to a flywheel, to which in turn is coupled a direct-current generator of much greater output than the primary motor, delivering its current to a direct-current motor whose field is excited by the Ward Leonard control, constitutes what is known, from the name of the inventor, as an Ilgner set. It was originally designed for winding in collieries, and was subsequently employed for driving rolling mills.

Imagine for the moment that nothing is connected up except the primary motor and the flywheel, and that a current from the central station, capable of giving out a steady load of 1,000 H.P., be switched on to the primary motor, and that this power, when exerted for five minutes, just brings the flywheel up to its maximum speed of 400 revolutions per minute. There will then be stored in the revolving wheel 5,000 horse-power-minutes.

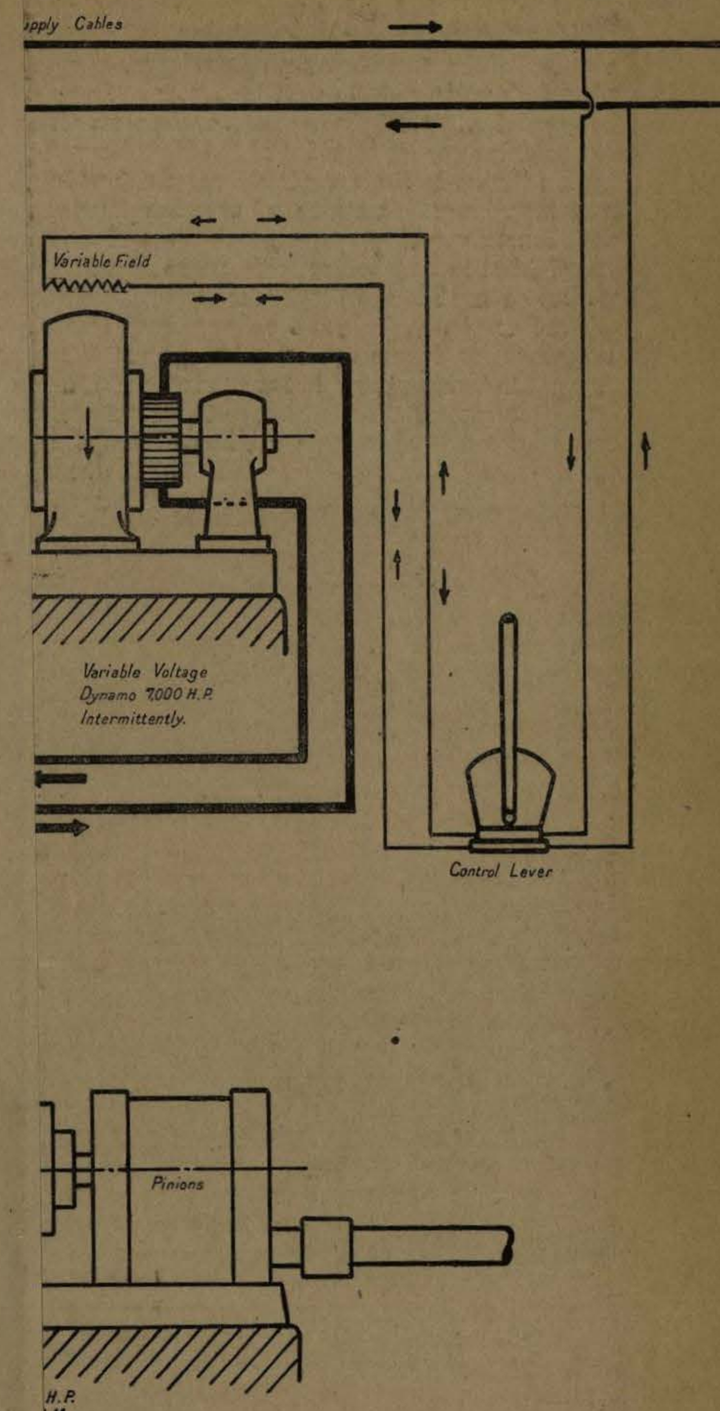
Suppose that the supply then ceases, and that at the same instant such a load be thrown on to the flywheel as to reduce its speed to 380 revolutions per minute. As the power stored in any moving body is proportional to the square of its velocity, that portion of the energy stored in the flywheel, which it will have given out again before it falls to 380 revolutions per minute, will be a tenth of that stored in it. If this happens in 30 seconds, the rate at which the power is given out will be the same, if in 15 seconds twice, and if in 10 seconds thrice that at which it was originally put in. Thus we can obtain from the revolving wheel the same power for the same time, twice the power for half the time, or thrice the power for one-third the time, and so on, according to the intensity of the resistance it encounters.

To simplify the description the supply from the central station was assumed to be switched off simultaneously with the demand from the mill, but in reality it would continue, and so proportionately delay the moment when the flywheel would fall to its predetermined speed. Thus, during the pauses or light running periods, the flywheel gathers speed and accumulates energy, to be given out again by its retardation during the periods of maximum demand, its function being to protect the central station from the fluctuations in the demand for power, which occur at the rolls. It may be used for this purpose, whether the mill reverses or runs only in one direction.

Plate xxxv. shows how it is possible to determine graphically beforehand the requisite sizes of the motors, and the amount of energy which must be stored in the flywheel, if a fairly uniform supply of energy from a power house is to be made to provide at the mill a rapidly fluctuating effort, the intensity of which shall vary from nothing up to several times that of the source of supply, at every few seconds. The first two figures on the plate are the graphic calculations, the last three the results obtained in an actual instance.

Fig. 453 shows the power which it was estimated would be required at each pass in the mill, and its duration, and fig. 454, assuming the supply of current to be constant, the variations which it was calculated would occur in the speed of rotation of the flywheel. Fig. 455 gives the energy actually absorbed, as shown by the recording ammeter at the mill, the power taken while the mill was rotating in one direction appearing above, and in the reverse direction below the centre line; fig. 456 shows the energy taken from the power house, and fig. 457 the speed of rotation of the flywheel, both being obtained from automatically recording instruments. While the demand at the mill fluctuated continually between 0 and 2,000, and once to nearly 3,000 amps., the supply actually taken from the power house to perform this work only varied between 1,000 and 1,200 amps., save for two short periods—short enough to be dealt with by the flywheels on the engines in the power house.

'E XXXIV. [To face p. 732.



eversing Mill Motors and Ilgner Balancing Set.

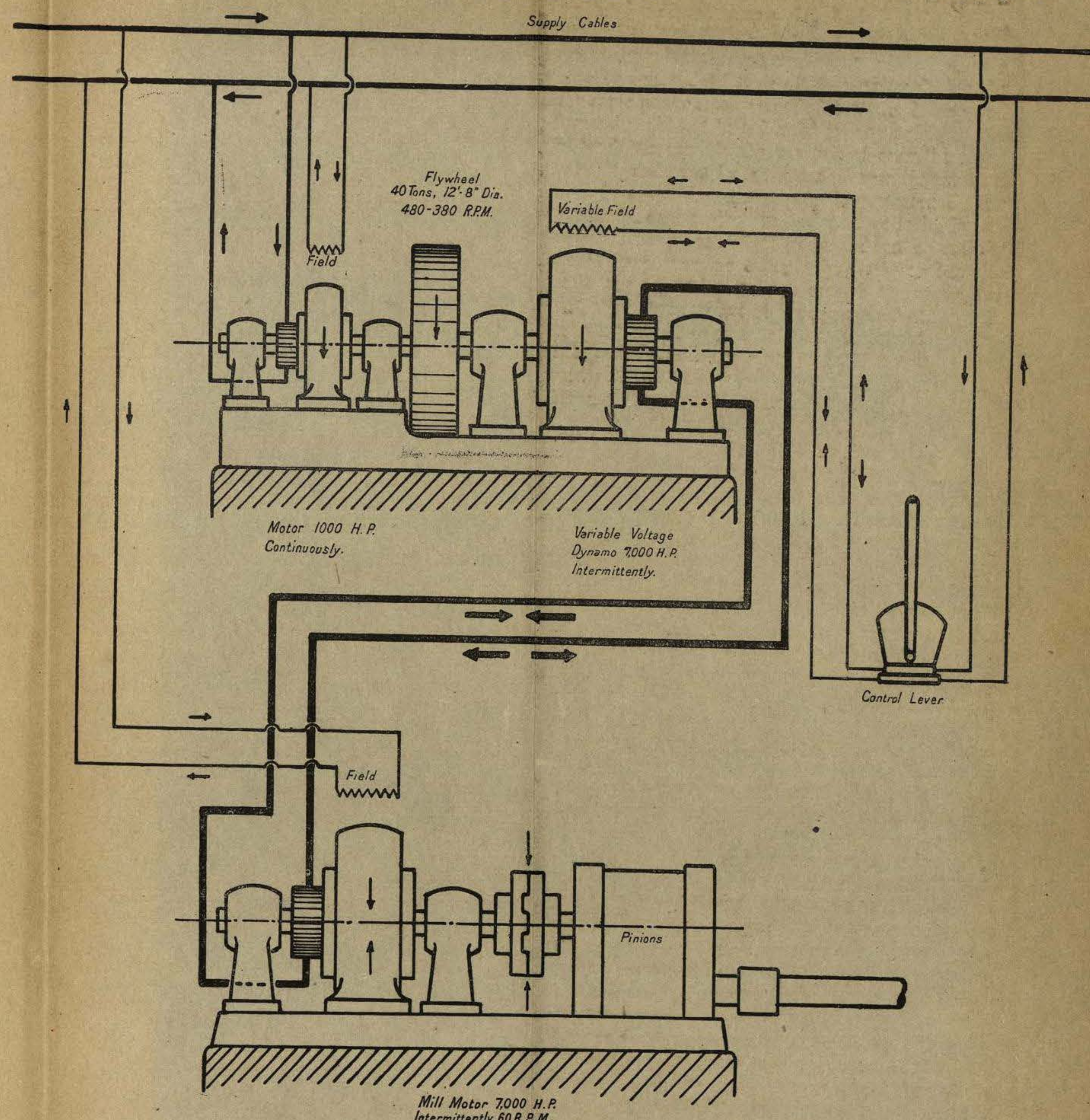
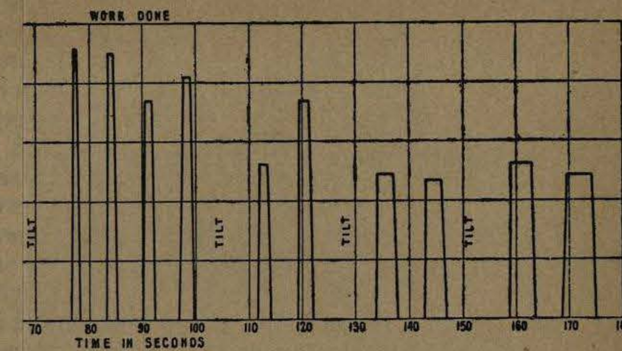
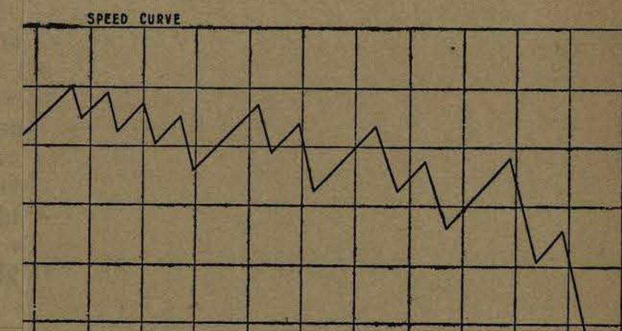


Fig. 452.—Diagrammatic View of Electric Reversing Mill Motors and Ilgner Balancing Set.



stimated to be absorbed by the Mill.



as the wheel, if allowed to run free, would continue running for an hour or more, a brake, sometimes water-cooled, is provided to stop it in two or

PLATE XXXV.

[To face p. 732.

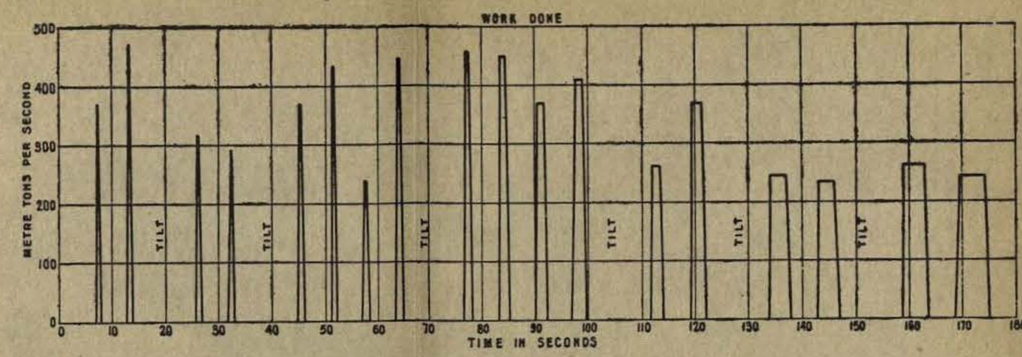


Fig. 453.—Power estimated to be absorbed by the Mill.

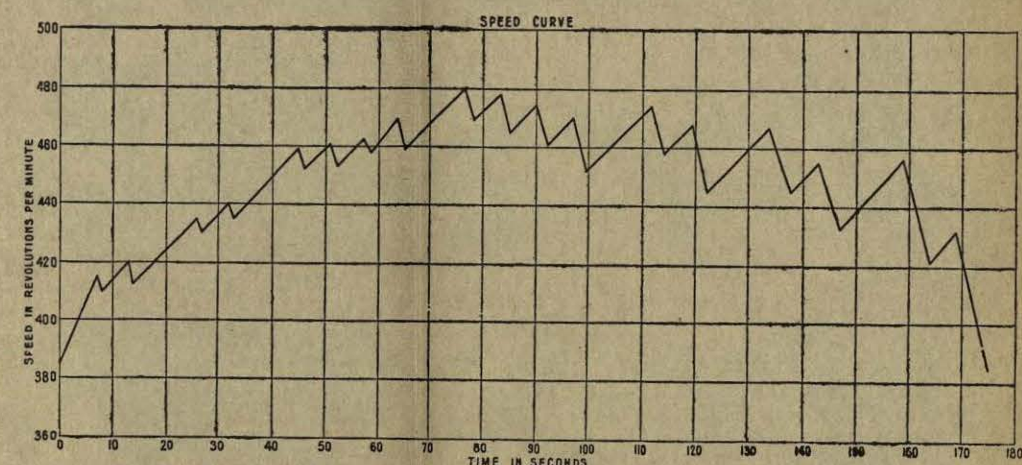


Fig. 454.—Anticipated Variation in Speed of Flywheel.

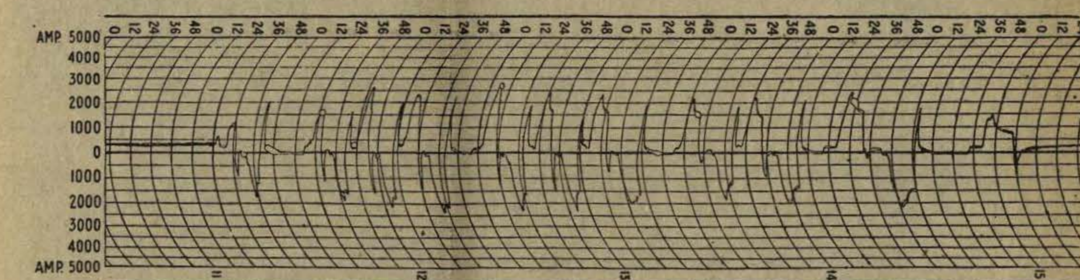


Fig. 455.—Energy actually absorbed by the Mill.

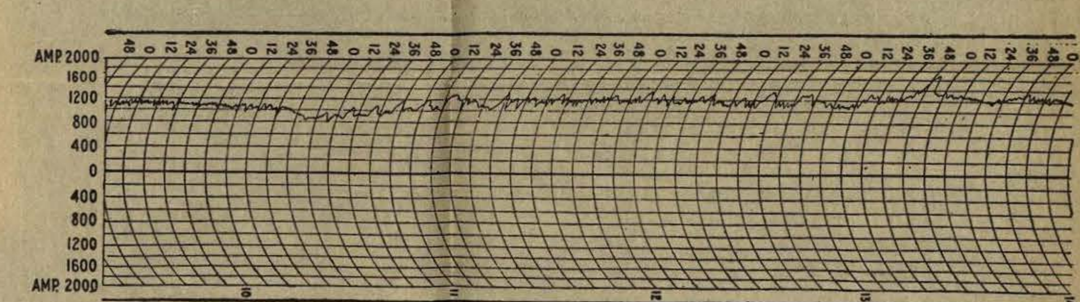


Fig. 456.—Energy actually supplied from the Power House.

Fig. 457.—Variation actually occurring in Speed of Flywheel.

In actual practice the maximum rate of output of an Ilgner set is usually from three to seven times the rate of input, and the fall in speed of the flywheel is sometimes as much as 20 per cent., thus utilising as much as 36 per cent. of the total power stored in it.

The variable voltage generator is shunt-wound, and, therefore, at constant speed, supplies a current, the voltage of which is proportional to the strength of its field; and as the field of the mill motor, which is also shunt-wound, is maintained constant, its speed varies in almost direct proportion to the voltage of the current supplied to its armature from the armature of the variable voltage generator. So the driver, by varying the strength of the field of this generator, varies the speed of the mill motor in practically the same ratio, and by reversing the flow of the current in this field he reverses the mill.

When the current in the armature of the mill motor is reversed, the motor acts as a generator, drives the variable voltage generator as a motor, and so brings the mill to rest. The kinetic energy stored in the revolving parts of motor and mill, which may amount to as much as 17½ per cent. of the total power taken to drive the mill, is thus returned to the flywheel; therefore, reversing the motor does not waste current, as steam is wasted when an engine is reversed.

The turning moment exerted by the motor is practically independent of the speed, so that the mill cannot race when the ingot leaves the rolls, as may occur if a reversing steam engine is carelessly handled; and, unlike a steam engine, the turning moment exerted by the motor is the same whatever the position in which the armature may chance to stop.

Details of Ilgner Plants.—Fig. 452 shows diagrammatically the essential parts of an Ilgner set in its simplest form, when the source of supply is a continuous current. In that case the decrease in speed of the primary shunt-wound motor necessary to enable the flywheel to give up its stored energy is obtained by relays actuating a rheostat in the field circuit of the motor. As the field currents dealt with are comparatively small, this variation is obtained without appreciable loss of power.

When the generating station supplies a three-phase current, the relay operates a liquid resistance in the rotor circuit of the primary motor, which entails an appreciable, but not serious, loss of power. In the case of an alternating supply a small motor generator is also needed to supply the constant continuous current required for exciting the field magnets.

The flywheels are disc-shaped steel castings machined all over and carefully balanced. The difficulty of joining the portions together, if the wheels were made in segments, practically necessitates making them in one piece, and to permit of their removal by rail from the maker's works the diameter cannot well exceed 13 feet, so that to take full advantage of their weight they must run at 400 to 500 revolutions per minute. In the diagram the flywheel is shown on the same shaft as the motor and generator, but in actual practice it is carried on its own shaft, and connected by flexible couplings to the motor and generator spindles, so that in the event of the weight of the flywheel, which may be as much as 60 tons, causing wear in the bearings, its drop will not drag the rotor or armature out of the centre of their respective fields; this would greatly increase the friction of the bearings, owing to the large magnetic forces set up. The flywheel bearings are sometimes water-cooled, and are usually provided both with ring and forced lubrication; as the wheel, if allowed to run free, would continue running for an hour or more, a brake, sometimes water-cooled, is provided to stop it in two or three minutes, in the event of any emergency, such as the heating of the bearings.

To protect the variable voltage generator and mill motor from excessive overload in case of an accident in the mill, an automatic maximum current cut-out is provided in the circuit between them; and to prevent pieces being put through the mill faster than the flywheel can provide energy to roll them satisfactorily, a lamp on the driver's platform lights up when the flywheel falls below a certain predetermined speed.

The arrangements of the motors and generators in other respects are not usually quite those shown in the diagram. The mill motor is often a double machine, having two armatures, which, from an electrical point of view, are more convenient than one only, providing more surface for cooling and reducing the radius of gyration, thus facilitating rapid reversal. If a single armature is employed it is cooled by an electric fan supplied with filtered air. The variable voltage generator may be similarly split up into two or more machines, in order to reduce the size and surface speed of the commutator, and in some cases two flywheels are also used.

Examples of Electrically-driven Reversing Rolling Mills.—The first of such mills was put down by the Siemens-Schuckertwerke for the Georgs-Marien-Bewerks-Verein, at Osnabrück, for rolling ingots 19½ inches square down to billets 3 inches square. There were two mill motors arranged to give together a turning moment of 275 foot-tons at 60 revolutions, equivalent to about 7,000 B.H.P. These were supplied with direct current at a pressure of 500 volts, generated by gas engines, the flywheel of the Ilgner set being 35 tons in weight, running at a maximum speed of 450 revolutions per minute, and being allowed a drop of 15 to 20 per cent. to give the power which it was expected would be required. The power was calculated from experiments made by Mr. C. Koettgen on the cogging mill at Gutehoffnungshütte in 1903, and proved remarkably accurate, the mill reversing from full speed in one direction to full speed in the opposite direction in a little over two seconds. A maximum speed of 90 revolutions per minute was obtained, the overall efficiency at full load being 60 per cent.

Since then Messrs. Siemens, and their allied companies, have constructed over a dozen mills, and about as many more have been constructed by other licensees. The largest mill of the sort so far constructed is the one at the Reinische Stahlwerke, shown in Plate xxxvi., fig. 458, where the existing reversing steam engines driving the 45-inch cogging mill have been replaced by a pair of very powerful motors capable of giving a turning moment of 225 metric tons, equivalent to 12,700 H.P., but at Peine, near Hannover, a reversing motor having a normal output of 12,600 and a maximum of 19,000 H.P. is being put down to drive a mill for rolling heavy beams.

The system has not made so much progress in this country as on the Continent, probably for reasons given on p. 715, but Messrs. Dorman, Long & Co., Ltd., of Middlesbrough, have a large mill of this kind made by the A. E. G., and Alfred Hickman, Ltd., of Bilston, have one working on a very similar principle, made by the Electric Construction Company, Ltd., of Wolverhampton, but differing in detail; as the question of the patents in connection with this installation are still *sub judice*, it cannot be described at the present time.

An Ilgner reversing mill, which has just been started (July, 1911) in the North of England, is interesting in several respects. After inspecting most of such mills at work in this and other countries, the Skinningrove Iron Company gave to Messrs. Siemens instructions to supply the electrical

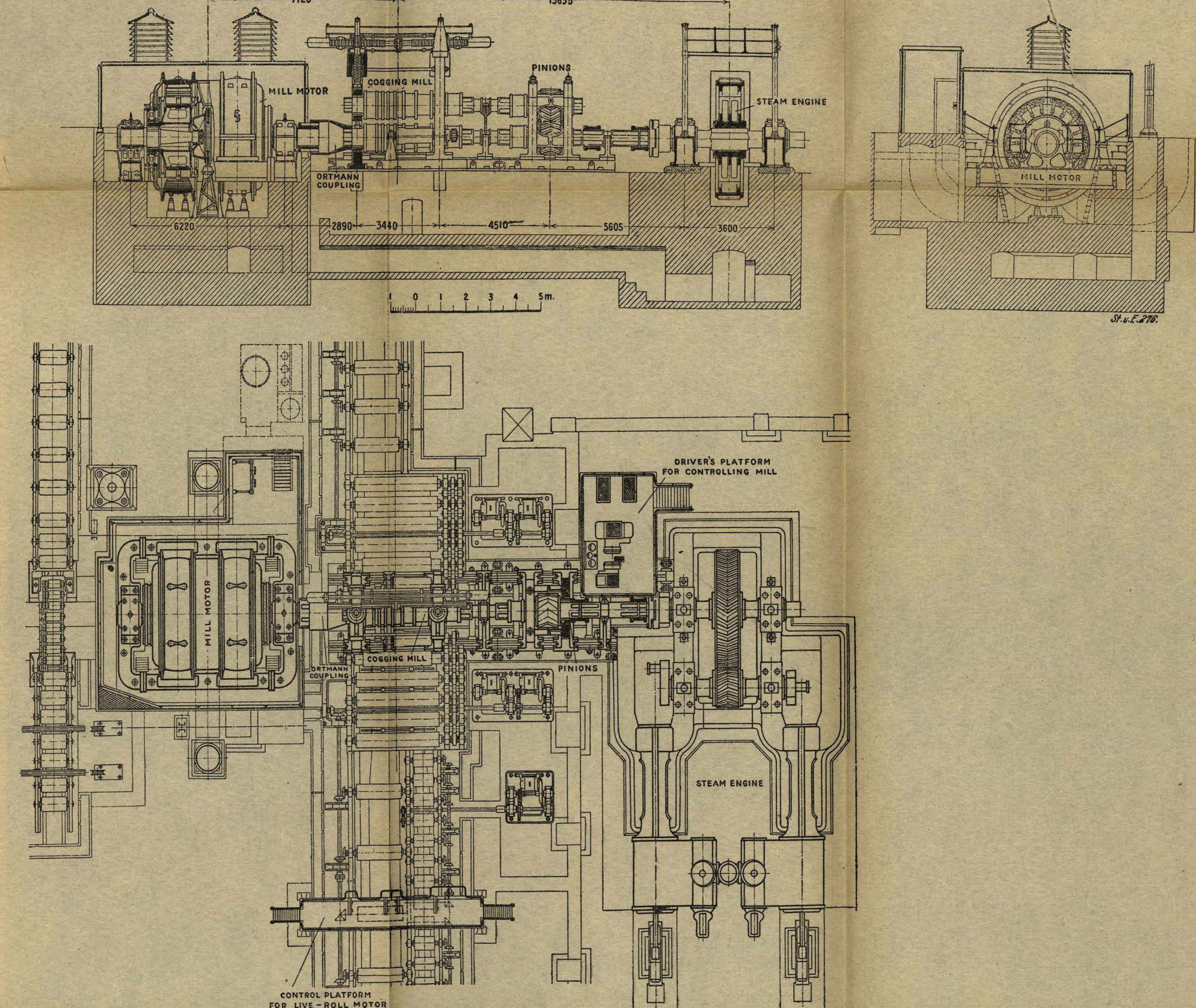


Fig. 458.—Plan and Elevations of the Electrically-driven 45-inch Reversing Cogging Mill at the Rheinische Stahlwerke.

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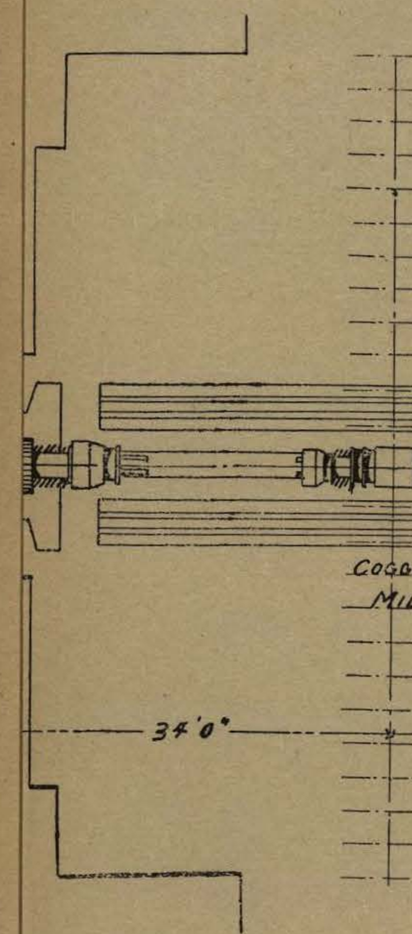

gging, Roughing and Finishing Mill at th

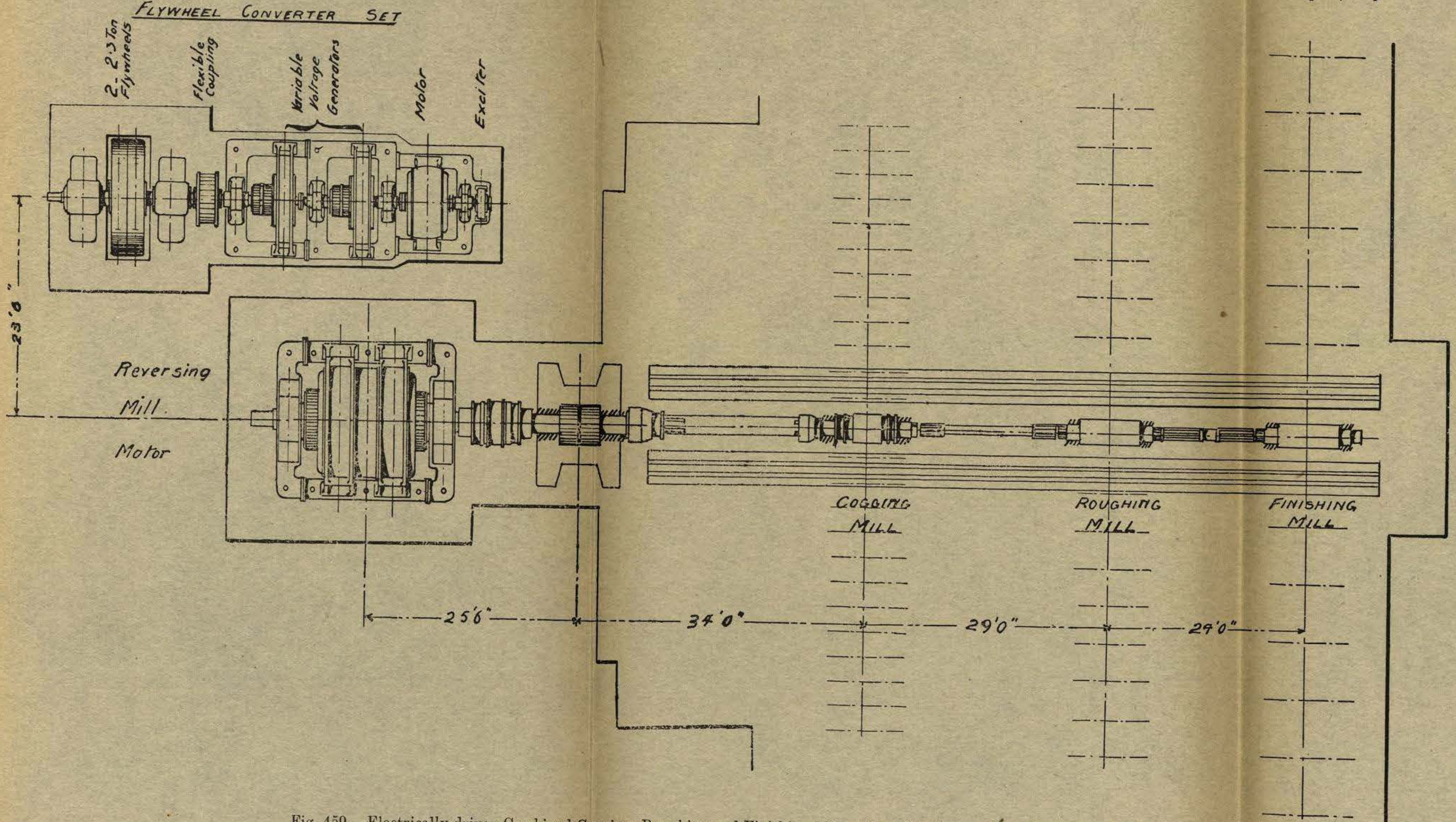

Fig. 459.—Electrically-driven Combined Cogging, Roughing and Finishing Mill at the Skinningrove Iron Company's Works.