ELECTRIC WINDING-MACHINES.

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(Translated from the French.)

The ever-increasing application of electricity to mining machinery, and the economy resulting from centralising the generation of energy required for working large undertakings, has not been kept back for want of finding means for working winding-machinery electrically. When it is a question of underground mechanical winding, the electric transmission offers enormous advantages over all other systems (steam, compressed-air) with regard to economy and facility of installation. But the exaggerated fear of introducing electric plant into explosive mines, the cheapness of machines by compressed air and also the possible utilization of existing compressed-air plants, have retarded the great development of electric winding in underground workings. Even in the case of the main winding-machines, which can be placed close to the steam-engines, electric driving has been introduced during the last years with the object of reducing the consumption of steam. This economy is, however, doubtful. The losses due to the transformation of electric energy may, in fact, equal the unfavourable conditions under which a steam

winding-engine is working if the latter be an economical condensing engine.* The economy is certain, however, when the winding-machine must be placed further away from the steam-engine or when the use of electric transmission permits of doing away with boilers.

In designing a steam winding-engine, it was generally considered sufficient to determine the resultant statical moment of the rope-roll. The use of electric driving has necessitated a study of the dynamic conditions of the problem, which is not without importance also in designing steam winding-engines, if it be desired to work the engine under the most economical conditions. The author brought to notice, at the Exhibition of electric winding-engines at Düsseldorf 1902,† the study of the dynamic conditions of winding for machines with ropes and perfectly balanced; winding-machines with cylindrical drums, and with counterbalancing ropes; and machines with Koepe's pulley. The latter was at that time the only machine to which direct driving by electric motors had been applied.

At present the application has been extended to machines with variable rope-roll, notably to the machine installed at the coal-mines of Grand Hornu.‡ It seems therefore desirable to investigate the question more closely.

DYNAMIC INVESTIGATION OF WINDING.

Statical Moments.—The law governing the relation between the statical moments and the number of revolutions made by the shaft which carries the winding gear of the ropes may be

* See R. A. Henry, "Étude théorique et expérimentale de la Machine d'Extraction"; 'Revue Universelle des Mines,' 4th series, 1903, vol. ii, and 1904, vol. vii.

† See Paul Habets, "Exposition de Düsseldorf, 1902, des Machines d'extraction électriques"; 'Revue Universelle des Mines,' 4th series, 1903, vol. i, and 1904, vol. vi.

‡ See E. Troussart, "L'Installation de Transport d'Énergie électrique aux Usines et Mines de Houilles de Grand Hornu"; 'Revue Universelle des Mines,' 4th series, 1904, vol. vii.

determined by calculation or by a graphical method shown by M. H. Dechamps.* As an example, the author has selected the electric winding-engine installed at the coal mines of Grand Hornu. The following data have been furnished by M. E. Troussart:—† Depth, 1,000 m. (3,300 ft.); useful load, 6 wagons, 2,600 kgs. ($2\frac{1}{2}$ tons); dead load, 6 wagons, 1,260 kgs. ($1\frac{1}{4}$ tons); dead load, one cage, 2,000 kgs. (2 tons). The flat aloes rope is taper and of the following dimensions:—

TABLE 1.

Length.		Thickness.		Weight per	
M.	Feet.	Mm.	Inches.	Mètre.	Foot.
				Kgs.	Lbs.
0 to 120	0 to 394	50 to 48	1·97 to 1·89	14·65	9·84
120 „ 220	394 „ 722	48 „ 46	1·89 „ 1·81	13·75	9·24
220 „ 320	722 „ 1050	46 „ 44	1·81 „ 1·73	12·50	8·40
320 „ 420	1050 „ 1378	44 „ 42	1·73 „ 1·65	10·90	7·32
420 „ 520	1378 „ 1706	42 „ 39·5	1·65 „ 1·56	9·25	6·21
520 „ 620	1706 „ 2034	39·5 „ 36·75	1·56 „ 1·45	8·90	5·97
620 „ 720	2034 „ 2362	36·75 „ 35·25	1·45 „ 1·39	8·40	5·64
720 „ 820	2362 „ 2690	35·25 „ 33	1·39 „ 1·30	8·25	5·54
820 „ 920	2690 „ 3018	33 „ 33	1·30 „ 1·30	8·12	5·45
920 „ 1020	3018 „ 3347	33 „ 32·9	1·30 „ 1·29	7·68	5·15
1020 „ 1120	3347 „ 3675	32·9 „ 32·7	1·29 „ 1·28	7·10	4·77

The diameter of the bare drum is 1·40 m. (4 ft. $7\frac{1}{8}$ ins.), the initial radius is 1·20 m. (3 ft. $11\frac{1}{2}$ ins.), and the final radius

* See H. Dechamps, "Application de la Méthode graphique à l'étude de l'Équilibre des Câbles d'Extraction"; 'Revue Universelle des Mines,' 3rd series, 1902, vol. lviii.

† See E. Troussart, loc. cit.

3.73 m. (12 ft. $2\frac{7}{8}$ ins.). The number of revolutions for one haul is 64. To draw 56 tonnes (55 tons) per hour it will be required to make 25 hauls per hour; it takes 144 seconds to make one ascension, and reckoning 38 seconds for manipulating the machine, there remain 106 seconds for the actual ascension. To prevent the speed from exceeding 15 m. (49 ft. $2\frac{1}{2}$ ins.) per second in the pits, a constant angular acceleration is allowed for 15 seconds to reach the rated speed of 42 revolutions per minute in 77 seconds. The stopping is effected in 14 seconds by a constant retardation. The moment of inertia of the two drums, including the brake-drum, is $5,606.5 \text{ kg.-m.}^2$ ($133,000 \text{ lb.-feet}^2$). The moment of inertia of the motor is $2,548.4 \text{ kg.-m.}^2$ ($60,460 \text{ lb.-feet}^2$), and that of a head-gear 407.7 kg.-m.^2 ($9,675 \text{ lb.-feet}^2$). By the aid of these data the conditions for manipulating the winding-machine can be found.

The curves (Figs. 1 to 5, pages 433 to 437) may now be drawn according to M. Dechamp's method for flat tapered ropes winding on drums:—

(1.) Curve A_0A_{10} representing the weight of the rope per metre run as a function of the depth.

(2.) $B_0B_5B_{10}$ representing the weight of the unrolled part of the rope as a function of the depth.

(3.) $B_0B'_5B_{10}$ representing the weight of the unrolled part of the rope as a function of the number of revolutions of the machine.

(4.) The curve of statical moments x_0x_{10} of the ascending loads referred to axis CC' .

(5.) The curve of statical moments $x'_0x'_{10}$ of the descending loads referred to axis HH' .

(6.) The invert $x''_0x''_{10}$ of $x'_0x'_{10}$ referred to axis CC' .

(7.) The curve X_0X_{10} of the resultant statical moments.

Resistances (Figs. 1 and 4, pages 433 and 436).—Besides the statical moments, the motor has also to overcome the resistance of the air to the motion of the cages, the frictions in the pit and at the bearings of the head-gears and of the shaft of the

(Continued on page 438.)

Fig. 1.

Abscissæ Scale.

1 Div. = 100 m. (328 ft.) or 6.4 Revs.

FIG. 3.

FIG. 4.

FIG. 5.

machine, and finally the resistance of the rope to bending. These various factors may be assimilated to a load suspended at the ascending rope and whose moment may be added to the statical moment. This load has been found to be 15 per cent. of the useful load in the trials made on the electric winding-machine at Preussen II.* In the absence of exact data, and also for the sake of simplicity, the moment of resistances may be taken as constant during the whole winding, and a value given equal to 15 per cent. of the maximum statical moment of the loads. The value of the statical moment, including resistances, is measured by the ordinate of the curve X_0X_{10} by lowering the axis of abscissæ an amount CK_0 equal to 15 per cent. of the maximum moment C_1X_1 .

To the statical moments must further be added the moments of the accelerating forces required for the moving masses. These masses are fixed to the shaft of the motor and participate in its rotation. The moment of the accelerating forces may be deduced from the moment of inertia I of the moving masses referred to the shaft of the motor, and from the law of rotation of the shaft, as will be shown further on.

For the purpose of determining the moments of inertia of the masses, it will be convenient to consider the following:—

- (1.) The masses of the loads suspended on the rope.
- (2.) The masses of the rope-rolls.
- (3.) The masses of the head-gears.
- (4.) The mass of the drums and pulleys.

Moments of Inertia of the Suspended Loads (Figs. 1 and 4, pages 433 and 436).—The suspended loads P may be considered as concentrated at the end of the instantaneous radius ρ of the rope-roll, which is, therefore, also their radius of gyration. The moment of inertia is then—

$$I = \frac{P}{g} \rho^2 = P\rho \rho_g.$$

* See P. Habets, "Les Machines d'Extraction électrique" (2^e article); 'Revue Universelle des Mines,' 4th series, 1904, vol. vi.

$P\rho$ is the statical moment of the suspended load; it will, therefore, be sufficient to multiply the statical moment by $\frac{\rho}{g}$. The moments of inertia may be found graphically from the values of the statical moments of the ascending and descending loads. It may be noticed that in determining the statical moments, the lengths of rope between the winding-gear and the pit's mouth were neglected, which are in equilibrium. But as these lengths are 40 to 50 mètres (131 to 164 feet) they cannot be neglected in making determination of the moment of inertia. New curves of moments $P\rho$ must be determined, by adding to the curve $B_0B_5B_{10}$ the weight of 50 mètres (164 feet) of rope; one thus obtains $B''_0B''_{10}$ which serves to determine the curves of moments $y_0y_5y_{10}$ and $y'_0y'_5y'_{10}$. The latter should be inverted and referred to axis CC' . This operation may be done on the curve of moments of inertia.

Proceeding as follows:—On the ordinate through C , the ordinates of the curves $y_0y_5y_{10}$ and $y'_0y'_5y'_{10}$ are projected, and through the projections thus obtained lines are drawn to pole D in case of curve $y_0y_5y_{10}$ and to pole F in the case of $y'_0y'_5y'_{10}$. One of the moments of inertia that is easy to obtain is next calculated; for instance, the moment corresponding to the small radius of the rope-roll. Taking $\frac{P}{g}r^2$ for the ascending load, its value is Ci_0 ; a horizontal line drawn through i_0 intersects the pole-ray Dy_0 in a_0 ; a vertical through a_0 intersects the pole-rays in points $a_5a_{10}a'_5a'_{10}$; these points are then projected on the ordinate through C , and through the projections thus obtained pole-rays are drawn emanating from poles D or F as the case may be. To obtain the moments of inertia $i_0i_5i_{10}$ and $i'_0i'_5i'_{10}$ of the ascending and descending loads the pole-rays are produced until they intersect the corresponding radius of the rope-roll. In fact, $Aa_0 = Ci_0 = Cy_0 \frac{r}{g}$; $Aa_5 = Vy_5 \frac{r}{g}$; $Vi_5 = Aa_5 \frac{\rho}{r} = Vy_5 \frac{\rho}{g}$, and so on.

Curve $i'_0i'_5i'_{10}$ of the moments of inertia of the descending loads referred to axis HH' must be inverted and referred to the same axis, CC' , as the moments of inertia of the ascending loads. Curve $i''_0i''_{10}$ is thus obtained.

The moments of inertia of the ascending and descending loads are now added, by adding the ordinates of their respective curves. Curve $I_0 I_5 I_{10}$ is thus produced.

Moment of Inertia of the Rope-Roll (Figs. 1 and 4, pages 433 and 436).—The weight P' of the rope-roll may be determined by taking the differences between the weight of rope OB''_0 and the weight of the unrolled rope represented by curve $B''_0 B''_5 B''_{10}$. The moment of inertia depends on the radius of gyration.

In the case of winding on constant radius, the radius of gyration is the same as that of the rope-roll, and it is not necessary to consider the different parts of the rope separately. The useful load of the cages and the ropes is simply multiplied by $\frac{r^2}{g}$.

In the case of conical and spiral drums, the variation of the radius of gyration must be taken into account. When the rope is not taper, the radius of gyration of the rope-roll (radius ρ) is $\frac{r^2 + \rho^2}{2}$,* where r is the smallest radius of the rope-roll. If the rope is taper, the error committed by not taking into account the decreasing thickness of the rope is negligible. The moment of inertia is determined by multiplying $\frac{r^2 + \rho^2}{2}$ by the mass $\frac{P}{g}$ of the rope-roll. The curves $C_0 C'_5 X$ and $OC'_5 C'_{10}$ referred to axis OX represent the moments of inertia of the two ropes.

The two curves are identical, but inverted with regard to each other; the sum of their ordinates will give the total moment of inertia ($C_0 C_5 C'_{10}$) of the rope-rolls.

The latter moment should be added to the moments of inertia ($I_0 I_5 I_{10}$) of the loads, thus determining the total moments $I_0 I_5 I'_{10}$, Fig. 1 (page 433).

Moment of Inertia of the Head-Gears.—The moment of inertia (I_m) of the head-gears may be determined from the drawings. I_m must, however, be multiplied by $\frac{\rho^2}{R_m^2}$, ρ and R_m being the radius

* The moment of inertia of that part of the rope which is never unrolled is constant, and may be added to the moment of inertia of the winding-gear.

of the rope-roll and head-wheel-rim respectively; the two sets of reduced moments of inertia are represented by the ordinates to curves $m_0 m_5 m_{10}$ and $m'_0 m'_5 m'_{10}$ (referred to OX). These curves are identical but inverted with regard to each other; by adding their ordinates, the total moments of inertia ($M_0 M_{10}$) of the head-gears are found. The ordinates to curve $I''_0 I''_5 I''_{10}$, Figs. 1 to 5 (pages 433 to 437) are equal to the sum of the ordinates to curves $M_0 M_{10}$ and $I_0 I_5 I_{10}$.

Moment of Inertia of the Winding-Gears and of the Motors (Figs. 1 and 4, pages 433 and 436).—The moment of inertia of the drums, brake-drum and gearing may be determined by referring to the drawings. In the case of electric driving, the moments of the motors must be added. The moment of inertia of the winding-machinery is constant, and must be added to the moment determined above. This may be done by setting its value CU off from CC' downwards; the ordinates of curve $I''_0 I''_5 I''_{10}$, referred to UV as axis of abscissæ, will then be a measure of the total moment of inertia. The curve $I''_0 I''_5 I''_{10}$ may be called the "Characteristic of Inertia" of the winding-engine.

Speed of Rotation of Machine-Shaft.—The moments of the accelerating forces may be determined by the total moment of inertia and by the speed of rotation of the motor-shaft.

For this purpose, curve $I''_0 I''_5 I''_{10}$ must be referred to abscissæ representing time. The abscissæ of $I''_0 I''_5 I''_{10}$ are proportional to the number of revolutions made by the motor-shaft, and the total number of revolutions of this shaft during each draw is 64, so that each division of the axis of abscissæ will represent 6.4 revolutions. The time required for each revolution must also be known, if the relation between speed and time is to be determined. This depends, however, on the manner in which the machine is manipulated by the driver.

There are two simple cases:—

(1) Starting with a uniformly accelerated angular velocity, which implies a constant angular acceleration.

(2) Starting with a uniformly decreasing angular acceleration. Analogous laws may be adopted during the period of retardation.

The first case has been adopted in connection with the data supplied by M. Troussart, by allowing a time of fifteen seconds to get up a speed of 42 revolutions per minute, which is an angular velocity $\omega = \frac{2\pi \times 42}{60} = 4.39$ radians per second; the constant angular acceleration is thus $\frac{4.39}{15} = 0.292$; the rate velocity is maintained 77 seconds, and the stopping is effected in 14 seconds with a constant negative acceleration $\frac{4.39}{14} = 0.313$. Curve *OMNX* (Figs. 2, 3 and 5, pages 434, 435 and 437) represents the variation of the angular velocity. The integral of *OMNX* for a given abscissa t represents the total angle Ω through which the motor-shaft has turned since starting, and by dividing Ω by 2π , the total number of revolutions made by the shaft during time t is obtained.

The curves which represent the relation between the statical moments (X_0X_{10} , Figs. 1 to 5) and time, and also between the moments of inertia ($I''_0I''_{10}$) and time, can now be drawn, by taking the ordinates of these curves, Fig. 1 (page 433), which correspond to each revolution.

Moments of the Accelerating Forces.—The energy exerted by the accelerating forces during time t is $\frac{\omega^2}{2} I$, where ω is the angular velocity at the end of time t and I the moment of inertia ($I''_0I''_{10}$).

If M be the moments of the accelerating forces, then the energy exerted by these forces during time t may also be expressed by $\int_0^t M \omega dt$; hence

$$\int_0^t M \omega dt = \frac{\omega^2}{2} I.$$

As M , ω and I are functions of t , by differentiation the following is obtained :

$$M\omega = I\omega \frac{d\omega}{dt} + \frac{\omega^2}{2} \frac{dI}{dt}, \text{ or}$$

$$M = I \frac{d\omega}{dt} + \frac{\omega}{2} \frac{dI}{dt}.$$

$\frac{d\omega}{dt}$ is constant during the period of acceleration and retardation, and is zero during the period of constant speed. Multiplying the ordinates of curve $I''_0 I''_{10}$ by the corresponding values of $\frac{d\omega}{dt}$, and then adding the results (algebraically) to the ordinates of $X_0 X_{10}$, the portions AB and CD , Fig. 2 (page 434), are obtained.

For the purpose of calculating $\frac{\omega}{2} \frac{dI}{dt}$, the derived curve of $I''_0 I''_{10}$ is graphically constructed. The ordinates of this new curve ($i_0 i_{10}$), estimated from the line through i_0 as axis of abscissæ, are now multiplied by the corresponding values of $\frac{\omega}{2}$ taken from $OMNX$, and the results are added (algebraically) to the ordinates of $ABX_1 X_0 CD$. In this manner the total torque ($AB'B''C'D$, Fig. 2) which must be exerted by the motor at any instant is obtained.

It will be seen that the torque varies considerably; it attains a maximum of 16,500 kg.-m. (119,345 ft.-lbs.) at the end of the period of acceleration, and then suddenly drops to 10,000 kg.-m. (72,330 ft.-lbs.) at the beginning of the constant speed period; during this period the maximum value is 10,600 kg.-m. (76,670 ft.-lbs.), and the minimum 5,200 kg.-m. (37,612 ft.-lbs.). The torque is negative during the period of retardation.

Power and Expenditure of Energy.—The torque of the motor multiplied by the corresponding value of ω is the power which must be developed at each moment. This power is represented by curve $O EFGHX$ (Figs. 2, 3 and 5), the integral of the latter is the energy spent during each draw.

At the end of the acceleration period, the power attains a value of 950 H.P., whilst during the constant speed period, it varies between 620 and 370 H.P.; the latter figures differ from those

found by M. Troussart, which have undoubtedly been found by a less exact method than the one adopted by the author.

The case of uniformly decreasing acceleration has also been treated; the results are indicated by the curves, Fig. 3, which are marked with the same letters as the corresponding curves in Fig. 2; it may be noticed that the curve *OM*, which represents the variation of the angular velocity ω during the acceleration period, is the integral curve of the straight line which represents the variation of the acceleration $\frac{d\omega}{dt}$. It will be seen that although a rather greater torque is required during the acceleration period, which is not difficult to obtain with an electric motor, the power required varies much less. It would, therefore, be advantageous to start the machine with a decreasing acceleration.

It might be asked whether the power would not be less variable if the radii of the rope-roll were chosen so as to make the statical moments less regular. The author has treated the machine at Grand Hornu with regard to this question for $r = 1.10$ m. (43.4 ins.) instead of 1.20 m. (47.24 ins.). The results are shown in Figs. 4 and 5 (pages 436 and 437), the same letters as on Figs. 1 and 2 (pages 433 and 434) being used all through. It will be seen that the power diagram is much more regular. The ordinates of the power diagrams which have been determined should be divided by the efficiency of the motor so as to obtain the total power spent; the integral of the latter curve would give the total energy required. The useful work divided by this energy is the efficiency of the winding-machinery. The efficiency of electrical motors differs with the kind of motors and their starting devices.

ELECTRIC MOTORS FOR WINDING: THEIR STARTING PROPERTIES.

The machines used for electric winding are either three-phase asynchronous motors or continuous-current motors. The latter may be shunt-wound, or separately excited. Both types of machines possess a remarkable degree of self-regulation, that is, their speed only varies slightly with a considerable variation of

load.* This property makes the machine very easy to manipulate. The driver need not trouble about the speed, as it never exceeds the normal speed much, even when the resisting torque is negative, in which case the motors turn into generators sending energy back to the station. Continuous-current series machines, although used for electric traction, are not suitable for winding, as they run away when the load diminishes. The advantage of a better starting torque, which these machines can furnish, is, however, only relative, as motors of the other types can easily produce torques three or four times the normal one. Such torques are necessary, as the resisting moment at the end of the acceleration period is often double that at other velocities.

The starting of electric motors requires special contrivances, on the design of which the consumption of energy during acceleration depends. It has been shown that during the acceleration period the motor must develop a torque given by curve AB' , Figs. 2, 3, and 5, in the cases already treated.

As the author wishes to discuss the starting properties of these motors more thoroughly, he thinks it would not be out of place to give a short account of their mode of working.

Three-phase Asynchronous Motors.—The torque produced by a polyphase asynchronous motor is (1):—

$$C = \frac{K^1 H^2}{r} \times \frac{\omega_1}{1 + \frac{\omega_1^2 L^2}{r^2}} = K^1 H^2 \frac{1}{\frac{r}{\omega_1} + \frac{L^2}{r}}.$$

K^1 is a coefficient; H the rotary magnetic field due to the inducing currents; ω_1 is the slip which is equal to the difference of the angular velocities (ω) of the rotary field and (ω^1) of the induced field or rotor; r the electric resistance of the rotor circuits; L their coefficient of self-induction.

The angular velocity ω is equal to $\frac{2\pi f}{2p}$, where f is the frequency of the current and $2p$ the number of inductor-poles.

* On condition that the difference of potential between the terminals of shunt or separately excited machines is constant.

Under normal conditions, the velocity ω^1 does not differ more than 2 or 3 per cent. from ω , hence $\omega_1 = 0.02$ to 0.03ω .

When the intensity of the field is constant, the torque will be a function of the slip only. In curve I, Fig. 6, the ordinates represent the torque, and the abscissæ, which are reckoned positive to the left of the origin O , represent the slip. When the slip is zero the torque is also zero; and if the rotor was driven at a speed ω^1 larger than ω , due to a negative resisting moment, the

FIG. 6.

FIG. 7.

*Liquid Rheostat at Preussen II.
and at Grand Hornu.*

motor would become a generator and would oppose the resisting moment. Curve I also shows that in the neighbourhood of synchronism, the torque of the motor may vary between wide limits without causing much variation in speed.

When ω_1 increases progressively from zero, the torque will also increase progressively, and becomes a maximum when $\frac{r}{\omega_1} + \frac{\omega_1 L^2}{r}$

is a minimum, that is, when $\frac{r}{\omega_1} = \frac{\omega_1 L^2}{r}$ or $\omega_1 = \frac{r}{L}$; the maximum torque will be $C_{\max} = \frac{K^1 H^2}{2L}$. The torque will now diminish as ω_1 increases progressively from $\frac{r}{L}$, and when ω_1 is equal to ω , then ω^1 will be zero and the motor will come to a standstill; then—

$$C = \frac{K^1 H^2}{r} \times \frac{\omega}{1 + \frac{\omega^2 L^2}{r}}$$

It will be noticed that the torque changes sign with ω_1 , that is, it becomes a resisting moment when ω_1 is greater than ω . The maximum torque may attain a value three to four times greater than the normal torque corresponding to $\omega_1 = 0.02$ to 0.03ω .

Curve 1, Fig. 6, shows how the current varies with ω_1 ; it will be seen that at starting (standstill of rotor), the current is notably stronger than at the normal speed. In the case of powerful motors (above 5 or 7 H.P.), a current of such strength cannot be taken from the mains without causing an inadmissible fall of voltage, nor are the motors designed to carry such a current; the small torque which corresponds to $\omega_1 = \omega$ is not sufficient to start the rotor, especially if it has to drive a winding-machine.

For this reason, some contrivance must be adapted by which the torque can be increased and the current reduced.

Starting Rheostat.—The only method which has been used with three-phase motors for driving winding machinery consists in inserting variable resistances r^1 in series with the three circuits of the rotor. Substitution must therefore be made of $r + r^1$ for r in the formulæ, if r^1 is non-inductive. The maximum torque may thus be produced when the slip is $\omega_1 = \frac{r + r^1}{L}$, and by giving r^1 a value which will make $\omega_1 = \omega$ the maximum torque at starting will be arrived at. These conditions are represented by curves VI and 6. The resistance r^1 inserted in the rotor circuits prevents the currents from rising too much, notwithstanding the large slip ω_1 , and hence the currents in the inductors will not exceed the normal strength. By reducing the resistance r^1

successively, the torque and current curves change respectively to V, 5; IV, 4; III, 3; II, 2; and finally to I, 1, when the last resistance has been cut out.

The use of a starting rheostat causes considerable loss of power during the period of acceleration. The current will be proportional to the resisting moment given by curve *AB'*, and as the voltage is constant, the electrical energy absorbed will be equal to this moment multiplied by the angular velocity and the efficiency of the motor at such a charge. This loss will be less felt when the startings are less frequent; when the pit is very deep, the period of acceleration will be small compared with the period of constant speed. With regard to simplicity, this method is certainly superior to any other, and for this reason it is always adopted where three-phase motors are used for driving winding machinery.

The Allgemeine Elektrizitäts Gesellschaft of Berlin have designed a rheostat with liquid resistance, consisting of two vessels, the one above the other. The liquid is kept in motion by a small centrifugal pump driven by an electric motor of 2 to 3 H.P. The pump takes the liquid from the lower vessel and forces it back into the upper vessel in which three metallic plates (one for each rotor circuit), electrically insulated, are suspended, Fig. 7 (page 446). The upper vessel has an overflow, and the plates are only immersed to a depth corresponding to the required resistance. By manipulating the starting lever, which works the reversing switch and closes the inductor circuit, a stop-valve V_2 will be closed; the level of the liquid in the upper vessel will therefore rise, and the plates will be more and more immersed. The rate at which the water rises can be regulated by a cock on the inlet pipe. The maximum speed of the machine is reached when the liquid has risen up to a second overflow, which is always open and which causes the liquid to overflow continually from the upper vessel into the lower one. The circulation of the liquid prevents it from getting heated. When the lever of the reversing switch has been pushed home, to the right or left, according to the direction in which the machine is to turn, it may be moved

back through a certain angle without breaking the circuit. In doing this the stop-valve is gradually opened so that the water can run out again and the speed will be reduced as desired. The circuit will not be broken until the lever is turned back into its vertical position; as the level of the liquid is falling steadily, the current as well as the speed of the motor will be gradually reduced; the interruption therefore will not be sudden.

The immersion of the plates may be further limited by an overflow V_1 so as to reduce the speed when persons are carried up and down. When the pit or the ropes are to be examined, the speed may be still further reduced by regulating V_1 . The conditions, when using starting resistances, are very unfavourable to the electric brake; one cannot count on recovering the energy, but one must try to utilize the energy stored in the moving masses as much as possible, and to let the cage arrive at the mouth of the pit with a much reduced speed which will only require the brake for holding the cage.

The intermittent working of winding machinery and the increased energy wanted for starting a three-phase motor with the rheostat causes sudden and irregular demands on the generators at the power-station. The latter machines are to be designed accordingly large enough and supplied with sufficiently heavy fly-wheels. If this is not the case the result will be a fall of speed and voltage which will be felt all over the area of distribution; this is the case at Preussen* and even at the coal mines at Grand Hornu, where the generating plant comprises engines, one of 2,100 H.P. with 75 tons fly-wheel, and one of 4,200 H.P. with 100 tons fly-wheel. This engine is to be worked with three winding-machines. Only one is at work at present with the 2,100 H.P. engine. The electrical energy delivered varies from 300 kw. to 900 kw., and the fall of voltage is about 10 per cent.

Direct driving of winding-machinery by asynchronous motors requires generators capable of standing a considerable overload,

* See Paul Habets, "Les machines d'extraction électriques." 'Revue Universelle des Mines,' 4th series, 1904, vol. vi.

and the installation of very powerful sets at the power-station. This means an increased expenditure for extra boilers, steam engines and alternators, but, on the other hand, the use of three-phase machines is much simpler and much less costly than transforming alternating currents into continuous currents.

Continuous-Current Motors.—The fundamental equations for continuous-current motors are (1):—

$$i = \frac{E - e}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)^*$$

$$p = i e = i n N \mathfrak{N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$c = \frac{i n \mathfrak{N}}{2 \pi} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\omega^1 = 2 \pi \frac{N}{60} = \frac{2 \pi}{60} \left[\frac{n \mathfrak{N} E - 2 \pi r C}{n^2 \mathfrak{N}^2} \right] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$\omega^1 = \frac{2 \pi}{60} \times \frac{E - i r}{n \mathfrak{N}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

i is the current passing through the armature.

E the difference of potential between the terminals.

e the counter electromotive force.

r the resistance of the armature.

p the mechanical power given off.

n the number of inductors on the armature.

$\mathfrak{N}$ the total number of magnetic lines through the armature.

N number of revolutions per minute.

ω^1 the angular velocity of the armature.

Shunt motors and separately excited motors possess somewhat similar properties, at least when they are supplied at a constant difference of potential. In separately excited motors the flux $\mathfrak{N}$ is constant, save for the slight reduction due to armature reaction. The torque (3) in this case is proportional to the current i . When the motor is supplied with a constant current, its torque is also constant, and its speed (4) is proportional to the difference of potential between the brushes. By varying the difference of potential, the motor could be worked with a constant torque at

* See "Principes d'Electrotechnie," par Em. Piérard, page 138 and following.

different speeds, provided that the current through the armature is kept constant. Under these circumstances the mechanical characteristic of the motor, that is, the curve which represents the torque as a function of the speed, will be a straight line parallel to the axis of abscissæ, Fig. 8. The machine may then be started with any desired torque by progressively increasing the difference of potential between the brushes.

FIG. 8.

FIG. 9.

Auxiliary Starting Dynamo.

If the constant difference of potential be maintained, the current in the armature will always be strong enough to produce a torque which can overcome the resisting moment (3); the speed varies with the torque; when the torque is zero, the speed will be

$$\omega^1 = \frac{2\pi}{60} \times \frac{E}{n\mathcal{R}}.$$

This is the maximum theoretical speed which the motor can attain when running with no load; the current in the armature is then zero, and the counter electromotive force is equal to the difference of potential between the brushes.

On account of the losses of energy due to hysteresis, eddy currents and mechanical friction, the torque of the motor will become zero before the current and at a lower speed. When the resisting moment becomes negative, tending to drive the motor at a speed greater than $\omega^1 = \frac{2\pi}{60} \times \frac{E}{n\mathfrak{N}}$, then the counter electromotive force e will be greater than E ; the current in the armature will be reversed and will flow from the motor back into the mains; and the motor becomes a generator and acts as a brake by transforming the mechanical energy which it receives into electric energy. As soon as there is a resisting moment, the speed will fall below $\frac{2\pi}{60} \times \frac{E}{n\mathfrak{N}}$, and the current absorbed by the motor will be just sufficient to produce a torque equal to the resisting moment. The relation between ω' and C is represented by a straight line (4), passing through the point corresponding to $\omega^1 = \frac{2\pi}{60} \times \frac{E}{n\mathfrak{N}}$, and inclined slightly towards the axis of ordinates (Fig. 8, page 451); the ohmic resistance of the armature r is small, and hence $\frac{2\pi r}{n^2 \mathfrak{N}^2}$ is also very small. The speed is therefore practically constant for all loads; it varies between the values OB and OB' for loads between $+C'$ and $-C'$ (Fig. 8). Separately excited motors supplied at constant difference of potential possess therefore the same self-regulating properties as three-phase motors. The same is the case with shunt motors, which behave, when supplied at a constant difference of potential, like separately excited motors.

When a shunt motor is supplied at a constant voltage, the field current as well as the flux will be constant, and the motor will therefore behave like a separately excited machine. It is however not always possible to keep the flux constant; for instance, when starting the motor, the mains will be almost short-circuited through the armature, whose resistance is very small, and this causes a momentary fall of potential across the terminals, resulting in the field-current, and therefore also the flux, being reduced.

For this reason, a resistance must be inserted in the armature-circuit to prevent the armature-current from exceeding three or four times its normal strength. The field-current, and therefore also the flux, will remain constant, as they are not affected by the resistance. The resistance is now gradually reduced, as the speed of the motor and, therefore, also the counter electromotive force increase, and in this manner a constant armature-current as well as a constant torque may be maintained. Under these conditions, a shunt motor will behave like a separately excited machine supplied with a constant current. Continuous-current motors may be started without much loss of energy, and the different methods which have been used for this purpose will now be examined.

1. *Starting Rheostat*.—This method is used when a shunt motor is connected across a pair of mains, between which a constant difference of potential is maintained. A buffer-battery may also be inserted across the same mains. The field current is thus constant.

A variable resistance R is inserted in series with the armature. If the difference of potential between the brushes be E^1 , the power absorbed in the resistance will be $(E - E^1) i = i^2 R$.

During the period of acceleration, the resistance R is reduced progressively, and the current i , and therefore also the torque C , may be kept constant; this requires that $E^1 - e$ must also be kept constant.

The speed cannot be kept quite constant independent of the load, with the resistance R inserted. This resistance increases the ohmic resistance of the armature. The relation between the torque C , and the speed (4) will be found by substituting $r + R$ for r . This relation is represented by a straight line through the point corresponding to $\omega^1 = \frac{2\pi}{60} \times \frac{E}{nR}$, and the inclination of the line towards the axis of ordinates will be the greater, the greater R is. The straight lines AR , AR' , AR'' , &c., Fig. 8 (page 451), which correspond to increasing values of R ,

show that the greater the resistance is, the more will the speed increase in proportion to the torque.

This method of starting a shunt motor causes the same loss of energy as is found with three-phase motors.

2. *Series-Parallel Method.*—When using two motors for driving the winding-machinery, the starting may be done by the series-parallel method, the same as used for regulating the speed of electric tramcars. It consists in starting the two motors by connecting them in series; the difference of potential across each armature, if no resistance is inserted, will be $\frac{E}{2}$.

The normal speed will thus be reduced to half; when later on the motors are connected in parallel and the total difference of potential E is applied across the armature, the full speed will be attained. For the purpose of preventing jerks, while switching over from series to parallel, a kind of rheostat (controller) must be used.

This method of starting gives a more satisfactory efficiency than the preceding methods, but the two motors together cost more than one motor of the same total power, and the circuit controller is complicated.

This principle has been adopted by Messrs. Siemens and Halske at the Thiederhall Mines, at Thiede, near Brunswick.

By using electric sources with variable pressure, the voltage between the brushes may be varied. For this purpose, a battery of accumulators split up into sections may be used, or a special generator, or an auxiliary dynamo.

3. *Batteries in Sections.*—A battery of accumulators, which is inserted across the mains, is split up into sections; the latter are, however, connected in series so as to make up a total voltage equal to the pressure between the mains. During the period of acceleration, the brushes of the motor are connected across one or more sections of the battery, the number of sections being increased as the speed of the motor rises; the normal speed will be attained when all the sections are switched on.

The motor may be reversed by reversing the connections between the brushes and the poles of the battery (the current in the armature will thus be reversed), and the different sections of the battery will then be equally discharged, provided that their number is even.

The motor will have as many normal speeds as there are sections; for instance, four sections will give normal speeds equal to $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and full speed. For the purpose of avoiding jerks when switching a new section into the motor circuit, a rheostat must be used. The total resistance R required for each battery section must be equal to the resistance of the armature; R is however subdivided into smaller resistances, which are cut out progressively as the speed of the motor increases.

The economy of this system as compared with that of the armature-rheostat is only obtained by great complications, which was shown, only too clearly, in the case of the winding-machine at pit No. II. Zollern, installed by Messrs. Siemens and Halske.

4. *Special Generator*.—In this system the winding-motor is separately excited by a constant current, and the difference of potential is varied, and therefore also the speed, by regulating the electromotive force of the generator, which supplies the motor, by means of a field rheostat; the loss of energy is almost nil. But as one cannot use a buffer-battery, the generator must be able to stand all the variation of the load, and the engine which drives the generator will be running on no load during the stoppages. The work of the engine might be equalised by providing it with a large fly-wheel, which could store up the energy during the stoppages of the winding machines; or the engine might drive another generator, which, in connection with a buffer-battery, could supply a circuit at constant pressure. It is, however, always necessary to have reserve sets at the power-station, and this makes the undertaking costly. The use of a special generator is not practical unless the winding machinery is close to the supply-station. This system has been adopted by the Allgemeine Elektrizitäts-

Gesellschaft in 1895 at the Hollertszug mines, and recently for two machines at the Alexandre pits of the Arnim Collieries at Planitz, near Zwickau, in Saxony.

The system of a special generator may be worked more economically by adopting high-tension three-phase currents. In this case, the special generator is driven by an asynchronous motor, and the two machines are installed close to the winding machinery; by using high-tension currents, the distance from the power-station is not of much importance.

For the purpose of storing the energy during the stoppages of the winding-machinery, M. Ilgner uses a large flywheel mounted on the shaft of a motor-generator, the latter consisting of an asynchronous motor and a continuous-current generator. As the motor-generator is running continuously, the current from the supply-station will not vary much. The mean power is also less than in the case of an asynchronous motor driving the winding-machinery direct. The continuous-current generator, as well as the winding motor, is excited by a small continuous-current machine driven by an asynchronous motor. This system has been adopted by the Allgemeine Elektrizitäts-Gesellschaft at the pits of St. Nicolas at the collieries of Espérance and Bonne-Fortune, Montegnée, near Liège. The installation, together with the results of some trials, will be described further on in the Paper. Messrs. Siemens and Schuckert have adopted the Ilgner fly-wheel system to the machine at pit No. II. Zollern.* In this case the motor is a continuous-current machine.

5. *Auxiliary Starting Dynamo.*—In this system, the armature of the winding motor *M*, Fig. 9 (page 451), is connected in series with the armature of an auxiliary dynamo *Da*, across the mains of a constant-pressure circuit and a buffer battery can also be inserted; the fields of both machines are connected direct to the mains. The auxiliary dynamo is driven, at a constant speed, by the steam-

* See Paul Habets, "Les machines d'extraction électriques." 'Revue Universelle des Mines,' 4th series, 1904, vol. vi.

engine G working a set of dynamos. The field is regulated by a rheostat, and the electromotive force generated in the armature opposes the pressure between the mains. When the difference of potential E'' between the brushes is equal to the pressure between the mains, no difference of potential will be available at the brushes of the winding motor M , which will therefore be at a standstill. By reducing the resistance R , the difference of potential E' between the brushes of M will be $E' = E - E''$; a torque will now be exerted by M which will be increased by reducing E'' . When the motor M has attained its full speed, the counter electromotive force in the armature of Da should be as near zero as possible, and E'' should only be sufficient to overcome the resistance of the armature. The dynamo Da works therefore as a motor, aiding the steam-engine; but when the resisting moment becomes negative, then the auxiliary dynamo will work as a generator, taking energy from the engine. The current will now flow against the pressure of the mains, and the energy generated by M , which has also become a generator, will increase, and therefore cause M to go slower. In this manner the auxiliary dynamo will keep the speed of M almost constant. The speeds as well as the startings are obtained without other losses than those due to driving the auxiliary dynamo. It is, however, inconvenient to have to regulate the field of the dynamo if this machine cannot be placed near the haulage motor.

The auxiliary dynamo may be driven by a motor. The two machines mounted on the same shaft constitute a booster, which may be connected with the mains and the winding motor in different ways, but can be placed close to the winding-machine. This arrangement makes the winding-machine more independent of the power-station, which may be at a considerable distance from the pit.

6. *Starting. Boosters.*—The booster, which has just been described, consists of an auxiliary dynamo with a field rheostat driven by a shunt motor which receives current from the mains. With regard to economy, the booster is inferior to an

auxiliary dynamo driven by an engine, because the efficiency of the booster is less, on account of the double transformation of energy. The cost of installation is higher, as the motor and the auxiliary dynamo of the booster must both be of the same power as that of the winding motor. The speed of the booster may however be high, whilst the winding motor, being direct coupled to the winding-machine, cannot have a speed exceeding 50 to 60 revolutions per minute.

By reversing the field-current of the auxiliary dynamo, the booster will work as a booster proper, that is, it will raise the voltage of the mains. Matters might therefore be arranged so that the pressure of the circuit will be doubled when the winding motor is running at full speed. Under these conditions, the power of each of the booster-machines need not be more than half of that of the winding motor, thus making the booster less costly. For this purpose, the voltage of the winding motor must be twice that of the mains, and one must therefore either reduce the pressure of the distributing system or design a high-tension motor, which with continuous-current machines is difficult when the tension exceeds 500 volts. The problem may also be solved by driving the winding-machine by two motors connected in series, each of which will therefore only receive half of the total voltage.

The latter system, which was brought forward by the Union Elektricitäts Gesellschaft, has been adopted by Messrs. Schuckert and Co. in the case of the winding-machine at the Friederich-Franz mine at Lüththeen (Mecklenburg). Fig. 10 is a diagram of connections. An Ilgner fly-wheel may be mounted on the booster shaft. This solution has been applied by W. Lahmeyer and Co. to the winding-machine of the Tiremonde pit of the Mining Co. of Liguy-les-Airs. For the purpose of bringing the fly-wheel into proper play, a second booster is connected in series with the armature of the starting booster, in such a manner as to vary the speed of the latter automatically, and also inversely as the strength of the armature current of the winding motor.

M. Creplet reduces this group to a single dynamo, the shaft of which carries a special fly-wheel. As it is possible to allow a great

variation of speed for this dynamo, the fly-wheel can be much reduced. A machine on this system has been installed by the Compagnie Internationale d'Electricité de Liège for the Fléron pit of the Hasard Collieries at Micherot, near Liège.

Very few trials on electrically-driven winding-machines have been published up to the present time; the trials made on the machine at pit No. II. Preussen afford a unique account of the working of a machine driven by a three-phase motor.* A great number of trials have been made on the machine installed

FIG. 10.

at St. Nicolas, at the collieries of Espérance and Bonne-Fortune, Montegnée, and a detailed description will now be given of this installation, together with the results obtained.

IV. *Electrically-driven Winding-Machines at the pit of St. Nicolas at the Collieries of Espérance and Bonne-Fortune, Montegnée.*

1. *Description of the Installation* (Fig. 11, page 461).—The machine was supplied by the Société Belge d'Électricité A.E.G.

* See Schulte, "Glückauf," No. 13, 26 March 1904, and P. Habets, "Les machines d'extraction électriques"; 'Revue Universelle des Mines,' 4th series, 1904, vol. vi.

It is designed to draw 500 tonnes (492 tons) from a depth of 800 m. (2,625 feet) in eight hours. The loads are: four tubs holding 535 kgs. (1,102.3 lbs.) of coal or 750 kgs. (1,653.4 lbs.) of stone; each tub weighs 250 kgs. (551.1 lbs.) and the cage weighs 1,800 kgs. (1 $\frac{3}{4}$ tons). The electric energy is supplied from the power-station, which was constructed in 1899, at the pit of *Espérance*, and which contains three sets of three-phase generators working at 1,000 volts and with a frequency of 44; the output of each machine is 200 kw. Two of the sets also supply current for pumping, ventilation, picking, etc., at the pits of *Espérance* and *St. Nicolas*; the third is a reserve set.

The coal is drawn from four underground landing-stages at depths of 368 mètres (1,207 feet), 342 mètres (1,122 feet), 288 mètres (945 feet), and 185 mètres (607 feet). On account of the nature of the deposition of the beds and the extent of the field of exploitation, it may eventually be necessary to draw simultaneously from several seams, which will require one or two stoppages during each lift. The time spent in unloading the cage at the bank of the pit, and simultaneously loading the cage at the bottom landing-place, is 30 seconds, and loading the cage at intermediate landing-stages takes 20 seconds. Under these conditions, the maximum winding speed need not exceed 12 mètres (39 feet 4 $\frac{1}{2}$ inches) in order to draw a total of 500 tonnes (492 tons) from a depth of 800 mètres (2,625 feet). When the depth is less or the tonnage is smaller, the speed may be slower. Local circumstances have led to the adoption of a Koepe-pulley with a central groove for a flat-wire rope, and two brake-rims, one on each side of the groove. The motor and the Koepe-pulley are mounted on the same shaft; the diameter of the pulley is 3 mètres (9 feet 10 $\frac{1}{8}$ inches) and requires therefore only a medium size motor. The winding speed is 10 mètres (32 feet 9 $\frac{3}{4}$ inches) when the motor makes 64 revolutions per minute.

Notwithstanding the high frequency, a three-phase motor might have been designed for this slow speed. Preference has however been given to a continuous-current motor; and a motor-generator of the *Ilgner* type, consisting of a three-phase motor

FIG. 11.—*Winding-Engine Installation.*
(See also Fig. 12, page 463.)

and a continuous-current generator, has been adopted for the following reasons :—

During the period of acceleration, the three-phase motor would have absorbed 615 H.P., a power which the central station would not have been able to supply with the present plant. Besides, a three-phase motor with a starting rheostat is very wasteful, and the loss of power in this case would have been still higher on account of the intermediate stoppages.

Notwithstanding the conversion of the three-phase current, the motor-generator is in this case more economical, as it almost entirely prevents any losses during acceleration, and during the slow speed, which must be adopted when the winding is reduced, and also during the night-shift. A motor-generator with an Ilgner fly-wheel will also equalise the demand on the power-station, no matter how the load varies. The power-station will then be able to supply the other motors, if the pumping is done during the night.

The winding motor M, Fig. 12 (page 463), is a separately excited continuous-current machine, its rated power is 320 H.P. at 64 revolutions per minute, and at 500 volts. It will carry an overload of 40 per cent. for half-an-hour, and of 100 per cent. for 5 minutes. It will reverse, without moving the carbon brushes, and gives no sparking even when the voltage is considerably reduced.

The terminals of the winding motor are electrically connected with the generator G_1 , Fig. 12, of the Ilgner motor-generator M_1-G_1 ; and a maximum current release, which acts when the current reaches 1,500 ampères, is inserted in one of the leads. The output of the continuous-current generator, which is separately excited, is 650 kilowatts at 500 volts, when making 285 revolutions per minute; the rise of temperature, measured by the increased resistance, does not exceed 45° . The carbon brushes have no lead, even when the machine is generating the maximum current required by the motor. The machine will also generate the current without sparking, at voltages varying between zero and ± 500 . These results are due to the large proportions of the generator, whose power is more than double that of the winding motor.

FIG. 12.—*Diagram of Installation.*
(See also Fig. 11, page 461.)

The generator and the winding motor are of similar design. The cast carcass carries the pole-pieces of laminated iron, which are fixed by bolts in such a manner that they can be removed laterally without dismounting the armature. The field-coils are protected by the carcass, and the bobbins are divided into sections for the purpose of ventilation. The armature is a drum, the conductors being tooled and placed in the grooves of the sheet-iron core; the openings between the conductors allow of an effective cooling by circulation of air.

The winding motor M and the generator G_1 are both excited by a small motor-generator M_2-G_2 , which supplies a continuous current at 110 volts. This motor-generator consists of a 27-H.P. asynchronous motor M_2 —supplied with current from the power-station and making 820 revolutions per minute—and an 18 kilowatt continuous-current shunt-generator G_2 .

The armature of the main generator G_1 is mounted on the end of the shaft, which also carries, between its two bearings, a fly-wheel of cast steel, 4 mètres (13 feet $1\frac{1}{2}$ inches) in diameter and weighing 40 tonnes (39.3 tons). The rotor of the asynchronous motor M_1 , which drives the Ilgner-group, is mounted on the other end of the shaft; it will exert 250 H.P. at a continuous run of 285 revolutions per minute. For the purpose of inserting a liquid rheostat in the rotor circuits, on starting the machine, the rotor is provided with slip-rings. An electro-magnetic brake F when excited will generate eddy currents in the fly-wheel rim, and will stop the motor-generator in about a quarter-of-an-hour. Without this contrivance, it would take several hours to bring the machines to a standstill on account of the large amount of energy stored in the fly-wheel.

The bearings of the motor-generator are lubricated by means of rings; the steps are cooled by circulation of water from a vessel at a higher level. The water flows into the grooves of the bearings, and into the reservoir of the starting rheostat, and falls into a cistern. A small centrifugal pump, worked by a 2 H.P. asynchronous motor M_4 , takes the water back to the high-level vessel. The pump can lift 5 litres (1.1 gallon) of water per

second through a height of 15 mètres (49 feet $2\frac{1}{2}$ inches), and forces the water as a spray against a cooling screen.

The reversing of the winding-motor is brought about by manipulating the lever L_1 of a controller. According to the position of the lever, the following will take place: (1) reversing of the field-current of the generator G_1 , whereby the rotation of the winding-motor M will be reversed; (2) reducing the field-current of the winding-motor and interrupting the field-circuit of the generator, when the motor is stopped; (3) increasing the field-current of the generator progressively, by cutting resistances out and thus causing the voltage of the generator as well as the speed of the motor M to increase progressively. While the lever L_1 is turned back towards the position "stop," the counter electromotive force generated in the winding-motor (driven by the inertia of the moving masses) will become higher than the electromotive force generated in G_1 . The motor will become a generator and will act as a brake, thereby reducing the period of retardation.

The Koepe-pulley K is provided with two brake-rims. The brake, which is worked by compressed air, is only used by the driver for holding the pulley during the standstill of the machine, and is manipulated by means of a lever for admitting the compressed air into the cylinder. It also acts as a safety-brake when the three-phase circuit is interrupted. An electro-magnet E , excited by the field-current, will then be demagnetised; a counterpoise will be released and the brake will be brought into action. The brake will also act when the maximum release breaks the circuit, as the field circuit will also be interrupted. When the cage overshoots the landing-stage, the indicator, showing the travelling of the cages, will cause the maximum release to break the circuit, and the brake will consequently be brought into action. The brake may also be applied by working the pedal P , which will release a counterpoise.

The retardation is also brought about by the indicator, which causes the lever L_1 to be moved towards the position "stop," as the cage approaches the pit-bank. This automatic movement is often limited, so as to allow the driver to finish the "lift," and to

manipulate the machine. The compressed air required for the brake is supplied by a small compressor driven by a 5-H.P. three-phase motor at 120 volts.

The different machines and apparatus, as well as the electrical connections, are shown in Fig. 11 (page 461), and Fig. 12 (page 463).

2. Description of the Trials and the Results.—The winding-machine just described has been submitted to a series of trials with the object of giving an account of the performance of the Ilgner system; also of testing the consumption guaranteed by the contractor, and finally of determining the consumption of energy under actual working conditions. The trials were made on the 8th, 10th, 29th and 30th of January, 1905.

(a) *No-Load Trials.*—The difficulty of starting the heavy fly-wheel, which squeezes the oil out from the bearing-surfaces, makes it necessary to keep the Ilgner machine-group in permanent motion, as the winding-machine does not stop for very long. The consumption of energy, while the Ilgner group is working on no load, has an important bearing on the economy of the system, and it was therefore decided to determine this consumption. A Siemens wattmeter and an electricity-meter were inserted in one of the motor-leads (M_1), and readings were taken every 5 minutes during a period of 35 minutes, the machine making 313 revolutions per minute. According to the readings of the wattmeter, which had been specially standardized, the consumption was 31.94 kw.-hours; the electricity-meter showed a consumption of 30.85 kw.-hours. The temperature of the oil on the bearings was 30.8°C . (87.4°F). By stopping the circulation of water for $4\frac{1}{2}$ hours, the temperature of the oil on the bearings rose to 45.5°C . (113.9°F); under these circumstances, and the shaft making 315.5 revolutions per minute, the consumption according to the wattmeter and the electricity-meter was 30.55 kw.-hours and 29.82 kw.-hours respectively. According to another trial, repeated on the 29th of January, the consumption was found to be 28 kw.-hours at a speed of 314 revolutions per minute; the temperature of the oil was

35.7° C. (96.3° F.). The latter consumption corresponds to that guaranteed by the contractor. The efficiency of the motor at this reduced load was 0.6; the windage of the Ilgner group and the friction between the journals and the bearings absorbed, therefore, about 17 kw.-hours.

(b) *Passive Resistances in the Pits and in the Winding-Motor.*—

These resistances were determined by giving the masses a certain velocity and measuring the height through which the useful load was lifted. The energy consumed by the passive resistances would then be equal to the kinetic energy stored in the moving masses minus the work done on the useful load.

The suspended loads were:—

460 + 400 = 860 mètres (2,820 feet) of rope at			
5.6 kgs. per mètre (3.76 lbs. per foot)	4,800 kgs. about (10,600 lbs.)		
2 cages with attachments at 2,100 kgs. (4,630			
lbs.)	4,200 "	"	(9,260 lbs.)
8 empty tubs at 250 kgs. (551 lbs.)	2,000 "	"	(4,408 lbs.)
4 loads of coal at 535 kgs. (1,180 lbs.)	2,140 "	"	(4,720 lbs.)
Total	13,140 kgs.	"	(28,988 lbs.)

The diameter of the Koepe-pulley (reduced by wear) was 2.88 mètres (9 ft. 5 $\frac{3}{8}$ ins.). The moment of inertia of the suspended loads was = $\frac{13,140 \times 1.44^2}{g} = 2,780$ kgs.-mètres² (65,970 lbs.-feet²).

The moments of inertia of the rotating masses were:—

1. Moment of inertia of the Koepe-pulley	630 kgs.-mètres ² (14,950 lbs.-feet ²)
2. " " " motor armature	250 " " (5,932 " ")
3. " " " head pulleys	675 " " (16,018 " ")
	<u>1,555</u> " " (36,900 " ")

The moment of inertia of the masses was thus: $I = 2,780 + 1,555 = 4,335$ kgs.-mètres² (65,970 + 36,900 = 102,870 lbs.-feet²).

The kinetic energy corresponding to a speed of 8 mètres (26 ft. 3 in.) per second equals $\frac{I\omega^2}{2}$ $\omega = \frac{8}{1.44} = 5.55$, and therefore $\frac{\omega^2}{2} = 15.4$, hence the kinetic energy = $\frac{I\omega^2}{2} = 66,759$ kgs.-mètres (482,900 foot-lbs.).

2 L 2

The loads travelled through a height of 29 to 30 mètres (95 to 98 feet) after the current had been cut off from the motor. The work done by the non-balanced load was thus $2,140 \times 29 = 61,060$ kgs.-mètres (441,647 foot-lbs.) to 64,200 kgs.-mètres (464,400 foot-lbs.). The kinetic energy of the masses is between $\frac{66,759}{64,200} = 1.04$ and $\frac{66,759}{61,060} = 1.095$ times the work done in raising the non-balanced loads, that is, the useful work. The resistances in the pits and in the machine are therefore only 4 to $9\frac{1}{2}$ per cent. of the useful work. It will be seen that these figures, which may at first seem rather small, agree with other tests.

(c) *Guarantee Trials.*—The object of these trials is to determine whether the consumption in kw. per useful H.P. developed by the machine comes within that guaranteed by the contractor. The guarantee had been fixed by assuming a winding of 30 up-and-down journeys per hour; each journey included a loading at the bottom landing-stage at a depth of 368 mètres (1,207 feet), and a stoppage on the way at one of the intermediate loading stages, at depths of 342, 288 and 185 mètres (1,122, 945 and 607 feet).

Three series of trials were made on the 10th of January and repeated on the 30th of January; each trial included 10 up-and-down journeys made as quickly as possible.

Series I comprised journeys with loadings at 368 and 342 mètres (1,207 feet and 1,122 feet).

Series II comprised journeys with loadings at 368 and 288 mètres (1,207 feet and 945 feet).

Series III comprised journeys with loadings at 368 and 185 mètres (1,207 feet and 607 feet).

At each of these trials, the following observations were taken every ten seconds:—

(1) Readings of the Siemens wattmeter (the same as used at the no-load trials) which was inserted in the joined circuit of the Ilgner group and the motor-generator M_2G_2 . These readings were plotted with time as abscissæ, and the integration of the curve gave the total electric energy spent during the test. This

energy was also determined by means of the electricity-meter by taking readings at the beginning and at the end of the tests.

The results obtained by these two instruments differ only 1 to 3 per cent.

(2) Readings of a Weston ammeter and voltmeter which were connected to the same circuits. From these data may be plotted the curve of apparent alternating watts; and by dividing the watts found by the wattmeter by the apparent watts, a curve is obtained representing the variations of $\cos \phi$ of the installation.

(3) Readings of the ammeter in the field-circuit. The latter was maintained at 110 volts.

Recording instruments give an account of the volts and ampères of the continuous current which drives the winding-motor. By multiplying the simultaneous volts and ampères, the watt-curve of continuous current is obtained, which represents the power spent at any moment during the winding; and by integrating the corresponding parts of the curve, the energy spent during the different parts of the journey is determined.

The variation of speed of revolution of the Ilgner group was shown by a recording speed-indicator. The variation of kinetic energy of the group, from the beginning to the end of each trial, had to be added (algebraically) to the consumption of the electric energy, found by means of the electricity-meter or the Siemens wattmeter, in order to determine the total expenditure of energy.

The moment of inertia of the rotor of motor

M_1	65	kg.-mètres ²	(1,543 lbs.-ft. ²)
The moment of inertia of fly-wheel	1,000	" "	(23,730 " ")
The moment of inertia of the armature of generator G_1	160	" "	(3,796 " ")
The moment of inertia of shaft.	5	" "	(118 " ")
Total $I = 1,230$		" "	(29,187 " ")

The variation of kinetic energy $= \frac{(\omega_1^2 - \omega_2^2)}{2} \times I = \frac{(n_1^2 - n_2^2) 2 \pi^2}{3,600}$
 $\times I$,

where n represents the number of revolutions of the Ilgner group as indicated by the recording speed-indicator.

FIG. 13.—Results from Three Up-and-Down Journeys.

(Trial II. 30 January 1905.)

(continued on next page.)

Abscissæ scale, 1 div. = 10 secs.

FIG. 13.—Results from Three Up-and-Down Journeys.
(Trial II¹. 30 January 1905.)
(concluded from opposite page.)

The author does not consider it necessary to publish all the figures and curves obtained by these trials, as their number is very considerable. Fig. 13 (pages 470 and 471) represents the results from three up-and-down journeys of trial II¹ made on the 30th January. The trials comprised ten complete journeys from landing-stages at depths of 368 and 288 mètres (1,207 and 945 feet). The performance of the Ilgner system is indicated by this diagram; it will be noticed that the power absorbed by the winding-motor (continuous watts) varies considerably, namely, from zero to about 300 kw., then falls to 200 kw. and returns to zero; the power supplied by the power-station (alternating watts) varies only between 110 and 160 kw.

The results which may be deduced from these trials will be found below, and from these have been determined the efficiency R_1 = ratio of useful power to power supplied to the winding-motor (continuous watts), and efficiency R_2 = ratio of useful work to the sum of the energy spent by the alternating current and the kinetic energy stored in the Ilgner group. The watts consumed per useful H.P. spent in drawing coal is determined by dividing 736 watts by R_2 .

The consumptions given above are slightly smaller than those guaranteed by the contractor.

The consumption at the power-station of Espérance is 11 kgs. (24½ lbs.) of steam per kw.-hour; the consumption at the trials would therefore be between 17.75 and 20.3 kgs. (39.1 and 44.75 lbs.) of steam per useful H.P.-hour, which is very small for a winding-machine. It is possible to produce a kw.-hour by a much smaller consumption of steam; the consumption guaranteed for a steam turbo-alternator working at a pressure of 6.5 kgs. (14.3 lbs.) and superheated 300° C. (572° F.) is 8.95 kgs. (19.73 lbs.). Adopting this figure, one would require 14.40 to 16.5 kgs. (31.74 to 36.37 lbs.) of steam per useful H.P.-hour, and one may even go below these figures. The electric winding-machine can therefore compete with the very best steam winding-machines. M. Henry, engineer to the Hasard Collieries, has not succeeded in reducing the consumption below 18.94 kgs. (41.7

lbs.) of steam per useful H.P.-hour, notwithstanding the best known improvements.*

It will be noticed that the efficiencies R_1 are very high. If the mean value of R_1 , 0.855, (from the trials on 30 Jan.) be divided by the efficiency of the winding-motor, the reciprocal of this quotient will be the factor by which the useful power must be multiplied,

Trial.	Number of up-and-down journeys per hour.	R_1	R_2	Mean useful work per hour in H.P.	Consumption per useful H.P. in kw.
Winding from stages at depths of 368 and 342 mètres (1,207 and 1,122 feet).					
I 10 Jan.	28½	0.80-0.89	0.4513	81.25	1.63
I ¹ 30 Jan.	28½	0.855	0.453	80.00	1.61
Winding from stages at depths of 368 and 288 mètres (1,207 and 945 feet).					
II 10 Jan.	25	0.73-0.80	0.413	67.50	1.78
II ¹ 30 Jan.	29	0.85	0.429	76.75	1.715
Winding from stages at depths of 368 and 185 mètres (1,207 and 607 feet).					
III 10 Jan.	28½	0.68-0.88	0.399	64.25	1.845
III ¹ 30 Jan.	28½	0.86	0.406	63.00	1.81

in order to obtain the power required by the winding-motor to overcome the useful loads and the passive resistances. If the efficiency of the winding-motor (neglecting the field-current) be taken as 0.95, then we have $\frac{0.855}{0.95} = 0.90$ and $\frac{1}{0.90} = 1.11$; the

* See R. A. Henry: "Étude théorique et expérimentale de la Machine d'Extraction." 'Revue Universelle des Mines.' 4th series, 1904, vol. vii.

passive resistances therefore do not exceed 11 per cent., which agrees fairly well with the figure already found above.

(d) *Consumption of Energy under Working Conditions.*—For the purpose of determining the consumption in kw. per useful H.P., the winding-machine at the pits of St. Nicolas has been submitted to a permanent set of trials, lasting from 17th January to 1st March 1904. The consumption was measured by the electricity meter, inserted as in the guarantee trials. The readings were taken every day at 6 and 8 a.m., and at 3 and 6 p.m. The number of revolutions made by the Ilgner group were read off simultaneously with the readings of the electricity-meter, and a record was made of the coal and stones drawn during the different intervals of time. By means of these data, the useful work done by the machine may be determined, as well as the mean work per hour. The consumption of electric energy, to which is added or subtracted the kinetic energy of the Ilgner group, admit of determining the consumption in kw. per useful H.P. The large number of results from the trials, which lasted over a period of one month and a half, have been plotted, Fig. 14 (page 475), by taking as ordinates the consumption in kw. per useful H.P., and as abscissæ the mean useful H.P. given off by the machine. The points lie evidently on an hyperbolic curve. During the night, when the winding is less, the ordinates are longer on account of the permanent consumption of the Ilgner group. The ordinates will be shorter as the winding becomes more active, and will be about 2 kw. per H.P. between 8 a.m. and 3 p.m. The results from the guarantee-trials have also been plotted; these points lie on the continuation of the curve. It may be remarked that the hyperbolic curve is similar to that representing the consumption of a steam-driven winding-machine.*

The high consumption during the night may be attributed to the Ilgner system, and would therefore not take place if the winding-machine were driven by an asynchronous motor; but

* See R. A. Henry, *loc. cit.*

then one would have to take into account the consumption of energy required to keep a dynamo at work at the power-station, which should be large enough to generate the maximum power required for starting the winding-machinery. As the result of the trials of the machine at pit No. II Preussen, the author has shown that the variation of consumption of a winding-machine driven direct by an asynchronous motor follows also an hyperbolic law.*

The electric winding-machine at St. Nicolas has replaced a steam-driven machine, which was put down in 1874. According to trials made on the 17th February 1903, the steam-driven machine consumed 53.1 kgs. (117 lbs.) of steam per useful H.P.-hour during the period of maximum winding from 8 a.m. to 3 p.m. By installing the electric machine, a battery of six boilers, working at a pressure of 5 atmospheres, has been abolished. These boilers were in such a bad state that they would soon have had to be replaced by new ones. Besides being economical in consumption, the electric machine has also caused a reduction in wages, as the stokers, who were dismissed from St. Nicolas, have not been taken into service at the power-station. As the electrically-driven machine is much simpler to manipulate than the steam-driven machine, the drivers (two in number) needed very little instruction before taking over the new machine. The consumption of the accessories is very small.

The rope is a flat steel rope. The two ropes, which were used at first, consisted of six hawsers of four strands each, on a core of hemp; each strand contained seven wires of 2 mm. ($\frac{5}{84}$ inch) diameter. The ropes were 92 mm. ($3\frac{5}{8}$ inches) wide and 20 mm. ($\frac{5}{8}$ inches) thick, weighing about 5.7 kgs. per mètre (3.8 lbs. per foot). The wires were of steel with a breaking-strength of 145 kgs. to 150 kgs. (320 to 330 lbs.), and would bear fourteen bendings over a mandrel of 5 mm. ($\frac{1}{8}$ inch), and 30 torsions on a length of 200 mm. ($7\frac{7}{8}$ inches) before rupture. The total breaking

* See Paul Habets: "Les machines d'extraction électriques." 'Revue Universelle des Mines.' 4th series, 1904, vol. vi.

strength of the rope was 77,750 kgs. (76.5 tons). The first rope was removed after only 3 months of service, on account of unnecessary precaution. It was found by a tensile test that the total breaking strength of the weakest part of the rope was still 66,000 kgs. (145,504 lbs.); the second rope lasted $4\frac{1}{2}$ months. It was replaced by a rope consisting of seven hawsers of four strands each, on a core of three wires of 1.2 mm. ($\frac{1}{32}$ inch) diameter, each strand containing seven wires of 1.8 mm. ($\frac{5}{64}$ inch) diameter. The rope, being 110 mm. ($4\frac{21}{32}$ inches) wide and 18 mm. ($\frac{45}{64}$ inch) thick, weighs about 5.75 kgs. per mètre (3.8 lbs. per foot). The wires are of steel with a breaking strength of 130 kgs. to 135 kgs. (286.6 to 297.6 lbs.); the 1.8 mm. ($\frac{5}{64}$ inch) wire would bear eighteen bendings over a mandrel of 5 mm. ($\frac{13}{32}$ inch) and 30 torsions on a length of 200 mm. ($7\frac{7}{8}$ inches). The 1.2 mm. ($\frac{1}{32}$ inch) wire would bear 36 bendings, and 30 torsions on a length of 150 mm. ($5\frac{33}{32}$ or 5.9 inches). The total breaking strength of the rope is 77,000 kgs. (75.8 tons). On account of the small diameter of the Koepe-pulley, it was desirable to give the new ropes more flexibility by making them thinner and of finer and more ductile wire.

It is interesting to compare the cost, with regard to ropes, of the Koepe-machine with that of the old steam-driven machine with bobbins and flat aloes ropes. The latter ropes weighed about 4,600 kgs. (10,141 lbs.), and cost during later years from 1.65 francs to 2 francs per kg. (7 to 8.71d. per lb.). Adopting the lowest figure, a rope will then cost 7,600 francs (£304), and two ropes will therefore be 15,200 francs (£608). These ropes last about 26–32 months, say 30 months on an average. The rope expenses per month would therefore be 500 francs (£20). The ropes which were rejected cost 2,250 francs (£90), which, for a period of $4\frac{1}{2}$ months, is 500 francs (£20) per month, the same as was found for the aloes ropes. One may however expect to find the steel ropes more economical, as their construction is more suitable for the purpose, and may therefore last more than $4\frac{1}{2}$ months. A rejected winding-rope may be used as counter-rope.

It may safely be concluded from these trials that the electric winding-machine, even if it is not more economical than the best steam-driven machine, is certainly not more expensive. The greater facility and safety with which it can be manipulated, the smoothness with which it works, and its much greater flexibility, will often make it preferable to the steam-driven machine, even in the case where transmission of energy is not required. There can be no hesitation in the choice between the two systems, when the power has to be transmitted from a distance, or, as in the case of the pits of St. Nicolas, where the production of energy can be centralised at one power-station.

The Paper is illustrated by 14 Figs. in the letterpress.

Discussion.

Professor PAUL HABETS said that in the Paper, which the Institution had been good enough to accept, he had not given all the data obtained from experience and during the tests that had been made with the electric winding-machines employed at the colliery of St. Nicolas. To do so, it would be necessary to publish innumerable tables and exceedingly voluminous drawings. He however proposed to put up in the engine-room, during the visit of the Members of the Institution to the colliery, all the graphical representations of results obtained. The Members would thus be able to realise the procedure, and would be better able to study the behaviour of these machines.

M. CREPLET described the electrical winding-plant laid down at the Hasard collieries at Micheroux by La Compagnie Internationale d'Électricité of Liège. This electrical winding-plant was calculated to extract 2 tons of coal from a depth of 1,313 feet at a maximum speed of about 16·3 feet a second. The feeding current disposed of was three-phase, 2,000 volts, 50 periods, produced by two units of 250 H.P. each.

Three suggestions, A, B and C, were successively considered, namely :—

(A) *Direct Three-Phase System*.—The winding-machine being driven by a three-phase motor of 2,000 volts, and the alterations of speed being obtained by means of a starting-switch, either metallic or liquid.

With such a driving-system, the power necessary for starting would have been 400 H.P. coming down to 200 H.P. during running, Fig. 15 (page 480). This system, however, was abandoned on account of the enormous variations in the power required, and subsequent losses in the starter.

(B) *Ilgner System*, Fig. 16 (page 480).—The winding-machine being driven by a continuous-current motor, which takes its current at a rotary transformer, regulation of speed being obtained by acting on the excitation of the transformer's generator. A fly-wheel is fixed on the transformer to render the demand for power at the central station uniform. According to the calculations established it was shown that the weight of this fly-wheel would have amounted to at least 15 tons. This second solution was rejected for the following reasons, viz. :—

- (1)—The excessive weight of the fly-wheel might have given rise to mishaps of different natures.
- (2)—If at any time something had happened to the fly-wheel—such as might have been occasioned by overheating of the bearings—it would have caused the machine to stop forthwith.
- (3)—On account of the rotary transformer turning incessantly, the power expended for maintaining the speed of the fly-wheel would have been considerable.

(C) *Continuous Current System (Creplet)*. Figs. 17 and 18 (pages 480 and 481).

Through the medium of La Compagnie Internationale d'Électricité of Liège, a continuous-current system was suggested, bearing many points of resemblance with the previous one, at the same time there being a great many differences.

FIG. 15.—*Direct Three-Phase System.*

FIG. 16.—*Ilgner System.*

FIG. 17.—*Creplet System.*

- (1)—The fly-wheel, in the present instance, was entirely independent of the rotary transformer; it was coupled to a dynamo connected in series between the transformer's generator and the winding motor, Fig. 17 (page 480).
- (2)—The generator incessantly produced current, which caused its power to be invariable. Whilst stopping, this power was absorbed by the fly-wheel dynamo, which was accelerated accordingly; whereas, whilst winding, the energy absorbed

FIG. 18.—Creplet System.

by the fly-wheel was conducted into the winding-motor, so as to be added to the energy produced by the generator, Fig. 18.

- (3)—With this system the variation of speed of the fly-wheel was enormous, inasmuch as a fall of speed of 50 per cent. was obtained, which, according to established calculations, was equal to a restoration of 75 per cent. of the kinetic energy of the fly-wheel.
- (4)—With the Ilgner system it has been observed that the variation of speed of the fly-wheel hardly ever surpassed 8 per cent. Hence the energy produced by the fly-wheel was only

(M. Creplet.)

15 or 16 per cent. From this it may be deduced that with this system the weight of the fly-wheel required was reduced to one-fifth.

The working of the machine necessitated the employment of:

(1)—A bar or lever, reversing the direction of the current in the armature of the motor, also regulating the excitation process.

(2)—A bar or lever, acting upon the excitation of the fly-wheel dynamo, so as to reverse it, by making it pass through nought.

The engineer moved the first bar with the right hand, and the second with the left hand, hence it would be observed that the working was exactly the same as with an ordinary steam-winding engine.

The Creplet system contained the following advantages over other systems:

(1)—The fly-wheel being independent of the rotary transformer, it was possible to do the work without the aid of the latter. The working of the winding-machine was thus arrived at by regulating the excitation of the transformer's generator. At night-time, or when not winding, the power required was small. It being useless to render the discharge uniform, the fly-wheel was stopped.

(2)—On account of the great variation of speed of the fly-wheel, its weight might be reduced to one-fifth.

(3)—On account of the rotary transformer being able to turn with a constant speed, a synchronous motor could be used in order to improve the power-factor at the central station.

(4)—Owing to the slight weight of the fly-wheel, to the facility of doing the work without its assistance, and also to the complete absence of starting-switch, the current consumed was far less than with any other system. At a medium discharge of 20 E.H.P. in lifted coal, the trials have shown that the consumption did not exceed one 8-kilowatt-hour for 1 E.H.P.

The whole installation had been calculated for the power of 80 E.H.P. For such an installation the consumption would go down to one 3-kilowatt-hour for 1 E.H.P.

The winding-machine was started in February last, and had since been at work without interruption. The fact that since the laying down of the electric plant the boilers have not had to be re-lit, went far towards proving the excellence and absolute reliability of this plant, and its steadiness of working. The whole plant complete cost £3,000, and the economy, in fuel only, amounted to £440 a year.

Mr. WALTER DIXON said he had had an opportunity some months ago of seeing the plant which had been described as the Ilgner system, and he thought it certainly was of mechanical interest, and, under certain conditions, would probably be an advantage in Great Britain. The last remark in the Paper was somewhat disquieting, namely, that it might safely be concluded from the trials that the electric winding-machine, even if it was not more economical than the best steam-driven machine, was certainly not more expensive. It was also pointed out that where the transmission was over long distances the system might certainly work both economically and well, and perhaps that was the one condition where its use in Great Britain might be recommended. The system that had been explained by M. Creplet appeared to have advantages, and it would be well for those interested in the subject to investigate the matter while they were on the spot.

The PRESIDENT thought that few Papers required more careful study than the present one, and he was sure they all would agree that Professor Habets deserved the best thanks of the Institution for the able Paper he had communicated.