Variable Voltage Made Easy
Using Print No. C-1469-A

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Edited by Robert S. Caporale, MSc

Learning Objectives

After reading this article, you should have learned about

◆ the theory of variable-voltage control applied to elevators, using the Ward-Leonard system.
◆ methods of obtaining control of acceleration, deceleration and leveling.
◆ how to circumvent residual currents.
◆ the best way to obtain smooth control of elevator motion.
◆ the use of damping-field and shunt-field motor control.
◆ the design and operation of a self-excited generator.
◆ the methods designed to prevent the hoist motor from pulling through the brake.
◆ what happens when motor load and slip increase.
◆ resistance and Star-Delta methods of AC-motor starting.
◆ troubleshooting noises in the driving motor on a motor-generator set.
◆ causes of sparking in generators and hoist motors.
◆ how to check a DC machine or motor-generator set for electrical neutral.
◆ how to trace various variable-voltage problems to parts of the system.
◆ how to determine the synchronous speed of a motor.
◆ determining the causes and finding remedies for rough stops.

The following article is an edited version of the one originally published in the October 1959 issue of ELEVATOR WORLD. It was so well received that ELEVATOR WORLD sold out all extra copies of the magazine within two weeks of publication. Over the past 50 years, thousands of copies of the article have been sold as reprints and in the ELEVATOR WORLD Educational Package. The subject matter of the article is still pertinent to elevator field personnel today as a great deal of this vintage elevator equipment is still in service.

Long accepted, the variable-voltage method of control has been widely used for elevator control. Known under several names, such as unit multivoltage, generator field control (a very apt name), variable voltage, Ward-Leonard Control and many others, it has a long history. Invented in Germany, it was brought to the U.S. and first used for propulsion control on marine craft, primarily ferry boats. It is used in marine control, machine tool drives, conveyors, textile drives and many other places where a rapid change of speed, precise control, and a definite and powerful low speed may be required. The attempted scope of this article will be to explain variable-voltage operation and theory as applied to elevators so that it can be understood. The writer hopes to do this without resorting to language that would require an electrical engineer to interpret its meaning.

In Figure 1 you will see a constant source of DC power. This power may be from any source, such as a small generator called an "exciter," rectifiers or vacuum tubes. The left wire is marked +, or positive, for convenience. The right wire is marked -, or negative. The amount of power required is small – only about enough to light three 100-watt lamps. Accordingly, the associated switch gear need not be large. You will also note in Figure

Value: 3 contact hours

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1 that the elevator motor field is between + and -. Thus, it has power applied at all times in our simplified diagram. We say it is "constantly excited."

The generator field, between terminals GF1 and GF2, is interrupted by the up and down switches. It has resistors R1, R2, R3 and R4 that are cut out of the circuit by the speed switches 1, 2, 3 and 4. As the generator field has a fixed amount of electrical resistance, these resistors will cause a reduced voltage to be applied to the field. As the speed switches are operated, the voltage rises. Thus, for illustration, we have 15 volts applied to GF1-GF2. When all the switches are open, we will have minimum excitation. This is true when the car is leveling into the floor, or when it is starting out.

When switch 1 closes, the field voltage rises. This voltage continues to rise as switches 2, 3 and 4 are closed. At this point, the field has its highest applied voltage, having R5 in the circuit. R5 is for the purpose of regulating the top speed of the car, as will be explained later. You will also note that when the up switch is closed, the + line is connected to GF2 and the - line is connected to GF1. However, when the down switch is closed, the + line is to GF1 and the - line is to GF2. This effectively reverses the flow of current through the field, or "reverses its polarity." In the lower

section of Figure 1, we see the generator armature and the elevator motor armature. The brushes of the generator were connected solidly by large wires to the elevator motor brushes. This is, again, a simplified circuit, and will be expounded upon later.

The armature of the generator is constantly revolved by a suitable motor, which is usually on a common shaft with the generator. At this point, we will absorb a little very simple theory: the output of a generator armature (that is, the power it will generate at a fixed speed) is relative to the current applied to its fields. Thus, with R1, R2, R3, R4 and R5 in the circuit to the generator field, the output in voltage generated will be small. However, with R1, R2, R3 and R4 shorted out by the speed switches, its output will be at almost maximum. The only drop from maximum will be that occasioned by resistor R5.

At this point, the meaning of the "generator field control" and "variable voltage," etc. becomes apparent. By again inserting the resistors in the field circuit, the output of the generator will be reduced and, if the direction switches up and down are open, its output will be zero or very near to zero.

Now, a little more theory: the polarity of the generated current will be in relation to the polarity of the generator fields. If the up switch is closed, the current will flow through the fields in one direction, and if the down switch is closed, the current will flow in reverse. As this current flow reverses, the "polarity" of the field changes. As the polarity of the field changes, the polarity of the generator changes. Thus, we may have wire 1 as positive (or +) when the up switch is closed, and wire 2 as -. When the down switch is closed, the reverse is true: wire 1 will be - and wire 2 will be +.

The elevator (or "hoist") motor will now be examined. The field of this motor, as noted before, has a

constantly applied voltage. We have determined, however, that the voltage applied to the armature of this motor by wires 1 and 2 will vary in voltage. Another dose of theory: a DC motor with constantly excited fields will vary in speed relative to the voltage applied to the armature.

Now we have the whole picture. By changing the amount of resistors in the generator field, we have changed the speed of the elevator. Varying this resistance means handling small currents. A 2-ampere current can control a car of 3000 pounds at 300 fpm, for example. We have noted that our direction switches change the polarity of wires 1 and 2 by reversing the generator field current direction flow. As the polarity of these wires change, the direction of rotation of the hoist motor will also change. With a 2-ampere switching current, we can reverse our 40-HP hoisting motor.

We will discuss explicit methods of obtaining good control of accelerations, decelerations and leveling, together with methods of circumventing residual currents. As this control is old, many methods have been used to obtain the desired results. Obviously, if we closed switches 1, 2, 3 and 4 simultaneously, the generated voltage would shoot up rapidly. The hoist motor would be almost a short circuit when at rest, so severe damage would result to the generator, motor brushes and commutators. It is imperative that the time required for the voltage rise on the generator fields be spread over a definite time interval to prevent excess current being required by the hoist motor. If we successively close 1, 2, 3 and 4 with a time interval between each, we will still get sudden (but not as large) surges as each switch closes. This will give "stairstep" control, and would be objectionable to the passengers.

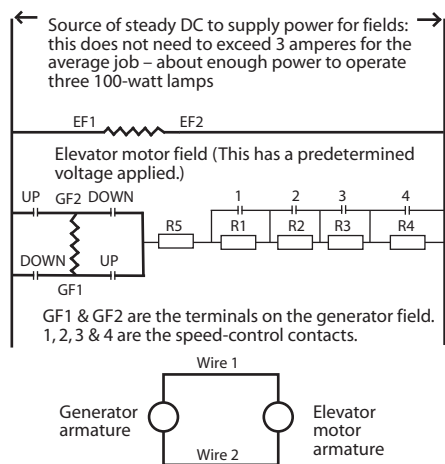As many readers are engaged in the servicing of all types of elevator

Source of steady DC to supply power for fields: this does not need to exceed 3 amperes for the average job – about enough power to operate three 100-watt lamps

Elevator motor field (This has a predetermined voltage applied.)

GF1 & GF2 are the terminals on the generator field. 1, 2, 3 & 4 are the speed-control contacts.

Figure 1

control, we will discuss the older (as well as the newer) methods of "smooth control."

One of the earliest methods was the damping field, as shown in Figure 2. We have the same shunt field as used in Figure 1, GF1-GF2. We also have another field, wound with heavy wire, on the same pole pieces as GF1 and GF2. This wire was usually wound directly on the iron poles, with GF1-GF2 wound over it. The terminals of the damping field were connected, causing the field to short-circuit itself. The purpose of the field was to resist sudden changes in the magnetic strength of the poles. A dashpot or other timed switch closed four contacts: 1, 2, 3 and 4. Instead of "stairsteps," the dampening field smoothed out the steps to a large degree. It was used until leveling came in, then it defeated itself: when the leveling switch opened the circuit to the shunt field, the dampening field would not let the generator stop its output quickly, so the car would not stop accurately. Many expedients were tried, such as "reversed series" or "differential field," but they were awkward to handle, requiring large switches and complex generators. These "reversed fields" will be discussed later in the article.

Another method was large, iron-core reactors placed across the shunt field. These were, in effect, much the same as damping fields, but more flexible. Their results could be varied by moving the position of the iron core. These were costly and had somewhat the same "hold-on" characteristics as the damping field.

A third method (used by a large company) was the self-excited generator. In Figure 3 you will see F1-F2. This is a high-resistance field that would give leveling speed. Its initial purpose was to determine the polarity of the generator. When F1-F2 was excited, the generator would put out about 15 volts. When the HS contact

closed, the generated current would be applied to GF1-GF2. This flow of current through GF1-GF2 would further increase the output of the generator, and this rise would continue to a point where the rated output would be reached. To slow down, HS would be opened, R1 would be inserted and the voltage would decay to the leveling voltage.

Another large company used our familiar 1, 2, 3 and 4 switch idea, only it used a large number – sometimes as many as 20 – closed by a motor-driven cam switch. Slowdown was achieved by reversing the cam motor.

Another method was the pilot motor generator set (see Figure 4). This was a small (about one-third-HP) motor generator with the generator connected to the big generator's field, as in Figure 4. The AC driving motor had a very small adjustable

reactor in each phase. By screwing in the iron core, the applied voltage to the AC motor would be reduced while accelerating, and the rate of acceleration would be reduced. Backing out the iron core would increase the rate of acceleration. This was very easy to adjust. Deceleration was simple – the pilot generator continued to generate as it slowed down. When the slowdown (SD) contact closed, a resistor would be placed across the pilot generator so that it decelerated more rapidly and the car slowed accordingly. Leveling was from a fixed low-voltage source.

The writer worked on the development of the following control, and one company still used it and had a patent on it. General Electric pioneered the damping motor control in the mid 1920s. In the writer's opinion, it was one of the most dependable, easiest adjusted and most stable types of

Figure 2
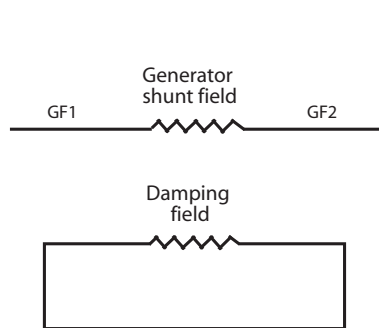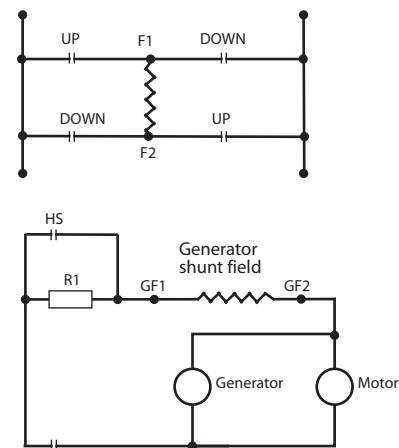

Figure 3

Figure 4

Figure 5

control. With this biased opinion, we shall describe this method in detail.

In Figure 5, we have the scheme outlined. The field of the damping motor is connected across the power source. The armature is across the generator field. We have the same top-speed control resistor as in Figure 1 (R2 in this diagram). R3 is the low-speed or leveling resistor; AR is a voltage-controlled resistor. A little theory: a DC motor's armature is almost a short circuit when at rest, and if under no load, it will draw less and less current as it accelerates to its rated speed. When the car is to start, the direction and high-speed (HS) switch close; no timing is required. The damping motor armature, being almost a short, will allow very little current to flow into GF1-GF2. The "lost voltage" will be dropped by R2 and AR resistors.

As the damping motor starts to revolve, it will pass more and more voltage to GF1-GF2 until full voltage is obtained. Thus, we have an infinite number of points of speed control – much smoother than our 1, 2, 3 and 4. To adjust the rate (time) of acceleration, we increase or decrease the amount of flywheel on the motor shaft: the heavier the wheel, the more gradual the acceleration. Once
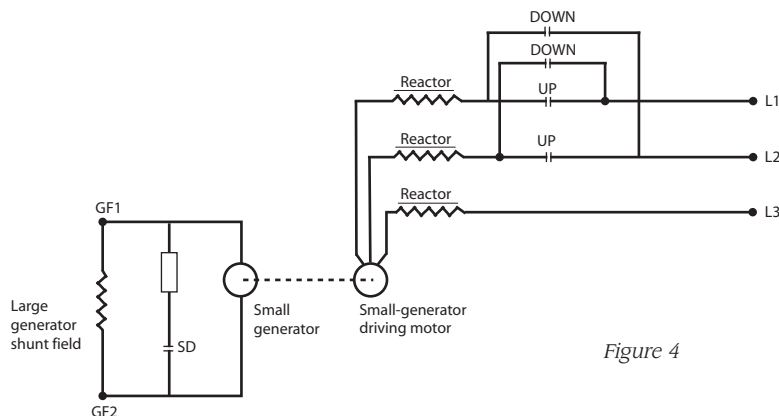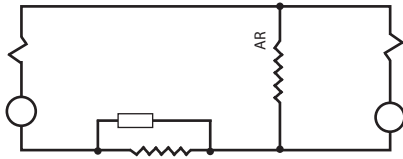
set (with a motor of good quality) there is no change, as the inertia of the wheel does not vary. The coil AR is connected across the generator armature. The AR contact will close when the voltage applied to the armature reaches a predetermined value. The purpose of the resistor/relay combination is to prevent excessive voltage from being applied to the damping motor armature, as the AR resistor helps the R2 resistor dissipate the applied voltage.

To slow down, the HS switch opens, dropping the applied voltage to the leveling voltage. However, we do not get a sudden slowdown – our damping motor becomes a generator, driven by its mass and the stored energy of the flywheel. The leveling speed is reached gradually, and only after the damping motor has decreased its speed. To change the rate of deceleration, we move the top on resistor R1. The more of this resistor that is bypassed (or shorted out by the contact on the slowdown relay), the more rapid the rate of deceleration.
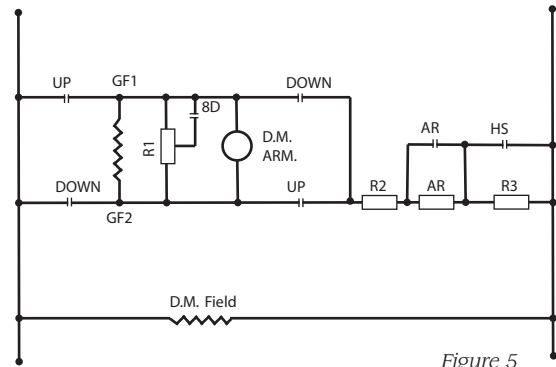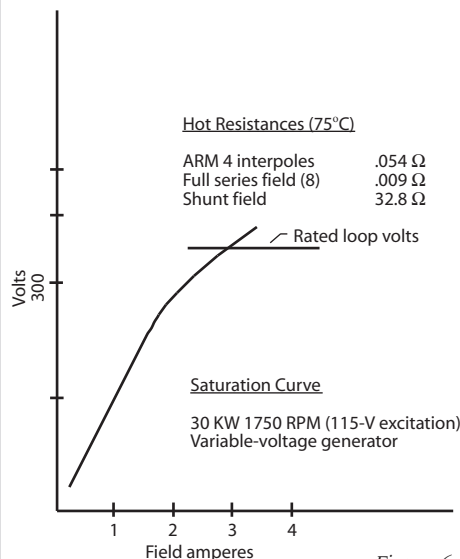

Figure 6

This control requires no timers, tubes, switches or trick fields in the generator. There are methods of control that were used on high speed jobs called Rototrol (Westinghouse) and Amplidyne (General Electric). Amplidyne has been described in ELEVATOR WORLD (October 1964). Both of these are speed-reference, feedback systems, but would not, in our opinion, fit the subject of this article. We have accelerated and decelerated the car, so we will now discuss varying loads, overloads and overhauling loads, and the method of compensating for them.

Figure 6 is a typical generator saturation curve ("output in relation to field current" is another way of saying it). These curves are furnished by the manufacturer of the rotating equipment to the control designer so that he may more accurately predict the car speeds under varying conditions. From this curve, we see that the armature voltage (represented in numbers from 0-300 in the left margin) is affected by the amperes of the field circuit. We can thus determine that 0.1 ampere will give us an armature voltage of about 10 volts, enough for a good leveling speed. An amperage of 2.8 will give us an armature voltage of 225 volts, or full speed. A generator will, as we see from this, put out a voltage in proportion to the field saturation. The field strength (or saturation) is expressed in "ampere turns." The ampere turns in a field are determined by multiplying the amperes of current flowing through the field by the number of turns of wire in the field. For example, a current of 1 ampere through a field of 1,000 turns will give 1,000 ampere turns. A current of 100 amperes through a field of one turn will give 100 ampere turns.

Most generators used in elevator controls are compound wound. This means that we have a "shunt field." This consists of a coil of relatively small wire wound on each pole

Figure 7

piece. This is the "1 ampere at 1,000 turns" field in the example above. We also have a "series field." This consists of a very few turns of large wire – often less than five turns. It is in series with the armature, hence its name. All main power of the generator flows through this field. It is the "100 ampere at one turn" field in the example. We will now discuss the purpose of this field. (See Figure 7 for the series-field location.)

If the current in the generator shunt field were adjusted to give an exact output at a no-load condition, the voltage would not remain constant. As the load increases, the current (or amperage) will rise. As all parts of the system have a fixed electrical resistance, the voltage will tend to drop in accordance with Ohms' Law. This is expressed by the equation $I = E/R$. I = current in amperes, R = resistance and E = voltage. Thus, if we require 10 amperes at a balanced load, we have a very small current flow. The resistance as shown on the curve is as follows: armature and interpoles, .054 ohms; series field, .009 ohms; and the hoist motor armature and interpoles (now shown), about .054 ohms. The wire resistance will be approximately .07 ohms on the average job. This is a total resistance of .187 ohms. Using the equation of Ohms' Law, we have, at a full load of 100 amperes, 100 = E/O .187. The answer is a voltage drop of 18.7 volts. As the car speed varies with the voltage, the speed would be 225 - 18.7 = 207.3 volts full speed, or full rated speed. If, for example, the rated car speed is 225 fpm, the full-load speed would drop to 207 fpm.

The speed drop of the generator is aggravated by the speed drop of the hoist motor. As the hoist motor in our variable-voltage systems are shunt machines (i.e., they have only shunt fields and no series fields), we have a speed drop as outlined in Figure 8. By means of the series field, we can raise the armature voltage 18.7. As it is not practical to divide the series-field into fractions of turns, we bypass the series field coils with a large adjustable resistor. This resistor is in the form of strips of resistance material that does not change its value too greatly with a rise in temperature. These strips are connected so that they are in parallel with the series field. If a strip is removed, the series-field effect is greater, because more current will flow through the series field and less through the resistor. Thus, it is simple for the adjustor to compound the generator so that, with full load, the upward and downward leveling speeds are exactly equal. If he does this, his full-load speeds should have less than a 5% variation. Usually the variation is from 1% to 2%.

Some older control systems used taps on the series field to obtain this adjustment. This was very difficult on small generators, and it was very easy for the adjustor to have a coil connected in reverse, with a bad effect on the commutator. Let us assume that the shunt field has 1,000 turns. The current, according to the curve, is 2.8 amperes. This results in 2,800 ampere turns, as our voltage "sags" 18.7 or 8%. If we raise our saturation, 8% of 2,800 is 224 ampere turns. If the current is 100 amperes and we use three turns, we will have 300 ampere turns. A shunt of .027 ohms will give the required results. This is determined by the series-field resistance. The .027 shunt will give us a

means of adjustment to compensate for the motor-speed drop. Naturally, the worker in the field does not concern himself with these figures. The control designer has worked out the problems, and the adjustor merely "trims" for the slight variations of the equipment.

We can now run the car with a balanced load at 225 fpm, and with a full load at the same speed. When we lower the load, the series field again helps us. When lowering a load, the motor, because of its excited field and the fact that it is driven by the load on the car, becomes a generator. The voltage at the motor and generator brushes rises in proportion to the degree of overspeed caused by the overdriving effect and the loaded car. This causes the generator to become a motor as more voltage is present than it generates. The generator speed cannot rise, for the AC motor driving it has as much power to prevent overspeed as it does to drive the set up to speed. The current forced into the generator flows through the series in the reverse direction. This tends to reverse the polarity of the generator pole pieces. The amount of magnetism generated by the series field will be subtracted from the shunt-field magnetic strength, and this will lower the loop (or armature voltage), causing the speed to remain constant.

We now come to "circulating current." Once magnetized, all steel or iron will retain some flux of magnetism. How much the material retains in a given volume of steel is relative to its hardness. The harder the metal, the more flux it will retain.

When we open the circuit to the generator field by dropping out the direction switch, the generator does not completely stop generating of its own accord, but must receive some help from the control system. The armature revolving in the magnetic field created by the residual magnetism will continue to produce a certain

DO NOT SCALE THIS DRAWING: WORK TO FIGURES
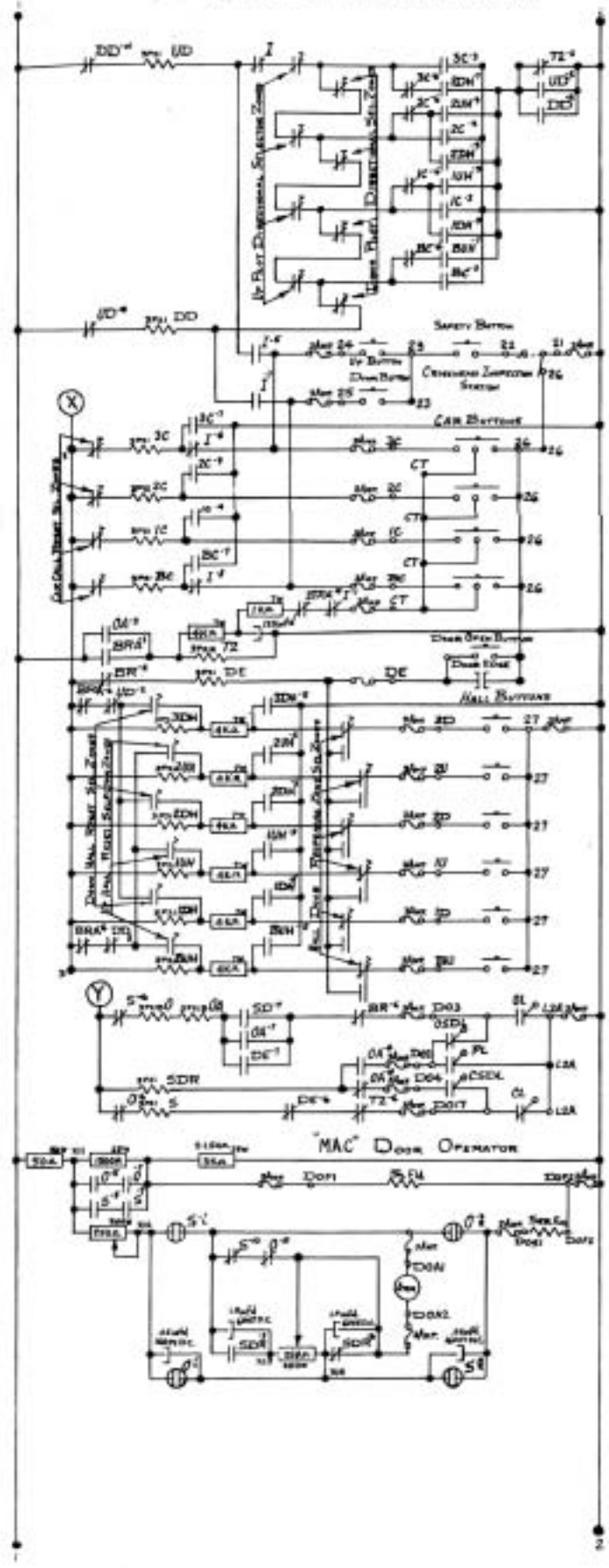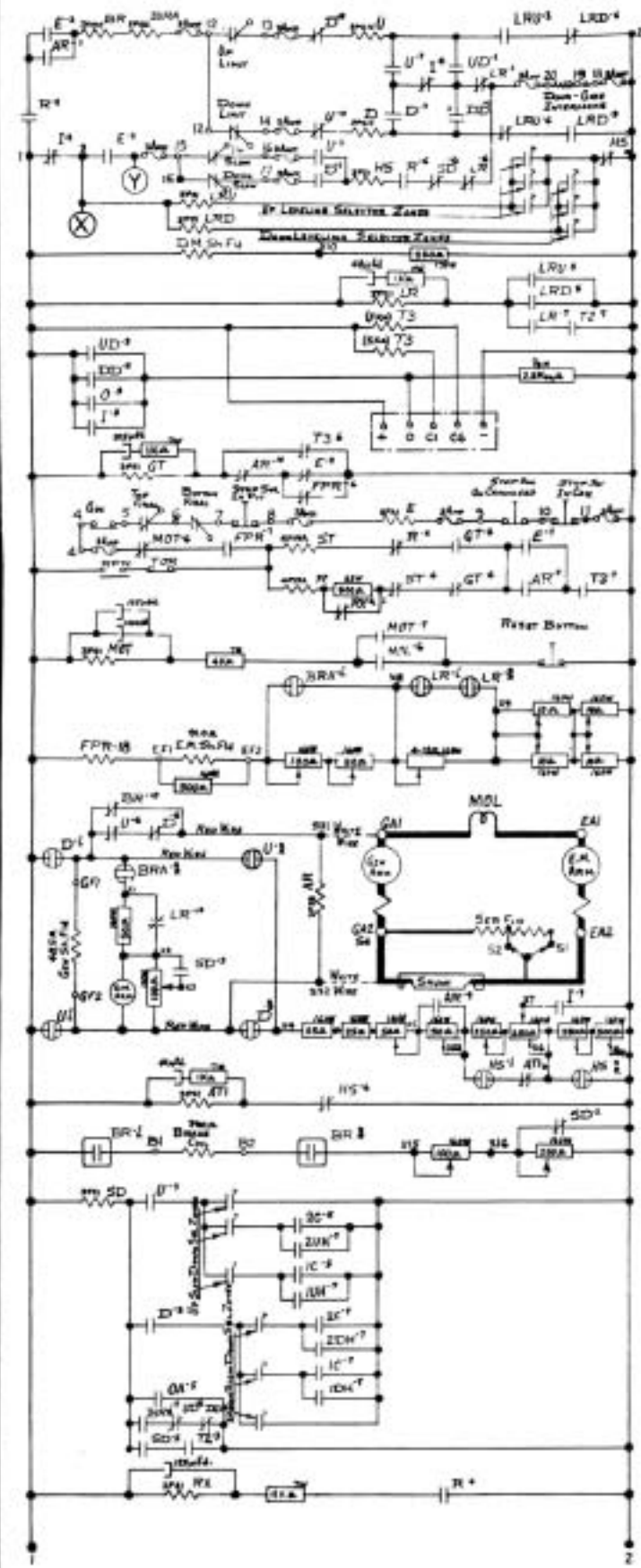
RELAY NOMENCLATURE FOR C-1469-A

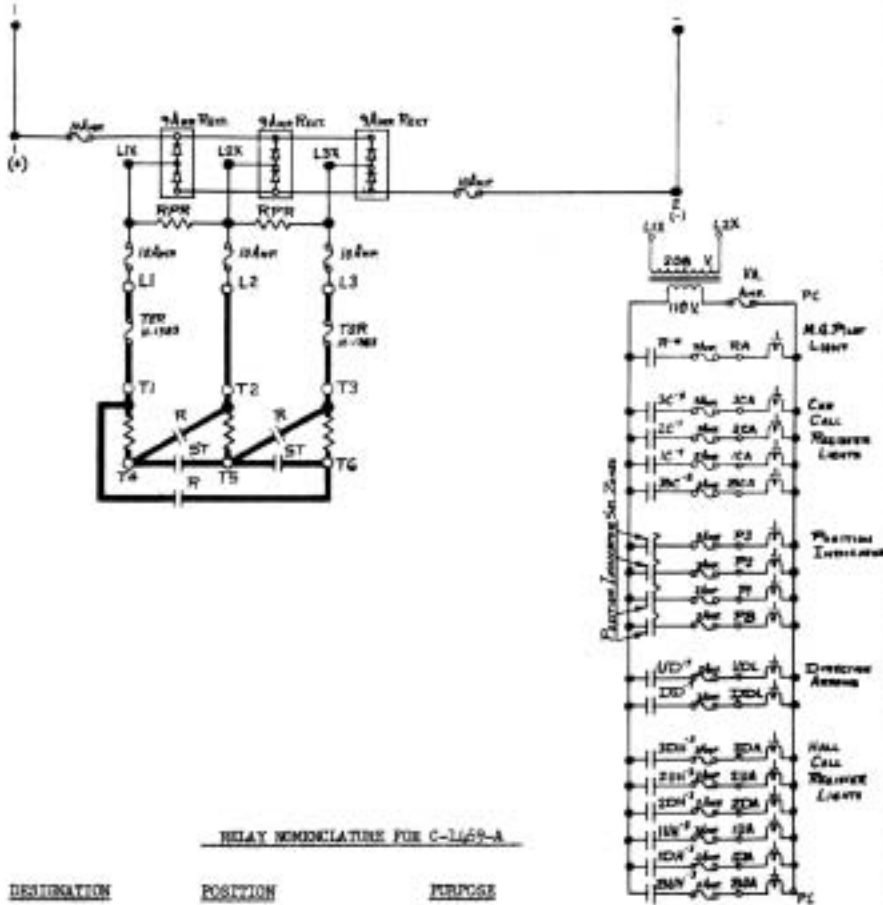| DESIGNATION	POSITION		PURPOSE
AR	10	C	Low Voltage Control Relay
ATL	12	B	High Speed Acceleration Timer Relay
BC	5		
to	to	I	Car Call Relays
JC	6½		
BK	1	A	Brake Contactor
BRA	1	B	Aux. Running Relay
BUH	8		
to	to	I	Hall Call Relays
JDH	10½		
D	2	D	Down Direction Contactor
DO	3-3/4	I	Down Pilot Directional Relay
DE	7½	J	Door Edge Relay
E	6	D	Emergency Stop Relay
FPR	8½	A	Field Protection Relay
GT	2½	A	Generator Starting Timer Relay
HS	2½	D	High Speed Contactor
I			Inspection Relay (Manual on Controller)
LN	3-3/4	D	Leveling Timer Relay
LRD	3	B	Down Leveling Relay
LRU	2-3/4	B	Up Leveling Relay
MOL	9	E	Magnetic Overload Relay
MOT	7½	A	Magnetic Overload Timer Relay
O	11	I	Door Open Relay
OA	11	J	Aux. Door Open Relay
R	6-3/4	C	Generator Running Contactor
RFR	2½	P,Q	Reverse Phase Relay
RX	16	B	R Coil Protection Timer
S	12	I	Door Shut Relay
SD	13	A	Slow Down Relay
SDR	11-3/4	I	Door Slow Down Relay
ST	6½	C	Generator Starting Contactor
T2	7½	J	Door Timer Relay
T3	4	D	M.G. Shut Down Timer

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voltage. Of course, when the direction switch drops out, the brake sets on the hoist motor. Oddly enough, this aggravates the condition. When the brake sets, the armature of the hoist motor becomes very close to a short circuit. While the generated voltage may be low, the stalled armature makes the amperage (flow) of the current become rather high.

This brings about a vicious circle: All the current flows through the series fields of the generator. We have a large number of ampere turns in effective work. Our generator puts out more power due to these ampere turns, and this adds to the initial ampere turns. The current will very rapidly rise to such a point that the hoist motor will pull through the brake and run away. It may do this with the hoistway and car doors open. There have been many methods worked out to prevent this condition, and we will outline a few of them.

One method was to short out the series field when the car stopped. This required a large contact, with almost perfect contact surfaces – and they must stay that way. Refer back to our sample generator and you will see the very small resistance of the series field involved. The contact would have to have far less, for if any resistance was present in the contact, the generator would generate in proportion of the contact resistance to the resistance of the series field. Small contact leakage could allow enough generation not to pull the brake, but still enough to burn out the coil under the brushes of the hoist motor.

Another method was to have a "killer," or a magnetizing field. This was a small shunt field that was excited in the reverse direction to kill the residual. This was rather difficult to balance out in practice.

The third method was to open the loop circuit between the generator and the motor. This had its problems, too. The large contact involved would develop some resistance. As the contact must pass 15 to 20 volts in leveling, a very small voltage drop was so large (percentage-wise) that leveling tended to be erratic.

Probably the most widely used is the "suicide circuit." This is, as it implies, a device to cause the set to "kill itself." On Print No. C-1469-A, you will see a complete schematic. One side of the loop circuit is tied to one end of the shunt field. When the brake switch drops out, or if both direction switches are out, the other side of the loop is hooked to the remaining shunt-field terminal. This circuit is polarized so that if the circulating current starts to rise, the shunt field is automatically built up in the reverse magnetic direction. The circulating current is held to less than 1.5 volts – usually .5 to .7 volts. In this switching arrangement, we have a double circuit: that is, two independent ones, so that either could fail and the remaining one would still operate. All switches are "fail safe" in that the contacts are normally closed. An open coil will close the circuit.

We will now discuss some of the problems met by the adjustor and service workers. We will address these problems in four stages: the set driving motor, the generator, the hoist motor and the control system.

The synchronous (no-load) speed of a motor is determined by the frequency of the current (usually 60 cycles) and the number of poles. In theory, a four-pole machine would run at 1,800 rpm. In practice, however, it runs at a slower speed. The difference between the synchronous speed and the actual speed under load is the slip. This figure is given as a percentage figure. As a DC generator's output voltage varies directly with its armature's speed, we desire the driving motor to have as little slip as possible.

When the slip increases as torque increases, it approaches a point of "no return." To understand this, we will review what happens as the load and slip increase. The speed will drop, due to the applied load. The rate at which the secondary conductors – the squirrel-cage rotors – cut (or slip backward through) the revolving field will increase. The induced electro-motive force will increase, and the current and the torque will increase until the torque just meets the demand of the load. However, this can only go so far. As the slip increases, the frequency induced in the squirrel cage increases, as does the leakage reactance in direct proportion. This results in a lag in the secondary (the squirrel cage) current behind the flux of the revolving field. This results in a decrease in effective torque.

A point is reached where the motor slips badly and starts to rapidly slow down. This is the "pull-out" point. Due to the overloads imposed during acceleration of heavy loads, we must have a high pull-out torque on our rotor design. Also, due to the fact that we desire a steady output as described above, we must have a low slip. Elevator MG sets are started unloaded. This fact allows us to use a motor of low starting torque. The result of this is low starting current and less heat in the machine. The rotor used to satisfy these requirements is, therefore, a low-resistance (low-slip) squirrel cage with deep section bars (low starting current, high pull-out torque), and it usually has slots not parallel to the axis to reduce noise.

The AC motor may be started in several ways:

1) Resistance starts: In this method, resistance is inserted in each phase to reduce the voltage to the motor terminals. As the motor reaches

its rated speed, the resistance is shorted, and full voltage is applied to the terminals. This method requires high starting currents:

2) Star-Delta start and run: In this very popular scheme, the motor is connected (in Star or Wye) to start, and when full speed is obtained, the windings are connected in Delta. The voltage impressed in each phase when Star-connected is 58% of the running voltage. The current in starting is proportionately reduced. This means less heat in the machine, and less stress on the rotor. See Figure 8, line 2.

3) Increment start: In this method, a part (usually half) of the motor winding is connected to the supply lines. When speed is almost synchronous, the remainder of the winding is connected. This method is used in other industries, but the elevator industry has not used it to any great extent due to the reluctance of the set manufacturers to furnish the proper motors.

If a driving motor on an MG set is noisy when at full speed, there may be either a mechanical or electrical condition causing this trouble, so the first procedure is to determine which it is. This can be most difficult. Let us assume that the noise level is low when the car is at rest, and that it is high when the car accelerates and decelerates. Usually this noise is the hum or "howl" of an AC characteristic.

Remove the end plug of the machine and attach a tachometer. Observe the speed at varying loads. The motor should run very close to its rated speed (assume 1,800 rpm) when under no load. If the slip or speed loss is excessive when the load peaks are reached, we have a clue.

The 1,800-rpm machine should not drop below 1,750 rpm under peaks of load. Following our clue, a voltmeter should be applied to the motor terminals at the motor junction box. Each pair of leads should be tested. The voltage should be equal on each pair of leads, and should not drop appreciably – from 208 to 200 volts is not excessive. If the voltage drop is excessive or unequal, look for trouble external to the motor. If the voltage drop is equal and within acceptable limits, we must assume that the noise is occasioned by the motor.

Using an ammeter (preferably a clamp-on type), check the amperage in each motor lead. If the current is equal, we may assume it is not the stator. If they are unequal, we may be assured the trouble is in the stator, for we have determined that the applied voltage is equal on each terminal.

If the current is unequal, we may have a motor that is wound with several circuits in parallel – either two, three or four Star or Double Delta, with one circuit opened. This will unbalance the machine so that it will be noisy under load.

If it is not the stator and the trouble is in the motor, we have the rotor left to check. To further determine the cause, we must disassemble the machine. Inspect the outer diameter of the rotor carefully to see if the bearings are failing and if the rotor is rubbing the stator when the load surges occur.

If no apparent rubbing is noted, we are usually faced with trouble in the squirrel cage. In a motor with copper or copper alloy bars, we have the bars inserted through an end-ring of copper or copper alloy. These bars are fused to the end-ring. If one or more of these bars is not securely fastened, we have a noisy motor that will slip excessively under load. The most common point of failure in this respect is in the middle of the end-ring. The broken bars are located by light, by tapping or by gently prying them to detect motion.

One supplier of rotating equipment secures the bars by melting down the projected ends by means of a carbon arc. This is inexpensive, but leads to one of our troubles. As the copper is raised to the fusion point, it picks up oxygen and becomes porous and brittle. When the stresses of starting the set and the loads of acceleration and deceleration are applied, these embrittled points will sometimes fail, and we will have a noisy set. This damage may be repaired by carefully silver-soldering from the rear or inboard side of the end-rings.

Mechanical noises are usually easy to locate and correct. Examples are a loose fan, a dynamically unbalanced set that causes vibration or a bad bearing. One particular noise that should be mentioned in passing is caused by a periodic vibration of high frequency. It is apparent at times as the set is accelerating, and quite often it is evident when the set is coasting to a stop. At other times it will slowly build up and slowly die down while the set is running. You will find that this will only occur if two conditions are met: 1) A pressed steel end bell and 2) a ball bearing. Various remedies can be used. A shot of light oil in the bearing will temporarily alleviate the condition. A more permanent remedy is to bend one arm of the pressed steel end bell, or to weld or bolt a substantial piece of metal in the end bell to break up the harmonics.

If high circulating current is encountered, we have a condition that must be corrected. All sets should be periodically checked for this condition. A voltmeter connected to adjacent brushes immediately after a stop is a good check. The stop that is checked should be one after up travel under load or after down travel empty. This will usually show the highest

voltage, but checks should be made under the reverse conditions. Most manufacturers recommend that with a nominal loop voltage of 230 volts, the circulating current is not over 2.5%. Practice, however, indicates this figure to be too high, as a continued voltage of this value will cause hoist-motor heating, and there is a very direct danger of the car running away if the condition should slightly change for the worse. High circulating current can be caused by a defect in the suicide circuit or, if other means are used, a defect in the demagnetizing circuit.

High circulating current may also be caused by too much series field. Make the full-load leveling check. It may also be caused by the brushes being out of neutral. Usually, the series field effect is not strong enough. Make the full-load leveling test, correct the series field and adjust the point of slowdown. Of course, the leveling speed must not be too high.

It may be of interest to note one case in particular. The customer, a very able elevator adjuster, complained that at intervals the car would be found in the overhead with the top-floor door open, or it would be in the pit with the bottom-floor door open. This would occur about five or six times a week, and never when it was under observation. Careful checks were made on compounding and the suicide circuits. It was a new set – the brush yoke was pinned at the factory.

With no load on the car, it was run to the top floor and the circulating current was 1 volt. On successive runs to the top floor it was 0.5 volts, 0.75 volts, 0.5 volts and 1.4 volts. As an experiment, when the circulating current was 1 volt at the top floor, the brushes were pushed hard against the commutator and the voltage went up to 28 volts, and the car pulled through the brake and landed

the weights. It was determined that the brushes were so far out of neutral that the interpole effect had changed. If the commutator film broke down, the generator would become a series machine and the car would run away. Setting the machine on neutral corrected the trouble.

An uncommon trouble in generators is a reluctance to change their magnetic polarity. These troubles are more common and, in many cases, easier to cure. Sparking at the commutator is one difficulty often encountered. It may be caused by one or more conditions; we will discuss each, with the reasons therefore.

If the sparking occurs only under heavy loads of accelerating and decelerating, then the generator may be overloaded. The peak currents in the loop circuit should be noted, and they must not exceed 2.5 times the full-load rating of the generator. If they do, reduce the rate of speed change by control adjustment until they are less than this value. If sparking occurs under all load conditions and is excessively heavy but with little or no sparking under no load, check for reversed interpoles. If sparking occurs under one brush in one direction and moves to another brush when the direction of travel is reversed, we either have a single reversed or shorted interpole, or a reversed or shorted shunt field.

If a shunt field exists, the car speed will be less than it should be and a resistance check of the field coils will reveal the short, if that is the trouble. To determine the polarity of the shunt fields, a visual check of the connecting wire will often reveal the reversed unit. The wire should enter the opposite side of each alternate field. A positive check may be made by means of two pieces of steel, such as large nails or saw blades. Excite the fields with direct current, and place the bars on adjacent poles

with their ends touching. They should attract each other. A reversed pole will cause them to repel. This, of course, must be done with the armature removed. Interpoles may be visually checked in the same way, and they may be magnetically checked by passing current through them by means of a storage battery.

Sparking of varying intensity may be occasioned under all load conditions. This is often a result of an incorrect brush grade and/or a rough commutator. The wrong brush will often roughen the commutator. Sparking can occur at all times, even when the set is running idle. This may be caused by the generator being out of electrical neutral, or it may be occasioned by uneven air gap. Bad ball bearings that would cause the brushes to bounce or oscillate would also cause this trouble.

To check a DC machine, either motor or generator, for electrical neutral is a very simple procedure. All that is required is a source of direct current and a millimeter. With the machine fully assembled, disconnect at least one armature lead. Also, disconnect the two shunt field leads, GF1 and GF2. Make sure the AC motor cannot start. Connect the millimeter to two adjacent brush holders: see Figure 9.

Connect GF1 solidly to one side of the DC supply. Hold GF2 to the other source. If the meter rises when the field is excited, reverse the two meter wires. Hold GF2 on the DC source until all motion in the meter has stopped. Rapidly remove GF2 from the circuit, and note carefully how much the meter rises. Move the brush yoke in either direction – we have no clue as to the proper rotation. Try the application and removal of current again. If the meter rises higher, the brushes were moved the wrong way. If the meter direction is
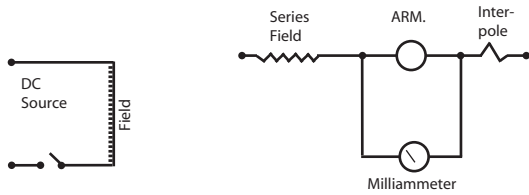
Method of Checking Electrical Neutral

Figure 8

reversed, they were moved too far in the correct direction. When in the exact neutral position, no appreciable motion will be noted on the meter.

Be sure to check again after tightening the yoke. Some manufacturers use a split yoke, which will hold position. One uses a cup-point set screw, and the yoke often moves when this is tightened. If this occurs, grind off the end of the set screw until it is square and smooth. Note that any brush shift will change the compounding or series field effect of the generator. Movement against ro-

tation will increase the effect, and movement with rotation will decrease the effect. These changes must be compensated for by series field adjustments. If it is not possible to get the brushes on exact neutral, and if the meter kicks one way when current application rises over zero, and kicks the same way and again crosses zero, the brushes are not evenly divided. That is, if four sets of brushes are used, they are not on 90° spacing. This should be corrected.

Other conditions that can cause sparking are shorted commutator segments, shorted turns in the armature, an open armature circuit or partially shorted fields. These conditions call for a competent re-wind shop. Another generator trouble may be occasioned by variation in leveling speeds with varying loads. This is

caused by incorrect compounding, by being off neutral or both. To check the compounding, put a full load on the car and run up and down at leveling speed. If the hoisting speed is lower than the lowering speed, increase the series field. If hoisting is faster than lowering, decrease the series field.

If "spotting" occurs in slowing down (that is, if the car pauses and then continues in its direction, or even reverses itself before continuing in its direction), we are either slowing too rapidly or have too much series. Make the full-load leveling speed check outlined above. If the compounding is correct, either start the slowing earlier or do this and decrease the rate of slowdown.

If "overshoot" occurs at the floor (that is, if the car runs through the floor at some loads), we have the opposite condition of spotting. This is

evidenced by several things. The most apparent is that when the car goes through the floor, it will not relevel until either a high voltage is applied or until considerable time has elapsed.

This trouble can be one of three things. The first is hard or high carbon iron in the frame. If this condition occurs, expert help must be obtained, as the pole pieces must be isolated with brass shims and bolts. So many design factors enter into this condition that it should not be lightly undertaken. The second condition that might cause this is too-low leveling speed and/or incorrect series adjustment. These conditions are evident, as are their cures. The third condition is field-pole design. If too high a voltage is required to excite the main poles, we have a clue. This means we have a pole of very many turns of fine wire for its shunt winding. The series firld is wound on the outside of this, making a reactor of very slow operation.

One manufacturer uses 85-volt fields. This means relatively few turns of wire. The releveling is rapid. Another manufacturer uses a much higher voltage, and the releveling is slower. In passing, it might be well to note that the "low-voltage" shunt field will ensure better suiciding.

In investigating a case of slow releveling and excessive high-speed overshoot on one of these field structures, new poles were wound for 75 volts, and the results were spectacular. Releveling was rapid, and the high-speed overshoot was reduced 20 fpm on a 500-foot job

The hoist motor, being a cousin of the generator, has a group of ills that are parallel to the ones of the generator. Sparking troubles are identical to the ones of the generator, and may be cured in a like manner. The only variation is that we cannot have sparking when idle. Speed regulation, particularly third speed, can be affected by brush position. If the generator has been thoroughly checked as to series effect and neutral, and speed variation between up and down full load is encountered, check the hoist motor and its wiring. If the wiring is of ample size and all connections are good (no heat at any terminal), see if the brushes on the motor are well seated. If they are, check for neutral as described under the method outlined in the generator discussion. If you desire to raise the full-load hoisting speed, move the brushes against the direction of rotation when hoisting. A very slight motion is necessary for this correction.

We now approach some of the general problems of variable voltage that may be traced to various parts of the system. They are generally classed as rough starts, rough and/or uncertain stops, and speed and control variations. Rough starts can be caused by applying too much voltage to the shunt field of the generator for the initial start. A voltmeter on GFH GF2 will determine this. The value of the first application of voltage should generally not be over 15% of the full-speed voltage. Your control manufacturer should be consulted on this point. A very common cause of rough starts is the failure of the brake to fully and rapidly release before the car starts to accelerate. Many factors can enter into this – too low a voltage applied to the brake, too rapid an increase in generator voltage, poor brake design, partially shorted coils in one or more brake coils or a dragging brake. A contact on the brake that will close when the brake is fully opened is an excellent device. This contact should be so connected that it will hold down the generator excitation until the brake is fully opened.

Another cause of rough starts that is little understood or considered is the shunt field of the hoisting motor. One manufacturer rates the fields of its motors so that only about 50% excitation may be used for holding or standing. A DC field takes a considerable time to saturate after voltage is applied, providing a very adverse condition. When the doors close and the interlock circuit is made up, we raise the field from a 50% to a 100% value, voltagewise. However, the magnetic flux does not rise immediately. Accordingly, the car starts with a weak motor field, which tends to make the motor run faster with a given loop voltage. It also requires higher amperage to run – this increases the series-field effect and further raises the loop voltage. A graph of this condition shows an unpleasant speed hump. (See Figure 9.) A very startling demonstration may be made of this condition by applying full field to the same motor before the doors close and noting the change in the start due to the increased time of field buildup.

Stalling in leveling may sometimes be traced to the hoist motor. If it has been determined that the series field is correctly adjusted, that the level-
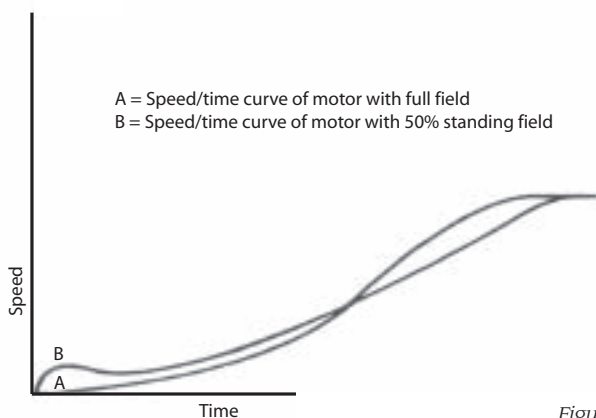

A = Speed/time curve of motor with full field
B = Speed/time curve of motor with 50% standing field

Speed

B

A

Time

Figure 9

ing speed is as high as is desired, and that the car will still stall under load when leveling, a quick check will determine if it is the hoist motor that is at fault. Try increasing the field current on the motor. Caution should be exercised in this maneuver, and the manufacturer's recommendation should not be exceeded.

It is a characteristic of a DC machine that the torque at a given voltage and amperage will increase with field strength up to the saturation point of the magnetic structure. This "saturation point" is the limit of the iron to pass more magnetic lines of force, regardless of the current passing through the magnet coil (in this case, the pole piece). It is also a characteristic, derived from this statement, that with a given flow of current (the ability of the generator to deliver power) that a given load can be lifted with less amperage with a stronger motor field. Of course, with the same loop voltage the speed will be less with a stronger field, so to maintain the same leveling speed, if we increase the shunt field of the motor, we can increase the exciting current of the generator to raise the loop voltage.

Speed changes from cold to hot operation can often be traced to the hoist motor. If the field design is such that field temperature rises with continued use, its resistance must increase as the temperature rises. As the resistance increases, the current flow, due to Ohm's Law, decreases. We now have a motor running with a weaker field, and consequently operating at a higher speed. The cure for this is in the province of the motor designer. It has two choices. One would be to design a field structure that would not heat. The second would be to operate the motor at full magnetic saturation. If he does this, a small drop in field current will not have an appreciable effect.

In discussing the hoist motor, it might be well to mention the two-speed DC motor. This is a machine of necessarily larger dimensions than a single-speed machine. It is largely used on elevators that are normally for passenger duty but on some occasions must hoist a heavier load. When operated as a passenger unit, the motor is operated on a partially excited field and will run at its top rated speed. When it must hoist a full load, full field is applied. This is either done automatically or by a manual switch. When operated at maximum field, the motor will run at either 1/2 or 1/3 speed, according to the design. The motor will be at a constant horsepower. This means that as the speed is decreased to 1/2 or 1/3, the torque will rise to two or three times the full-speed torque. This is a very handy application.

The control system of variable voltage may be approached from so many directions that it is difficult to generalize on difficulties to be encountered. We have outlined the necessity for the gradual application of current to the generator field, and it follows that the decrease in current to the generator field must be smooth, positive and carefully determined as to position as the stop is made.

One of the common complaints on variable voltage is the final stop. Due to the fact that the rest of the operation is so inherently smooth, a jar on the final stop is very objectionable, and much work has been done on this. In determining the causes and remedies for this rough stop, a simple procedure may be followed. This may be done with a fully loaded car, and then checked with a balanced car and with an empty car. The first step is to determine the electrical stop. Assuming that the series field and leveling are properly adjusted as to characteristics and speed, the brake is held off so that it will not set. Stops

are made with the brake lifted, and their severity is noted, as is the amount that the floor is passed – not on drift after stop, but on the stop. If this stop is hard, which is a rare event, it may be necessary to somewhat cushion the suicide circuit with a resistor. We repeat that this is most unusual. The resistor in the suicide circuit should be added with caution, and the circulating current should be rechecked.

In most cases, the stop will be satisfactory, or the car will run through the floor to some extent. If it does run through the floor, either the suicide circuit is not satisfactory and is not operating properly, the series field is not properly adjusted or we have a defective generator. After these factors have been carefully determined, we must set up a brake operation to suit their conditions. If the initial stops were good and no run through was encountered, the brake may be electrically controlled so that it will apply after the car has stopped. This may be accomplished by a delay in the dropout of the brake relay or by making the brake set slowly. This can be done with resistance in parallel with the brake coil. It is evident that no hard-and-fast rule may be laid down for this procedure due to the wide variation in magnetic and electrical brake designs. If the initial stops were through the floor, we must apply the brake in a different manner, for if we delay the application, leveling will obviously vary with load. Accordingly, we must work out a system whereby the passenger will not feel the brake application.

When the leveling zone is reached, a considerable amount of resistance is inserted in the brake circuit, and a parallel resistance is connected across the brake coil. This will accomplish a dual purpose. The resistance in series will allow the brake to partially set. The amount of the series resistance should be varied until the brake shoes

just rub the wheel. The parallel resistance should usually be equal to the resistance of the brake coil.

The parallel resistance is to prevent the brake from setting rapidly. It will be useful at two points: 1) when the shoes go from a wide-open position to the initial contact with the wheel, and 2) when the current is totally removed from the brake, making the final setting not so harsh. Properly worked out, the brake application under either method will not be felt. One manufacturer has seven different variations of partial brake setting. These variations are worked out according to load and direction.

Author:

Joseph C. Tamsitt was an engineer and educator who served as technical editor for ELEVATOR WORLD from 1961-1965. During an industry career that spanned more than 50 years, he served as chief engineer for General Elevator Co. and Keystone Electric Co., and later as director of Engineering, Production and Education for Horner Elevator Co. In addition to his engineering work, Tamsitt found the time to write numerous articles for EW in the 1950s and 1960s, develop correspondence courses for the elevator industry and serve as director of Education for the National Association of Elevator Contractors (NAEC) for five years. He also chaired several ASME A17.1 committees and is credited with developing the Type C safety for passenger elevators. After leaving the corporate world, he was appointed executive director of NAEC and later founded Elevator Educators, which helped many understand the intricacies of elevator codes and safety measures. In 1974, he teamed with the National Association of Elevator Safety Authorities (now NAESA International) to create the Elevator Educators Academy, which trained and certified elevator safety professionals. Among his numerous honors was the 1960 NAEC Man of the Year award. Tamsitt was a graduate of Southern Methodist University. He died in 1984.

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Learning-Reinforcement Questions

Use the below learning-reinforcement questions to study for the Continuing Education Assessment Exam available online at www.elevatorbooks.com or on page 143 of this issue.

◆ What is the operation theory of variable-voltage control as applied to the Ward-Leonard system?
◆ What are the various methods tried to achieve good control of acceleration, deceleration and leveling with variable-voltage control?
◆ In the author's opinion, what is the most dependable method of control?
◆ Explain the operation of a self-excited generator.
◆ How does a damping motor field work to control speed and leveling?
◆ How are ampere turns in a field determined?
◆ What does "shunt field" mean?
◆ What is Ohm's law?
◆ How does Ohm's law apply to an increase in load in the elevator system?
◆ Explain "circulating current" and retained magnetized flux.
◆ Examine the methods used to prevent rapid current rise and the hoist motor pulling through the brake (a runaway).
◆ What is the difference between synchronous speed and actual speed?
◆ What is this difference in synchronous and actual speeds called?
◆ What are some of the problems of variable-voltage control?
◆ How do you trace these problems to various parts of the system?

ELEVATOR WORLD Continuing Education
Assessment Examination Questions

Instructions:

◆ Read the article **"Variable Voltage Made Easy** (Using Print No. C-1469-A)" (page 77) and study the learning-reinforcement questions.

◆ To receive **three hours** of continuing-education credit, answer the assessment examination questions found below online at www.elevatorbooks.com or fill out the ELEVATOR WORLD Continuing Education Reporting Form found overleaf and submit by mail with payment.

◆ Approved for Continuing Education by **NAEC for CET and NAESAI for QEI**.

1. Variable-voltage control is known as:
   a. Unit multivoltage.
   b. Generator field control.
   c. Ward-Leonard control.
   d. All of the above.

2. Variable-voltage control was invented in:
   a. The U.S.
   b. Italy.
   c. Germany.
   d. Sweden.

3. In variable-voltage control, the elevator motor field:
   a. Is constantly excited and has power applied at all times.
   b. Has power applied only when the car is in motion.
   c. Has power applied only when the car is running at full speed.
   d. None of the above.

4. The armature of a generator is constantly revolved by a motor, which is on a common shaft with the _____.
   a. Generator
   b. Door-operator motor
   c. Hoist machine motor
   d. None of the above

5. The polarity of the generator current will be in relation to the polarity of the generator fields.
   a. True
   b. False

6. A direct-current (DC) motor with constantly excited fields will vary in speed relative to the voltage applied to the:
   a. Commutator.
   b. Fields.
   c. Brake coil.
   d. Starting contacts.

7. The company that pioneered the damping motor control in the mid 1920s was:
   a. Westinghouse.
   b. Otis.
   c. Dover.
   d. General Electric.

8. A DC motor's armature is almost a short circuit when at rest and will draw less and less current as it _____.
   a. Decelerates
   b. Accelerates
   c. Runs at full speed
   d. Comes to rest

9. What type of control requires no timers, tubes, switches or trick fields in the generator?
   a. Damping motor control
   b. Two-speed alternating current (AC)
   c. Single-speed AC
   d. VVVF-AC

10. Generators that are used in elevator control that are compound wound have a _____.
    a. Series field
    b. Isolated base
    c. Shunt field
    d. None of the above

11. With a generator properly compounded so that the leveling speeds in the up and down directions are exactly equal the full-load speeds in both directions should have a variation of no less than _____.
    a. 10%
    b. 5%
    c. 24%
    d. 15%

12. When lowering a load, the motor becomes a generator because it has an excited field and is driven by the load.
    a. True
    b. False

13. Once magnetized, the degree to which a piece of iron or steel will retain some flux of magnetism is dependent on the material _____.
    a. Hardness
    b. Length
    c. Temperature
    d. All of the above

14. Switches that are "fail safe" normally have contacts that are normally _____.
    a. Closed
    b. Open
    c. Large in surface area
    d. Redundant

15. The synchronous (no-load) speed of a motor is determined by the frequency of the current and the _____.
    a. Level of the voltage applied to field
    b. Number of poles of the motor
    c. Sound levels
    d. None of the above

16. The amount of the difference between the synchronous speed and the actual speed under load of a motor is known as _____.
    a. Creep
    b. Slip
    c. Shift
    d. All of the above

17. The point at which the motor slips badly and starts to rapidly slow down is known as the _____ point.
    a. Breaking
    b. Tripping
    c. Pull-out
    d. Failing

18. The voltage impressed in each phase of an AC motor when star-connected is _____ of the running voltage.
    a. 33 1/3%
    b. 66 2/3%
    c. 58%
    d. 25%

19. A noisy motor on an MG set when running at full speed may be caused by a mechanical or _____ condition.
    a. Electrical
    b. Environmental
    c. Overload
    d. None of the above

20. Sparking of a generator commutator when running idle may be caused by:
    a. The generator being out of electrical neutral.
    b. Uneven gaps between the brushes and the commutator bars.
    c. Bad ball bearings.
    d. All of the above.

ELEVATOR WORLD
Continuing Education
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Article title: **"Variable Voltage Made Easy"** (EW, April 2007, page 77).

Continuing-education credit: This article will earn you **three contact hours** of elevator-industry continuing-education credit.

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6.	a	b	c	d	16.	a	b	c	d
7.	a	b	c	d	17.	a	b	c	d
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