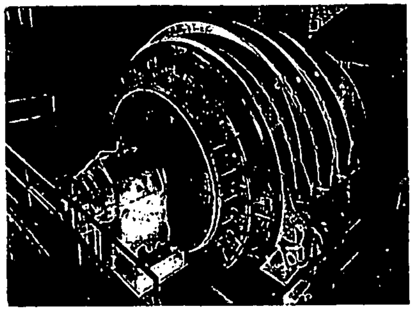
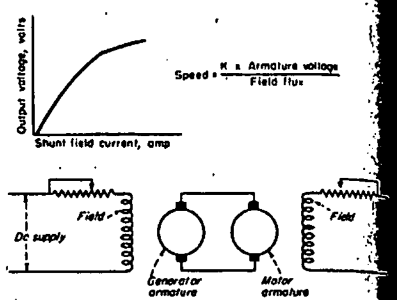
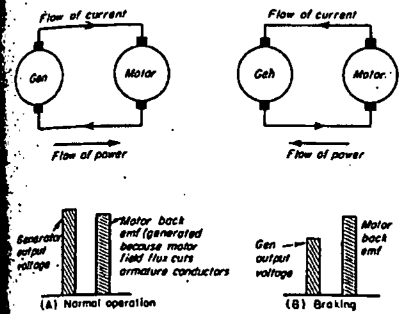


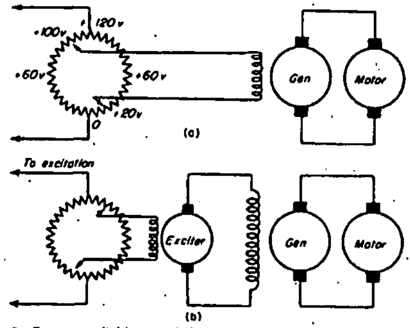
1 Equipped with Ward-Leonard speed control, this 7000-hp dc motor, at 40-rpm base speed, reverses to 40 rpm in two sec



2 Generator feeds armature of controlled motor. Motor speed changed by varying armature voltage with generator field



3 Regenerative braking or pump back occurs when generator voltage drops and connected motor has load with high WR^2



4 Generator field control for reversing motor. If generator is large, variable voltage exciter is used for field supply

Ward-Leonard System Assures Exact Speed Control For DC Motors

Dc shunt motors, using Ward-Leonard speed-control system, suit drives which call for wide speed variation or the maintenance of exact speed, regardless of load changes

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▶ SQUIRREL-CAGE INDUCTION motors are adequate for most industrial drives. They are simple, relatively inexpensive and reliable. However, there are some applications that require exactly constant speed under conditions of variable load. Other drives require an unusually wide range of speed. For these, and other special applications where exact control is needed, the Ward-Leonard system, although 57 years old, is hard to beat.

The basic patent, issued to the late Harry Ward Leonard on November 24, 1891, covered speed variation of a dc motor by changing its armature voltage. Variable armature voltage was obtained by varying the field of an intermediate generator. Since that time many patents have been issued covering modifications and refinements.

How It Works. Output voltage of a dc generator is produced by rotating armature conductors through lines of flux created by stationary field poles. Amount of voltage depends on rate at which these lines of flux are cut. By simply adjusting rheostat in generator shunt-field circuit, it is possible to increase or decrease current in the field, and hence the flux. Thus, output voltage of the d-c generator can be varied, as shown in Fig. 2, by simply adjusting field rheostat.

A dc motor has a speed characteristic described approximately by the formula:

$$\text{Speed} = \frac{K \times \text{Armature Voltage}}{\text{Field Flux}}$$

K, the constant, depends upon electrical design of the motor. Field flux can be varied by adjusting the motor field current with a rheostat. If field current is held constant, then motor speed varies directly with armature voltage. If armature voltage is held constant, speed varies approximately inversely with field current.

Obviously, it isn't desirable to reduce field current of a motor to zero with armature voltage on the machine, since speed would tend to approach infinity. It is interesting to note that speed in an ideal machine is not influenced by load torque, although torque does have a slight effect on the speed of a practical dc motor. However a motor can be designed so variation in speed caused by load fluctuations is small.

The Ward-Leonard speed-control system is made by simply connecting generator to motor as in Fig. 2. Motor speed can be adjusted either by varying generator or motor field. A properly designed motor will stay close to its speed under all load conditions. Additional controls can be incorporated in generator field circuit to keep motor speed within a value which does not vary from its set speed by more than 0.1 percent of the motors rated speed. Generator of a Ward-Leonard system is usually driven by a synchronous or induction motor, or by a prime mover such as a diesel engine or steam turbine.

Reversing Service. With the Ward-Leonard speed-control system, it is as easy to reverse a machine as to change speed. From the equation for the speed of a dc motor, Fig. 2, it is apparent that if armature voltage is negative, the speed of the motor will become negative (reverse).

A potentiometer type of field control permits reversing generator field, Fig. 4a. In the position shown, potentiometer contacts place +60 volts on generator field. If contacts are rotated counterclockwise to the horizontal position, no voltage is impressed on generator field, and hence no current flows. Further counterclockwise rotation of potentiometer contacts impresses negative voltage on generator field. Generator output voltage then reverses, and motor starts going backwards.

This reversing feature is especially useful in large blooming mills where the steel ingot is sent through the rolls several times to reduce it to a long bloom. It is especially suitable for diesel-electric marine propulsion drives where it is necessary to reverse the propeller to stop or maneuver the vessel.

Sometimes, when generators and motors are large, variable-voltage exciters are used in field circuit, Fig. 4b. The controlling rheostat or potentiometer can then be relatively small, and there is no need for power-consuming resistors in main generator or main motor field circuits. The Ward-Leonard system operates just as effectively with exciters in the field circuits as it would with a constant-voltage supply and rheostats in the field circuit. Furthermore, the exciter can have special fields which permit precise control of speed, torque or power.

Regenerative Braking. Another important feature of Ward-Leonard system is its regenerative-braking or pump-back ability.

Normal operation of the drive is shown in Fig. 3a where generator voltage is slightly higher than the back electromotive force of motor. This back emf, measured in volts, is result of motor armature conductors cutting lines of force generated by motor field. Product of armature current and back emf in the motor represents electrical power actually converted into mechanical power.

Difference between generator terminal voltage and motor back emf represents voltage required for forcing the load current through motor armature circuit. This drop within armature is normally quite low, about six to ten volts for a 240-v motor.

Now suppose generator voltage is suddenly reduced by changing generator field rheostat setting. If motor is connected to a mechanical load having high inertia, it will not slow down instantly. Consequently, motor back emf will remain at a high value until motor and its connected load slow down. If motor back emf is higher than terminal voltage of generator, then current will flow in the reverse direction, and flow of power will be from motor to generator.

As a result, the motor will absorb mechanical power from its load and pour it back into the generator. Generator will then try to speed up its prime mover; and when an alternating current motor is used to drive generator, it will actually put power back into line. This process is known as regenerative braking.

Flywheel Mg Sets. Sometimes load of a Ward-Leonard drive is intermittent and there are frequent regeneration impulses. A typical example is a reversing metal-rolling mill, where periodically inertia of rolls has to be absorbed by motor, and then supplied again when rolls start turning the other way. On top of that, a peak in power requirement occurs every time an ingot or bloom hits the rolls.

For this type of application, a flywheel is often installed on the supplying motor-generator set which is usually driven by a wound-rotor induction motor. When a regenerative impulse occurs, flywheel is speeded up slightly by generator. When a sudden load peak occurs, flywheel slows down slightly. Hence power requirement for the drive is smoothed out.

Often automatic slip regulators are installed in secondary of wound-rotor induction motor which drives generator. If input current to wound-rotor motor becomes high, the slip regulator adds resistance to rotor circuit, causing motor to slow down slightly. This permits flywheel to give up energy to do generator. When input current to wound-rotor motor drops off, the slip control reduces secondary resistance permitting motor to catch up in speed by putting energy into flywheel.

Economic Limitations. Ward-Leonard drives are expensive because (1) dc machines are more expensive than ac; (2) it takes three machines to drive one load viz, an ac motor, dc generator and a dc motor. Certainly if a wound-rotor motor or a mechanical speed-changer can do the job more economically, it should be used. Keep in mind physical limitations of equipment itself as well as control type required.

However, there are many drives which call for precise control, a wide variation in speed, or exact speed regardless of load. For these drives, the Ward-Leonard system is suitable.