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CHARACTERISTICS OF MOTORS FOR LARGE SHEARS

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The function of a fly-wheel in a system with a rapidly fluctuating load is to equalize the power requirements, thus reducing the sudden shocks to the moving parts and thereby the strains on the machine frame and both the mechanical and electrical strains on the driving motor. For the fly-wheel to be effective the speed characteristic of the motor should be such that the motor will slow down as the load increases and will increase in speed as the load decreases. In the case of large shears the full working load is applied suddenly and the fly wheel is called upon to deliver energy through a very short space of time, varying from one-half a second to two seconds, according to the size of the machine and the size and condition of the material cut. Thus it is evident that the speed characteristics of the driving motor must be inherent, as the time is too short to depend upon a practical control means for changing the motor characteristics.

The ideal working condition for motor-driven shears would be one in which the fly-wheel does all of the cutting work, leaving for the motor only the friction load and the work of accelerating the fly-wheel after the cutting and subsequent slowing down period. The results of a test made on a large bloom shears, which is referred to later, show that this ideal condition can be approximated very closely when the speed characteristics of the motor are properly chosen.

Before outlining the exact conditions which the motor speed characteristics should meet, it would be well to analyze the speed curves of a shunt, a standard compound, a 50 per cent compound, and a series direct current motor. These curves as shown in Fig. 1 are designated by the letters A, B, C and D, respectively, and are given for a 50 h.p., 220-volt, direct-current motor.

For shears requiring a motor of 25 h.p., or of larger capacity, the friction load will approximate 25 per cent of the motor rating; for smaller shears the friction load varies from 15 per cent to 20 per cent of the full load.

The speed variation for a given change in load and the percentage of energy given up by the fly-wheel for the respective changes in speed are as follows:

Curve A.

Shunt motor, speed variation from light to full load . 5 per cent.
The energy of a fly-wheel varies as the square of the speed and the amount given up for 5 per cent speed variation is .... 10 per cent.

Curve B.

Standard compound motor, speed variation from light load to full load .... 15 per cent.
Standard compound motor, speed variation from friction or 25 per cent load to full load .... 10 per cent.
Energy given up by fly-wheel for 10 per cent speed variation .... 19 per cent.

Curve C.

50 per cent compound motor, speed variation from light to full load .... 50 per cent.
50 per cent compound motor, speed variation from friction or 25 per cent load to full load .... 30 per cent.
Energy given up by fly-wheel for 30 per cent speed variation .... 51 per cent.

Curve D.

Series motor, speed variation from 25 per cent load to full load .... 66 per cent.
Speed at 25 per cent load .... 1500 rev. per min.
Speed at full load .... 525 rev. per min.

With but few exceptions the electric motor drive is now used in all machine shops, and the replacing of worn-out engines with motors for individual and group drive is completing this evolution. Where such a change is to be considered in regard to engine-driven shears, it is comparatively a simple matter for an engineer to determine the size of the motor and the proper speed characteristics to give the best results. For example, in the case of a large hot bloom shear

The fly-wheel capacity of the machine .... A h.p. seconds.
Friction load of machine .... B amperes.
(obtained by test) .... (at a given voltage)
Cutting period .... 2 seconds.
Period between cuts .... 6 seconds.
(This cycle is to be considered continuous.)

If the power is cut off when the machine is running light at full speed, the number of consecutive cuts that can be made before the machine comes to rest is four. For the ideal case, where the fly-wheel does all of the work, it should give up 25 per cent of its energy per cut and must slow down 13 per cent.

Let the light load of the motor = *C* rev. per min.

During the cutting period the speed must fall to *C* rev. per min. 100 per cent − 13 per cent = 87 per cent *C* rev. per min.

Energy delivered by the fly-wheel during two seconds' cutting

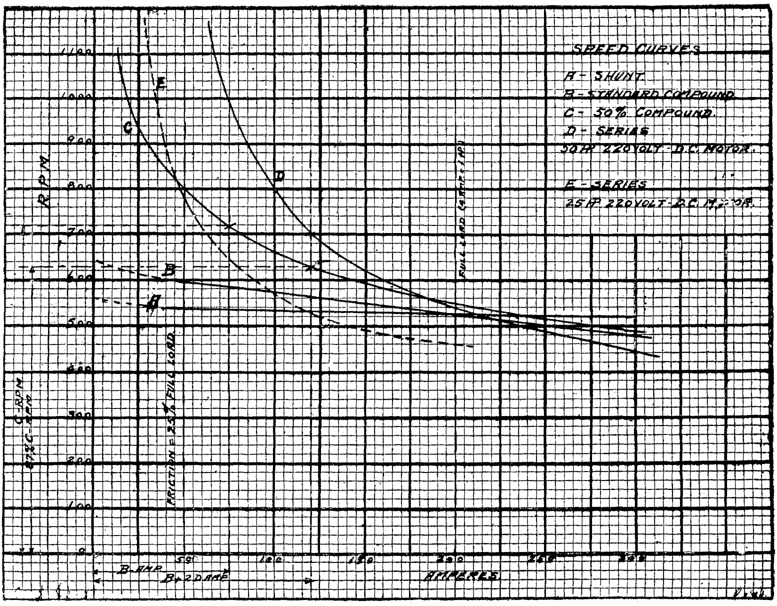

FIG. 1

period and energy stored in the fly-wheel during the six seconds interval = 25 per cent *A* h.p. seconds.

Let the average current required to store 25 per cent *A* h.p. seconds energy in the 6 seconds interval = *D* amperes.

The current curve which corresponds to the power curve with constant voltage will vary through an economical range when the motor speed-characteristic governs the variation as follows:

The minimum value of the current should be equal to a friction load at the end of the interval between the cuts. The maximum value of the current should be equal to the friction load plus twice the value of the average current required to store the fly-wheel energy expended during one cut. The curve in Fig. 2 illustrates this.

During the cutting period the current rises to a maximum value as shown at point X, and falls to a frictional load value as shown at Y at the end of the 6-sec. interval. Thus, at the point Y, B amperes corresponds to C rev. per min., and establishes one point on the motor speed curve. This shows that it

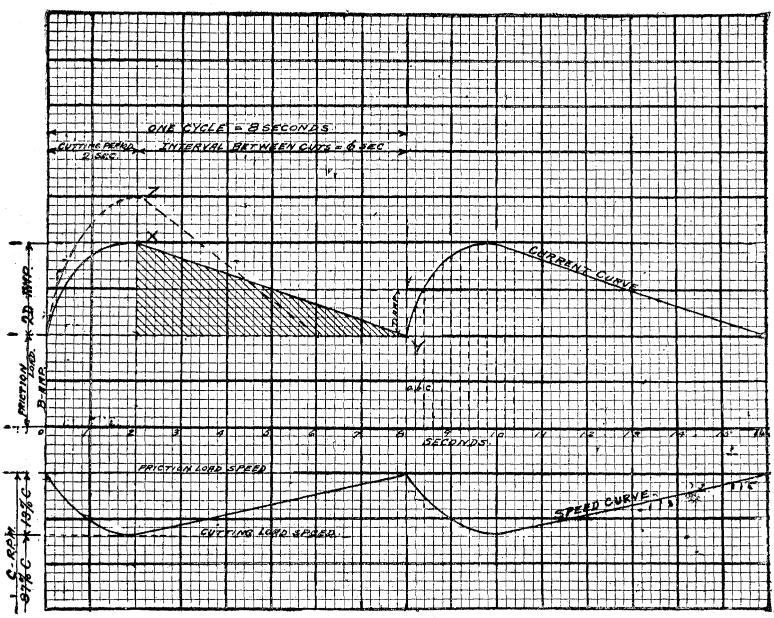

FIG. 2

requires D amperes as an average to store the 25 per cent A h.p. seconds energy in the fly-wheel. Thus the maximum value of the current at point X equals 2 D amperes, which must correspond to 87 per cent C rev. per min., and a second point on the motor curve is established. By this means a speed curve for the working range required can be plotted. As an illustration, these points are designated on curve C, Fig. 1.

The heating effect of the motor load varies as the square of the current and is represented by the square root of the mean square current. This value of current can be closely approximated by dividing the current curve into a number of parts along the time ordinate, squaring each sectional current value and multiplying by the time-increment. These several values are then added and the sum divided by the total time period. The square root of this dividend is the square root of the mean square current. For example, refer to Fig. 2.

Square root mean square current

$$= \sqrt{\frac{(a^2 \times 0.2) + (b^2 \times 0.2) + (c^2 \times 0.2) \text{ etc.}}{8}}$$

and this is the value of a continuous current which would produce the same heating effect as the varying load shown. The capacity of the motor required for the above condition can thus be calculated.

With the principal portion of the speed curve constructed and the capacity of the motor known, the next point for consideration is the type of motor winding and consequently the speed characteristic which is best suited for the given conditions.

As has been explained before, the speed variation of a series motor covers too great a range between the friction load, or 25 per cent full load, and the working of full load of the motor. This value is approximately 66 per cent, and therefore the series motor can be eliminated from the list.

The next motor to be considered is one with a 50 per cent compound winding, in which case the full-load speed is 50 per cent of the light-load speed.

Fig. 3 is a recorded current curve of a 50 per cent compound motor operating a large bloom shears which has the following characteristics:

Style of machine	Vertical, bloom.
Maximum section the machine will cut	10 in. by 10 in.
Weight of fly-wheel	20,000 lb.
Diameter of fly-wheel	9 ft. 10.5 in.
Section of fly-wheel rim	12 in. by 13 in.
Rev. per min. of fly-wheel	110
Energy of fly-wheel at friction load	2500 h.p. for 1 sec.
Size of motor	50 h.p., intermittent rating.
Voltage of motor	220
Type of motor winding	50 per cent compound.
Motor	direct-current, geared
Motor speed	500 rev. per min. full load.
Friction load	50 amperes, 235 volts, 800 rev. per min.
Cutting load, maximum	110 amperes, 235 volts,

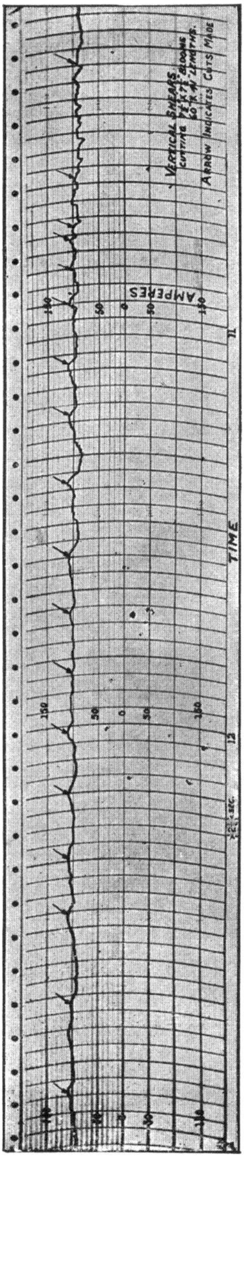
VERTICAL SHEARS
ARROW INDICATES CUTS MADE
AMPERES
TIME

FIG. 3

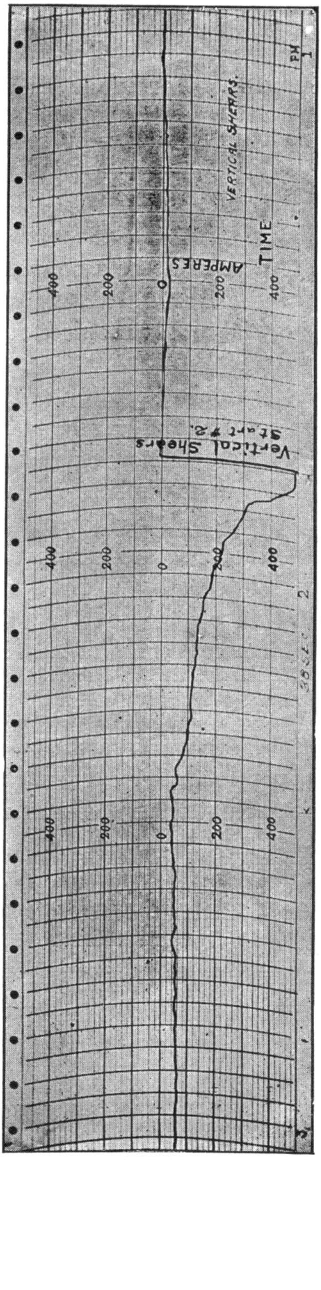
VERTICAL SHEARS
AMPERES
TIME
Vertical Shears
Start #2.

FIG. 4

Section of material cut......................7.5 in. by 7.5 in.
Kind of material cut..............................hot steel

When the machine is running light at full speed and the power is cut off the number of consecutive cuts that can be made before machine comes to rest is four.

Motors used for intermittent duty, such as street car and crane service, are given an intermittent rating and will operate at full load for one hour without injurious heating; this heating is generally stated as 75 degrees cent. rise above the surrounding atmosphere. The above motor is rated on this basis, and the continuous load which it will carry with the same temperature rise is equal to practically one-half of the 1-hr. rating.

As shown on the curve, the motor is working between an average minimum load of 95 amperes and a maximum of 110 amperes. Estimating on the square root of the mean square basis, the equivalent heating current is approximately 100 amperes at 225 volts; this requires a 25-h.p. motor, continuous rating, or a 50-h.p. motor of intermittent rating.

The starting conditions as shown in Fig. 4 require a maximum of 100 h.p. which falls gradually to the friction load of 125 h.p. in 40 sec.

The curve in Fig. 3 shows virtually a uniform load on the motor, a much greater load than that given for the theoretical case in Fig. 1. An analysis of the condition shows, however, that the motor is working in a very steep portion of its speed curve; and the speed change for this working portion of the 50 h.p., 50 per cent compound-wound motor of intermittent rating is equal to 75 per cent of the speed change of a 25 h.p. series motor of continuous rating.

50 per cent compound motor	95 ampere	670 rev. per min.	
" " " "	110 "	640 rev. per min.	
Reduction in speed.................		30 rev. per min.	= 4.5 per cent.
Series motor..............	95 ampere	580	
" "	110 ampere	545	
Reduction in speed.................		35 rev. per min.	= 6.0 per cent.

The steeper the speed curve the more gradual is the fall of the current curve from the peak to the minimum value. Referring to the theoretical curve in Fig. 2, a motor with a certain percentage of compounding will require a maximum current, as designated at point X, to give the required speed change of 13 per cent; a motor with less compounding will require a maximum current rising to point Z for the same speed reduction. The shaded portion of the curve from point X to point Y represents the work done in restoring energy to the fly-wheel. It is obvious that an increase in the peak load or vertical component causes a corresponding decrease in the horizontal or time ordinate, as the area described by the curve beyond the peak remains constant. Therefore the steeper the motor speed-curve the more gradual the decrease of current value between the cutting periods. On account of this sluggish characteristic, it requires quite an appreciable time, virtually 14 seconds, Fig. 4, for the motor described above to increase the speed of the fly-wheel from the speed corresponding to 110 amperes to that corresponding to 50 amperes, or friction load. As a cut is made in about every 9 sec. the minimum value of the current does not reach the friction load. This is the principal reason why the obtained load curve is so much smoother than the theoretical curve of Fig. 2.

For the particular application given above, the 50 per cent compound motor proves to be a fairly good series motor regarding speed characteristics; it requires only a slight increase in load to give the speed reduction required by the fly-wheel in order that it may do the greater portion of the work. Compared with its continuous electrical capacity, this type of motor has great mechanical strength, and it is capable of standing heavy overloads for a short period of time. Thus it is apparent that both mechanically and electrically this motor has better characteristics than the motor of continuous rating for a heavier kind of work.

The curve of Fig. 5 shows the working load of a hot bloom shears driven by a direct-current, 220-volt motor of 25 per cent compounding. The general characteristics of the machine and motor are as follows:

Style of machine	horizontal bloom.
Maximum section the machine will cut	10 in. by 10 in.
Length of blade travel	15 in.
Rev. per min. of cam or crank-shaft operating blade	17 at 850 rev. per min. of motor.
Weight of fly-wheel	12,700 lb.
Diameter of fly-wheel	8 ft.
Section of fly-wheel rim	10 in. by 12 in.
Rev. per min. of fly-wheel at friction load	350
Energy of fly-wheel at 350 rev. per min.	5900 h.p. for 1 sec.
Size of motor	125 h.p.
Type of winding	25 per cent compound.
Motor	direct-current, geared.

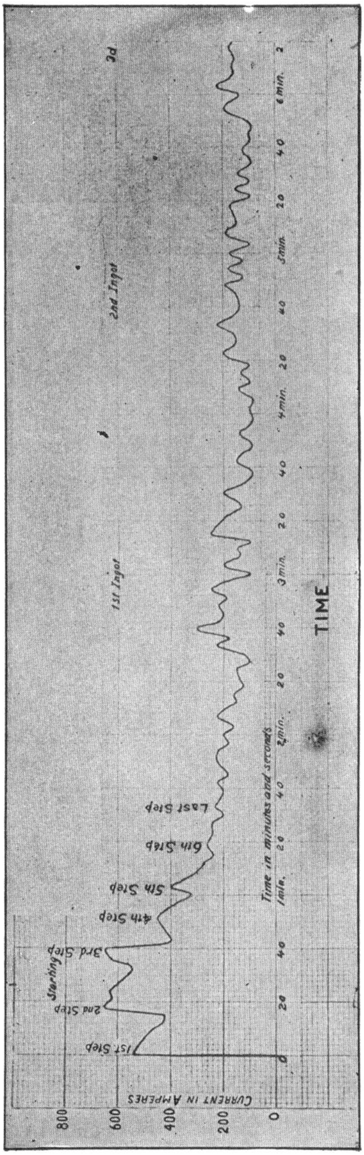
CURRENT IN AMPERES
800
600
400
200
0
1st Step
2nd Step
Starting
3rd Step
4th Step
5th Step
6th Step
Last Step
Time in minutes and seconds
1st Ingot
2nd Ingot
3d
TIME

Fig 5

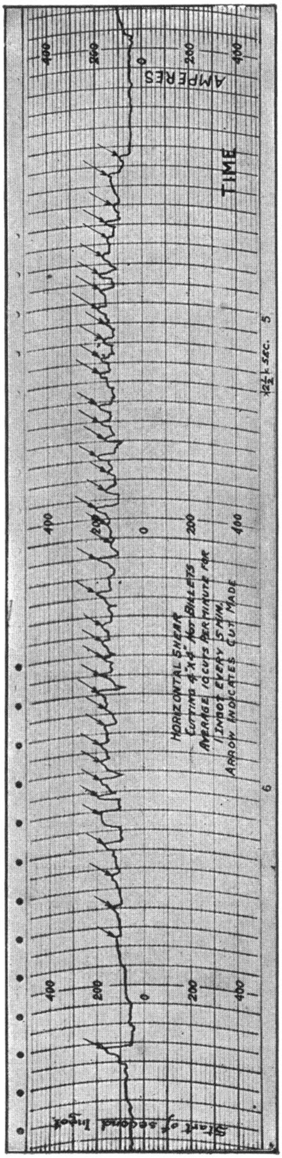
AMPERES
TIME
HORIZONTAL SHEAR
CUTTING 4"x4" HOT BILLETS
AVERAGE 10 CUTS PER MINUTE FOR
1 INGOT EVERY 5 MIN.
ARROW INDICATES CUT MADE
Start of second Ingot

Fig 7

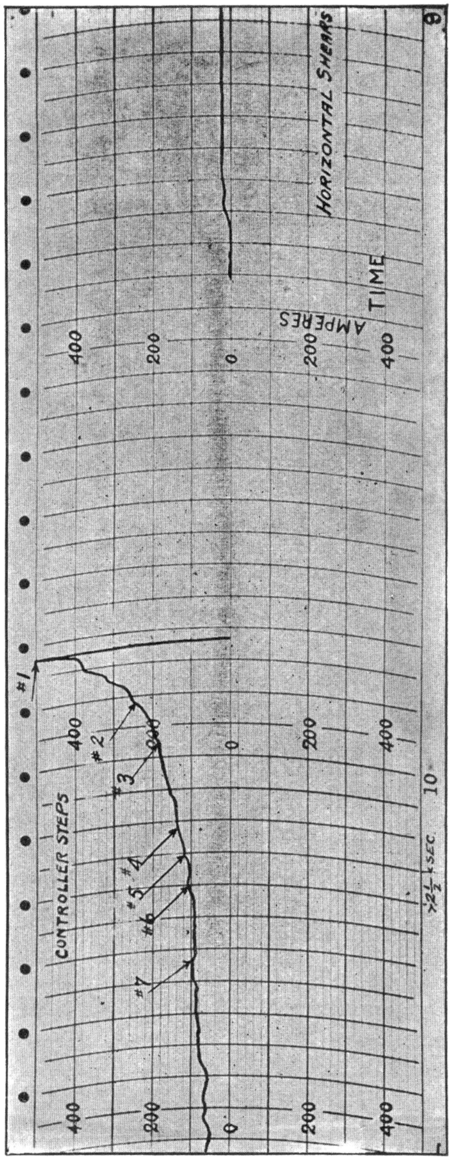
HORIZONTAL SHEARS
TIME
AMPERES
400
200
0
200
400
CONTROLLER STEPS
#1
#2
#3
#4
#5
#6
#7
10

Fig. 6

Motor speed .... 660 rev. per min. full load.
Friction load ...... 100 amperes at 225 volts, 850 rev. per min.
Cutting load .... 200 amperes, at 225 volts.
Section of material cut .... 8.5 in. by 7.25 in.
Kind of material cut .... hot steel.

When the machine is running at full speed and the power is shut off, the number of consecutive cuts that can be made before machine comes to rest is four.

The curve was plotted from readings taken at 3-sec. intervals The current reaches a maximum value of 300 amperes and is much more fluctuating than that indicated by the curve of Fig. 3, although the fly-wheel effect is more than double. With a motor of increased compounding the load fluctuation could be materially decreased.

The current would have excessive peak values with either a standard compound or shunt motor, although it has been found in some cases that for the same work done the heating effect on the standard compound motor was 25 per cent less than that on a shunt motor.

Increasing the fly-wheel capacity of the system has the same effect on the load curve as increasing the compounding of the motor, and it will consequently tend to flatten the load curve. If the fly-wheel capacity is decreased the load becomes very fluctuating, which is the same as decreasing the compounding of the motor, giving it a flatter speed curve. Fig. 6 shows the starting current and Fig. 7 the running current of a hot bloom shear driven by a motor of standard, or 15 per cent, compounding. If the fly-wheel capacity of this machine or the compounding of the motor were increased, a flatter current curve would be obtained.

Horizontal billet.

Maximum section the machine will cut .... 5 in. by 5 in.
Rev. per min. of cam or crank operating blade 28
Weight of fly-wheel .... 3000 lb.
Diameter of fly-wheel .... 5 ft. 6 in.
Section of fly-wheel rim .... 14 in. by 3 in.
Rev. per min. of fly-wheel 190
Size of fly-wheel .... 60 h.p.
Voltage of motor 220
Type of winding .... standard compound.
Motor .... direct current, belted.
Speed of motor .... 640 full load.
Cutting load .... 45 amperes at 230 volts.

Section of material cut........................4 in. by 4 in.
Kind of material cut.............................hot steel.

When the machine is running light at full speed and the power is cut off, the number of consecutive cuts that can be made before machine comes to rest is three.

Alternating-current Motors for Shears

The motors considered are designed for either 25-cycle or 60-cycle, three-phase circuits and are of the induction type. When it is necessary to start a fly-wheel type machine frequently, the motor should have a wound rotor provided with slip rings and external resistance for control. This type of motor gives very good starting conditions, as full-load torque is obtained at approximately 1.25 times full-load current as compared with 3 to 3.5 times full-load current for full-load torque with a squirrel-cage rotor.

Shears are usually operated continuously, so the starting current required is not of particular importance. It is desirable to have a motor of simple construction for continuous duty, and although some sacrifice is necessary regarding starting conditions, an induction motor with a cage secondary should generally be used for operating shears. The motor should be provided with high-resistance end-rings, as this form of construction gives very good starting conditions. As a maximum a 50 per cent increase in torque with a 30 per cent decrease in current and a 6 per cent decrease in efficiency at full load may be obtained. A second advantage in using high-resistance rings is that the motor has a speed characteristic very similar to that of a direct-current compound-wound motor, thus allowing the fly-wheel to be effective during the cutting period.

The amount of resistance that can be included in the end-rings without undue heating is limited, as this heat energy must be dissipated in the motor. Where the motor operates continuously under virtually full load the maximum slip that can be obtained with high-resistance rings is approximately 10 per cent; but for intermittent service the slip can be increased to 15 per cent without undue heating. The efficiency and power curves of the motor will be similar to those of a standard direct-current shunt-wound motor having sufficient resistance in its armature circuit to give 15 per cent drop in speed from light to full load; in other words, the slip of the motor varies according to the resistance in the end-rings. As the fly-wheel effect obtained from the system varies as the square of the speed at the high and low points during the cutting period, a slight increase in the resistance will produce a material reduction of the maximum load on the motor.

In shearing plates, the load is applied gradually and a motor with 15 per cent slip will have a fairly smooth load curve, the fly-wheel being of liberal proportions. In the cases of hot bloom and scrap shears, where the section to be cut is quite large and practically square, the nature of the work becomes more severe. The actual cutting period is short and the power required large, which makes it necessary to include large fly-wheel capacity; and in order to prevent excessive loads motor should have a steep speed-curve. In the case of direct-current work it has been shown that increasing the compounding of the motor to 50 per cent has materially improved conditions, giving in the case shown almost a uniform load curve. For induction motors, however, 15 per cent slip is a practical limit, therefore to reduce the peak load for the heavier classes of machines fly-wheel capacity must be added.

In any class of machines where the load is intermittent, especially when cast tooth gears are used in the reduction, the driving motor will be subject to considerable vibration. In many cases it is necessary to mount the motor on a frame or bracket support, although it is difficult to provide sufficient rigidity with this construction. This vibration causes undue wearing of the motor-bearings and tends to deteriorate the rotor-windings. The most effective way to prevent this vibration where gearing is to be used is to mount flexible coupling between the rotor and the driving pinion, which is keyed to a short length of shaft supported by two bearings. This form of construction has been adopted for a number of different drives where the work is very severe. It gives excellent results with little wear of the coupling parts and shows a decided decrease in motor maintenance.

The starting conditions are rather severe when the machine has large fly-wheel capacity and for shears as described above. The motor-starting apparatus should be of liberal capacity and should be provided with protective means to insure a gradual starting of the motor, thus preventing excessive starting currents. An autostarter is used for this work.

The starter consists of a double-throw, oil-immersed switch with the autotransformers mounted in the same case. Several extra taps are provided so that the most suitable starting condition can be obtained. In starting, the handle of the autostarter is first thrown to the right which closes the switch on the starting side. A lock is provided to prevent the handle from being thrown in the wrong direction, and unless held in position by hand on the starting side it will return automatically to the off position. After the motor has attained a nearly constant speed the handle is thrown quickly to the left and is locked automatically.

Fuses or a circuit-breaker may be employed to protect the motor against overloads while running, and these can be so connected that the starting current may exceed the running current without blowing the fuse or tripping the circuit-breaker.

Where there are a number of motors to be started, as in a steel mill, it is a practical arrangement to provide a single transformer centrally located for each group of motors. The transformers should be supplied with an extra tap to give approximately 65 per cent line voltage; for three-phase motors five line wires would be required for the motor feeder circuit. Thus instead of a number of individual transformers, one transformer of large capacity is used and the starting apparatus is limited to a double-throw switch.