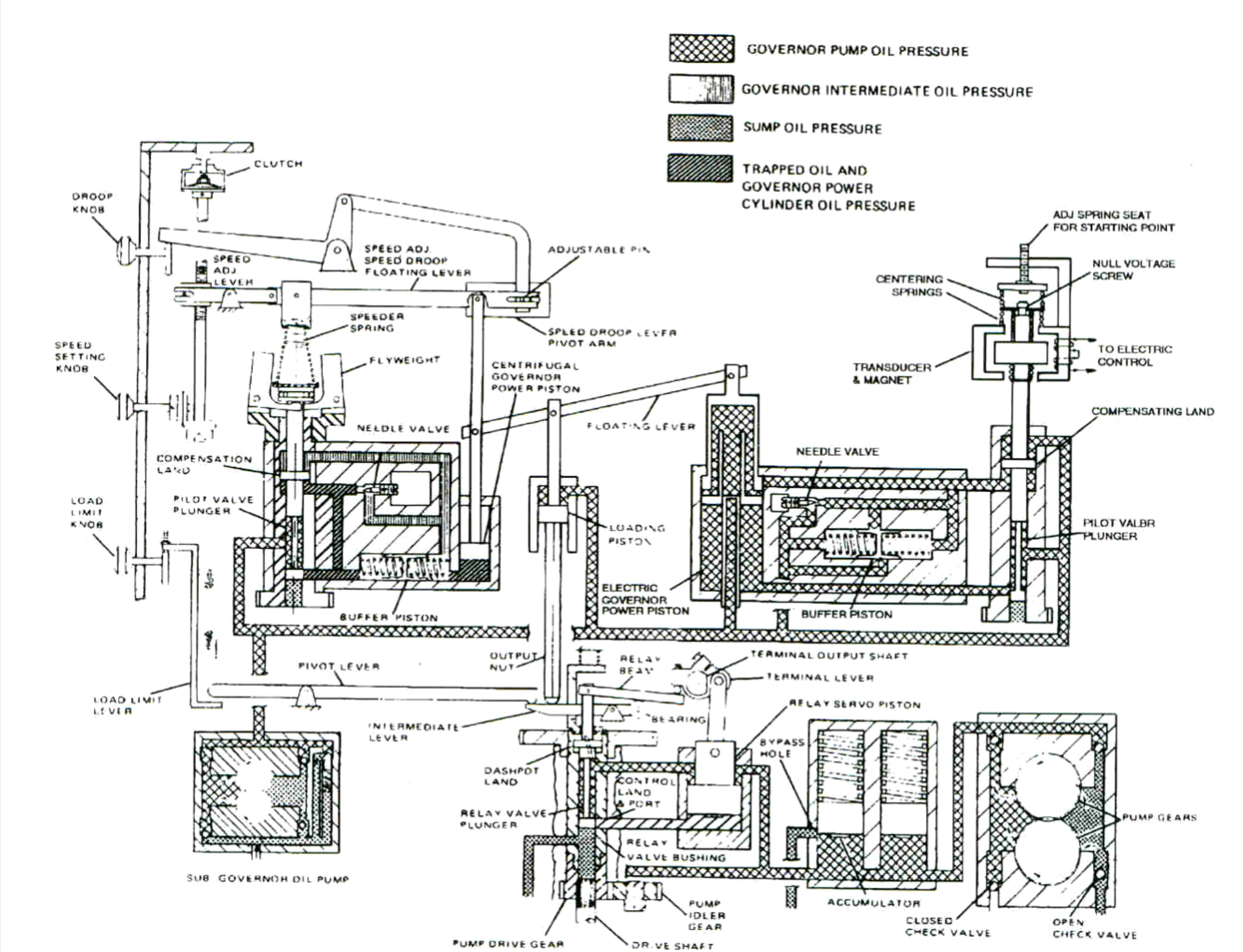


Figure 8-6A EGB-10C Actuator Schematic

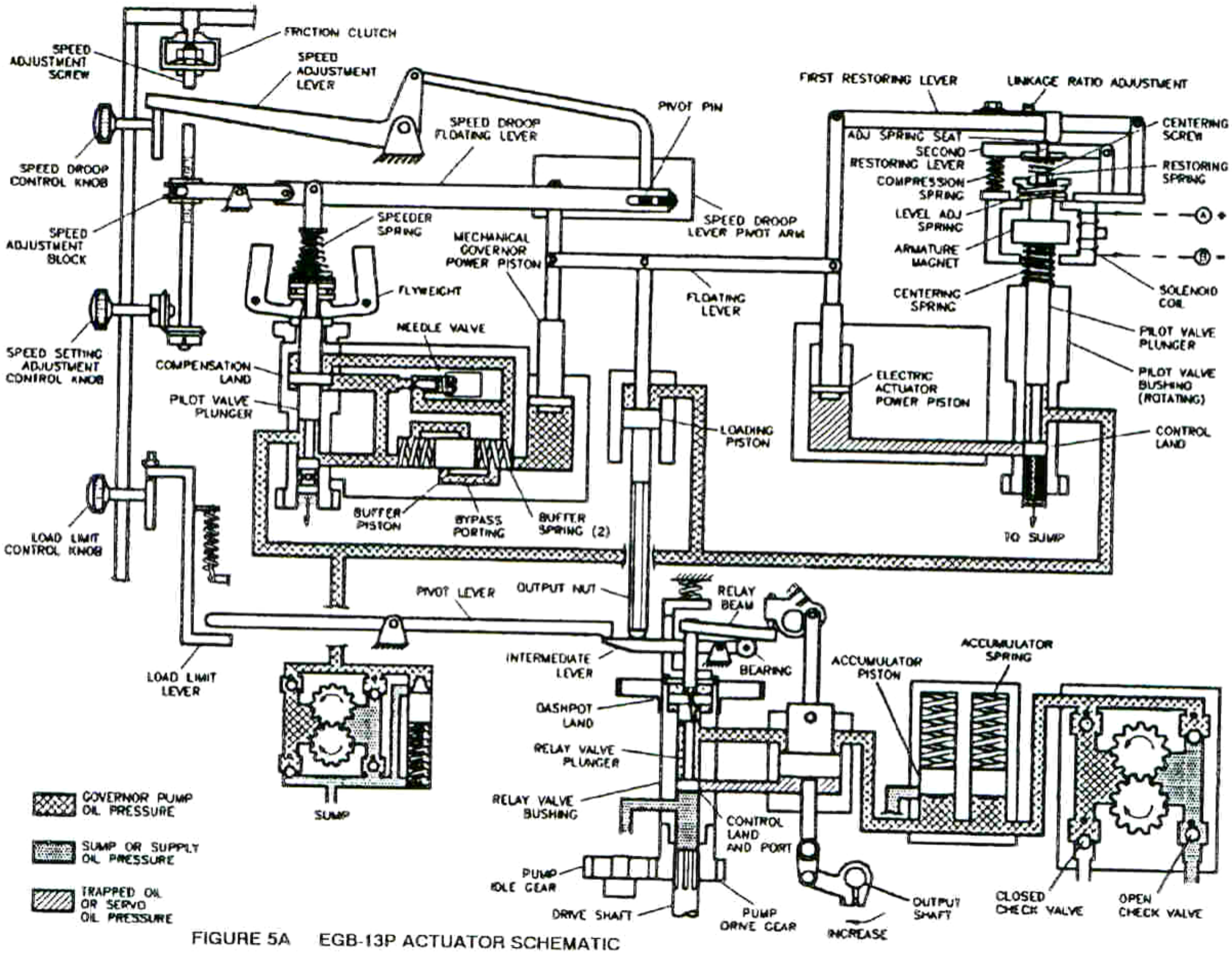
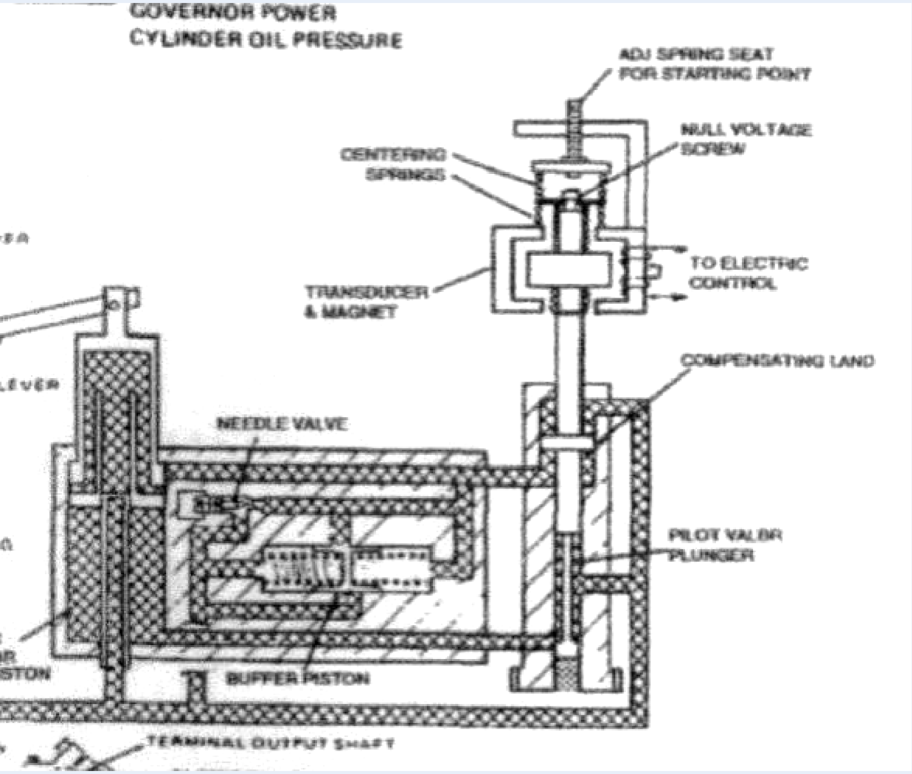
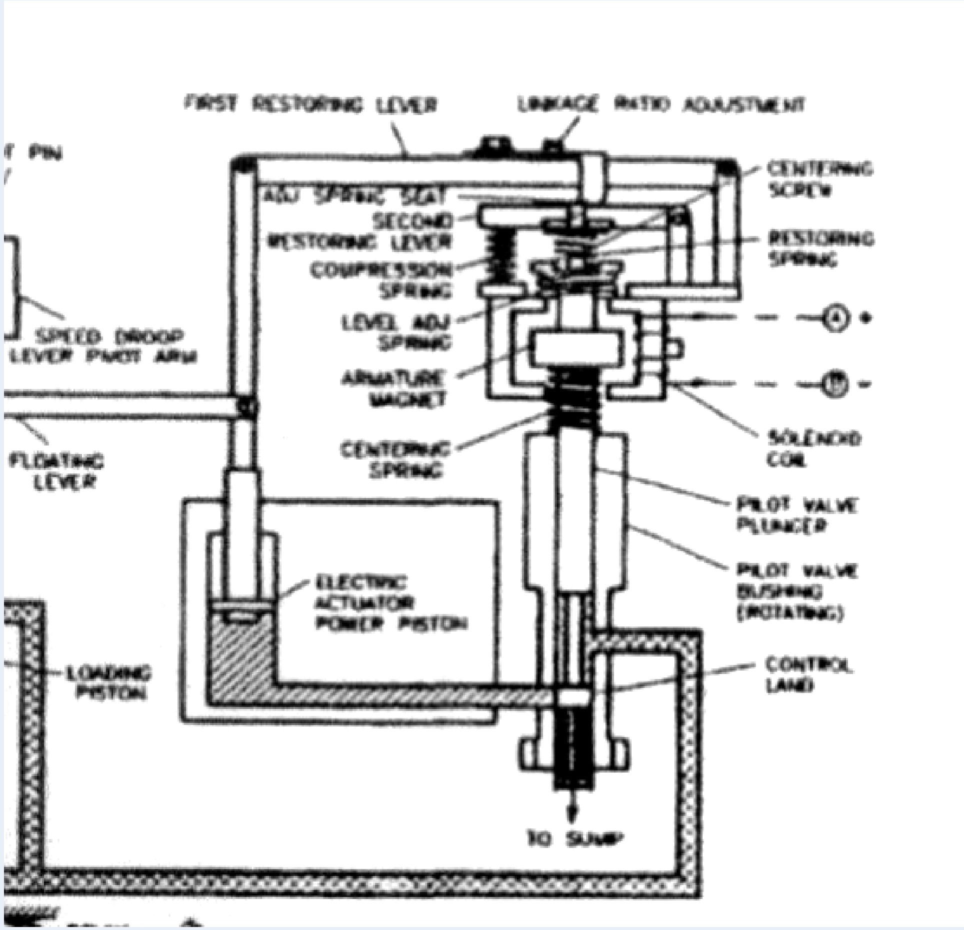


Figure 8-6B EGB-13P Actuator Schematic



EGB-10C



EGB-13P

Figures 8-6 A-B (Close-Up) Major Differences Between EGB-10C and EGB-13P Actuators

Droop - Isochronous Relationship

- Droop is defined as the percent change in speed as a unit goes from no-load to rated load condition. It can be expressed as:

  Droop (%) = Speed Change ∗ 100 / Rated Speed

  Speed Change = no-load speed – full-load speed

- Isochronous means iso (same) chronous (time). Each engine revolution takes the same time… speed is constant.

- Unit must be in Droop mode when paralleled to the offsite power system. Unit is most desirably in Isochronous when required to carry plant emergency bus loads.

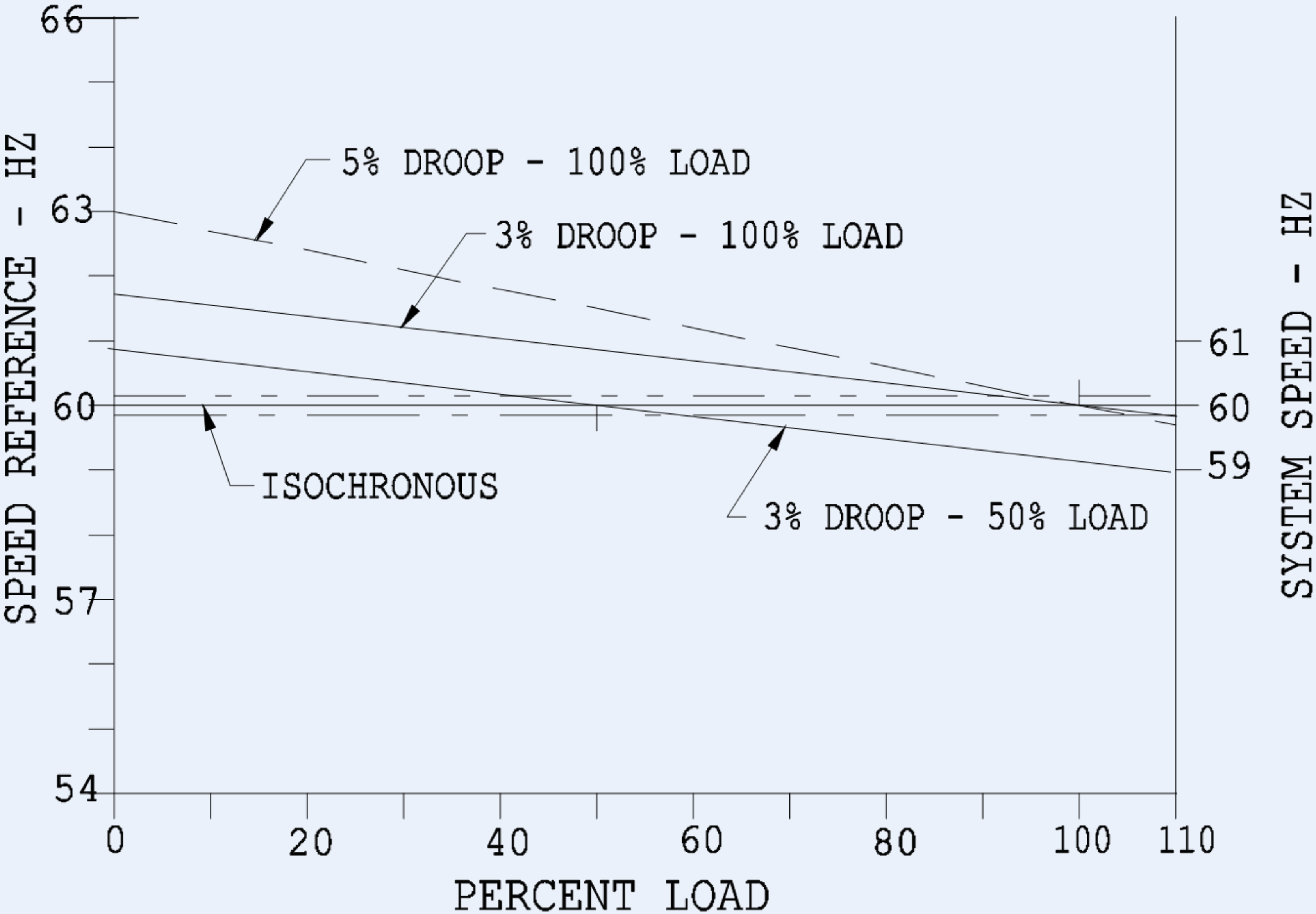


Figure 8-1 Droop-Isochronous Relationship

Control Packages

Controls are mounted in the control panels and/or switchgear and connected to the electrical system as shown in subsequent Figures.

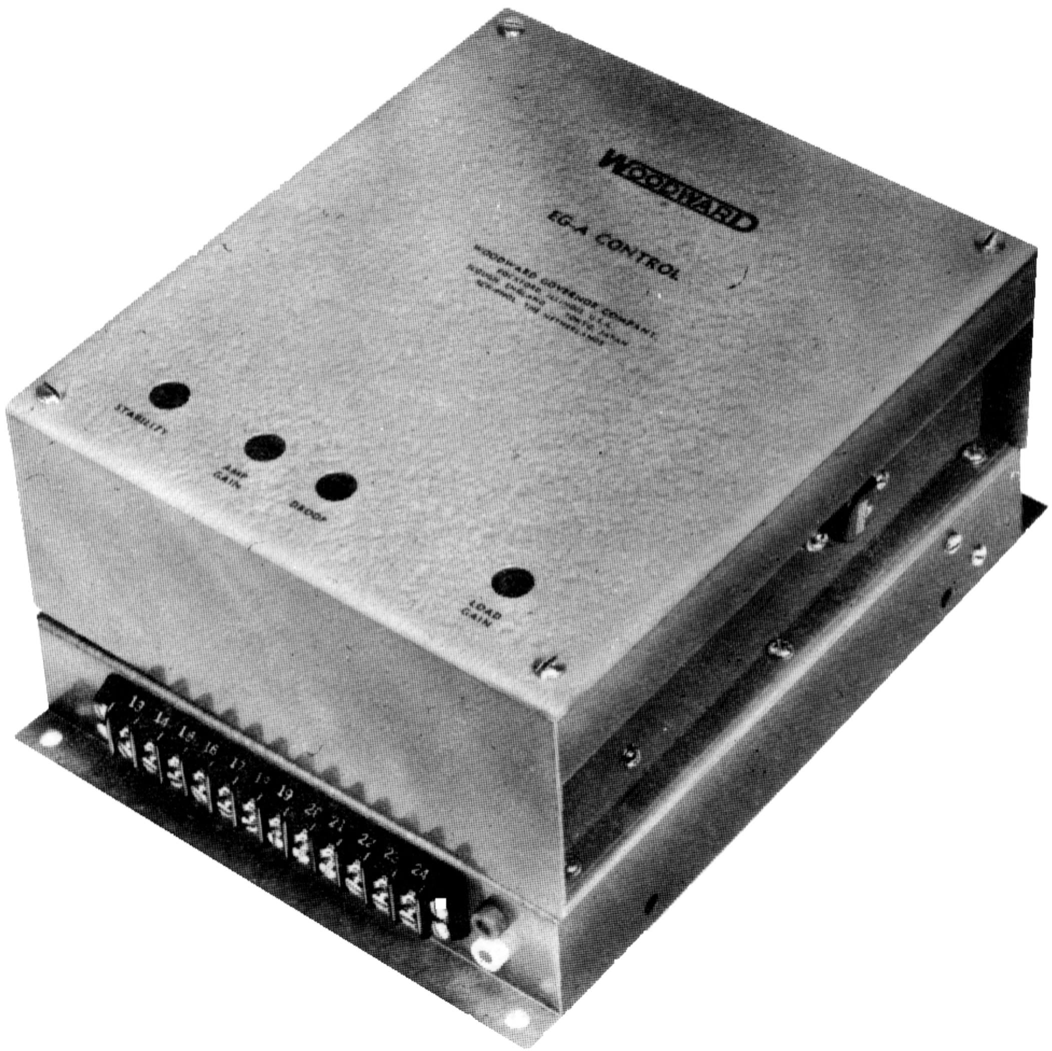


Figure 8-7

EGA Control Box

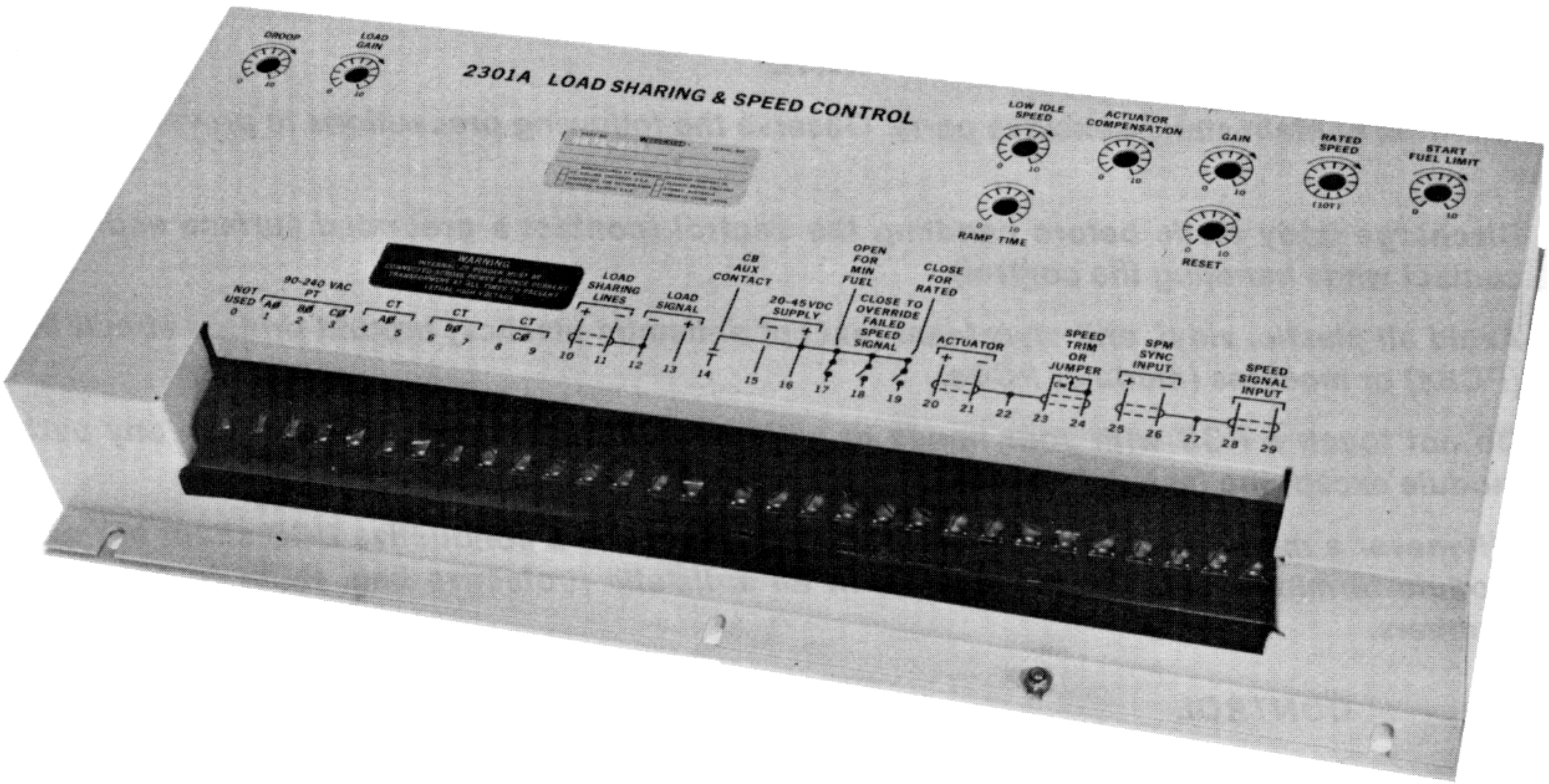


Figure 8-8 2301A Control Box

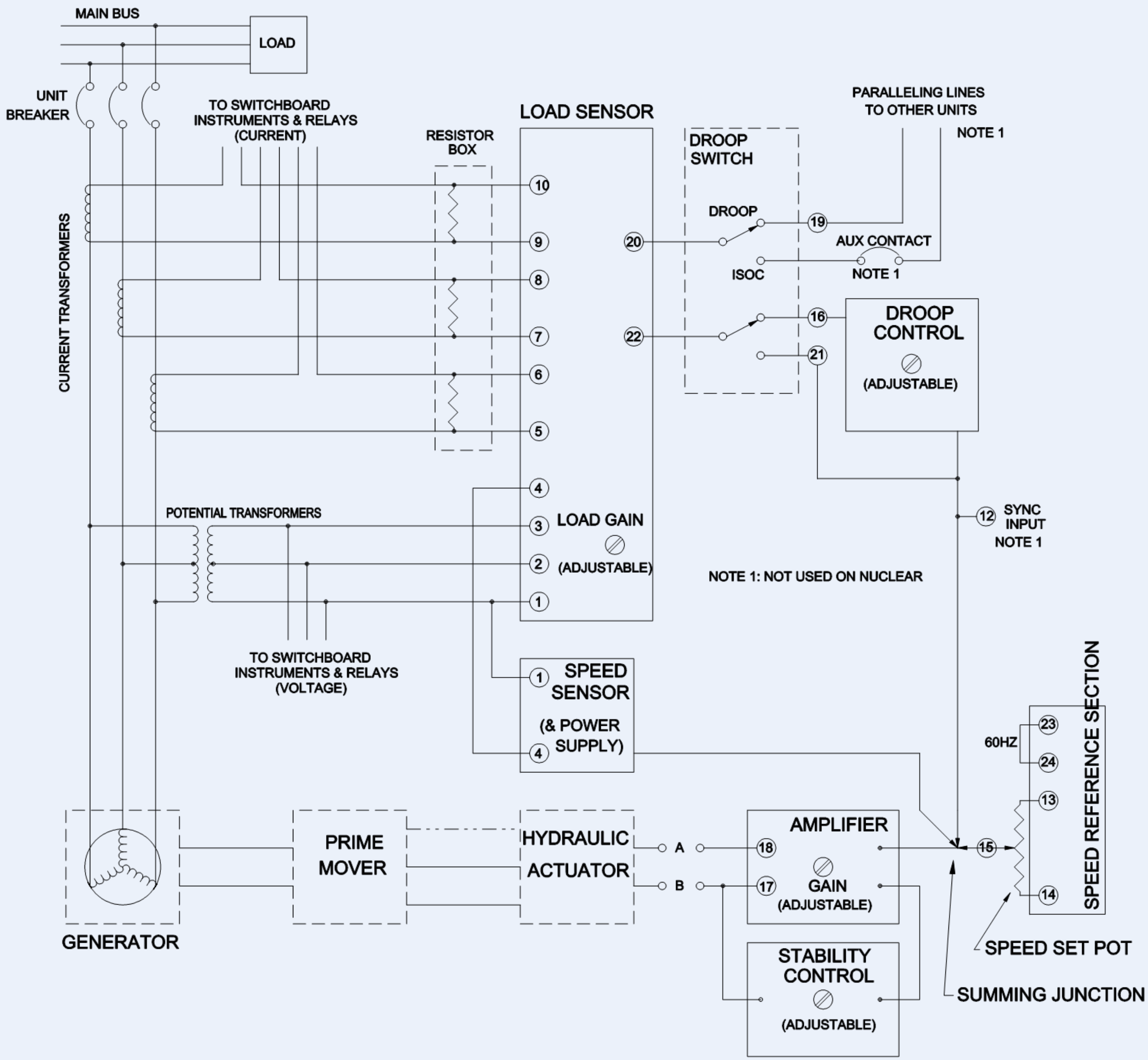


Figure 8-9 EGA Control Block Diagram

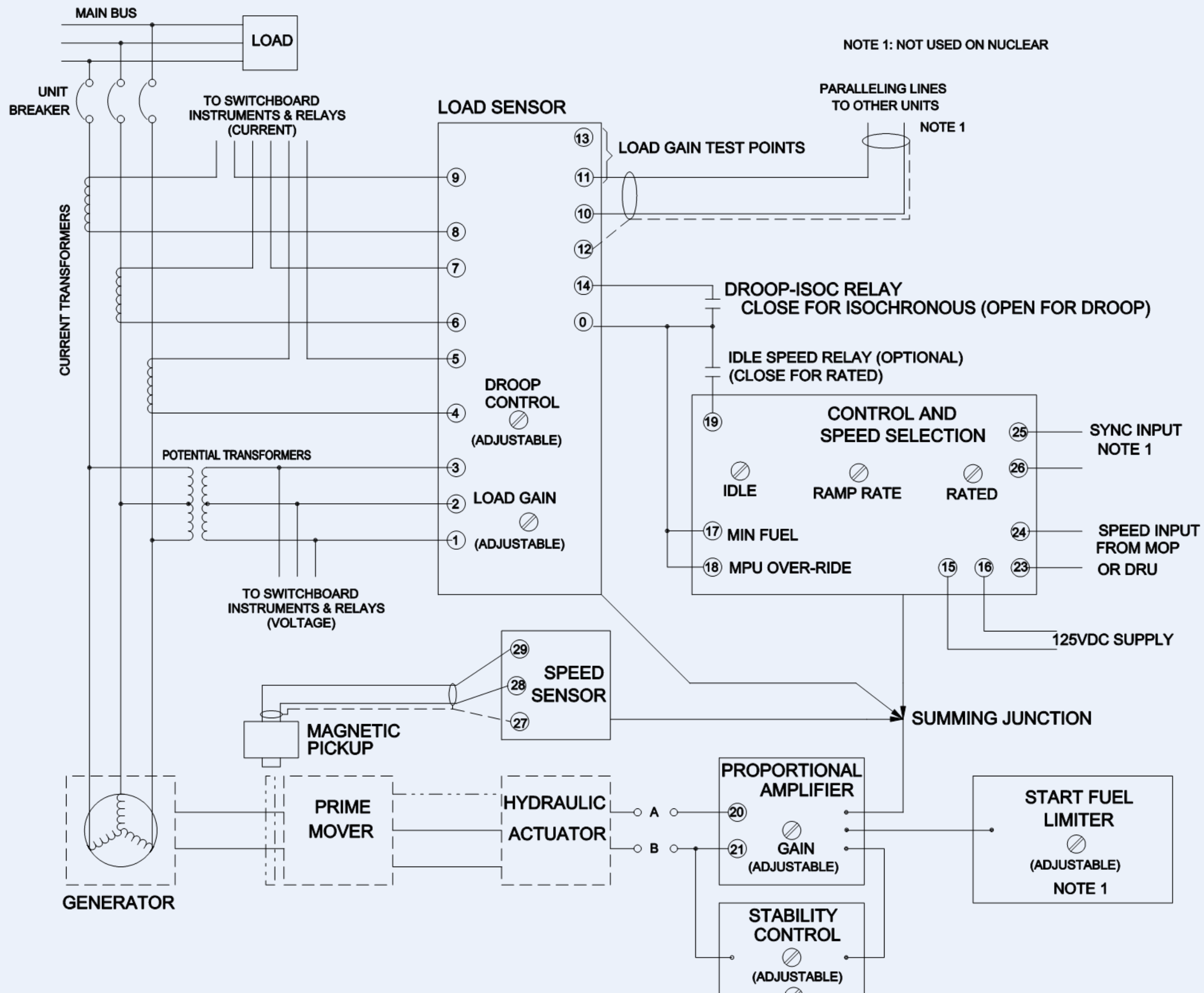
EGA Advantages and Disadvantages

Advantages of EGA

- Powered from Generator Voltages – Self Sufficient
- Will respond to emergency signals with engine shut down, for fast start

Disadvantages of EGA

- No governing until Generator is at voltage
  - for power supply and
  - for Speed Sensing
- Part of compensation is hydraulics within actuator, subject to oil temperature and condition.



[redacted] - 2301A CONTROL BLOCK DIAGRAM

Figure 8-10 2301A Control Block Diagram

2301A Advantages

- Control under all conditions (not dependent on generator voltages).
- All compensation is electronic – tuned for best performance.
- Can control at idle or rated speed equally well.
- Use of a Digital Reference Unit (DRU) with the 2301A enhances operational flexibility…
  - Can respond to Emergency signal at shutdown/idle (Fast start)

2301A Disadvantages

- Requires external power (125 VDC) to operate
- Requires Magnetic Pickup (MPU) for speed input

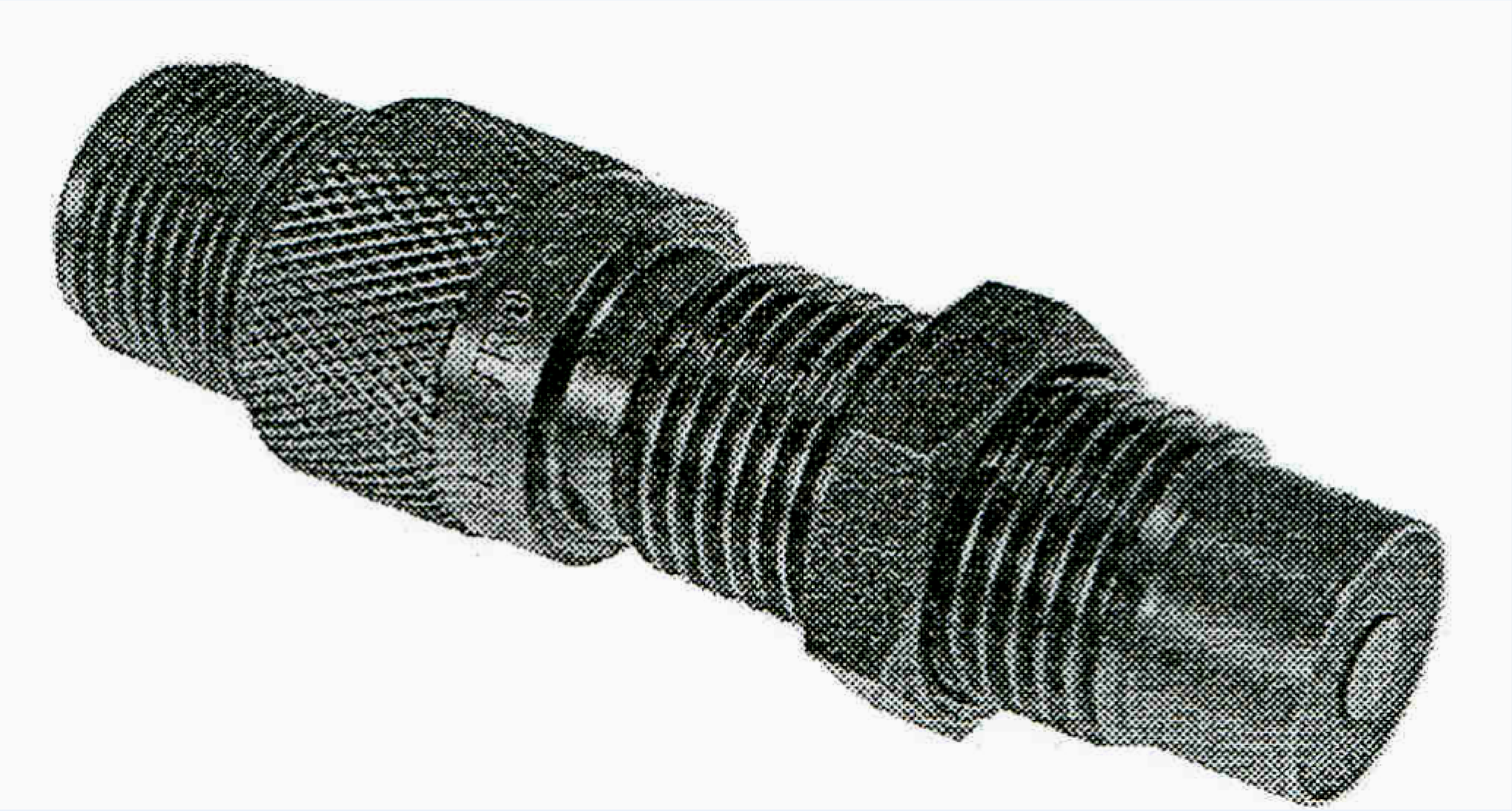


Figure 8-11 Typical Magnetic Pickup

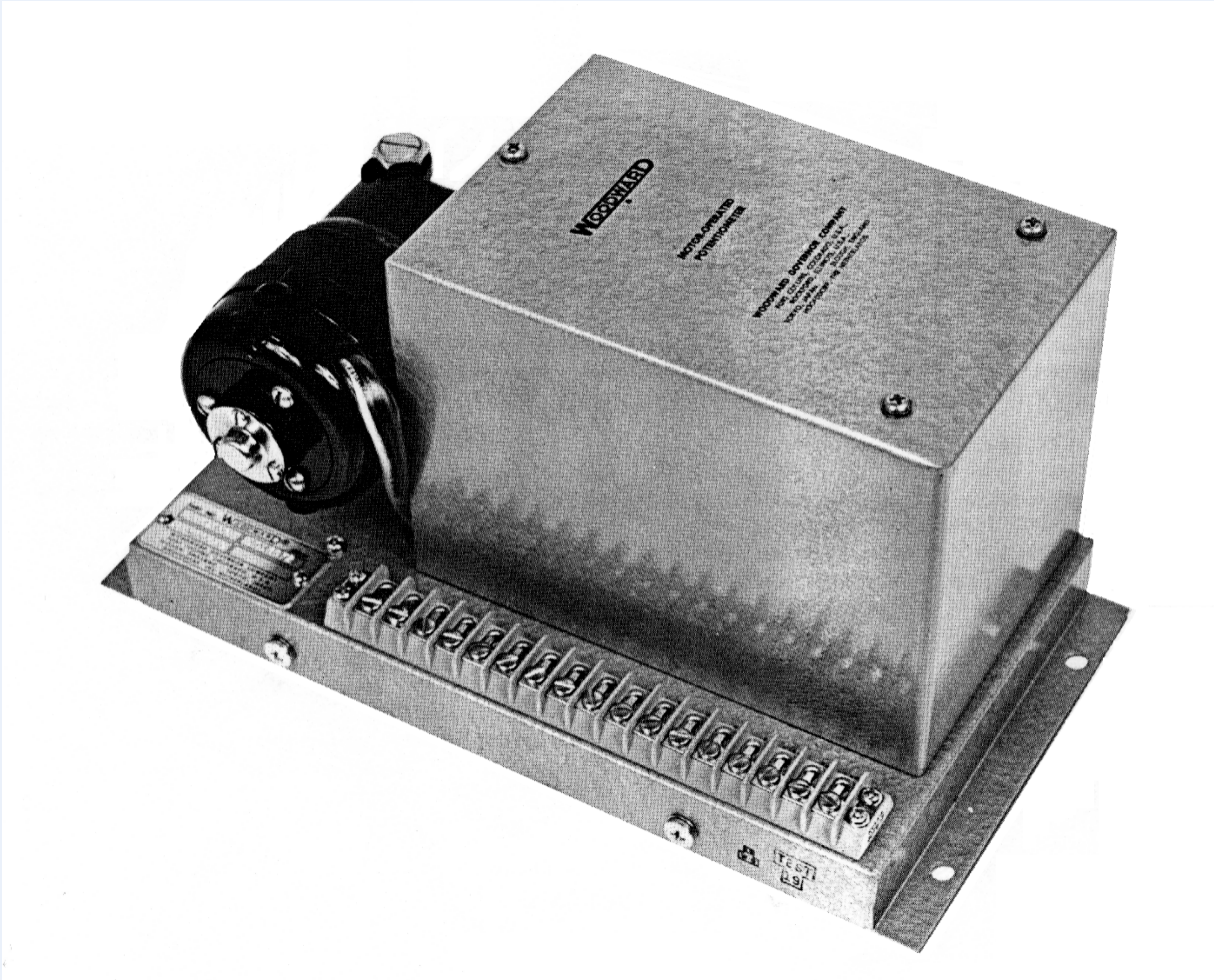


Figure 8-12 MOP with 125 VDC Motor

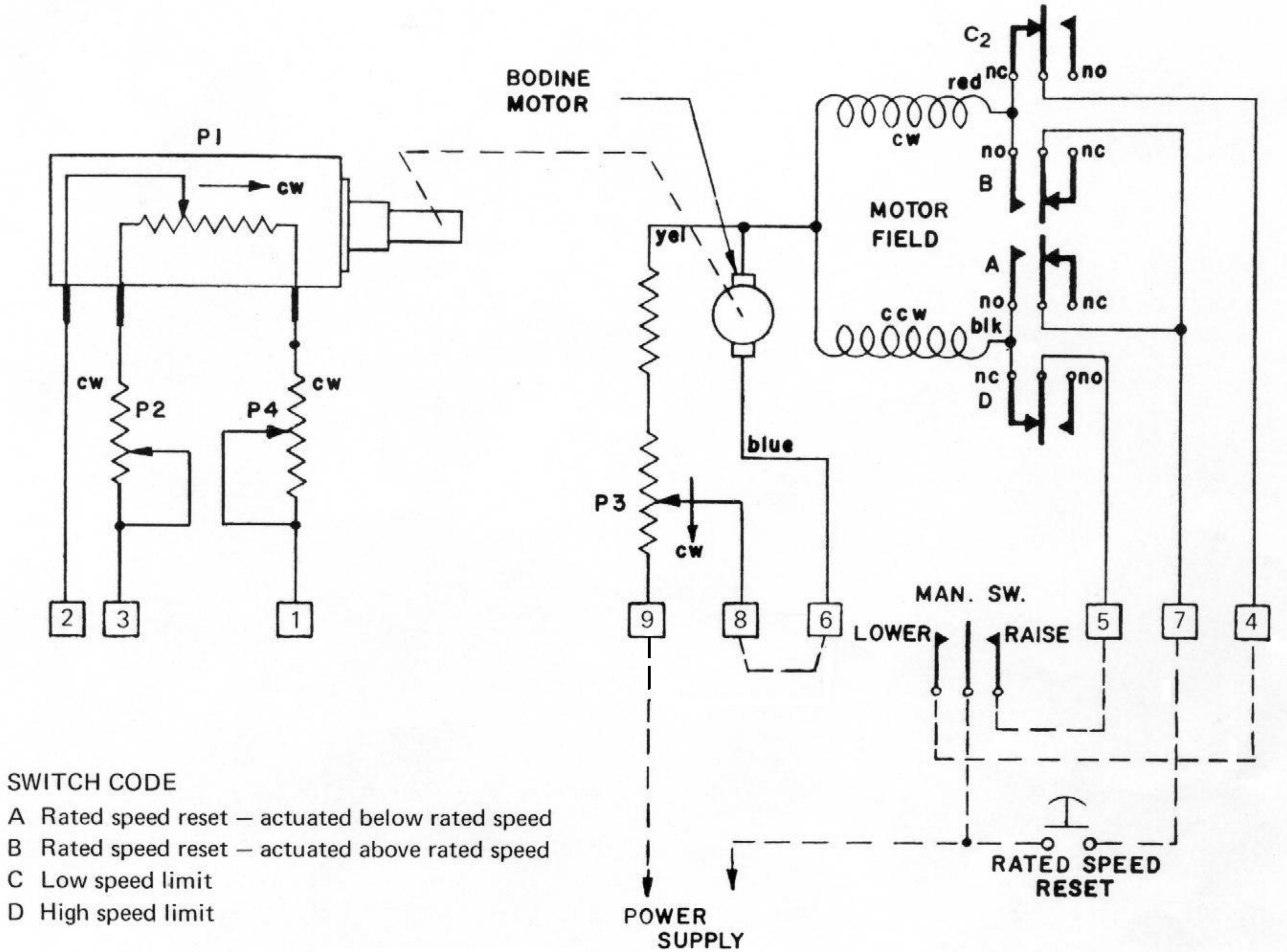


Figure 8-13 Schematic of MOP Unit

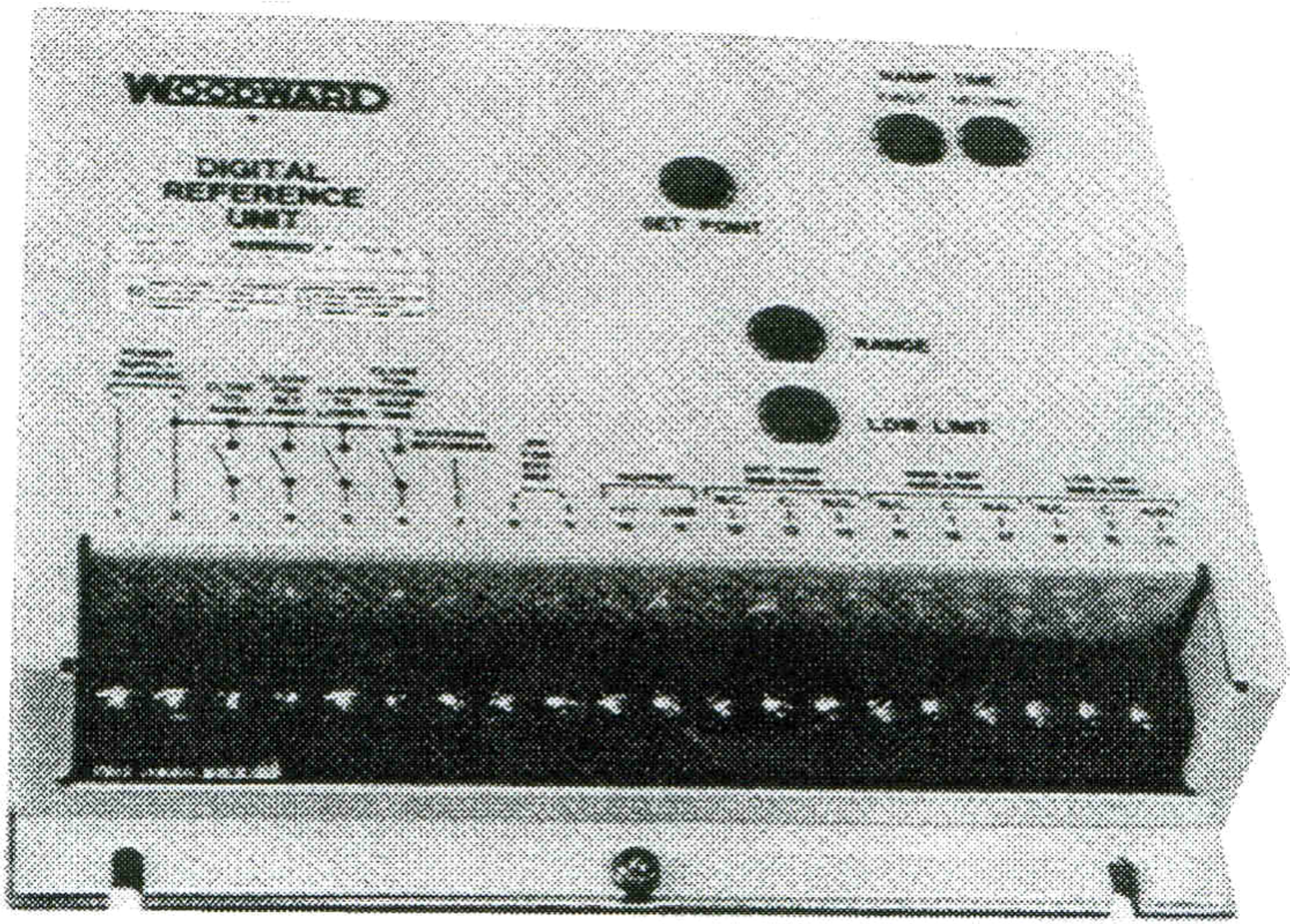


Figure 8-14 Digital Reference Unit (DRU)

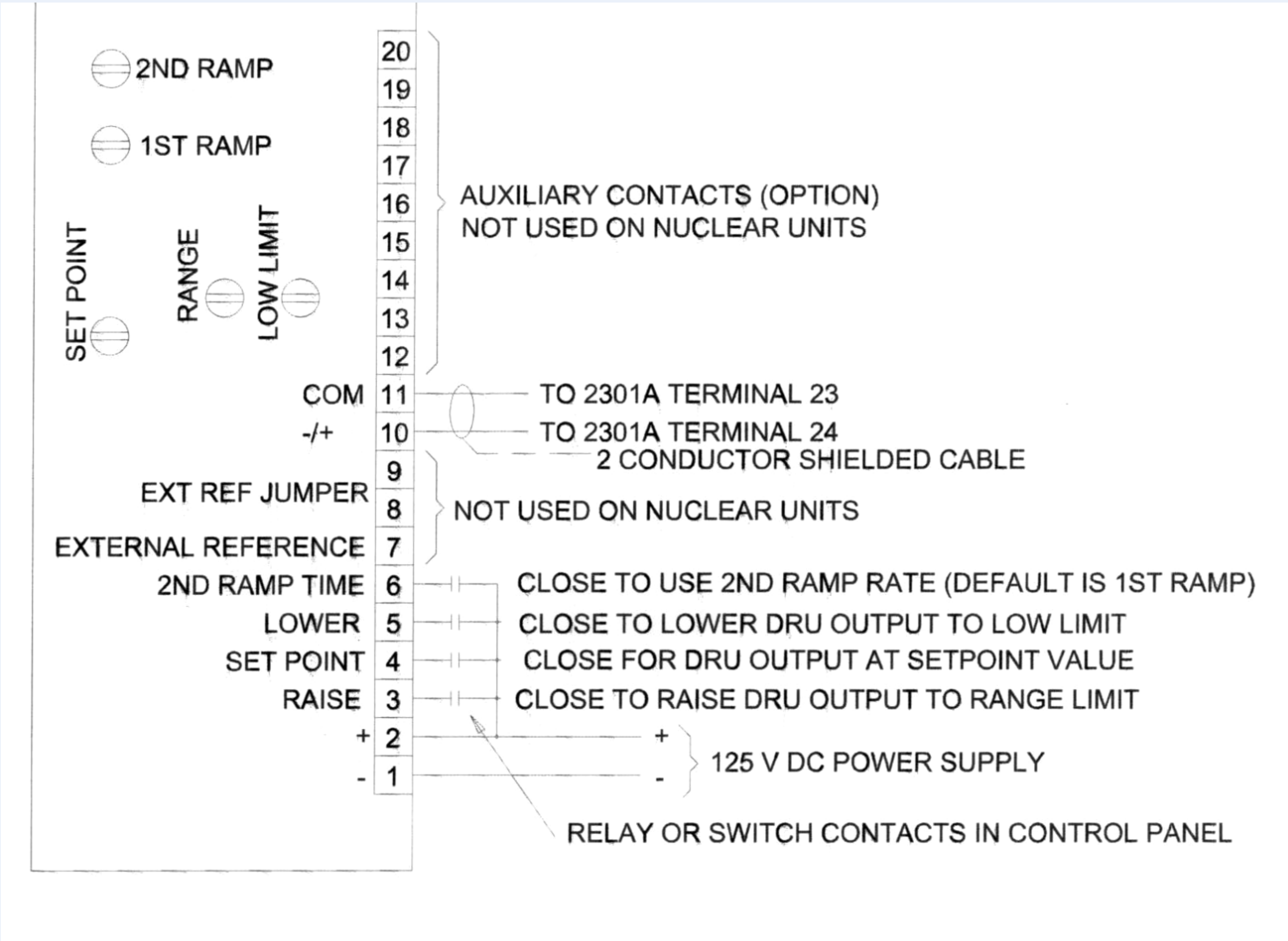


Figure 8-15 DRU Connections

The relationship between governor actuator output shaft rotational position and the engine fuel input is illustrated in Figure 8-16.

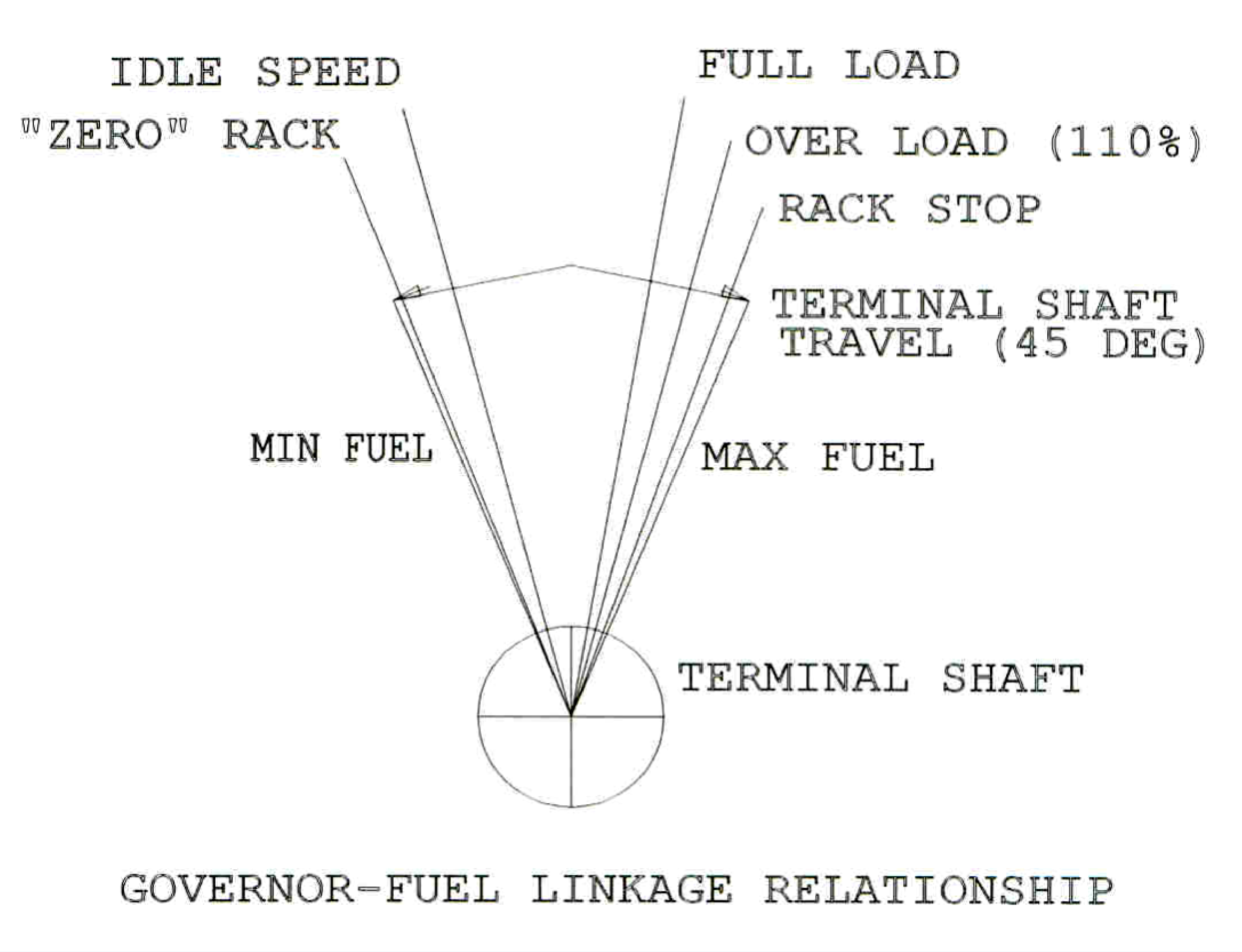


Figure 8-16 Relationship Between Governor Output and Fuel Control (Rack)

The 2301A Solves the Fast Start Problem

- A fast start (10s) with loading ≈ 30-50 hours engine operation at rated load. Fast starts reduce EDG life, reliability.
- NRC Generic Letter 84-15 encouraged plants to make slow starts during routine testing. However, the EGA governing system cannot make a slow start on the electric governor…
- Its mechanical backup governor can be used for slow starts. But in this state, the unit **cannot** respond to an emergency start signal and is effectively "inoperable."
- The 2301A governor with a DRU will ramp up-down slowly under electronic governor control and also **can** go to rated speed immediately (≈5 seconds) upon an emergency signal.

In Summary…

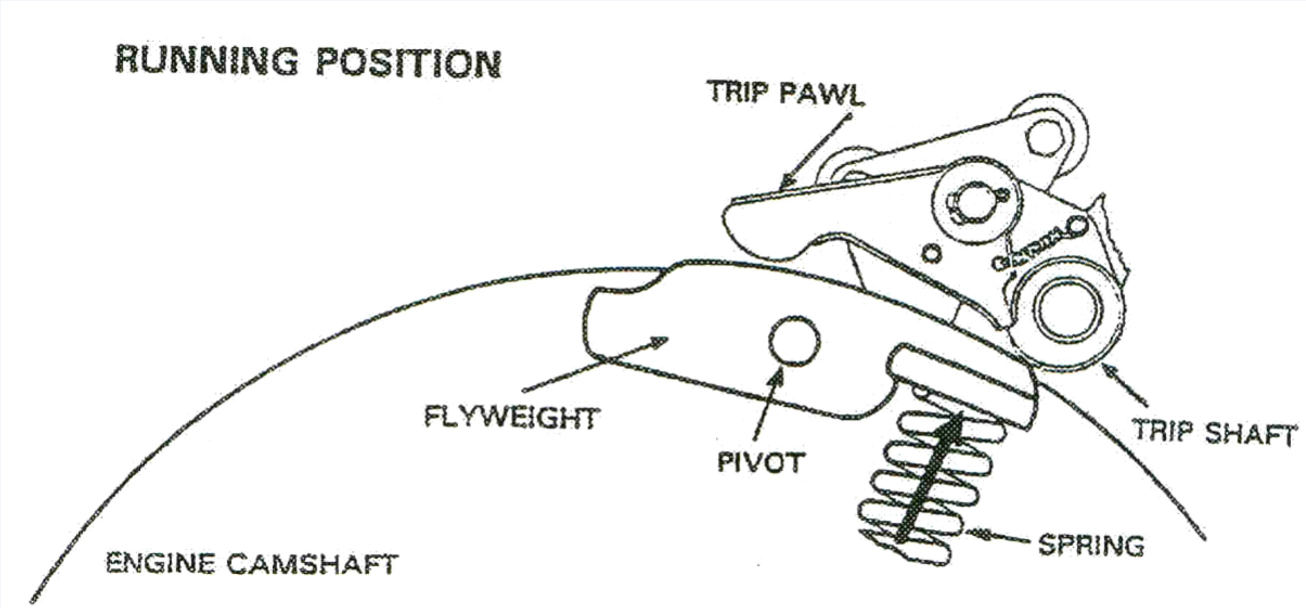
- Woodward will no longer provide or repair type EGA controls but they can be replaced by the 2301A. MOPs can be replaced with DRUs.
- When coupled with a DRU, the 2301A will reduce EDG stress and wear during test, by eliminating fast starting, and yet assure the system is immediately available for automatic emergency service in isochronous mode.

Engine Over-speed Protection

EDGs are provided with an over-speed trip:

- Independent, strictly mechanical device
- Shuts engine down to prevent damage
- Requires manual reset before restarting

Figure 8-17 is a typical over-speed device.



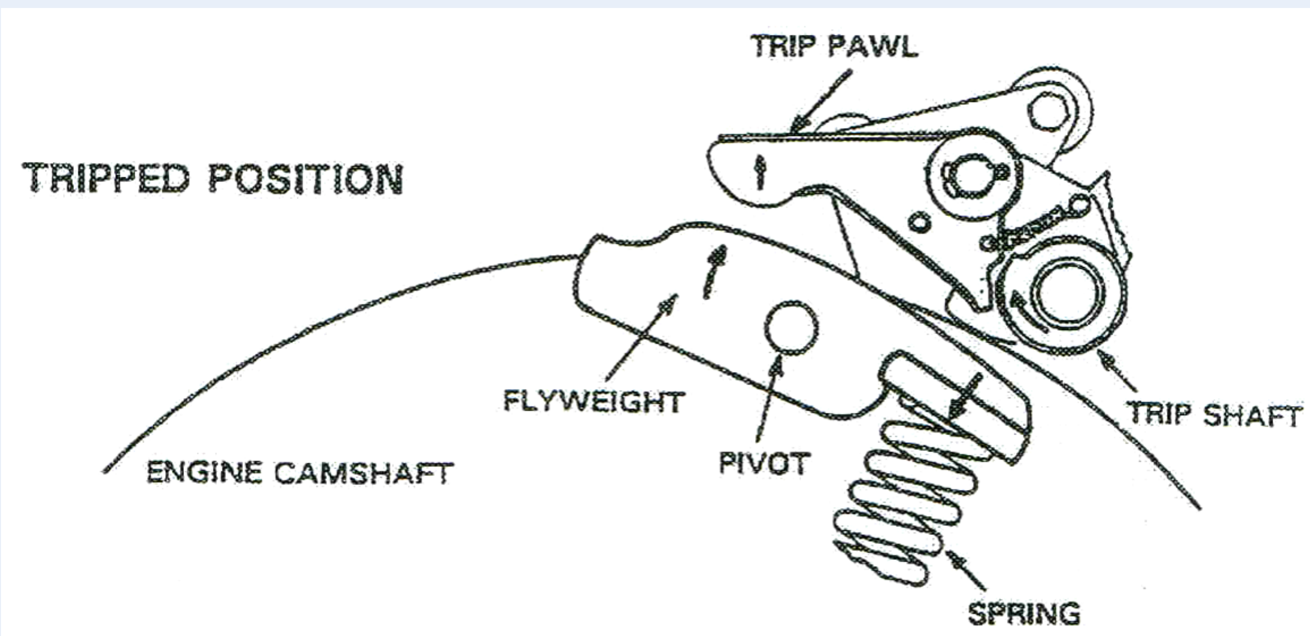


Figure 8-17

Over-Speed Trip (Governor) Mechanism

Some Digital Governing Systems

- Woodward 2301D, a digital version of the 2301A
- Woodward 723PLUS series of governors and components

Many features for wide range of special applications such as automatic load sharing / peak shaving, unattended and/or remotely controlled generation, etc. Those added features:

- Not applicable to nuclear plant service
- Increase system complexity, and cost

Digital Governing (continued)

Digital systems need DC power from a source such as:

1. Dedicated separate battery system for the governor power ($24V_{DC}$ typical)
2. Inverter power supply, where DC input is converted to AC, transformed to lower voltage, then rectified back to DC and regulated to the desired output voltage.
3. Simple voltage dropping circuit – hard to regulate when the input voltage can vary from 90 to $140V_{DC}$ and the governor load is not constant.

Digital Governing (continued)

- Applying the 2301D would be equivalent to the 2301A installation and would be a candidate for replacement of the EGA systems except for the power supply problem.
- Using the 723 series for EDG systems would require a DSLC (Digital Synchronizer Load Control) unit. Both are powered with 18 – 40 VDC and the equipment would take more space than available in replacing EGA components.
- Neither would improve frequency response or recovery. For large motor starting loads, that's much more controlled by the engine than response time of the governor system.

Digital Governing (continued)

- Governing systems in Nuclear plant are simple and provide:
  - Good control of frequency when the EDG is supplying power to the emergency bus.
  - Means to load the EDG on the offsite power bus for periodic surveillance testing.
- Digital governor components are much more expensive than the analog (2301A) systems.

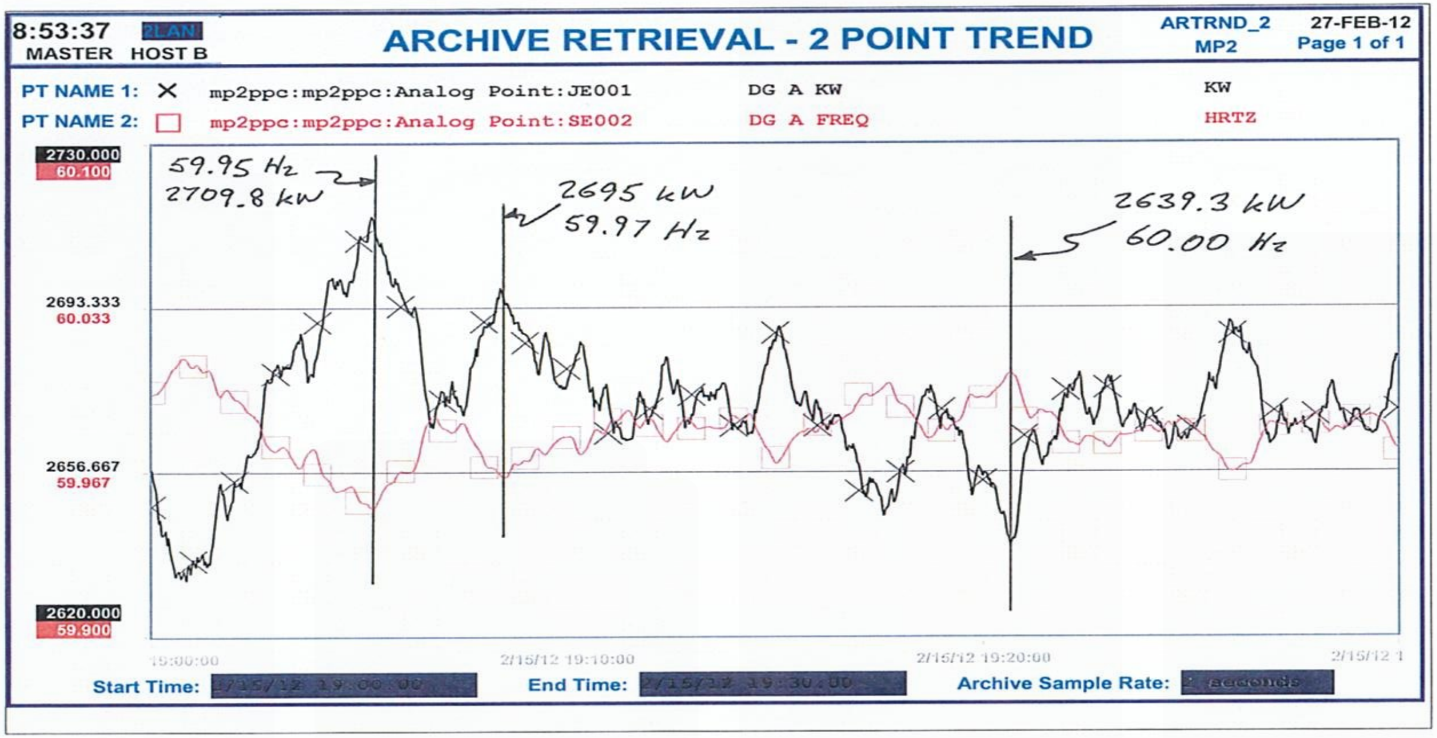
A Revealing Example of Grid Dynamics

The power grid is not static and the next slide illustrates how dynamic it can be. This has some important load implications for all power plants, and for EDGs when connected to the grid for testing.

Operating EDGs in "droop" when on the grid causes load on the EDG generator to change because of grid dynamics.

Detroit Edison – Load Swings – Bus HZ changes

3% Droop – 61.8 hz @ rated load – 1.8 hz change



Frequency Recorded	KW Load Recorded	Frequency Change	Percent Change	Computed KW Change	Predicted KW Load
60	2639.3	0	0	0	2639.3
59.97	2695.0	0.03	1.66%	43.93 KW	2683.28
59.95	2709.8	0.05	2.77%	73.31 KW	2712.6

END OF CHAPTER 8