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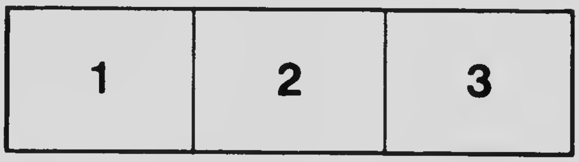
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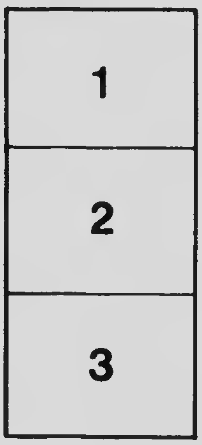
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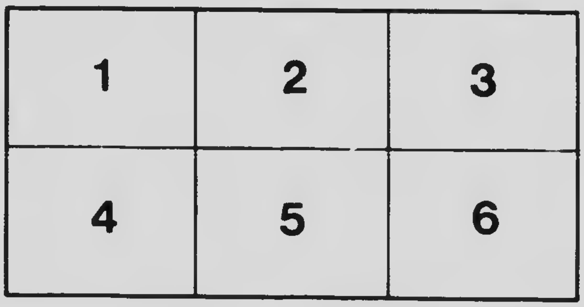
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## THE ELECTRICAL DRIVING OF WINDING ENGINES AND ROLLING MILLS

BY

C. ANTONY ABLETT, A. M. INST. C. E., AND H. M. LYONS, A.M.I.E.E.

*To be read at a Mining Section Meeting, March 12th, 1914.

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The use of electrical machinery for driving hoisting engines in mines and reversing rolling mill plants in steel works is comparatively recent, the first winders of importance having been introduced in 1902, and the first electrically driven reversing rolling mill being installed in 1906, though non-reversing rolling mills were driven electrically some eight or ten years earlier.

The developments along these lines have been extremely rapid, as is shown by the fact that at the present time about one thousand large winding engines and nearly sixty reversing rolling mills are being driven electrically, and still greater developments may be expected in the future.

Under these circumstances a paper dealing with the modern aspects of the subject and giving the results of the experience obtained in the past would appear desi ower ma

The earlier winding engines were extravagant in power and had the disadvantage of drawing ver heavily upon the source of electrical supply at the moment of starting. It was, therefore, impossible to use them on systems where the supply of current was limited, and even on comparatively large plants their use resulted in serious interference with other machinery. These disadvantages were, however, practically done away with when the

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*This paper has also, by special arrangement, been communicated to the Canadian Mining Institute.

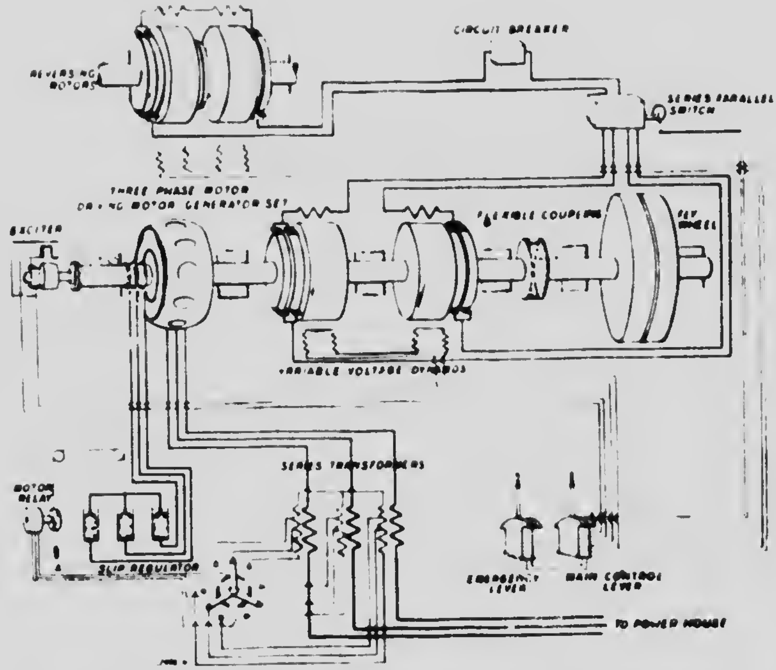


Fig. 1 Diagrammatic view of Ilgner system of driving winding engines or reversing rolling mills.

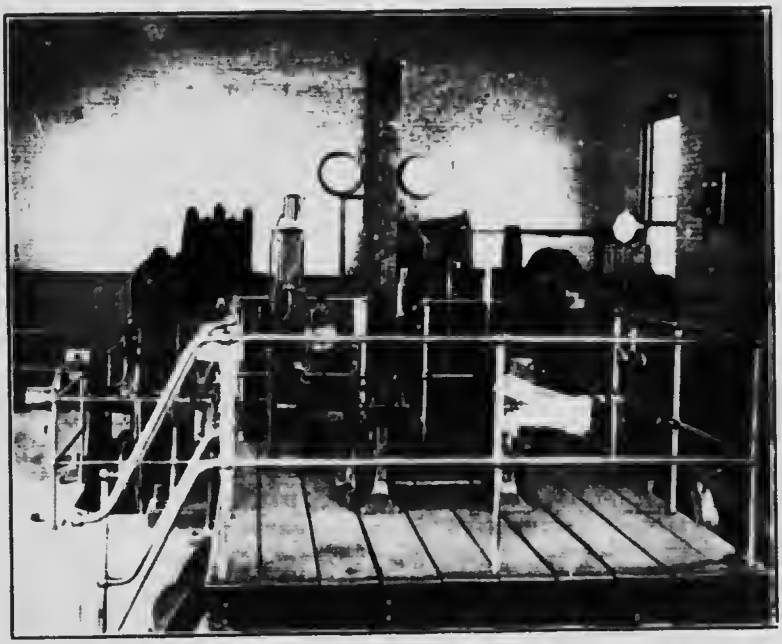

Fig. 2 Ward Leonard hoist at the Dominion Coal Company's Lingan Pit, showing control levers and depth indicator.

Ward Leonard system and Ilgner's adoption of the flywheel to this system were introduced, but the last few years have seen greater improvements in the Ward Leonard and the Ilgner system.

The present paper will deal chiefly with the developments of these systems by the various Siemens Companies, who have installed about half the total plants in existence, and with whom the authors have the honor to be associated.

The illustrations accompanying this paper comprise numerous diagrams which are essential to it, and are referred to in the text, and reproductions of photographs which, though not definitely referred to in the text, serve to illustrate the application of the principles referred to therein.

## WARD LEONARD SYSTEM

### Introductory Remarks

A short description of the so called Ward Leonard System, illustrated in Fig. 1, is desirable as an introduction.

In this system a direct current motor is used to drive the winding engine or rolling mill, the motor being supplied with power from a direct current dynamo, and the essential feature of this system is that the voltage supplied to the motor, and consequently the speed of the motor, is controlled by controlling the field current of the generator, instead of by varying the resistance in the armature circuit of the motor.

Thus, as the field current of the generator is increased from nothing to a maximum, the motor speeds up from standstill to full speed, and if the field current of the generator is reversed, the motor reverses its direction of rotation.

This system enables a very exact control of the speed to be obtained, because the speed of the motor is practically proportional to the strength of the generator field, whatever the load on the motor may be, while with any control system where resistances are inserted into the armature circuit of the motor, the speed would vary within very wide limits with a change of load, rendering the exact speed control quite impossible.

The control of the dynamo field involves scarcely any waste of electrical power, but where resistances are inserted into the armature circuit the loss of power may be, and usually is, very great.

The field currents of the generator are small, so that the control mechanism is small, compact and very easy to handle, the armature currents are perhaps fifty times as great, so that any control mechanism which varies the resistance of the armature circuits is large, clumsy and difficult to handle, in fact a complicated relay system is often necessary to enable it to be handled at all.

The dynamo used to supply the motor in the Ward Leonard system is usually driven by a motor supplied from the available power

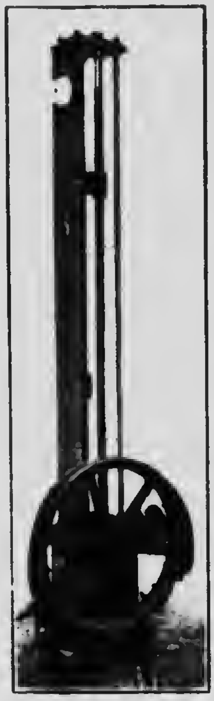

Fig. 3 Depth indicator for Ward Leonard or Ilgner hoist, showing cams for limiting acceleration and deceleration, and showing cage before it reaches the bank.

Fig. 4 Diagrammatic view of Ward Leonard or Ilgner control and brake gear for a winding engine.

circuit, forming a motor generator set, and this motor may be either direct current or three-phase, according to the power available. The dynamo may be and sometimes is driven by an engine, water turbine, or other prime mover, if this happens to be more convenient.

## Application of Ward Leonard System to Winding Engines and Hoists

### *Speed Control*

The main control lever for operating the winding engine is coupled to the regulating resistance in the field circuit of the generator, so that when this lever is in the mid position there is no current in the generator field. As the lever is moved in one direction the generator field current increases, and as it is moved in the other direction the generator field current is also increased, but in the opposite sense.

From what has been said in the introductory remarks it will be seen that when the lever is in the mid position, the winding engine is at a standstill, and that it starts and speeds up as the lever is moved from the mid position in one direction, while if the lever is moved from the mid position the other way the winding engine increases in speed in the other direction, and that the speed of the winding engine is practically proportional to the displacement of the lever from the mid position, and is not affected by the weight of material being hoisted.

The driver has not absolute control over the speed, for two cams are provided on the depth indicator, one for each cage, which operate levers coupled to the control lever in such a way as to prevent the cages being accelerated at too rapid a rate, and to slow up the winding engine at the proper point so that the bank is approached at a crawling speed.

Provided that these limits set by the cams are not exceeded the speed of the wind is entirely within the driver's control.

To slow up the winder and bring it to a standstill, the control lever is brought back toward the mid position, thereby reducing the field current of the generator, and reducing its voltage below the voltage of the winding motor, so that the current between the motor and the generator reverses and the winding motor gives back power to the generator, thus producing a strong electric braking effect. The more rapidly the lever is moved backwards towards the mid position the stronger the electric braking effect will be.

The kinetic energy of the moving parts of the winder is converted to electrical energy and returned to the system. The lever may be brought toward the mid position to produce this electric braking effect, either by hand or automatically by the cams, as mentioned above.

The depth indicator and the cams are positively driven from the drum of the winding engine and the cams are so geared that they make less than one revolution per wind. (Figs. 3 and 4.)

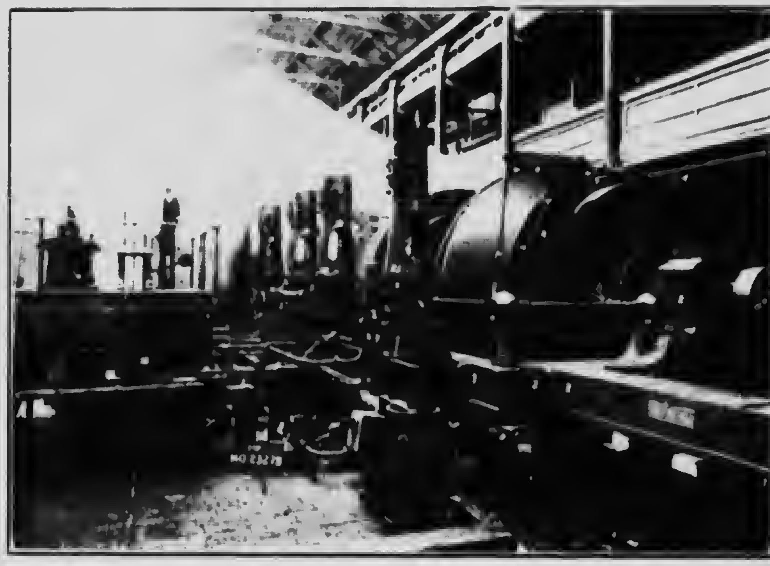

Fig. 5 Conical Drum Ward Leonard winder, at the Canadian Collieries Company's Cumberland Colliery, showing brake gear and control levers. Depth, 1 000 feet; nett load per wind, 3½ tons.

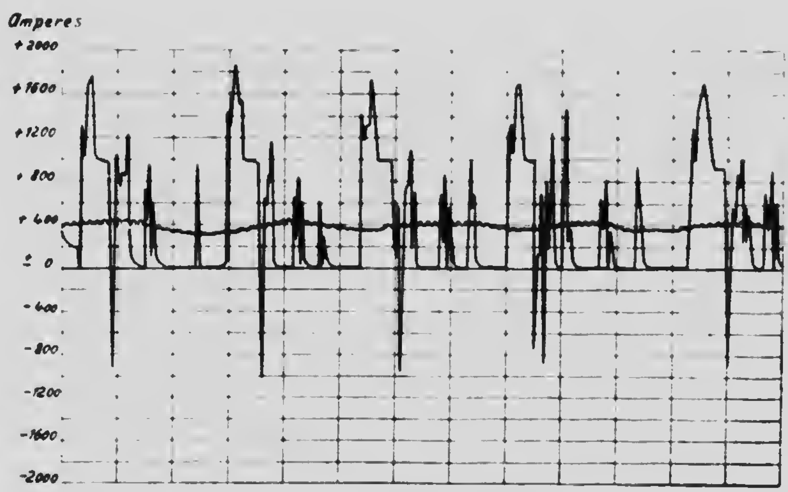


Fig. 7 Diagram showing the equalizing effect of the flywheel on Ilgner's adaptation of the Ward Leonard system. The wavey line at about 400 amperes is the current taken from the supply system. The curve which shows the great variations represents the current taken by the winding engine.

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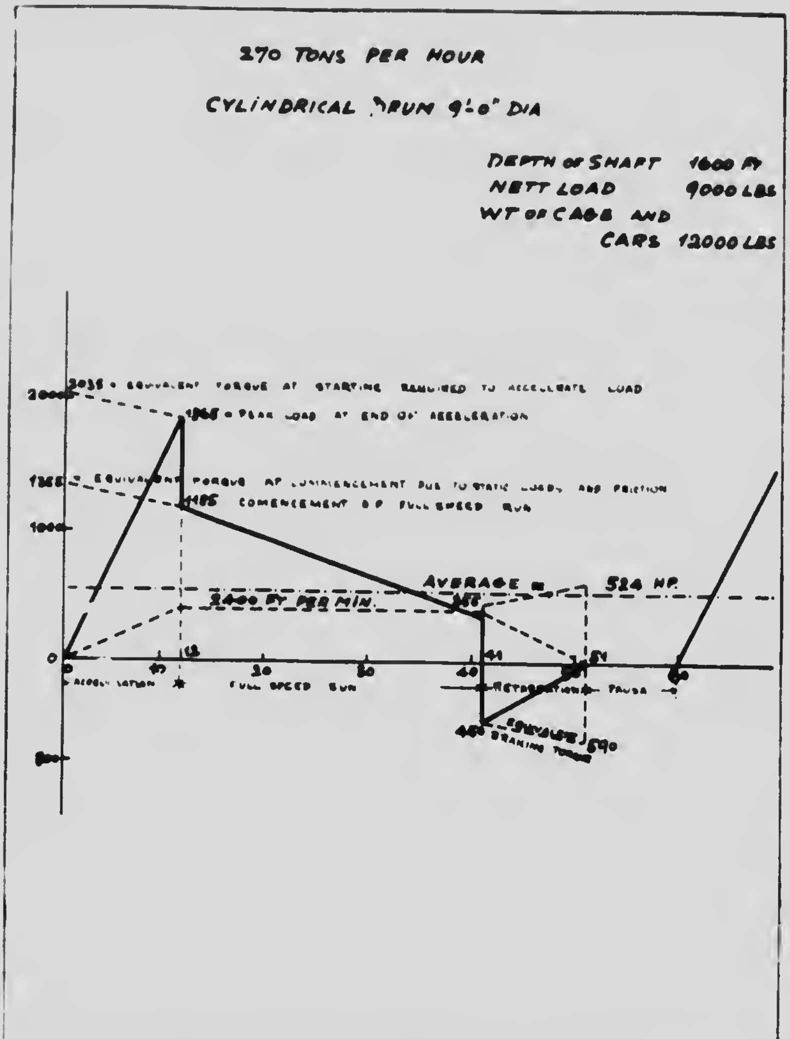


Fig. 6 Typical power diagram for a Ward Leonard winding engine.

### Use of Flywheel

Fig. 6 shows the typical horse power diagram for a winding engine. The inertia of the drums, cages, head sheaves, material wound, and the ropes, which altogether weigh about 60 tons in this particular case, necessitates a horse power at the end of the acceleration period of each wind of 1865, which is about three and a half times the average power demand of the winding engine, in this case 524 horse power, and it is found that the maximum acceleration peak is usually between three and four times greater than the average demand.

The consumption of energy for this Ward Leonard control rises gradually during the starting period, and the maximum is only reached at the end of the time of acceleration, i.e., from ten to fifteen seconds after the start, because the speed of the winding motor is increased while it is giving the requisite turning moment by increasing the field of the generator, and consequently there is no loss of power in starting.

Since this acceleration peak is of short duration and only comes on gradually, it [illegible] possible to supply Ward Leonard winders from power stations of comparatively small total output, provided that the machines in the power station have a sufficient overload capacity to maintain their speed during peak loads, as is usually the case with steam turbo generators where the generators are provided with modern voltage regulators.

Where, however, this is not the case, and the acceleration peaks of the winding engine are large compared with the average demand on the power station, or where the winder is supplied through a long transmission line from a distant power station, it is sometimes necessary to couple a flywheel to the motor generator set.

In this case provision must be made so that during a peak load the motor generator falls in speed, enabling part of the stored energy of the flywheel to be used to supply the heavy demand, and when the load is small the motor generator set is speeded up again, the surplus power being taken to restore the energy of the flywheel, so that the demand from the power house or supply system is maintained at about the average.

This is the Ilgner system, so-called after the engineer who first used it in practice.

Fig. 7 illustrates the effect of the flywheel in equalizing the load taken by the winder, where it will be seen that the current taken by the winding motor varies between + 1900, and − 1000 amperes, while the current taken from the supply system is maintained practically constant at 400 amperes, the maximum voltage supplied to the winding engine and the supply voltage being the same.

Three-phase motors are usually used to drive the motor generator sets supplying winding engines and their speed can only be conveniently varied by inserting resistances into the rotor circuits, which causes a loss of power. In addition to this a certain power is required to drive the flywheel to overcome the friction and windage loss, so that while the use of the Ilgner system prevents peak loads being taken from the supply system or power house, it entails a certain loss of power.

In many cases the cost of this loss of power which is justified by the benefit of the steady load to the supply system, which improves the economy and voltage regulation of the power house, may avoid the installation of extra plant in the power house, or where the winding engine is being supplied through a long transmission line, will enable a cheaper transmission line to be used than would otherwise be the case, and will improve the voltage regulation of this transmission line.

The following example will give an idea of the power taken by the Ilgner system under practical working conditions with a winding engine arranged to wind 240 tons per hour from a depth of 1960 feet, making as a maximum $14\frac{1}{2}$ winds per hour, where the flywheel is used whenever the full output is being wound at the full speed, but where a lesser output is being wound at reduced speed, so that the acceleration peaks become less serious, the flywheel is uncoupled to save power.

These results are conveniently expressed in terms of the kilowatts taken by the electric winding engine plant per shaft horse power.

| | Output in tons per hour | Kilowatt per Shaft Horse Power. |
|---|---|---|
| With Flywheel | 240 | 1.49 |
| " | 160 | 1.60 |
| " | 108 | 1.77 |
| Without Flywheel | 160 | 1.35 |
| " | 108 | 1.48 |

It will thus be seen that when working the winding engine on the Ilgner system there is an increased loss of power of from 16% to 17%, as compared with the Ward Leonard system, and naturally with the latter where the flywheel is uncoupled the resistances are cut out of the rotor circuit of the three-phase motor to avoid loss of power.

To avoid misunderstanding of the above results, it should be specially pointed out that shaft horse power is taken to mean the actual work done in raising the load, i.e., if the actual weight of coal or ore, expressed in lbs, which is raised per minute is multiplied by the depth of the shaft in feet, and divided by 33,000, the shaft horse power is obtained. The shaf horse power thus does not include the mechanical friction of the windin engine, the sheaves, the guides or the rope losses, and the figure of th kilowatts divided by the shaft horse power brings in the mechanica efficiency, as well as the electrical.

*Details of Ilgner System*

To enable the speed of the motor generator set to be automaticall reduced so that the flywheel may give up part of its stored energy the three-phase motor of this motor generator set must be of the sliprin type. The sliprings are connected to the automatic or intermitten slip regulator which inserts resistances into the rotor circuit when the spee is to be reduced.

This slip regulator usually consists of liquid resistances in whic are immersed plates connected to the sliprings, and it is operate by means of motor relay supplied by current from a series transforme connected in the circuit of the main three-phase supply, so that when th speed is to be reduced, the immersion of the plates is decreased, increasin the resistance between them, and when the speed is again allowed to rise immersion of the plates is increased.

The series transformer is usually supplied with tappings connecte to a dial switch so that the average load maintained by the slip regulato can be adjusted to the work which is being done by the winding engine. A typical slip regulator is shown diagrammatically in Fig. 1.

Flywheels are usually designed to equalize the load by falling in spee from 15 to 20%, and it is found that this entails a loss of power in the slip regulator of about 7½% to 10%.

The flywheel is usually coupled to the motor generator set by means of flexible coupling, though in some very recent Ilgner motor generator sets, where there happens to be no advantage in running with the flywheel uncoupled, the electrical machines and the flywheel are arranged to be carried by two bearings only, reducing the first cost and the friction losses.

Of recent years the capital cost of Ilgner plants has been greatly reduced, owing to the adoption of higher speed for the motor generator sets and to the improvements in the manufacture of such flywheels, which enable them to run at very high peripheral speeds compared with those used in the earlier winding engines.

For example, the provision of flywheel capacity to equalize peak loads of 60,000 horse power seconds, in the early days of Ilgner winding, where peripheral speeds of 15,000 feet per minute were used, would require two flywheels of a total weight of about 80 tons, the friction and windage loss of which would be about 150 horse power. Under modern conditions where the regular peripheral speeds are 27,000 and 30,000 feet per minute a single flywheel of 22 tons weight would be used, instead of the two flywheels having a total weight of 80 tons, and the friction and windage losses would not exceed 100 horse power.

A sheet metal casing is usually placed outside the rims of the flywheel to reduce the windage loss of the flywheel to a minimum, and this is found to be sufficient for the purpose, because practically all the windage loss is caused by the outside surface of the rim, the web producing very little windage. This can be shown in a striking manner by holding a handkerchief against the web near the inner surface of the rim while the flywheel is running, there being scarcely enough wind to blow the handkerchief out.

The Ilgner system was used on practically all the early European winding engines, but as at the present day power stations are being installed of much greater capacity than those of a few years ago, and high speed turbo generators of large overload capacity are being adopted, the Ward Leonard system at the present time is being used to a much greater extent than the Ilgner system for winding engine work.

Generally speaking, the Ilgner system of winding may be preferable to the Ward Leonard system in the following cases:

(1) When the time occupied by the wind is short.
(2) For vertical shafts.
(3) For large outputs.
(4) Where the winding speed is very high.

The above conclusions may be considerably modified by the nature of the electrical supply. Where the power station is small or the winder is supplied through a transmission line of considerable length, the Ilgner system will be more suitable, but where the power station is large and near the winder, the Ward Leonard system is the better.

Where power is being purchased from a Supply Company the choice of system would be very greatly influenced by the method of charging adopted by the Supply Company and by their regulations as to the permissible overloads and the amount of disturbances which they will permit to the regulation of their system. It is always advisable to consider each case on its own merits.

Where there are a number of winding engines supplied from the same power station the Ward Leonard system would prove very suitable, because the combined effect of these winding engines working together will be to reduce the percentage of fluctuations on the power station load.

Fig. 8 gives an illustration of this principle, and shows a case where three rolling mills are supplied from a single power station, and although the load of each one varies about 73%, the total fluctuation in the power station load is about 28%.

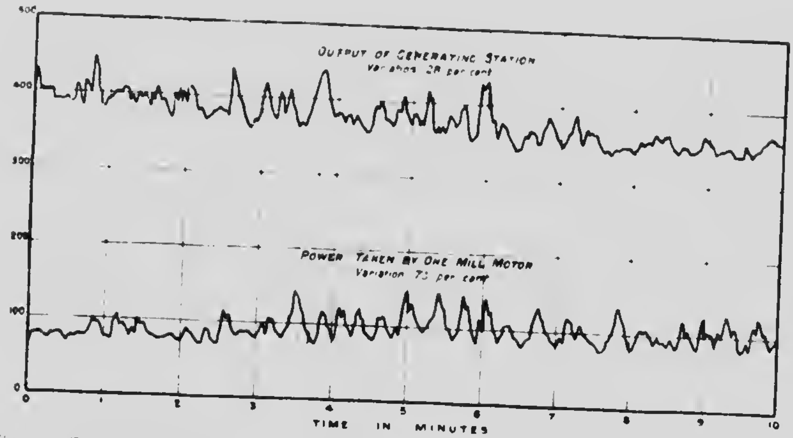


Fig. 8. Test results, showing the natural balancing effect on the generating plant of three rolling mill motors whose power varies considerably.

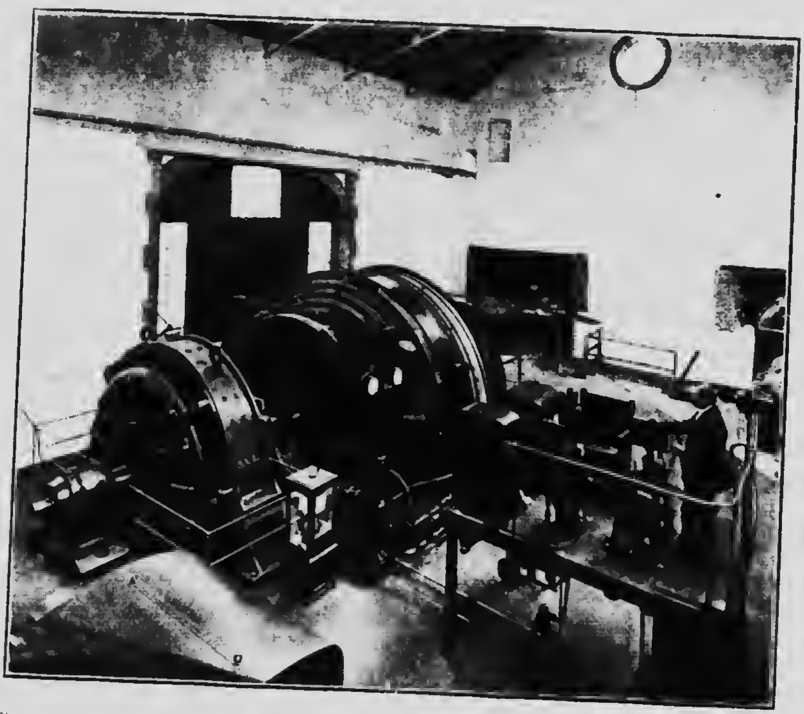

Fig. 9.—Scroll Drum Ilgner winder at the Markham Steam Coal Company's Holly Bush Colliery, showing control gear, brake gear, depth indicator, and cams.

### *Brake Gear*

The mechanical brake is so arranged that when it is required to bring it into action it is actuated by a weight at the end of a lever, but it is normally held off the drum by an air cylinder.

Under normal conditions the cams on the depth indicator actuate the control lever, so that the cages approach the bank at a very slow speed. When they reach the bank the driver brings them to rest by means of his control lever, and then puts on the mechanical brake to hold the cages in position by means of the brake lever. The brake lever is interlocked with the control lever, so that the driver cannot put on the brake by means of the brake lever until the control lever is at about its middle position, i.e., unless the cages are moving at a comparatively slow speed.

To enable the driver to stop the winder in case of any emergency arising, a third lever, the emergency lever, is placed on the driver's platform and if this is operated it puts on the mechanical brake through the emergency gear and at the same time cuts off the excitation from the dynamo of the motor generator set. A throttle valve is fitted to the air cylinder to prevent the air from escaping too rapidly, so that if the mechanical brake is put on through the emergency gear it takes a second or two to apply it with full force, and damage would not be caused by the winding engine being pulled up too rapidly.

### *Safety Devices*

From what has been said above, it will be seen that the brake is applied by the positive action of the weighted lever, and if the air pressure should fail the brake is promptly put on. The armatures of the winding motor and the generator are permanently connected by heavy cables, and there are no cut-outs or switches in this circuit, so that the circuit between the armatures cannot be interrupted; electrical braking is always available as well as the mechanical brake, unless the excitation should fail.

To protect the electrical machinery and the winding engine against undue overloads an overload relay is connected in this circuit between the armatures, which if brought into operation cuts off the excitation from the dynamo and puts on the mechanical brake through the emergency gear.

As mentioned above, cams are provided on the depth indicator which keep the acceleration within safe limits, and the cage is brought gradually to a slow speed by the time it reaches the bank. An overwind device is provided, usually both on the depth indicator and in the shaft, which puts on the mechanical brake through the emergency gear and cuts off the excitation should the cage overwind the bank, thereby bringing the winding engine instantly to a stop. Should the air pressure or the excitation fail, the mechanical brake is put on by means of the emergency gear.

If the motor generator set should speed up when a load is being lowered and energy is being returned to the system by the winding motor, either

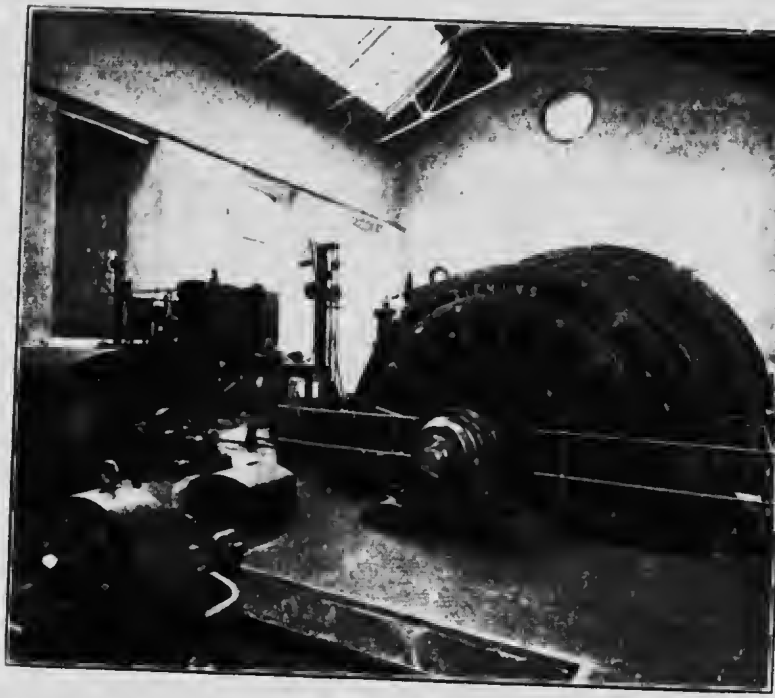

Fig. 10 Direct current winding motor at the Markham Steam Coal Company. Depth of wind, 1,800 feet. Nett load per wind, 3½ tons. Maximum winding speed, 2,900 feet per minute. Motor, 1,400 horse-power, at 51 r.p.m.

Fig. 11 Ilgner flywheel motor generator set supplying the two winders at the Markham Steam Coal Company. Consists of two flywheels, two variable voltage D.C. generators driven by two three-phase motors, each 660 horse-power, 510 to 590 r.p.m. on 6,600 6,000 volt, three-phase, 50 cycle circuit.

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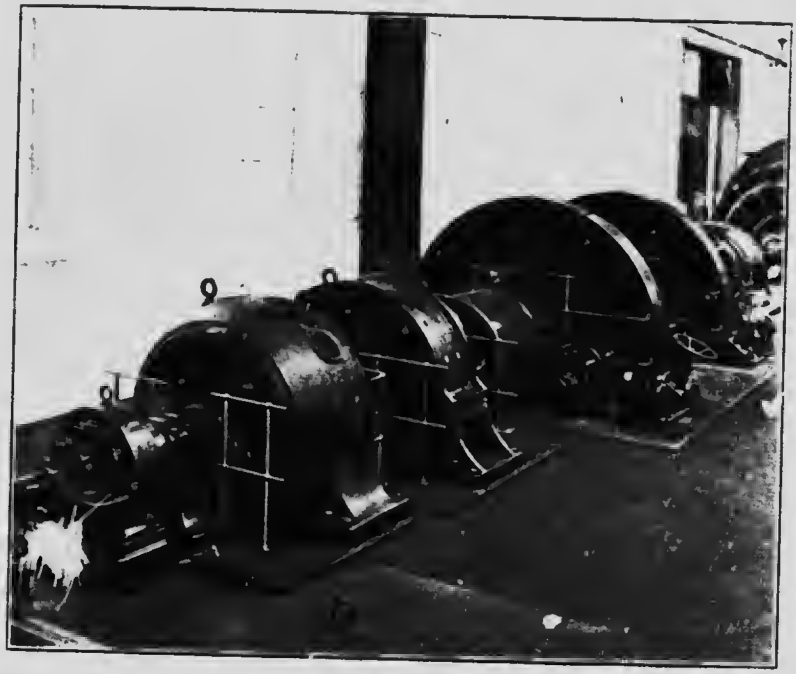

Fig. 12 Ilgner flywheels at the Markham Steam Coal Company's plant, showing brake gear and oil pumps. Each flywheel is 10 feet 6 inches diameter weight, $8\frac{1}{2}$ tons.

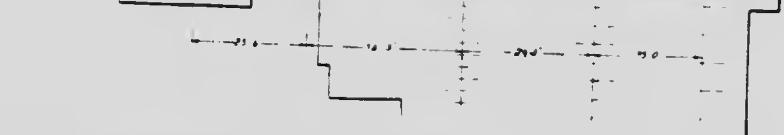

Fig. 14 General arrangement of the reversing rolling mill and electrical plant at Skinningrove Iron Works.

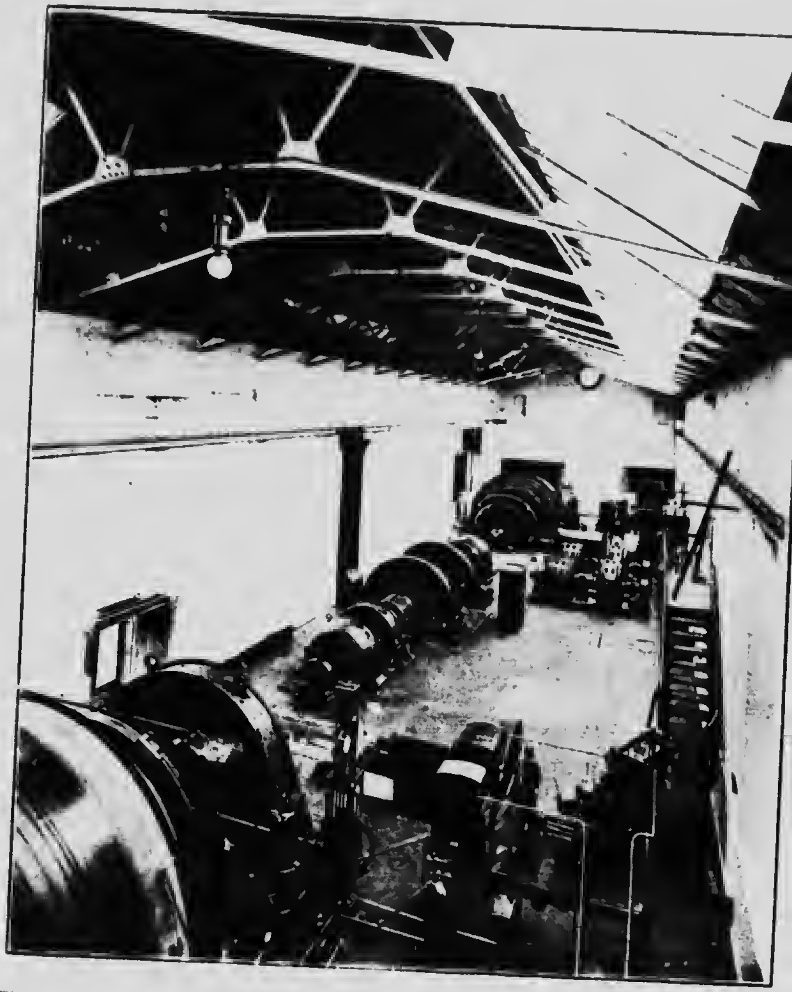

Fig. 13 General view of the winding engine plant at the Markham Steam Coal Company's plant, showing both winding engines.

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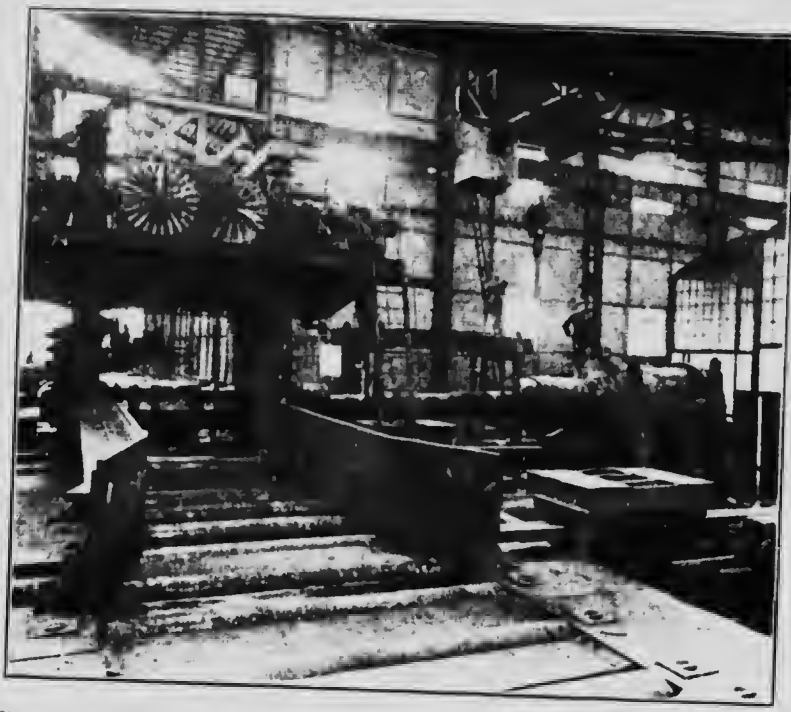

Fig. 15—General view of 36-inch electrically driven reversing blooming mill at the Skinningrove Iron Works.

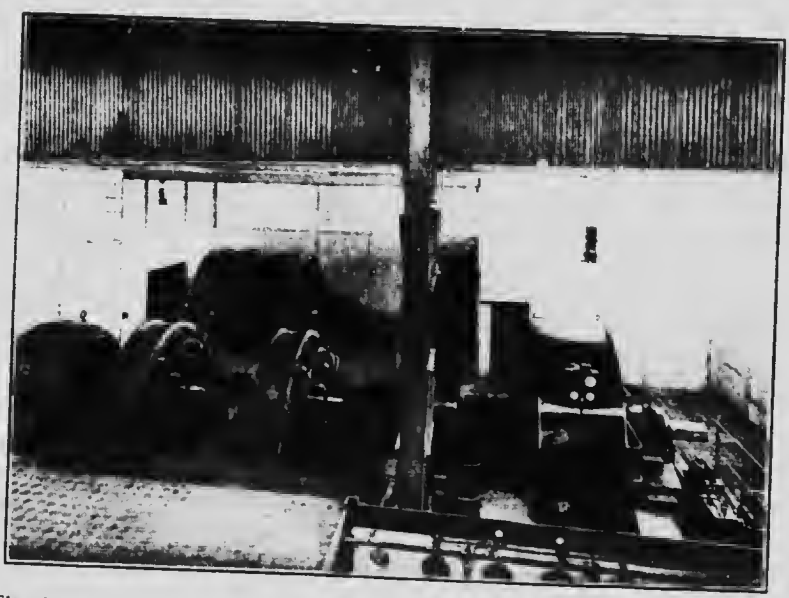

Fig. 16—General view of the electrical plant for driving a 36-inch reversing blooming, roughing and finishing mill at the Skinningrove Iron Works. The 12,000 horse-power reversing motor will be seen in the background. The Ilgner motor generator set is in the foreground, consisting of a three-phase motor, two variable voltage dynamos and a 46-ton flywheel.

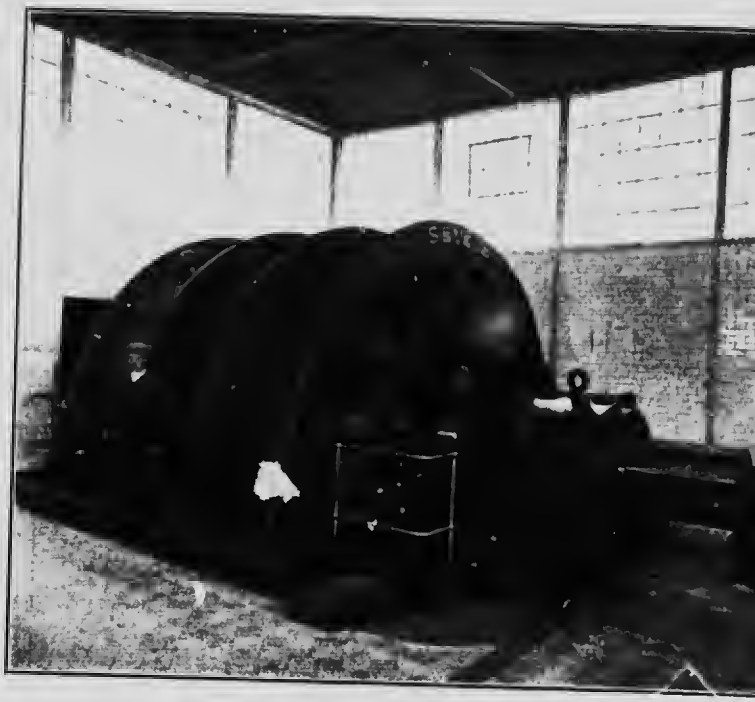

Fig. 17—A reversing rolling mill D.C. motor at Skinningrove, 12,000 horse-pow
at 60 r.p.m., maximum speed, 120 r.p.m. Total weight about 200 to
Weight of revolving parts 72 tons.

owing to the circuit breaker in the supply system coming out or to the demand for power from the system being insufficient to absorb the energy being returned to the system by the winding engine, then the excitation is cut off and the mechanical brake is put on through the emergency gear.

When men are being wound the throw of the main control lever is limited by means of a switch on the bank, so that the winding engine cannot be run above a certain speed.

Where electrical driving is adopted it is very easy to provide safety devices, and all those mentioned are designed to protect the plant against careless handling, but if the majority of safety devices were dispensed with, the Ilgner and the Ward Leonard winder would still be better protected against careless handling than the steam winder. The fact that it is impossible for an Ilgner or a Ward Leonard winder to race or run away makes it inherently safer than the steam winder.

horse-power,
out 200 tons.

### Application of Ward Leonard System to Reversing and Three High Rolling Mills

Nearly 60 large reversing mills are being driven electrically in different parts of the world and a modification of the Ward Leonard system has been installed in almost every case to meet these special requirements.

The power requirements of a reversing rolling mill impose much more severe conditions on the electrical plant than those of a large electrically driven hoist. With a large 36-in. or 45-in. blooming mill, ten to twelve passes are often made in a minute, and the power during individual passes may rise to 12,000 H.P. or more, while the total time of the passes, i.e., the total time that the ingot is between the rolls, is very short compared with the total time taken to roll an ingot down to a bloom or billet. It is thus easily seen that the average power required from the power station is very much less than the maximum power which the mill motor has to give.

For example, in many electrically driven blooming mills, the average power is only one-sixth or one-seventh of the maximum power.

The diagrams in Fig. 18, in which the triangular or rectangular spaces show the work done per pass, illustrate how small the average power is, compared with the maximum power which has to be given by the mill motor.

In the case of an electrically driven hoist, the duration of a wind would be perhaps one minute, followed by a pause of 20 seconds or so, and the maximum power required seldom exceeds 3,000 to 4,000 horse power, so that the average power is of the order of one-third of the maximum power. While, as has already been pointed out, it is frequently necessary to employ flywheels with winding engines it is always necessary to couple a flywheel to the motor generator set which supplies a reversing rolling mill motor, and to make provision so that the motor generator set falls in speed when the mill motor requires a heavy power to enable the flywheel to give up some of its power, and then rises in speed again when mill motor is not requiring power, thereby using the supply of the po house to store up energy in the flywheel.

Experience has shown that in a steel works where electrical pow being generated in a blast furnace gas engine power station, the flyw of the motor generator set has a very beneficial effect in keeping down cost of this power station.

The flywheel of the motor generator set can be arranged so tha not only reduces fluctuations in the demand of power made by the motor to a minimum, but is also capable of reducing or even obvia peaks of short duration in the power demand, which may occur in o parts of the plant which are supplied from this power house. Thi particularly the case where direct current power is being supplied.

As the blast furnace gas engine has a very small overload capa this will obviate the necessity of running extra generating sets in orde take care of the peaks, and it will, therefore, both enable the total insta horse power of the power house to be kept to a minimum, and will also down the running costs.

A reversing rolling mill motor, on account of the rapidity with whi has to reverse, must be so designed that its moment of inertia is kept d to a minimum and special precautions must be taken to see that the of the generator supplying this reversing motor should build up as rapid possible. This has been accomplished so successfully that it has found possible to reverse a large reversing mill motor having rotating p weighing over 70 tons, 30 or 40 times per minute between a speed o revolutions in one direction and 60 revolutions in the other, when no is being rolled. Such tests naturally cannot be made while steel is b rolled because it would be quite impossible with the present type of roller tables to return the ingots to the mill quickly enough, but such are useful in showing the very high rate of acceleration of the mill m which can be obtained, and as a measure of the handiness of the mill.

### *Power Diagram for Reversing Blooming Mill*

Under ordinary conditions the power diagrams for each wind of a are identical and can be calculated with considerable exactitude fron conditions of working, but with a rolling mill the power diagrams for pass vary very greatly from one another, and cannot be calculated any accuracy, for the following reasons.

During the earlier passes heavy drafts are taken but the ingot is short, consequently large powers are required for very short times; b the ingot is gradually rolled out to a bloom of considerable length reduced in section the drafts are diminished, as the reduction in area be kept moderate, otherwise the bloom is damaged by the formatio surface cracks etc., so that during the last passes the necessary power i very great, but it is required for a considerable time. This is shown by results of the test given in the following table.

| No. of pass | Groove No. | Length of Ingot | Thickness of Ingot | Breadth of Ingot | Max. Speed of rolls r.p.m. | Turning Moment, Ft. tons | Time of Pass, Secs. | Interval between Passes, Secs. | Total time of Pass, Secs. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 6′ 1″ | 18.2″ | 18.2″ | | | | | | |
| 1 | I. | 6′ 8″ | 18.4″ | 15.2″ | 28.7 | 355 | 2.5 | 3.75 | 6.25 | |
| 2 | I. | 7′ 5″ | 18.6″ | 13.1″ | 31.0 | 350 | 3.0 | 8.0 | 11.0 | |
| 3 | II. | 8′ 7″ | 13.3″ | 15.4″ | 28.9 | 420 | 3.0 | 4.0 | 7.0 | |
| 4 | II. | 9′ 9″ | 13.5″ | 12.9″ | 31.8 | 315 | 3.25 | 6.25 | 9.5 | |
| 5 | II. | 11′ 3″ | 13.1″ | 11.4″ | 33.1 | 335 | 3.75 | 4.0 | 7.75 | |
| 6 | II. | 13′ 9″ | 13.4″ | 9.15″ | 36.9 | 328 | 3.75 | 7.75 | 11.5 | |
| 7 | III. | 15′ 5″ | 9.4″ | 11.6″ | 39.0 | 244 | 4.0 | 5.0 | 9.0 | |
| 8 | III. | 19′ 0″ | 9.6″ | 9.2″ | 39.3 | 273 | 4.25 | 9.0 | 13.25 | |
| 9 | III. | 21′ 0″ | 9.5″ | 8.5″ | 41.2 | 158 | 4.75 | 3.75 | 8.5 | |
| 10 | III. | 24′ 1″ | 9.7″ | 7.2″ | 41.2 | 168 | 5.5 | 14.5 | 20.0 | |
| 11 | IV. | 30′ 1″ | 7.5″ | 7.5″ | 46.0 | 184 | 6.5 | 3.5 | 10.0 | |
| 12 | IV. | 38′ 8″ | 7.7″ | 5.6″ | 47.2 | 220 | 6.75 | 5.75 | 12.5 | |
| 13 | V. | 58′ 4″ | 5.9″ | 4.8″ | 44.5 | 210 | 10.25 | 11.25 | 21.5 | |
| 14 | VI. | 77′ 0″ | 5.1″ | 4.2″ | 47.6 | 128 | 10.75 | 4.5 | 15.25 | |
| 15 | VII. | 91′ 8″ | 4.5″ | 4.0″ | 48.5 | 79 | 13.25 | 10.5 | 23.75 | |

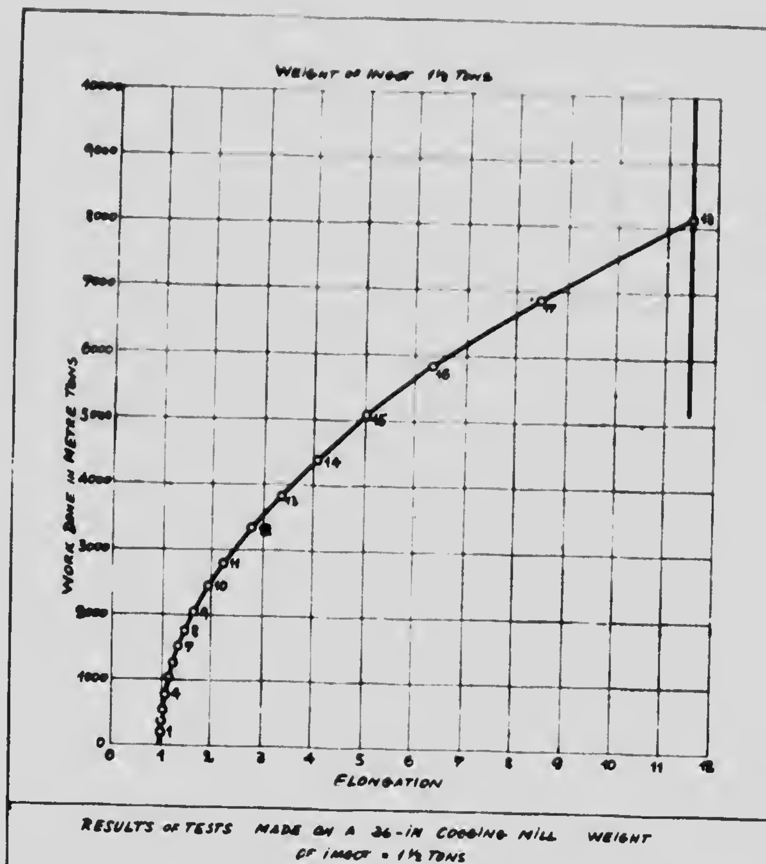


Fig. 19 Typical parabolic curve of work done in rolling down an ingot.

The above table of figures represents one of the first ingots which was rolled in a new mill, and while the table of results serves to illustrate the remarks made above, a close inspection will show that the men were not well used to the mill, as the drafts taken were somewhat irregular and the time taken to handle the ingot between passes, particularly where the ingot had to be tilted, was considerable, compared with normal working conditions.

It will be noticed in the table that the maximum peripheral speed of the rolls is only about 575 feet per minute. Billets are now being finished in this mill at a peripheral speed of over 1,000 feet per minute.

During the first two or three passes the ingot still has its tapered shape and the metal is very spongy in character, so that the powers required are not very heavy and are very irregular. By the time that the last passes are taken the bloom has cooled down considerably and while this cooling increases the specific power required, such drafts are taken that the power required for these passes remains much less than that for the first passes.

In a blooming mill the draft in each pass is regulated by screwing down the rolls, which brings in a personal element, so that it does not follow that the power diagrams for the rolling down of successive ingots resemble one another very closely, and in addition ingots do not always come to the mill at the same temperature, which also brings in variations in the power diagrams for successive ingots.

It will be seen that in the design of the electrical drive for reversing rolling mills, experience and judgment play a larger part than calculation, and in any case a good margin should always be allowed to ensure that the mill is not underpowered.

Many tests have been carried out on electrically driven reversing mills to obtain data for the work done in rolling the various sections, and such results are usually plotted out with the elongation of the ingot as the abscissa, and the work done as the ordinate, yielding a parabolic shaped curve, Fig. 19 being a typical curve.

Experience has shown, however, that such data should always be accepted with caution, for even where tests are made on the same mill, rolling the same material under conditions which are as similar as it is possible to reproduce in practice, considerable differences are found in the work which has to be done in rolling down the ingots, because the slight differences in the speed of rolling, in the time taken between passes etc., which cannot be avoided in practice, have a considerable effect on the results obtained.


an ingot.

*Action of Flywheel*

There is a great difference between the behaviour of the flywheel coupled to the motor generator set used for driving a hoist, and that used for driving a rolling mill. In the case of a hoist where the power diagrams for each successive wind are almost identical, and about an equal period

elapses between each wind, the flywheel gives up power during a w
regains it during the interval, thus serving to equalize the power l
individual winds and intervals. In the case of a rolling mill, and part
a blooming mill, the flywheel has to do a double duty, because dur
first passes made on an ingot the mill motor has to give a large
for a very short time as the ingot is short, so that the energy consu
during the earlier passes is much less than the energy consu
during the later passes, where, although the power given by the
is not so great, the ingot has been rolled out to a considerable
so that a very considerable energy is required per pass. The fly
therefore, has to give up energy during the passes and regain it dur
interval between passes, and also the flywheel gains energy duri
first passes of an ingot and loses energy during the later passes, so t
speed variation has a double period, namely, a short period of abo
10 seconds, corresponding to the partial equalisation of power b
the pass and interval, and a long period of about 3 minutes, corresp
to the equalisation of power over the whole time of rolling an ingot.
is shown in the lower curve of Fig. 20.

Where ingots are being rolled regularly one after the othe
flywheel, in consequence of this, is at about its lowest speed when
ingot enters the rolls. When the ingot is about half rolled down the
is at its maximum, and the flywheel is again at its lowest speed wh
ingot has been rolled down to its final section.

As the flywheel used in connection with a rolling mill has to eq
the power over a period of three minutes or so, it is usually found that
flywheels are much heavier than those applied to winding engines.
motor generator set for a blooming mill is usually supplied with a fly
weighing about 40 tons, while a motor generator set provided for a
mill, or a finishing mill, is generally supplied with a flywheel wei
anything from 60 to 100 tons, depending on the work which has to be
The motor generator set for supplying hoists or winding engines is gen
provided with a flywheel of not more than from 20 to 30 tons.
flywheels would run at a peripheral speed of about 20,000 per m
though in some cases this peripheral speed has been considerably incre

Such a 100-ton wheel running at this speed would have a s
energy of about 300,000,000 foot lbs. or 545,000 horse power seconds
in falling 20% in speed would give up 108,000,000 foot lbs. or 19
horse power seconds.

The total work required to roll a $1\frac{1}{2}$ ton ingot to a $4\frac{3}{4}$ x $4\frac{3}{4}$ bil
59,000,000 foot lbs. or 108,000 horse power seconds.

*Safety Devices*

The safety devices provided for an electrically driven rolling
are of a much simpler character than those provided for a hoist, bec
it is not necessary to provide against the possibility of an overwind o

loaded cage falling to the bottom of the shaft due to the failure of the electric power. It is only necessary to protect the electrical plant and the mill itself against careless handling.

Shell couplings are usually provided to couple the pinion wobblers to the leading spindles to prevent the motor or pinions being shifted from their bedplate by axial thrust due to a broken roll. This feature is usually also introduced into well designed steam driven mills. A circuit breaker is provided in the main circuit between the generator of the motor generator set and the mill motor to cut off the power from the motor in case, through carelessness, an attempt is made to roll a cold ingot, or too great a draft is taken on an ingot, imposing a greater strain on the motor and mill than they were designed for.

The circuit breaker is a protection against broken rolls as well as against damaging the motor, and it must be remembered that many rolls, especially the bottom roll, have a very small factor of safety. (Dr. Puppe, Iron and Steel Institute, Carnegie Scholarship Memoirs, Vol. II, page 300). Such a circuit breaker would be most objectionable if used with a hoist, as only the prompt application of the brakes would prevent the cage falling in the shaft when the breaker opened, but with a mill, when the circuit breaker acts the motor merely comes promptly to a standstill, and if there is an ingot between the rolls, the mill can be reversed, the circuit breaker put in, the ingot run out of the mill again, and no damage is done.

This circuit breaker can either be operated instantaneously by a maximum current cut out in the main circuit or else opened by a lever under the control of the driver. In the latter case the field currents in the generator and motor field are reduced to zero before the circuit breaker operates; in practice this hand lever is seldom used.

During the latter passes, when the ingot has been rolled out to a bloom of considerable length, there is time to accelerate the mill to a much higher speed than is possible when rolling a comparatively short ingot, and this is desirable in order to get the work done as quickly as possible, while, as the section has become much reduced and the draft is small, a relatively small turning moment is required. This is clearly shown in the table on page 11.

The mill motor is of course accelerated to the maximum speed at which full turning moment is required by increasing the field of the variable voltage generator. The most convenient way of obtaining the additional speed without increasing the size and capital cost of the plant is by decreasing the mill motor field, though of course at the expense of reducing the possible turning moment, which decreases at a faster rate than the speed increases, but which, however, agrees very well with the requirements of the mill.

There is always the possibility, however, of too heavy a draft taken through carelessness when the mill is running at this high causing an overload against which the circuit breaker would not proper protection. To prevent this a relay is provided, which, w operates, strengthens the motor field to its full value and reduces the speed to the maximum at which it can exert its maximum turning mo thus both reducing the overload and putting the motor in a better po to meet it, but if the overload is still too great for the motor the breaker will open.

The purpose of the flywheel coupled to the motor generator mentioned above, is to ensure that the rolling mill plant takes an av steady power from the power station irrespective of any fluctu in power the mill may require, but the value of the average steady depends on the work that the mill is doing, i.e., the output and the s that is being rolled.

If the regulating mechanism is set for the maximum average power, corresponding to the heaviest work that is done in the mill, and much lighter work is done, rolling slabs for plates for instance power taken will fluctuate considerably, but will not exceed the va average power for which the regulator has been set.

As this fluctuation may adversely affect the regulation of the house, means are provided to enable the regulator to maintain a value of average steady power, corresponding to the work that is done.

If the regulator is set for this lower value and heavy wo again done in the mill, the surplus power will be drawn from the fly to give the necessary energy, the speed of the motor generator se sink lower and lower till at last the flywheel, whose store of energy is portional to the square of its speed, will not be able to supply enough p to drag the billets through the mill and the mill will stall.

To prevent this, two colored lamps are provided on the dr platform to signal the speed of the flywheel. The first one, the ca signal, lights up when the flywheel is about 22% below full speed, to the driver that the average power is inadequate to the work he is d and that the regulator must be set to a higher value. The secon danger signal, lights when the flywheel is 30% below speed, and w the driver that if he goes on he will stall the mill.

A good deal of space in this paper has been devoted to descripti safety devices but it should not be considered on this account that the any inherent risk in using such electrical plant, as the safety devices a protect the plant against damage due to careless handling. The de applied to steam hoisting engines, and particularly to steam reve rolling mill engines, are of a much more rudimentary description, and safety of such steam plants really depends on the skill and experienc the driver.

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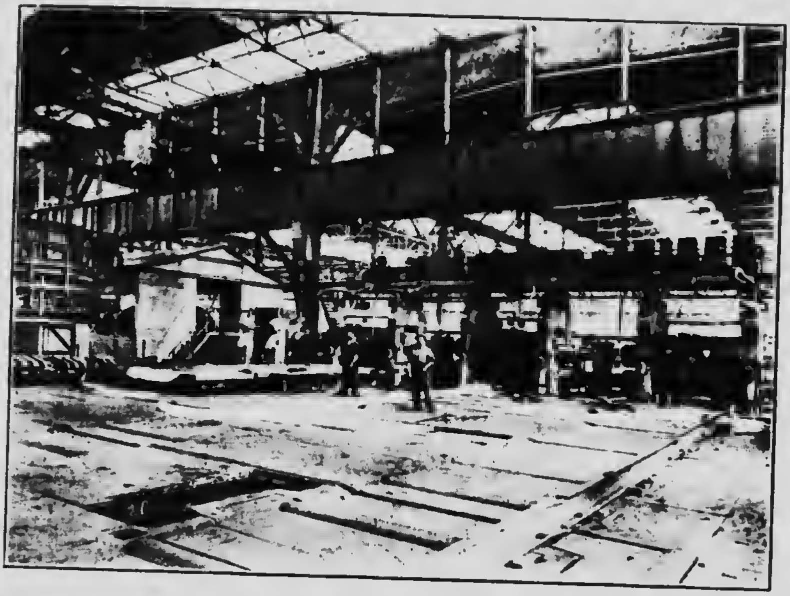

Fig. 21 30-inch three high rolling mill with five stands of rolls driven on the Ilgner system. Motor, 11,600 horse-power, at 52 r.p.m. Maximum speed, 180 r.p.m. This mill is rolling beams and rails.

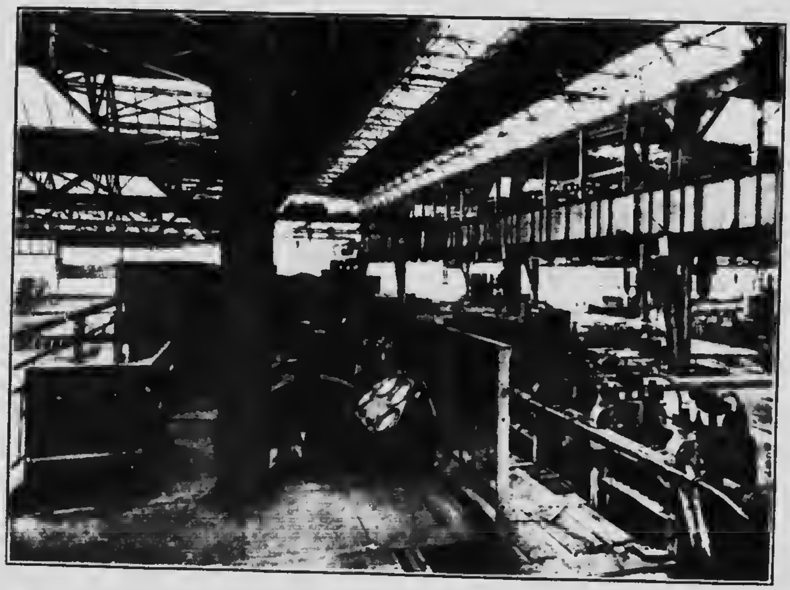

Fig. 22 Driver's platform of mill shown in Fig. 20. The main control lever, emergency lever and instruments indicating power and speed of mill motor are seen to the right of the column.

It should be particularly pointed out that the electrically reversing mill does not increase in speed as the ingot passes out rolls, while the steam engine, unless carefully handled, will race an away.

### *Three High Mills*

The authors have selected the electrically driven blooming mill example, and space unfortunately does not permit the discussion modification of the Ward Leonard system to suit the requiremen plate mills and finishing mills.

It is, however, important to mention that there is an increa tendency in Europe to use the Ward Leonard system for the drivir three high finishing mills, instead of a continuous running motor flywheel coupled to the mill.

The reason for this is that the Ward Leonard system enables a n greater output to be obtained from the mill, because the bars ma entered at a low enough speed to prevent damage being done, and, as as the rolls have gripped the bar, the speed is run up to a maximu diminished again so that the bar leaves the rolls at a reasonably low sp

As a 100 lb. rail rolled from a $4\frac{1}{2}$-ton ingot finishes about 90 long and bulb angles and channel often finish 200 ft. long, the savin time which may be effected can be appreciated, and as this enables material to be finished much hotter, the work done in rolling, and sequently the cost of power, is reduced.

Where a three high mill is driven on the Ward Leonard system is found that there are far fewer broken rolls than when it is coupled t continuous running motor and flywheel.

These advantages are found in Europe to outweigh the increa capital cost of the plant.

## THREE-PHASE SYSTEM

### Application of Three-Phase Motors to Winding Engines and Hois

A three-phase motor cannot be built for a very low speed without power factor being bad, which tends to upset the regulation of the sup system, and for this reason where three-phase motors are driving windi engines they nearly always run at higher speeds than the drums, and a geared to them. In the Ward Leonard or Ilgner system, however, where direct current motor is used, this is almost invariably direct coupled to t drum.

### *Control*

The speed of a three-phase motor is controlled by varying the r sistance in the rotor circuit so that all three-phase winding engine moto are naturally slipring motors, while the direction of rotation is reversed b interchanging two of the connections to the stator, so that a reversin

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Fig. 23—Cylindrical drum three-phase winder at the Acadia Coal Company, Stellarton, Nova Scotia, showing motor and double reduction gearing. Total length of slope, 4,921 feet. Nett load per wind, 11 tons.

Fig. 24—Control gear of three-phase winder shown in Fig. 22, showing main control lever, emergency lever and clutch levers. The reversing oil switch is on the right hand side and the liquid controller on the left hand side.

switch must be provided for this purpose. The main control leve small three-phase winder does not move backwards and forward quadrant with a straight line motion, but the quadrant has two p slots connected by a cross slot. When the main control lever is along the cross slot it operates the oil switch and reverses the When it is moved along one of the parallel slots it speeds up the w engine in one direction, when it is moved along the other slot the w engine speeds up in the other direction.

With larger winders the reversing switch is operated electr and the control lever moves backwards and forwards in a straight sl quadrant. The winding engine is at rest when the lever is in the m position and as the lever passes through the middle position it mak electrical contact which actuates the reversing switch.

In order to explain the differences between the control of a t phase winder and that of a Ward Leonard winder, it is necessary to briefly to the behaviour of a three-phase induction motor when resist are connected in the rotor circuit.

When the stator of a three-phase motor is connected to the p circuit, and the rotor revolves, a voltage is produced in the rotor portional to the difference between the synchronous speed and tha which the rotor is rotating, and this voltage causes a current to flow in rotor which produces the turning moment.

If a resistance is connected in the rotor circuit, there will be a cer drop in pressure across it proportional to the current in the rotor and the value of the resistance and, consequently, the rotor must fall in sp to provide sufficient voltage to overcome this drop in pressure, so that current and turning moment which the motor is giving is maintain

If the amount of resistance is increased the motor will naturally d more in speed. If the motor is required to give a less turning mome requiring a reduced current in the rotor, the drop in pressure across resistances becomes less and the motor will speed up until the balan between the rotor voltage and the drop in pressure is restored, un finally at light load the speed of the motor will approximate to the sy chronous speed. Thus, if the proper resistances in the rotor circuit o three-phase induction motor are connected to reduce the speed by a giv amount for a definite turning moment, the speed of the motor will increa if the turning moment which it has to give decreases, and it will decrea if the turning moment increases.

It will thus be seen that while with a Ward Leonard or Ilgner winde the winder runs at a definite speed for each position of the control leve and the speed of the winder is independent of the load in the cages, with three-phase winder the speed does not solely depend on the position of th control lever, but also depends on the turning moment which the moto has to give, so that for a definite position of the control lever the speed ma vary according to the position of the cages in the shaft and according t the load that is being hoisted, for as the loaded cage is being hoisted, it

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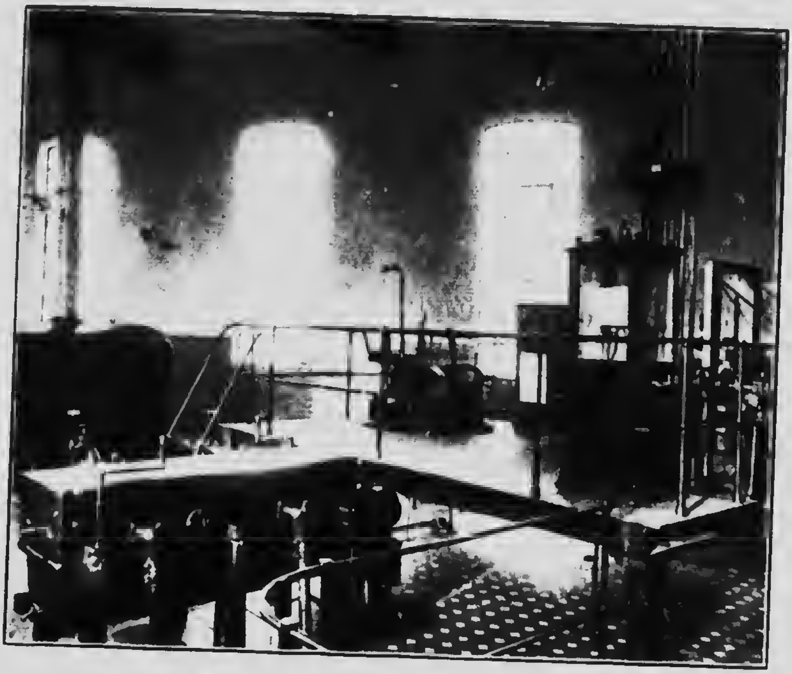

Fig. 25 Control gear of the Harton Coal Company's three-phase winder, showing control levers, depth indicator, reversing switch and liquid controller.

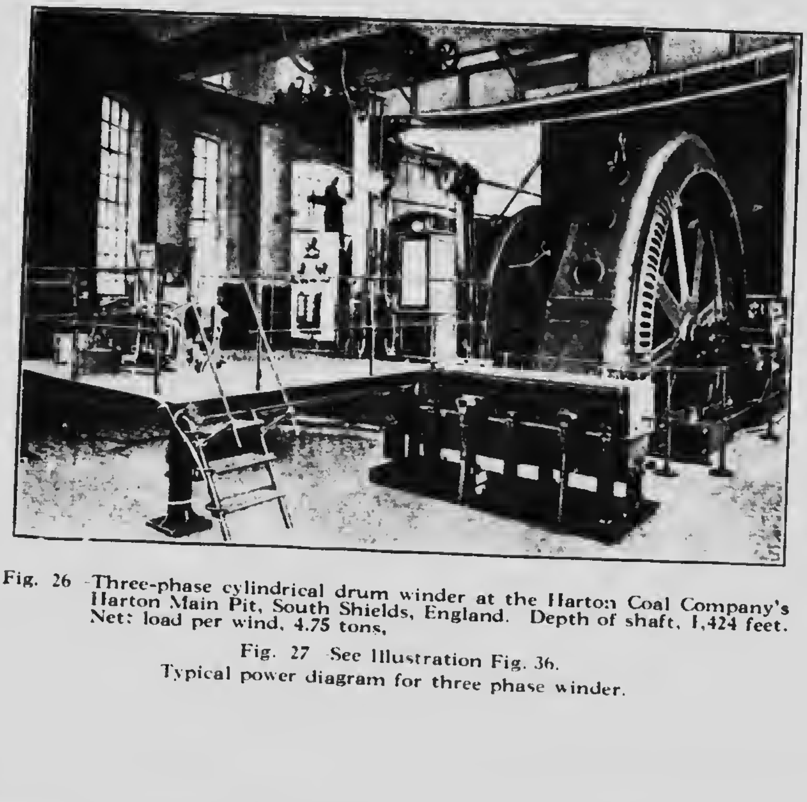

Fig. 26 -Three-phase cylindrical drum winder at the Harton Coal Company's Harton Main Pit, South Shields, England. Depth of shaft, 1,424 feet. Net: load per wind, 4.75 tons,

Fig. 27 -See Illustration Fig. 36.
Typical power diagram for three phase winder.

weight becomes more and more balanced by the weight of the rope atta
to the empty cage.

With the three-phase winder, therefore, the manipulation of the l
would be different as different loads are being hoisted, and it is ther
impossible to employ cams on the depth indicator to limit the acceler
and to bring the loaded cage to a slow speed by the time it reaches the b

In the three-phase winder, therefore, we come back to the case
steam engine where the wind is entirely in the hands of the drive
reliance must be placed in his skill for the safe handling of the plant.

*Power Diagram of Three-Phase Winder*

Where the speed of a three-phase induction motor is controlle
placing resistances in the rotor circuit, and the motor is giving a def
turning moment, the same amount of power will be taken from the su
system whatever the speed of the motor may be. The turning mon
multiplied by the speed gives the amount of power which the motor
and the remainder of the power is wasted in the resistances. T
the three-phase motor involves great waste of power.

Fig. 27 is a power diagram for a three-phase winder with a cylind
drum winding at the rate of 270 tons per hour from a shaft 1,600 feet d
the maximum speed being 40 feet per second. The shaded portions of
diagram represent the power which is wasted in the resistances of
starter in starting and stopping the motor, and in this particular case
useful work done by the winder is 524 horse power minutes per wi
The amount of energy wasted in the starter is 325 horse power min
per wind. Taking into account the efficiency of the three-phase motor
energy taken by the winder from the supply system is 910 horse po
minutes per wind. The average efficiency of the electrical plant, theref
is only 57.5%.

*Comparison of Three-Phase Winder with Ward Leonard and Ilgner Winders*

Fig. 27 shows how large the power losses are in starting and stopp
a three-phase winder. It also illustrates a case that is much more su
able for a Ward Leonard or Ilgner winder than a three-phase winder, a
as the loss in starting and stopping a three-phase winder is very great,
will be seen that it is most advantageous to employ a three-phase win
where the starting and stopping is infrequent, and where there is a lo
run at full speed, when the three-phase winder is economical, or wh
there is a considerable interval between winds. These are practica
the conditions of a long slope haulage.

Under such conditions a three-phase winder can easily prove mo
economical in power than the Ilgner or the Ward Leonard winder, becau
with the latter, the motor generator set would have to be kept runni

continuously and this involves an unceasing though small expenditure of power, so that the energy taken to run the motor generator set can easily be more than the energy wasted in starting and stopping the three-phase winder.

The three-phase winder is advantageous:—

(1) Where the capital cost of the plant is a prime consideration, as the total cost of the three-phase winder is from 20% to 25% lower than that of a Ward Leonard winder.

(2) Where the starting and stopping is infrequent and long runs at full speed are required, as is particularly the case with slope haulage.

(3) Where the winder is working very intermittently, when, if a Ward Leonard set were installed it would have to run for long periods without doing any work.

The three-phase winder is disadvantageous:—

(1) For vertical shafts, as it cannot be fitted with the safety appliances used with the Ward Leonard winder.

(2) Where the winds are short and the winding speed is high, i.e., large outputs.

(3) Where the power station from which the winder is supplied is relatively small, because in the case of a three-phase winder the load comes on instantaneously, and not gradually as with the Ward Leonard winder, so that the three-phase winder would disturb the regulation of the electrical supply system.

(4) Where there is a long transmission line between the power station and the winder, and the fluctuations in demand of a three-phase winder would cause considerable variation in voltage. This would not only have a bad effect on other plant supplied in the same circuit, but would have an adverse effect on the three-phase winder itself, because the turning moment which a three-phase motor can exert is proportional to the square of the voltage, so that a small drop in voltage could greatly reduce the turning moment which a three-phase motor could give, and in bad cases it might even be found difficult or impossible to start the winder until the regulation of the system was restored.

### *Lowering Load*

There are three methods by which the load can be lowered with a three-phase winder:—

(1) By controlling the speed with the mechanical brakes.

(2) By lowering at such a speed that the motor is run above its synchronous speed and so acts as a generator and returns power to the supply system.

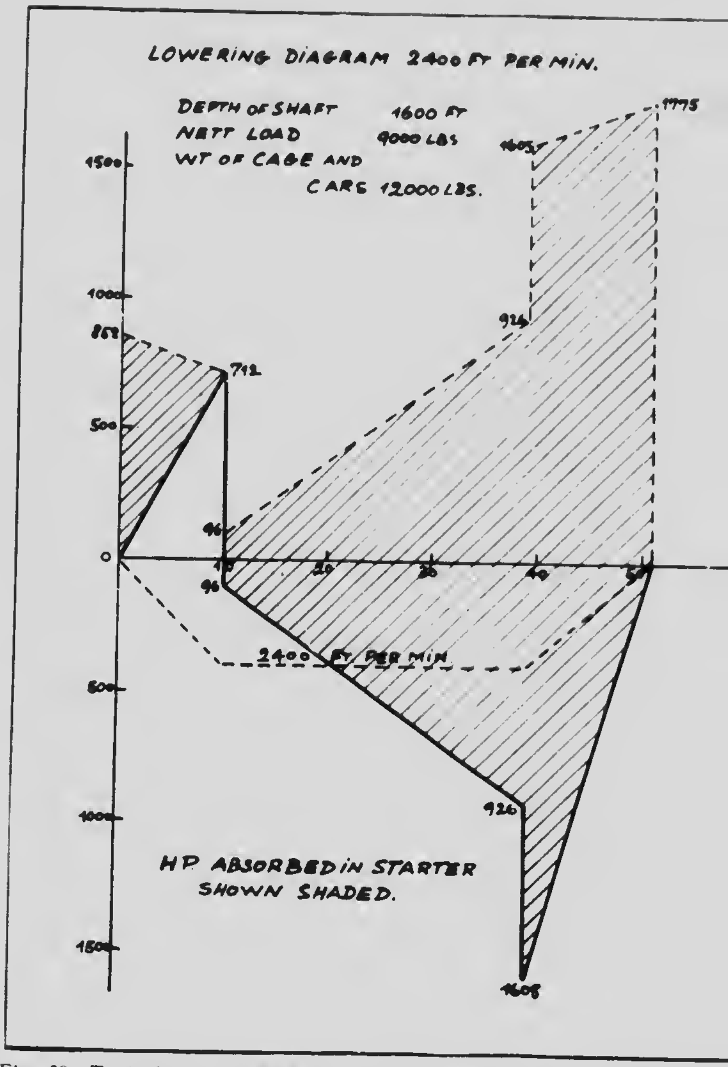


Fig. 28 Typical power diagram for three-phase winder, lowering with r
current, showing excessive power which is taken from the supply s
and wasted.


ing with reverse
ic supply system



(3) By reversing the connections to the motor so that it is giving its turning moment in the reverse direction to the rotation, and controlling the speed by the use of the ordinary control lever with reverse current.

The first of these methods is objectionable, as it produces very considerable wear and tear on the brakes, and it is difficult to design the brake paths so that the heat generated is dissipated and burning of the brake blocks is prevented.

The second method is economical in power but it is difficult to control because the electrical braking action does not take effect until the speed of the motor has exceeded synchronous speed. The motor must first be switched on in the lowering direction when the motor power is increasing the acceleration due to gravity, and in some cases to prevent this acceleration being too great the speed has to be checked with the mechanical brake. As soon as the motor exceeds synchronous speed the electrical brake will take effect and the speed of the motor will increase until it is four or five per cent. above synchronous speed, which is higher, of course, than the ordinary hoisting speed, and the motor will remain practically steady at this speed and act as an induction generator, returning power to the line.

It is not possible to use this generating effect to bring the cage to rest, but the lever may be brought back past the mid position so that the cage is brought to rest by giving the motor reverse current, but while the lever is being moved over there is no electrical braking effect whatever, and to prevent the cage increasing in speed it has to be checked with the mechanical brake.

It will thus be seen that this method of control is distinctly difficult and should only be used in the case of long winds, such as a slope haulage, where there is plenty of time to execute these manoeuvres.

The third method by which the connections of the motor are reversed, so that it is exerting its torque against the rotation, is extremely wasteful, because the motor takes power from the line in proportion to the turning moment which it is exerting, as well as the power which is given out by the winder corresponding to the work done by the loads in descending.

As an example of this attention may be call to the lowering diagram, with reverse current, shown in Fig. 28. The amount of energy given up by the lowering of the load is 20,900 horse power seconds. The amount of energy taken by the motor from the supply is 42,900 horse power seconds. Therefore, in order to exert the braking effect on the winder, and to absorb the power given up in lowering the load, which amounts to 20,900 horse power seconds, the starter has to dissipate 63,800 horse power seconds.

It will easily be seen, therefore, that when a load is lowered in this manner, the amount of energy which the starter has to dissipate is very large, and in order to enable lowering to be carried out in this way it would,

Fig. 29 Underground three-phase hoist, showing liquid controlling resis

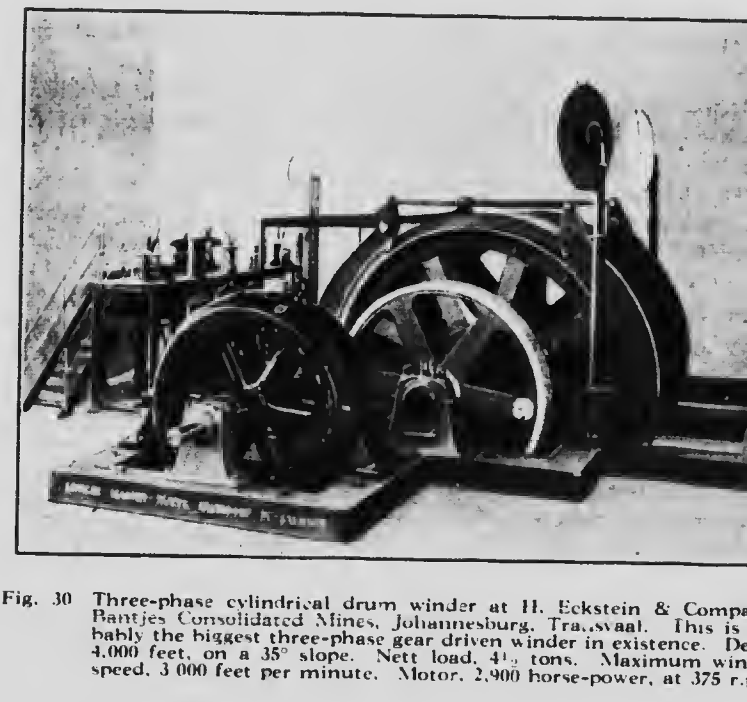

Fig. 30 Three-phase cylindrical drum winder at H. Eckstein & Compa
Bantjes Consolidated Mines, Johannesburg, Transvaal. This is
bably the biggest three-phase gear driven winder in existence. De
4,000 feet, on a 35° slope. Nett load, 4½ tons. Maximum win
speed, 3,000 feet per minute. Motor, 2,900 horse-power, at 375 r.

lling resistance.

& Company's
This is pro-
tence. Depth.
mum winding
, at 375 r.p.m.

in many cases, be necessary to employ a much larger starter than is required for controlling the winding engine when hoisting.

This method of lowering is the easiest to control, and, for this reason, although it is very wasteful, it is generally adopted for large three-phase winders.

### *Starter and Controlling Resistances*

From what has been stated above it will be seen that for the control of large three-phase winding engines, resistances have to be provided which will dissipate a considerable amount of power.

In the case illustrated in Fig. 28, 325 horse power will have to be dissipated continuously, and means have to be adopted for absorbing this power in the controlling resistance and carrying away the resultant heat developed, while, at the same time, the controlling resistance is of a form which can be easily operated by the driver.

A very usual type of controlling resistance is a liquid resistance and consists of two tanks arranged vertically one above the other, in the upper tank of which are fixed the electrodes which are connected to the sliprings of the three-phase motor.

When the winder is at a standstill the liquid is practically all contained in the lower tank, but is being continuously pumped into the upper tank by means of a small motor-driven pump, from which it flows back into the lower tank over a movable weir.

In starting the winder the switch in the stator circuit is first closed by the control lever, and then, as the control lever is moved over, this weir is gradually raised, thereby raising the level of the liquid round the electrodes in the upper tank and reducing the resistance in the rotor circuit.

This enables a very large controlling resistance to be operated easily by the driver without the complication of electrical auxiliary gear etc.

The liquid in the lower tank is cooled by means of water circulating through a coil of pipes, which forms a ready way of carrying away the heat generated owing to dissipation of energy in the resistances.

### *Emergency Gear*

A three-phase winding engine is provided with a mechanical brake, which is brought into action by means of a weight attached to a lever, but the brake is normally held away from the brake drum by air pressure. If this air pressure fails, then the weight brings the brake on to the brake drum and stops the winder. As the speed of a three-phase winder for a given position of the control lever depends on the load which is being hoisted, it is not possible to provide cams on the depth indicator in order to slow down the cage before it reaches the bank. The proper slowing down of the cage depends on the skill of the driver, but an overwind device is fitted both in the shaft and on the depth indicator,

and in case the cage over-runs the bank cuts off the power from t
and applies the brake by means of the emergency gear.

An emergency lever is provided on the driver's platform l
he can cut off the power and apply the brake, stopping the wi
mediately in case of necessity. In case the power supply fails t
is at once applied through the emergency gear.

*Winding Men*

With the three-phase winder the speed for winding men c
limited automatically, as in the case of a Ward Leonard winder,
speed depends entirely on the skill of the driver.

*Shaft and Rope Inspection*

For shaft and rope inspection the slow speed is obtained by
a very large amount of resistance in the rotor circuit of the moto
the speed at which the winder runs for a given position of the
lever depends on the turning moment which is being exerted, an
turning moment varies continually from the commencement of t
owing to the adjustment of balance produced as one rope is wo
and the other rope is wound off, the speed can only be maintai
stant by the driver continually adjusting the position of the cont
and the winder cannot, as in the case of the Ward Leonard system
alone to maintain the speed at which it has once been set.

These slow speeds involve a very considerable waste of powe
controlling resistances and may require that additional large co
resistances should be installed in order that slow speed runs may b
which if frequently made will materially reduce the overall eco
the three-phase winder.

## Winding Engines with Three-Phase Commutator Mot

As a number of winding engines have been equipped with thre
commutator motors, the following brief account of th[illegible] system ma
interest.

*Characteristics of the Three-Phase Commutator Motor*

The three-phase commutator motor has somewhat similar ch
istics to those of a direct current series motor, i.e., it develops
turning moment at the moment of starting, and as the load decrea
speed rises until at no load the motor will attain a dangerous speed
it is properly controlled.

The motor has a large overload capacity and does not stop eve
very heavy overloads but only slows down. The speed of a thre

er from the motor

platform by which
ng the winder im-
bly fails the brake

ng mer cannot be
d winder, and the

tained by leaving
the motor, but as
on of the control
erted, and as the
nent of the wind,
ope is wound on
maintained con-
the control lever
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e of power in the
large controlling
ns may be made,
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TOR MOTORS

with three-phase
ystem may be of

*Motor*

imilar charac
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of a three-phase

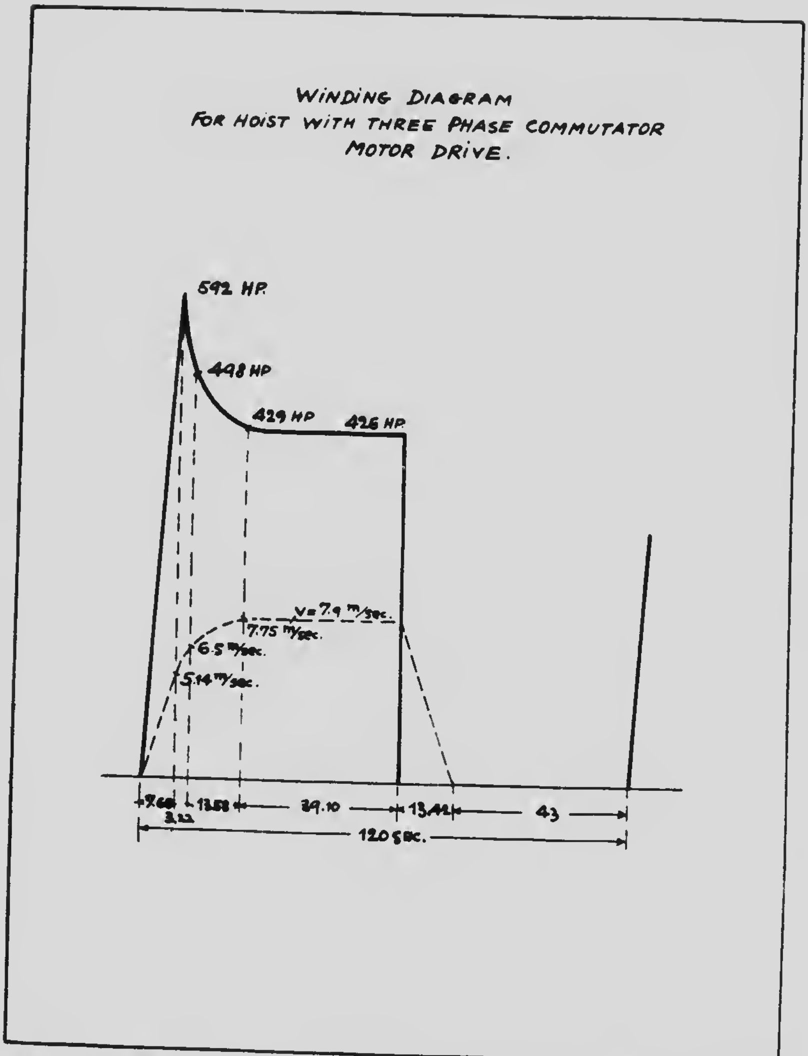


Fig. 31 –Typical power diagram for hoist driven by three-phase commutator motor.

commutator motor can be closely regulated, within wide limits, by sl
the brushes on the commutator, and the efficiency and the power
are high throughout the whole range of speed regulation.

A mechanical device can be fitted to the motor which by sh
the brushes prevents the speed rising above a determined value, ho
small the load may be.

A powerful and easily regulated braking effect can be obtained
trically by moving the brushes back through the neutral position, and
braking in this manner, especially when lowering loads, the motor act
generator and will return about 70% of the mechanical energy to th
as electrical energy. The direction of the rotation of the motor c
reversed by moving the brushes to the other side of the neutral pos
but it is desirable at the same time to reverse the stator current in ord
prevent sparking at the commutator. The stator can be constructe
any reasonable line voltage, but as the commutator can only be
for comparatively low voltages, it is usually necessary to instal a t
former between the stator and the commutator.

There are constructional reasons which make it difficult to
very slow speed three-phase commutator motors, so that such a
mutator motor is usually geared to the winding engine.

The arrangement of a winder with a three-phase commutator m
is very simple. The winder is controlled by a single lever which shift
brushes on the commutator and operates the changeover switch.

The commutator motor shares with the three-phase induction m
the disadvantage that for a definite position of the control lever its s
depends on the load in the cage, consequently, the safety devices emplo
with such a motor are very similar to those used with a three-p
induction motor, and protection is afforded by the release of the emerge
brake and the interruption of the supply circuit in case the motor or wi
is overloaded, or in any other contingency.

The three-phase commutator motor possesses the great advan
over the induction motor that its power factor at full load is about u
and the power factor maintains its high value practically for the w
range of speed regulation, so that the conditions for the electrical sup
circuit are very favourable.

The actual full load efficiency of the three-phase commutator mo
is about 5% less than that of the corresponding induction motor, but
commutator motor can be started and its speed can be regulated with
loss of power, and during braking periods or periods of lowering a lo
70% of the mechanical energy can be returned to the supply system
electrical energy, so that the total efficiency of a winder driven by a thr
phase commutator motor can be better than that of a correspond
winder driven by a three-phase induction motor.

As a winder driven by a three-phase commutator motor can be star
without loss of power, the power taken by such a motor rises gradua
from the moment of starting to the end of the acceleration period, so th

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e power factor

ch by shifting
value, however

obtained elec-
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motor acts as a
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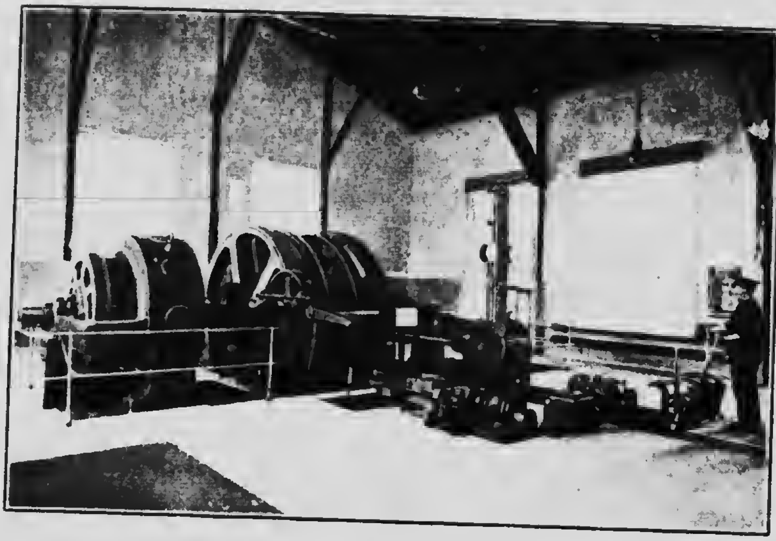

Fig. 32 Three-phase commutator motor driven winder at the Bartensleben Pit, Germany. When sinking is completed a second motor will be added when a nett load of 3.2 tons per wind will be wound from 1,600 feet. Each motor is 310 horse-power, synchronous speed, 300 r.p.m. Maximum speed, 370 r.p.m. Maximum winding speed, 1,575 feet per minute.

Fig. 33 Ward Leonard conical drum winder at the General Mining & Finance Corporation Rand Collieries, Transvaal. Depth of shaft, 3,165 feet. Nett load per wind, 5½ tons. Maximum winding speed, 3,300 feet per minute. Motor, 2,450 horse-power.

there is sufficient time to enable the generators in the power house to the load fluctuations. Such winders, therefore, can conveniently b plied with current from comparatively small power stations provide the generating sets are fitted with modern voltage regulators.

The capital cost of a winder provided with a three-phase comm motor is higher than that of a winder provided with a three-phase ind motor.

The following are some particulars of the largest winders fitted three-phase commutator motor which have come to the au knowledge:—

Depth of wind.................... 1,650 feet.
Weight of load.....................7,000 lbs.
Maximum winding speed.............1,575 feet per minute.
Output............................94 tons per hour.

This winding engine is driven by two 310 horse power three-phase mutator motors, having a synchronous speed of 300 revolutions maximum speed of 370 revolutions. This winding engine is supplied a three-phase, 25 cycle, 500 volt circuit. The authors have not any available regarding the power consumption of this winding engin smaller winding engine driven by a three-phase commutator motor gi average power consumption of 1.4 kilowatt hours per shaft power, which compares very favourably with other electrical syste winding.

## CHOICE OF DRUM FOR STEAM OR ELECTRICAL DI

The conditions governing the selection of the type of drum very considerably, according to whether the winder is to be driven trically or by a steam engine, and it is, therefore, very desirab discuss this question in a paper on electrical driving.

It is characteristic of the steam engine that its overload capaci not very great and that the turning moment varies according to position of the cranks. For a two cylinder engine with cranks at angles, such as is usually used for a steam winder, the minimum tu moment is .785 of the mean turning moment, and the maximum tu moment is 1.112.

The engine naturally must be able to start the hoist with the cr in any position, so that the minimum turning moment must be at sufficient to overcome the static load and friction.

An electric motor, on the contrary, has a very large overload capa in proportion to the mean power which it will give, and, conseque the motor for winding engines is usually selected with reference to equivalent continuous load, and it is very rarely indeed that the sta moment or acceleration peak needs to be considered.

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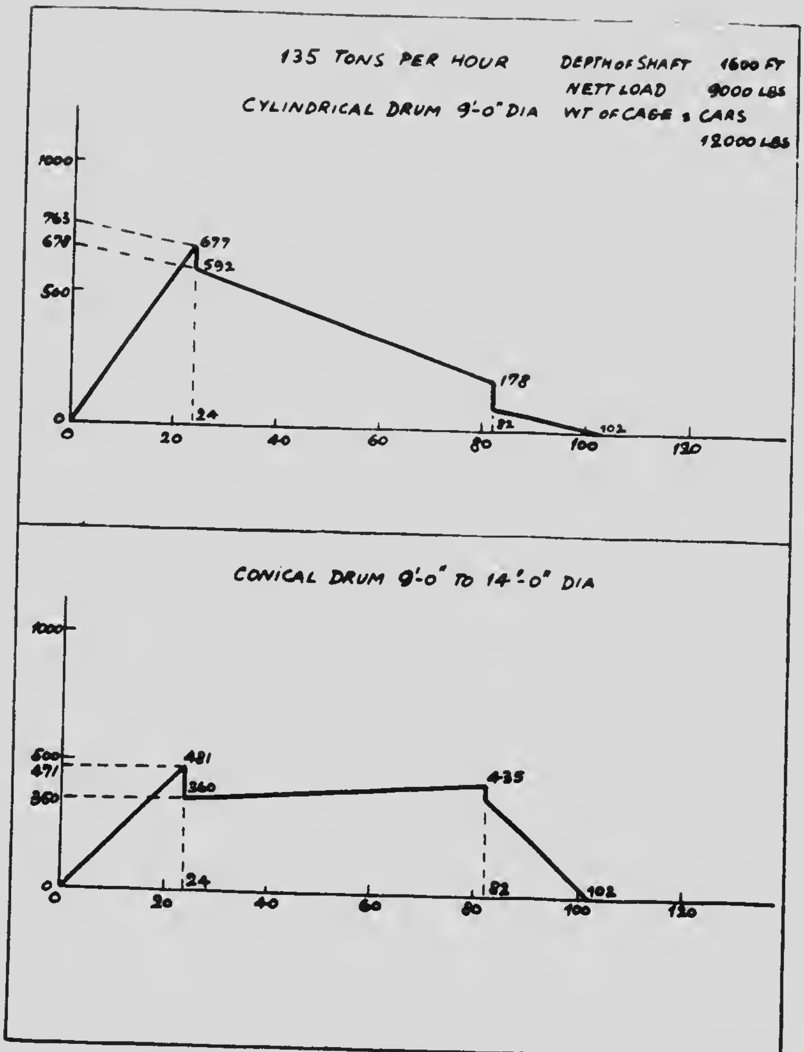


Fig. 34 Power diagram for cylindrical drum winder, winding speed, 20 feet per second.

Fig. 35 Power diagram for conical drum winder, winding speed, 20 feet per second.

## Cylindrical and Conical Drums

The first type of drum to be employed for winding engines w cylindrical drum, but later the conical drum was introduced. In cases the latter gives easier starting conditions and is beneficial to the engine, because the rope supporting the cage at the bank top is wou the greatest diameter, while the rope attached to the loaded cage pit bottom is wound on to the least diameter, so that the empty partially balances the rope and the loaded cage at the start wind.

To illustrate the relative advantages of the cylindrical and the c drum for the electrical or the steam drive at various speeds, Figs. 3 36, 37, 38 and 39 have been worked out, while Fig. 40 is worked out scroll drum, and Fig. 42 for a Koepe pulley, under the same cond as are illustrated in Figs. 36 and 37. These diagrams are worked o the following conditions:—

| | |
|---|---|
| Nett load | 9,000 lbs. |
| Weight of empty cage and cars | 12,000 lbs. |
| Depth | 1,600-ft. |
| Diameter of rope | $1\frac{5}{8}$". |
| Diameter of rope sheaves | 16-ft. |
| Lead | 250-ft. approximately. |
| Cylindrical drum | 9-ft. diameter. |
| Conical drum | 9-ft. to 14-ft. diameter. |
| With cylindrical drum and empty cage at the bank, unbalanced load | 16,800 lbs. |
| With conical drum and empty cage at the bank, unbalanced load | 10,000 lbs. |

Figs. 34 and 35 are drawn for an output of 135 tons per hour. Fi represents the cylindrical drum where the maximum winding spee 20 feet per second. Fig. 35 represents the conical drum with an equiva winding speed. If the cylindrical drum in Fig. 34 is driven by a st engine the horse power equivalent to the starting torque would be and this starting torque has to be developed in the worst position of cranks. The horse power equivalent to the corresponding average tur moment would be 865, which gives an ample turning moment for acce ation, and the maximum speed of the engine would be 42 r.p.m.

In the case of the conical drum the horse power equivalent to starting turning moment would be 350, and to the average turning mom 445. This horse power, however, is not sufficient to provide for the ac eration turning moment, so that an engine having a maximum horse po of 481 would be required, running at a maximum speed of 33 r.p.m.

Thus, for the cylindrical drum, an 865 horse power engine running 42 r.p.m. is required, and for the conical drum a 481 horse power eng at 33 r.p.m. is required, so that for the cylindrical drum an engine giv 20.6 brake horse power per revolution is necessary, and for the coni

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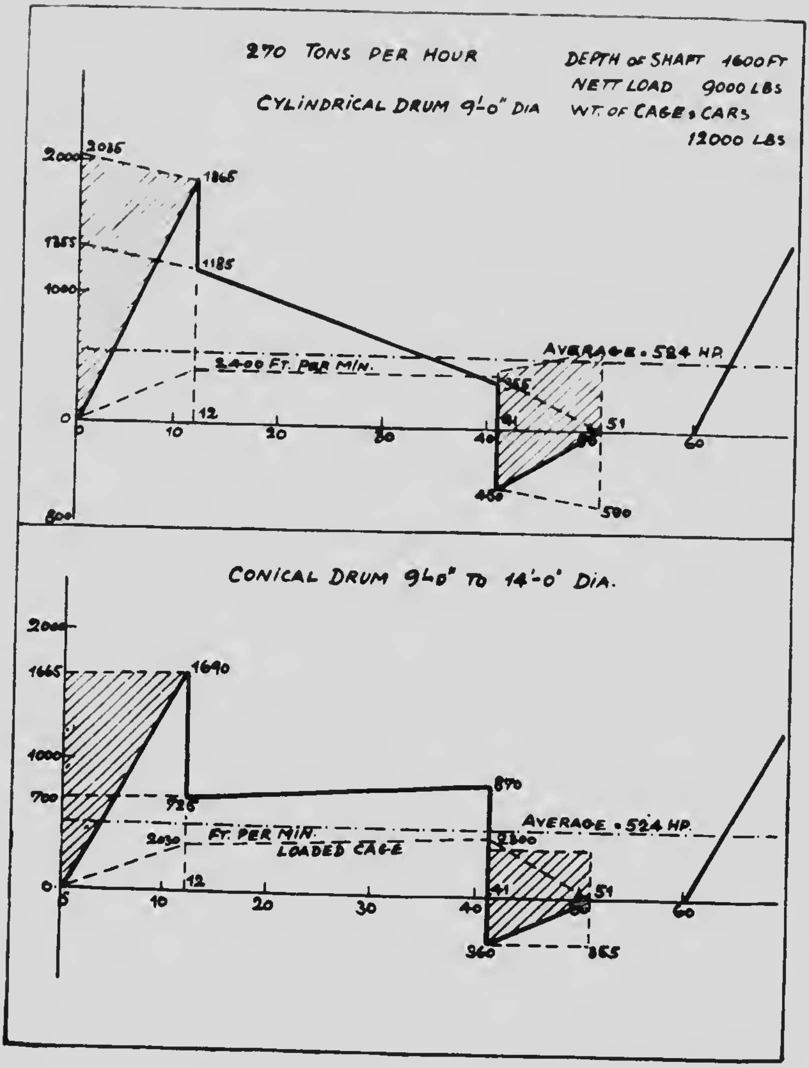



Fig. 36 Power diagram for cylindrical drum winder, winding speed, 40 feet per second.

Fig. 37 Power diagram for conical drum winder, winding speed, 40 feet per second.

drum, an engine giving 14.6. The use of the conical drum, ther demands a much smaller steam engine.

If the winder is driven electrically a 378 horse power motor r.p.m. would be required with the cylindrical drum, and a 290 horse motor at 33 r.p.m. for the conical drum. If the horse power per re tion be worked out, it will be seen that these motors are of approxin the same size.

In this case, therefore, it would be of advantage to employ a co drum for a steam winder, but for the electrical winder, so far as ca cost is concerned, it would be distinctly disadvantageous, because th no saving effected with the electrical plant and the winding engine conical drums is considerably more expensive than that with cylind The maximum power, however, taken from the supply system, is rec nearly 30%.

It should be remarked, however, that these two diagrams were wo out to show the advantages of the conical drum with a steam engine in particular case, but for the electrical drive a diagram can be worked with a cylindrical drum, to give the same output and to take a consider smaller motor.

The diameter of the drum is usually fixed as not less than 60 time diameter of the rope, so that, given the depth of the wind, the length o drum, either cylindrical or conical, necessary to carry the rope is at fixed. Where cylindrical drums are employed the travel of the two r on the drum can overlap (except in cases where the head sheaves are apart, and the drum cannot be placed sufficiently far back), so that cylindrical drum for two ropes is not very much longer than that requ by the travel of one rope.

Where conical drums are employed the minimum diameter can safely be reduced and consequently the drum must be made with a la average diameter, and although the length of drum occupied by each r is actually less than with a cylindrical drum, yet the turns of the r cannot lie close together, and a space of at least ¼-inch between each t must be allowed. In addition, the cone paths for the two ropes must quite distinct, as with conical drums the travel of the two ropes can overlap, and therefore the conical drum is much longer than the equival cylindrical drum. As, therefore, both the diameter and the length c conical drum are greater than those of the equivalent cylindrical dru its moment of inertia is much greater. In the case illustrated Figs. 34 and 35, the moment of inertia of the conical drum is more tha times as great as that of the cylindrical drum, and as considerably m power is required to accelerate the conical drum, it may easily happ that all the advantage of the conical drum is lost for this reason.

Figs. 36 and 37 are worked out for an output of 270 tons per ho Fig. 36 shows the case of the cylindrical drum where the maximum spe of winding is 40-feet per second, and Fig. 37, that of the conical drum w an equivalent speed. An inspection will show that in these cases the s

TABLE SHOWING THE INFLUENCE OF THE DIFFERENT TYPES OF DRUMS ON THE ELECTRICALLY DRIVEN WINDING ENGINE

Depth—4,600 feet. Output—270 tons per hour.

| | Cylindrical Drum | Conical Drum | Scroll Drum | Koepe Pulley |
|---|---|---|---|---|
| Power of motor | 1,090 | 965 | 780 | 935 |
| Speed of motor | 84 | 66 | 62.7 | 97 |
| H.P. per revolution | 13 | 14.6 | 12.4 | 9.6 |
| Maximum peak with Ward Leonard system | 1,865 | 1,690 | 1,390 | 1,276 |
| Average loss of power with three-phase system | 325 H.P. | 260 H.P. | 170 H.P. | 341 H.P. |

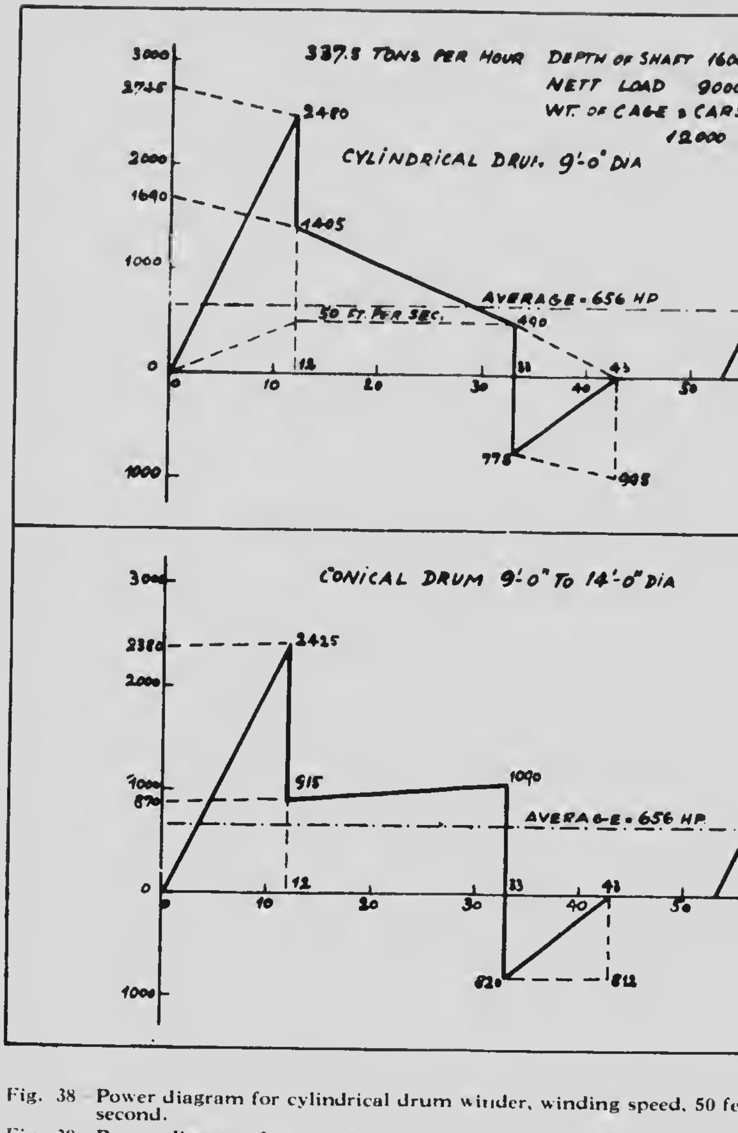
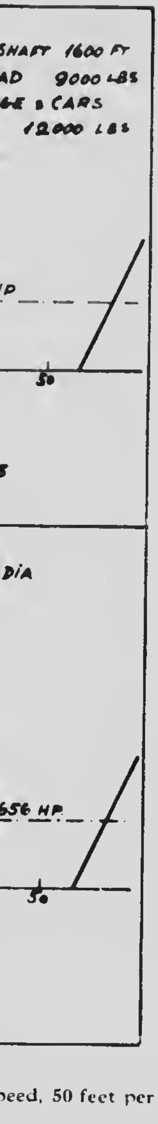



Fig. 38 Power diagram for cylindrical drum winder, winding speed, 50 fe second.

Fig. 39 Power diagram for conical drum winder, winding speed, 50 fe second.




peed, 50 feet per

eed, 50 feet per

of the steam engine is determined by the turning moment corresponding to the acceleration peak. For the cylindrical drum a steam engine capable of giving 2,035 horse power at 84 revolutions will be required, and for the conical drum a steam engine capable of giving 1,690 horse power at 66 revolutions will be required, i.e., a slightly larger steam engine will be required for the conical drum. It should be noted, however, that in the case of the cylindrical drum if constant acceleration is not assumed it would be possible to reduce the maximum horse power of the steam engine from 2,035 to 1,950.

Should the electrical drive be adopted, a 1,090 horse power motor at 84 revolutions would be required for the cylindrical drum, and a 965 horse power motor at 66 revolutions for the conical drum, so that a larger motor is required for the conical drum.

In this particular case, if the Ward Leonard system is to be employed, the effect of using a conical drum would be to increase the size of the winding motor by 12%, but to decrease the size of the motor generator set by 11½%, the net result of this being that the cost of the electrical equipment would be the same, and the cost of the winding engine would be greatly increased. The adoption of the conical drum would diminish the maximum acceleration peak by about 10%.

If the Ilgner system is to be employed it will be found that the use of the conical drum enables a very slight reduction in the capacity of the flywheel to be made, but this reduction is so slight that there is no advantage in employing this drum, as it will only increase the capital cost of the winding engine.

If, however, the winding engine is to be driven by a three-phase motor the use of a conical drum would increase the motor in size by 12%. Consequently, the total cost of the winder is considerably increased, but, on the other hand, the average power wasted in the starter is reduced from 325 horse power to 260 horse power, which means that a saving of 65 horse power minutes per wind is effected. Taking the cost of power at 1 cent per K.W. hour this represents a saving of 65 cents per hour, or about $2,000.00 per year.

Figs. 38 and 39 are worked out for an output of 337.5 tons per hour. Fig. 38 shows the case of a cylindrical drum where the maximum winding speed is 50-feet per second, while Fig. 39 shows the case of a conical drum with an equivalent winding speed.

It is easily seen that if a steam engine is used to drive this winder, a larger engine will be required for the conical drum than for the cylindrical. In the case of the electrical drive a 1,490 horse power motor at a maximum speed of 105 revolutions would be required with the cylindrical drum, and 1,390 horse power motor at a maximum speed of 83 revolutions for the conical drum.

It will thus be seen that if the Ward Leonard system is used the effect of the conical drum will be to increase the size of the winding motor by 18%, and to reduce the size of the converter set by about 7%, so that with

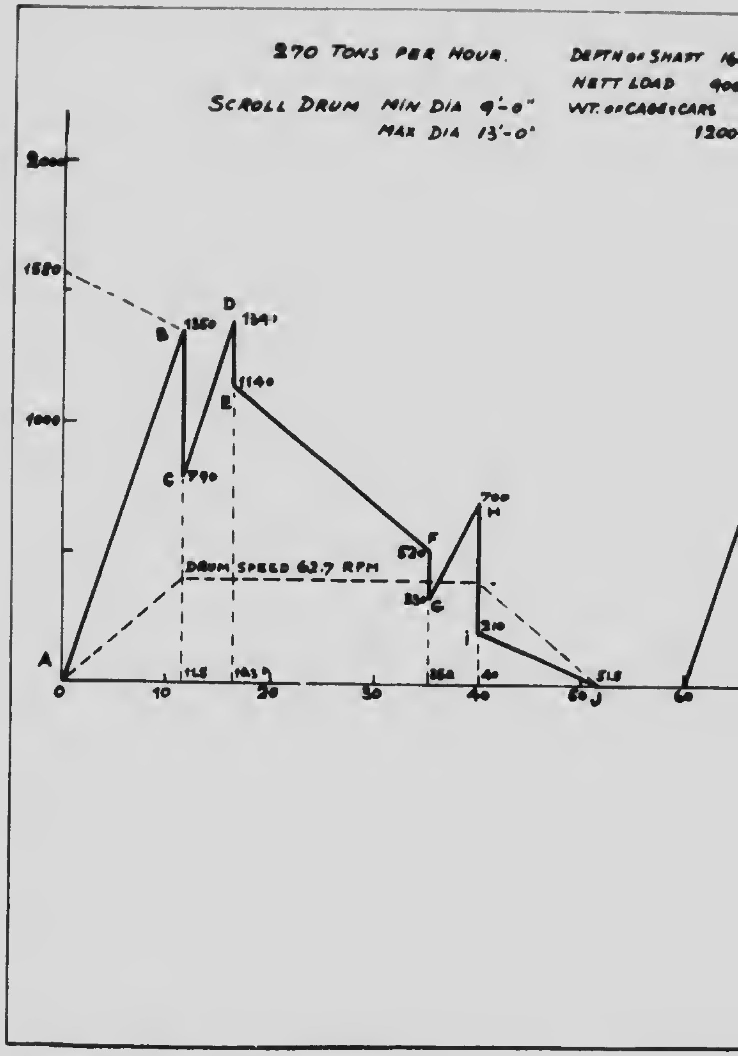
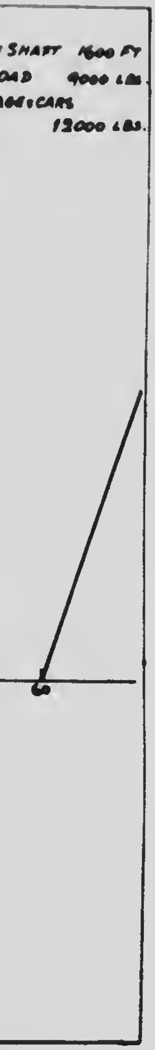



Fig 40—Power diagram for scroll drum winder, winding speed, 40 feet per second.




ed. 40 feet per



the Ward Leonard system or the Ilgner system it is a distinct disadvantage to use a conical drum for this high speed winder.

If a three phase motor were used to drive this winder the provision of a conical drum would increase the size of the motor 18%, but would reduce the average power lost in the starter from 620 horse power to 5[illegible] horse power.

## Cylindroconical or Scroll Drum

Fig. 40 is a power diagram for a winder provided with a cylindroconical drum worked under the same conditions as those assumed in working out Figs. 36 and 37.

The cylindroconical drum is a drum which has a cylindrical portion of large diameter at the middle of its length. At each end of this large cylinder there is a short cone reducing the diameter of the drum, and the remainder of the drum at each end consists of a short cylindrical portion of small diameter. In commencing a wind the rope hoisting the loaded cage from the bottom of the pit is wound on to one of the small cylindrical portions, while the rope lowering the empty cage is wound off the large cylindrical portion. Such winders are usually proportioned so that the drum reaches full speed while the rope from the loaded cage is still being wound on to the smallest diameter, but at this point the loaded cage has not reached full speed, although the empty cage has, and the loaded cage does not reach full speed until the rope has reached the top of the cone. The greater portion of the run is made with the ropes on the large diameter. Towards the end of the run the rope lowering the empty cage runs down the cone at the other end of the drum, decelerating the cage, and when this rope has reached the small diameter cylinder, the drum is then decelerated.

It will be seen that on the large diameter cylindrical portion of the drum the travel of the two ropes can overlap, and they are always designed to do so unless the head sheaves are too far apart to permit of this.

The possibility of overlapping the travel of the ropes with a scroll drum enables a scroll drum to be constructed of shorter length than the corresponding conical drum, and it may easily be even shorter than the corresponding cylindrical drum. It will be found also that the moment of inertia of a scroll drum is less than that of the corresponding conical drum, but greater than that of the cylindrical drum, and in the case illustrated in Fig. 40 the stored energy of the scroll drum is about two-thirds that of the conical drum illustrated in Fig. 37, which produces a marked reduction in the acceleration peak.

In the case illustrated in Fig. 40 the small cylindrical portions at each end of the scroll drum are 9 feet in diameter, and each carry six turns of the rope. The conical or scroll portions increase in diameter from 9 feet to 13 feet, and each carry five turns of rope. The large cylindrical portion is 13 feet in diameter and carries thirty-one turns of rope.

In Fig. 40 line AB represents the constant acceleration of the dr the descending cage and rope to full speed, and the partial acceleratio the ascending cage and rope, while this latter rope is being wound o one small cylindrical portion of the drum. The line BC shows the d in power corresponding to the completion of the acceleration of the dr and the descending cage. The line CD shows the continuation of acceleration of the ascending cage and rope as this rope is being wound one of the scroll portions of the drum.

The line DE shows the fall in power at the completion of the acce ation of the ascending cage and rope. The line EF shows the power ta by the full speed run of both cages, and this power gradually decrease the descending rope lengthens and the ascending rope shortens, so that descending rope gradually balances a greater portion of the ascend load.

The line FG shows the decrease in power, corresponding to the celeration of the empty cage, as its rope commences to run down the sc

The line GH shows the gradual increase in power as the rope to empty cage runs down the scroll, and therefore balances the ascend load to a less extent.

The line HI shows the fall in power at the commencement of deceleration of the drum, the ascending cage and the rope, and the IJ shows the gradual fall in power during the deceleration period.

In this case it will be noticed that power is taken by the winding m during the deceleration period, and this is not a case where electr braking is necessary.

If a steam engine were used to drive this scroll drum winder, an eng capable of giving 1,465 horse power at a maximum speed of 62.7 revoluti will be required, and this is a smaller engine than would be required the conical drum of Fig. 37, and slightly smaller than that required for cylindrical drum in Fig. 36.

If this winder is driven electrically a 780 horse power motor at ( revolutions would be required, and this is a smaller motor than would required for the conical drum winder of Fig. 37, or the cylindrical dr winder of Fig. 36, the latter being about 4% smaller than that requi for the cylindrical drum winder.

If this winder is driven on the Ward Leonard system, the size of motor generator set can be reduced by 30%, and if it is driven on the Ilg system, the same reduction can be made in the motor generator set, the weight of the flywheel can be reduced about 13%.

The capital cost of the mechanical parts of the scroll drum winder of course, more than the cost of that for a cylindrical winder, but it is so great as that of the mechanical parts of a conical drum winder, an this winder is to be driven on either the Ward Leonard or the Ilg system, it is probable that the scroll drum winder represents one of cheapest combinations in capital cost that can be put in to do the wo

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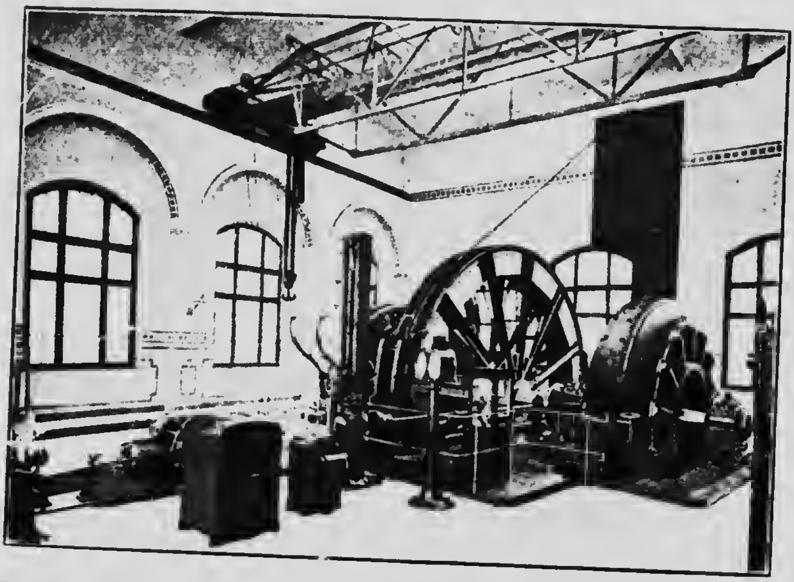

Fig. 41—Koepe Pulley Ilgner winder at the Emscher-Lippe Pit. Depth of shaft, 3,000 feet. Nett load per wind, 6 tons. Maximum winding speed, 3,950 feet per minute.

Should this winder be driven on the Ward Leonard system it sh be pointed out that the maximum peak in power which it requires is less than that required with the cylindrical drum winder.

If a three-phase motor is used for driving this winder, the size of motor is slightly less than that which would be required for the cylind drum winder, but the waste of power is very much less, the average w being 170 horse power continuously as compared with 260 horse p for the conical drum winder, and 325 horse power for the cylindrical d winder.

## Koepe Pulley Winder

This type of winder is used to a considerable extent in Eur particularly in Germany. It differs from any other type, as the rop not wound on to and off drums but is carried over the pulley and m contact with it for less than a single turn. Thus the rope from the asc ing cage comes up the shaft over the driving pulley of the winder, and down to the descending cage, being suitably guided by head sheaves.

It will thus be seen that the winding rope is driven by friction al and, consequently, there must be a very definite limit between the in the ascending rope and the pull of the descending rope, other the rope will slip on the pulley, and, to keep the difference in pull of two sides of the rope as small as possible, a balance rope is always necess

It should be noted that such a winder cannot work with a very acceleration, otherwise slipping of the rope will take place. As the r is bound to creep on the pulley to a certain extent, the depth indica must frequently be reset to ensure its accuracy.

As with a Koepe pulley winder the axial length of the pulley is short indeed compared with that of a drum on which the rope has t wound, and as the weight of the winding drum is not increa by the rope which it is carrying, the moment of inertia of the revolv parts of a Koepe pulley winder is small, and this, together with the us the balance rope, keeps the maximum acceleration peak comparati small compared with that of other types of winder.

For purposes of comparison, Fig. 42 has been drawn for an outpu 270 tons per hour, and may be compared with Fig. 36 showing a cylindr drum, Fig. 37 showing a conical drum, and Fig. 40 showing a scroll dr

In this case, however, the time of acceleration has had to be increa from twelve to twenty-two seconds, so that the acceleration should not so great as to cause the rope to slip on the drum, and to enable the out to be obtained with this slower acceleration the maximum speed has to be increased from 40 to 46 feet per second.

In European practice the diameter of a Koepe pulley is usually ta as 100 times that of the rope but for purposes of comparison with the ot cases a 9-foot pulley has been considered, which is 66 times the diame of the rope.

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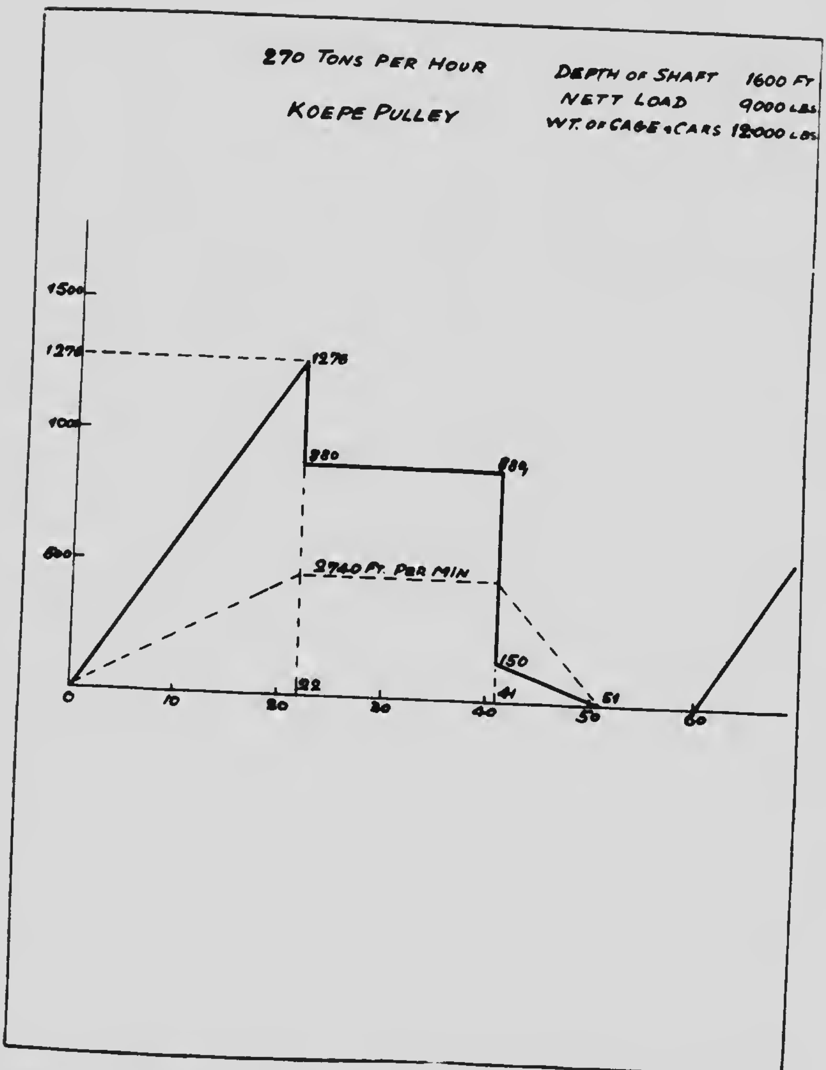


Fig. 42—Power diagram for Koepe pulley winder for output of 270 tons per hour.

A 935 horse power motor running at maximum speed of 97 revolut
will be suitable for driving this winder, and comparing this with the m
required for the cylindrical drum in Fig. 36, it will be seen that the K
pulley winder can be driven with a 25% smaller motor.

If it should be driven by the Ward Leonard system, the motor gener
set would be 14% smaller, and if it should be driven on the Ilgner sys
the motor generator set will be similarly reduced, and the weight of
flywheel can be reduced about 12%.

As the cost of the mechanical parts of the Koepe pulley wind
not great this will be the cheapest form of winder for doing the work,
as the maximum power required at the end of the acceleration peri
1,276 horse power, or over 30% less than the maximum horse p
in the case of a cylindrical drum winder, it will, if driven on the W
Leonard system, have the least severe demand on the source of elect
supply.

If the winder should be driven by a three-phase motor, it will be
that while the small moment of inertia of the moving parts keeps down
acceleration peak and so tends to decrease the waste of power in
controlling resistances the fact that a long time of acceleration has t
allowed may increase these losses. In the present case losses in the
trolling resistance correspond to a continuous loss of 241 horse power
compared with 325 in the case of a three-phase motor driving a cylind
drum winder, and 170 in the case of a three-phase motor driving the s
winder.

Generally speaking, the Koepe pulley winder shows to the grea
advantage with deep shafts as it avoids the use of excessively long dr
and, from the electrical point of view, where the winding speed is not
high and where the acceleration period is short compared with the t
time of winding. It has the disadvantage that if the rope breaks, b
cages are detached from the winder.

### General Conclusions Concerning Winding

Generally speaking, the authors are of opinion that the Ward Leo
or Ilgner system of electric winding is the most suitable for vertical sh
and for all cases where large outputs are required and short and freq
winds are made.

The three-phase winder always has the disadvantage that it canno
so completely protected against careless handling as either the Ward
nard or the Ilgner, but it may prove more economical for long slopes w
the full speed run is a long one and the periods of acceleration are c
paratively infrequent.

Regarding the choice of drums for the winding engine, the aut
are of opinion that in many cases where electrical drive is adopted,
cylindrical drum winder will prove the most suitable, but that in case
deep shafts where the winding speed is high the scroll drum winder

prove better than the cylindrical drum winder, but that the field of application of the conical drum winder to electric winding is very small.

The authors have purposely avoided any comparison between the running costs of a steam and an electrically driven hoist or rolling mill, because each case should be considered on its own merits and comparisons made for one case will not be valid for another where conditions are different. No general comparison has any practical value, sometimes the steam engine is the more economical, and sometimes the electrical plant, according to conditions, and in deciding which is the more advantageous there are other factors besides running costs to be considered.

As, however, the authors wish to see a fair comparison made in every case they should draw attention to a very fallacious method sometimes used for establishing the running cost of a steam engine, namely, either indicating the engine or measuring the water rate over an hour or two when the engine is running under the most favourable conditions, and establishing the yearly running costs from these. If tests are carried out over a prolonged period, say several months, a much higher running cost will be obtained, in some cases half as much again, as the standby losses of a steam plant are very considerable, much higher in proportion than those of an electrical plant.

## THE ELECTRICAL DRIVING OF NON-REVERSING MILLS

For the driving of a non-reversing mill, that is to say, a two-high, three-high, or double-two-high mill, a flywheel is nearly always used in conjunction with the motor, so that the flywheel assists the motor in providing large powers necessary during the passes, when a bar is going through the rolls, thus enabling a smaller motor to be used than would be required if no flywheel were employed, and reducing the variation in power taken from the supply system.

In a few special cases, such as those of a tyre mill, a wire mill and of some continuous finishing mills where the power may remain at a steady value for a minute or so, there is little advantage in employing a flywheel and it is usually omitted.

The motor and flywheel may be either direct coupled to the mill pinions, or the flywheel may be coupled to the mill pinions and a high speed motor provided which drives the flywheel shaft through a gear, rope or belt drive, and in the case of a rope or belt drive, the flywheel itself is often made the large pulley.

There are such great advantages in driving a mill by a direct coupled motor and flywheel, that this method has been adopted in a great many instances, and it may be shown that even for a sheet mill running at so slow a speed as 28 to 30 r.p.m., there are very great advantages in employing a direct coupled motor and flywheel in spite of the high capital cost, which has led to this direct coupled drive being adopted for a number of sheet and tin-plate mills.

Where a high-speed motor is installed, the flywheel should alw be coupled to the mill pinions, for it is a bad practice to instal a high sp flywheel coupled to the shaft of the high speed motor, because the stres due to the power given up by the flywheel are undeterminate, as th depend on the rate of deceleration of the flywheel, and if these stresses l to be transmitted through gears, ropes or belts, they either have to designed with a very large margin of safety, or else they are liable to unduly stressed and suffer damage. It is always a good principle to cou the flywheel to the mill pinions in as direct a manner as is possible.

To enable the flywheel to assist the motor by giving up some of stored kinetic energy so as to provide part of the power required during passes, provision must be made so that the motor and flywheel fall in sp as the power required increases, that is to say, the motor must be artificia made to decrease in speed to a considerably greater extent than normally would with an increase in power. This artificial increase of the of speed can be obtained by either of two methods:—

(1) By arranging that the speed shall steadily decrease as the pov given by the motor increases. Where the mill motor is a dir current motor, th's is done by providing the motor with a compou winding, which causes the necessary fall in speed without loss in pow

W. ere a three-phase mill motor is installed, resistances must inserted in the rotor circuit, which cause a definite loss in power as the spe decreases.

(2) By arranging that the speed shall commence to decrease af the motor has reached a predetermined load. This is done by introduci some electro-mechanically operated device, such as a relay, which dimi ishes the resistance in the shunt field of a direct current mill motor wher predetermined load is reached, or a relay, which in the case of a thr phase motor, increases the resistance in the rotor circuit.

This second method of artificially increasing the fall in speed or sl is often spoken of as automatic slip regulation, but the term "automati is a misleading one, because both methods are automatic, and it would more correct to call the first method "permanent slip regulation", and t second "intermittent slip regulation".

### Permanent Slip Regulation

Without making a great error, it may be said that the fall in spee of the motor varies with the power which it gives, and as the pow which is given by the flywheel varies as the rate of change in speed, and th power which the motor gives is the difference between the power requir by the pass and that given by the flywheel, it will be seen that the mot power rises during a period of heavy load and falls during the period light load according to a logarithm curve, and that these curves for th rise and fall of the motor power are very analogous to the heating and coo ing curves for electrical machinery. The power of the motor, howeve

rises to practically its full value in a few seconds, while the temperature of an electrical machine takes a number of hours to reach its full value. This reasoning may be illustrated by mathematical symbols as follows:—
Let

$P$ = power required to drive rolling mill during a pass when a bar is between rolls.
$K_{si}$ = full-load power of motor.
$s_i$ = slip of motor at full load.
$v_o$ = speed of motor at no load.
$v$ = speed at which motor is running at any particular time.
$s$ = corresponding slip.
$I$ = moment of inertia of flywheel.

$$\text{Stored energy of flywheel} = \frac{Iv^2}{2}$$

supposing speed of flywheel is reduced from $v_o$ to $v$

$$\text{Stored energy given up} = \frac{I(v_o^2 - v^2)}{2}$$

or—

$$\frac{I}{2}(v_o + v)(v_o - v);$$

$v_o - v$ is the slip $s$, and $v_o + v$ may be put equal to $2v$ without making much error.

Stored energy given up by the flywheel is—

$$I\,v\,s;$$

that is, the stored energy which has been given up is proportional to the slip. The sum of the power given by the motor and the flywheel must be equal to the power required to drive the rolling mill. This can be expressed by the linear differential equation—

$$Iv\frac{\delta s}{\delta t} + Ks = P,$$

the solution of which is—

$$\text{Motor power } Ks = P\left(1 - \epsilon^{-\frac{Kt}{Iv}}\right)$$

showing that the motor power increases according to a logarithm curve.

Similarly, when the bar is out of the rolls, the motor power is equal to the power taken to speed up the flywheel, thereby restoring its stored energy, or—

$$Iv\frac{\delta s}{\delta t} + Ks = o$$

the solution is—

$$\text{Motor power } Ks = (P\epsilon)^{-\frac{Kt}{Iv}}$$

showing that when bar is out of the rolls the motor power decreases also according to a logarithm curve.

The friction of the mill has been left out of these calculations for the sake of simplicity, but it can be very easily taken account of in drawing the curves by shifting the zero line.

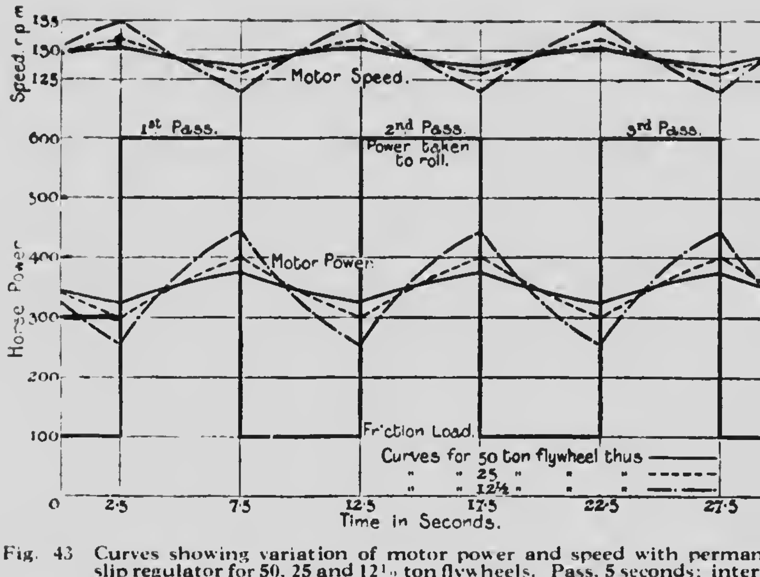


Fig. 43 Curves showing variation of motor power and speed with perman
slip regulator for 50, 25 and 12½ ton flywheels. Pass, 5 seconds; interv
5 seconds.

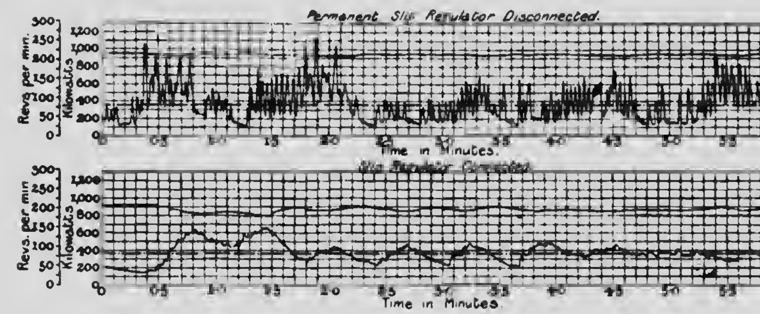


Fig. 44—Test results showing the benefit of a permanent slip regulator connec
to a sheet mill motor for reducing the fluctuations of power.

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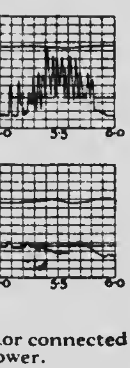
ds: interval.



or connected
ower.



The expression $\frac{Iv}{K}$ expressing the relation of motor power to flywheel capacity is the "time constant" in this case and is exactly analogous to the "time constant" in the case of the heating or cooling of electrical machinery.

The value of the time constant for a motor and flywheel, however, does not usually exceed about 33 seconds. The value of the time constant to be selected naturally depends on the type of mill. In a sheet mill where duration of the passes is very short, the time constant need not be so big as in the case of a bar mill, where the finishing passes may take a considerable time. The greatest time constants are found in the case of motor and flywheel for the motor generator set of an Ilgner electrically driven reversing rolling mill.

Fig. 43, which is drawn for a theoretical case where each pass takes 5 seconds and where there is an interval of 5 seconds between each pass, and where the power required in each pass is equal, serves to illustrate the variation in the motor speed and power, but in any practical case, the time of duration of the passes will gradually increase as the bar is being rolled down, the intervals between the passes will depend largely on the men working the mill, while the powers required by each pass vary considerably so that in practice much more complicated curves are obtained.

Fig. 44 illustrates the benefit of the permanent slip regulator in allowing the speed of the flywheel to fall, so that the variation in power taken from the supply system is not excessive. The top curve shows the variation in power where the permanent slip regulator is disconnected and the speed remains fairly constant. The lower curve shows how greatly the variation in power is reduced when the slip regulator is connected in circuit, so that the speed varies.

In rolling mill work it should always be remembered that the power required by the mill during a pass increases almost instantaneously to its maximum value as soon as the bar enters the rolls and not gradually, for it will easily be seen that as soon as the rolls have gripped the bar the full power needed for rolling the bar has to be provided. If there is any interval in the time at all between the bar being gripped by the rolls and the maximum power being required, this could only be due to slogger in the mill spindles and pinions, and when a mill is in good condition the amount of slogger is reduced to a minimum.

If the rolling mill motor is only provided with a light flywheel and a permanent slip regulator, the effect will be that the motor has to give practically the full power required to roll the bar towards the end of the pass, and that the power given by the motor has gradually increased, the flywheel having supplied the greater part of the power during the early part of the pass; so that the provision of the flywheel, while not actually keeping down the maximum value of the peaks, has given time for the

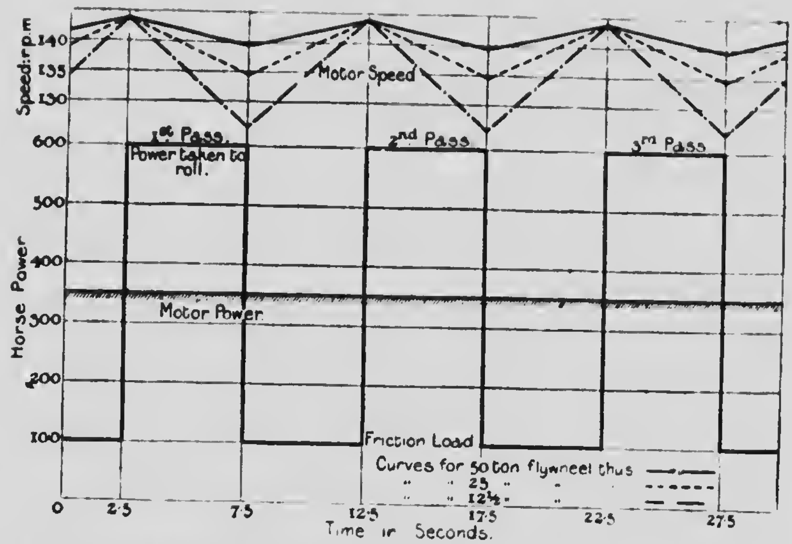



Fig. 45—Curves showing the theoretical action of intermittent slip regulator, where inertia of the moving parts is neglected.

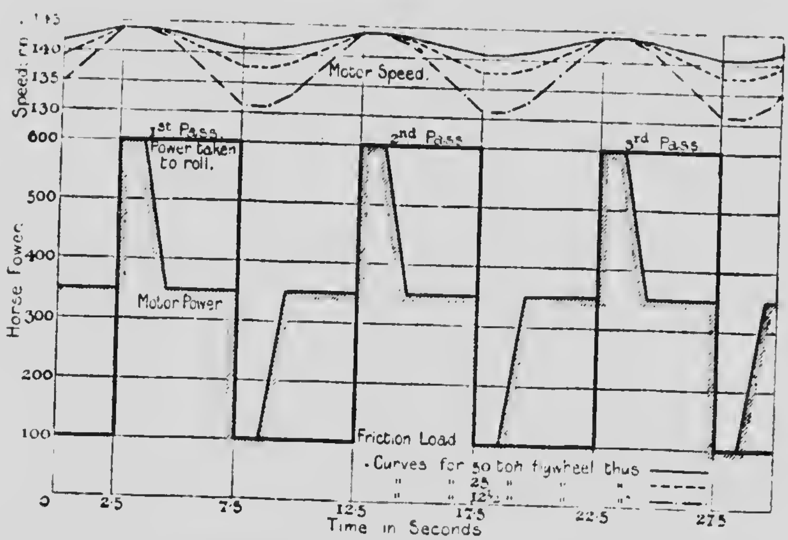



Fig. 46—Curve showing behaviour of intermittent slip regulator in practice where severe peaks in the power are caused by the inertia of the moving parts.

governors of the power house engines or turbines to adjust themselves, to meet the heavy demand for power. It will, therefore, be seen that where there is large overload capacity in the power house, it is not necessary to go to the expense of providing the mills with very heavy flywheels. If, however, a flywheel of very considerable weight is employed, the peak will be materially reduced. It will be easily seen in Fig. 13, that the variation in power is much less with a 50-ton flywheel than with 12½-ton flywheel, and it will also be seen that if the pass had lasted for 15 seconds with 12½-ton flywheel, the motor would be giving almost the maximum power required to roll the bar before the bar was out of the rolls.

## Intermittent Slip Regulation

If the provision of intermittent slip regulation is considered purely from the theoretical standpoint, it sounds very attractive, for, if the regulator were set to come into operation as soon as the motor had attained a predetermined load, so as to cause the flywheel to provide any power in excess of this predetermined load by reducing the speed, it would give almost an ideal condition. In practice, however, this intermittent slip regulator is found very unsatisfactory, because it takes a definite time to come into operation, and as the power required to roll a bar increases almost instantaneously as soon as the rolls grip the bar, the motor is giving the full power required during the pass before the slip regulator has come into operation, and the effect of the intermittent slip regulator is that instead of preventing large peaks in the power demand it actually creates them, and these peaks are so sudden that they impose the very worst possible condition on the generating station.

Fig. 15 illustrates the theoretical action of the intermittent slip regulator, and Fig. 46 illustrates the manner in which it is found to behave in practice. A combination of the permanent slip regulator and the intermittent slip regulator finds an application in certain cases, as the permanent slip regulator prevents the instantaneous peak in the power as the bar enters the rolls, and the intermittent slip regulator prevents the power rising to too great a value towards the end of the pass, but this has the disadvantage from the point of view of the rolling mill, that the intermittent slip regulator causes too great a fall in speed and sets a limit to the output.

The combination of the permanent and the intermittent slip regulator finds a very useful application in the case of the motor driving the motor generator set of an electrically driven reversing rolling mill, as the permanent slip regulator takes care of the variation in power between pass and interval, while the intermittent slip regulator is well adapted to take care of the variation in power between ingot and ingot, which has a comparatively long period.

## Speed Variation

In Europe the ordinary three-high merchant mill with roll diameters ranging from 10″ to 18″ is required to roll as many different sections as possible to meet the conditions of trade, and the smaller mills have to roll sections from either steel billets, scrap piles or puddled iron bars.

To meet these conditions such mills have to be able to run at a considerable number of different speeds.

It is always desirable to run at as high a speed as possible to get large outputs, but it is not possible to roll large steel billets at as high a speed as small billets, for it would be a physical impossibility for the men to catch a large and heavy steel billet thrown from the first pass of the roughing mill at a high speed

Iron must be rolled at a much slower speed than steel, for if iron bars are rolled at a high speed they would be torn up and spoiled.

Guide rounds or squares can be rolled at a much higher speed than hand rounds or squares, for where guides can be used they hold the bar in position, but in rolling hand rounds the roller has to hold the bar in position with his tongs, and the speed of rolling must not be faster than he can walk or else he cannot follow up the bar.

To exemplify these remarks, the following mills may be quoted.—

(1) 12″ mill with 4 stands of rolls driven by a direct coupled motor which can run at any speed between 240 and 120 r.p.m.

This mill rolls the following section from steel billets:—

| | |
|---|---|
| Hand rounds | $1\frac{7}{16}''$ to $2\frac{1}{2}''$ |
| Guide rounds | $\frac{1}{2}''$ to $1\frac{3}{4}''$ |
| Hand squares | 1″ to $2\frac{1}{2}''$ |
| Guide squares | $\frac{1}{2}''$ to $\frac{7}{8}''$ |
| Angles | 1″ by 1″ to 3″ by 3″ |
| Tees | $1\frac{3}{4}''$ by $1\frac{3}{4}''$ to $2\frac{1}{2}''$ by $2\frac{1}{2}''$ |
| Flats | 1″ to 4″ |
| Flange rail | 12 lbs. to 24 lbs. |
| Small I beams | |
| Channels | |
| Bulb tees | $2\frac{1}{2}''$ by $2\frac{1}{2}''$ |
| Tram angles | 3″ by $3\frac{3}{4}''$ |
| Fish plates | 12 lbs. to 30 lbs. |

These sections were being rolled from steel billets ranging from 2″ by 2″ to 4″ by 4″. It was found that the lowest speed, viz., 120 r.p.m., was too high for rolling $2\frac{1}{2}''$ hand rounds, and that 100 r.p.m., or even 90 r.p.m., would have been more suitable.

(2) 11″ mill driven by a direct coupled motor which can run at any speed between 250 r.p.m. and 60 r.p.m.

This mill is rolling abo[illegible]ons as detailed above from steel billets, and in addition is [illegible] iron and scrap piles (muck bars).

(3) 16" mill driven by a direct coupled motor which can run at any speed between 140 r.p.m. and 70 r.p.m. This mill is rolling a large number of sections ranging from 3" by 3" angles to 6" by 3" I beams from 5", 4" and 3" billets.

The conditions for driving such a mill are very well fulfilled by the direct current compound wound compensated motor, because it can be set to run at any basis speed suitable to the section being rolled by regulating the shunt field, while the compound winding acts as a permanent slip regulator, and gives the necessary fall in speed, without wasting power, to enable the flywheel to give up part of its stored energy to assist the mill motor when required.

When the billet is out of the rolls the mill motor will not run above the basis speed to which it has been set, so that there is no difficulty in entering the next billet.

The three-phase induction motor is not at all well suited for driving such merchant mills, because its speed can only be reduced to that suited to the section being rolled by inserting resistances in the rotor circuit, and attention has already been called in the three-phase winding engine section of this paper to the great variation of speed which takes place with change of load, when the speed of such a motor is reduced in this way.

Suppose that the mill quoted under example 1 were driven by a three-phase induction motor having a synchronous speed of 250 r.p.m., and, in order to roll large billets, such resistance was inserted in the rotor circuit to bring down the speed to 120 r.p.m. at a *definite load*. As soon as the bar was out of the rolls the motor would speed up, and, if the interval before the bar was re-entered was at all long, the speed of the motor would be nearly up to 250 r.p.m., so that it would be very difficult to re-enter the bar, and to re-enter a fresh billet at this speed would be almost impossible, as the rolls running at such a high speed would not grip the large billet.

A mill driven in this way would be practically unworkable.

Suppose the motor were a 500 h.p. motor, then, if the speed were reduced to this extent, about 250 horse power would be wasted in the resistance if the motor was giving the turning moment corresponding to its full load. Such a three phase drive is also extremely wasteful.

The above mentioned resistance will act as the permanent slip regulator, reducing the speed during periods of heavy load to enable the flywheel to give up some of its stored energy, but this entails an additional waste of power.

A number of methods have been evolved for utilizing three-phase current for driving such a mill, and the following have found practical application:—

(1) Where there is room for a rope drive an ordinary three-phase motor may be provided having 3 rope pulleys of different sizes on its shaft, and the ropes are changed from one pulley to another in order to provide three different speeds for driving the mill. To enable this to be done the

motor bedplate has been made to slide in two directions, so that any one of the three pulleys can be brought opposite to the main rope pulley flywheel, which is coupled to the mill, and also that the motor can be moved away from the main pulley to tighten up the ropes. This arrangement is really rather a poor compromise, as it only enables three speeds to be obtained, which are not nearly enough for a mill rolling such a range of sections as has been described above. In practice, it is usually found that the ropes are put on to the pulley which will give a higher speed than that actually required for rolling, and then the speed is reduced by connecting the resistance into the rotor circuit of the motor.

This is, of course, a wasteful method of working, and tests on such mills show that the power consumption for the quantity of steel rolled is unduly high.

Three or four mills have been equipped with this drive, but it is not very likely that it will be repeated.

(2) The same effect as this, viz., the possibility of running the mill at two or three set speeds has been obtained, electrically instead of mechanically, by provision of pole changing motors, or a combination of pole changing and cascade motors. This arrangement has the same disadvantages as the one described above, and, in addition, the three possible speeds cannot be selected at will but must bear a definite relation to one another, which still further limits the choice of speeds.

Where large billets are being rolled at slow speeds, a greater turning moment is required than for rolling small billets at the high speeds, but some of these pole changing motors actually give less turning moment at the low speeds, where a large turning moment is required, than they give at the high speeds.

(3) The most successful method of utilising three-phase current to drive merchant mills working under such conditions, which has yet been devised, consists in installing a three-phase motor direct coupled to a smaller compound wound direct current motor for driving the mill and providing a rotary converter having its sliprings connected to the sliprings of the rotor of the three-phase motor and its commutator connected to the commutator of the direct current motor. When it is desired to run this mill motor combination at speeds below synchronous speed, the power which would otherwise be lost in resistance in the rotor circuit for the three-phase motor is converted from three-phase to direct by the rotary converter and beneficially used in the direct current motor to assist the three-phase motor in driving the mill.

This system is therefore economical and the three machines together behave something like a direct current compound wound motor. That is to say, the mill motor set can be adjusted to run at any basis speed suitable to the section being rolled by regulating the shunt field of the direct current motor, while the compound winding of this direct current motor acts as a permanent slip regulator, giving the necessary fall in speed to allow the flywheel to take effect, without entailing any loss in power.

It will also be seen that, when the bar is out of the rolls, this set will not speed up to the synchronous speed, but will be limited by the basis speed to which the direct current motor has been set. Such variable three-phase sets have been installed for driving 8 or 9 different merchant mills, with very good results, the largest being a 1,300 h.p. set, and it is quite easy to obtain a 3 to 1 speed regulation, economically, in this way, and to get any speed at all, within these limits, while the turning moment which the set can give, increases as the speed is reduced.

(4) Some attempts have been made to obtain a similar result as that described in Section (3) installing either a frequency converter or a three-phase commutator motor driven by an induction motor in conjunction with a three-phase induction mill motor, the difference in this case being that the power taken from the rotor circuit is returned to the supply system instead of being utilized to drive the mill, so that the turning moment does not increase as the speed falls, but the authors are unaware that any such systems have found much application.

(5) The three-phase commutator motor may possibly find application in the future for driving rolling mills, but the authors are unaware that such a machine has been installed for this purpose up to the present.

## The Effect of Conditions of Trade on the Driving of such Mills

In the United States of America ordinary three-phase motors find a very large application for driving merchant and bar mills, because the conditions of trade are such that it is found possible to limit the number of sections which are rolled in these mills, and to allocate a few sections only to each mill and to keep the mill busy on these sections. This may perhaps be said to be a direct consequence of the very large output of steel in the United States and the commercial conditions there. As a consequence of this, such a mill can be run at practically constant speed under favourable conditions and a three-phase induction motor proves fairly suitable for driving it. Up to the present time, such small mills, in Canada, are also only rolling a comparatively small range of sections, so that it has been found possible to run them at practically constant speed, and to use three-phase induction motors in many cases for driving them. The authors, however, think that in the future less manufactured steel will be imported into Canada, and, instead, it will be rolled in the country, so that the tendency in the future will be that Canadian mills will have to meet such conditions of trade by working more under European conditions, that is to say, each mill will have to roll a large number of sections, because it is unlikely for many years to come that the steel output in Canada will be such that there will be enough mills to enable arrangements to be made that each mill is producing a large output of a few sections only. It is therefore likely that, in the future, Canadian merchant and bar mills will have to be arranged to run at a considerable number of different speeds, so as to be able to roll a large number of different sections from varying sized billets. It is, however, doubtful whether there will ever be the demand in Canada for puddled iron sections, as there is in Europe, where climatic conditions are different.

The above remarks, naturally, do not apply to such mills as sheet-mills, tinplate mills etc., which are always run at practically constant speed, and which can be driven by three-phase motors without entailing much disadvantage from the point of view of the mill, although tests on sheet and tinplate mills have shown that, in such mills, there is a very considerable waste of power in the permanent slip regulators, amounting to from 12 to 15% of the total energy expressed in kilowatt hours taken to drive the mill.

## Conclusions Concerning Rolling Mills

The authors are of opinion that direct current is much better adapted for driving mills and machinery in a steel works than three-phase current.

Where large reversing rolling mills are driven electrically, and the motor driving the motor generator set is supplied from a direct current system, it is found that the power supplied to the rolling mill plant can be maintained at a much steadier value than if it is supplied from a three-phase system, and with the direct current motor about a ten per cent. saving in power can be effected, as there is no loss of power in slip resistances.

With a direct current system the flywheel of the motor generator set can be utilized to a great extent for neutralising sudden peaks of short duration in the power demand on other parts of the system, for, during such a peak, the motor generator set would not only cease to take power from the supply, but the motor can be actually reversed, and give its full output as a generator returning the energy of the flywheel as electrical energy to the supply system.

With a three-phase system, peaks in other parts of the system cannot be neutralised to anything like the same extent, for the motor can only be made to cease to take power from the supply system and cannot act as a generator returning power to the supply system.

It has been shown that the direct current compound wound motor is very well adapted to fulfil the conditions for driving three-high merchant and bar mills and that considerable complication and difficulties are involved in adapting the three-phase motor for this purpose.

Direct current motors are also particularly well adapted for driving slow speed sheet and tinplate mills, as it is very easy to provide a slow speed direct coupled motor and gain the advantage and economy of this drive, and, as there is no loss of power in slip resistances, the direct current motor will prove from twelve to fifteen per cent. more economical than the three-phase motor on this current alone.

The advantages of direct current table and live roll motors are so fully recognized that they need not be recapitulated here, but it is interesting to note that in perhaps the largest steel works on the American Contiment, where the main power supply is three-phase, all the table motors are direct current and a large and costly installation of converting machinery has been provided to convert the three-phase current to direct current to supply these table motors.

It may be argued that the cost of cables with a 500 volt direct current system is much higher than for a high voltage three-phase system, but it must be remembered that a well laid out steel works is comparatively compact and the distances are relatively short, so that the cost of cables is not a very serious item, and that the additional capital cost of three-phase generating plant to produce power, which is wasted in the slip resistance etc., will pay for a good deal of extra cable.

In steel works where there are blast furnaces and coke ovens, the modern tendency is to instal large gas engines using blast furnace or coke oven gas, both for driving the blast furnace blowers and for generating electrical power, and experience shows that a direct current gas engine power house is cheaper in capital cost and easier to operate than a three-phase power house.

Gas engine driven three-phase alternators present the most difficult problem in parallel running, and while sufficient experience has been gained in the past ten years to enable these difficulties to be overcome by proper design, the provision of very heavy flywheels is always necessary, and these largely increase the capital cost of the three-phase generators, which are intrinsically more expensive than direct current generators.

The higher the periodicity the heavier the flywheels for the three-phase generators become.

Where a steam turbine power house is installed the conditions are reversed and a three-phase power station is both cheaper in capital cost and easier to operate than a direct current power station, and it becomes a serious question whether the disadvantages of three-phase current for driving the mill etc., should be incurred to secure better conditions for the power house or not —possibly the best solution in such a case is to instal three-phase turbo-generators with rotary converters, so that direct current is provided without incurring the difficulties of the direct current turbo-generator.

The 500 volt direct current system has found very wide application in the steel works on the Continent of Europe.

In conclusion, the authors wish to express their thanks to the Siemens Company of Canada, Limited, to Messrs. Siemens Brothers Dynamo Works, and to the Siemens Schuckertwerke for the information which they have furnished and for the assistance which they have rendered in the preparation of this paper.

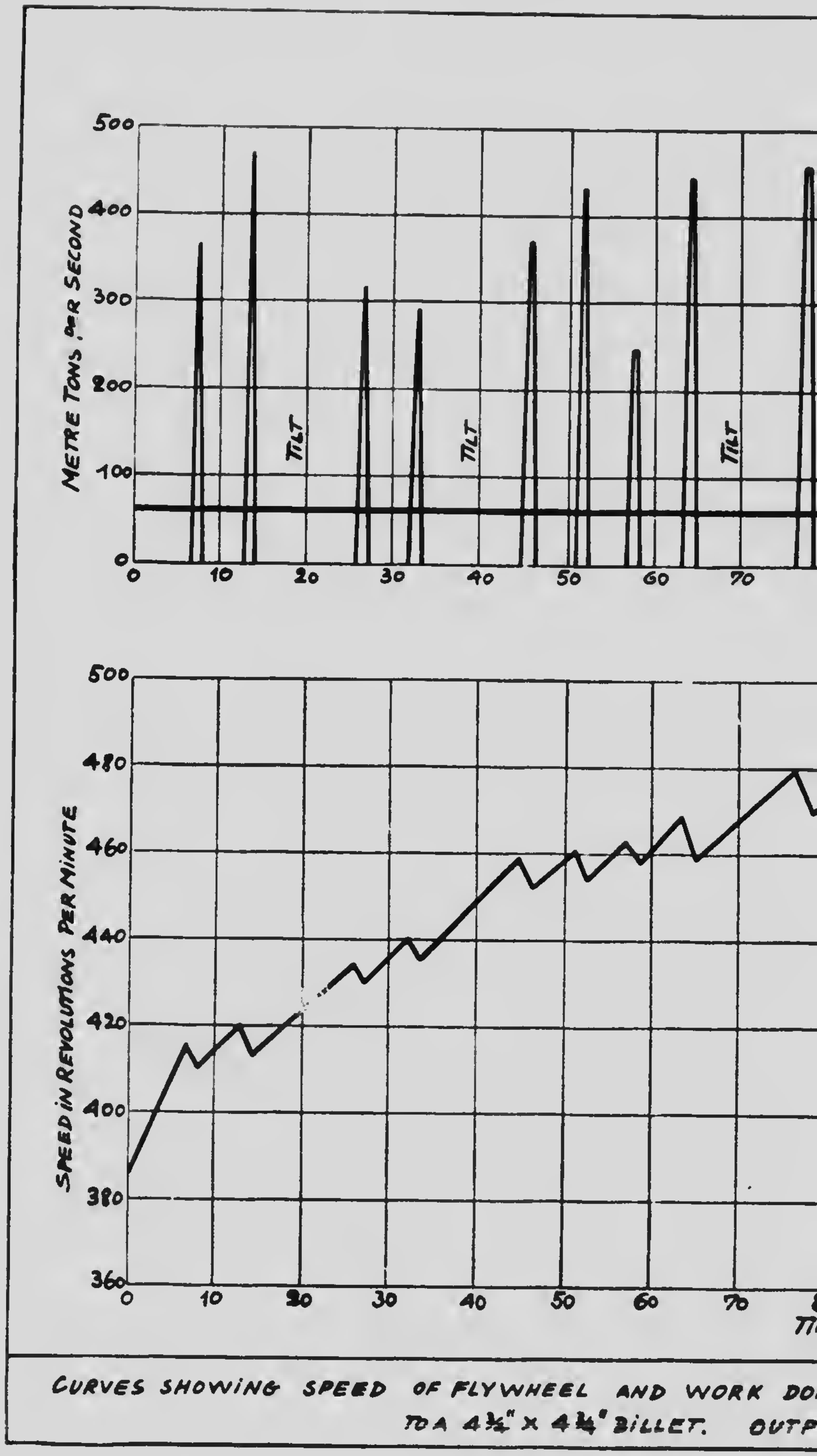
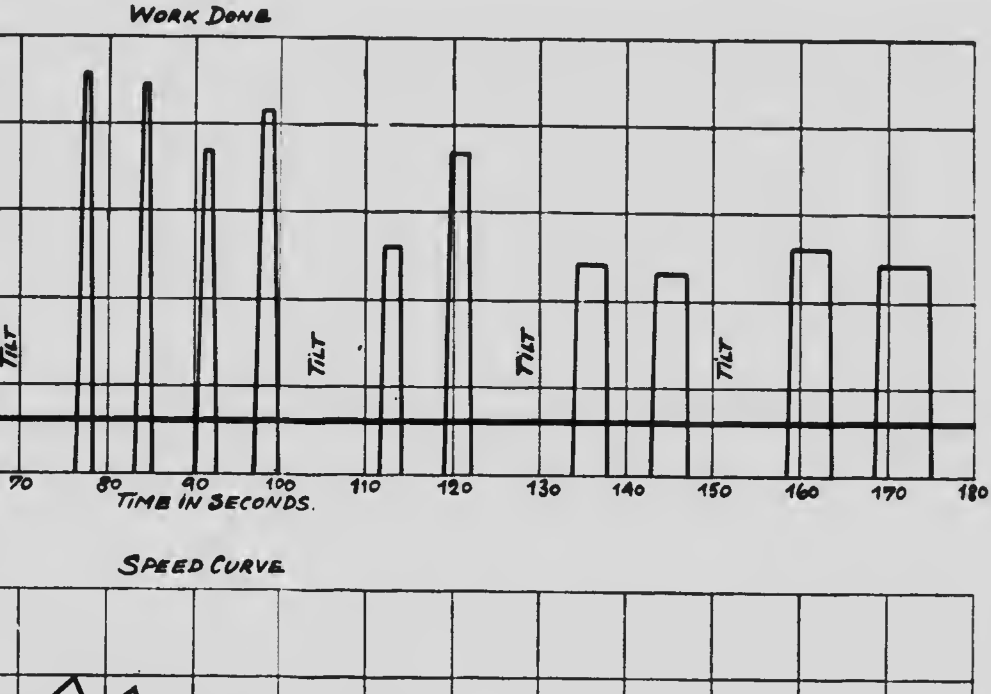



Fig. 18—Power diagram for bl
and rectangular space
the thick horizontal li
system.




...ORK DONE PER PASS IN COGGING DOWN A 1½ TON INGOT, 16" × 16",
OUTPUT 30 TONS PER HOUR.

...am for blooming mill. In the top diagram the triangular, ...ular spaces show the work done in driving the mill, while ...rizontal line shows the actual power taken from the supply

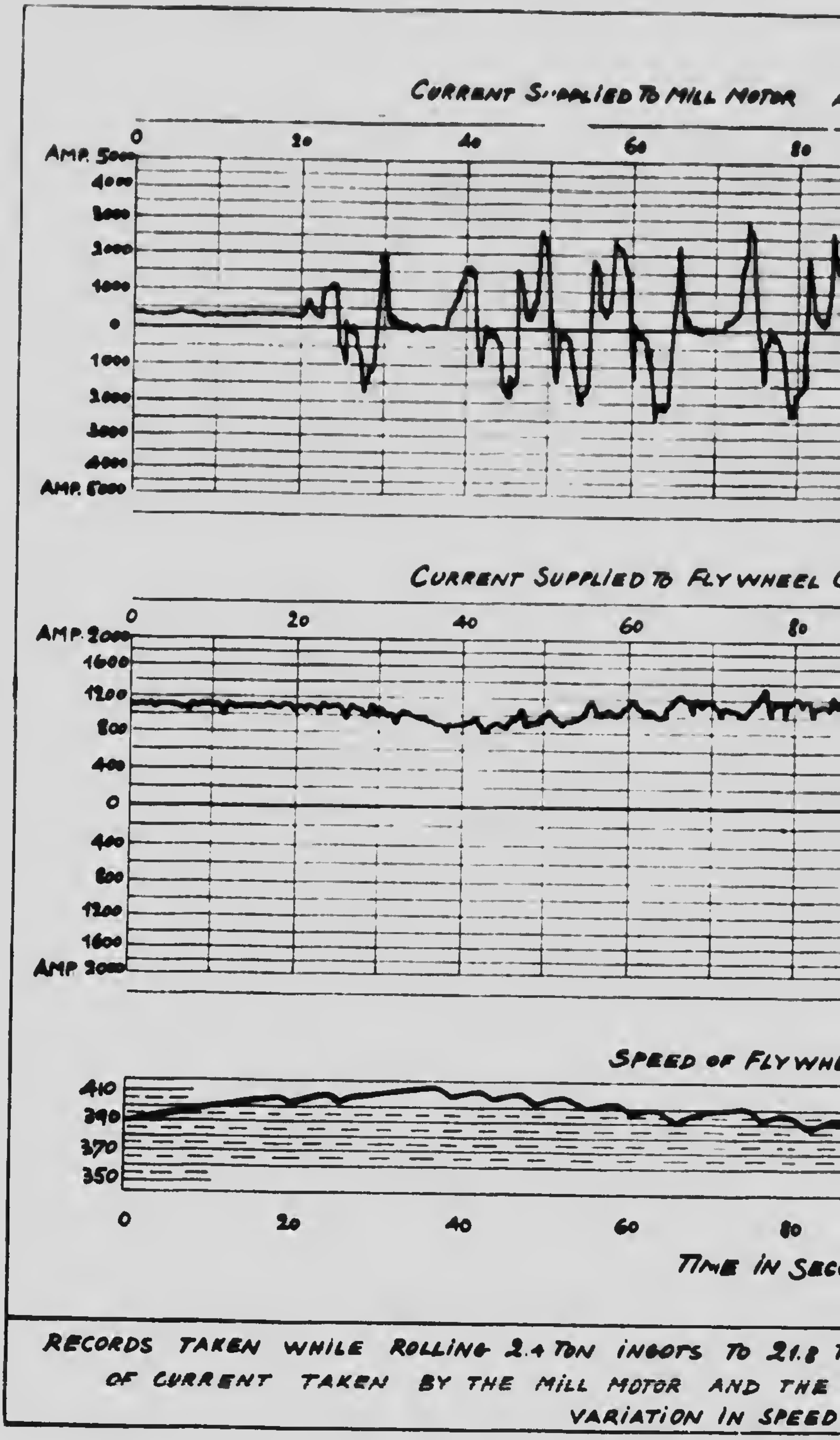
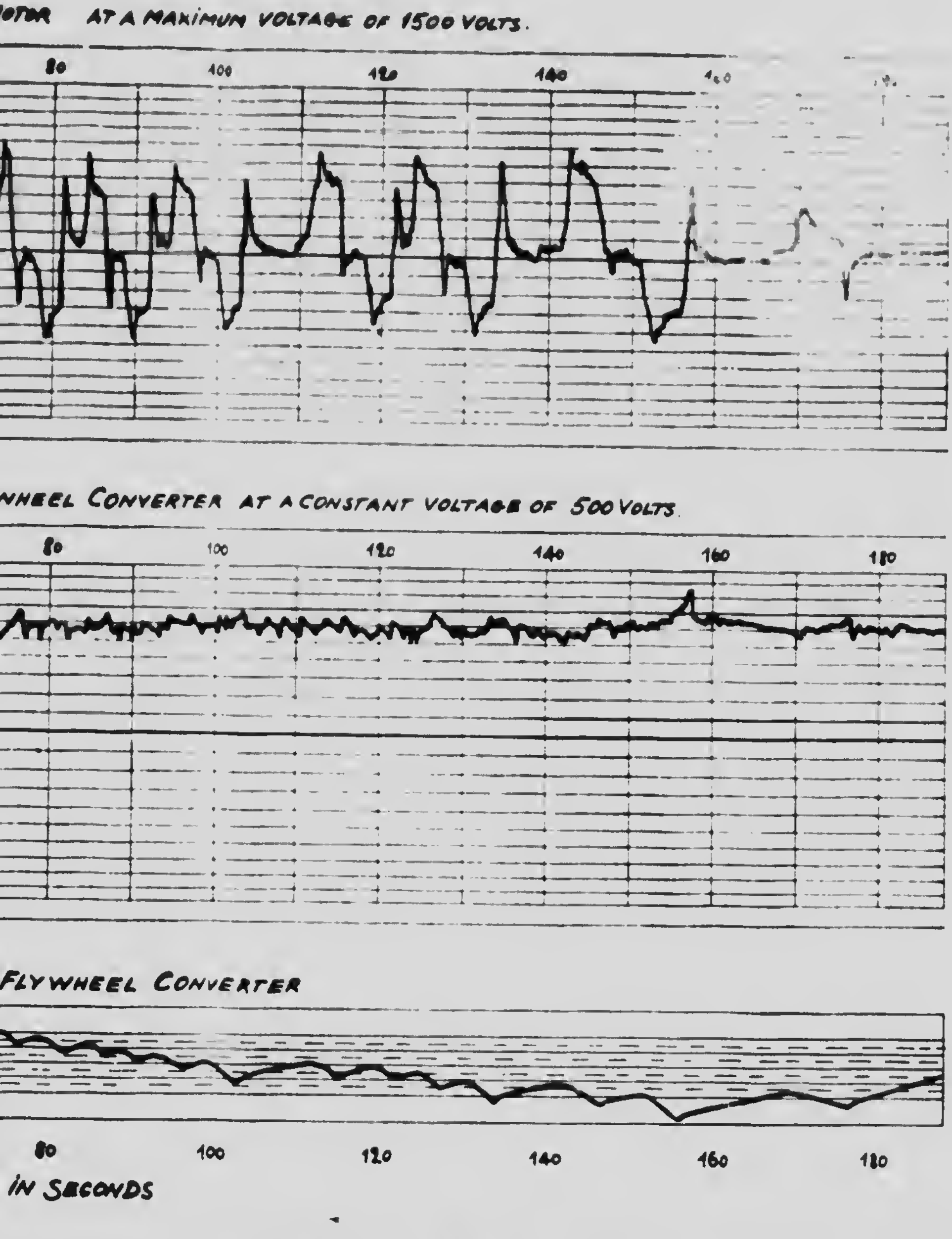



Fig. 20—Results of tests showing
rolling mill motor, curre
in speed of Ilgner motor




...D 21.8 TIMES THEIR ORIGINAL LENGTH. CURVES SHOWING THE VARIATION
...D THE FLYWHEEL CONVERTER SET RESPECTIVELY AND THE
... SPEED OF THE FLYWHEEL.

...s showing variation in current supplied to reversing
...tor, current taken from the power house, and variation
...er motor generator set.