Discussion on "Function of Fly-wheels in Connection with Electrically Operated Rolling Mills." "Rolling-mill Motors." "Electric Driven Rolling Mills." "Power Requirements for Rolling High Carbon Steel of Small Section." "Electric Control for Rolling-mill Motors." "Automatic Motor Control." "Electric Power Problems in Steel Plants." Frontenac, N. Y., June 30, 1909.

D. B. Rushmore: The subject of steel-mill work is certainly as important as anything at hand just now in the way of electrical development, and the most important requirement of steel-mill work is reliability. It is unfortunate that steel mills will to some extent buy on prices, but they are outgrowing that, because price always means a sacrifice of engineering features. The value of the output is so great in comparison with that of the machines which are used in its production that I think it is a wrong policy to make any very great difference in the equipment due to a difference in price, assuming that several alternative schemes are presented; that is, putting all the manufacturers on the same basis, the ordinary factors of competition, it seems to me, should in these cases give way. In reality, the man who is to control this situation should be the engineer of the steel mill and not the purchasing agent, because all manufacturers are to a large extent interested together in the success of electricity as applied to steel-mill work. At the present time there is no phase of the electrical development of steel-mill work more important than the control apparatus, for the steel mills must electrify generally if they are going to compete with those which have already done so and the controlling apparatus must be perfected so that the output of the mill will not be interfered with.

Mr. Tschentscher has touched the edge of the subject of getting power from the waste gas, but whether burning the gas directly under gas engines or burning it under the furnaces, or utilizing it in connection with steam turbines, is the best means of using it is still an unsolved problem. The design of gas engines for blast-furnace gas, for large powers, is by some considered somewhat of an open question; for while it is easy to figure out the supposed thermodynamic efficiency and the actual cost of the power which one will get, yet the development is not on such a basis that that is all which needs to be considered. What the steel-mill man wants is the net return on the gas from the operation of the steel mill; one of the factors is the output, and any interruption to service goes heavily against the cost of this, and has to be considered in estimating the cost of power. The proprietors of steel mills say they can handle electrically driven mills better than steam driven mills, for the reason that the piece always goes through the roll at approximately the same speed and it is in better shape to start the succeeding movement. The reciprocating apparatus is practically doomed, it seems, with the possible exception of the gas engine, and that has a threatening successor in the gas turbine. The use of gas turbines and the possible use of gas through the furnace and for steam turbine work, would practically remove all reciprocating apparatus from the steel mill.

Mr. Specht has picked out, perhaps, the most interesting problem in steel mill work, the fly-wheel capacity for special service. Unfortunately, this particular determination is not always left to the motor manufacturer. It seems that steel mill men, realizing that it is difficult to maintain normal conditions continuously on roll trains, often specify motor capacity and fly-wheel capacity much in excess of that needed for normal operation.

On the other side, there has been of late a carefully performed series of experiments to determine the power required for rolling steel, and some very interesting results have been obtained in regard to the variation of this power with the temperature of the piece. That is one case to illustrate the point that there is necessarily in all this class of work a very large margin, because the factors which enter into it cannot all be determined with precision, and are susceptible of considerable variation.

Brent Wiley: The following formula offers a convenient method of calculating the fly-wheel capacity of a system, and for an average case the run of the fly-wheel is figured as two-thirds of the total weight and the spokes and hub one-third of the total weight.

$$\text{Wt.} = \frac{F\,s \times 2 \times 32.2}{B}$$

Wt. = weight in pounds.

$Fs.$ = foot-pound-seconds = h.p. $\times$ 550 $\times$ sec.

B = difference of velocity squared at high and low speed in feet per second at radius of gyration.

I understand that originally the automatic features in the Indiana Steel Company's plant were incorporated in the motor-control apparatus and that later the system of control was changed somewhat; that is, to the extent of operating the controllers instead of automatically cutting in and out the resistances operating the motors with a permanent resistance.

K. A. Pauly: When the proposition for the rail-mill motors was being considered, the use of a small permanent resistance versus a variable resistance in the rotor circuit, to allow the fly-wheel to take the peaks, was discussed thoroughly; and it was finally decided that because of the ease of removing the automatic variable feature, it would be better to install the automatic control. Tests made after the apparatus was installed indicated clearly the use of a permanent resistance to be preferable. However, the direct-current contactor (because of the high inductance of its operating coils and the lack of opportunity of raising the impressed potential sufficiently above the operating potential by the insertion of resistance in series with the solenoids) is necessarily more sluggish than the alternating-current contactor. Possibly with the alternating-current contactor, recently developed, which operates more rapidly, there may still be something in the automatic acceleration and retardation over a small range. However, as the control with permanent resistance operates satisfactorily, and eliminates one of the possible troublesome parts of the control equipment, the automatic feature should be, at least for the present, omitted entirely.

With reference to Mr. Specht's paper, it must be borne in mind in determining the capacity of a fly-wheel to meet any given cycle, that the fly-wheel is employed as a means of reducing the operating cost of rolling. There are, therefore, many factors which must be taken into consideration in determining the most economical fly-wheel capacity. Among the important ones which are frequently overlooked are:

1. The cost of power, the first cost of the generating station and of the rolling-mill motor.

As pointed out in the paper, by the use of the fly-wheel we reduce the capacity of the rolling-mill motor necessary for performing the work, and of the generating station supplying the power, but at the expense of efficiency. When the cost per unit of power and the cost per kilowatt of generating capacity are high the economical size of fly-wheel is greater than when these costs are low.

2. The capacity of the fly-wheel is affected by the overload capacity of the generating units. For example, the most economical weight of the fly-wheel is greater where power for rolling is supplied from gas-engine-driven generators (which because of the better economy of the engines near the maximum load frequently have little overload capacity) than when the power is from a turbine station the momentary overload capacity of which is very large, due to the immense fly-wheel energy of its discs.

3. The capacity of the fly-wheel is affected by the number of mills or motors driven from the same generating station and, therefore, the number of intermittent cycles, which are combined to form the generator load curve. As the number of mills increases the peaks of the station load curve decrease. Beyond a certain point, depending on the overload capacity of the generating station, the advantages of the fly-wheel are confined to the rolling-mill motor, and the fly-wheel capacity may be reduced to a minimum

A fourth advantage of the fly-wheel that is difficult to capitalize at present, is the increase in reliability and life of the rolling-mill motor resulting from the reduction in mechanical and electrical strains in the windings.

A great many advantages have been put forth in favor of the steam turbine as a generating unit for supplying power for rolling mills. I think, however, little consideration has been given to the possibility of increasing the efficiency of the rolling by the use of turbine-driven generators.

M. O. Dellplain: There is a matter which might be brought up at this time and one regarding which steel-mill engineers would probably all appreciate information, as it has to do with the only portion of the mill in which electricity has not as yet been positively accepted. I refer to the use of motor-driven air compressors for operating the hammer shop. The successful application of air for use in the hammer shop would mean practically the complete solution of the problem of the electrification of the steel mill.

Clark S. Lankton (by letter): Mr. Specht says that in motor-driven sheet mills the automatic control can not be used to advantage, that it would do more harm than good. I wish to take the ground that a proper control for induction motors driving sheet mills is a very much desired feature. The advantages of control do not make themselves felt in the way it was first intended they should; that is, to smooth out the peaks. This is not practical because, as Mr. Specht says, the fluctuating load is too quick for the automatic feature to act. The control is practical, however, in that it affords a large amount of protection.

A sheet mill has from four to ten stands of rolls connected to the same shaft and each set of rolls is manned by a separate crew, each working independently of the other, hence the total load on the motor is made up of as many components as there are mills. Each unit requires power over and above its friction load but a relatively short period of the total time; that is, the actual time that iron is being passed through the rolls is short, say one-eighth of the total time, or 3 hours out of 24.

The different crews have no relation to one another, and, with several mills operating, combination loads of almost any magnitude might result. A motor of gigantic proportions would be required to meet every possible combination of peak loads which occur, although the square-root of the mean-square load would not require so large a motor. The advantage of a large fly-wheel reserve is apparent.

It has been suggested that a permanent amount of external resistance be inserted in the circuit of the motor secondary in order to obtain slip enough to allow the utilization of the fly-wheel energy. By this method the motor would run with lessened efficiency, not only at times of heavy load, but also at times of medium and light loads, which is by far the greater part of the time. The efficiency could be improved by installing a larger motor which would allow of less slip, but, on the other hand, it would have increased capacity and greater first cost.

It would not be so bad to sacrifice efficiency for a few seconds during a heavy jam, and, with proper control, it would be possible to hold the motor to the load until the load became excessive;

then to allow the motor to give way and receive aid from the wheel—thus the lower efficiency would be operative only occasionally and then for only a few seconds at a time. I have seen a sheet mill successfully operated in this way and no trouble apparent in control for some period of time.

Let us give up trying to smooth out every fluctuation, but do not discard the control feature. Set the control to operate at a high load, however, and use it as a protection against the unusual peak rather than to level all peaks. If the source of supply is a little larger than the capacity of the mill, these smaller fluctuations will not be troublesome, and because of their frequency with the added number of mills the resulting load approaches a continuous load.

H. C. Specht: The amount of fly-wheel effect of an induction motor, with wound rotor particularly, is fixed mainly by the design itself, and it is very difficult to add more fly-wheel effect unless the additional weight is placed on a smaller radius, where it is not as effective. Further, it is not often desirable for mechanical and other reasons to put all the fly-wheel effect in the motor. Assuming, for instance, that a motor has to drive certain machinery, and a specific fly-wheel effect is desirable, also that at some later date the machinery driven by the motor is to be changed or the motor has to be used otherwise; under these circumstances the fly-wheel effect first placed in the rotor may be no longer the right one. Then the motor would have to be changed, and in such a case it would be more desirable to make the motor of normal design in the first place without particular reference to the required fly-wheel effect. Any additional necessary fly-wheel effect is then secured by coupling to a separate fly-wheel. A further advantage of this arrangement is that the motor is relieved of any sudden shocks.

The equations which I give for the torque curve have also been worked out by Mr. I. E. Hanssen in a similar way, and agree exactly with mine.

Chas. F. Scott: The problem of power generation which has been presented, the peculiar conditions of power supply through gas at the steel mill, the severe conditions of fluctuating load—all these bring severe and peculiar conditions which must be taken into consideration and treated in a broad way by the engineer who is handling them. It was said by one of the speakers that the electrical engineer in the steel mill is only 40 per cent an electrical engineer and 60 per cent a business man. I am rather inclined to think that some of the things classed as business in that position are properly engineering, engineering in the broader sense, as the engineer must take into consideration not merely the formulas on which his apparatus is based, not merely the electrical phases of his apparatus, but that larger engineering consideration which applies means to the accomplishment of results. This larger view also includes the mechanical conditions in which the various elements are controlled by the electrical apparatus, and the various operations in which the electrical apparatus simply plays a part. There are other considerations. He must be human, and must be able to handle the rather obtuse mill operators who do not like to do anything differently from the way in which they have been accustomed to do it. All this emphasizes the fact that the steel mill engineer must be a pretty large and progressive man.

The matter of power-factor was referred to. Power-factor has a rather disagreeable reputation, and when one finds it attached to anything, it is usually regarded as quite discreditable. Mr. Tschentscher takes pride in telling that he has been able to save $10,000 a year in wiping out this power-factor, and I take it this is a case where auxiliary machines are fully justified. They are installed at the end of the transmission line, so they relieve the line of carrying an extra amount of current. But, after all, has he accomplished something which is large and fundamental? He saves $10,000 a year on 7000 h.p. of motors, or something less than $1.50 a year per motor horse power. That is equivalent to the saving of $1.50 a year in the power supplied to the motor for each horse power rating. I do not know what the power is estimated as costing; it is probably fairly high for the rated horse power of the motor, because motors in the cement mill are called upon to do fairly continuous duty. If the power costs $15 per year, the saving would be about ten per cent on the power; that is, the power would cost $15 instead of $16.50. If the cost were $30 a year, it would be a saving of about five per cent, so that in this case the power-factor of the motor is a matter which would increase the cost of power by five per cent or ten per cent. If direct-current motors were used, and the power-factor avoided by discarding the induction motor, there would be new objectionable features introduced, such as the loss in transmission apparatus, synchronous converter, or motor-generator, as well as a higher first cost and attendance.

In applying electricity to steel mills the first thing that is usually thought of, the thing that has been given large consideration here to-day, is the supply of power. The supply of power, considered in comparison with the total cost of production, is probably a relatively small factor, the larger matters being considerations of operation, of continuity of service, of applying the power effectively. If the motor can work more effectively—if, in conjunction with the mill which it operates, it can do better service, or produce a saving in labor, or more uniform or greater output—then these savings will far overbalance the saving in power, will far overbalance the fixed charges on the first cost of the motors. Consequently, effective operation is a point of far more value than the others I have mentioned.

I have been interested in Mr. Friedlander's paper in the description of the operation of certain mills by motors, and in the number of points which be brings out showing the indirect advantages of the motor, not simply because it does what the engines already do or could do, with possibly a saving in the power cost, but also is doing things which the engine did not do and could not do. In his second paragraph he tells us that the rolling mill drive has taught us how to get the best relation among rotating masses, speed, time, and horse power. It has helped the roll designer to calibrate rolls in such a manner that the power characteristic for all the passes is uniform, thereby avoiding high power peaks, decreasing the size of the prime-mover, and reducing first cost and fuel consumption. The watt-hour meter warns the roller that bearings or rolls are becoming tight and hot, or that steel is causing excessive friction in the passes, often due to overfilling, cold steel, or faulty calibration, thereby guarding against damage to the rolls and bearings. The meter indicates that lower heat, greater elongation, and especially change of profile in different directions, increase the power required at the rolls much more rapidly than do chemical hardness, high tensile strength, or large draughts.

After analyzing the conditions in reciprocating engines for this work, we find that the characteristics of the electric motor are much better. A little further on he says that heavy reciprocating engines cannot run at such high speed, and must be connected to the rolls by means of gears, ropes or bolts. Again:

> To obtain accurate information as to the exact power requirements for rolling steel, indicator diagrams were taken on reciprocating engines doing similar work, but these in many instances were misleading. * * *. With the use of electric motors in place of reciprocating engines, the problem of reversing rolls becomes much simpler and better, in regard to manipulation, fuel consumption, and cost of maintenance.

Now, these are all indirect things, points of inherent superiority of the electric drive over the steam drive, points which show a reaction or interrelation between the motor and the mill, which indicate that the motor is going to have a vital effect upon mill work because it does what the engine cannot do.

John C. Reed: Have controllers ever been designed for obtaining dynamic braking in connection with an induction motor?

H. E. White: So far as I am aware, there is no method of applying current to the induction motor that will bring it to rest, without a tendency to start it in the opposite direction. In some installations now being made, current is being applied with reversed phases, and some means is used to shut off the reverse current when the motor stops.

In reference to Mr. Wiley's question concerning the automatic features of the control of large induction motors, Mr. Pauly has given the principal points. From the controller designer's standpoint it appears to be very desirable that the arrangement of the control be chosen so that a permanent resistance can be left in the motor circuit. It is a simple matter to arrange it so that the permanent resistance can be changed by changing the position of the master controller.

If automatic overload features are used, and a number of excessively heavy loads occur at short intervals, the speed has a tendency to be greatly reduced; if, however, resistance is left in permanently without automatic overload features, the torque will increase to the limit of the motor and the work will be carried through. I think that with the use of alternating-current contactors instead of direct current we would not have very much difference in action in either case. If the motor is running synchronously with all resistance cut out, the current will increase very greatly with a slight change in speed, but it is difficult to get automatic overload devices that will operate before the current shows an undesirably great increase.

I should have said no method of applying alternating current. The large induction motors at Gary are now equipped to apply direct current to the stators of the motors, and this will stop these motors and fly-wheels in a few minutes, when they might run unretarded for as many hours. I understood the question to apply to alternating current only.

In my experience with contactors for alternating current, which has recently been extensively increased, I find that under all the conditions of design with which I am familiar they permit of very quick closing. While I have no doubt that an oscillogram of the operating current would show some very curious things, yet the contactors I am familiar with always close practically instantaneously; it is easy to see that this must be so, for even on 25-cycle current the time between the minimum and the maximum current value is only about one one-hundredth of a second.

A. M. Dudley: Mr. Parker asked about the relative desirability of having the entire amount of fly-wheel effect desired rotating at the same angular velocity as the motor, or connected to the motor by belting or gearing, and running at a higher speed. Mr. Specht, I believe, did not quite cover that point. Mr. Parker's statement is true, that there is no advantage in the one over the other, as far as the actual weight of the active material in the fly-wheel itself is concerned; that is to say, the same weight will have to be kept but disposed differently. It has been my experience, however, that when the extra weight is taken out of the motor structure and not carried on the motor spider, it is possible to build the entire motor somewhat lighter. It seems to me there might possibly be some advantage in that direction.

Mr. White said that he believed there was no method of employing dynamic braking in connection with the wound secondary motor and bringing it absolutely to rest. This holds good unless direct current is used in connection with the windings; that is, direct current is introduced into one member or the other, in which case the same effect is obtained as on a direct-current machine.

H. K. English (by letter): Mention is made of the fact that the time required to accelerate or decelerate a heavy fly-wheel must not be overlooked. This is especially true in plate-mill work, where it is often desirable to increase the rolling speed considerably after the first heavier passes are through. As an illustration, take the example used in the paper. Should it be decided to change at the end of the ninth pass, from 52 to 104 rev. per min. for the remaining 10 or 12 passes, the 120,000,000 lb-ft.^{2} fly-wheel would obviously be out of the question on account of the time and energy required to accelerate it to 104 rev. per min.

Again, it is an advantage, where possible, to have in the fly-wheel enough stored energy to clear the rolls should the power fail, or should the motor, for any reason, become momentarily inoperative. Referring once more to the data sheet, pass No. 9, Fig. 3 represents some 11,700,000 ft. lb., while a 20,000,000 lb-ft.^{2} fly-wheel running 52 rev. per min. has but 9,250,000 ft. lb. stored energy. Should the power fail just as the steel is entering for pass No. 9, the rolls would not be cleared, making it necessary to loosen the rolls, reverse the motor, and back out the steel. This consideration is of more importance in a rail mill with a number of motors in a train, and large quantities of steel, in different stages of completion, in the mill at one time.

I mention these two points to emphasize the fact that the choice of a fly-wheel for any given installation will be governed, more by an all-round practical consideration of the case in hand than by any mere efficiency calculations.

There has just been completed a series of tests on an electrically driven rail mill which has recently been put in operation, and it has been very gratifying to see how closely the test values check the original calculations both as to power required for the several passes, and as to motor performance. In view of this fact, and the successful record this mill is making, it would seem that Mr. Specht is scarcely justified in assuming that careful study has not been given these first installations.

Arthur C. Eastwood (by letter): I believe attention should be directed to the conditions under which controllers must operate in a steel mill. I refer to the controllers described by Mr. White and Mr. Henderson in which a separate series relay is associated with each contactor in a controller, the closure of each successive contactor being governed by the current flowing through the motor, and each series relay being susceptible of individual adjustment.

In steel mills I believe it is common practice when records are in view to doctor the controller relays with bolts, nuts, and wrenches. In other words, under mill conditions a controller designed automatically to limit the current input of a motor may, in a few seconds, lose all semblance of current-limit acceleration, the cutting out of the resistance being governed solely by the time element of the contactors or magnetic switches. Further, the larger the number of adjustments provided, the greater the chance for maladjustment where uneducated and electrically unskilled rollers, table men, shear men, millwrights, etc., have access to the controller, and where the adjustments are purely mechanical, consisting in weighting a plunger or tightening a spring. Even in the hands of a skilled electrician, to secure accurate adjustment of a controller having a relay on each switch, a recording ammeter is almost a necessity.

As to the advantage found by Mr. Henderson for the multiple relay system of acceleration; that is, the ability so to adjust the relays as to interpret the commutation curve of a motor—it is conceivable that this is an advantage under some conditions but not one which is likely to appear in a steel mill. A steel-mill engineer would hardly install a motor so near the limits of commutation that special provisions would be required to help it out, and if such a motor were inadvertantly installed it should be very promptly torn out and a motor installed better suited to conditions.

There is another system of automatic relay acceleration not described by either Mr. White or Mr. Henderson, which was specifically designed to meet conditions as they exist in steel-mill service, and it is extensively used in many of the largest steel works in the country. In this system only a single accelerating relay is employed. Hence there is but one adjustment; and accurate adjustment as to maximum accelerating current can be determined by the use of an ordinary indicating ammeter. The relay has a single winding of coarse wire, controls only a single pair of contacts, and in service is ordinarily enclosed in an iron box which can only be opened by a key in the form of a special horseshoe magnet with which only those properly qualified to make the adjustment are provided. This prevents tampering with the apparatus by those not properly equipped to adjust it.

Further, the adjustment for varying the maximum accelerating current is electrical and not mechanical. Consequently an unskilled worker who would not hesitate to hang a weight on the ordinary form of relay is very likely to keep hands off, since he will hesitate to tamper with electrical connections.

The adjustment is obtained by varying the portion of the total motor current which passes through the winding of the relay, and is accomplished by shunting the winding of the relay, The constants of the relay itself remain fixed. It will always lift its plunger when a certain definite current flows through its winding. Assuming this current to be 50 amperes and the desired maximum motor current to be 100 amperes, the relay will be so shunted that one-half of the motor current will pass through its windings. If the desired maximum motor current be 200 amperes, the shunt will be so adjusted that one-quarter of the total motor current will pass through the winding of the relay.

This method of shunting the winding of the relay not only provides means for adjusting the maximum accelerating current in case of a given motor and controller, but also permits of adapting a standard relay for use with motors varying widely in capacity. In an equipment installed in one of the large steel works of the country, embodying some 65 automatic magnetic controllers for motors varying in size from 25 to 250 h.p. duplicate relays were used in all the controllers, the adjustable shunt in each instance adapting the relay to operate at the required maximum motor current.

A diagram of connections of this system of automatic acceleration is shown in Fig. 1, in connection with a reversing controller for a series-wound motor.

A is the armature and *F* the field winding of the motor.

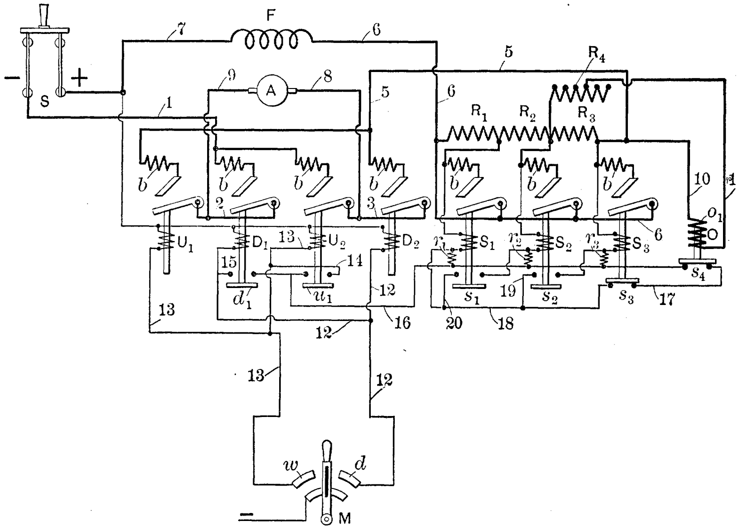
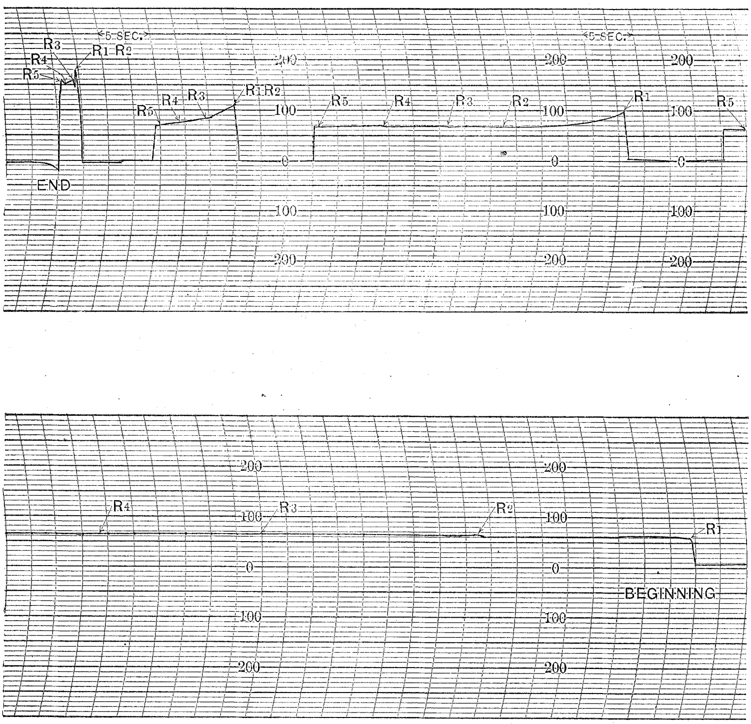


Fig. 1—Automatic accelerating controller

*R*1, *R*2, *R*3, and *R*4 are sections of resistance. *D*1 and *D*2 are reversing switches which give one direction of rotation, while switches *U*1 and *U*2 give the reverse direction of rotation. *S*1, *S*2, and *S*3 are magnetic switches controlling the sections of resistance *R*1, *R*2 and *R*3. *M* is the master controller through the operation of which the motor is started, stopped, and reversed. *O* is the accelerating relay which governs the closure of the resistance controlling switches *S*1, *S*2, and *S*3. *R*3 is an adjustable resistance which shunts the winding of the relay *O*. It will be seen that the main current flows from positive through the field *F*, the resistances *R*1 and *R*2 where it divides, a part flowing through the resistance *R*3, the wire 5, the reversing switches, and armature of the motor to negative, and the remainder flowing through the adjustable resistance *R*4 and the winding of the relay *O* to the wire 5 where it joins the other path. Obviously, the portion of the motor current which flows through the winding of the relay may be adjusted by altering the relative resistance of the two paths. It will be noted that resistances *r*1, *r*2, and *r*3 are associated with the windings of the switches *S*1, *S*2, and *S*3. These resistances are so proportioned that when in circuit with the winding of a switch-operating magnet they



ACCELERATION CURVES OF 25 H.P. 220 VOLT SERIES MOTOR WITH AUTOMATIC CURRENT-LIMIT CONTROLLER.

Fig. 2

will not permit sufficient current to flow to cause the switch to close, but will permit sufficient to flow to hold the switch closed after its plunger has been raised. The function of the contacts of the relay *O* is to control the resistances *r*1, *r*2, and *r*3. When the plunger of the relay is down, these resistances are short-circuited; when the plunger of the relay rises, these resistances are cut into circuit with the windings of the switch-operating magnet with which they are associated.

Assuming that the switch *S*-1 has closed, and in closing has produced a current value which causes the relay *O* to lift, the winding of switch $S2$ then receives current through the resistance $r2$ which, as previously mentioned, will not permit sufficient current to flow to cause the switch to close. It should be noted, however, that a small current flows through the winding of the switch which is about to close, thus partly building up the magnetism of its closing magnet and leaving the switch prepared to close promptly. This largely eliminates the time element of the successive switches in closing. When the motor has accelerated, thus reducing the current flowing through its windings to the proper point, the relay drops, thus short-circuiting the resistance $r2$ and permitting the switch $S2$ to close. Switch $S3$ is controlled in a similar manner.

The relay O is provided with but a single pair of contacts, and only a single electrical interlock is associated with the control circuit of each switch.

The curves shown in Fig. 2 were taken with a recording ammeter, and illustrate the acceleration of a 25-h.p. 220-volt series motor in which the maximum accelerating current, and hence the time of acceleration, has been varied by varying the resistance of the shunt round the accelerating relay, as above described. These curves illustrate the wide range of adjustment which may be secured in the total time of acceleration, showing as they do that the period of acceleration may be varied from 65 sec. to less than 2 sec. the accelerating current in the two cases being respectively 60 to 65 amperes and 160 to 165 amperes. These curves also illustrate the sensitiveness of the accelerating relay, showing that it will raise and drop its plunger with current variations of less than 5 amperes.

As to the Hulett unloader, which was described by Mr. Henderson as offering particular advantages for automatic control, the writer can speak with some authority as he designed and installed the controlling equipment for the first electrically operated Hulett unloaders in 1902 and 1903. On the first Hulett unloaders (installed at Conneaut, O.) the machines were driven throughout by steam and hydraulic power. The next machines (the first three installed on the Lackawanna Steel Company docks at Buffalo, N. Y.) were driven electrically with the exception of the bucket-closing and rotating mechanisms, which were operated by means of hydraulic cylinders. This necessitated mounting on each machine a motor-driven pressure pump operating at 1000 lb. pressure, a motor-driven air compressor, an air-hydraulic accumulator, and an elaborate system of high-pressure piping, swivels, valves, etc., which was a prolific source of trouble not only in itself but on account of damage to electrical apparatus which occurred through frequent leaks in the hydraulic system.

Hydraulic power was selected for the operation of the bucket because of the absolute necessity of limiting the torque or pull which occurred in closing and rotating the bucket. The bucket of the unloader is suspended from a structural leg some

40 ft. in length, as illustrated in Fig. 3, which shows the bucket of one of these machines in the hold of the steamer " Wolvin ". In scraping ore from between hatches, or in case the bucket should entrain more ore than it could hold, or if the bucket happened to foul a stanchion or other obstruction, obviously the torque or pull must be limited, as the bucket has a leverage of some 40 ft. on the frame of the machine, and a wreck would result if a definite maximum pull were exceeded. An electric motor, with its ability to increase its torque to perhaps ten times full-load value before stalling, appeared altogether unsuited to the purpose.

After experimenting with a number of other schemes, a form

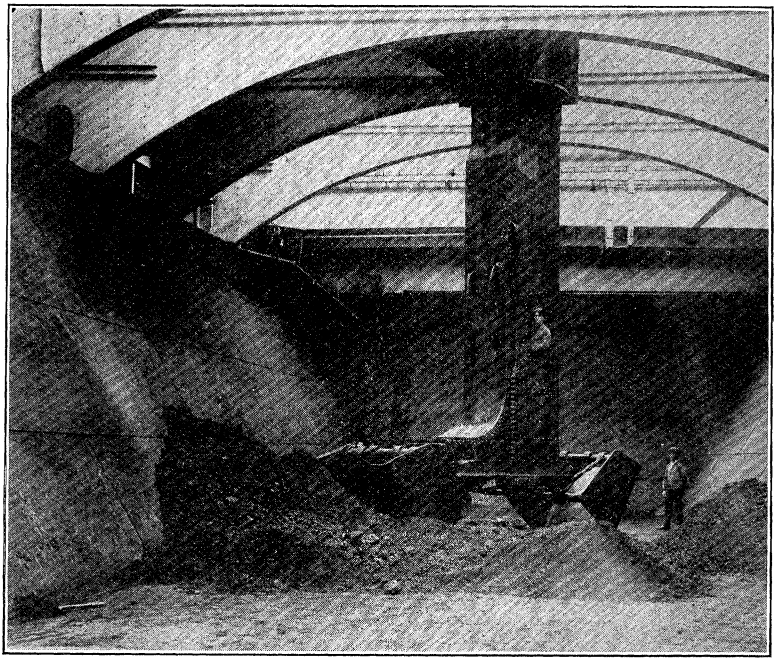


FIG. 3—Bucket leg of an ore unloader working in the hold of a steamer

of controller was devised by the writer which gave to the operation of a motor substantially the characteristics of a hydraulic cylinder. In this controller a series relay was introduced, which weighed the load and when a given normal current was exceeded, automatically cut resistance into the motor circuit, thus limiting the current, and consequently the torque, to a safe maximum value. The arrangement was such that current would not be cut off from the motor when an overload occurred, but the current would be automatically limited and the current limiting resistance would be automatically cut out when the load was relieved. This arrangement successfully displaced the hydraulic

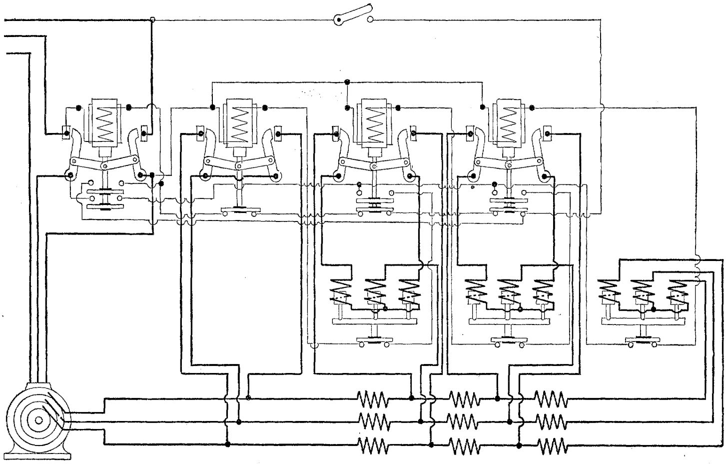


Fig. 1

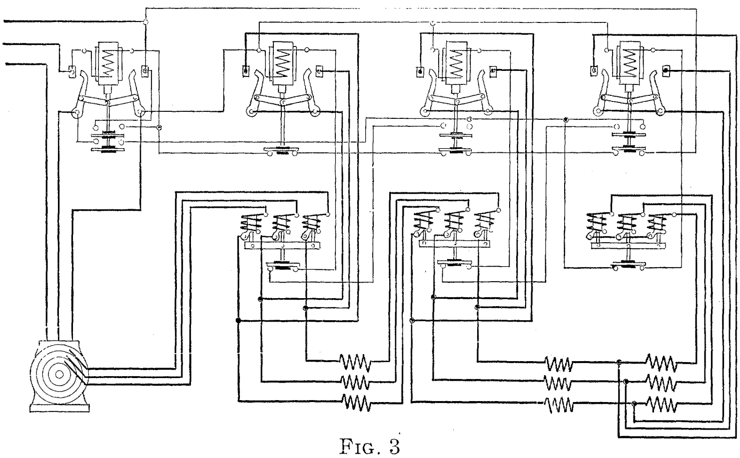


Fig. 3

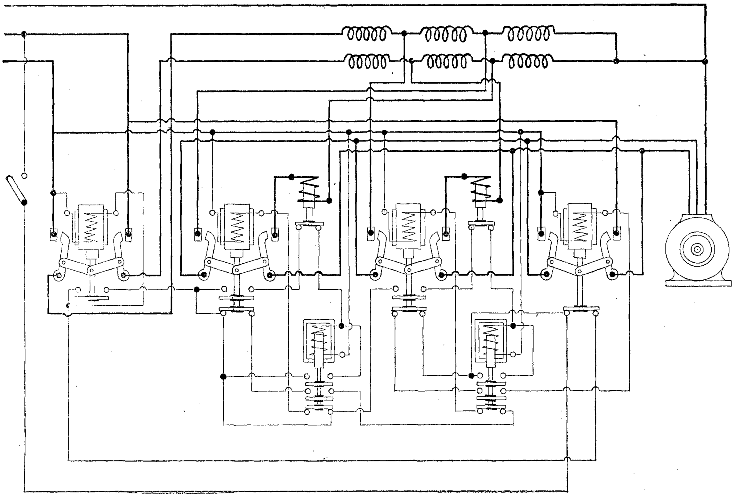


Fig. 4

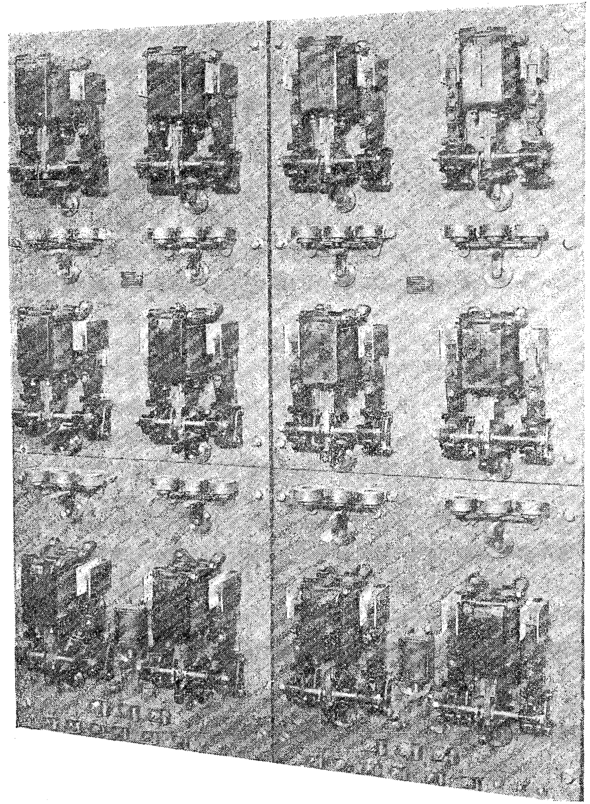


Fig. 2

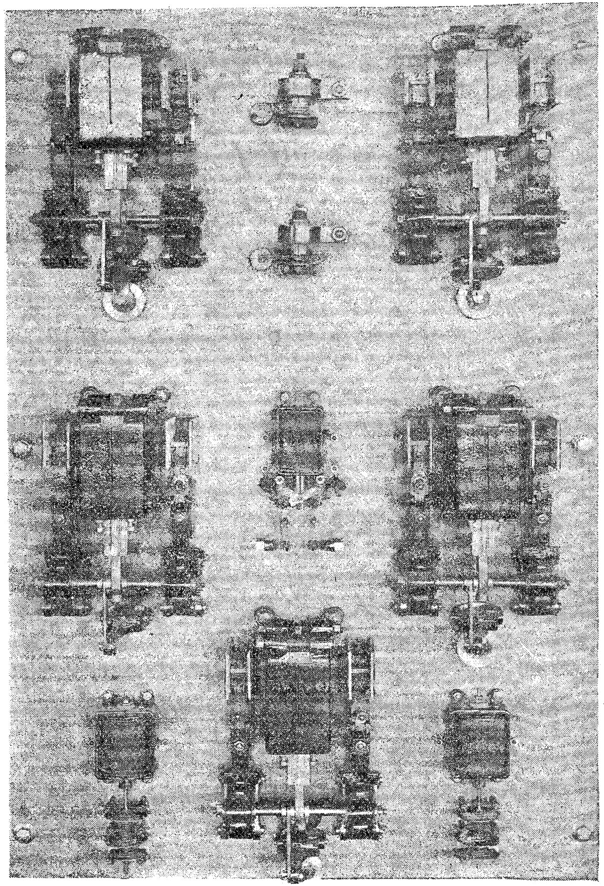


Fig. 5

cylinder and all subsequent Hulett unloaders have been similarly equipped. The Hulett unloaders on the docks of the Indian Steel Company at Gary are equipped in this way, and are also equipped throughout with the system of current-limit acceleration above described.

Arthur Simon (by letter): Mr. Specht states that the automatic regulation of resistance in the secondary circuit of the slip-ring type of motor is not desirable on account of the sluggishness of the controlling apparatus, and he therefore restricts himself to the calculations of a slip-ring type motor with a fixed resistance and a fly-wheel. This method of operation is undoubtedly the simplest, but by no means the most economical. Mr. Specht agrees that theoretically the variable resistance method with a lighter fly-wheel would be preferable, but the writer is not convinced that it will be impossible to produce a controller which will follow quickly the changes in load on the motor.

As far as the writer is aware, the controllers which were designed to accomplish the automatic regulation of the secondary resistance were all influenced primarily by a current relay connected in the primary circuit of the motor. Furthermore, most of these controllers, or all of them, were of the pilot-motor type. In other words, there were several elements, which, with regard to the cycle of operation, were connected in series. The ultimate result was obtained only after the successive operation of all parts, which necessarily must consume considerable time. The writer is satisfied that it would be possible to connect proper relays in the secondary circuit of the motor. As the secondary current is the first quantity which is influenced by a change in speed, that is, the change in load, it is only logical to accomplish the control by means of a relay in the secondary circuit. This relay should influence directly contactors which control secondary resistance, and this method will give entirely satisfactory results as far as the speed of response is concerned, and, furthermore, be still more desirable for other reasons, which will be discussed in the following:

Mr. White says that the 6000-h.p. motors at Gary are controlled by a pilot motor which is influenced by a current relay. A diagram of this control scheme was published in the "*General Electric Review*", and I note that the current relays are connected in the primary circuit. For the same reasons as stated above, these relays should be connected in the secondary circuit of the motor, and it is obvious that the scheme as shown in his Fig. 1 is preferable to the pilot-motor control. Fig. 2 shows a double panel of this type. With the pilot-motor control the entire operation of the motor, and with it the operation of the plant, depends upon the pilot motor and the current relays controlling it. The failure of any one part will shut down the motor entirely, while with the control scheme shown in the diagram all parts are interchangeable and the failure of one element does not necessitate the shutting down of the entire plant for repairs, but merely the short-circuiting of this element while the motor can then operate with a reduced number of accelerating speeds, and it is still possible to keep the mill running while repairs on the part which is in trouble are being made. This control scheme also reduces the time element necessary for the action of the automatic slip regulation. If such automatic slip regulation in connection with a flywheel is desired, it will of course be necessary to change the connections of the relays somewhat, for instance, as suggested by Fig. 3.

Mr. White further states that the current relay control is undesirable for squirrel-cage motors started with potential starters. The writer cannot share this opinion and submits, herewith, in Fig. 4 a connection diagram, and in Fig. 5 a self-starter for squirrel-cage motors controlled by current relays. The objection to the constant-time-element control is that the motor is switched from the starting to the running tap of the transformer at a variable speed, which causes considerable variation in the surges on the line. Suppose that the motor-speed at which same is connected to full line voltage was 10 per cent below normal and the normal slip of the motor was 4 per cent, in this case the momentary current inrush would be 250 per cent of normal. Such slight variations in the speed when switching over are entirely possible with the constant-time-element control, while it is possible to set current-relay controllers very closely, say, within at least 10 per cent, which will entirely avoid the danger of momentary overload on the line to which the motor is connected, or the tripping of the circuit-breaker during starting.