EXCITATION SYSTEM
AND
POWER PLANT REGULATING SYSTEM

LOCOMOTIVES WITH MODEL 244 ENGINES

ALCO-GE DIESEL-ELECTRIC LOCOMOTIVE SCHOOL
INSTRUCTION SERIES
No. 800A

EXCITATION SYSTEM

AND

POWER PLANT REGULATING SYSTEM

SECTION 1 - PROPULSION EQUIPMENT

Propulsion equipment on ALCO-GE road locomotives includes the diesel engine, traction generator, traction motors and excitation system. The locomotive's source of power is an ALCO Model 244, V-type, turbosupercharged, 4-stroke cycle diesel engine. A $9 \times 10\frac{1}{2}$, 12 cylinder engine is installed in each road freight or road switching locomotive.

A 16-cylinder $9 \times 10\frac{1}{2}$ engine is installed in each road passenger locomotive Mechanical horsepower developed by the diesel engine is converted to electric power by the locomotive's traction generator. The traction generator of freight and road switching locomotive is a General Electric Type GT564, 10-pole, direct-current, commutating-pole type, separately-excited shunt generator. The same description fits the traction generator of the passenger locomotive, except that the latter is a 12-pole, Type GT566.

The traction generator's armature is directly coupled to the diesel engine crankshaft. As the engine's crankshaft rotates, it rotates the armature.

The armature has a general cylindrical shape and is made of laminated iron. Insulated copper conductors are laid in slots cut lengthwise in the surface of the cylinder.

As the armature is rotated by the diesel engine, its conductors cut across magnetic lines of force which are produced by the electro-magnetic "pole pieces of the traction generator. These magnetic lines of force are usually referred to as "flux lines" or "flux". The pole pieces each consist of a block of iron, around which is wound a coil of wire called the "field winding" or "field coil". When current from a small generator called an "exciter" is passed through the field winding, the iron pole pieces will become magnetized. Flux lines will pass from one pole piece to another. As the armature is rotated, its conductors pass the pole piece faces and cut across the flux lines (Figure 1). When the conductors cut flux a voltage (electrical pressure) will be generated in them. The strength of the generated voltage depends on how many flux lines the conductors cut in a given time. If only a few flux lines are cut, the voltage will be weak. If many lines are cut the voltage will be stronger. The voltage can be varied as follows:

1 - By varying the number of flux lines.
2 - By varying the speed of the conductors.
3 - By varying both speed and flux.

→ -Indicates direction of field current flow

↷ -Indicates rotation of armature conductors

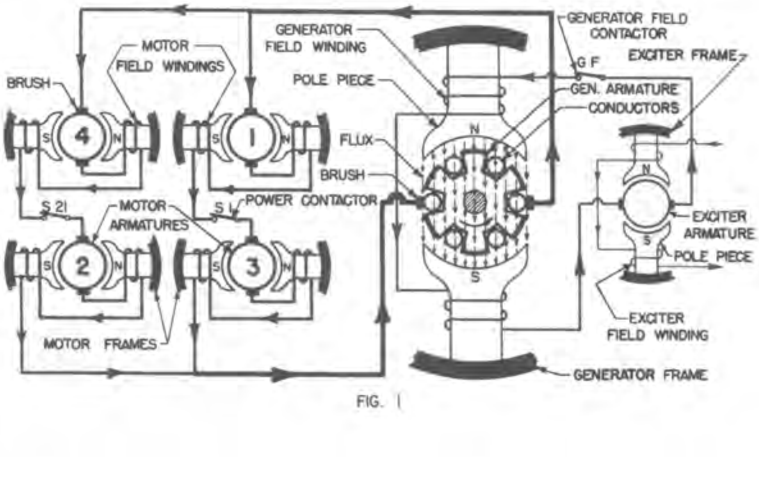


FIG. 1

The flux may be varied by changing the current which the exciter supplies to the field winding. An increase in current will increase the number of flux lines and a decreased current will have the opposite effect.

The speed of the conductors may be varied by changing the speed of the diesel engine. Slowing the diesel engine speed will decrease the rotational speed of the traction generator armature and slow the conductor speed. Increasing diesel engine speed will increase conductor speed.

Thus, voltage will be generated in the traction generator armature conductors, whenever the armature is being rotated by the diesel engine and the exciter is supplying the field winding with current to magnetize the pole pieces.

Both rotation and field current must exist at the same time.

Armature conductors are each connected to one of many copper bars which form the generator commutator. When the brushes, which are in contact with the commutator bars, are connected to the traction motors by the closing of switches called "contactors", a complete circuit from the traction generator armature conductors to the traction motors will exist (heavy lines in Fig. 1 show this circuit). When a complete circuit exists, the voltage in the traction generator armature conductors will push current through the connecting cables to the traction motors. The amount of current flow to the traction motors depends on two things:

a - Resistance of the traction motors and the cables which connect them to the traction generator.
b - Strength of the voltage developed by the traction generator.

Traction motors used in ALCO-GE locomotives with 244 Type engines are General Electric Type GE752, 4-pole, direct-current, series-wound, commutating-pole motors, with single reduction gearing, which connects their armature shafts to the locomotive driving axles. The current which the traction generator supplies to the traction motors will cause them to develop torque which will rotate the motor armatures and turn the driving axles to produce locomotive movement. The traction generator of each locomotive unit supplies power to four traction motors which are represented by numbers 1, 2, 3 and 4 in figures 1 and 2.

When the engineman desires to move the locomotive and its train, he operates the locomotive throttle, selector handle and reverse handle. Movement of these levers to the desired positions will cause the power contactors to close. The traction generator field winding will be energized with current from the exciter and, with the generator armature being rotated by the diesel engine, current will reach the traction motors and produce locomotive movement.

The excitation system of the locomotive acts to make the diesel engine and the traction generator operate together efficiently. It controls the amount of current which the exciter delivers to the traction generator field winding. The excitation system will automatically vary the field current to suit operating conditions. As will be explained in detail, later in this instruction, the excitation system will decrease the generator field current if the diesel engine or traction generator is in danger of overload. It does this by decreasing the exciter field current. The exciter, too, is a generator with an armature and a field winding. The current which the exciter supplies to the generator field can be varied by varying the exciter's field current.

Figure 1 illustrated a fundamental 2-pole generator with four traction motors connected to it in a series-parallel connection. Figure 2 shows generator and motors as they would be illustrated on a wiring diagram. The generator armature is represented by a circle with a "G" in it. Each traction motor armature is represented by a circle with a number in it. The field windings of both generator and motors are represented by the zig-zag symbol "-ΛΛΛ-". These symbols, the circle and the zig-zag, will be used throughout this instruction to represent the armature and field winding of a motor or generator.

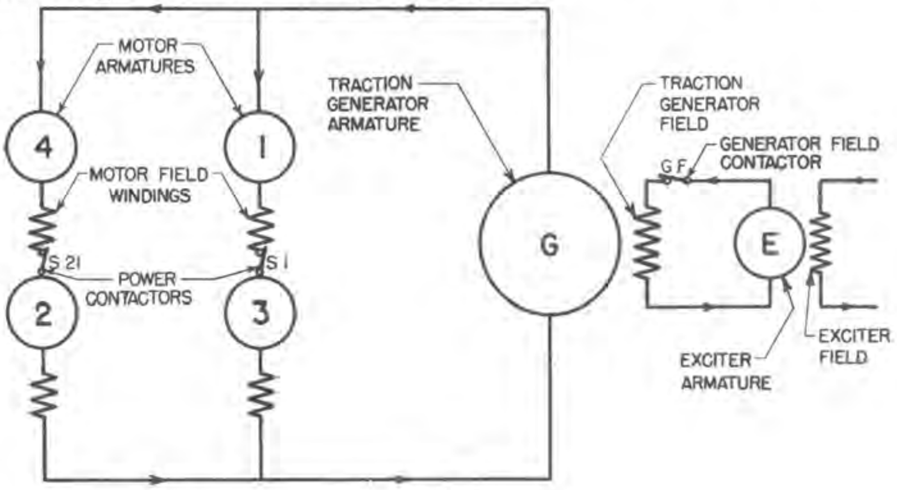


FIG. 2

Figure 3 illustrates the relationship of the diesel engine, main generator, exciter and traction motors and the positions they occupy on the locomotive.

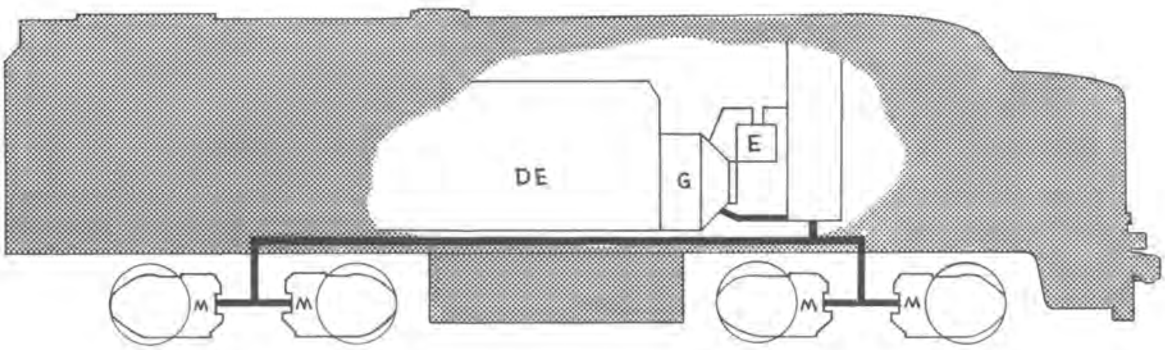


FIG. 3

The excitation system and the power plant regulating system work in very close coordination. They are two of the most important parts of the diesel-electric locomotive's control equipment.

The excitation system controls the traction generator's operation and the power plant regulating system controls the diesel engine's operation.

The fact that the diesel engine (mechanical equipment) and the traction generator (electrical equipment) are combined to supply the power which drives the locomotive, means that these radically different equipments must work together efficiently. If they were left to their own devices, that is, without any control equipment to regulate their operation, efficient operation would be impossible.

CONTROLLING DIESEL ENGINE OPERATION

The engineman who operates the locomotive is provided with a throttle. The throttle has an "Idle" position and eight power positions, numbered 1 through 8. As he advances the throttle from one power position to another, the diesel engine will increase its speed from one constant number of RPM to another constant number of RPM. The throttle, in advancing, causes the power plant regulating system to allow an increase in fuel injection and the increased quantity of fuel will make the engine run faster. When the throttle is in any one of its several positions, the power plant regulating system will regulate the fuel injection and generator loading in such a manner, that the engine speed will be held constant in accordance with Table 1. By the term "Engine Speed" as used throughout this instruction, is meant diesel engine revolutions per minute—not locomotive miles per hour.

TABLE 1

Throttle Position	Engine Speed
Idle and 1	350 RPM
2	450
3	550
4	655
5	765
6	860
7	920
8	1000

It is important that engine speed be held constant in each throttle position. If allowed to surge it will cause the horsepower of the engine to surge. Horsepower surges make smooth train handling a difficult job and they should be held to a minimum.

The power plant regulating system has the job of keeping engine speed constant in each throttle position and changing engine speed whenever the throttle position is changed. The power plant regulating system, through the governor accomplishes this, because it controls the operation of the diesel engine's fuel injection pump With a steady unchanging load on the engine, speed will be constant as long as the rate of fuel injection is held constant. If fuel injection is increased, engine speed will increase or if fuel injection is decreased the engine speed will decrease.

If the load on the diesel engine increases, the engine will slow down. The governor will immediately increase fuel injection to bring the speed up again. If diesel engine load decreases the engine will tend to speed up, but the governor will then decrease fuel injection to bring the engine back to its proper speed.

Thus the speed of the diesel engine can be affected in two ways:

a - By a change in load.
b - By a change in the quantity of fuel injected.

As the governor's primary function is to control engine speed, it should therefore be capable of controlling both fuel injection and load, because both affect speed.

The 17MG3 governor controls both fuel injection and load. In addition to the control of fuel which has already been mentioned, the governor's equipment includes a rheostat which acts as a variable resistance in the exciter field circuit. If the governor has allowed the engine maximum fuel injection, but additional load slows the engine below its rated speed, the governor will cause its "Load Control Rheostat" to add resistance to the exciter field circuit. When resistance is added to the circuit, the current in the circuit will reduce. With exciter field current reduced, the exciter output current, which is supplied to the traction generator field, will be reduced. This reduces the electrical load of the traction generator and thus allows the engine to regain its speed. This action is called "Load Control". It is fully explained under "Power Plant Regulating System" in Section 3.

TRACTION GENERATOR CONTROL

The load control mentioned above is actually a type of traction generator control, but it is referred to as diesel engine control because its effect primarily concerns the diesel engine.

The excitation system controls the power output of the traction generator. The output must be properly controlled or inefficient operation and equipment damage will result. The traction generator converts the horsepower of the diesel engine into voltage and current. The latter two combine to produce electric power.

The voltage output of a given size generator depends on the speed at which the armature is rotated and on the amount of flux produced by the magnetized pole pieces. Flux depends on exciting current being passed through the field winding.

Because the excitation system controls the amount of current which flows through the field winding, it therefore controls the voltage output of the generator In doing this it protects the generator against excesses of voltage and current which would damage the generator.

It is important that voltage and current be prevented from exceeding their safe limits. If the generator is permitted to generate too high a voltage, the generator's insulation might be damaged. Voltage is electrical pressure and excessive electrical pressure will puncture insulation. The other type of electrical excess, too much current flow, will have a different effect. The flow of current causes heat. Too much current flow through the generator's conductors would generate excessive heat. The generator's insulation would eventually be destroyed by high temperature.

The excitation system, through its control of the generator's field current can prevent the generation of too much voltage or too much current. Whenever either of these excesses occur, the excitation system automatically reduces the generator field current. With reduced field current the voltage and current output of the generator is reduced and overloads are prevented.

TRACTION GENERATOR CURRENT CONTROL

In a well designed diesel-electric locomotive, no two types of overload will ever occur at the same time. At very low locomotive speeds, when a heavy train is being started, very high current is being generated by the traction generator. The excitation system should control this current and prevent it from becoming excessive. The General Electric excitation system uses a pair of Saturable Core Reactors to measure the generator output current and determine its value. If it is excessive, the reactors will act to reduce the exciter field current and thus bring the traction generator output current down to a safe value. This is called Current Limit Control or Load Current Control and is fully explained in Section 2.

As the locomotive accelerates its train, the traction generator current reduces. With 65 MPH gearing, when a speed of 9 to 10 miles per hour is reached the current will have reduced to a value which will no longer severely overheat the traction generator. Danger of current overload is now minimized.

ENGINE LOAD CONTROL

While the locomotive accelerates its train from 0 to 10 miles per hour, the horsepower output of the engine and the voltage of the traction generator increase with locomotive speed. The horsepower demand on the engine depends on the amount of voltage and current generated by the traction generator. The product of voltage and current is watts.

Volts x Amps = Watts

The unit of electrical power is the watt. 746 watts is equal to one horsepower. At speeds below 10 miles per hour high tractive effort is needed to get a train rolling. The high current flow will cause the traction motors to produce this necessary tractive effort. But although current is high, voltage is quite low and therefore the total watts of the generator represent a horsepower demand on the diesel engine which the engine can easily meet. With locomotive acceleration, voltage increases and current decreases but the former increases at a more rapid rate than current decreases. Therefore watts increase and the diesel engine must supply the generator with steadily increasing horsepower in order that the generator may produce these watts. At about 10 miles per hour the diesel engine will be developing its full rated horsepower in order to meet the demands of the generator.

Further locomotive acceleration would require steadily increasing horsepower, unless the generator output in watts is prevented from increasing. The natural characteristic of the generator would be for its watts to increase as the locomotive accelerated to about 13 to 14 miles per hour, and to then decrease with further acceleration to 18 miles per hour. But this characteristic would allow the generator to overload the diesel engine.

This overload is prevented by the load control system which acts to prevent the generator from increasing its wattage above the value which is produced at approximately 10 miles per hour. By doing this, it will protect the diesel engine against too high a horsepower demand by the generator. The load control system is operated by the diesel engine governor and functions whenever the generator would normally attempt to overload the engine. It thus matches the generator output with the engine's ability to supply horsepower. On the 65 MPH geared locomotive, the load control system functions in the speed range between approximately 10 miles per hour and 60 miles per hour. At transition points (18, 24 and 50 MPH) it does not reduce generator watts below what they would normally be at these points, because the normal wattage, at these speeds, would be about the same as it is at 10 miles per hour. This wattage, as previously mentioned, would not cause an engine overload.

TRACTION GENERATOR VOLTAGE CONTROL

As the locomotive accelerates its train, the traction generator voltage increases. This occurs because the excitation system permits the generator field current to increase, in order that voltage will increase. By increasing voltage, the traction motor speed increases and this, of course, accelerates the train. At transition points and at maximum locomotive speed, traction generator field current and hence traction generator voltage will be at maximum value. Any increase in field current will overheat the field winding and damage it.

A second pair of saturable core reactors is used to measure the field current. If the field current exceeds the maximum safe value, the reactors automatically reduce the current in the exciter field. This, of course, reduces the exciter output to the generator field. The generator field current is thus prevented from reaching a value which would overheat the field winding by the controlling action of the reactors. This is called "Field Current Limit" and is fully explained in Section 2.

By preventing field current from exceeding a maximum safe value, the generator voltage is also held at a maximum safe value, because voltage depends on number of flux lines the generator conductors cut in a given time. In limiting field current, flux is limited and therefore, so is voltage.

VOLT-AMPERE CURVE

The volt-ampere curve of Figure 5A is a graphic picture of voltage and current values which are generated by the traction generator of a locomotive while the locomotive is accelerating a train from zero speed to about 18 miles per hour. The curve in Figure 5A represents traction generator voltage-current values which would result during eighth notch operation of the diesel engine (1000 RPM).

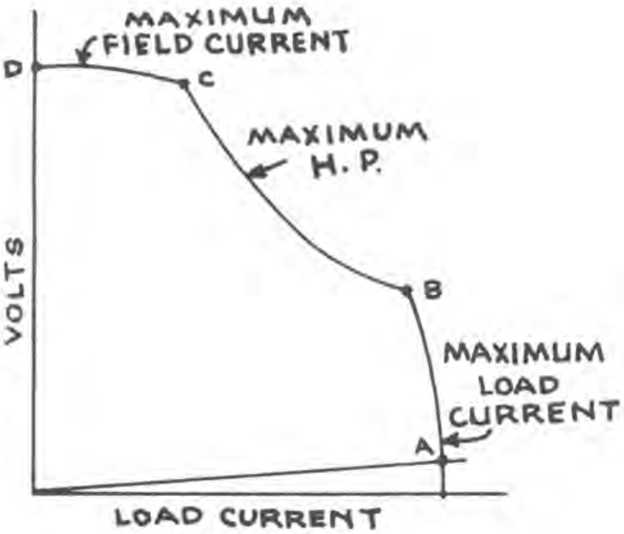


FIG. 5A

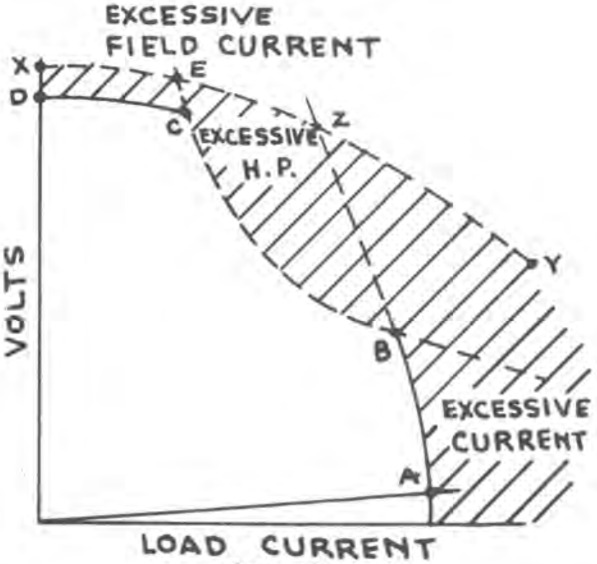


FIG. 5B

At zero locomotive speed, just before the traction motors begin rotating, voltage current values would be at "A". This would be maximum current value with very low voltage. Current is high because the resistance of the traction motors and their connecting cables is very small. Voltage is low because the excitation system reduces field current to a very low value. If field current was not reduced to a low value, the traction generator voltage would be higher and excessive current, such as is represented by the shaded area of Figure 5B, would result. Excessive current would cause wheel slippage, sparking of traction generator brushes and overheating of the generator and traction motors.

As the locomotive begins to move, the traction motors begin generating a counter voltage which opposes the flow of current from the traction generator. Generator current is thus forced to reduce as the locomotive accelerates. However, voltage is increased because the excitation system permits generator field current to increase, and the increased voltage prevents the current from dropping off too sharply.

Point "B" on the curve represents voltage and current values which would be generated at a locomotive speed of 9 or 10 miles per hour. The diesel engine develops its full rated horsepower at this point.

Further acceleration would cause increased voltage and gradually decreasing current along line BZ, Figure 5B, but these voltage-current values would represent too great a horsepower demand on the engine. Engine overload would result. To prevent this, the load control system reduces excitation so that voltage-current values are held to line BC, Figure 5A. Voltage-current values at any point on this line would represent maximum safe engine horsepower.

As the locomotive accelerates, voltage increases and current decreases along line BC until at about 18 miles per hour point C is reached. Field current at this point is approaching its maximum safe value. It is prevented from increasing further by the field current limit system and overheating of the generator field coils is avoided.

By limiting load current, engine horsepower output, and field current, the volt-ampere curve of Figure 5A results. If the excitation system did not impose these limitations the excessive values shown in Figure 5B would result and poor operation and equipment overload could not be avoided.

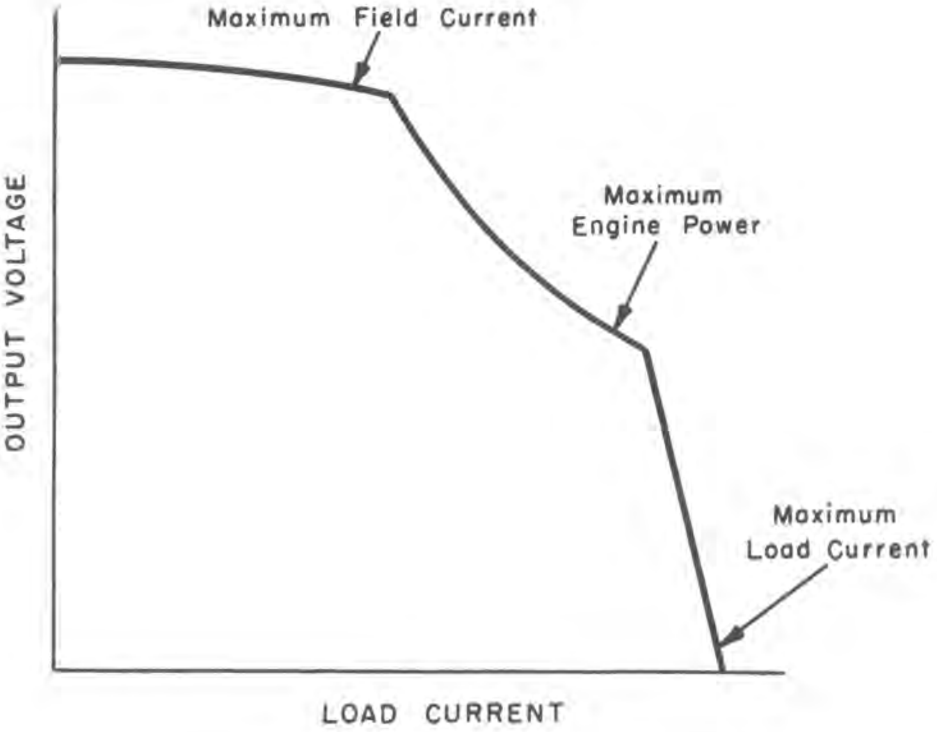


FIGURE 6 GENERATOR OUTPUT CURVE DETERMINED BY LIMITATIONS OF ENGINE POWER, MAXIMUM GENERATOR FIELD CURRENT AND MAXIMUM GENERATOR LOAD CURRENT

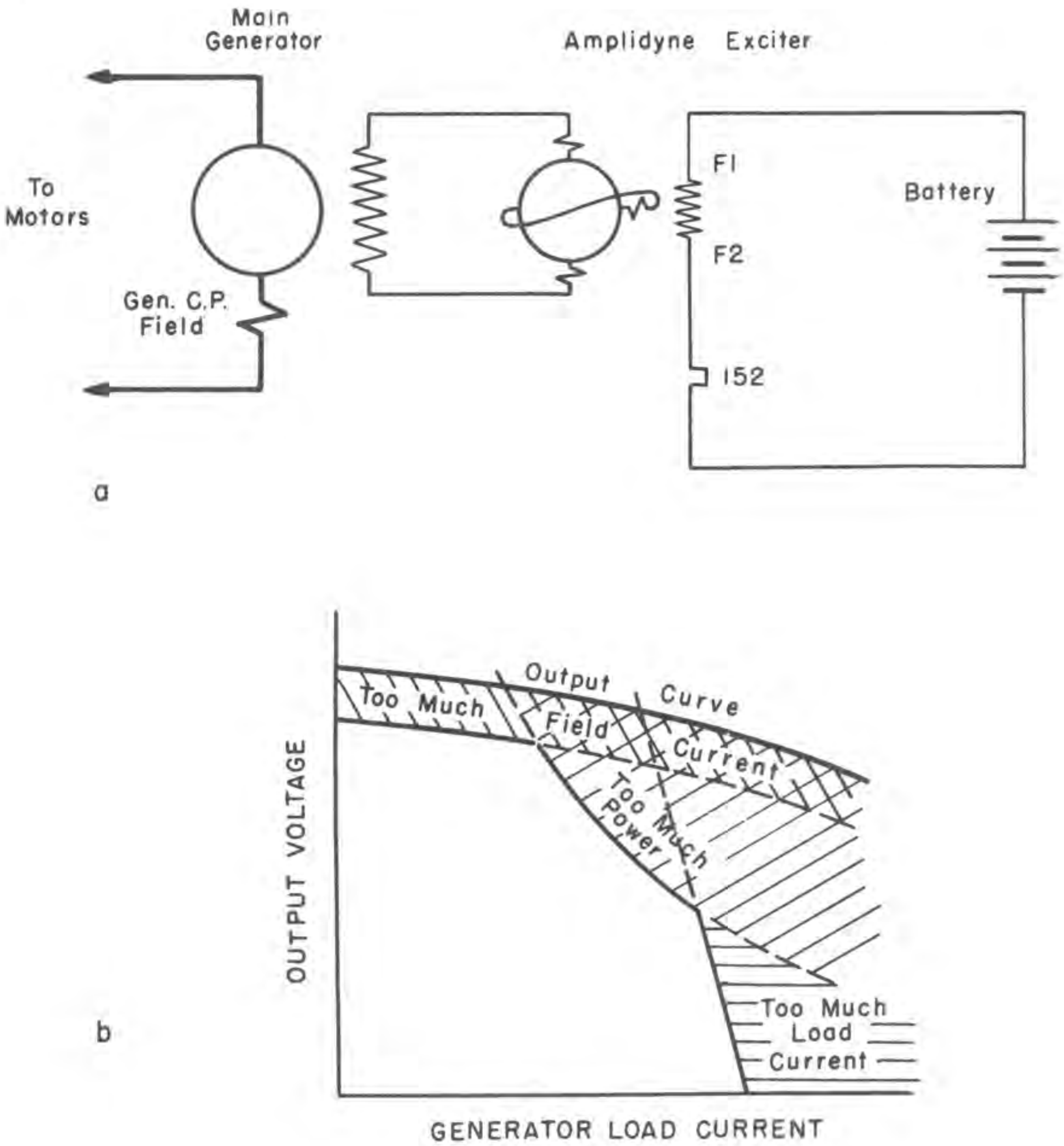


FIGURE 7 SIMPLE GENERATOR EXCITATION SYSTEM AND RESULTING GENERATOR OUTPUT

SECTION 2 - EXCITATION SYSTEM

BASIC SYSTEM

The excitation system furnishes current for the field of the traction generator. Figure 7 illustrates a simple excitation system. With an excitation system of this type the traction generator would supply power to the traction motors, but it would be impossible to control this power, because there is no control equipment to adjust the exciter field current. The current which the battery supplies to the F1-F2 field of the exciter would depend of the voltage of the battery and the resistance of the circuit. Assuming that battery voltage is constant, then current flow through the field would be constant, if we ignore the slight resistance increase caused by the heating of the field and resistor 152 due to current flow.

Figure 7A illustrates the addition of a control device to the exciter field circuit. "Load Control Rheostat 125" will reduce the F1 - F2 field current, whenever the generator overloads the diesel engine and slows it below its rated speed. This device protects the diesel engine against overloads, and also assists in controlling diesel engine speed. The load control rheostat, and the diesel engine governor which operate the rheostat, will be described later (see "Load Control" - Section 3).

With the traction generator armature and exciter armature rotating at maximum speed, the current flow to the traction motors would be high enough to damage the motors and the generator itself through excessive heating. The heavy current flow would also force the motors to develop such a high torque that drawbar damage and wheel slippage would also occur.

TRACTION GENERATOR LOAD CURRENT LIMIT

These conditions can be prevented by addition of the control circuit illustrated in Figure 8. The commutating pole field of the traction generator has been connected through the blocking rectifier R3 to resistor 152 in the exciter field circuit. The addition of this control circuit will prevent the excessive current flow which the system in Figure 7 would have permitted.

This system works as follows:

The commutating pole field is in series with the traction generator armature, and therefore, full armature current (load current) will pass through it. As current flow increases the voltage drop of the C.P. field increases proportionately. This can be proven by application of Ohm's Law which states that voltage is equal to current multiplied by resistance. If, for instance, the current flow from the generator armature, which is passing through the traction motors and the C.P. field is 500 amperes and the resistance of the C.P. field is 0.002 ohm then the voltage at the C.P. field will be 1 volt.

Voltage - Current x Resistance
Voltage - 500 x 0.002
Voltage - 1

If current is doubled, C.P. field voltage will be doubled.

1000 x 0.002 = 2 volts

Further increases in generator current will cause the C.P. field voltage to rise as per Table II.

TABLE II

Generator Current	C.P. Field Volts
500	1.0
1000	2.0
2000	4.0
2500	5.0
2550	5.1
2600	5.2
2750	5.5
2950	5.9
3000	6.0

Let us assume that it is desirable to prevent generator current from exceeding 2500 amperes. The control circuit of Figure 7 will do this for us by automatically reducing the current flow through the F1 - F2 field of the exciter, whenever generator current flow rises above 2500 amperes. By reducing exciter field current, the exciter output current (generator field current) will be reduced and this will lower the generator current flow to the safe maximum of 2500 amperes.

Assume the following values for the exciting circuit devices.

Battery - 6 volts
F1 - F2 field resistance - 1 ohm
152 resistance - 5 ohms

By use of Ohm's Law, normal exciting circuit current flow may be found.

Current equals voltage divided by circuit resistance.

1 ohm (F1 - F2) plus 5 ohms (152) equals 6 ohms circuit resistance. Current therefore equals 6 volts divided by 6 ohms.

$\frac{6}{6}$ = 1 ampere current flow

To find normal voltage of F1 - F2 and of 152.

Voltage - current x resistance
F1 - F2 voltage - 1 x 1 or 1 volt
152 voltage - 1 x 5 or 5 volts

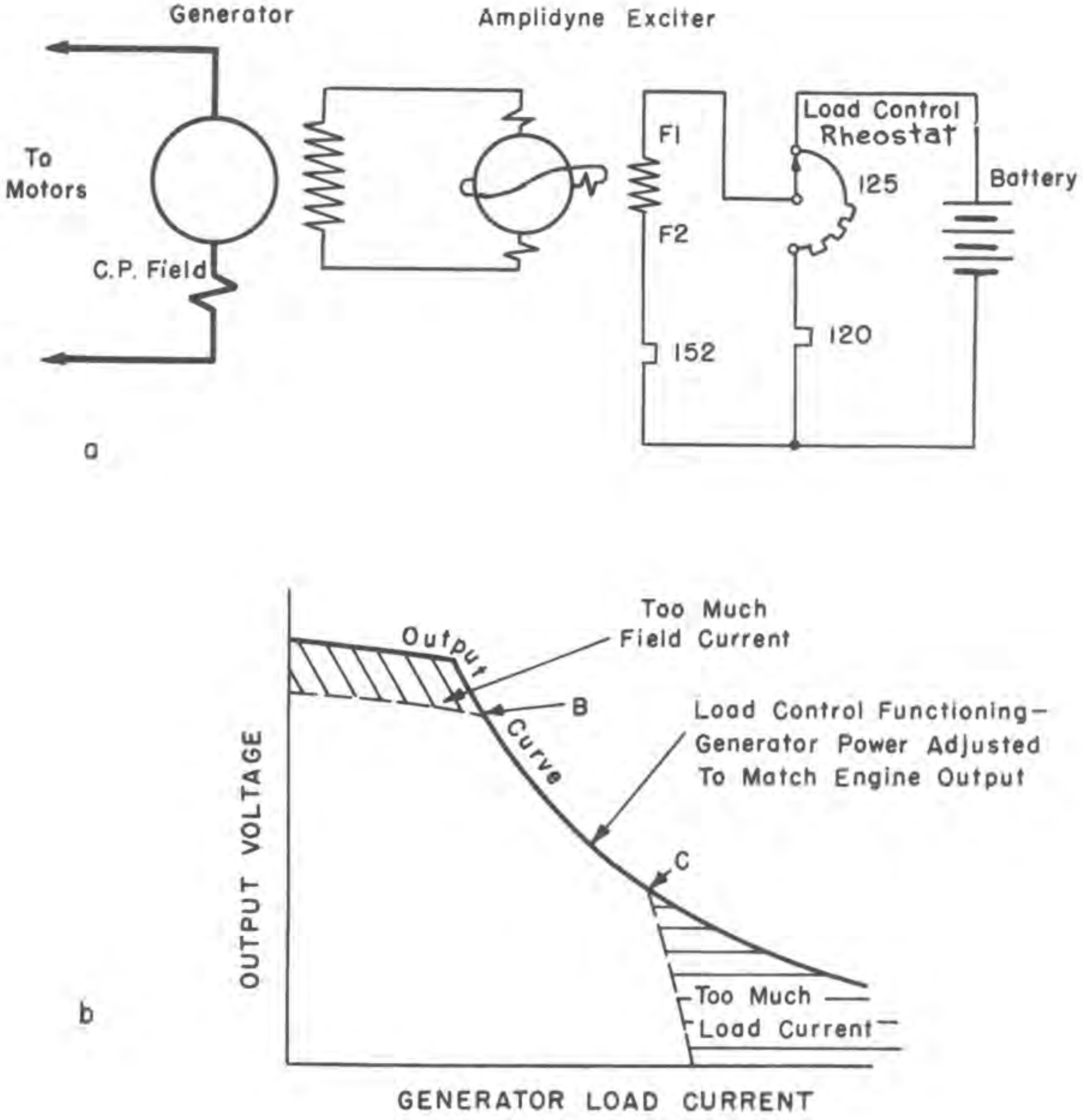


FIGURE 7A LOAD CONTROL ADDED TO EXCITATION SYSTEM

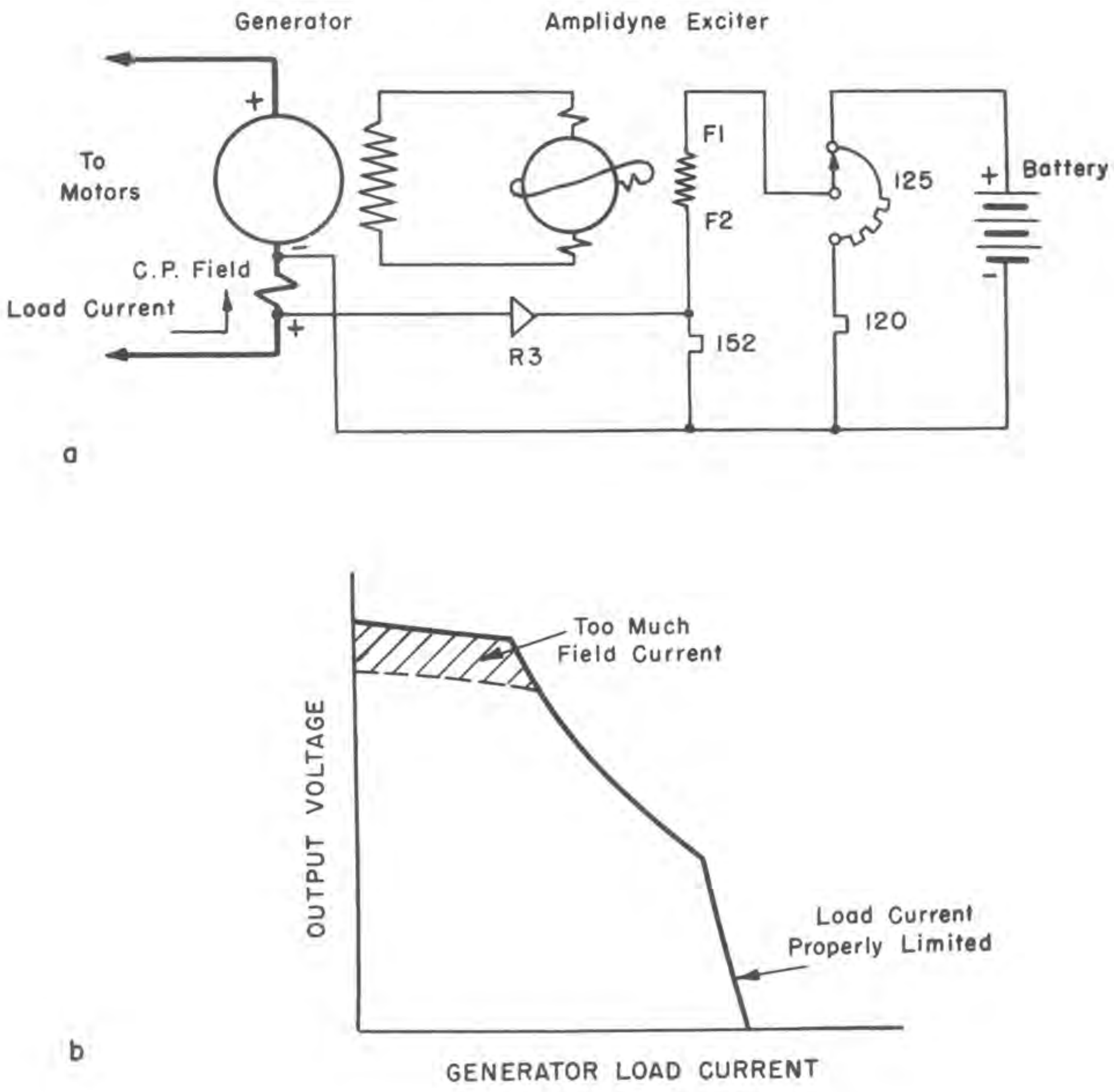
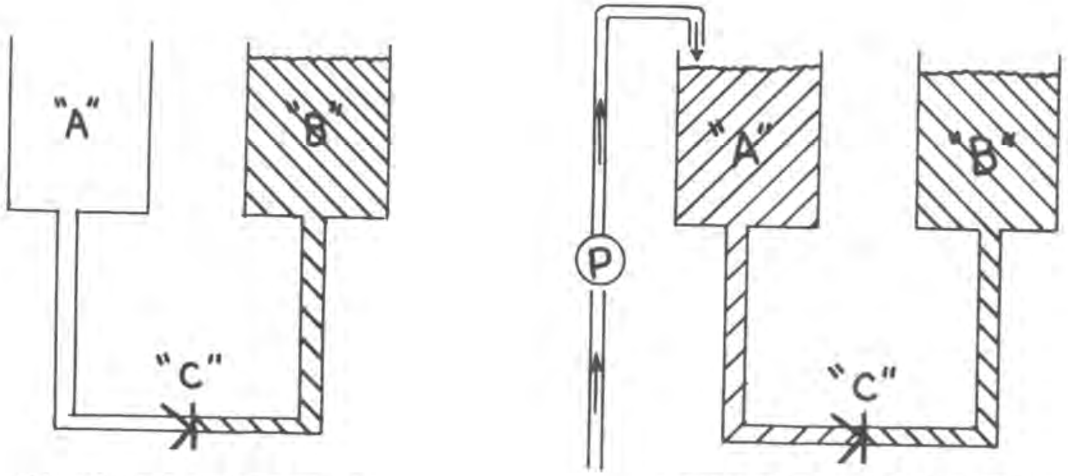


FIGURE 8 GENERATOR LOAD CURRENT LIMIT ADDED TO EXCITATION SYSTEM

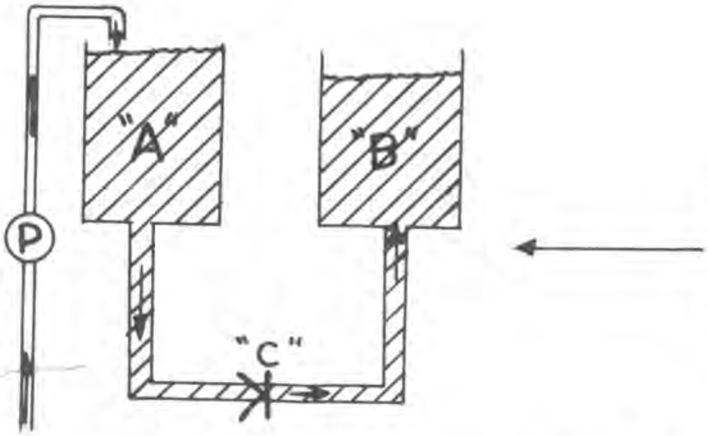
By adding the two voltages we get 6 volts or battery voltage. This will always be true in the exciting circuit. If 152 voltage should be raised to 5.1, the F1 - F2 voltage would be forced down to .9 because the sum of these two voltages will always equal battery voltage.

If C.P. field volts rise to 5.1 volts, the 5.1 volts will be impressed across resistor 152, because the field and the resistor are connected together through R3 rectifier. The latter prevents the normal 5 volts of 152 from being impressed across the C.P. field when the C.P. field voltage is below 5 volts. Figure 9 illustrates the action of a water system in which a check valve "C" permits flow of water from Tank "A" to Tank "B", but not vice versa, even if "A" is empty and "B" is full.



Check valve prevents flow from "B" to "A".

Pressure at "A" equals pressure at "B". No flow yet.



Pressure at "A" exceeds pressure at "B". Water flows from "A" to "B" through check valve.

FIG. 9

R3 rectifier works like the check valve in the water system. It permits the C.P. field voltage to raise the voltage of 152, whenever the C.P. field volts exceed 5 volts. But it will not permit 152 voltage to raise C.P. volts even if 152 volts are considerably higher than the voltage of the C.P. field.

The C.P. field voltage will not reach 5 volts until generator current is 2500 amperes (Table II). With generator current at this value, C.P. field voltage will equal the voltage of 152. With equal voltages nothing will happen to 152. But if generator current rises to 2550 ampere, C.P. field volts will rise to 5.1. This voltage will be impressed across 152, raising the latter's voltage to 5.1 also. This forces F1 - F2 voltage to reduce from 1.0 to .9 volts. When exciter field voltage drops, exciter output to the main field also drops and this forces generator current to reduce from 2550 to the safe maximum value of 2500.

Table III lists the relationship between voltages of the various devices. Note that until generator current reaches a value of 2500 amperes, the F1 - F2 voltage remains normal, but as soon as current exceeds 2500 amperes, F1 - F2 voltage immediately reduces.

TABLE III

Generator Current Amperes	C.P. Field Volts	152 Volts	F1-F2 Volts	Battery Volts
0	0	5.0	1.0	6.0
1000	2.0	5.0	1.0	6.0
1500	3.0	5.0	1.0	6.0
2000	4.0	5.0	1.0	6.0
2500	5.0	5.0	1.0	6.0
2550	5.1	5.1	.9	6.0
2600	5.2	5.2	.8	6.0
2750	5.5	5.5	.5	6.0
2950	5.9	5.9	.1	6.0
3000	6.0	6.0	0.	6.0

Note that the higher the generator current rises, the greater will be the reduction in excitation voltage (F1 - F2) volts.

Figure 11 illustrates this action graphically. Note that when current in excess of 2500 amperes is generated, F1 - F2 voltage reduces. At 2500 amperes (Point B) F1 - F2 voltage is 1 volt. At 2600 amperes, F1 - F2 volts is reduced to .8 volts, and so on.

Figure 11 should not be interpreted to mean that generator current increases as a result of a decrease in F1 - F2 volts. What it means, instead, is that if an excess of current is generated, the excitation voltage will reduce. This will reduce the

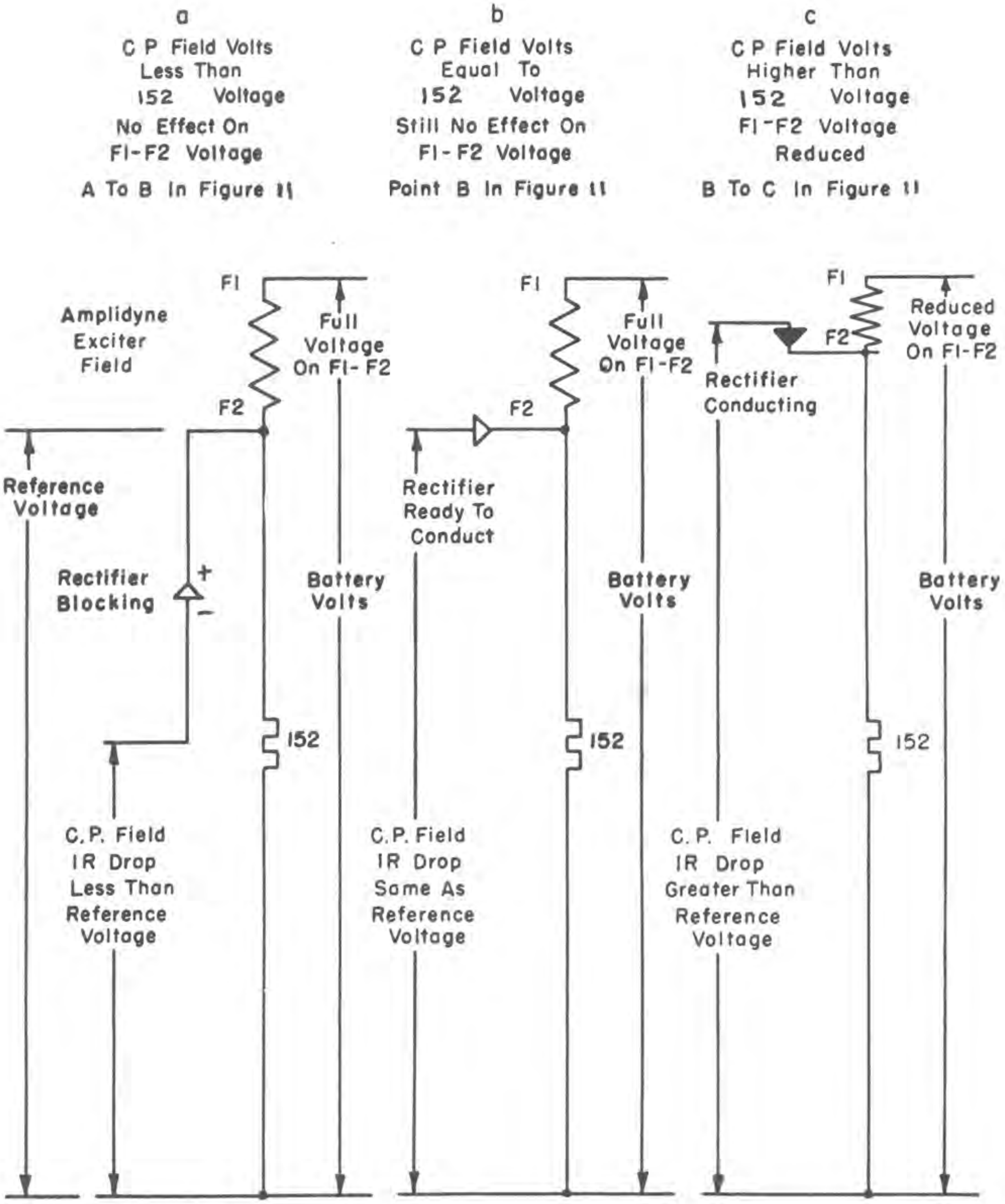


FIGURE 10 GRAPHICAL REPRESENTATION OF OPERATION OF GENERATOR LOAD CURRENT LIMIT CIRCUIT. CIRCUIT VOLTAGES ARE REPRESENTED BY VARYING VERTICAL DISTANCES

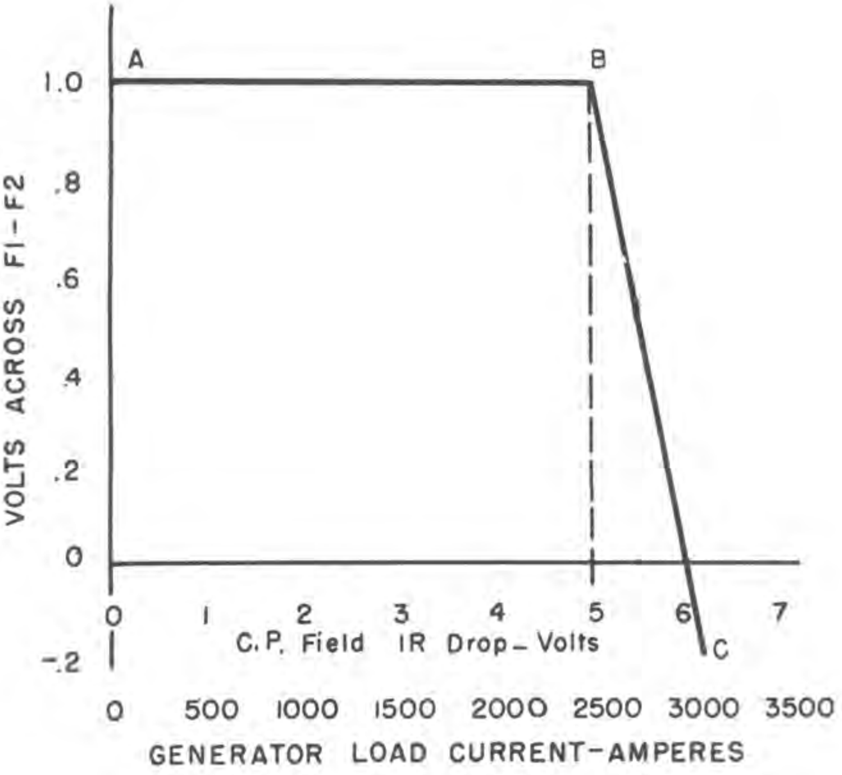


FIGURE 11 GRAPHICAL PRESENTATION OF DATA SHOWN IN TABLE III
GENERATOR LOAD CURRENT LIMIT CHARACTERISTICS

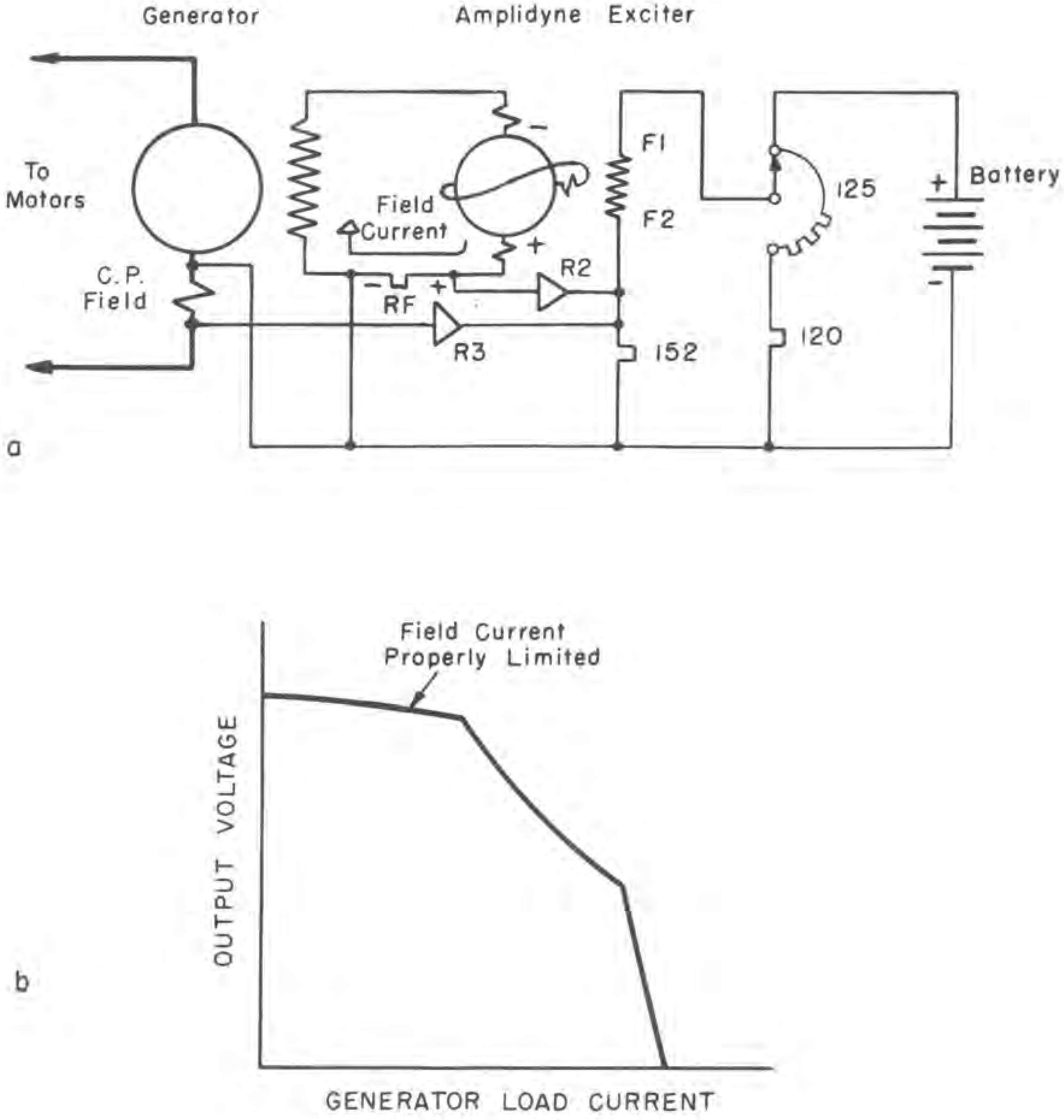


FIGURE 12 GENERATOR FIELD CURRENT LIMIT ADDED TO EXCITATION SYSTEM

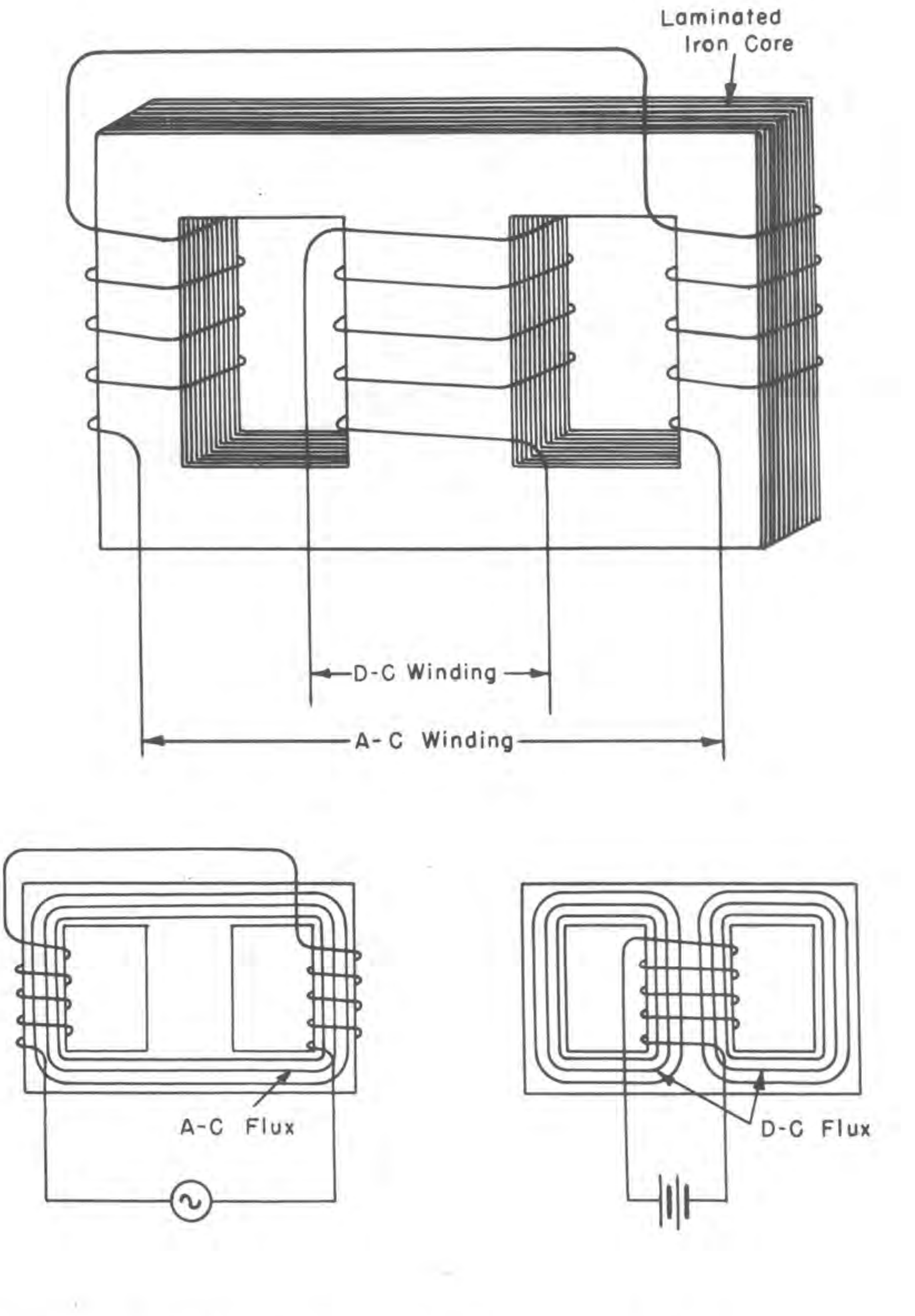


FIGURE 13 THREE LEGGED SATURABLE CORE REACTOR. LOWER DRAWINGS SHOW DISTRIBUTION OF FLUX PRODUCED BY A-C AND D-C WINDINGS

generator current to its safe maximum value. A balance condition is quickly reached where just enough excitation is left to hold the generator load current at its maximum safe value.

TRACTION GENERATOR FIELD CURRENT LIMIT

Figure 12 illustrates the addition of the field current limit circuit. To prevent overheating of the generator field coil, field current is automatically reduced whenever it rises to an excessive value. A resistor RF is added to the field circuit and its voltage drop is compared to the voltage of the 152 resistor, just as the C.P. field volts were in Figure 8. Whenever field current exceeds its maximum safe value, the voltage of RF will exceed the normal voltage of 152 and excitation will be reduced. Reduction of excitation will lower the field current to a safe value. R2 rectifier functions in the same manner as did R3 in Figure 7. It prevents current from the exciter field circuit from reaching the generator field circuit during periods when the normal voltage of 152 is greater than that of RF.

DEFICIENCIES OF THE SYSTEM

This excitation system was developed to explain the regulating principles involved in the system actually used. It has certain inherent deficiencies which prevent its being used on locomotives:

a - Traction equipment must be able to operate with one ground fault anywhere in the main circuit. A fault on the positive side of the generator would cause the parts of the main circuit normally near ground potential, including the generator CP field, to be at high potential. For this reason, it is dangerous to interconnect the main circuit and the low voltage battery and control circuits as is necessary in the system described.

b - A resistor in the generator field circuit would cause considerable loss of exciting power, requiring a larger exciter, as well as adding heat to the control compartment.

c - The voltage drop across the generator CP field is actually only a fraction of that used in the example.

d - The voltage across the generator CP field varies with temperature as well as current.

SATURABLE CORE REACTOR SYSTEM

1 ADVANTAGES OF SATURABLE REACTOR SYSTEM

To overcome the deficiencies inherent in the d-c system described above, we use a system similar in principle but making use of the isolating and amplifying properties of saturable-core reactors. The purpose of the saturable-core reactors is to produce d-c voltages (with the use of rectifiers) proportional to the d-c currents we must control. These d-c voltages are used in exactly the same manner as the voltages in the all d-c system just described. The advantage is that the voltages obtained are greater, allowing more accurate control and no connection is made between the battery circuits and the main circuit. In addition, by means of a special temperature-sensitive resistor, the effect of variations in the generator CP field voltage resulting from temperature variations are nullified, so a voltage is obtained which is a more accurate indication of actual generator load current than the uncompensated CP field voltage.

2 SOURCE OF POWER

Alternating-current power for the saturable-core reactor system is furnished by a 400-cycle alternator driven by a d-c motor fed from the 74-volt locomotive battery. A transformer is used to furnish power at the proper voltage for each part of the system.

3 SATURABLE CORE REACTORS - (See Figures 13, 14 and 15)

A brief review of the principles involved in the saturable-core reactors may be helpful before going on to the complete system.

The reactors used here have a three-legged iron core, with a-c coils on the outer legs and one or more d-c windings on the center leg. See Fig. 13. The a-c windings are connected in series in such a way as to create alternating flux in the outer part of the core without causing any change in the center leg on which the d-c coils are wound. Hence, a-c voltage is not induced in the d-c windings. However, current in the d-c windings creates flux not only in the center leg but in all parts of the core, saturating the iron to some extent, depending on the amount of current in the d-c windings. This "using up" of the iron by the d-c flux reduces the a-c flux produced by a given current in the a-c winding. The a-c voltage across the reactor will be proportional to the a-c flux. Consequently, for a given a-c current, the voltage across the a-c windings will decrease when the d-c flux increases and will increase when the d-c flux decreases.

Figure 14 shows the wiring diagram symbol for a saturable-core reactor. The markings on the d-c windings (D1, D2, D3, etc.) indicate the relative polarity of the windings. Current in one winding from the odd-numbered end to the even-numbered end (into D1, out D2, for example) would add to the d-c flux produced by current from odd to even in another winding (into D3, out D4, for instance). Current in another winding from the even-numbered end to the odd-numbered end (into D6, out D5, for example) would reduce the flux produced by the other windings.

In the system we are about to describe, two saturable-core reactors are used for each of the currents to be controlled. The a-c windings of the two reactors are connected in series across a constant a-c voltage. See Fig. 15. The d-c winding of one reactor XB is connected through a resistor to the locomotive battery. The current to be controlled is passed through the d-c winding of the other reactor XA.

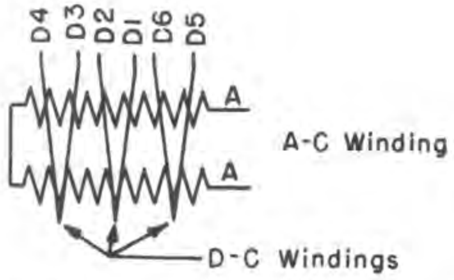


FIGURE 14 SCHEMATIC DIAGRAM SYMBOL FOR SATURABLE CORE REACTOR WITH THREE D-C WINDINGS. D-C WINDINGS ARE SOMETIMES SHOWN WHEREVER CONVENIENT ON THE DIAGRAM INSTEAD OF SUPERIMPOSED ON THE A-C WINDINGS AS SHOWN ABOVE

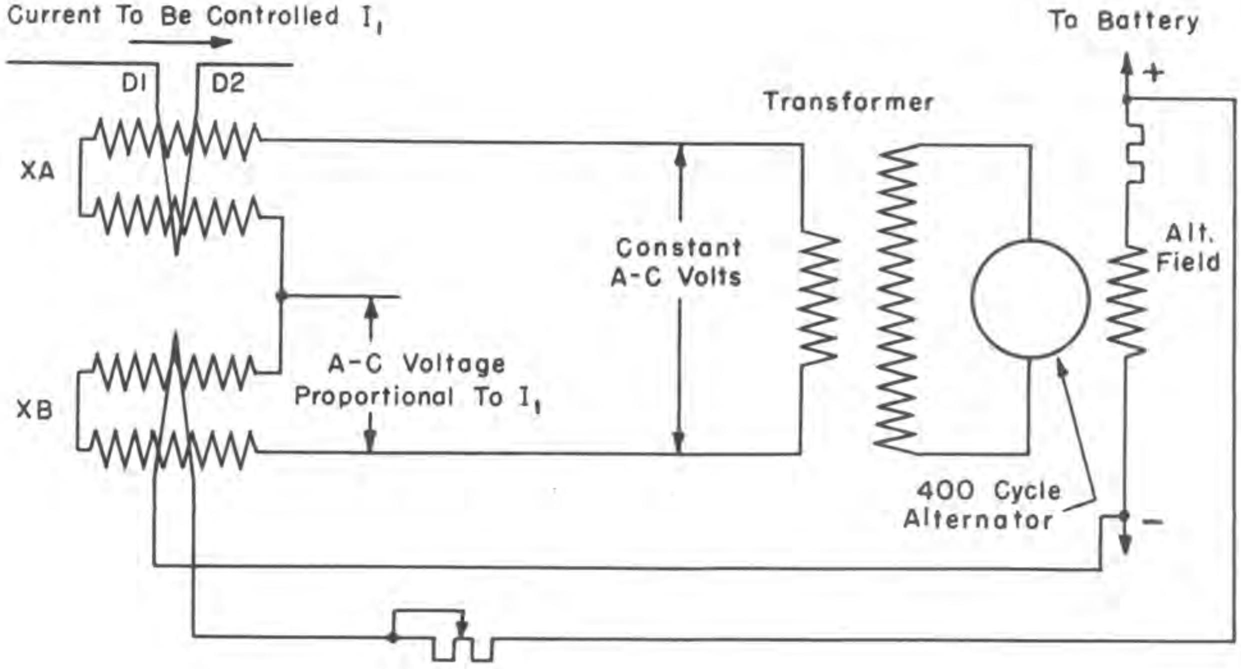


FIGURE 15 ARRANGEMENT OF PAIR OF SATURABLE CORE REACTORS TO OBTAIN A-C VOLTAGE PROPORTIONAL TO DIRECT CURRENT TO BE CONTROLLED

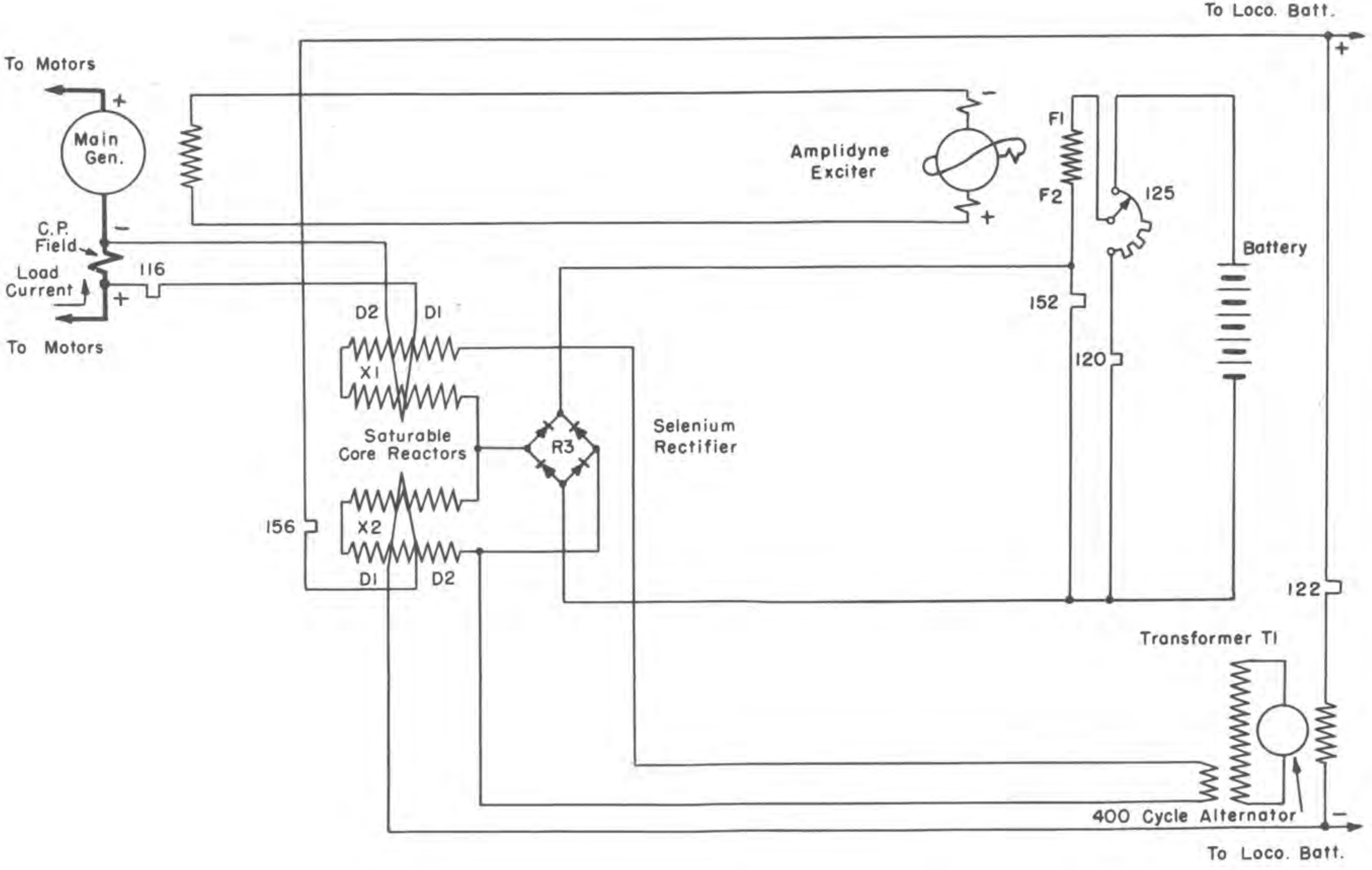


FIGURE 16 GENERATOR LOAD CURRENT LIMITED BY MEANS OF SATURABLE CORE REACTORS

Let us consider what happens when we vary the d-c currents in the two reactors. When there is no current in the d-c windings of either reactor, there is no d-c flux in either one, so the a-c voltage divides equally between them. If the d-c currents in both reactors are increased together so that the d-c flux in one reactor is always the same as in the other, the a-c voltage will still divide equally between the two. However, if the d-c flux in XA is increased without increasing the d-c in XB, the a-c voltage will no longer divide equally. Reactor XA, having more d-c flux in it, will have less a-c flux, so less a-c voltage will appear across its a-c windings. The sum of the a-c voltages across the two reactors is fixed, so the a-c voltage across XB must increase when the voltage across XA is decreased. Thus, increasing the d-c flux in XA without changing the d-c in XB, increases the a-c voltage across XB. Obviously, the greater the d-c flux in XB, the greater the d-c flux in XA must be to get the same a-c voltage division.

By connecting the d-c winding of reactor XB across the battery, with a suitable resistance in series, sufficient d-c flux is produced to reduce the a-c voltage across XB to a very low value when there is no d-c in XA. Then as the current in the d-c winding of XA increases, the a-c voltage across XB rises. This a-c voltage across XB is rectified by means of a full wave selenium rectifier.

The resulting d-c voltage is used just as if it were the voltage across the generator CP field or the drop across the resistor in the generator field circuit. If the output of the rectifier is connected across resistor 152 and the generator field current or part of the load current is put through XA, changes in the current will have exactly the same effect on amplidyne-field volts as when the voltages were used directly.

4 GENERATOR LOAD CURRENT LIMIT - FIG. 16

Figure 16 shows the current-limit saturable reactors and rectifier, instead of the CP field, connected across resistor 152. Compare this with Fig. 8. The d-c winding of reactor X1, corresponding to XA in the preceding discussion, is connected across the generator CP field through a special resistor. The purpose of the special resistor is to compensate for the increase in CP field resistance (which causes more voltage drop for the same load current) caused by heating up of the generator under load. The result is a current in the d-c winding of X1 which is always proportional to line current. Consequently the voltage output of the current limit rectifier is a more accurate indication of line current than the CP field voltage itself. Operation of the current limit is, of course, exactly the same as when the CP field voltage was used directly. When the load current increases, the current in the d-c winding of X1 increases, causing the voltage of rectifier R3 to rise. This causes the voltage across resistor 152 to increase, leaving less voltage for the amplidyne field, thus reducing the generator excitation.

5 GENERATOR FIELD CURRENT LIMIT - Fig. 17

Figure 17 shows the field limit saturable reactors and rectifier substituted for the resistor in the generator field circuit. The d-c winding of X3, the reactor corresponding to X1 in the load current limit or XA in the previous discussion, carries the generator field current. The output voltage of the rectifier R2 is proportional to the generator field current. It is used to regulate field current in exactly the same way as the voltage drop from the field circuit resistor (See Fig.12).

6 A-C EXCITATION SOURCE - FIG. 18

The output voltage of the 400-cycle MG set is affected somewhat by variations in load, battery voltage and set temperature. Variations in the 400-cycle supply voltage will cause the a-c voltage across the saturable reactors to vary. If nothing were done about it, this might cause serious variations in the limit settings. This variation in a-c voltage across the reactors can be cancelled, however, by making the voltage across the amplidyne field and resistor 152 vary in exactly the same way, so that the balance between the voltages is not affected. This is done by substituting a rectifier for the battery-excitation supply and supplying it a-c from another winding on the same transformer that supplies the saturable reactors, Fig. 18. Any fluctuation in the supply voltage appears in both the limit circuits and the amplidyne field circuit, so the net effect is negligible. The filter reactor 164 helps to smooth out the ripple in the rectified a-c.

7 LOAD CONTROL

Operation of the load control has not been affected by the substitutions made in the original system.

In Figure 18 the complete saturable reactor system is shown in its simplest form. The a-c and d-c voltages which are actually used in the practical locomotive control are indicated. It will be noted that corresponding voltages are considerably higher than those used in the basic d-c system originally described. The higher voltages allow greater accuracy of control.

8 TRACTIVE EFFORT CONTROL - FIG. 19, 20, 20A

In addition to protecting the generator from overheating from too much armature current, the current limit also serves to control low-speed tractive effort. On the first throttle notch the current limit is reduced, as will be explained below, to allow just about enough current to move the locomotive. As the throttle handle is pulled back, the current limit is raised a little on each notch, permitting smooth starting of the train. Full generator current is allowed only on the highest notch. See Fig. 19.

The current limit is reduced for the lower notches by two changes in the d-c winding circuits of the current-limit saturable reactors. First, the current in the d-c winding of X2 is reduced, so that less current is needed in the d-c winding of X1 to get the same a-c voltage distribution across the reactors and thereby reduce the excitation to the balance condition. In addition, current is put through a second d-c winding of X1 in the proper direction to aid the first (D1 - D2) winding. The

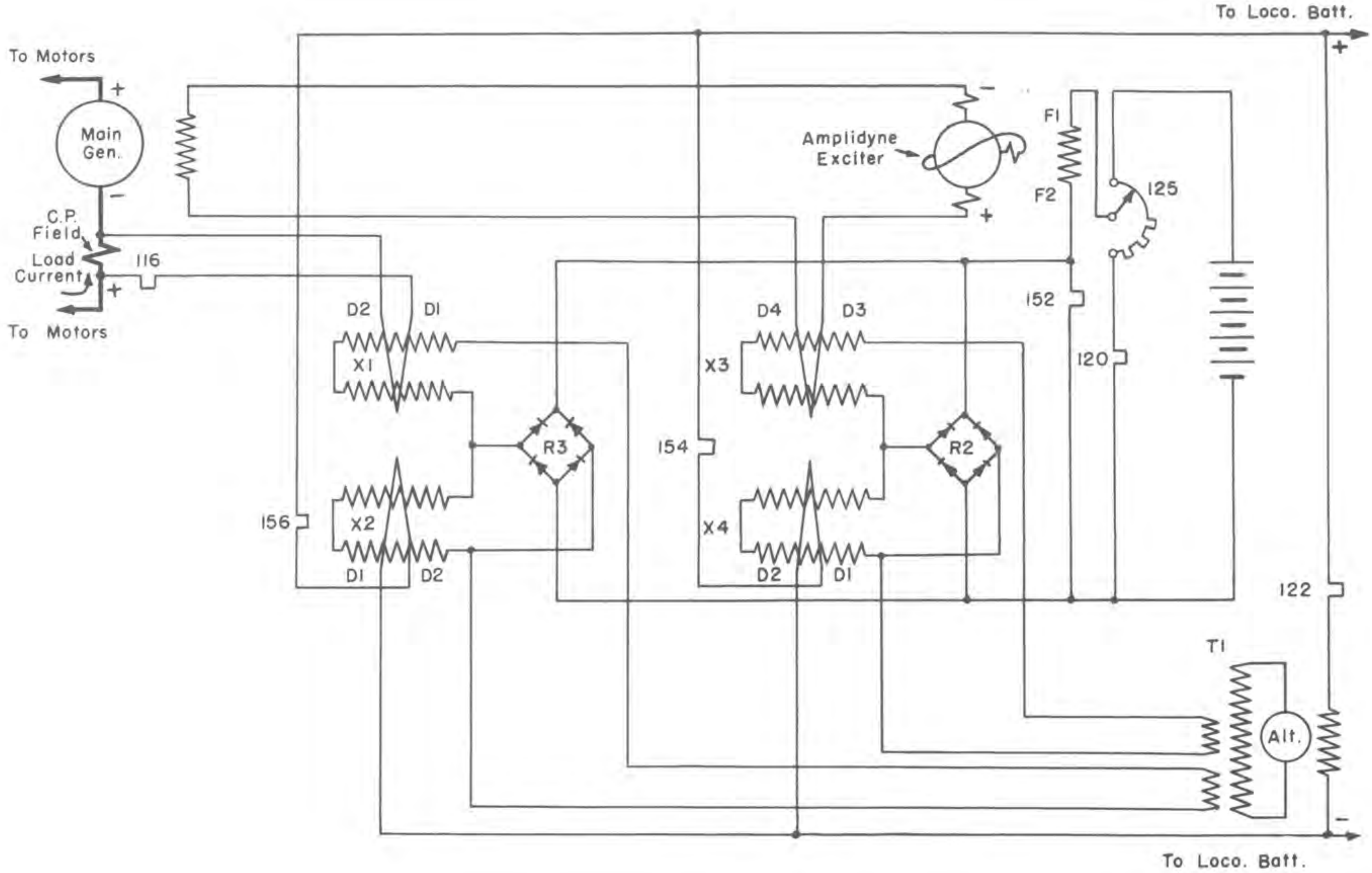


FIGURE 17 ADDITION OF GENERATOR FIELD CURRENT LIMIT USING SATURABLE CORE REACTORS

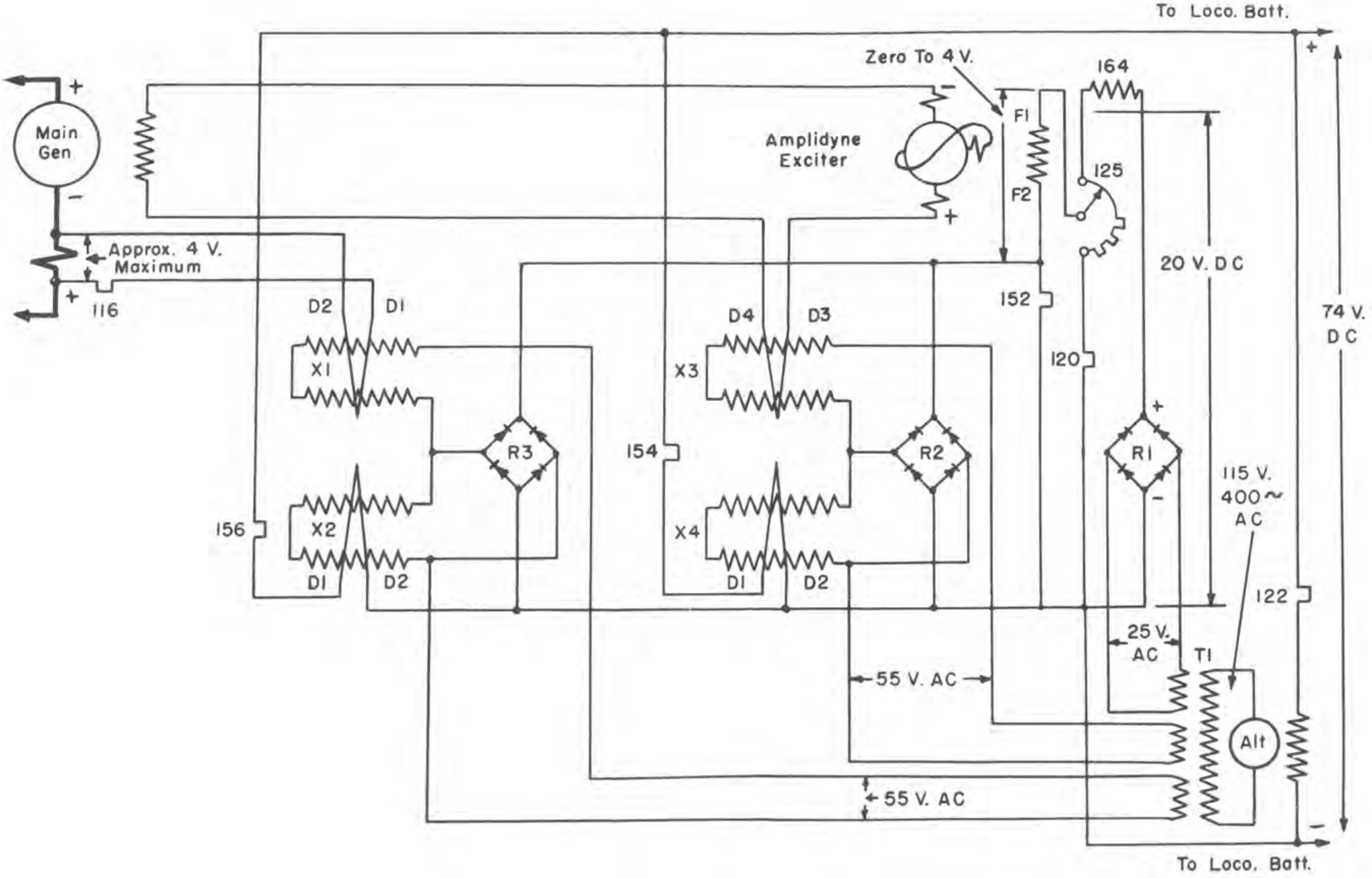
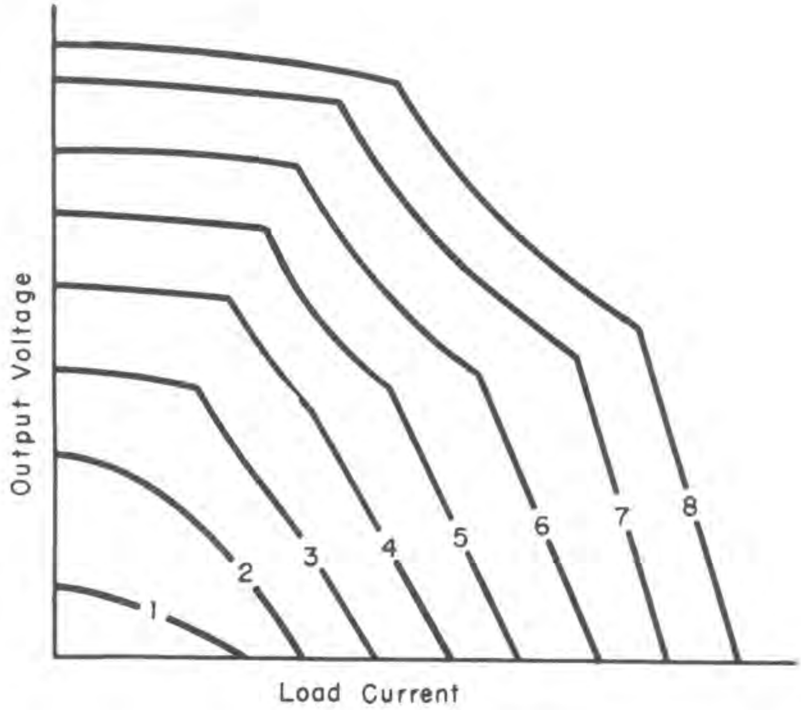


FIGURE 18 COMPLETE SATURABLE CORE REACTOR LIMIT SYSTEM IN SIMPLEST FORM WITH IMPORTANT VOLTAGES INDICATED



Steps In Maximum Load Current Result From Resetting Load Current Limit On Each Notch. Steps In Power And Maximum Voltage Result From Operating The Engine At A Different Speed On Each Notch

FIGURE 19 GENERATOR OUTPUT CURVES FOR ALL THROTTLE NOTCHES

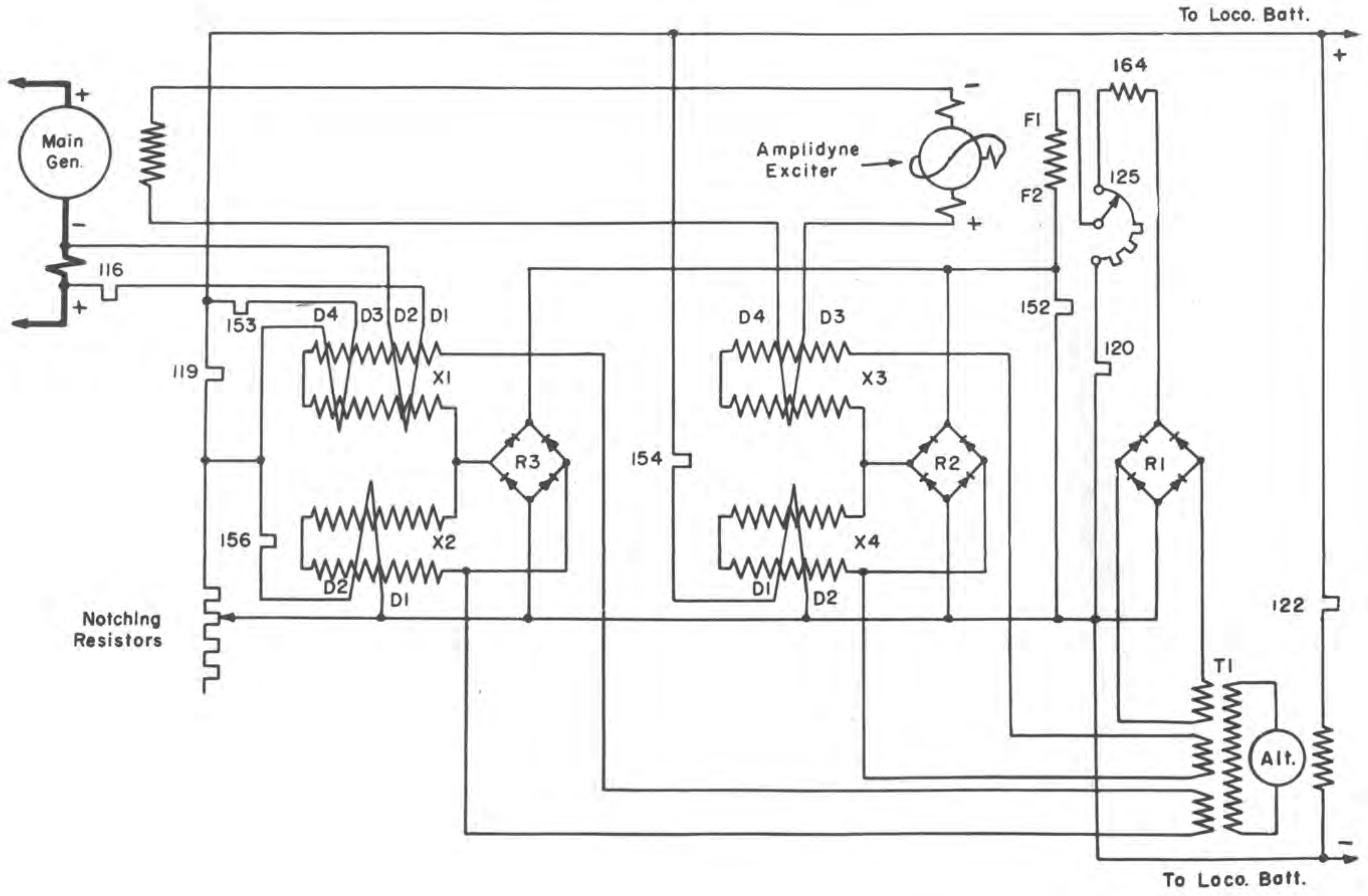


FIGURE 20 ADDITION OF TRACTIVE EFFORT CONTROL (MODULATED GENERATOR LOAD CURRENT LIMIT)

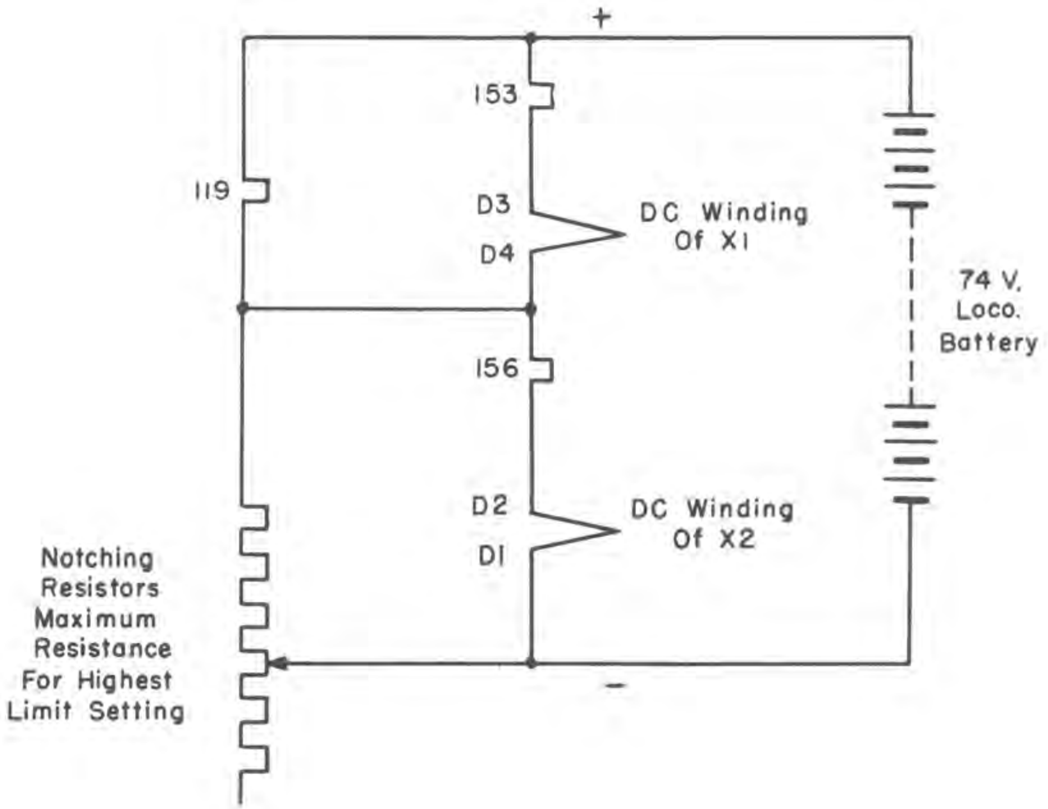


FIGURE 20A DC WINDING CIRCUITS INVOLVED IN TRACTIVE EFFORT CONTROL

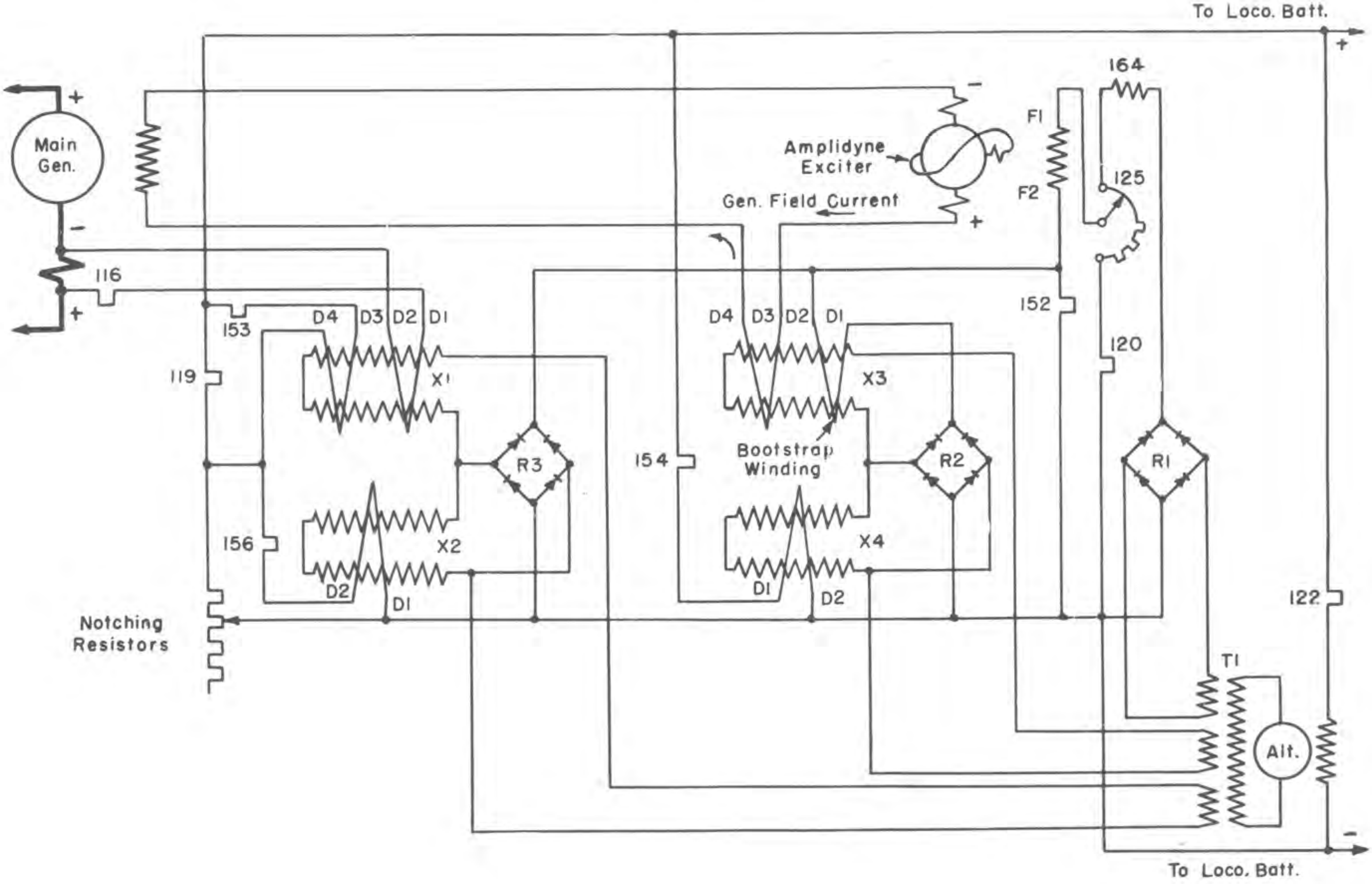


FIGURE 21 BOOTSTRAP WINDING ADDED TO X3 TO INCREASE ACCURACY OF GENERATOR FIELD CURRENT LIMIT

increased d-c flux in X1 causes more voltage across X2 and resistor 152, reducing the F1 - F2 amplidyne field current. The generator output drops until the D1 - D2 winding current has decreased enough to make up for the additional current in the D3 - D4 winding and the reduced d-c flux in X2. When this condition is reached, the balance between excitation and output will be restored, but at a lower generator current.

The circuit changes to get this tractive-effort control are shown in Fig. 20. The new d-c winding circuit is shown simplified in Fig. 20A. The notching resistor and resistor 119 act as a voltage divider or potentiometer. On the highest throttle notch, the notching resistor is open circuited. This results in the highest voltage across the d-c winding of X2 and the lowest voltage across the extra winding of X1. On lower notches, the resistance of the notching resistor is decreased, thereby reducing the voltage across the D1 - D2 winding of X2 and increasing it across the D3 - D4 winding of X1. On the first notch, all of the notching resistor is shorted out, which reduces the voltage across the d-c winding of X2 to zero and puts full voltage across the X1 d-c winding circuit. This, of course, gives the lowest generator load current-limit setting.

9 MODIFIED FIELD-LIMIT CIRCUIT - FIG. 21

A second d-c winding is added to reactor X3 to improve the accuracy of the generator field current limit, Fig. 21. The output current of the field-limit rectifier which serves to raise the voltage across resistor 152, passes through this new d-c winding (D1 - D2) and adds to the d-c flux created by the generator field current in the first winding (D3 - D4). This additional d-c flux in X3 causes the output current to increase, which in turn causes more flux. This "bootstrap" effect is not strong enough to go on indefinitely, however, and a balance is quickly reached. A small increase in the generator field current will first cause an increase in rectifier output current. This increased current in the "bootstrap" winding will reinforce the original increase in the generator field current, thereby causing further increase in output. Thus, a relatively small deviation in generator field current causes a large change in rectifier output and consequently in excitation. This results in more accurate control of field current than could be obtained without the "bootstrap" winding.

10 ELECTRIC BRAKING - FIG. 22, 22A

For electric braking, the motor armatures are disconnected from the generator and connected across braking resistors. The motor fields are connected in series and separately excited from the generator. The motors act as generators, taking power from the drivers and converting it into electrical energy which is dissipated by the braking resistors in the form of heat.

The amount of braking is controlled by the operator by means of a braking potentiometer which is connected across the locomotive battery and operated by the controller selector handle. The generator load current limit regulates the motor field current (generator output). The setting of the current limit is determined by the voltage between the brush arm and one end of the potentiometer. Its brush arm is connected to a train line to set the same current limit in trailing units when running two or more units in multiple. The current limit holds low motor field current when the train line voltage is low and raises the motor field current when the train line voltage is raised.

The current-limit circuit is rearranged for braking by means of a braking relay. The rearrangement is necessary because of the extreme range required - from zero to full motor field current - and to obtain sufficient accuracy of control to assure the same braking on all units over the full range of motor field current.

The circuits for braking are shown in Fig. 22. The simple schematic diagram Fig. 22A shows the current-setting circuit involving the d-c windings of X1 and X2. The diagram has been rearranged to show more clearly how the circuit functions. When the brush arm of the braking potentiometer is at the ZERO end, there is no voltage across the X2 winding. Sufficient current flows from the voltage divider 165 - 165A through the D3 - D4 winding of X1 to reduce the amplidyne excitation to zero with no current in the D1 - D2 winding. This, of course, results in zero motor field current.

As the potentiometer is rotated to get braking, the voltage across X2 is increased and the current in the D3 - D4 winding of X1 is decreased. The decreased current in D3 - D4 reduces the d-c flux in X1, thereby increasing the amplidyne excitation. The generator output (motor field current) increases until the current in the D1 - D2 winding (across the generator CP field) increases enough to make up for the drop in D3 - D4 current and the increased current in the d-c winding of X2. This is the same as what happens when notching up in motoring. However, as braking is increased further, one difference appears between the action of the current-setting circuit in braking and the way it works in motoring. The D3 end of the D3 - D4 winding is connected to the voltage divider 165 - 165A and so is always at less than full battery potential.

When the braking potentiometer is rotated to where the potential of its brush arm is higher than the potential of the voltage divider, the current in the D3 - D4 reverses. The current increases in the reverse direction as the braking potentiometer voltage is increased. This reverse current opposes the current in the D1 - D2 winding connected across the CP field. This acts exactly the same as the decrease in D3 - D4 current before it reversed. That is, the reduced d-c flux in X1 causes the excitation and generator output to rise until a new balance condition is obtained.

The maximum generator output during braking is less than one third what it is when motoring. In order to get about the same current in the D1 - D2 winding of X1 under both conditions, a part of the resistance in series with the winding is shorted out during braking by an interlock on the braking switch. This interlock is shown across resistor 116 in Fig. 23.

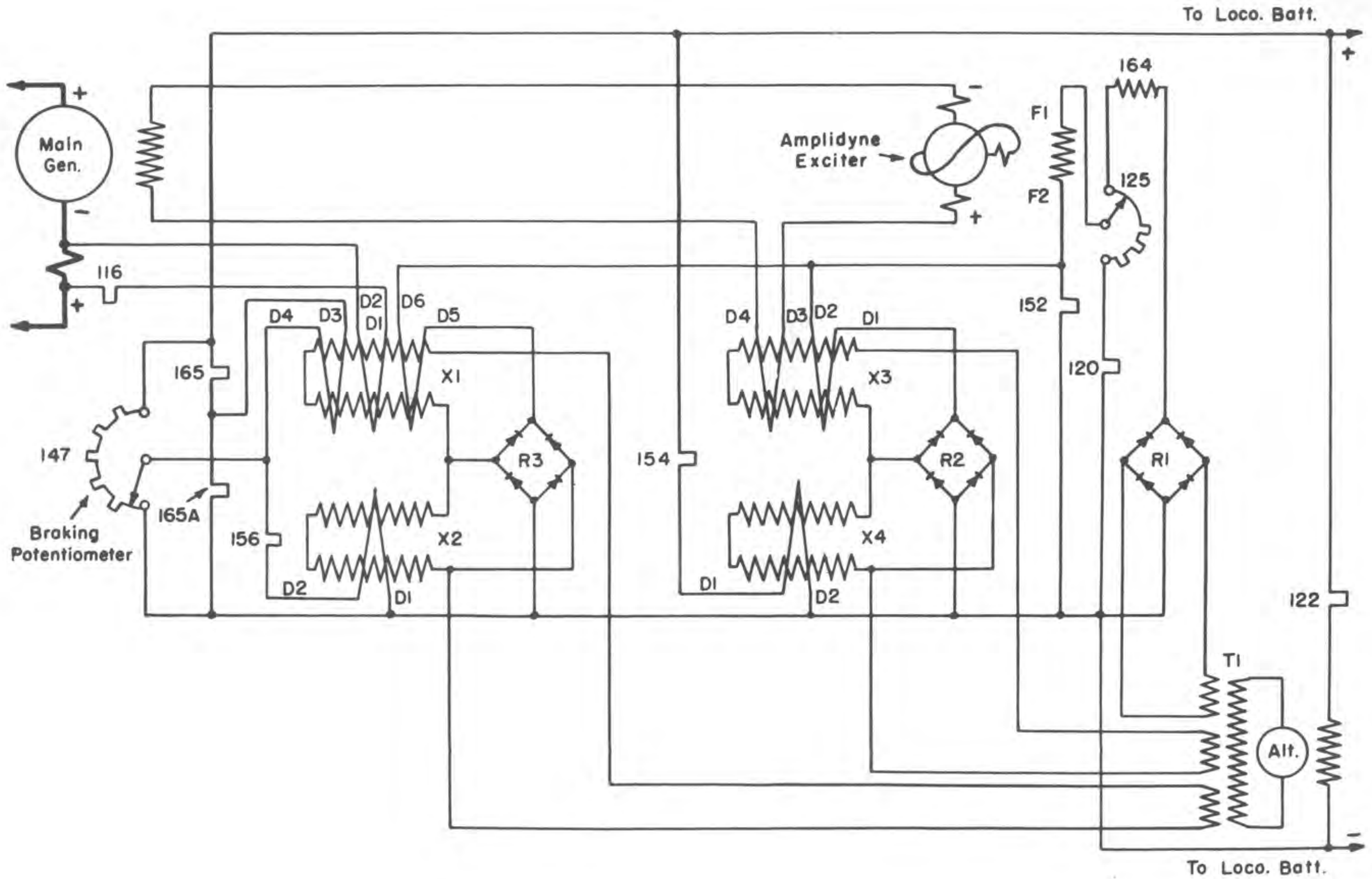


FIGURE 22 GENERATOR LOAD CURRENT LIMIT CIRCUITS RECONNECTED FOR ELECTRIC BRAKING

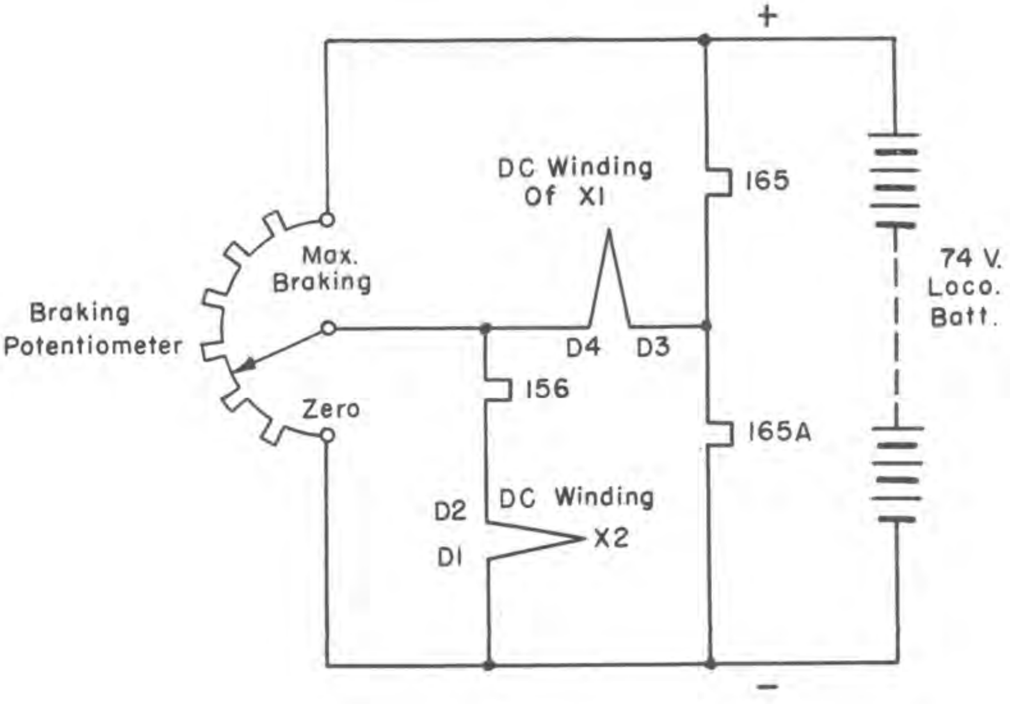


FIGURE 22A DC WINDING CIRCUITS INVOLVED IN ELECTRIC BRAKING

To increase the accuracy, a third d-c winding (D5 - D6) is added to X1. This winding acts in exactly the same manner as the second (D1 - D2) winding in the field limit reactor X3, as described under **MODIFIED FIELD LIMIT CIRCUIT.**

11 COMPLETE AMPLIDYNE EXCITATION SYSTEM - FIG. 23

The complete saturable-reactor amplidyne-control system is shown in Fig. 23. Several new circuit components have been added which require explanation.

In all preceding diagrams the "notching resistor" for setting the maximum load current for each throttle notch has been shown simply as a variable resistor. Multiple-unit operation of locomotives requires the use of relays operated from train lines to set the load current limit on all cabs. These relays (AVF - BVS - CVF - DVS), operated in proper sequence, increase the value of the notching resistor in eight steps as the throttle is notched up.

Resistors 157 and 157A are put across the "bootstrap" windings (D5 - D6 in X1 and D1 - D2 in X3) to prevent trouble from a-c voltage which may be induced in the d-c windings of the reactors when operating the reactors at high flux densities. The resistors partially short-circuit the d-c windings so far as a-c is concerned, thereby keeping the stray a-c flux out of the center (d-c) leg of the reactors. The d-c resistance of the "bootstrap" windings is much lower than that of the resistors, however, so very little of the limit circuit output is shunted around the windings. The stray a-c voltage, if not kept to a minimum, would desensitize the limit circuits and perhaps even reach dangerous values in many-turn windings. No such resistors are needed for X2 and X4 because their d-c winding circuits are of low enough a-c impedance to keep the "ripple" voltage down to a safe value.

The F3 - F4 amplidyne field winding is connected across the amplidyne armature whenever the relay EF is not energized. The polarity of the connection is such that any armature voltage causes current in the F3 - F4 field in the proper direction to reduce the voltage. This prevents residual field in the amplidyne exciter from producing generator excitation when it is not wanted. The EF relay is energized during normal operation. The F3 - F4 field is usually referred to as the "Suicide Field".

The F7 - F8 amplidyne field is used for stabilizing. The stabilizing capacitance needed during motoring operation is very low compared with that required during braking; mostly because the amplidyne voltage is much higher during motoring, making the capacitance more effective. Additional capacitance is connected in during braking by means of relay BR2.

12 DIFFERENCE BETWEEN FIGURES AND LOCOMOTIVE DIAGRAMS

Figure 23 has been built up step by step, starting from Fig. 15, by adding one or two parts at a time to a single basic circuit. The saturable reactors are shown with the d-c windings superimposed on the a-c windings.

To see how certain circuits actually function, it is clearer in some cases to show schematically only the portion of the reactor coils and associated resistors which belong in one electric circuit, and to show other coils of the same reactor in other locations on the wiring diagram where they naturally fit into the electric circuits. In the preceding test, **Fig. 20A** and **Fig. 22A** were made in this manner.

On the locomotive wiring diagrams, the circuits (with a few extra wires for purposes other than excitation) are exactly as shown on **Fig. 23**, but appear differently because they are shown schematically. A comparison will readily show that the connections are those of **Fig. 23**, except as follows: -

a - Each coil of the reactors is shown, properly labelled, wherever it logically goes in the electric circuit.

b - The positive side of the exciter is shown at the top instead of the bottom, as it seems to be more nearly standard practice and can be done by the schematic method with the minimum number of crossing wires.

c - The order in which parts are shown is slightly different.

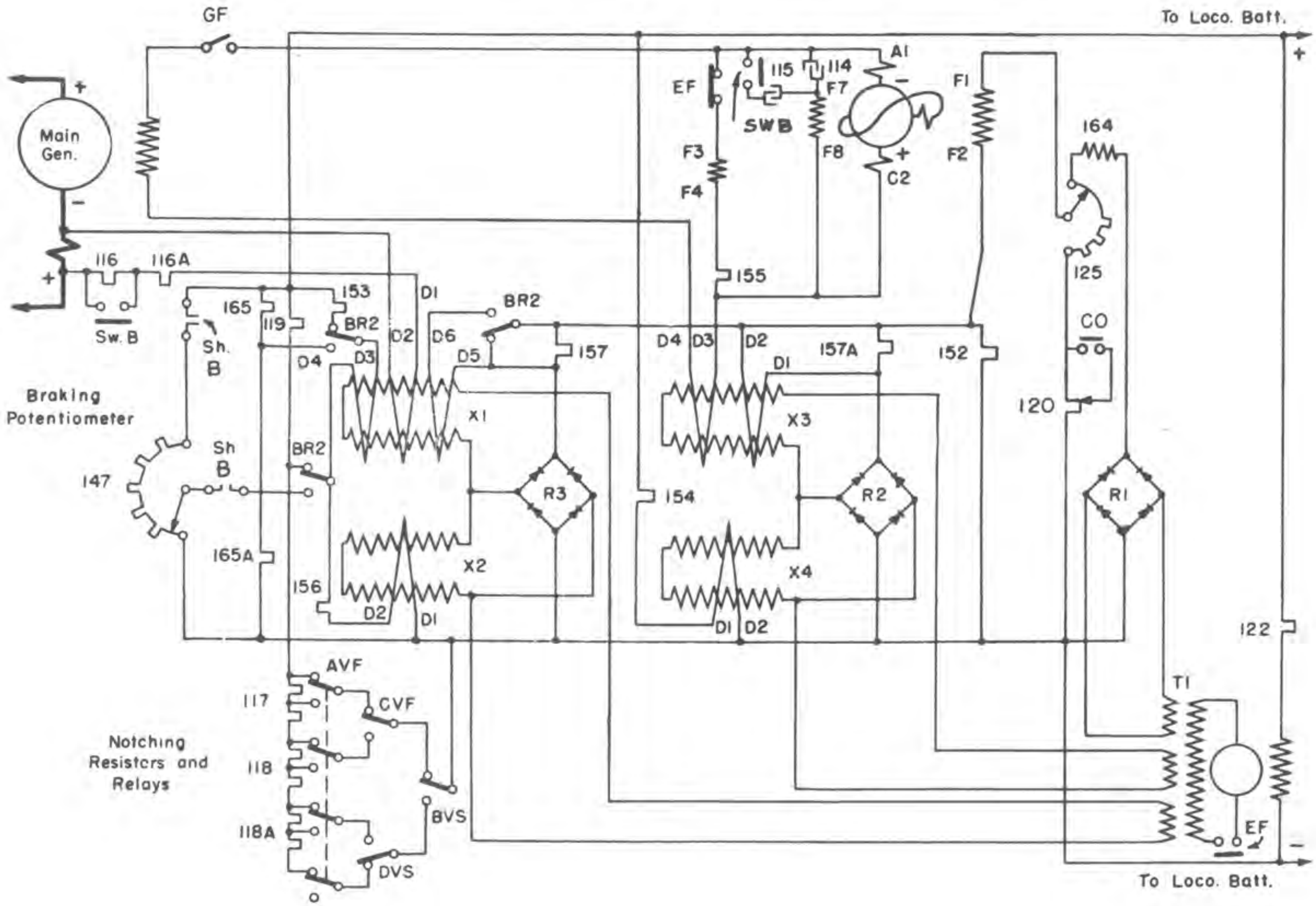
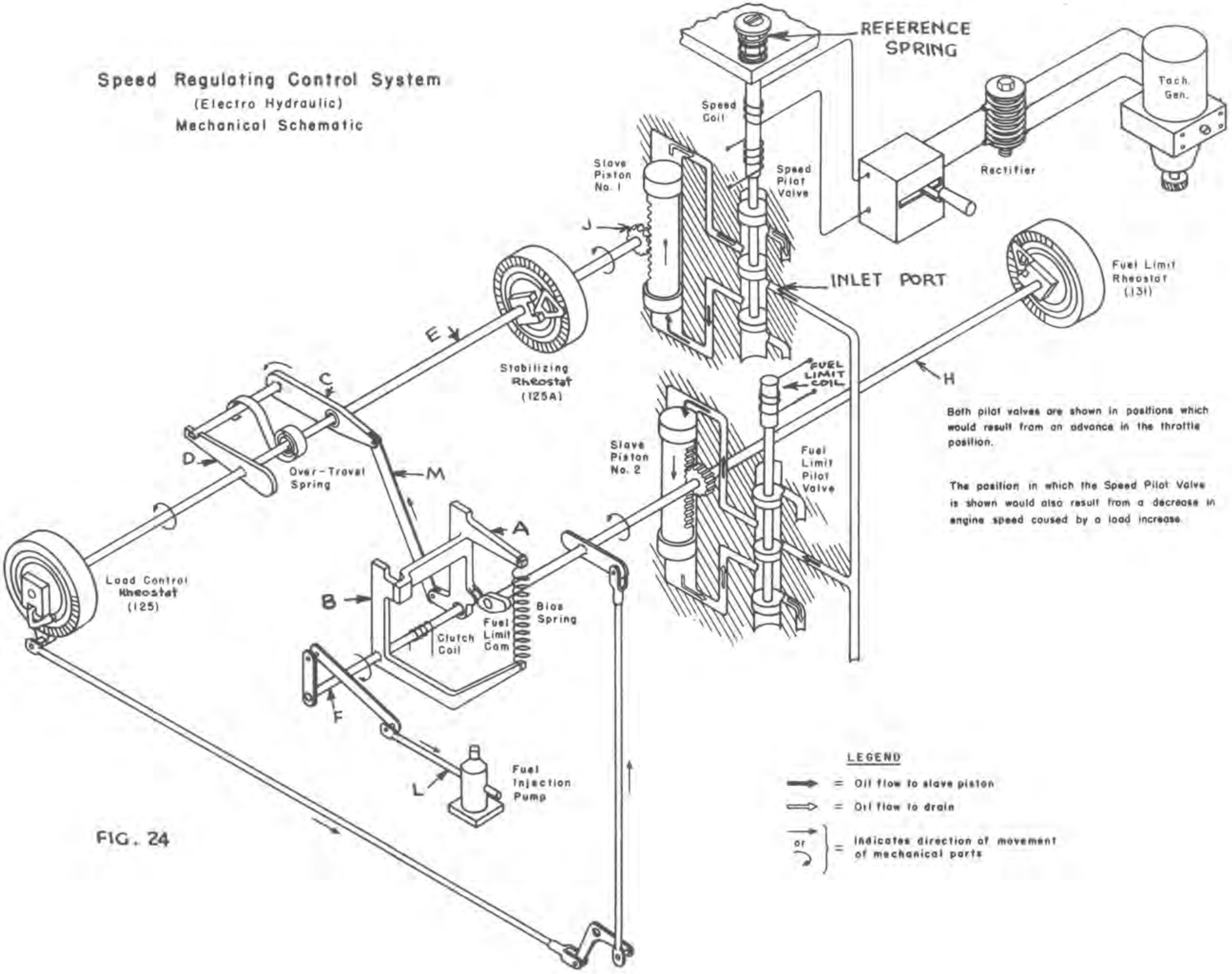


FIGURE 23 COMPLETE SATURABLE CORE REACTOR AMPLIDYNE EXCITATION SYSTEM

Speed Regulating Control System
(Electro Hydraulic)
Mechanical Schematic



Both pilot valves are shown in positions which would result from an advance in the throttle position.

The position in which the Speed Pilot Valve is shown would also result from a decrease in engine speed caused by a load increase.

LEGEND

➡ = Oil flow to slave piston

⇨ = Oil flow to drain

→ or ↷ = Indicates direction of movement of mechanical parts

FIG. 24

SECTION 3 - POWER PLANT REGULATING SYSTEM FOR LOCOMOTIVES EQUIPPED WITH 17MG3 GOVERNOR

The power plant regulating system controls Diesel engine speed. Its primary function is to hold the Diesel engine at whatever constant speed is called for by the setting of the engineman's throttle. Speed is held constant at all loads.

The power plant regulating system includes the following equipment.

1. Diesel Engine Governor
2. Engine Driven Tachometer Generator
3. Engine Control Panel
4. Hydraulic Power System

DIESEL ENGINE GOVERNOR

The General Electric Type 17MG electro-hydraulic governor controls the speed of the ALCO Type 244 Diesel engine. The Type 17MG governor is used on both the 12 cylinder and 16 cylinder, 9 x 10-1/2 Diesel engines. Diesel engine speed is controlled by regulating the rate of fuel injection and by adjusting the engine loading.

The governor includes speed controlling equipment and fuel limiting equipment.

SPEED CONTROLLING EQUIPMENT (See Figure 24)

The speed coil of the speed solenoid receives its control current from the engine driven tachometer generator. The solenoid operates a balanced four way pilot valve which controls the flow of oil to slave piston number one. This piston, when moved by the flow of oil against its top or bottom surfaces, rotates shaft "E". The latter rotates:

A. The governor output shaft "F" through the overtravel spring and the magnetic clutch coil. Shaft "F" controls the positioning of the Diesel engine's fuel injection pump racks.

B. The brush arms of the stabilizing rheostat (125A) and load control rheostat (125). These brush arms are actually gear driven from shaft "E". They are shown as directly driven in Fig. 24 for clarity. See Fig. 44 for illustration of gear drive.

FUEL LIMITING EQUIPMENT (See Figure 24)

The fuel limit coil of the fuel limit solenoid (Fig. 24) receives its control current from the locomotive battery. This solenoid also operates a balanced four way pilot valve which controls the flow of oil to slave piston number two. Movement of this piston either up or down in its cylinder, rotates shaft "H", on one end of which is the fuel limit cam. Shaft "H" positions this cam in such a manner that it limits the travel of arms "A" and "B" to a certain definite position in each throttle notch. This results in a maximum allowable rate of fuel injection for each position of the engineman's throttle. Shaft "H" also operates the brush arm of the fuel limit rheostat (131). This rheostat acts as a variable resistance in the fuel limit circuit. It, too, is actually gear driven as shown in Fig. 44.

ENGINE DRIVEN TACHOMETER GENERATOR

This is a 3 phase, 2 pole, alternating current generator with a permanent magnet alnico rotor. The rotor is gear driven from the diesel engine camshaft. The tachometer generator is used as a speed measuring device, because its output is proportional to diesel engine speed. Its current is rectified to direct current by a 3 phase selenium rectifier. The rectified current is supplied to the speed coil of the speed solenoid where it is used to control pilot valve action.

An alternating current generator is used to eliminate commutation problems. The tachometer generator has no commutator or slip rings and no brushes.

The ratio of diesel engine speed to tachometer generator speed is 1 to 3.42. Diesel engine speed of 1000 RPM results in generator speed of 3420 RPM.

Connection to the diesel engine cam shaft gearing is through a vibration dampener (flexible coupling).

ENGINE CONTROL PANEL

The engine control panel contains control apparatus which operates in conjunction with the diesel engine governor.

HYDRAULIC POWER SYSTEM

A motor driven pump supplies oil under 125 PSI regulated pressure, to the pilot valves for operation of the governor's slave pistons. The system includes suitable filters and strainers as well as a pressure regulating valve. This system is not connected to the diesel engine lube oil system, but is a completely separate system in itself.

OPERATION OF GOVERNOR

Figure 24 is a mechanical schematic diagram of the Type 17MG governor. The mechanical schematic diagram, of course, does not illustrate the various parts of the equipment in their true shapes and sizes. Its purpose, rather, is to give a clear picture of the inner workings of the governor, and to do this the various parts are separated from one another, so that each is visible. This would not be possible in the ordinary type of construction diagram. Figure 44, a one plane schematic diagram, shows the various parts in their true forms.

Figure 24 illustrates the action that would take place in the governor if a load increase had slowed the engine below its rated speed. The governor is functioning to increase fuel injection to bring speed back to normal by moving the fuel injection pump rack "L", to the right as viewed in the diagram.

To do this, slave piston number one has been forced upward in its cylinder by the flow of oil through the speed pilot valve. The teeth which are milled in the side of this slave piston mesh with the teeth of gear "J". An upward movement of the slave piston will thus force shaft "E" to turn CCW with gear "J". Lever "D" turns with shaft "E" and lever "C" is moved in conjunction with "D" by the overtravel spring. The inner coil of the overtravel spring is fastened to shaft "E" so that as the latter turns, it keeps tension of the spring. Lever "C" is supported by a bearing on shaft "E" and pivots on "E" like a "See-saw". As "C" pivots it pulls link "M" in an upward direction to pull arms "A" and "B" to the right. Arm "B" is keyed to output shaft "F" and as "B" moves to the right it turns "F" clockwise to increase fuel and bring the engine up to rated speed.

If diesel engine load had decreased, the engine speed would have increased beyond its rated RPM. If this had happened, slave piston number one would have been forced downward by a flow of oil into the top of its cylinder. In this case shaft "F" would have turned counter clockwise to pull rack "L" to the left and thus decrease fuel injection.

Movement of slave piston number one is controlled by the speed pilot valve plunger's position. The plunger is mechanically connected to the speed solenoid's moveable armature. As the plunger moves up or down in its ported cylinder it uncovers ports which permit oil from the hydraulic power system to reach and move the slave piston.

The current which is supplied to the speed coil by the tachometer generator will determine the plunger's position. When the diesel engine is rotating at its proper RPM, the tachometer generator will supply the speed coil with a current of 475 milliamperes (.475 ampere).

SOLENOID OPERATION

The speed solenoid consists of a moveable iron core positioned within a coil of wire called the speed coil. When the diesel engine is not running the tachometer generator will not be supplying the speed coil with current, and the solenoid core will be pulled to its uppermost point of travel by the reference spring. The pilot valve will also be at its uppermost point of travel because it is mechanically fastened to the solenoid core. When the engine is running the tachometer generator will be supplying current to the speed coil. Passage of current through the speed coil will set up a magnetic field within the solenoid. This magnetizes the core and pulls it in a downward direction. The reference spring, of course, compresses. The compressed spring tends to exert an upward pull on the core, but the downward magnetic pull will keep the plunger from going back to the top. When a current of 475 milliamperes is flowing through the speed coil, enough magnetism will be developed to pull the pilot valve plunger into the position shown in Figure 25. This is referred to as the "Balance Position" and 475 milliamperes is referred to as the "Balance Current"

When the plunger is in balance position the pilot valve's inlet port is blocked off and no oil can flow through it. However, if the diesel engine should slow down due to an increase in load, it will slow the tachometer generator. This weakens the current which the generator is supplying to the speed coil. With less than 475 MA of current in the coil the magnetism will also be weaker. The weaker magnetism will be unable to hold the plunger down and the reference spring can then pull it upwards as is shown in Figure 25A. This permits oil to flow through the now open inlet port to the bottom of slave piston number one. Reference to Figure 24 will show that an upward movement of the piston will cause fuel injection pump rack "L" to increase the rate of fuel injection. This, of course, speeds the diesel engine up. As the diesel engine speeds up the tachometer generator speeds up with it. When the engine reaches rated speed, the tachometer generator will be supplying 475 milliamperes to the speed coil and the plunger will be pulled down to block off the inlet port once again. This prevents further movement of the slave piston.

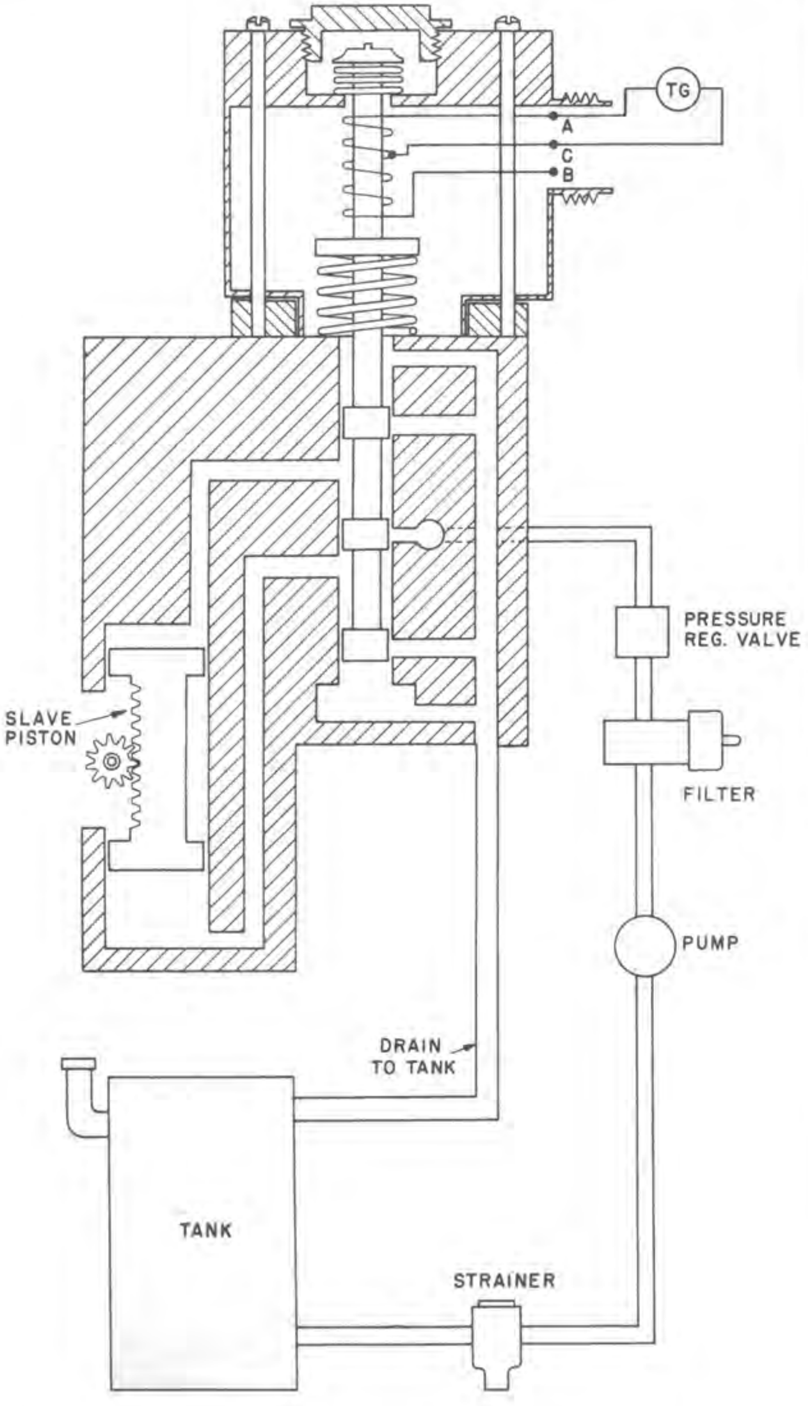
If diesel engine load had decreased instead of increased, the engine would have speeded up. The tachometer generator would be driven fast enough to increase current above 475 MA. This stronger current would increase magnetism sufficiently to pull the plunger downward from the balance position of Figure 25, to the position shown in Figure 25B. This action would have caused the slave piston to move downward to decrease the rate of fuel injection and thus bring the engine down to its rated speed once again.

A change in diesel engine speed of one RPM will result in sufficient speed coil current change to move the pilot valve plunger .004 inch. The pilot valve plunger is therefore very accurately controlled by the tachometer generator current.

GOVERNOR CLUTCH ARMS "A" AND "B"

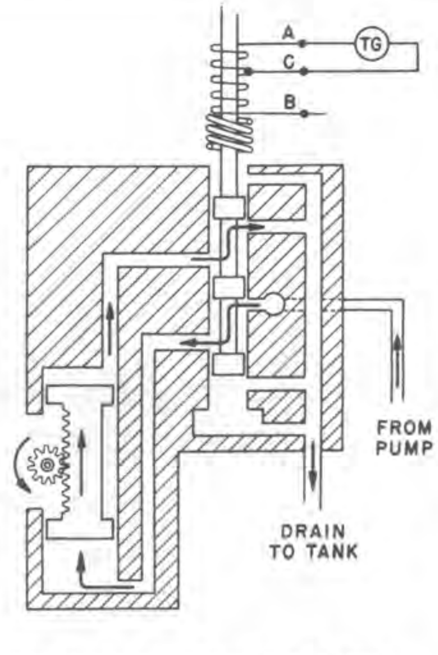
Governor output shaft "F" is keyed to arm "B" and the two operate together as one assembly. Because shaft "F" moves the fuel injection pump linkage, any movement of the pump racks to increase or decrease fuel means that arm "B" must move first. However, the slave piston which moves whenever a change in fuel is called for, is connected to arm "A". Arm "A" thus moves in response to slave piston movement.

When the diesel engine is not running the bias springs (Fig. 24) keep arms "A" and "B" apart. In order to operate the diesel engine it is necessary to bring arms "A" and "B" together so that they operate as one assembly. Because they have no mechanical connection with one another they are held together magnetically by the flow of locomotive battery current through the clutch coil. Current flow through this coil magnetizes both arms and enables them to stick together.



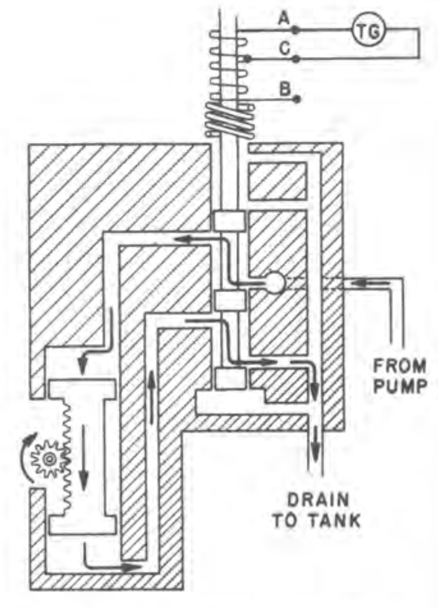
Pilot valve in balanced position. Engine speed is steady with no movement of engine fuel injection pump racks.

FIG. 25



Engine has slowed down due to load increase. Tach generator current is weak and spring pulls plunger UP. Oil pressure forces slave piston UP.

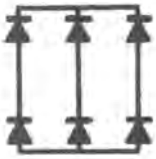
FIG. 25A



Engine has speeded up due to load decrease. Tach generator current is increased and plunger is pulled DOWN by stronger magnetic field. Oil pressure forces slave piston DOWN.

FIG. 25B

WIRING DIAGRAM SYMBOLS



Three phase selenium rectifier

Selenium rectifier used as blocking rectifier

Coil

Tube resistor

Rheostat

Contact in motor cut-out switch

"Governor off" switch

Normally open relay contact. (In Figure 27 the contacts of the hydraulically operated switches OPS1 and OPS2 are also represented by this type symbol).

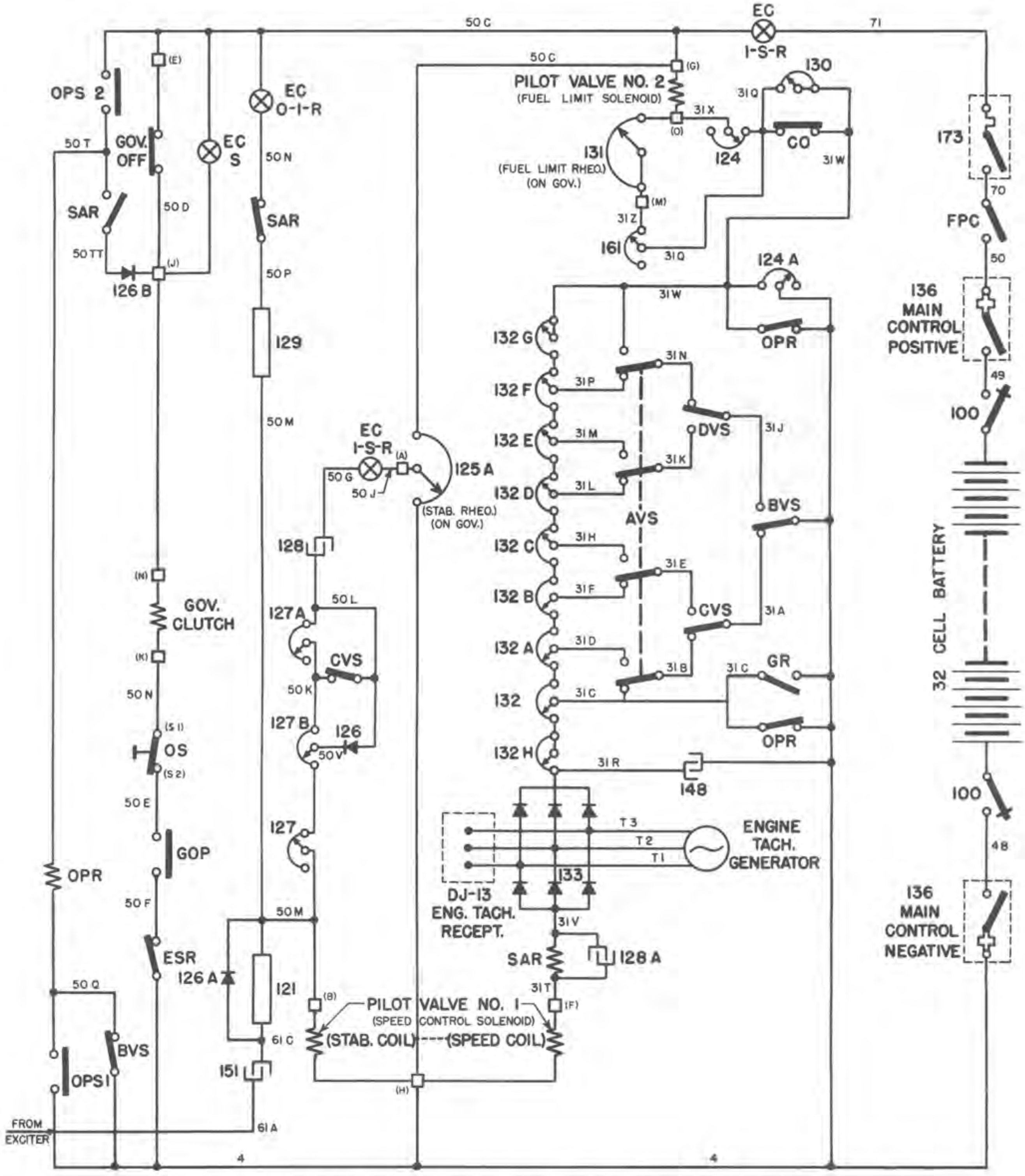
Normally closed relay contact

Hydraulically operated Governor Oil Pressure Switch (In Figure 26 the hydraulically operated switches OPS1 and OPS2 are also represented by this symbol).

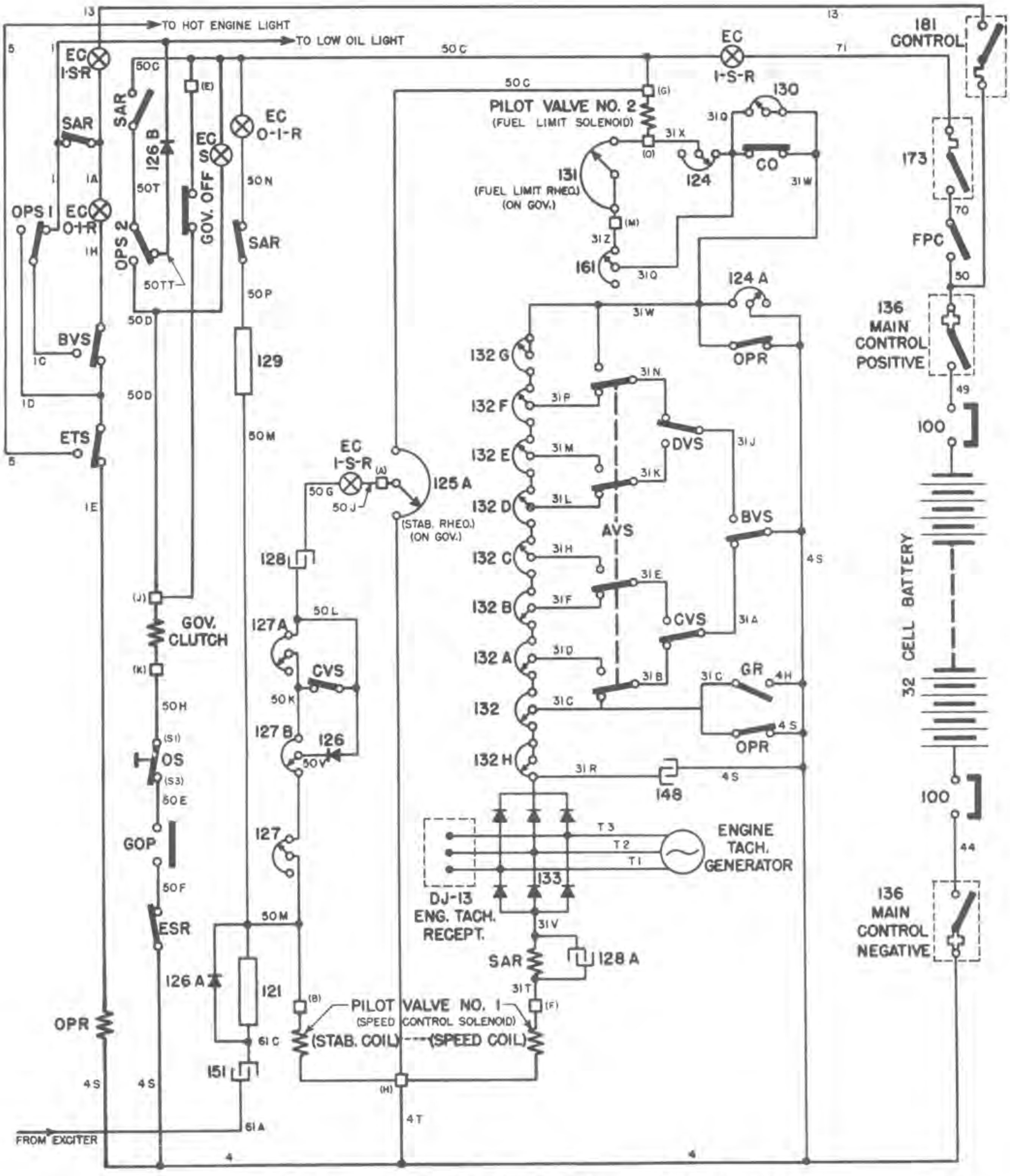
Contact in Engine Control Switch. The letters following EC, such as 2, 4, S, etc., indicate in which position of the switch the contact is closed. Example: EC (2) - Contact is closed only in 2 position. Note: When positions (I-S-R) or (O-I-R) are listed, the contact will close in those positions and also in positions 2, 4 and 6. In other than these two cases the contact will close only in the positions listed.

Amphenol plug point

Capacitor



COMPLETE GOVERNOR SCHEMATIC WIRING DIAGRAM
ROAD SWITCHER
FIG. 26

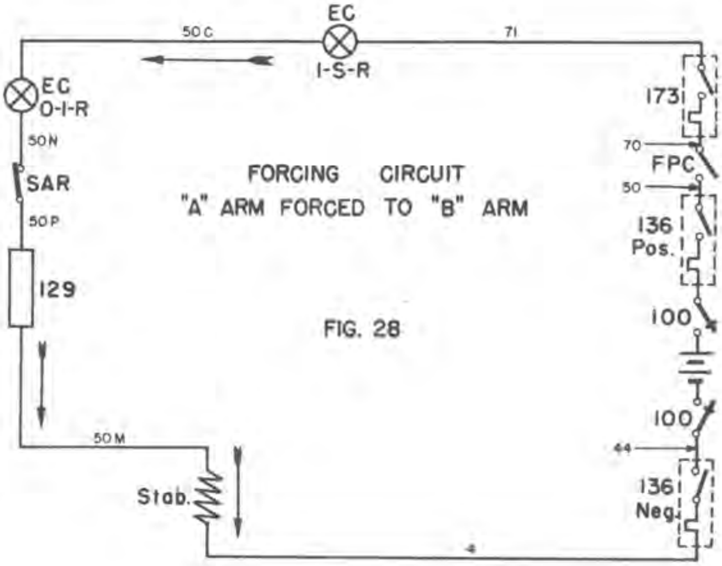


COMPLETE GOVERNOR SCHEMATIC WIRING DIAGRAM
ROAD FREIGHT AND PASSENGER LOCOMOTIVES
FIG. 27

STARTING THE DIESEL ENGINE

Figure 27 is a reproduction of section "D" of the schematic connection diagram which applies to any ALCO-GE road locomotive with Type 244 diesel engine. Figure 26 is a reproduction of section "D" of a road switcher. The small diagrams used with the following text represent a circuit analysis of Figure 27.

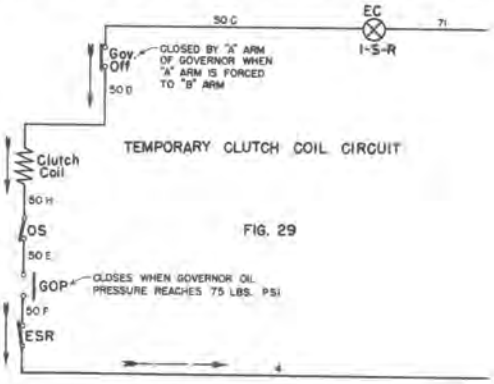
To start the diesel engine it is necessary to energize (pass current through) the stabilizing coil of the speed solenoid. This circuit is diagrammed in Figure 28. Main battery switch 100 and main control positive and negative circuit breakers "136" are closed to bring locomotive battery current to wire 50. The fuel pump contactor "FPC" is closed when circuit breaker "169" and switch "170" (refer to section "F" of schematic connection diagram) are closed. Circuit breaker "173" is closed to send current through wire 71. From wire 71 it then enters the governor circuits diagrammed in Figures 26 and 27.



FORCING CIRCUIT
"A" ARM FORCED TO "B" ARM

FIG. 28

The engine control switch "EC" is placed in "Idle" position. This closes contact 71-50C (Fig. 28) to permit current to flow in the direction of the arrows to the stabilizing coil "Stab". With current in the coil the pilot valve plunger will be pulled down to the position shown in Fig. 25B. Oil then flows through the pilot valve to force slave piston number one to the bottom of its cylinder. Shaft "E" turns clockwise to pull arm "A" over against arm "B". As arm "A" reaches arm "B", it closes the "governor off" interlock. When this interlock closes, it brings current from wire 50C to the governor clutch coil (Fig. 29). The coil now magnetizes arms "A" and "B" to hold them together. The engine control switch "EC" is now turned to the "Start" position. As the starting switch is turned it opens the 50C-50N contact to de-energize the stabilizing coil. This allows the pilot valve plunger to be pulled to the top of its travel by the reference spring and oil flows against the bottom of slave piston number one. The piston is then forced upward and arms "A" and "B" move to the right to cause fuel injection to begin.



TEMPORARY CLUTCH COIL CIRCUIT

FIG. 29

This sequence of events is as follows:

1 - Engine Control Switch to "Idle" position.

2 - This energizes stabilizing coil of speed solenoid with battery current.

3 - Pilot valve plunger is pulled downward.

4 - Oil reaches top of slave piston to force it down.

5 - This forces arm "A" to move "to" arm "B".

6 - Arm "A" closes "governor off" switch.

7 - This energizes clutch coil to magnetize arms "A" and "B".

8 - Engine Control Switch to "Start" position.

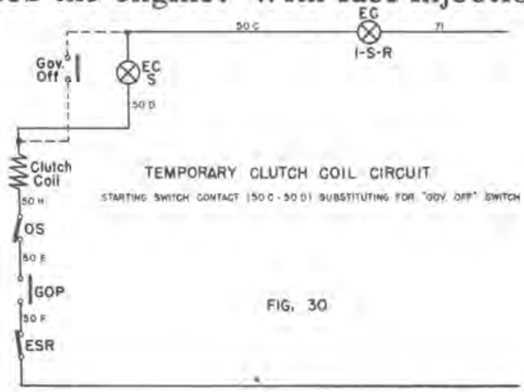
9 - This de-energizes stabilizing coil and allows pilot valve plunger to be pulled upward by reference spring.

10 - Oil reaches bottom of slave piston to force it upward.

11 - Arms "A" and "B" move to right to cause fuel injection to begin.

The starting switch also passed current to contactors GS1 and GS2. (Section H of schematic connection diagram). These contactors pass current to the starting field of the main generator and the generator rotates the engine. With fuel injection and rotation the engine will begin to run.

When arms "A" and "B" move to the right, arm "A" releases the "governor off" interlock. To keep the clutch coil energized, the starting switch contacts 50C-50D (Fig. 30) close when the switch is in "Start" position. This switch by-passes current around the now open "governor off" interlock.

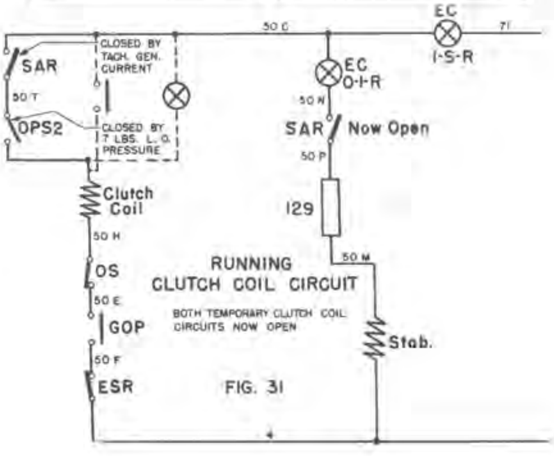


TEMPORARY CLUTCH COIL CIRCUIT

STARTING SWITCH CONTACT (50 C - 50 D) SUBSTITUTING FOR "GOV. OFF" SWITCH

FIG. 30

As the diesel engine begins rotating, its lubricating oil pressure builds up. When lube oil pressure builds up to 7 lbs. per sq. in. it closes oil pressure switch number 2 (OPS-2) (Fig. 31). When the engine reaches a speed above 150 RPM the tachometer generator current will be strong enough to energize the safety relay SAR. The latter closes its 50C-50T contact (Fig. 31).



RUNNING CLUTCH COIL CIRCUIT

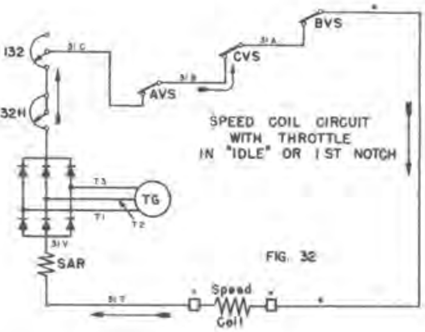
BOTH TEMPORARY CLUTCH COIL CIRCUITS NOW OPEN

FIG. 31

This completes the final running clutch coil circuit. The diesel engine will now continue to run unless the clutch coil circuit is opened by one of the automatic safety interlocks (OS, GOP, ESR, SAR, OPS-2). If this should happen the clutch coil will be de-energized and with no magnetism to hold them together, arms "A" and "B" will be separated by the bias springs. This action would pull arm "B" all the way to the left. Minimum rack travel would result and with no fuel injection the engine would shut down. When SAR is energized it also opens its 50N-50P contact in the stabilizing coil circuit to prevent current from reaching the stabilizing coil when the engine control switch is returned to "Idle" position. (Fig. 31)

After starting, the diesel engine will come up to a speed of 350 RPM. At this speed the tachometer generator will supply the speed coil with 475 MA. The pilot valve will be in balanced position (Fig. 25) as long as the engine speed remains at 350 RPM.

SPEED CONTROL



SPEED COIL CIRCUIT WITH THROTTLE IN "IDLE" OR 1ST NOTCH

FIG. 32

The circuit through which the tachometer generator supplies the speed coil with current is illustrated in Fig. 32. Current follows the direction of the arrows. The three phase rectifier "133", rectifies the alternating current of the tachometer generator to direct current for use in the speed coil.

The tachometer generator and the governor will hold engine speed constant in each of the nine different positions of the engineer's throttle. For example, when the engine is idling its speed should be 350 RPM. If the speed should tend to increase or decrease, the governor will immediately adjust fuel to bring it back to 350 RPM. If speed increases, the governor will decrease fuel injection. If speed drops below 350 RPM the governor will increase fuel to bring the speed up to 350 RPM. If, for example, speed should drop to 348 RPM, the governor action would be as illustrated in Figure 24. The sequence of events would be as follows:

1. Engine speed drops below 350 RPM. Tachometer generator slows down and current to the pilot valve speed coil drops below 475 milliamperes.
2. With less than 475 MA in speed coil, reference spring pulls pilot valve plunger upwards (See Figure 25A).
3. Oil pressure reaches bottom of slave piston No. 1 to push piston up.
4. Piston operates governor linkage to increase fuel injection (Figure 24).
5. With more fuel engine speeds up.
6. When speed rises to 350 RPM, the tachometer generator will once again put 475 MA through speed coil.
7. This current will cause pilot valve plunger to be pulled down far enough to block off inlet port and stop oil flow to power piston. Further increase in fuel is prevented.

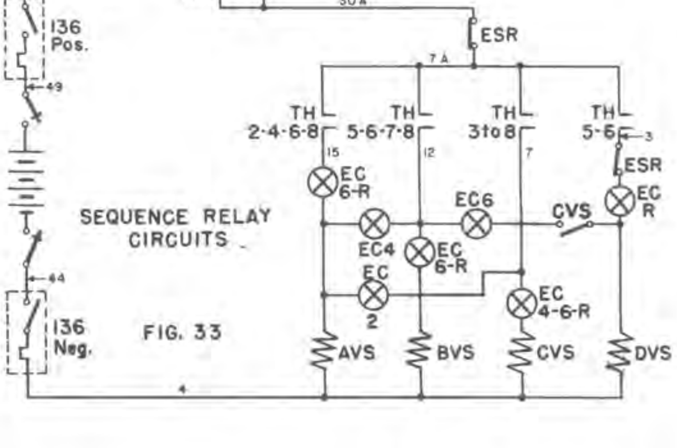
If the engine had speeded up, instead of slowing below 350 RPM, the governor would have decreased fuel instead of increasing it.

EFFECT OF THROTTLE MOVEMENT ON GOVERNOR

The engine control switch must be turned to the "2", "4", "6" or "Run" position before a movement of the engineman's throttle will have any effect on the diesel engine speed.

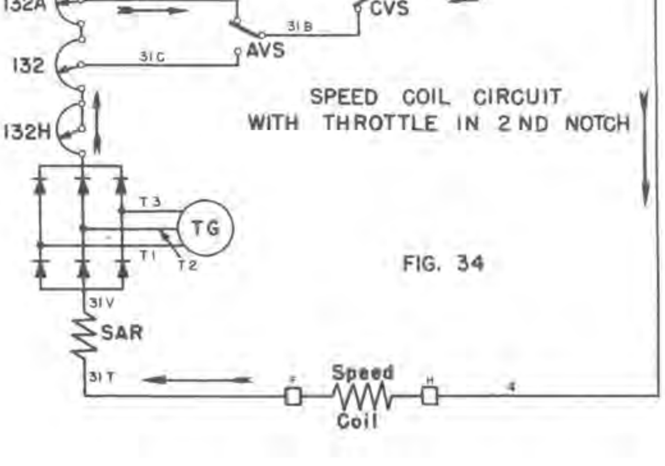
As long as the resistance of the tachometer generator circuit remains as illustrated in Fig. 32, the diesel engine will operate at 350 RPM. When the engine man desires to increase the engine speed he "notches up" the throttle. When the throttle is notched up from 1 to 2, it closes its 7A-15 contact to energize relay "AVS" (Fig. 33). "AVS" picks up its contact in the tachometer generator circuit to add rheostat "132A" to the circuit (Fig. 34). This added resistance weakens the tachometer generator current. When the current in the speed coil drops below 475 MA, the diesel engine will increase its speed (See Fig. 25A). When the diesel engine speed increases the tachometer generator will rotate faster and develop more voltage. At 450 engine RPM the voltage will be strong enough to bring the current up to 475 MA, once again, in spite of the added resistance of 132A. This current value will pull the plunger down to balance position, cutting off the flow of oil to the slave piston. The diesel engine fuel racks will now have a higher setting and the engine will be operating at its second notch speed of 450 RPM. The governor will hold it at 450 RPM until the throttle is moved again.

Movement of the throttle through positions 2 to 8 inclusive, operates speed setting relays "AVS", "BVS", "CVS" and "DVS". Everytime the throttle is notched up or down, one or more of these relays operate to change the resistance of the tachometer generator circuit, with a resultant change in diesel engine speed. Figure 35 illustrates the complete circuit with all four relays and all the "132" rheostats. The dotted line indicates that the four contacts which it connects are operated simultaneously by relay "AVS". Fig. 33 illustrates the throttle contacts ("TH") which cause the relay coils to become energized.



SEQUENCE RELAY CIRCUITS

FIG. 33

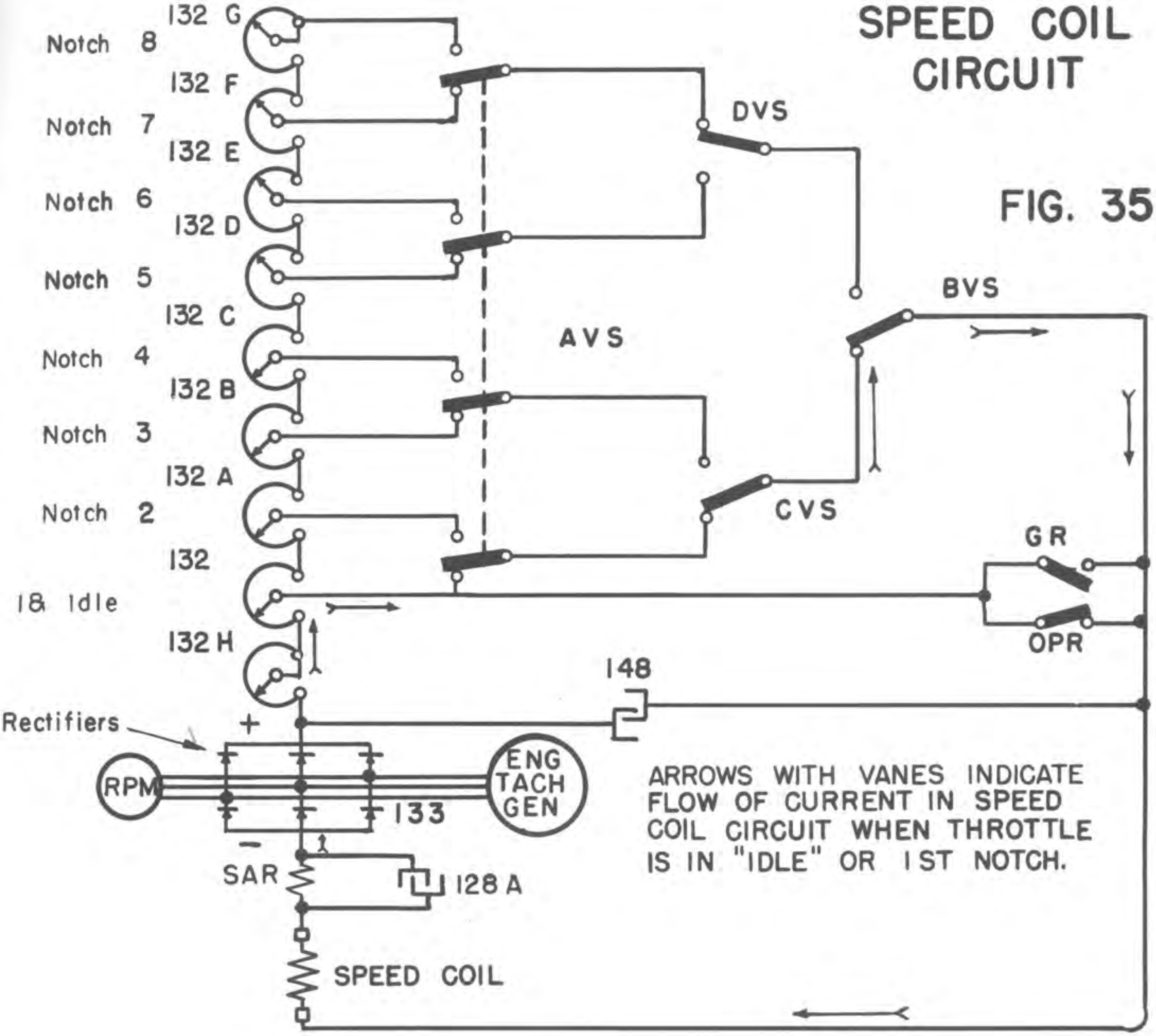


SPEED COIL CIRCUIT WITH THROTTLE IN 2ND NOTCH

FIG. 34

SPEED COIL CIRCUIT

FIG. 35



ARROWS WITH VANES INDICATE FLOW OF CURRENT IN SPEED COIL CIRCUIT WHEN THROTTLE IS IN "IDLE" OR 1ST NOTCH.

FUEL LIMIT COIL CIRCUIT

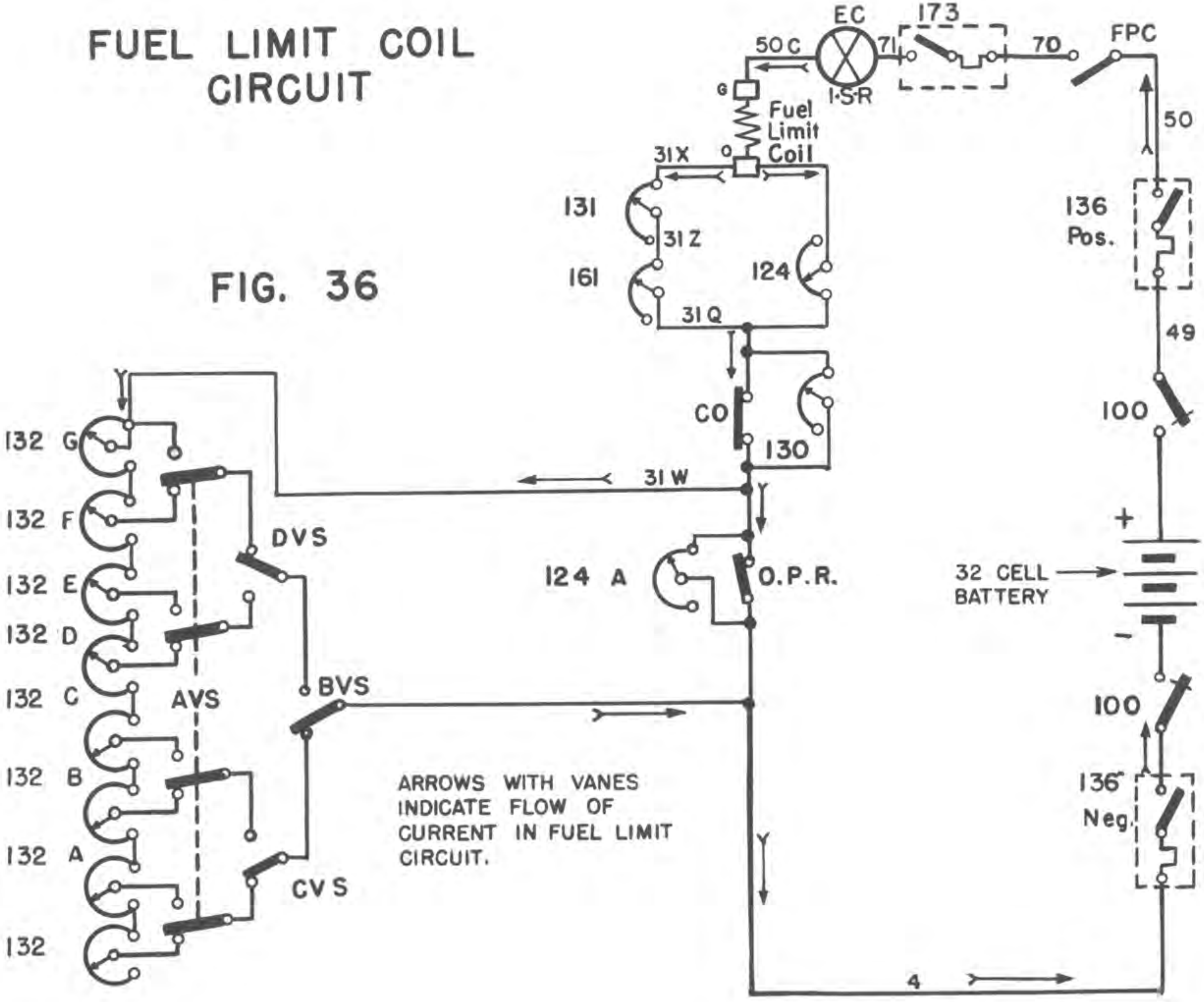


FIG. 36

ARROWS WITH VANES INDICATE FLOW OF CURRENT IN FUEL LIMIT CIRCUIT.

Table IV lists the relays which operate in various throttle positions and the diesel engine RPM which results from the various relay combinations.

TABLE IV

THROTTLE NOTCH	RELAY OPERATION	ENGINE RPM
1 & Idle	None	350
2	AVS	450
3	CVS	550
4	AVS, CVS	655
5	BVS, CVS, DVS	765
6	AVS, BVS, CVS, DVS	860
7	BVS, CVS	920
8	AVS, BVS, CVS	1000

FUEL LIMITING SYSTEM

Whenever the diesel engine is slowed down by an increase in load or whenever the throttle is notched up, the speed pilot valve acts to increase fuel by forcing arms "A" and "B" to the right as viewed in Figure 24. However, the movement of arms "A" and "B", and that of the diesel engine fuel racks which they operate, is limited to a certain set travel for each throttle notch. As the arms move to the right they come up against the fuel limit cam (Fig. 24). The cam prevents further fuel increase as long as the throttle is not moved to a higher notch.

By limiting fuel injection to a certain fixed amount in each throttle position, the designer ensures that for a given set of operating conditions, a certain horsepower will be developed in each throttle notch regardless of grade and tonnage conditions.

Fuel limit also prevents the injection of more fuel than the diesel engine can safely burn. If excessive fuel is injected into a diesel engine, high combustion pressures and temperatures with excessive carbonization of valves, cylinder heads, manifolds and pistons results.

Let us assume that the engine is operating in second throttle notch position and the engineman notches up to number three throttle notch. Arms "A" and "B" move to the right (Fig. 24) and engine speed increases. However, the arms hit the cam and fuel injection pump rack travel is held to a certain maximum. With this much fuel the diesel engine speed comes up to 540 RPM. It is necessary to get the speed up to 550 but it is not possible to do it by further increase in fuel because the cam prevents further rack travel increase.

The load control rheostat will now be operated by the governor. This rheostat will reduce generator loading. As load is removed from the generator the diesel engine speed will come up until 550 RPM is reached. The speed will balance at this point and the governor will hold it at 550 RPM until the throttle is again moved. The complete action of the load control rheostat will be described under "Load Control".

When the engineman calls for more diesel engine speed and more horsepower by notching the throttle up to 4th notch, the governor will increase fuel as described in "Effect of Throttle Movement on Governor". However, in order for the operation described to take place, the fuel limit cam must be turned a bit in order that arms "A" and "B" can move to the right and increase fuel. Turning the cam is accomplished by the action of the governor's second pilot valve, the fuel limit pilot valve. The fuel limit coil of this pilot valve is supplied with current by the locomotive battery circuit. When the engineman's throttle is in 3rd notch there will be 475 MA of current supplied to the fuel limit coil. This current will pull the plunger down just far enough to block off the inlet port and prevent oil from exerting pressure on slave piston number 2.

When the throttle is advanced from 3 to 4, the speed relay "AVS" operates to cut rheostat "132B" out of the fuel limit circuit (Figure 36 illustrates the complete fuel limit circuit - refer to Table IV for speed relay operation). This reduction in circuit resistance permits a higher current to flow through the fuel limit coil (more than 475 MA). This increased current pulls the pilot valve plunger down, opening the inlet port and permitting oil to force slave piston number 2 down (Fig. 24). As the piston goes down it turns shaft "H" counter-clockwise. Movement of the shaft turns the fuel limit cam, which is keyed to it, and arms "A" and "B" will then move to the right to increase fuel. The cam will turn only a little, however, and the arms will hit it again, Fuel injection will be at a new value and horsepower will increase accordingly

As shaft "H" turns, it turns the brush arm of the fuel limit rheostat 131 (Fig. 24 and 36) as well as the fuel limit cam. This rheostat brush arm adds resistance to the fuel limit coil circuit (Fig. 36). As the resistance increases, due to the moving brush arm, the current through the fuel limit coil is gradually reduced until it once again drops to 475 MA. This permits the reference spring to pull the plunger up far enough to balance the port and cut off oil flow. The cam is thus allowed to turn only a certain distance, thereby giving a certain definite fuel limit for each position of the engineman's throttle. Fig. 41 shows the fuel limit rheostat and its brush arm.

Figure 24 does not show a reference spring on the fuel limit valve, but one exists in the same relative position on this valve as is shown for the speed pilot valve.

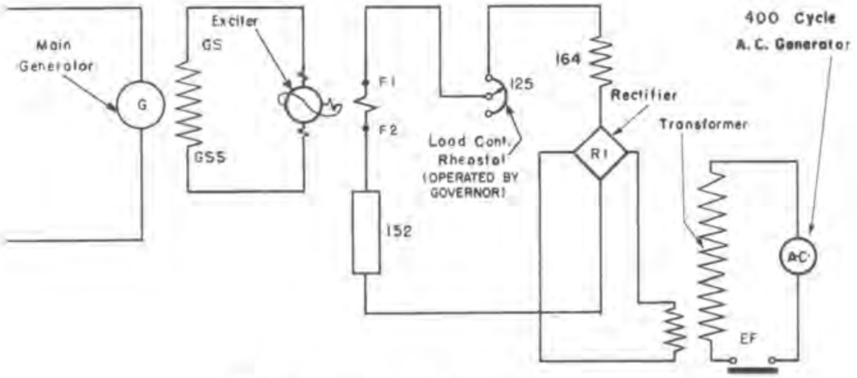
LOAD CONTROL (See page 7)

The governor's load control system, controls the speed of the diesel engine by preventing the traction generator from overloading the engine. During operation in notches 3 through 8, the governor arms "A" and "B" are pushed against the fuel limit cam. The arms contact the cam in each of these throttle positions. It is normal for the arms to be against the cam, because this ensures that the engine is receiving its full quota of fuel for that particular throttle position. There are only a few periods of locomotive operation when this maximum available fuel will hold the engine at its proper speed, however. The periods during which this fuel will be sufficient to maintain engine speed are at transition points and at two other points where the normal power output of the generator is equal to the engine's ability to supply power.

At all other periods of operation it is necessary to control the generator load in order to prevent it from slowing the engine down below its rated speed. Let us assume that the engineman advances his throttle from No. 2 notch to No. 3 notch. This causes arms "A" and "B" to move to the right (increase fuel). They increase fuel until they contact the fuel limit cam. Further increase in fuel is now prevented.

If the generator load is heavy enough to hold the engine speed below 550 RPM (normal 3rd notch speed), the tachometer generator speed will also be below normal, and speed pilot valve current will be less than 475 MA. With less than 475MA in the speed coil the speed pilot valve plunger will be pulled up by the reference spring. This movement of the plunger opens the pilot valve inlet port and allows oil pressure to force slave piston number one further up. Shaft "E" turns counterclockwise with lever arm "D". But lever "C" can turn no further because it is mechanically linked to arm "A" and the latter has been stopped by the fuel limit cam. So, shaft "E" winds up the overtravel spring as "D" moves away from "C". As "D" leaves "C" the brush arm of the load control rheostat "125" begins to travel across the rheostat segments. The brush arm thus adds resistance to the exciter field circuit. See Figure 37. The exciter field current is forced to weaken due to the increased resistance of the load control rheostat. This forces a reduction in exciter current which in turn forces a reduction in generator field current. Reduced generator field current lightens the load on the generator and with less generator load the engine can speed up to its rated 550 RPM.

The governor thus gives the Diesel engine a certain definite amount of fuel and then actually controls the Diesel engine speed by controlling the amount of generator load. When the cam is restricting fuel injection to a certain amount, the load control rheostat brings the engine up to rated speed by removing load from the generator. If load should drop off the generator, the engine would of course increase its speed. The load control rheostat brush arm would then be forced to reduce resistance to allow the load to increase sufficiently to slow the engine down to rated speed.



BASIC EXCITATION CIRCUIT

FIG. 37

RECALIBRATING LINKAGE

A recalibrating linkage is provided to allow correct positioning of the load control rheostat for each position of the engineer's throttle. When the fuel limit shaft turns to move the cam to a different position everytime the throttle is moved, it also turns the barrel of the load cnntrol rheostat. The barrel rotates on its shaft to move the rheostat face to a new position. This tends to move the segmented area of the rheostat away from the brush arm. If this was not done, the load control brush arm would sweep across the rheostat face to remove excitation and unload the generator everytime the throttle was advanced.

Figure 24 shows the recalibrating linkage as consisting of two rods and a bell crank connecting shaft "H" with the load control rheostat barrel (125). Actually, the barrel is moved by a gear, eccentric and link as is shown in Figure 41.

STABILIZING ACTION

Without some form of stabilization the speed controlling action of the governor would tend to be very ragged. For example, a slow down in engine speed would be followed by the speed coil acting to cause a fuel increase. The increase in fuel delivery to the engine would be continued until the engine had regained its rated speed, at which point the tachometer generator current would balance the pilot valve. However, although the pilot valve's inlet port would be immediately closed off by the plunger to prevent any further fuel increase, the diesel engine's momentum would carry its speed above the rated RPM. This action would cause the tachometer generator current to become strong enough to cause the pilot valve to force a fuel decrease. The diesel engine would slow down and the cycle would take place in reverse, thus causing the diesel engine to drop below the rated speed. This "up and down" action is referred to as "hunting".

To minimize this tendency of the diesel engine to hunt, a stabilizing coil in the pilot valve helps the speed coil to maintain steady diesel engine speeds. Whenever the speed coil causes the pilot valve plunger to move from its balance position, the stabilizing coil acts to partially oppose the movement. This tends to prevent the pilot valve plunger from opening the inlet port too widely.

Refer to Figure 24. The brush arm of the stabilizing rheostat (125A) will turn whenever shaft "E" turns. The latter always turns whenever the pilot valve plunger is forced from its balance position: that is, whenever the pilot valve is causing an increase or decrease in fuel to the diesel engine. The stabilizing rheostat is connected into the stabilizing coil circuit in such a manner that a movement of its brush arm will change the resistance of the circuit. When the resistance changes, a capacitor momentarily forces current through the stabilizing coil. This sets up a second magnetic field within the pilot valve solenoid. The stabilizing coil's magnetic field will oppose whatever movement of the plunger that was caused by the speed coil. This tends to prevent the speed coil from moving the plunger far enough to cause a radical change in fuel delivery . The stabilizing coil's magnetic pull is never strong enough to completely overcome the pull of the speed coil. It only partially opposes it to prevent an "overshoot" in diesel engine speed. The stabilizing rheostat is shown in Figs. 41 and 42. Figure 24 shows its brush arm mounted on shaft "E". Actually, shaft "E" rotates the brush arm by means of a gear train as shown in Fig. 44.

Assume that the diesel engine slows below its rated speed. The pilot valve operates to allow oil pressure to reach and move slave piston number one upwards in its cylinder. This turns shaft "E" (Figs. 24 and 25A). The brush arm of the stabilizing rheostat is rotated by the gearing which connects its shaft to shaft "E". As the brush arm moves it reduces resistance in the stabilizing circuit (Fig. 38). This permits the voltage to increase on the 50G wire side of capacitor "128". The increase in voltage on one side of the capacitor forces the capacitor to discharge current through the "127" rheostats to the stabilizing coil. This current causes the stabilizing coil to pull the pilot valve plunger down, to partially close the inlet port and prevent a heavy oil flow from moving the slave piston too far up. The original upward movement of the pilot valve plunger has been partially opposed.

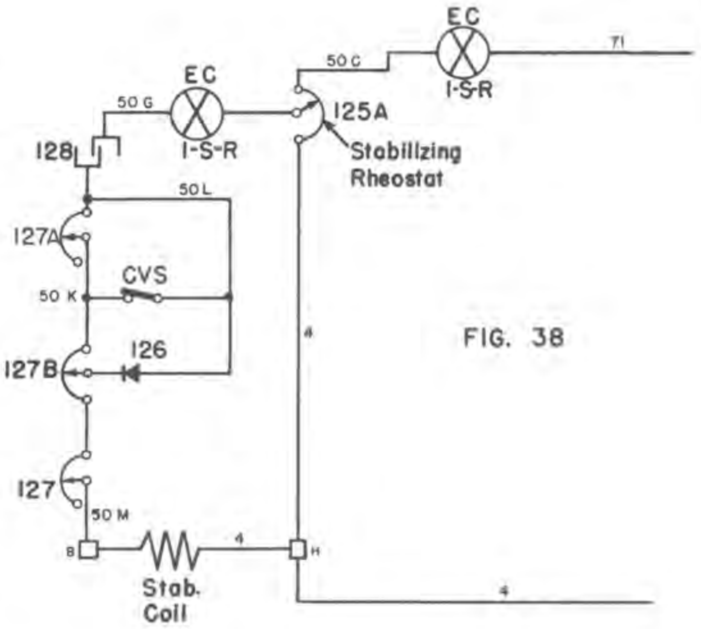


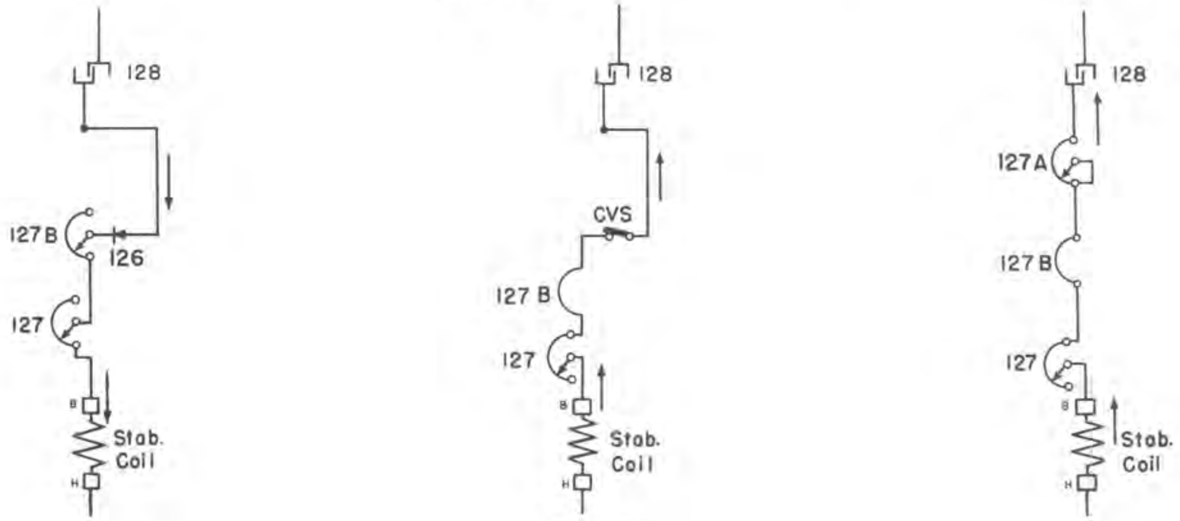
FIG. 38

The winding of the stabilizing coil is such, that a current flowing through it from "B" to "H" will cause it to pull the pilot valve plunger down to partially oppose a fuel increase. By preventing too great a fuel increase, sudden acceleration and speed overshooting of the diesel engine are avoided.

When the diesel engine increases its speed above its normal rated RPM, the pilot valve acts to decrease fuel. To prevent if from making too great a decrease, with a resulting radical drop in engine speed, the stabilizing coil again opposes the speed coil action. In this case, as the slave piston turns shaft "E" the stabilizing rheostat brush arm moves to add resistance to the circuit and decrease the voltage on the 50G wire side of "128" capacitor. Again the capacitor causes a transient current flow, but this time in the opposite direction. Instead of current flowing from "B" to "H" through the coil, it now flows from "H" to "B". This current flow causes the pilot valve plunger to be pulled up to partially close the inlet port and prevent the slave piston from moving too far down. This action effectively prevents too great a decrease in fuel. The stabilizing coil has acted to prevent the pilot valve plunger from being pulled too far down.

When the stabilizing coil acts to prevent too great a decrease in fuel the current flow through the coil is weaker than it is when too great an increase in fuel is being prevented. Current flow from "H" to "B" is weaker than it is when it is flowing from "B" to "H" due to the action of "126" blocking rectifier. This action is illustrated in the stabilizing coil circuit analysis of Figure 39.

When the circuit operates to prevent too great an increase in fuel, current flows from capacitor "128" through "126" rectifier, thru part of "127B" resistor and all of "127" resistor. In the reverse direction, current flows through "127" and all of "127B" resistor, through "CVS" interlock to capacitor "128". The current will be weaker in this direction because the resistance used is greater. In throttle notches 3 TO8, "CVS" coil is energized and its interlock will be open. Resistor "127A" will then be in the circuit and the current will be still weaker. (Figure 39)



Stabilizing current flow to prevent too great an increase in fuel.

Stabilizing current flow to prevent too great a decrease in fuel- 1st & 2nd throttle positions

Stabilizing current flow to prevent too great a decrease in fuel - 3rd to 8th throttle positions.

FIG. 39

Arrows indicate direction of current flow.
Refer to Figure 38 for complete stabilizing circuit.

The stabilizing circuits just described, cause the stabilizing coil to "buck" the action of the speed coil to prevent overshooting and undershooting of engine speeds.

However, during conditions of generator loading or unloading, an "aiding" instead of "bucking" action is needed. For instance, an increase in loading will slow the engine down. There would be a time lag between this drop in speed and the governor's response to it. To eliminate this time lag, a circuit is connected between the amplidyne exciter and the stabilizing coil as diagrammed in Figure 40.

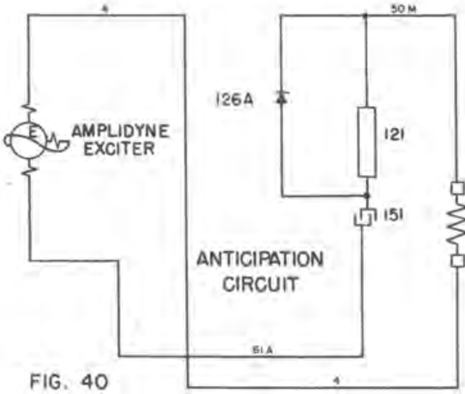


FIG. 40

A change in loading or unloading is always preceeded by a change in exciter voltage. This change will act upon capacitor "151" in the same manner as a change in voltage acted upon capacitor "128". That is, it will cause a transient flow of current across the capacitor. This current will act upon the stabilizing coil in such a manner as to cause operation of the pilot valve before the tachometer generator calls for operation. In other words, an increase in load will tend to decrease engine speed. Before the speed decrease has caused the tachometer generator to call for more fuel, the drop in amplidyne output will already have started the stabilizing coil to act to increase fuel. Thus the stabilizing coil anticipates the need of the engine for more fuel before the diesel engine actually begins to slow down. The circuit works in reverse in exactly the same manner, the stabilizing coil acting to decrease engine fuel before the engine requires a decrease in fuel. The feed back is always proportional to the rate of load change. That is, the greater the load change, the stronger will be the current flow from the exciter to the stabilizing coil. Blocking rectifier "126A" allows a heavier current flow through the stabilizing coil when fuel is to be decreased. The rectifier permits current to flow around "121" resistor in this case. When a fuel increase is called for the current flow from "H" through "B" will be weaker because the rectifier forces the current to flow through resistor "121".

Figure 35 illustrates the connection of capacitor "148" in the speed circuit. This capacitor acts as a "current booster" when an engine speed increase calls for a reduction in fuel. It is desirable to decrease fuel as rapidly as is possible. The increase in tachometer generator voltage causes the capacitor to discharge current through the speed coil. This action pulls the pilot valve down quicker than would be the case if the capacitor was not used and the fuel control racks of the injection pumps move quickly to decrease fuel. The capacitor action is only momentary and serves to produce an initial wider corrective opening of the pilot valve port. The strength of the capacitor's current discharge depends on how fast the diesel engine speed changes. A greater change in speed will result in more current and wider corrective pilot valve opening, than a slight speed change.

Capacitor "148" also reduces the current surge in the speed coil circuit whenever the resistance of the circuit is suddenly increased, such as when the throttle is advanced one notch. This action tends to prevent sudden acceleration of the engine, a condition which would set up severe mechanical stresses.

PROTECTIVE DEVICES

In order to regulate operation of the diesel engine, the governor clutch coil must be energized by power from the batteries. If the coil is de-energized it will allow clutch arms "A" & "B" to separate. Clutch arm "B" then returns to the "shut down" or "no fuel" position and the engine stops. Protective devices are incorporated in the clutch coil circuit as follows:

Governor oil pressure switch "GOP". If governor oil pressure drops to 75 pounds per square inch, "GOP" opens its 50E-50F contact and de-energizes the clutch coil, thereby shutting down the engine (Fig. 27).

Safety relay "SAR". Any opening in the speed setting circuits de-energizes "SAR" coil and opens "SAR" 50C-50T contact in the clutch coil circuit with the same result as for "GOP". SAR contact "50N-50P" in stab. circuit closes to energize stab. coil & force arms to shut down position (Fig. 27). This action protects the diesel engine against the sudden increase in speed, which would result if the speed coil circuit failed and allowed the pilot valve plunger to be pulled upward by the reference spring.

Overspeed switch "OS". If engine speed reaches 1100 to 1120 RPM, "OS" is tripped, thus opening its 50H-50E contact in the clutch coil circuit (Fig. 27) to shut down engine.

A drop in engine oil pressure to twenty pounds per square inch or below opens "OPS1" and thus de-energizes "OPR" relay (Fig. 27). With the latter de-energized, "OPR" interlock in the speed setting circuit closes (Fig. 35) and returns the engine to "Idle" speed. This action takes place only if the locomotive is operating in 5th notch or higher. If it is below 5th notch, "OPR" coil will remain energized even with OPS1 open and the diesel engine will not drop to idle.

Further drop in oil pressure to 7 pounds per square inch or below, opens OPS2 50T-50D contact and de-energizes the clutch coil, shutting the engine down (Fig. 27).

Ground relay operation will cause "GR" interlock in the speed coil circuit to closed (Fig. 35). With this interlock closed, the "132" resistors in the circuit are by-passed and the engine will drop to idle speed.

When traction motors are cut out, rheostat 130 is added to the fuel limit circuit when "CO" contact 31Q-31W opens (Fig. 36). This increased resistance reduces the current flow in the circuit and the fuel limit cam stops in a position which restricts fuel rack travel. By restricting fuel the diesel engine's horsepower is reduced and the remaining traction motors are not overloaded. Fig. 36 shows how this "CO" is connected to 130 rheostat. Normally, current flows through the CO (31Q-31W) contact but when this contact is opened by the motor cutout switch, current is then forced to flow through 130.

ACTUAL LINKAGE

Figure 24 shows the recalibrating linkage as represented by two rods and a bell crank. As previously mentioned the mechanical schematic diagram spreads the various devices apart for clearer views. Actually the rheostat barrel is rotated by an eccentric and link which are operated by a gear on shaft "H". Fig. 41, a front view of the 17MG3 governor illustrates this recalibrating linkage. Fig. 44 illustrates shafts "E" and "H" with their respective gearings. Note that the brush arms of both the fuel limit rheostat "131" and load control rheostat "125" are actually operated through gearing, rather than direct drive as is shown in Fig. 24. The action of these brush arms, however, is as described in the foregoing test.

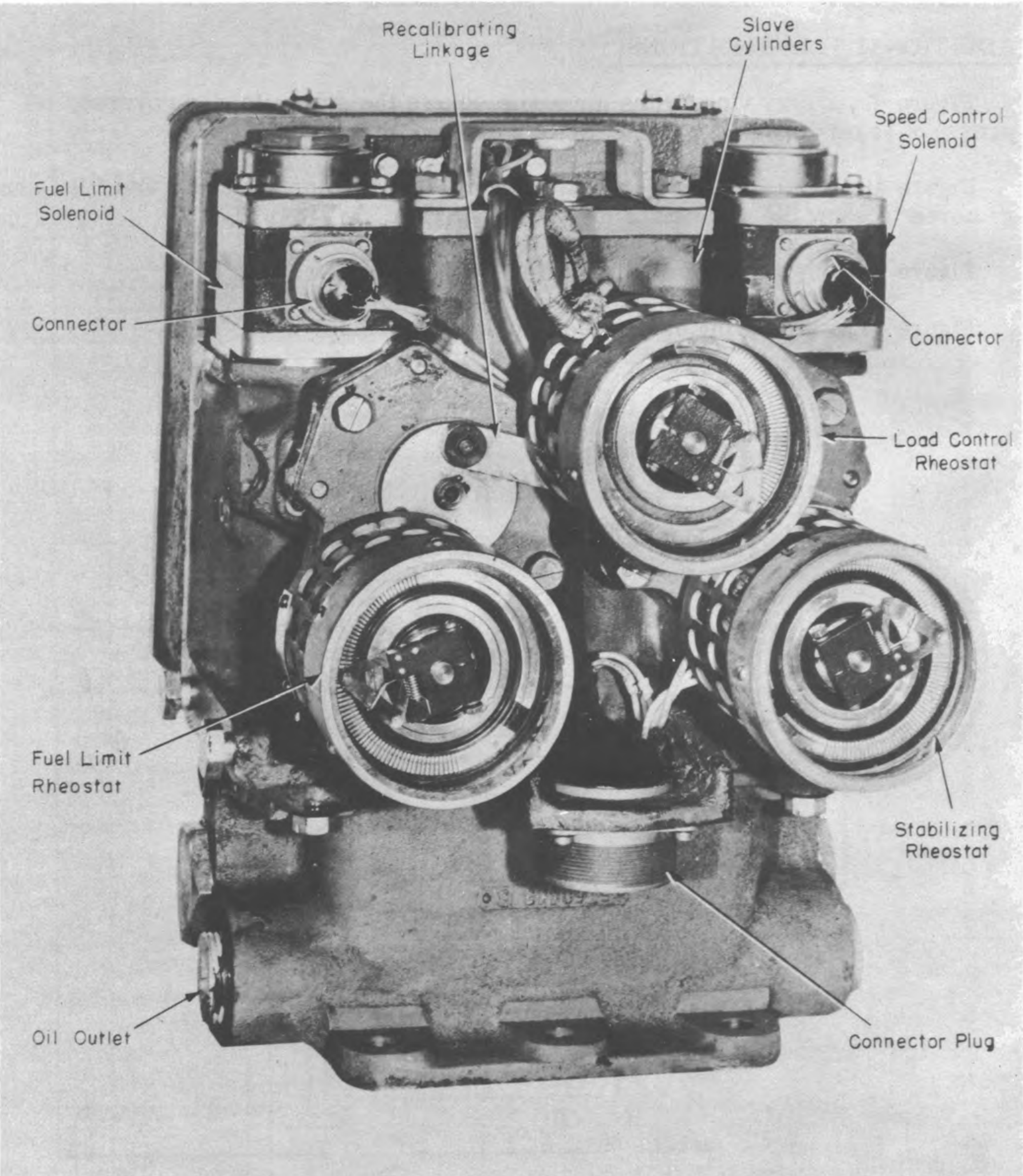
ADDITIONAL ILLUSTRATIONS

Figure 42, a rear view of the governor, shows the spring loaded governor oil pressure regulator and other cut-away views.

Figure 45 illustrates another rear view of the governor with "A" and "B" arms removed to show the position of the fuel limit cam.

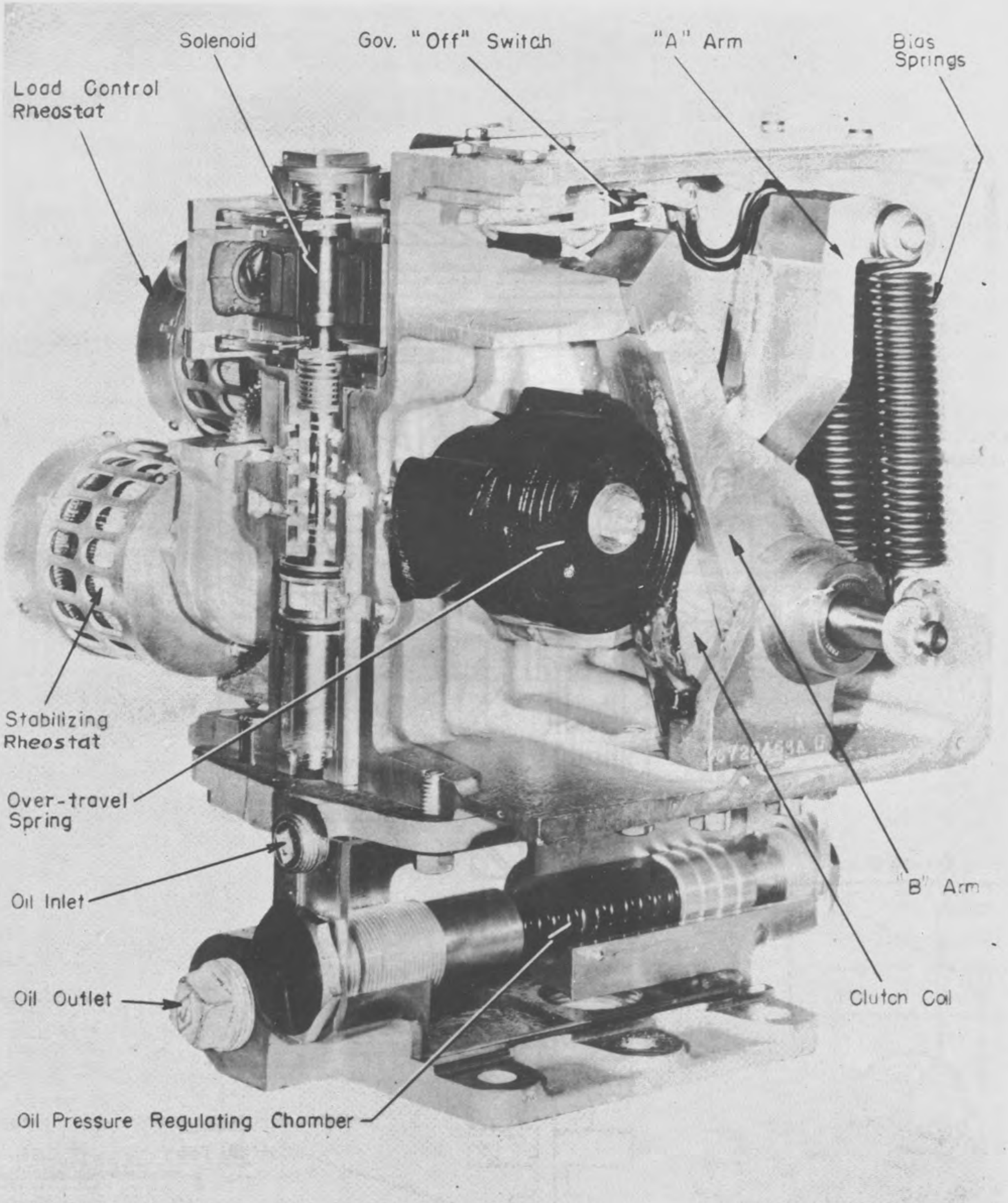
Figure 46 illustrates an exploded view of the governor.

Figure 43 is a drawing of a speed pilot valve assembly.



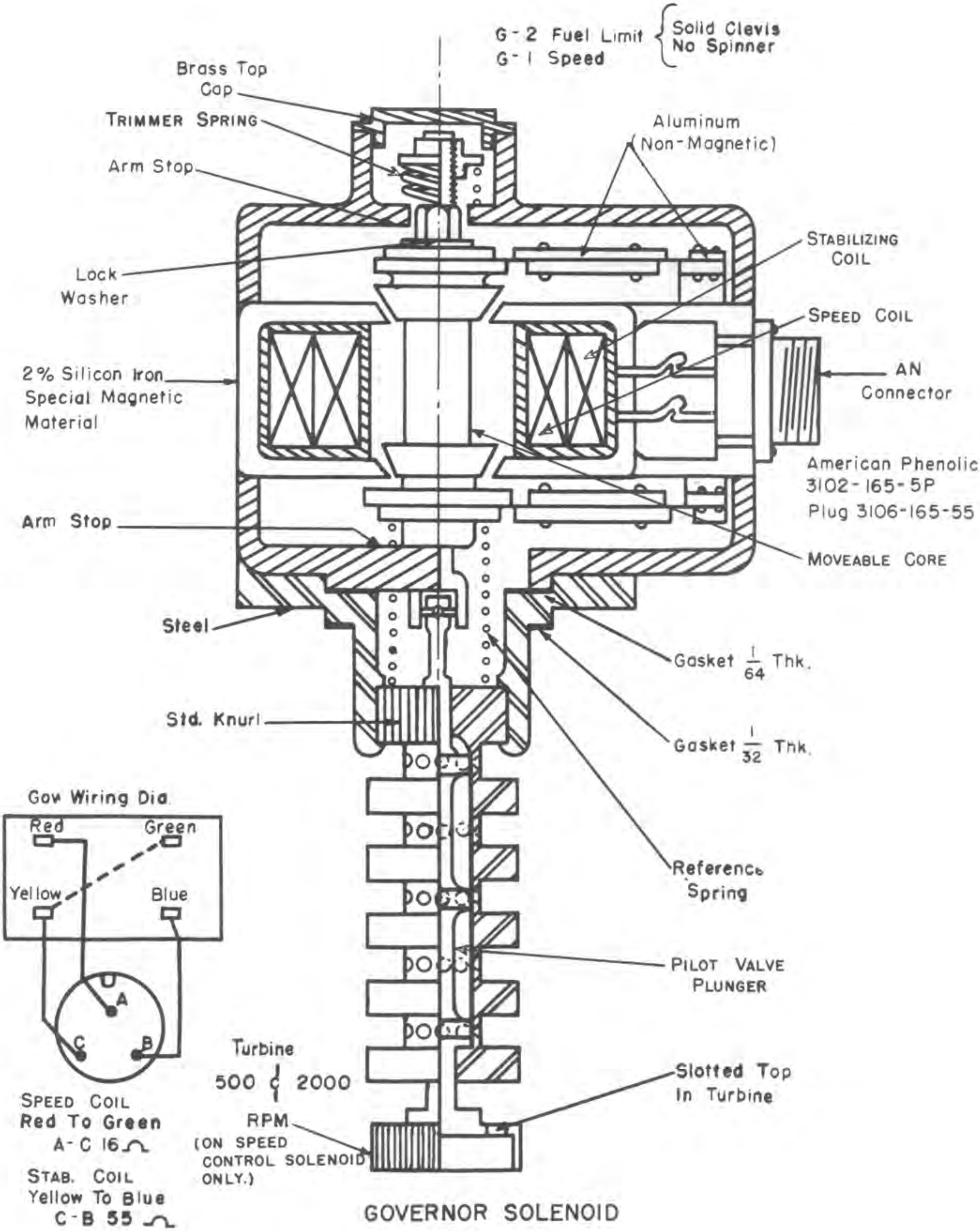
FRONT VIEW, TYPE 17MG3 GOVERNOR

FIG. 41

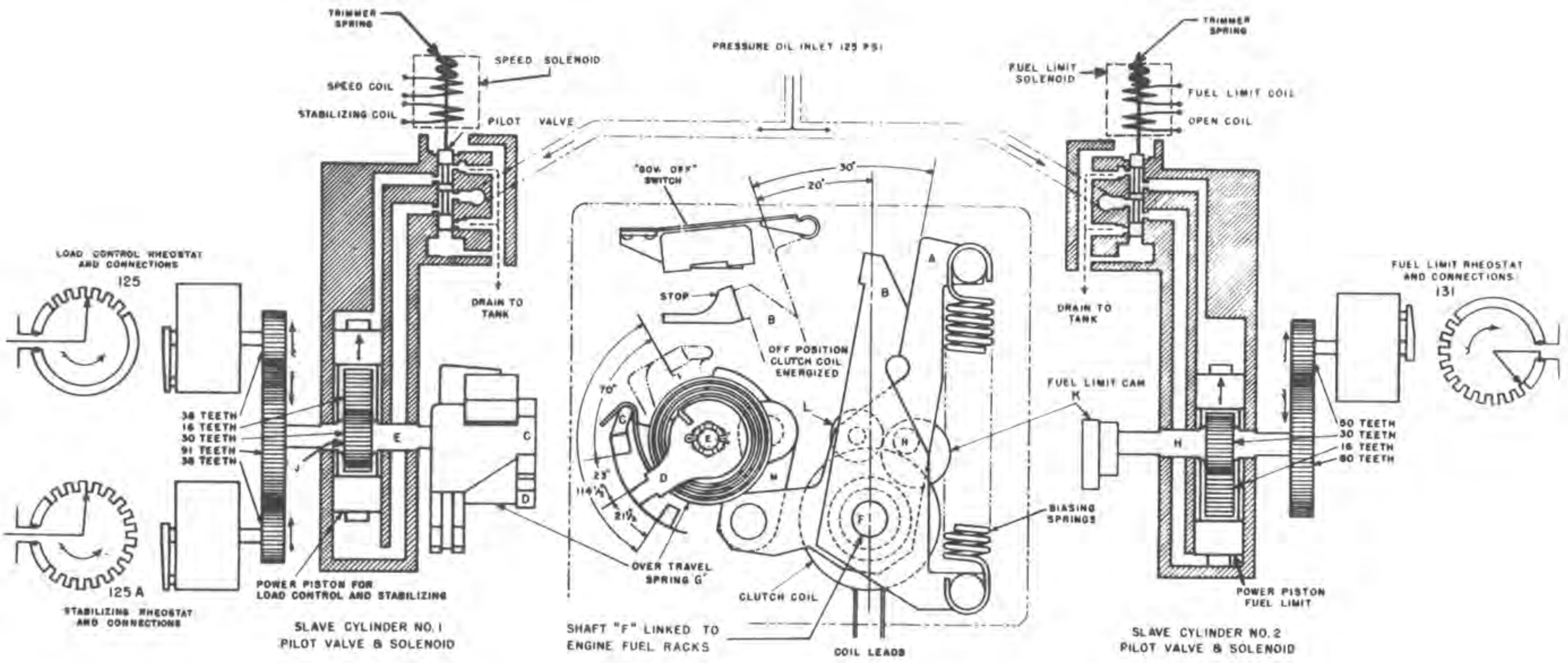


REAR VIEW, TYPE 17MG3 GOVERNOR

FIG. 42



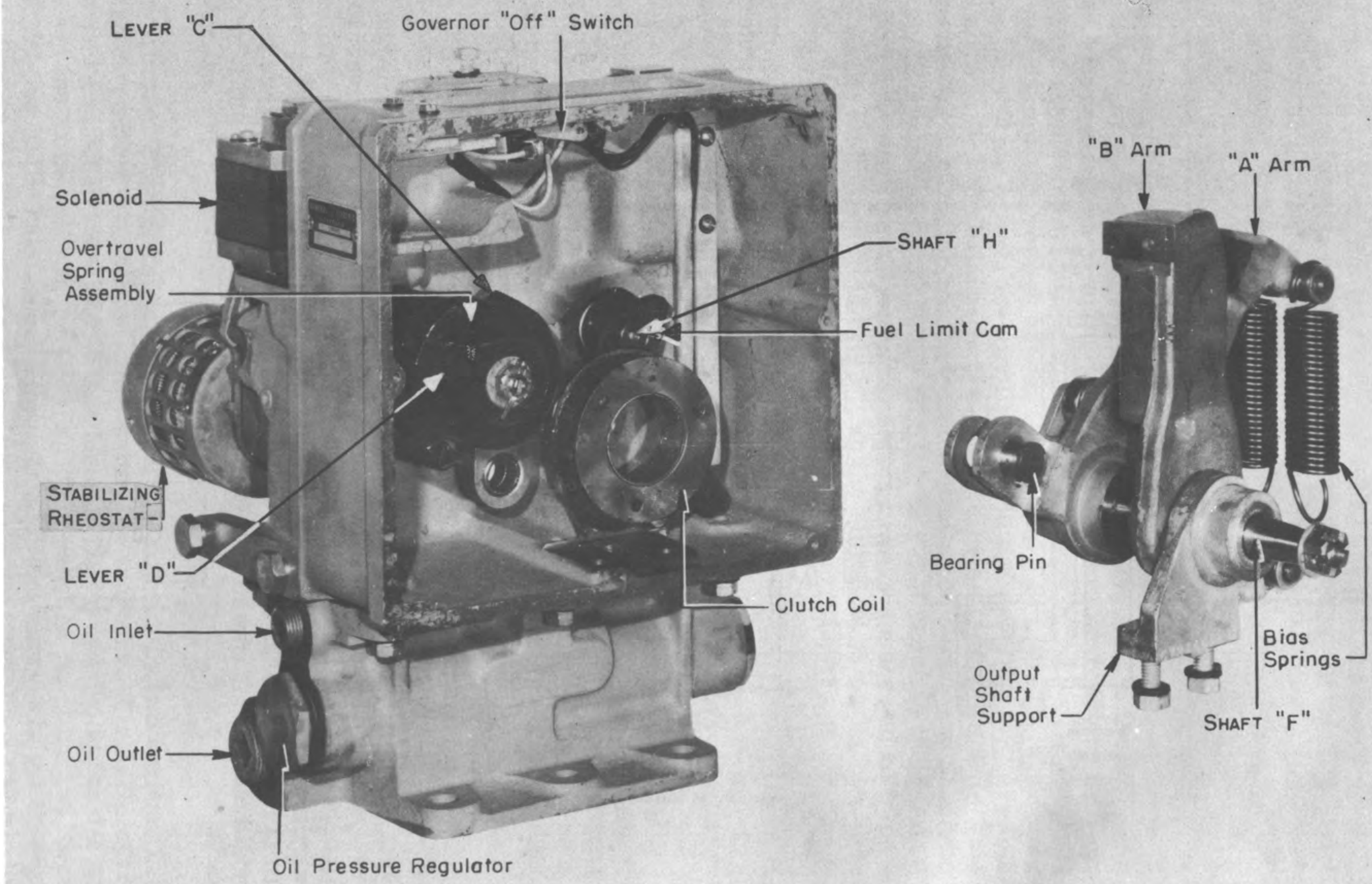
GOVERNOR SOLENOID
FIG. 43



ARROWS WITH VANES SHOW DIRECTION TO DECREASE LOAD AND FUEL LIMIT

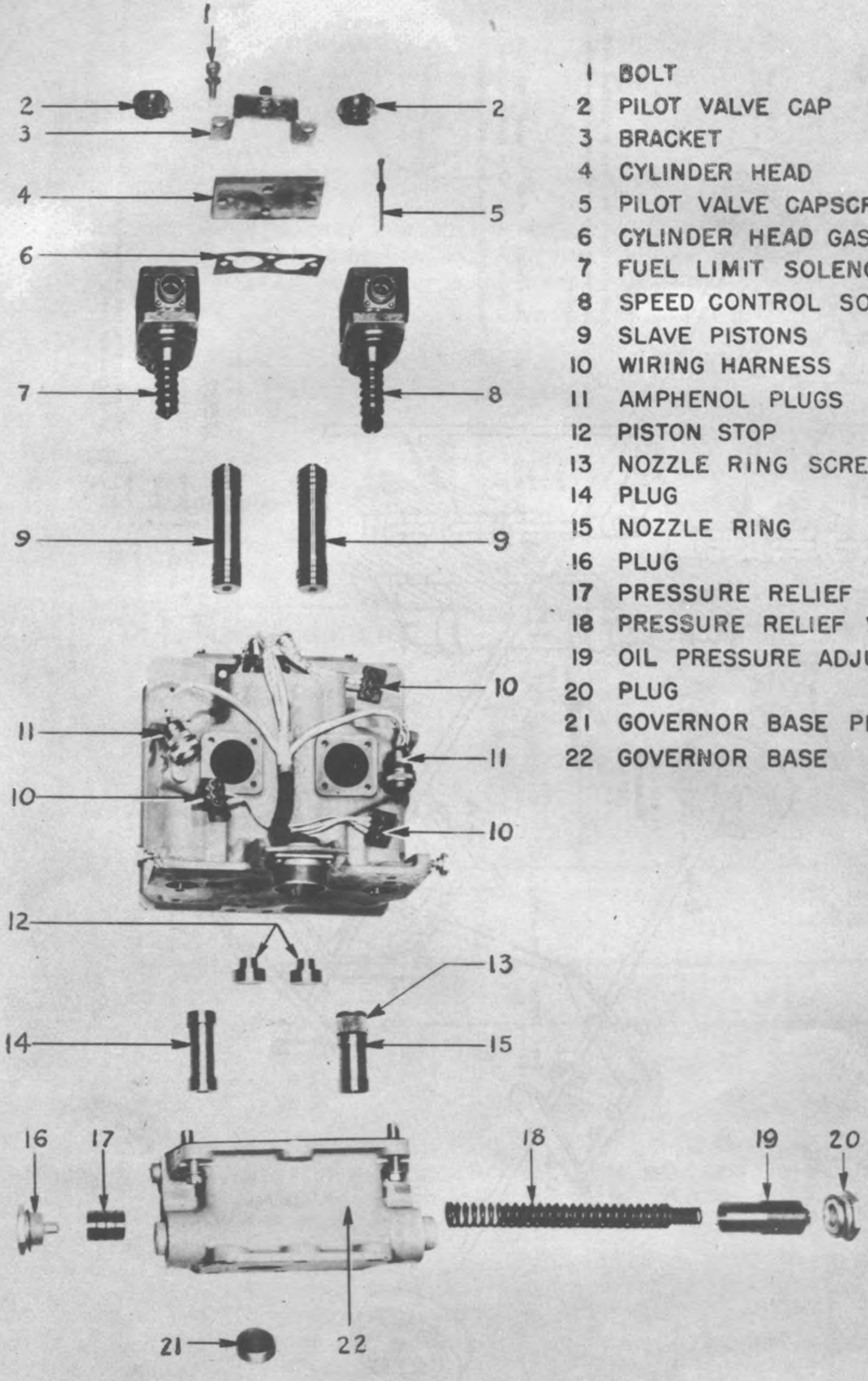
POWER PLANT GOVERNOR FOR DIESEL ENGINE - ONE PLANE SCHEMATIC

FIG. 44



REAR VIEW, TYPE 17MG3C GOVERNOR WITH ARMS REMOVED AND CLUTCH COIL EXPOSED

FIG. 45



1	BOLT
2	PILOT VALVE CAP
3	BRACKET
4	CYLINDER HEAD
5	PILOT VALVE CAPSCREW
6	CYLINDER HEAD GASKET
7	FUEL LIMIT SOLENOID
8	SPEED CONTROL SOLENOID
9	SLAVE PISTONS
10	WIRING HARNESS
11	AMPHENOL PLUGS
12	PISTON STOP
13	NOZZLE RING SCREEN
14	PLUG
15	NOZZLE RING
16	PLUG
17	PRESSURE RELIEF VALVE PISTON
18	PRESSURE RELIEF VALVE SPRINGS
19	OIL PRESSURE ADJUSTING PLUG
20	PLUG
21	GOVERNOR BASE PLUG
22	GOVERNOR BASE

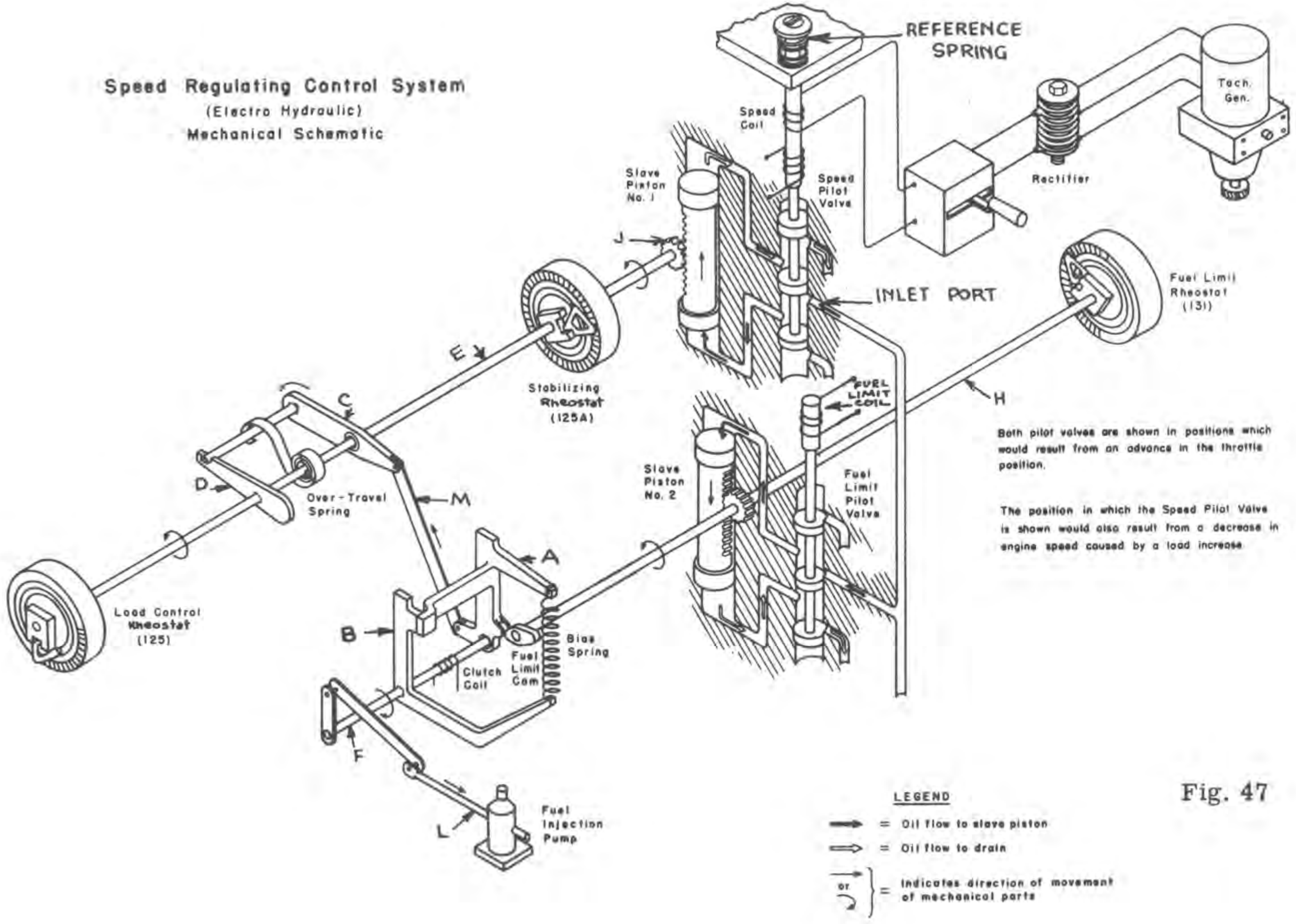
TOP AND BOTTOM DISASSEMBLY OF TYPE 17MG3C GOVERNOR

FIG. 46

Speed Regulating Control System

(Electro Hydraulic)

Mechanical Schematic



Both pilot valves are shown in positions which would result from an advance in the throttle position.

The position in which the Speed Pilot Valve is shown would also result from a decrease in engine speed caused by a load increase.

LEGEND

➡ = Oil flow to slave piston

⇨ = Oil flow to drain

→ or ↷ } = Indicates direction of movement of mechanical parts

Fig. 47

SECTION 4 - POWER PLANT REGULATING SYSTEM FOR 1950 LOCOMOTIVES EQUIPPED WITH TYPE 17MG6 GOVERNOR

The power plant regulating system controls diesel engine speed. Its primary function is to hold the diesel engine at whatever constant speed is called for by the setting of the engineman's throttle. Speed is held constant at all loads.

The power plant regulating system includes the following equipment.

1. Diesel Engine Governor
2. Engine Driven Tachometer Generator
3. Hydraulic Power System

DIESEL ENGINE GOVERNOR

The General Electric Type 17MG electro-hydraulic governor controls the speed of the Alco Type 244 diesel engine. The Type 17MG6 governor is used on both the 12 cylinder and 16 cylinder, 9 x 10-1/2 diesel engines. Diesel engine speed is controlled by regulating the rate of fuel injection and by adjusting the engine loading.

The governor includes speed controlling equipment and fuel limiting equipment.

SPEED CONTROLLING EQUIPMENT (See Figure 47)

The speed coil of the speed solenoid receives its control current from the engine driven tachometer generator. The solenoid operates a balanced four way pilot valve which controls the flow of oil to slave piston number one. This piston, when moved by the flow of oil against its top or bottom surfaces, rotates shaft "E". The latter rotates:

A. The governor output shaft "F" through the overtravel spring and the magnetic clutch coil. Shaft "F" controls the positioning of the diesel engine's fuel injection pump racks.

B. The brush arms of the stabilizing rheostat (125A) and load control rheostat (125). These brush arms are actually gear driven from shaft "E". They are shown as directly driven in Fig. 47 for clarity. See Fig. 65 for illustration of gear drive.

FUEL LIMITING EQUIPMENT (See Figure 47)

The fuel limit coil of the fuel limit solenoid (Fig. 47) receives its control current from the locomotive battery. This solenoid also operates a balanced four way pilot valve which controls the flow of oil to slave piston number two. Movement of this piston either up or down in its cylinder, rotates shaft "H", on one end of which is the fuel limit cam. Shaft "H" positions this cam in such a manner that it limits the travel of arms "A" and "B" to a certain definite position in each throttle notch. This results in a maximum allowable rate of fuel injection for each position of the engineman's throttle. Shaft "H" also operates the brush arm of the fuel limit rheostat (131). This rheostat acts as a variable resistance in the fuel limit circuit. Fig. 47 shows the brush arm of this rheostat mounted on shaft "H". It is actually gear driven by a gear on shaft "H" as shown in Fig. 65.

ENGINE DRIVEN TACHOMETER GENERATOR

This is a 3 phase, 6 pole, alternating current generator with a permanent magnet alnico rotor. The rotor is gear driven from the diesel engine camshaft. The tachometer generator is used as a speed measuring device, because its output is proportional to diesel engine speed. Its current is rectified to direct current by a 3 phase selenium rectifier. The rectified current is supplied to the speed coil of the speed solenoid where it is used to control pilot valve action. Diesel engine speed of 1000 RPM results in tachometer generator speed of 2384 RPM.

An alternating current generator is used to eliminate commutation problems. The tachometer generator has no commutator or slip rings and no brushes.

HYDRAULIC POWER SYSTEM

A motor driven pump supplies oil under 125 psi regulated pressure, to the pilot valves for operation of the governor's slave pistons. The system includes suitable filters and strainers as well as a pressure regulating valve. This system is not connected to the diesel engine lube oil system, but is a completely separate system in itself.

OPERATION OF GOVERNOR

Figure 47 is a mechanical schematic diagram of the Type 17MG6 governor. The mechanical schematic diagram, of course, does not illustrate the various parts of the equipment in their true shapes and sizes. Its purpose, rather, is to give a clear picture of the inner workings of the governor, and to do this the various parts are separated from one another,so that each is visible. This would not be possible in the ordinary type of construction diagram.

Figure 47 illustrates the action that would take place in the governor if a load increase had slowed the engine below its rated speed. The governor is functioning to increase fuel injection to bring speed back to normal by moving the fuel injection pump rack "L", to the right as viewed in the diagram.

To do this, slave piston number one has been forced upward in its cylinder by the flow of oil through the speed pilot valve. The teeth which are milled in the side of this slave piston mesh with the teeth of gear "J". An upward movement of the slave piston will thus force shaft "E" to turn CCW with gear "J". Lever "D" turns with shaft "E" and lever "C" is moved in conjunction with "D" by the overtravel spring. The inner coil of the overtravel spring is fastened to shaft "E" so that as the latter turns, it keeps tension of the spring. Lever "C" is supported by a bearing on shaft "E" and pivots on "E" like a "See-saw". As "C" pivots it pulls link "M" in an upward direction to pull arms "A" and "B" to the right, Arm "B" is keyed to output shaft "F" and as "B" moves to the right it turns "F" clockwise to increase fuel and bring the engine up to rated speed.

If diesel engine load had decreased, the engine speed would have increased beyond its rated RPM. If this had happened, slave piston number one would have been forced downward by a flow of oil into the top of its cylinder. In this case shaft "F" would have turned counter clockwise to pull rack "L" to the left and thus decrease fuel injection.

Movement of slave piston number one is controlled by the speed pilot valve plunger's position. The plunger is mechanically connected to the speed solenoid's moveable armature. As the plunger moves up or down in its ported cylinder it uncovers ports which permit oil from the hydraulic power system to reach and move the slave piston.

The current which is supplied to the speed coil by the tachometer generator will determine the plunger's position. When the diesel engine is rotating at its proper RPM, the tachometer generator will supply the speed coil with a current of 475 milliamperes (.475 ampere).

SOLENOID OPERATION

The speed solenoid consists of a moveable iron core positioned within a coil of wire called the speed coil. When the diesel engine is not running the tachometer generator will not be supplying the speed coil with current, and the solenoid core will be pulled to its uppermost point of travel by the reference spring. The pilot valve will also be at its uppermost point of travel because it is mechanically fastened to the solenoid core. When the engine is running the tachometer generator will be supplying current to the speed coil. Passage of current through the speed coil will set up a magnetic field within the solenoid. This magnetizes the core and pulls it in a downward direction. The reference spring, of course, compresses. The compressed spring tends to exert an upward pull on the core, but the downward magnetic pull will keep the plunger from going back to the top. When a current of 475 milliamperes is flowing through the speed coil, enough magnetism will be developed to pull the pilot valve plunger into the position shown in Fig. 48. This is referred to as the "Balance Position" and 475 milliamperes is referred to as the "Balance Current".

When the plunger is in balance position the pilot valve's inlet port is blocked off and no oil can flow through it. However, if the diesel engine should slow down due to an increase in load, it will slow the tachometer generator. This weakens the current which the generator is supplying to the speed coil. With less than 475 MA of current in the coil the magnetism will also be weaker. The weaker magnetism will be unable to hold the plunger down and the reference spring can then pull it upwards as is shown in Fig. 48A. This permits oil to flow through the now open inlet port to the bottom of slave piston number one. Reference to Figure 47 will show than an upward movement of the piston will cause fuel injection pump rack "L" to increase the rate of fuel injection. This, of course, speeds the diesel engine up. As the diesel engine speeds up the tachometer generator speeds up with it. When the engine reaches rated speed, the tachometer generator will be supplying 475 milliamperes to the speed coil and the plunger will be pulled down to block off the inlet port once again. This prevents further movement of the slave piston.

If diesel engine load had decreased instead of increased, the engine would have speeded up. The tachometer generator would be driven fast enough to increase current above 475 MA. This stronger current would increase magnetism sufficiently to pull the plunger downward from the balance position of Fig. 48, to the position shown in Fig. 48B. This action would have caused the slave piston to move downward to decrease the rate of fuel injection and thus bring the engine down to its rated speed once again.

A change in diesel engine speed of one RPM will result in sufficient speed coil current change to move the pilot valve plunger .004 inch. The pilot valve plunger is therefore very accurately controlled by the tachometer generator current.

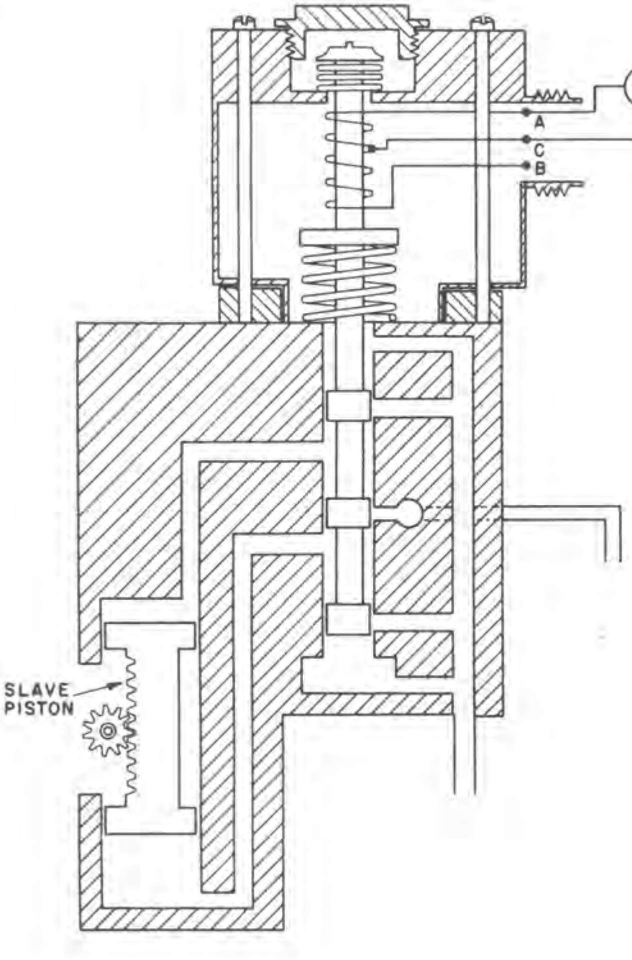
GOVERNOR CLUTCH ARMS "A" AND "B"

Governor output shaft "F" is keyed to arm "B" and the two operate together as one assembly. Because shaft "F" moves the fuel injection pump linkage, any movement of the pump racks to increase or decrease fuel means that arm "B" must move first. However, the slave piston which moves whenever a change in fuel is called for, is connected to arm "A". Arm "A" thus moves in response to slave piston movement.

When the diesel engine is not running the bias springs keep arms "A" and "B" apart. In order to operate the diesel engine it is necessary to bring arms "A" and "B" together so that they operate as one assembly. Because they have no mechanical connection with one another they are held together magnetically by the flow of locomotive battery current through the clutch coil. Current flow through this coil magnetizes both arms and enables them to stick together.

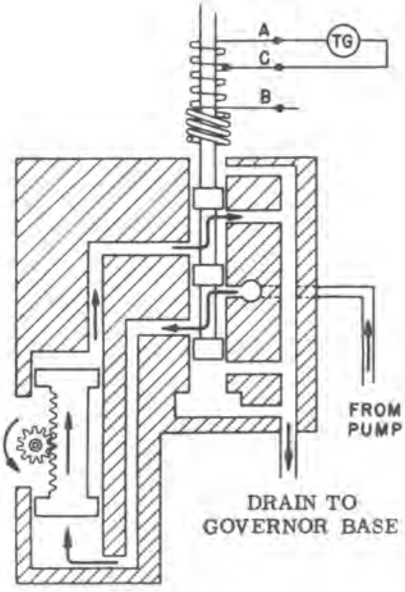
STARTING THE DIESEL ENGINE

Fig. 49 is a reproduction of sections "K" and "L" of the schematic connection diagram which applies to any Alco-GE 1950 road locomotive with Type 244 diesel engine and 17MG6 governor. The small diagrams used with the following text represent a circuit analysis of Fig. 49.



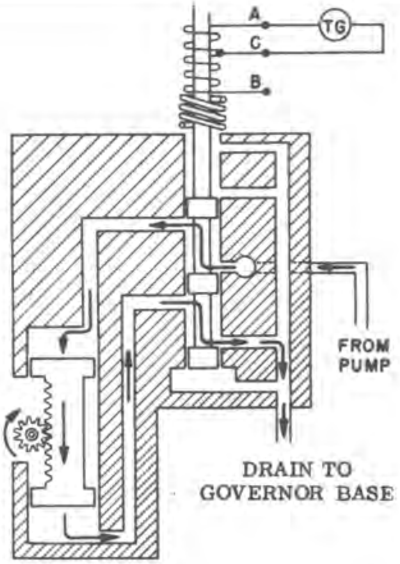
Pilot valve in balanced position. Engine speed is steady with no movement of engine fuel injection pump racks.

Fig. 48



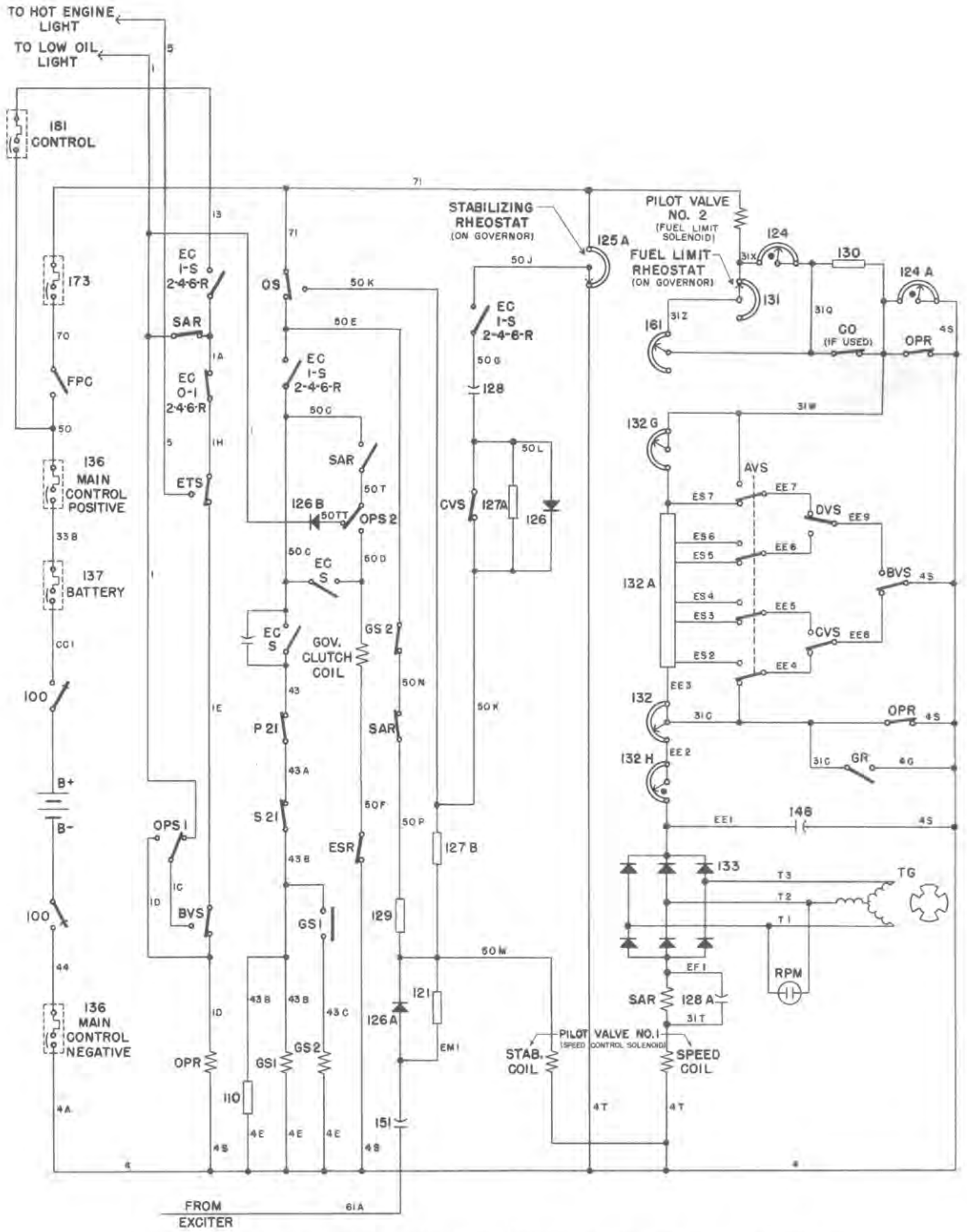
Engine has slowed down due to load increase. Tach generator current is weak and spring pulls plunger UP. Oil pressure forces slave piston UP.

Fig. 48A



Engine has speeded up due to load decrease. Tach generator current is increased and plunger is pulled DOWN by stronger magnetic field. Oil pressure forces slave piston DOWN.

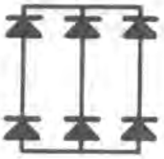
Fig. 48B



COMPLETE GOVERNOR SCHEMATIC DIAGRAM FOR LOCOMOTIVES EQUIPPED WITH 17MG6 GOVERNOR

FIG. 49

WIRING DIAGRAM SYMBOLS



Three phase selenium rectifier

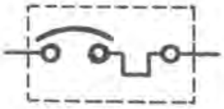
Selenium rectifier used as blocking rectifier

Capacitor

Tube resistor

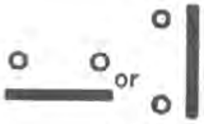
Rheostat

Operating coil



Circuit breaker

Normally closed bridge type contact or interlock



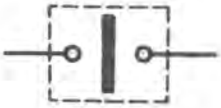
Normally open bridge type contact or interlock

Normally closed finger type contact or interlock

Normally open finger type contact or interlock

Shunt field winding

Commutating field winding



Snap switch

Main battery switch

Throttle contact or engine control switch contact. These contacts are marked to show throttle or engine control switch positions in which they are closed.

To start the diesel engine it is necessary to energize (pass current through) the stabilizing coil of the speed solenoid. This circuit is diagrammed in Fig. 50. Main battery switch 100, battery circuit breaker "137", and main control positive and negative circuit breakers "136" are closed to bring locomotive battery current to wire 50. The fuel pump contactor "FPC" is closed when circuit breaker "169" and switch "170" (refer to section "H" of schematic connection diagram) are closed. Circuit breaker "173" is closed to send current through wire 71. It then flows through the overspeed switch "OS" "GS2" interlock, "SAR" contact and 129 resistor to the stabilizing coil. With current in the coil the pilot valve plunger will be pulled down to the position shown in Fig. 48B. Oil then flows through the pilot valve to force slave piston number one to the bottom of its cylinder. Shaft "E" turns clockwise to pull "A" over against arm "B".

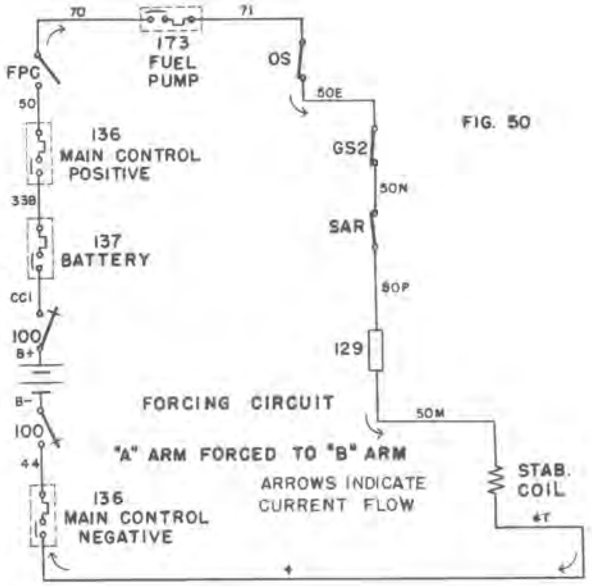
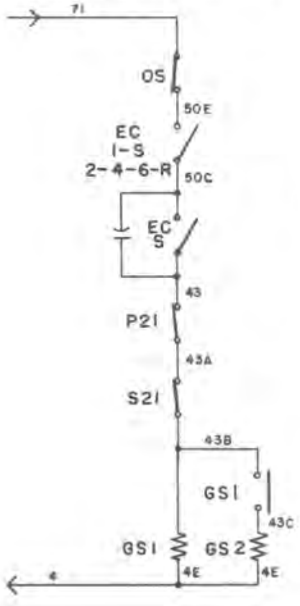


FIG. 50

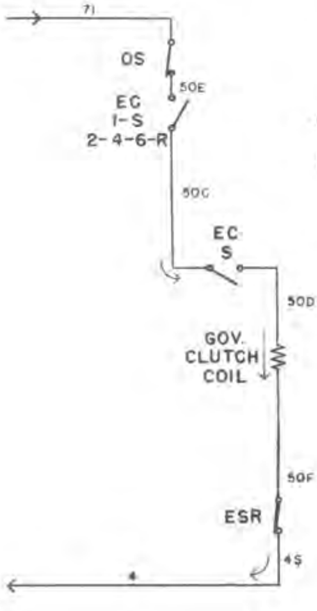
The oil pressure which moves the governor slave piston is supplied by the governor oil pump. This pump is driven by the fuel pump motor. The latter is supplied with current by circuit breaker "173". When the latter is closed, as mentioned in the previous paragraph, it causes governor oil pump operation and also energizes the stabilizing coil.

The Engine Control Switch knob is now turned to "Idle" position, to close its 50E-50C contact (Fig. 51). The start switch is then turned to close contacts 50C-43 and 50C-50D. The 50C-43 contact supplies current to the starting contactors GS1 and GS2 (Fig. 51). These contactors close to supply battery current to the main generator (Section F of schematic diagram). The generator operates as a motor to rotate the diesel engine crankshaft.



STARTING
CONTACTORS
CIRCUIT

FIG. 51



CLUTCH COIL
CIRCUIT
(STARTING)

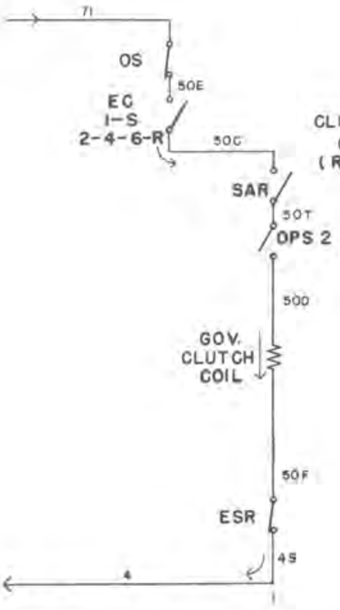
FIG. 52

When the 50C-50D contact (Fig. 52) is closed by the start switch, current from 71 wire flows through "OS", the two "EC" contacts to the governor clutch coil and then returns to the battery through "ESR" and wire 4.

Arms "A" and "B" will now be magnetized by the magnetic field of the energized clutch coil. The magnetism will cause them to stick together so that the two arms will operate as one assembly. Any further movement of slave piston number one will cause both arms to move and the movement of the arms will then cause the fuel injection pump racks to move.

It is necessary for arms "A" and "B" to move to the right to advance rack travel and thus cause fuel injection. With fuel injection and engine rotation the diesel engine will begin running under its own power. In order to cause fuel injection to begin, "GS2" contact 50E-50N (Fig. 50) will open when GS2 coil is energized. This opens the circuit to de-energize the stabilizing coil. The pilot valve plunger is then pulled upward by the reference spring to allow oil to reach the bottom of slave piston number one. Figure 48A illustrates the pilot valve in this position. The slave piston is forced upward by the flow of oil, arms "A" and "B" are moved to the right and fuel injection begins. The engine is being rotated by the main generator and with rotation and fuel injection, it will begin to run under its own power.

As the diesel engine begins rotating, its lubricating oil pressure builds up. When lube oil pressure builds up to 7 lbs. per sq. in. it closes oil pressure switch number 2 (OPS-2) (Fig. 53). When the engine reaches a speed above 150 RPM the tachometer generator current will be strong enough to energize the safety relay SAR. The latter closes its 50C-50T contact (Fig. 53). This completes the final running clutch coil circuit. The diesel engine will now continue to run unless the clutch coil circuit is opened by one of the automatic safety interlocks (OS, ESR, SAR, OPS-2). If this should happen the clutch coil will be de-energized and with no magnetism to hold them together, arms "A" and "B", will be separated by the bias springs. This action would pull arm "B" all the way to the left. Minimum rack travel would result and with no fuel injection the engine would shut down. When SAR is energized it also opens its 50N-50P contact in the stabilizing coil circuit to prevent current from reaching the stabilizing coil when GS2 contact 50E-50N returns to its normally



CLUTCH COIL
CIRCUIT
(RUNNING)

FIG. 53

closed position following the releasing of the start switch. These contacts are shown in Fig. 50.

After starting, the diesel engine will come up to a speed of 350 RPM. At this speed the tachometer generator will supply the speed coil with 475 MA. The pilot valve will be in balanced position (Fig. 48) as long as the engine speed remains at 350 RPM.

SPEED CONTROL

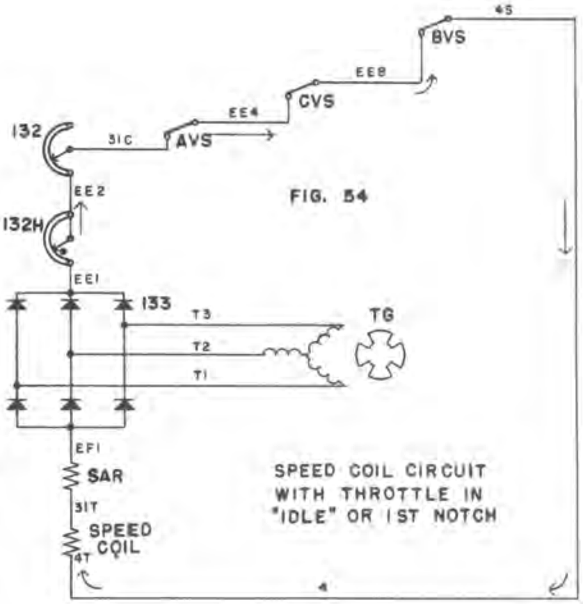


FIG. 54

SPEED COIL CIRCUIT WITH THROTTLE IN "IDLE" OR 1ST NOTCH

The circuit through which the tachometer generator supplies the speed coil with current is illustrated in Fig. 54. Current follows the direction of the arrows. The three phase rectifier "133", rectifies the alternating current of the tachometer generator to direct current for use in the speed coil.

The tachometer generator and the governor will hold engine speed constant in each of the nine different positions of the engineer's throttle. For example, when the engine is idling its speed should be 350 RPM. If the speed should tend to increase or decrease, the governor will change fuel to bring the speed back to 350 RPM. If, for example, speed should drop to 348 RPM, the governor action would be as illustrated in Figure 47. The sequence of events would be as follows:

1. Engine speed drops below 350 RPM. Tachometer generator slows down and current to the pilot valve speed coil drops below 475 milliamperes.

2. With less than 475 MA in speed coil, reference spring pulls pilot valve plunger upwards (See Fig. 48A).

3. Oil pressure reaches bottom of slave piston No. 1 to push piston up.

4. Piston operates governor linkage to increase fuel injection (Fig. 47).

5. With more fuel engine speeds up.

6. When speed rises to 350 RPM, the tachometer generator will once again put 475 MA through speed coil.

7. This current will cause pilot valve plunger to be pulled down far enough to block off inlet port and stop oil flow to power piston. Further increase in fuel is prevented.

If the engine had speeded up, instead of slowing below 350 RPM, the governor would have decreased fuel instead of increasing it.

EFFECT OF THROTTLE MOVEMENT ON GOVERNOR

The engine control switch must be turned to the "2", "4", "6" or "Run" position before a movement of the engineman's throttle will have any effect on the diesel engine speed.

As long as the resistance of the tachometer generator circuit remains as illustrated in Fig. 54, the diesel engine will operate at 350 RPM. When the engineman desires to increase the engine speed he "notches up" the throttle. When the throttle is notched up from 1 to 2, it closes its 7A-15 contact to energize relay "AVS" (Fig. 55). "AVS" picks up its contact in the tachometer generator circuit to add a part of resistor "132A" to the circuit (Fig. 56). This added resistance weakens the tachometer generator current. When the current in the speed coil drops below 475 MA, the diesel engine will increase its speed (See Fig. 48A). When the diesel engine speed increases, the tachometer generator will rotate faster and develop more voltage. At 450 engine RPM the voltage will be strong enough to bring the current up to 475 MA, once again, in spite of the added resistance of 132A. This current value will pull the plunger down to balance position, to cut off the flow of oil to the slave piston. The diesel engine fuel racks will now have a higher setting and the engine will be operating at its second notch speed of 450 RPM. The governor will hold it at 450 RPM until the throttle is moved again.

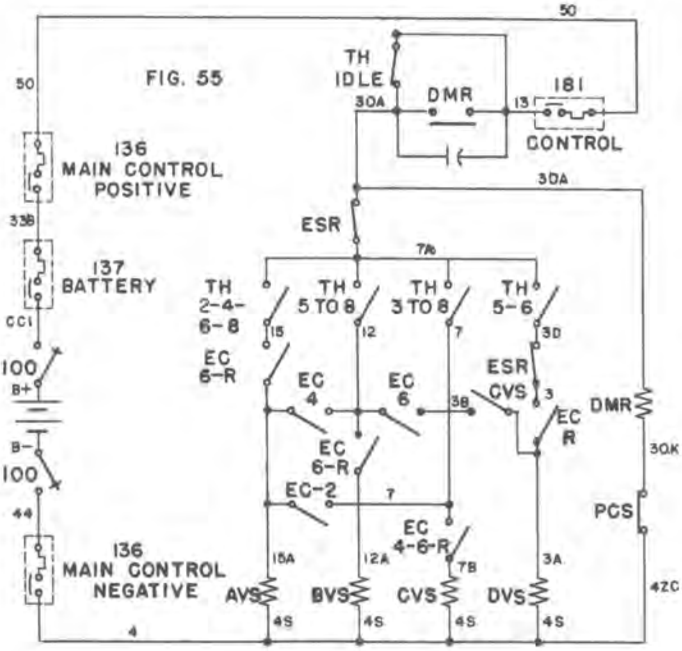


FIG. 55

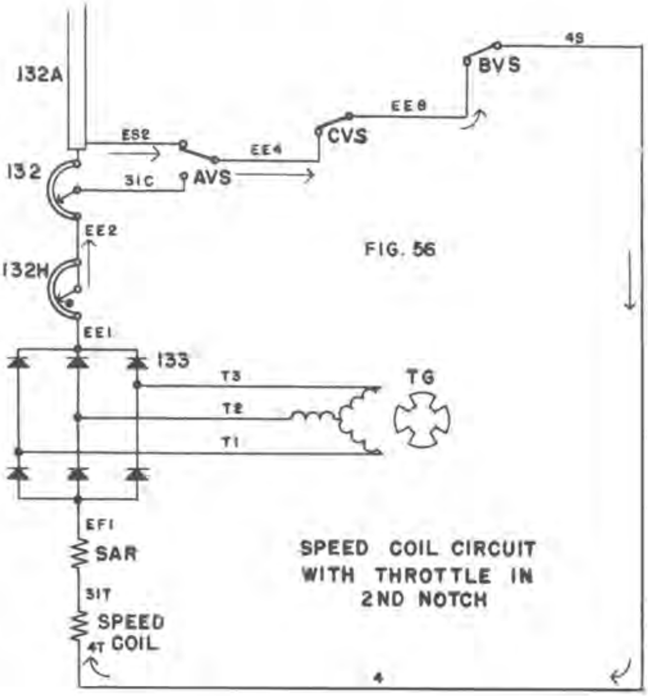
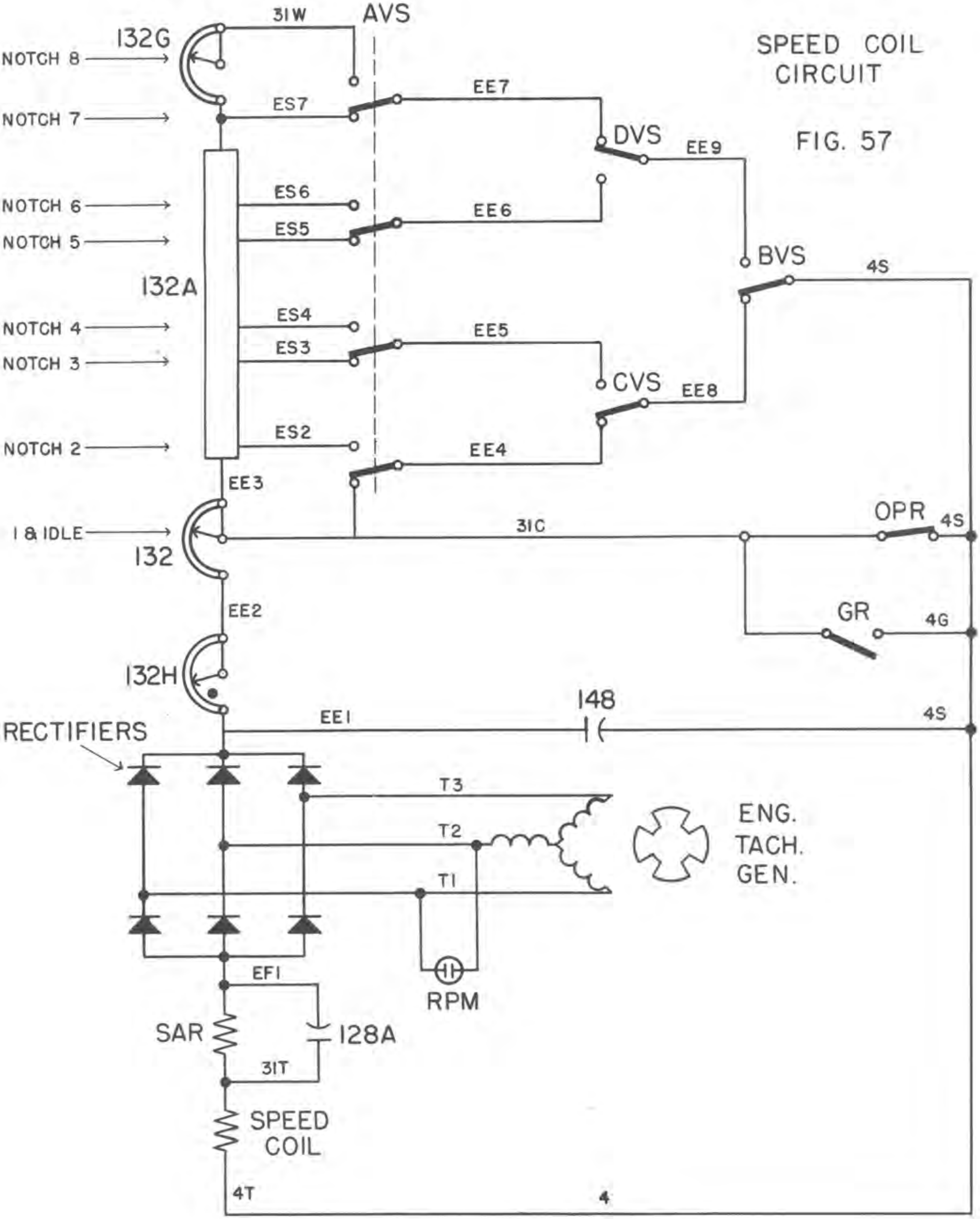


FIG. 56

SPEED COIL CIRCUIT
WITH THROTTLE IN
2ND NOTCH



SPEED COIL CIRCUIT

FIG. 57

Movement of the throttle through positions 2 to 8 inclusive, operates speed setting relays "AVS", "BVS", "CVS" and "DVS". Everytime the throttle is notched up or down, one or more of these relays operate to change the resistance of the tachometer generator circuit, with a resultant change in diesel engine speed. Figure 57 illustrates the complete circuit with all four relays. The dotted line indicates that the four contacts which it connects are operated simultaneously by relay "AVS". Fig. 55 illustrates the throttle contacts ("TH") which cause the relay coils to become energized.

Table V lists the relays which operate in various throttle positions and the diesel engine RPM which results from the various relay combinations.

TABLE V

Throttle Notch	Relay Operation	Engine RPM
1 & Idle	None	350
2	AVS	450
3	CVS	550
4	AVS, CVS	655
5	BVS, CVS, DVS	765
6	AVS, BVS, CVS, DVS	860
7	BVS, CVS	920
8	AVS, BVS, CVS	1000

FUEL LIMITING SYSTEM

Whenever the diesel engine is slowed down by an increase in load or whenever the throttle is notched up, the speed pilot valve acts to increase fuel by forcing arms "A" and "B" to the right as viewed in Fig. 47. However, the movement of arms "A" and "B", and that of the diesel engine fuel racks which they operate, is limited to a certain set travel for each throttle notch. As the arms move to the right they come up against the fuel limit cam (Fig. 47). The cam prevents further fuel increase as long as the throttle is not moved to a higher notch.

By limiting fuel injection to a certain fixed amount in each throttle position, the designer ensures that for a given set of operating conditions, a certain horsepower will be developed in each throttle notch regardless of grade and tonnage conditions.

Fuel limit also prevents the injection of more fuel than the diesel engine can safely burn. If excessive fuel is injected into a diesel engine, high combustion pressures and temperatures with excessive carbonization of valves, cylinder heads, manifolds and pistons results.

Let us assume that the engine is operating in second throttle notch position and the engineman notches up to number three throttle notch. Arms "A" and "B" move to the right (Fig. 47) and engine speed increases. However, the arms hit the cam and fuel injection pump rack travel is held to a certain maximum. With this much fuel the diesel engine speed comes up to 540 RPM. It is necessary to get the speed up to 550 but it is not possible to do it by further increase in fuel because the cam prevents further rack travel increase.

The load control rheostat will now be operated by the governor. This rheostat will reduce generator loading. As load is removed from the generator the diesel engine speed will come up until 550 RPM is reached. The speed will balance at this point and the governor will hold it at 550 RPM until the throttle is again moved. The complete action of the load control rheostat will be described under "Load Control".

When the engineman calls for more diesel engine speed and more horsepower by notching the throttle up to 4th notch, the governor will increase fuel as described in "Effect of Throttle Movement on Governor". However, in order for the operation described to take place, the fuel limit cam must be turned a bit in order that arms "A" and "B" can move to the right and increase fuel. Turning the cam is accomplished by the action of the governor's second pilot valve, the fuel limit pilot valve. The fuel limit coil of this pilot valve is supplied with current by the locomotive battery circuit. When the engineman's throttle is in 3rd notch there will be 475 MA of current supplied to the fuel limit coil. This current will pull the plunger down just far enough to block off the inlet port and prevent oil from exerting pressure on slave piston number 2.

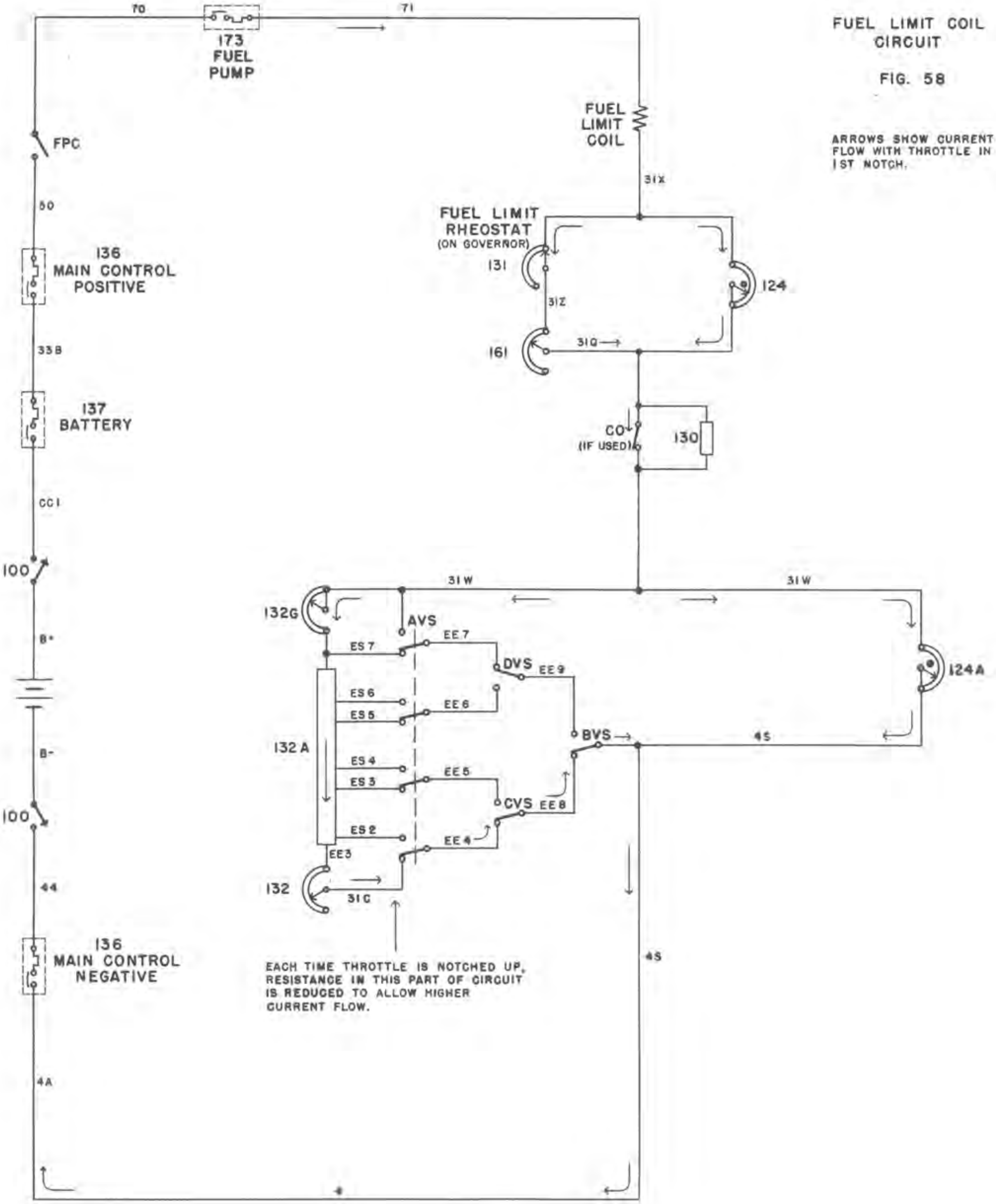
When the throttle is advanced from 3 to 4, the speed relay "AVS" operates to cut resistance out of the fuel limit circuit. (Fig. 58 illustrates the complete fuel limit circuit - refer to Table V for speed relay operation). This reduction in circuit resistance permits a higher current to flow through the fuel limit coil (more than 475 MA). This increased current pulls the pilot valve plunger down, opening the inlet port and permitting oil to force slave piston number 2 down (Fig. 47). As the piston goes down it turns shaft "H" counter-clockwise. Movement of the shaft turns the fuel limit cam, which is keyed to it, and arms "A" and "B" will then move to the right to increase fuel. The cam will turn only a little, however, and the arms will hit it again. Fuel injection will be at a new value and horsepower will increase accordingly.

As shaft "H" turns, it turns the brush arm of the fuel limit rheostat 131 (Fig. 47 and 58) as well as the fuel limit cam. This rheostat brush arm adds resistance to the fuel limit coil circuit (Fig. 58). As the resistance increases, due to the moving brush arm, the current through the fuel limit coil is gradually reduced until it once again drops to 475 MA. This permits the reference spring to pull the plunger up far enough to balance the port and cut off oil flow. The cam is thus allowed to turn only a certain distance, thereby giving a certain definite fuel limit for each

FUEL LIMIT COIL CIRCUIT

FIG. 58

ARROWS SHOW CURRENT FLOW WITH THROTTLE IN 1ST NOTCH.



EACH TIME THROTTLE IS NOTCHED UP, RESISTANCE IN THIS PART OF CIRCUIT IS REDUCED TO ALLOW HIGHER CURRENT FLOW.

position of the engineman's throttle. Fig. 63, a front view of the governor, shows the fuel limit rheostat and its brush arm.

Figure 47 does not show a reference spring on the fuel limit valve, but one exists in the same relative position on this valve as is shown for the speed pilot valve.

LOAD CONTROL

The governor's load control system, controls the speed of the diesel engine by preventing the traction generator from overloading the engine. During operation in notches 3 through 8, the governor arms "A" and "B" are pushed against the fuel limit cam. The arms contact the cam in each of these throttle positions. It is normal for the arms to be against the cam, because this ensures that the engine is receiving its full quota of fuel for that particular throttle position. There are only a few periods of locomotive operation when this maximum available fuel will hold the engine at its proper speed, however. The periods during which this fuel will be sufficient to maintain engine speed are at transition points and at two other points where the normal power output of the generator is equal to the engine's ability to supply power. At all other periods of operation it is necessary to control the generator load in order to prevent it from slowing the engine down below its rated speed. Let us assume that the engineman advances his throttle from No. 2 notch to No. 3 notch. This causes arms "A" and "B" to move to the right (increase fuel). They increase fuel until they contact the fuel limit cam. Further increase in fuel is now prevented.

If the generator load is heavy enough to hold engine speed below 550 RPM (normal 3rd notch speed), the tachometer generator speed will also be below normal, and speed coil current will be less than 475 MA. With less than 475 MA in the speed coil the speed pilot valve plunger will be pulled up by the reference spring. This movement of the plunger opens the pilot valve inlet port and allows oil pressure to force slave piston number one further up. Shaft "E" turns counterclockwise with lever arm "D". But lever "C" can turn no further because it is mechanically linked to arm "A" and the latter has been stopped by the fuel limit cam. So, shaft "E" winds up the overtravel spring as "D" moves away from "C". The brush arm of the load control rheostat "125" begins to travel across the rheostat segments. The brush arm thus adds resistance to the exciter field circuit. See Fig. 59. The exciter field current is forced to weaken due to the increased resistance of the load control rheostat. This forces a reduction in exciter current which in turn forces a reduction in generator field current. Reduced generator field current lightens the load on the generator and with less generator load the engine can speed up to its rated 550 RPM.

The governor thus gives the diesel engine a certain definite amount of fuel and then actually controls the diesel engine speed by controlling the amount of generator load. When the cam is restricting fuel injection to a certain amount, the load control rheostat brings the engine up to rated speed by removing load from the generator

If load should drop off the generator, the engine would, of course, increase its speed. The load control rheostat brush arm would then be forced to reduce resistance to allow the load to increase sufficiently to slow the engine down to rated speed.

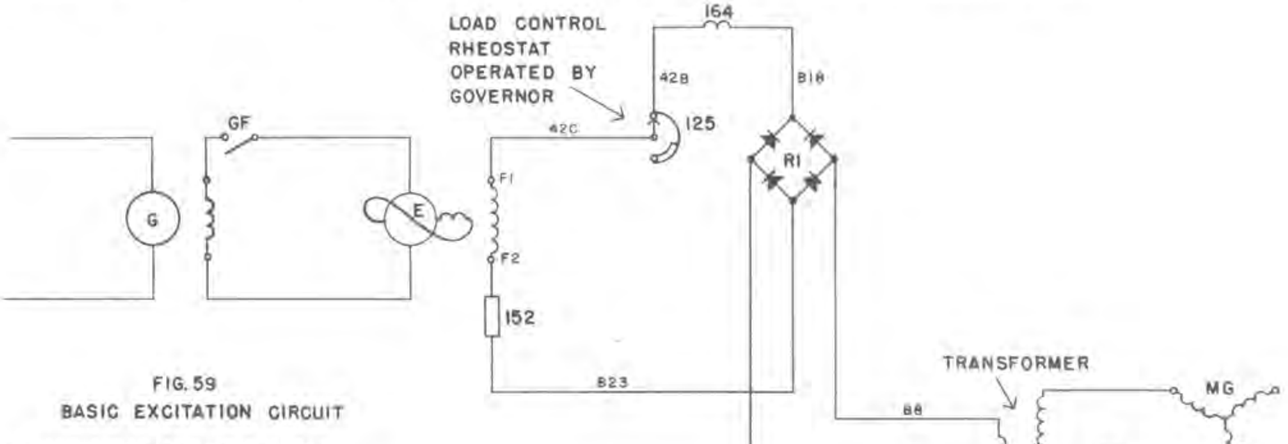


FIG. 59
BASIC EXCITATION CIRCUIT

STABILIZING ACTION

Without some form of stabilization the speed controlling action of the governor would tend to be very ragged. For example, a slow down in engine speed would be followed by the speed coil acting to cause a fuel increase. The increase in fuel delivery to the engine would be continued until the engine had regained its rated speed, at which point the tachometer generator current would balance the pilot valve. However, although the pilot valve's inlet port would be immediately closed off by the plunger to prevent any further fuel increase, the diesel engine's momentum would carry its speed above the rated RPM. This action would cause the tachometer generator current to become strong enough to pull the pilot valve down and force a fuel decrease. The diesel engine would slow down and the cycle would take place in reverse, thus causing the diesel engine to drop below the rated speed. This "up and down" action is referred to as "hunting".

To minimize this tendency of the diesel engine to hunt, a stabilizing coil in the pilot valve helps the speed coil to maintain steady diesel engine speeds. Whenever the speed coil causes the pilot valve plunger to move from its balance position, the stabilizing coil acts to partially oppose the movement. This tends to prevent the pilot valve plunger from opening the inlet port too widely.

Refer to Fig. 47. The brush arm of the stabilizing rheostat (125A) will turn whenever shaft "E" turns. The latter always turns whenever the pilot valve plunger is forced from its balance position: that is, whenever the pilot valve is causing an increase or decrease in fuel to the diesel engine. The stabilizing rheostat is connected into the stabilizing coil circuit in such a manner that a movement of its brush arm will change the resistance of the circuit. When the resistance of the changes, a capacitor momentarily forces current through the stabilizing coil. This sets up a second magnetic field within the pilot valve solenoid. The stabilizing coil's magnetic field will oppose whatever movement of the plunger that was caused by the speed coil.

This tends to prevent the speed coil from moving the plunger far enough to cause a radical change in fuel delivery. The stabilizing coil's magnetic pull is never strong enough to completely overcome the pull of the speed coil. It only partially opposes it to prevent an "overshoot" in diesel engine speed. The stabilizing rheostat is shown in Fig. 63. Fig. 47 shows its brush arm mounted on shaft "E". Actually, shaft "E" rotates the brush arm by means of a gearing as shown in Fig. 65.

Assume that the diesel engine slows below its rated speed. The pilot valve operates to allow oil pressure to reach and move slave piston number one upwards in its cylinder. This turns shaft "E" (Fig. 47). The brush arm of the stabilizing rheostat is rotated by the gearing which connects it to shaft "E". As the brush arm moves it reduces resistance in the stabilizing circuit (Fig. 60). This permits the voltage to increase on the 50G wire side of capacitor "128". The increase in voltage on one side of the capacitor forces the capacitor to discharge current through the stabilizing coil. This current causes the stabilizing coil to pull the pilot valve plunger down, to partially close the inlet port and prevent a heavy oil flow from moving the slave piston too far up. The original upward movement of the pilot valve plunger has been partially opposed.

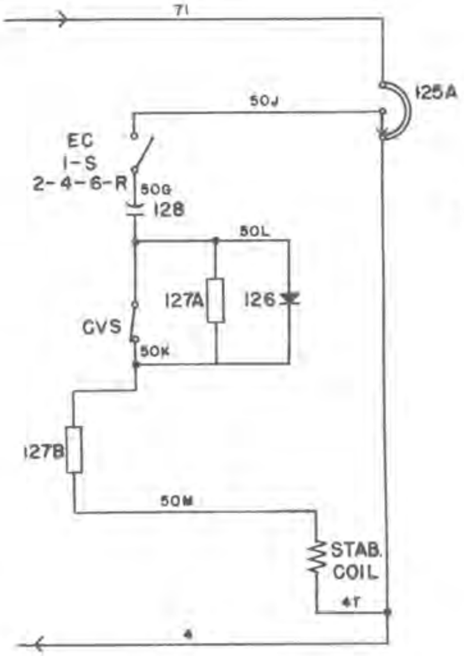


FIG 60

The winding of the stabilizing coil is such, that a current flowing through it from 50M wire to 4T wire will cause it to pull the pilot valve plunger down to partially oppose a fuel increase. By preventing too great a fuel increase, sudden acceleration and speed overshooting of the diesel engine are avoided.

When the diesel engine increases its speed above its normal rated RPM, the pilot valve acts to decrease fuel. To prevent it from making too great a decrease, with a resulting radical drop in engine speed, the stabilizing coil again opposes the speed coil action. In this case, as the slave piston turns shaft "E" the stabilizing rheostat brush arm moves to add resistance to the circuit and decrease the voltage on the 50G wire side of "128" capacitor. Again the capacitor causes a transient current flow, but this time in the opposite direction. Instead of current flowing from 50M to 4T through the coil, it now flows from 4T to 50M. This current flow causes the pilot valve plunger to be pulled up to partially close the inlet port and prevent the slave piston from moving too far down.

This action effectively prevents too great a decrease in fuel. The stabilizing coil has acted to prevent the pilot valve plunger from being pulled to far down.

In notches 3 through 8 the stabilizing coil acts to prevent too great a decrease in fuel the current flow through the coil is weaker than it is when too great an increase in fuel is being prevented. Current flow from 4T to 50M is weaker than it is when it is flowing from 50M to 4T due to the action of "126" blocking rectifier. This action is illustrated in the stabilizing coil circuit analysis of Figures 61A, 61B and 61C.

When the circuit operates to prevent too great an increase in fuel current flows from capacitor "128" through "126" rectifier and "127B" resistor to the stabilizing coil (Fig. 61A). The current is relatively strong when it flows through the stabilizing coil in this direction (from 50M to 4T).

When the engine is idling or operating in notch 1 or notch 2 and the stabilizing coil acts to prevent too great a decrease in fuel the action of capacitor 128 causes current to flow through the coil from 4T to 50M (Fig. 61B). In this direction, the current flow will be of the same strength as when it flows from 50M to 4T.

When the engine is operating in notches 3 through 8, and the stabilizing coil acts to prevent too great a decrease in fuel the current flow will again be in a direction from 4T to 50M. In this case, it will be weaker, because the CVS contact in the circuit will be open and the 127A resistor will be included in the circuit as shown in Fig. 61C. As a result of this additional resistance, the current flow will be weaker.

Stabilizing current flow to prevent too great an increase in fuel.

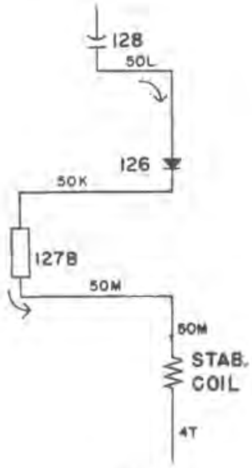


FIG. 61A

Stabilizing current flow to prevent too great a decrease in fuel - 1st & 2nd throttle.

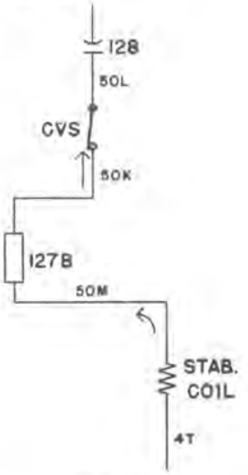


FIG. 61B

Stabilizing current flow to prevent too great a decrease in fuel - 3rd to 8th throttle positions.

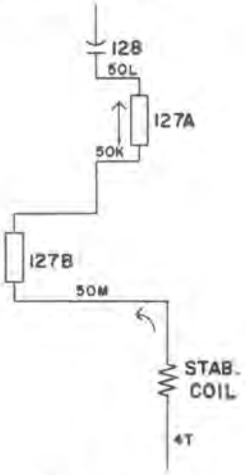


FIG. 61C

Arrows indicate direction of current flow.

Refer to Fig. 60 for complete stabilizing circuit.

The stabilizing circuits just described, cause the stabilizing coil to "buck" the action of the speed coil to prevent overshooting and undershooting of engine speeds.

However, during conditions of generator loading or unloading, an "aiding" instead of "bucking" action is needed. For instance, an increase in loading will slow the engine down. There would be a time lag between this drop in speed and the governor's response to it. To eliminate this time lag, a circuit is connected between the amplidyne exciter and the stabilizing coil as diagrammed in Fig. 62.

A change in loading or unloading is alway preceeded by a change in exciter voltage. This change will act upon capacitor "151" in the same manner as a change in voltage acted upon capacitor "128". That is, it will cause a transient flow of current across the capacitor. This current will act upon the stabilizing coil in such a manner as to cause operation of the pilot valve before the tachometer generator calls for operation. In other words, an increase in load will tend to decrease engine speed. Before the speed decrease has caused the tachometer generator to call for more fuel, the change in amplidyne output will already have started the stabilizing coil to act to increase fuel. Thus the stabilizing coil anticipates the need of the engine for more fuel before the diesel engine actually begins to slow down. The circuit works in reverse in exactly the same manner, the stabilizing coil acting to decrease engine fuel before the engine requires a decrease in fuel. The feed back is always proportional to the rate of load change. That is, the greater the load change, the stronger will be the current flow from the exciter to the stabilizing coil. Blocking rectifier "126A" allows a heavier current flow through the stabilizing coil when fuel is to be decreased. The rectifier permits current to flow around "121" resistor in this case. When a fuel increase is called for the current flow from 4T through 50M will be weaker because the rectifier forces the current to flow through resistor "121".

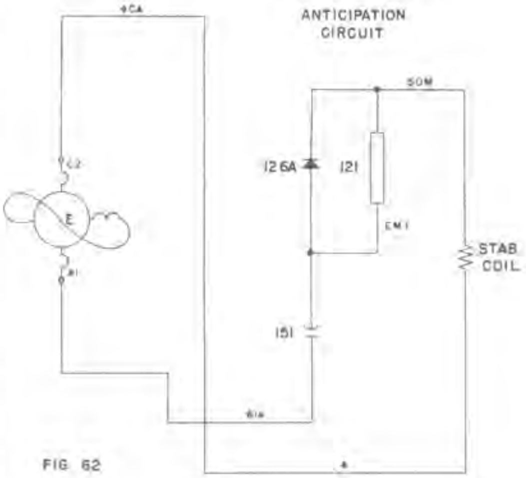


FIG 62

Fig. 57 illustrates the connection of capacitor "148" in the speed circuit. This capacitor acts as a "current booster" when an engine speed increase calls for a reduction in fuel. It is desirable to decrease fuel as rapidly as is possible. The increase in tachometer generator voltage causes the capacitor to discharge current through the speed coil. This action pulls the pilot valve down quicker than would be the case if the capacitor was not used and the fuel control racks of the injection pumps move quickly to decrease fuel. The capacitor action is only momentary and serves to produce an initial wider corrective opening of the pilot valve port. The strength of the capacitor's current discharge depends on how fast the diesel engine speed changes. A greater change in speed will result in more current and wider corrective pilot valve opening, than a slight speed change.

Capacitor "148" also reduces the current surge in the speed coil circuit whenever the resistance of the circuit is suddenly increased such as when the throttle is advanced one notch. This action tends to prevent sudden acceleration of the engine, a condition which would set up severe mechanical stresses.

PROTECTIVE DEVICES

In order to regulate operation of the diesel engine, the governor clutch coil must be energized by power from the batteries. If the coil is de-energized it will allow clutch arms "A" & "B" to separate. Clutch arm "B" then returns to the "shut down" or "no fuel" position and the engine stops. Protective devices are incorporated in the clutch coil circuit as follows:

Governor oil pressure switch "GOP". If governor oil pressure drops to 75 pounds per square inch, "GOP" opens its 50E-50F contact and de-energizes the clutch coil, thereby shutting down the engine. See clutch coil circuit (Fig. 49 and 53).

Safety relay "SAR". Any opening in the speed setting circuit de-energizes "SAR" coil and opens "SAR" 50C-50T contact in the clutch coil circuit with the same result as for "GOP". SAR contact "50N-50P" in stab. circuit (Fig. 50) closes to energize stab. coil & force arms to shut down position. This action protects the diesel engine against the sudden increase in speed, which would result if the speed coil circuit failed and allowed the pilot valve plunger to be pulled upward by the reference spring. See clutch coil circuit (Figs. 49 and 53).

Overspeed switch "OS". If engine speed reaches 1100 to 1120 RPM, "OS" will be tripped, thus opening its 71-50E contact in the clutch coil circuit to shut down engine. As the switch opens the 71-50E contact it closes the 71-50K contact to energize the stabilizing coil and force the fuel pump racks to minimum fuel position. (See Fig. 49).

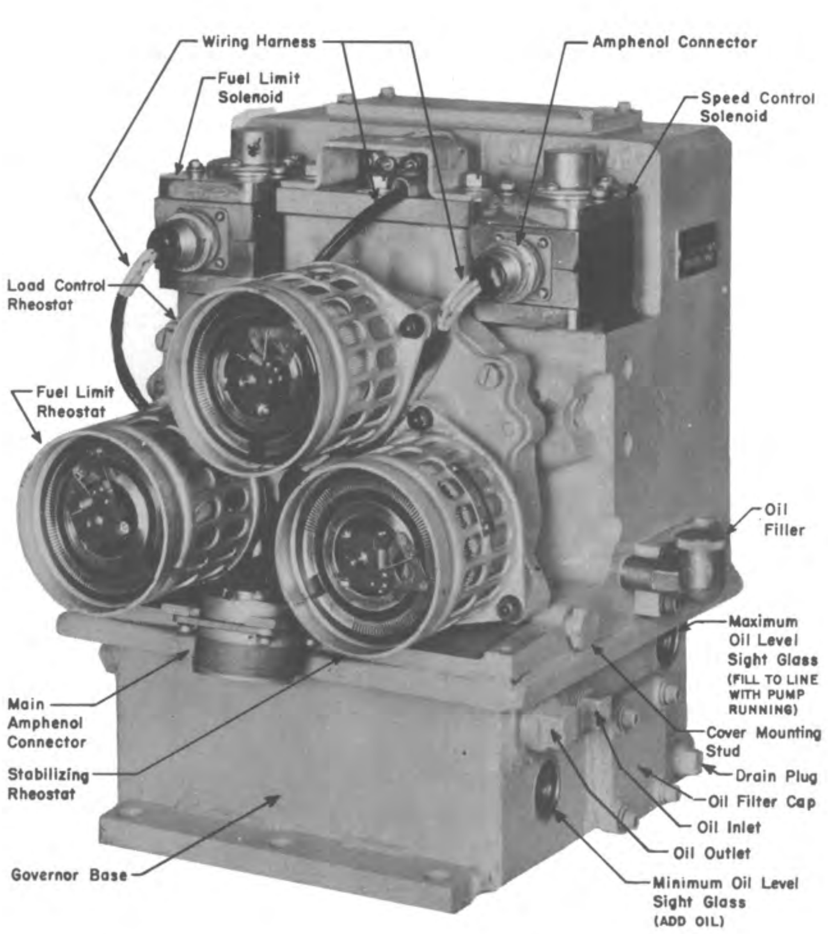
A drop in engine oil pressure to twenty pounds per square inch or below opens "OPS1" and thus de-energizes "OPR" relay (Fig. 49). With the latter de-energized, "OPR" contact in the speed setting circuit closes (Fig. 57) and returns the engine to "Idle" speed. This action takes place only if the locomotive is operating in 5th notch or higher. If it is below 5th notch, "OPR" coil will remain energized even with OPS1 open and the diesel engine will not drop to idle.

Further drop in oil pressure to 7 pounds per square inch or below, opens OPS2 50T-50D contact and de-energizes the clutch coil, shutting the engine down (Fig. 49).

Ground relay operation will cause "GR" contact in the speed coil circuit to close (Fig. 57). With this contact closed, the "132" resistors in the circuit are by-passed and the engine will drop to idle speed.

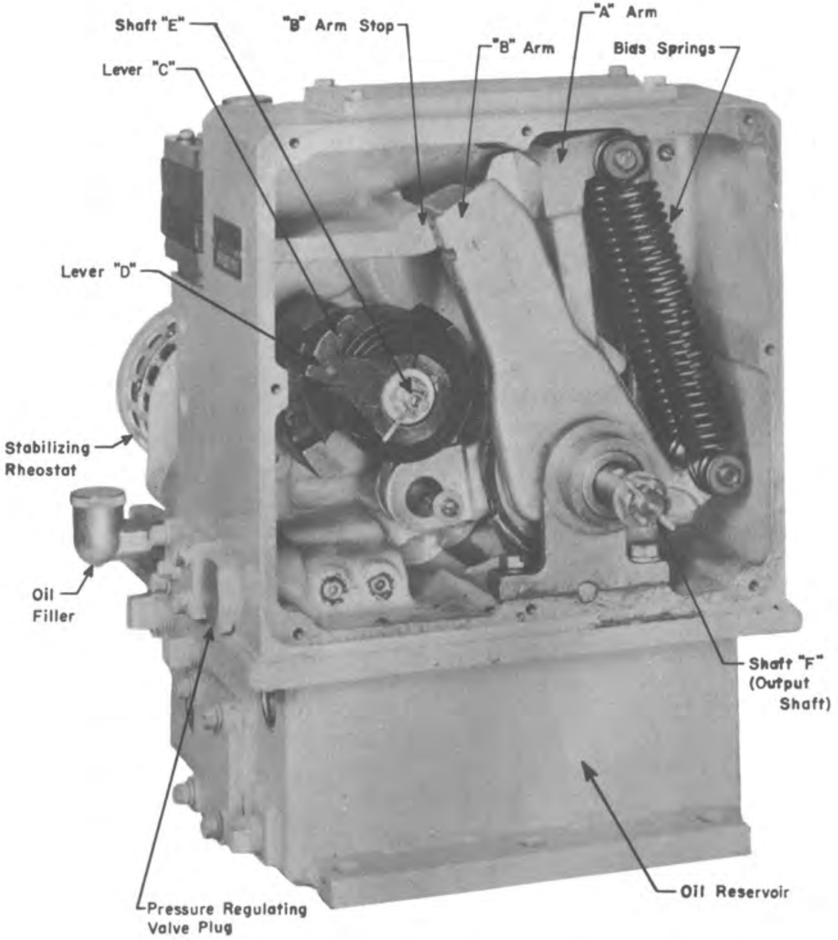
If diesel engine cooling water temperature rises to $180^{\circ}F$, the engine temperature switch "ETS" will open its 1H-1E contact to de-energize "OPR" coil (Fig. 49). "OPR" contact in the speed setting circuit (Fig. 57) closes to by-pass the 132 resistors and return the engine to idle speed.

Fig. 65 illustrates shafts "E" and "H" with their respective gearings. Note that the brush arms of all three rheostats are actually operated through gearing, rather than direct drive as is shown in Fig. 47. The action of these brush arms, however, is as described in the foregoing test.



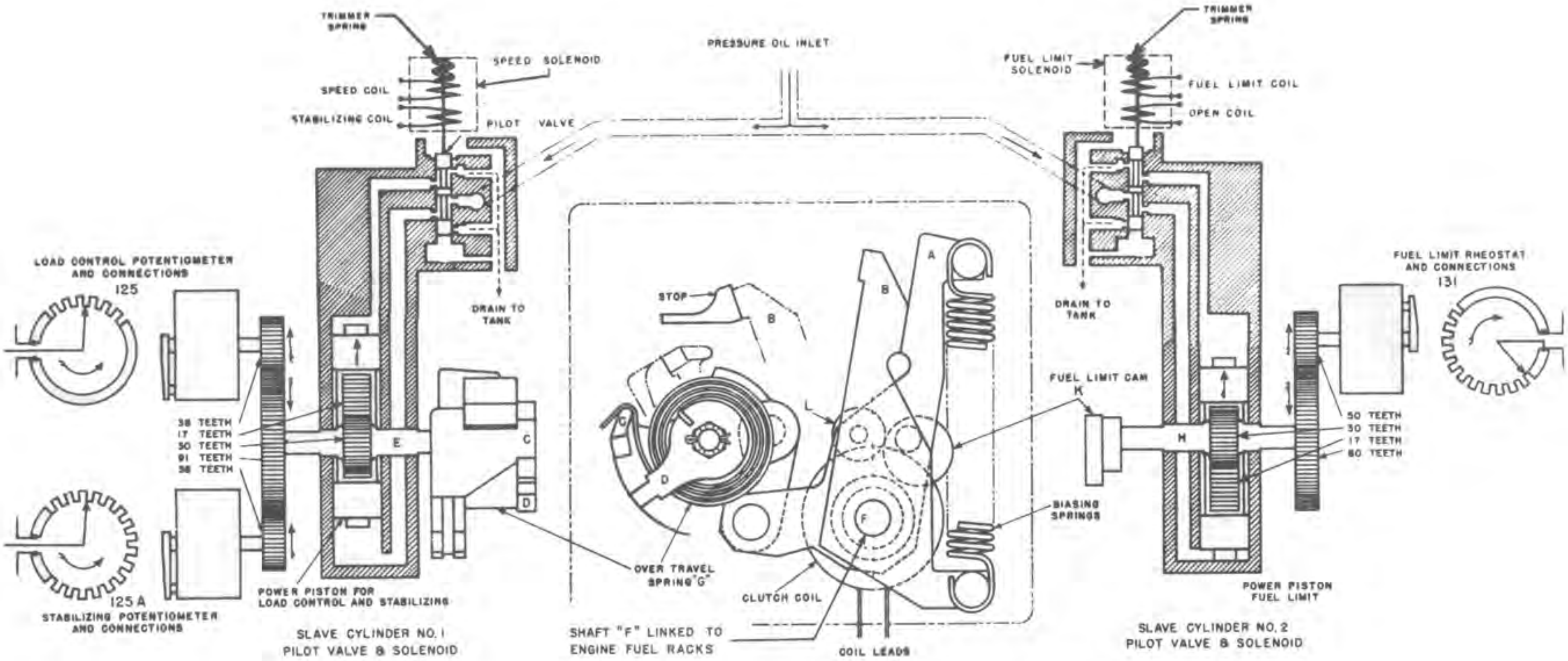
17MG6 DIESEL ENGINE GOVERNOR — FRONT VIEW

FIG. 63



17MG6 DIESEL ENGINE GOVERNOR — REAR VIEW

FIG. 64



ARROWS WITH VANES SHOW DIRECTION TO DECREASE LOAD AND FUEL LIMIT

POWER PLANT GOVERNOR FOR DIESEL ENGINE - ONE PLANE SCHEMATIC

Fig. 65

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