CHAPTER VII

THE KJELLIN AND RÖCHLING-RODENHAUSER STEEL REFINING FURNACES

The furnaces described in the preceding chapters of this work have all been of the arc or of the combined arc and resistance type. We have now to consider furnaces of the third class (see Chapter II. p. 10). Of these the Kjellin and Röchling-Rodenhauser furnaces are the most important, for the latest available figures show that ten of the former and seventeen of the latter are now actually operating, or are under construction, in Europe and America. A list of these furnaces, with details of their capacity and methods of charging, is given in the Appendix.

The largest furnace is installed at the Röchlingische Eisen u. Stahl Werke at Volklingen, and is of the Röchling-Rodenhauser type with a working capacity of 12,000 kgs. Other large furnaces of the same type are to be found in Germany, at the works of the Bergische Stahlindustrie at Remscheid, and also at the works of the Eicher Hüttenverein, Le Gallais Metz & Co., Dommeldingen.

As already indicated in Chapter II., the general principle of the induction furnace is to use the metal as the secondary circuit in a furnace which is practically a step-down transformer. The original type of Kjellin furnace was patented in the United Kingdom in 1900, and is shown in Figs. 49 and 50, the primary coil being shown at DD, and the ring of molten metal forming the secondary circuit at BB. The primary is supplied with alternating current. The intensity of the induced current in the secondary circuit of molten metal can be calculated roughly by multiplying the amperes of the primary current by

the number of turns contained in the coil. The method of work is as follows.

About 1,000 kgs. of molten pig-iron or scrap steel are poured into the annular ring BB of the furnace, and the current is switched on to the primary coil. A current of 90 amperes at 3,000 volts is utilised; this is transformed in the secondary to

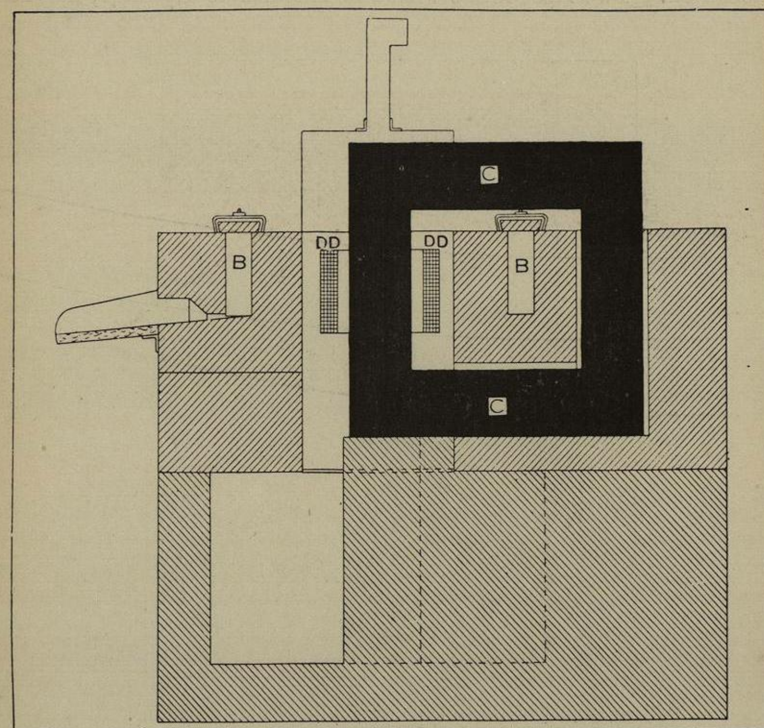

Fig. 49.—The early type of Kjellin Furnace (elevation).

a current of 30,000 amperes at 7 volts. Eight hundred kilograms of cold pig-iron and scrap steel of the required composition, and in calculated proportions, are now added to the molten metal in BB, the covers of which are made in short segments, in order to allow of this addition taking place equally all round the ring. The covers are now replaced, and the heating is continued for four to six hours with different fluxes, until the metal has attained the degree of purity desired. The plug is then removed from the tapping hole, shown on the left of Fig. 49, and from 800 to 1,000 kgs. of the metal are run off and cast into ingots. The remaining 800 kgs. are left in the furnace to carry the current until fresh raw materials are added. It is found that there is always less carbon in the finished steel than is contained in the charged raw materials, while the silicon has increased. Two runs made with this furnace at Gysinge, in the

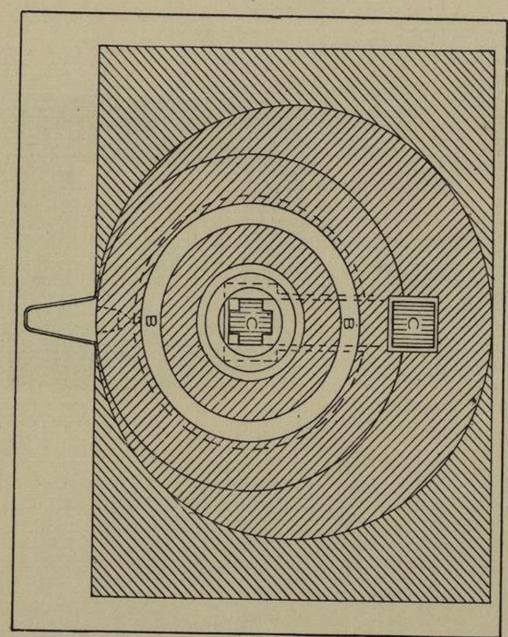

FIG. 50.—The early type of Kjellin Furnace (plan).

early days of the electric steel industry, gave 1,985 kgs. of steel with a power expenditure of 1,851 kw. hours in 12⅔ hours. The average power consumption was therefore 932 kw. hours per metric ton of 2,204 lbs. The raw materials in each case were best Swedish pig-iron and Wallon bar-iron, with scrap steel from previous charges. The steel produced contained only ·008 per cent. sulphur and ·010 per cent. phosphorus, with ·417 per cent. carbon in one case and 1·082 per cent. in the other.[1]

[1] See Report of Canadian Commissioners, 1904.

The temperature of the steel when tapped is about 1,700° C. Using electric power at 40*s*. per e.h.p. year, the cost of producing steel by the Kjellin furnace and process was estimated at £7 per ton of 2,000 lbs., and the cost of erecting a 600-h.p. furnace was stated to be £830.

Crushed magnesite or dolomite is used for the lining of the annular ring, which acts as the melting pot for the furnace, and a little lime is also employed as a protecting slag. Considerable

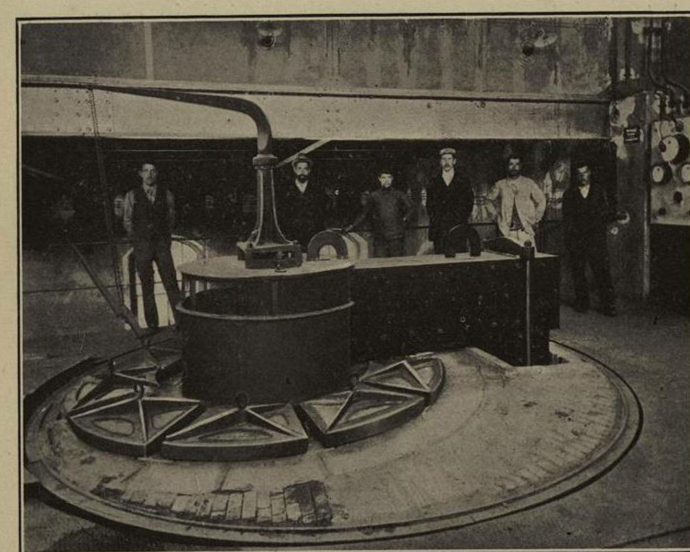

FIG. 51.—The 1,500-kg. Kjellin Furnace at Gysinge in operation.

care is necessary when drying out the magnesite or dolomite lining before the furnace is employed for melting metal, and from sixty to seventy hours are requisite for this preliminary work. A lining lasts from four to eight weeks, according to the tonnage put through the furnace and the heat employed. The cost under American conditions of work is estimated at $1.00 per ton of finished steel, and under European conditions would be proportionately reduced.

Tests made with a 125-kw. furnace of the original Kjellin type have shown that under the most favourable conditions of work, 1 metric ton of ordinary tool steel can be made with an expenditure of 650 kw. hours; while the highest grade steel requires from 750 to 800 kw. hours. The furnace efficiency in these cases is about 70 per cent. to 75 per cent.

According to Härden it has not been found practicable to make more than six melts in twenty-four hours with this older form of Kjellin furnace when a high grade tool steel is required, for the reason that the steel must be left quiescent in the furnace at a high temperature for a considerable period, in order to allow the occluded gases time to escape. Steel can in fact be melted in the Kjellin furnace with an expenditure of 590 kw. hours per metric ton, but the maintenance of the heat during the "killing" period adds from 60 to 200 kw. hours to this total.

Fig. 51 shows a 1,500 kg. Kjellin furnace in operation at Gysinge.

The disadvantages of the older form of Kjellin furnaces are stated by Härden to be as follows:—

(1) Only small quantities of metal can be dealt with at each melting. If the section of the bath be made wider, the resistance is lowered and the power-factor diminished; while if the ring be made of larger diameter and of smaller section, the distance from the primary will be increased and the power-factor again diminished.

(2) The comparatively low temperature makes it impossible to keep the slag sufficiently fluid to obtain rapid removal of the sulphur and phosphorus.

For these reasons the use of the original Kjellin type of induction furnace is confined to the melting down and mixing of scrap and fine steel that does not require purification, and its application as a refining furnace is no longer attempted. For the latter purpose, the furnace has been modified greatly by Rodenhauser and Schönawa, and what is generally known as the Röchling-Rodenhauser *combined* resistance and induction furnace has been evolved. The first furnace of this type was started

at the Röchlingische Iron and Steel works, at Volklingen, in Germany, in 1907. The following description of the furnace was given by Härden in a paper read before the Faraday Society in June, 1908:—

The combined furnace consists of a transformer furnace with two or three ring-shaped baths, adjacent and communicating with one another and with a square or rectangular hearth placed in the centre between the rings. Doors are provided in front and behind, and the external appearance is very much like that of a Siemens open-hearth furnace. On closer examination, however, the principal feature is seen to be a heavy secondary winding of copper cables, placed around and co-axial with the primary, one on each leg of the core and surrounded by the rings forming the charge. These copper secondaries, consisting of a few turns only, are connected to conductive plates built into the furnace wall, two in front and two at the back for a single-phase furnace. These plates consist of corrugated cast steel plates having a compound of magnesite, dolomite, and tar applied firmly over the corrugations. The plates do not conduct well when cold, but as soon as the furnace is charged with molten raw material they act as "conductors of the second class," and readily allow the current to pass. Thus about one-half of the power is transmitted to the charge by induction in the rings, and the other half of the power through the side plates. As the copper secondary is placed very close to the primary, the "leakfield" is very much smaller than with the original Kjellin furnace. A far more important gain, however, is to be found in the metallurgical possibilities obtained with the new design.

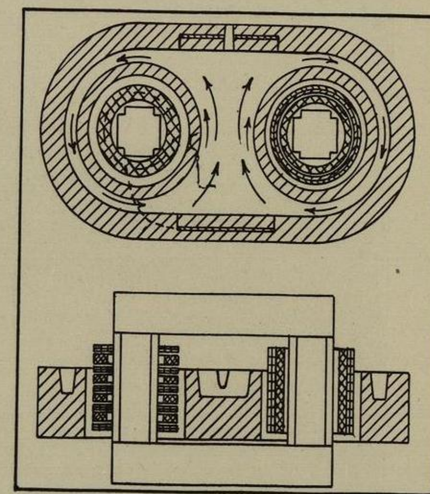

Fig. 52.—The Röchling-Rodenhauser Single-phase Furnace (elevation and plan).

For carrying out any refining process with steel, a sufficiently liquid slag and ways and means of handling the same, are required. This is obtained in arc furnaces by the arc, which plays between the carbon electrodes and the slag "blanket." In the combined furnace of Röchling-Rodenhauser, the slag is raised to and maintained at the required temperature in the resistance portion of the furnace, the conducting side plates of which are quite neutral. One portion of the power is converted into heat and utilised in the rings, thus heating the charge of metal; the remainder passes through the side plates to the

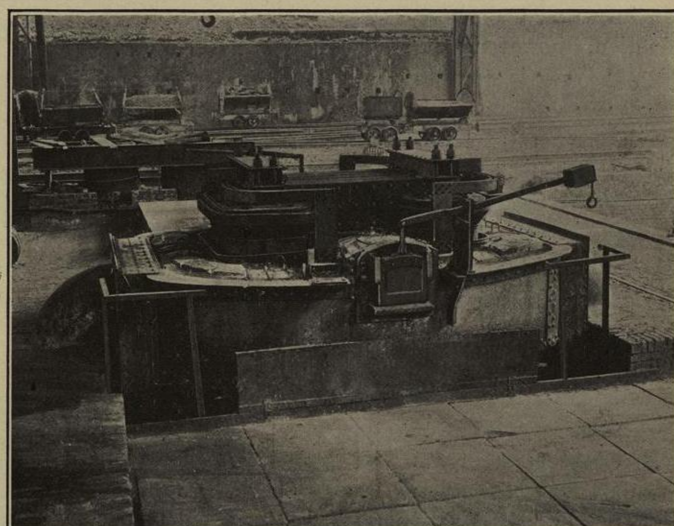

FIG. 53.—A Röchling-Rodenhauser Three-phase Furnace, under construction.

extent that experience has proved necessary, and is utilised chiefly in heating the slag. The ring-shaped portion of the furnace is covered with bricks at a height below the level of the charge in the centre bath. Thus no slag can enter into the rings; and as it is the slag which is injurious to the lining, the rings need hardly any repair during a long run. The rectangular bath in the middle, on the other hand, is easily accessible, and can easily be repaired. The lining is simply calcined magnesite or dolomite mixed with tar and tamped in hot. It has been said that the use of these steel side plates would be

equivalent to a return to the old system of carbon electrodes with all their disadvantages, but it is evident from what has been stated above that this is not the case. Practically no consumption whatever of these plates takes place, and they can hardly be called "electrodes" in the strict sense of the word. Figs. 52 to 56 explain clearly the construction of the combined resistance and induction types of furnace. The method of working is described by Härden as follows:—

After the lining is tamped in, the tar is burnt out either by heating a cast-steel ring, or by pouring a small quantity of molten pig-iron into the hearth. This method leaves behind a sintered mass, forming a solid brick of basic lining. The pig-iron used for this preliminary heat is teemed out and is utilised for treatment in the Bessemer converter; and a fresh charge is given, tapped direct from the converter. It has been found in practice more economical to burn out the carbon and the silicon in the converter, before refining from phosphorus and sulphur in the combined type of electric furnace. The largest furnace at Volklingen takes a charge of four tons. Calcined lime is added to form a suitable slag; this slag sometimes contains about 6 per cent. of magnesia. In case of need a small quantity of fluorspar is also added to act as a flux, but this is not always necessary. Plate scale from the rolling-mills is employed for decarbonising. When in a sufficiently fluid condition the slag takes up the phosphorus very readily, after which it is made more viscous by adding cold lime, and is then drawn off through the slag-door by a slight tilting of the furnaces. It is essential for a successful dephosphorisation that the charge should be what is called "hot brittle" (*i.e.*), have an excess of oxygen, in order to prevent the phosphorus striking back into the charge again. After removing the slag containing nearly all the phosphorus, ferrosilicon or carbon is added, in order to form SiO_2 or CO_2, thus depriving the charge of the oxygen. It has been found that the addition of ferrosilicon is advantageous since it shortens the time of the deoxidation. If power be cheap carbon may be employed; but in the case of a costly power supply, it is better to use the ferrosilicon. As soon as the dephosphorising is completed and the first slag has been entirely removed, a fresh slag of lime only is formed. This when the temperature is raised acts as desulphuriser by formation of iron sulphide. The oxygen is also driven out in this operation, partly by combustion of the ferrosilicon or carbon whereby the temperature is increased, and partly by adding a small quantity of other active reagents.

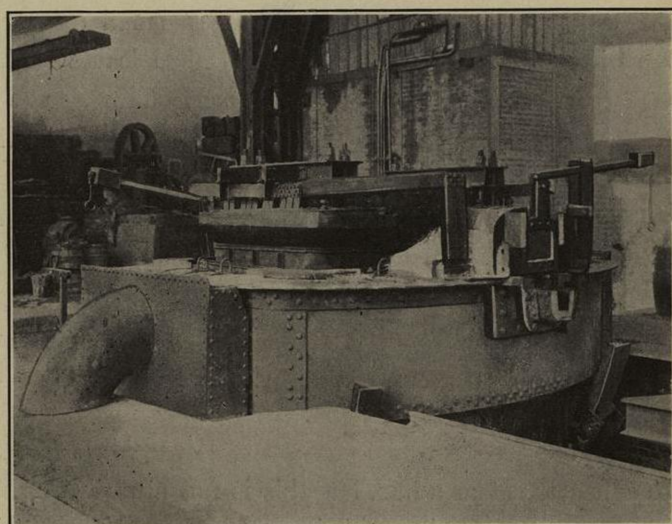

FIG. 54.—A Röchling-Rodenhauser Three-phase Furnace, under construction.

Calcium carbide is generally formed during this stage of the refining process.

Finally, the maximum power is applied, in order to drive out the last traces of oxygen, and as soon as no more gas bubbles are seen to leave the charge, a test piece is taken out and forged. If too soft for the purpose some coke powder is thrown in until the right proportions are arrived at. As a rule the operation is finished in from one-and-a-quarter to two hours, but if necessary the steel can be kept in the furnace for ten hours or more without disadvantage. It is thus possible to treat a material

which contains up to 0·1 per cent. phosphorus and 0·1 per cent. sulphur, so that a product will be obtained containing only

FIG. 55.—A Röchling-Rodenhauser Single-phase Furnace being charged with molten metal.

0·006 per cent. phosphorus, and 0·02 per cent. sulphur, with from 0·5 to 0·1 per cent. manganese and 0·01 silicon.

It has been urged against the Kjellin and Röchling-Rodenhauser types of induction furnace, that the steel produced is of irregular quality and composition, owing to the differences of temperature that exist in different parts of the bath. Engelhardt, in an article

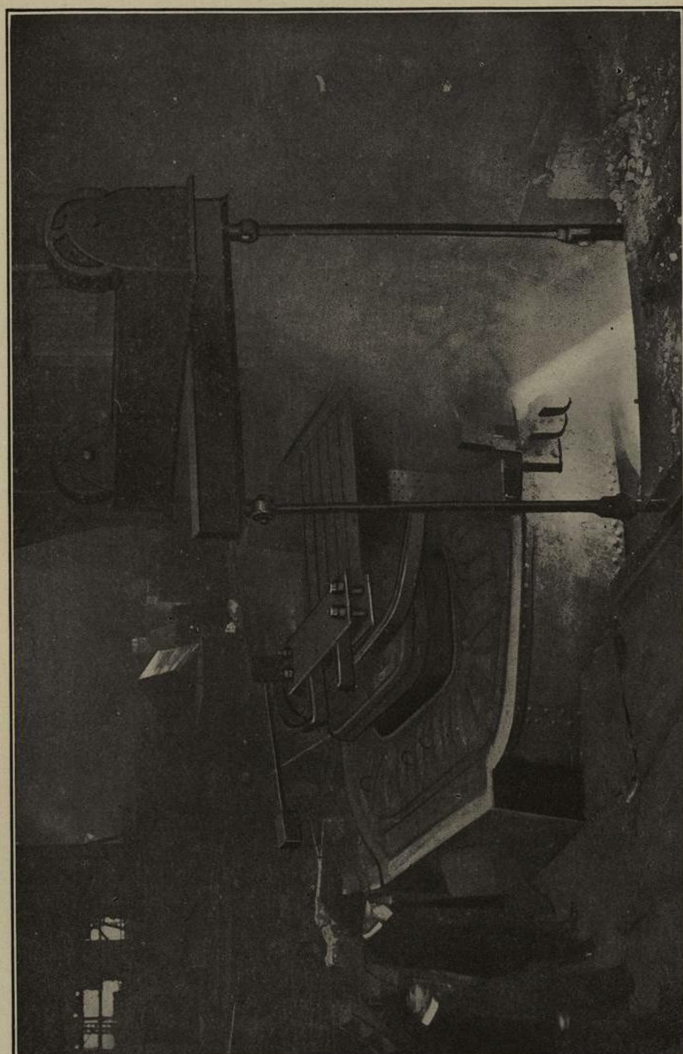

Fig. 56.—A Röchling-Rodenhauser Single-phase Furnace (discharging).

published in the German technical paper named below,[1] has examined into this charge, and has brought forward evidence to disprove it. The most interesting portion of this refutation is

[1] *Stahl u. Eisen*, No. 16, 1910.

that contained in Section IV. of his article, in which practical notes upon their experience with the Kjellin and Röchling-Rodenhauser furnaces are given by several German licensees who have installed this type of furnace in their works. Amongst the firms who stated they had not found any inequalities in the composition of the steel, made in the combined type of induction furnaces, are Messrs. Fr. Krupp & Co., of Essen, the Bergische Stahlindustrie, of Remscheid, and the Poldihütte, of Kladno.

As regards the power of consumption and costs of operating the "combined" type of induction furnace, Härden in the paper referred to above states that when molten metal from the Bessemer converter is charged into the furnace, only from 125 to 150 kw. hours are required per ton of finished steel, and that 130 kw. hours may be taken as a good average. Vom Baur, in a letter published in the issue of *Metall. and Chem. Engineering* for January, 1912, gives 200 to 250 kw. hours per metric ton for the work of a 10-ton furnace refining basic Bessemer steel, which contained before treatment in the electric furnace ·08 per cent. phosphorus and ·09 per cent. sulphur, and only one-tenth of these amounts after the refining operation. According to the same authority, the Röchling-Rodenhauser type of induction furnace will melt cold scrap, with an expenditure of 580 kw. hours per ton, and the following details were given by him in a paper read on May 23rd, 1911, before the American Foundrymen's Association, for the operating costs of a 2-ton furnace at Volklingen:—

Table XXIII.

	Dols.	Per long ton. Dols.
700 kw. hours for melting at ·6 cent. per kw. hour	4·20	
200 kw. hours for refining at ·6 cent. per kw. hour	1·20	
		5·40
Fluxes, etc., roll scale 22 lbs., lime 77 lbs., fluorspar 11 lbs., sand 20 lbs., ferro-manganese 8·8 lbs. .		·44
Loss of fluxes owing to a quarter of all metal remaining in the hearth		·16

Table XXIII.—*continued.*

	Per long ton. Dols.
Labour, two to three men	1·50
Tools, repairs, and lining	·67
Depreciation 10 per cent., interest 5 per cent. on 11,300 dols.—300 days, 6 tons per day of 12 hours—1,695 dols. ÷ 1,800 =	·94
Auxiliary apparatus (cooling air for transformer)	·04
Total	9·15
Adding this, we get—	
Raw materials	12·60
Conversion costs	9·15
Cost of one ton electric steel ready to pour	21·75

To this cost must be added a slight licence fee per ton, depending on the output.

Time of heat about 4 to $4\frac{1}{4}$ hours.

Working with hot metal—drawn from the blast furnace, mixer, cupola or other type of furnace—the consumption of power is, of course, considerably reduced, and the following figures are given by Vom Baur for the cost of refining hot metal taken from the mixer at Dommeldingen, under American conditions, of work.

Table XXIV.

	Dols.	Dols.
Raw material	12·00	
Oxidation loss 3 per cent.	·36	
		12·36
Current 280 kw. hours at ·6 cent. per kw. hour		1·68
Fluxes, etc.		·60
Labour		·50
Tools, repairs, and lining		·64
Depreciation 10 per cent., interest 5 per cent. on 17,000 dols.—300 days at 40 tons per day of 24 hours—2,550 dols. ÷ 12,000 tons =		·22
Auxiliary apparatus		·06
Total		16·06
Cost of preliminary refining, about		3·00
Total cost of one ton of electric steel ready to pour		19·06

Time of each heat about $2\frac{1}{2}$ hours.

The estimated cost of refining hot metal melted in the cupola, and consisting mainly of steel scrap, having about 2 per cent. carbon in the resultant mixture, is as follows:

Table XXV.

	Dols.	Dols.
Raw material	14·00	
Total oxidation loss 8 per cent.	1·12	
		15·12
Conversion cost similar to the above		4·90
Cost of preliminary melt in the cupola, about		3·00
Cost of one ton of electric steel ready to pour		23·02

Time of each heat about $3\frac{1}{2}$ hours.

A more detailed estimate of cost for English conditions of work was given by Kjellin in a paper contributed to the Niagara Falls meeting of the American Electro-chemical Society held in May, 1909. The production cost of steel for rails in a 7-ton three-phase Röchling-Rodenhauser furnace was given in this paper as 74*s.* 8*d.* per ton, and for soft boiler plate 79*s.* 3*d.* per ton; the following summary showing the various items which made up these totals:—

Table XXVI.

	For Rails. *s.*	*d.*	For Boiler Plate. *s.*	*d.*
Material charged	66	3	66	3
Power—				
Heating up	0	1	0	2
Refining	3	0	5	$9\frac{1}{2}$
Wages—				
On furnace	0	8	1	4
On linings	0	$0\frac{1}{2}$	0	1
Materials for lining	0	$3\frac{1}{2}$	0	7
Tools	0	$4\frac{1}{2}$	0	$4\frac{1}{2}$
Repairs	0	$9\frac{1}{2}$	0	$9\frac{1}{2}$
Depreciation and interest	0	8	1	5
Licences	2	6	2	6
Total costs, per ton of steel	74	8	79	$3\frac{1}{2}$

As a final estimate of power consumption and costs, that given by Thieme in an article contributed to the September 8th, 1910, issue of the *Elektrotechnische Zeitschrift* may be quoted, this article containing a very full and detailed description of the electric steel works of Le Gallais Metz & Co., at Dommeldingen, Luxemburg. The estimate is for steel produced in a three-phase Röchling-Rodenhauser furnace of 5 tons capacity, using fully blown molten raw material containing ·08 per cent. phosphorus, ·08 per cent. sulphur and ·12 per cent. carbon, and with power costing 4·5 pf. per kw. hour. It is assumed that this furnace can produce 10,000 tons of finished steel in 250 working days of eight heats per day.

TABLE XXVII.

	Marks per ton of finished steel.
Depreciation on 10,000 marks	1·00
Power consumption 280 kw. hours	12·60
Materials for slags, etc.	2·25
Linings and repairs	2·50
Wages	·75
Air blast for cooling transformer coils	·21
Total	19·31

This total is one for running costs only, no estimate for the cost of raw materials or for interest and royalty charges having been included in it.

Passing on now to a consideration of the chemical and physical tests of the steel produced in the Kjellin and Röchling-Rodenhauser induction furnaces, Härden states that the finished steel is distinguished by its great strength and homogeneity, and that rails have been made with much higher bending and breaking coefficients than the rails made from Bessemer or Thormas steel. These electric steel rails are also said to have sold at a price from 25*s*. to 45*s*. per ton higher in Germany than ordinary steel rails, owing to their greater durability. The following tests

are given as typical of the steel produced in the Röchling-Rodenhauser furnaces:—

TABLE XXVIII.

No.	C	Mn	Si	S	P	Tensile strength. Tons per sq. in.	Elongation. Per cent.	Con-traction. Per cent.
1	0·55	0·9	0·30	0·03	0·05	53·2	18·5	31·4
2	0·50	0·9	0·25	0·025	0·05	52·0	19·0	26·7
3	0·55	0·85	0·29	0·05	0·04	52·5	17·0	30·8
LOW CARBON ELECTRIC STEEL.								
1	0·094	0·30	0·086	0·025	Trace.	23·22	36·0	71·5

Vom Baur, in the paper read before the American Foundrymen's Association, already referred to, gave tables containing the chemical and physical tests of various classes of steel made in the combined Röchling-Rodenhauser furnace. From these tables the figures given in Tables XXIX. and XXX. are taken.

TABLE XXIX.—ANALYSIS OF STEEL MADE IN RÖCHLING-RODENHAUSER FURNACE.

No. of charge.	Quality.	C per cent.	Si Per cent.	Mn Per cent.	S Per cent.	P Per cent.	Cr Per cent.	Ni Per cent.
1,458	Very mild for welding	0·04	Traces.	0·24	0·006	0·007	—	—
1,406	Mild for case hardening	0·18	0·16	0·62	0·009	0·009	—	—
1,692	For machines and wagons	0·45	0·20	0·62	0·011	0·008	—	—
1,738	For machines and wagons	0·61	0·20	0·71	0·006	0·010	—	—
1,242	Nickel steel for case hardening	0·21	0·14	0·51	0·012	0·010	—	3·77
1,583	Nickel steel	0·33	0·20	0·36	0·009	0·010	—	3·06
1,509	Chrome nickel steel for case hardening	0·12	0·20	0·29	0·011	0·010	0·91	3·93
1,292	Chrome nickel steel	0·34	0·17	0·32	0·005	0·011	1·23	3·51
1,302	Special spring steel.	0·57	1·53	0·44	0·004	0·011	—	—

In conclusion, a few details may be given of the most notable installation of electric induction furnaces of the Kjellin and

Röchling-Rodenhauser type, namely that to be found at the steel works of Le Gallais Metz & Co., at Dommeldingen, Luxemburg. This electric installation of electric furnaces started work in September, 1909, and so far as the writer is aware, is still in successful operation. The firm possesses three blast furnaces working on the iron ores of the locality which contain 40 to 45 per cent. iron. Each furnace produces 4 × 25 ton

TABLE XXX.—TESTS OF STEEL MADE IN RÖCHLING-RODENHAUSER FURNACE.

Heat No.	Elastic limit. Lbs. per sq. in.	Tensile strength. Lbs. per sq. in.	Elongation. Per cent.	Reduction of area. Per cent.
1458	31,300	43,400	35·4	70·0
1406	44,100	69,400	26·5	54·6
1692	61,150	96,580	20·2	42·0
1738	70,250	114,360	15·0	35·6
1242	54,600	76,100	23·5	64·0
1583	65,130	86,760	21·9	50·0
1509	64,560	83,900	22·3	64·0
1292	104,680	123,740	13·3	48·0
1302	68,260	112,640	15·2	43·0

charges of pig-iron per day, and the waste gases are employed for running the electrical portion of the plant by means of a compound gas engine, built by the Maschinen-Fabrik Augsburg-Nürnburg. This engine is direct coupled to an alternating-current generator of 1,800 kilowatts capacity built by Felten and Guilleaume, with an output of 210 to 360 amperes at 5,000 volts.

A 25½ kilowatt 10-pole exciting dynamo is also driven by the same gas engine, while a Zoelly steam turbine coupled to a 1,000 kilowatt Siemens-Schuckert alternator provides the remainder of the power required.

The steel refining portion of the plant comprised originally two transformers, to reduce the E.M.F. and periodicity of the current as generated to that required for operating the furnaces, and three Röchling-Rodenhauser furnaces, two of 4 tons and one of 1½ tons capacity. Figs. 55 and 56 show one of the

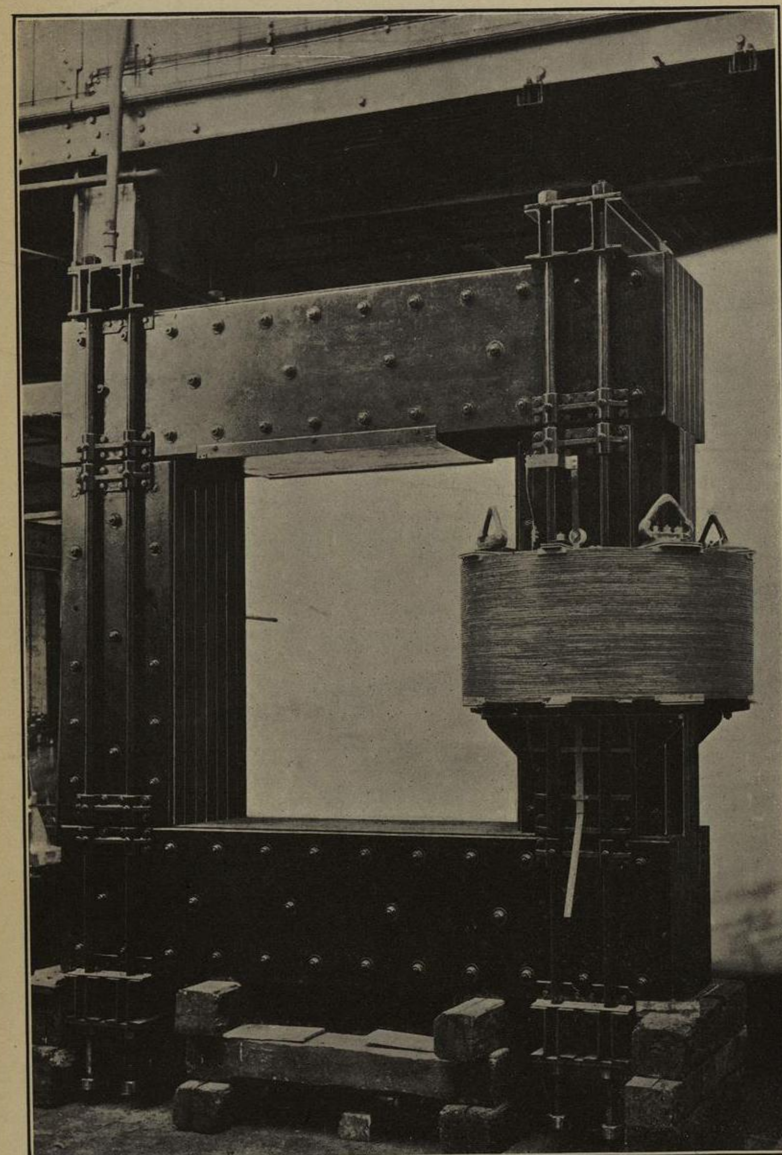

FIG. 57.—Details of Transformer Construction for a Kjellin Furnace.

single-phase furnaces at this works ready for operating an also discharging. A very complete account of the whole plant, illustrated by numerous photographs, is given by H. Thieme, in

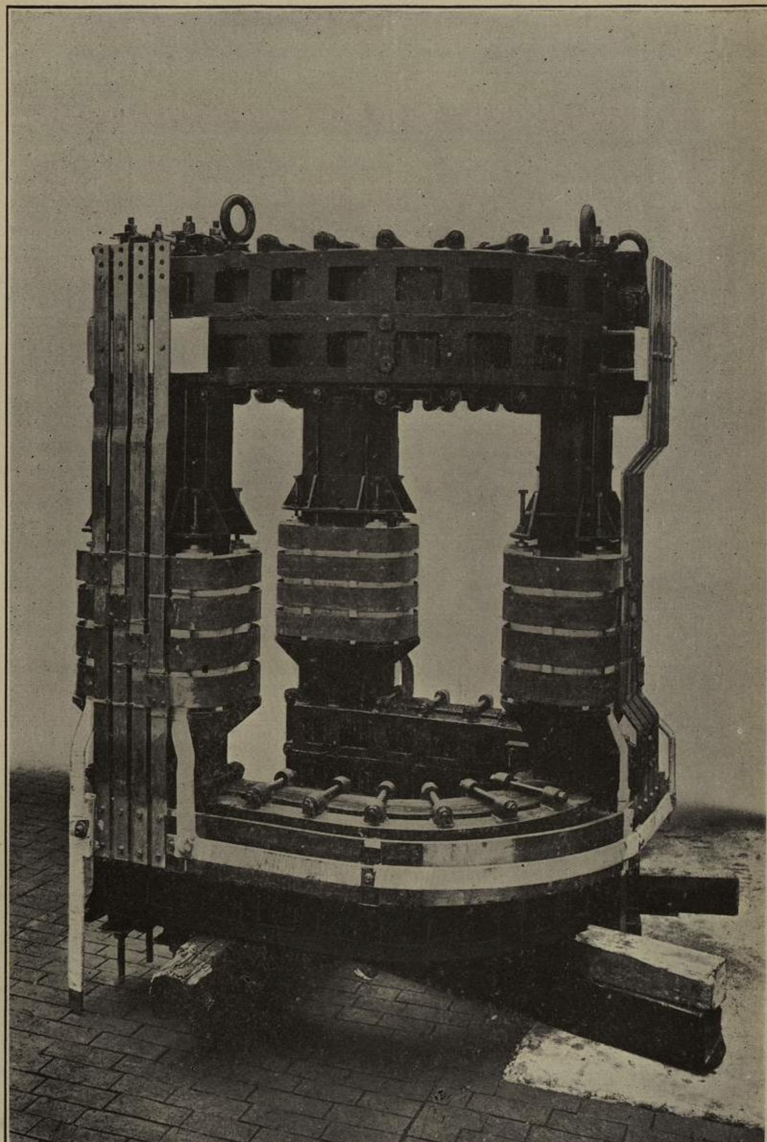

FIG. 58.—Details of Transformer Construction for Röchling-Rodenhauser Three-phase Furnace.

the issue of the *Elektro-technische Zeitschrift* for September 8th and 15th, 1910.

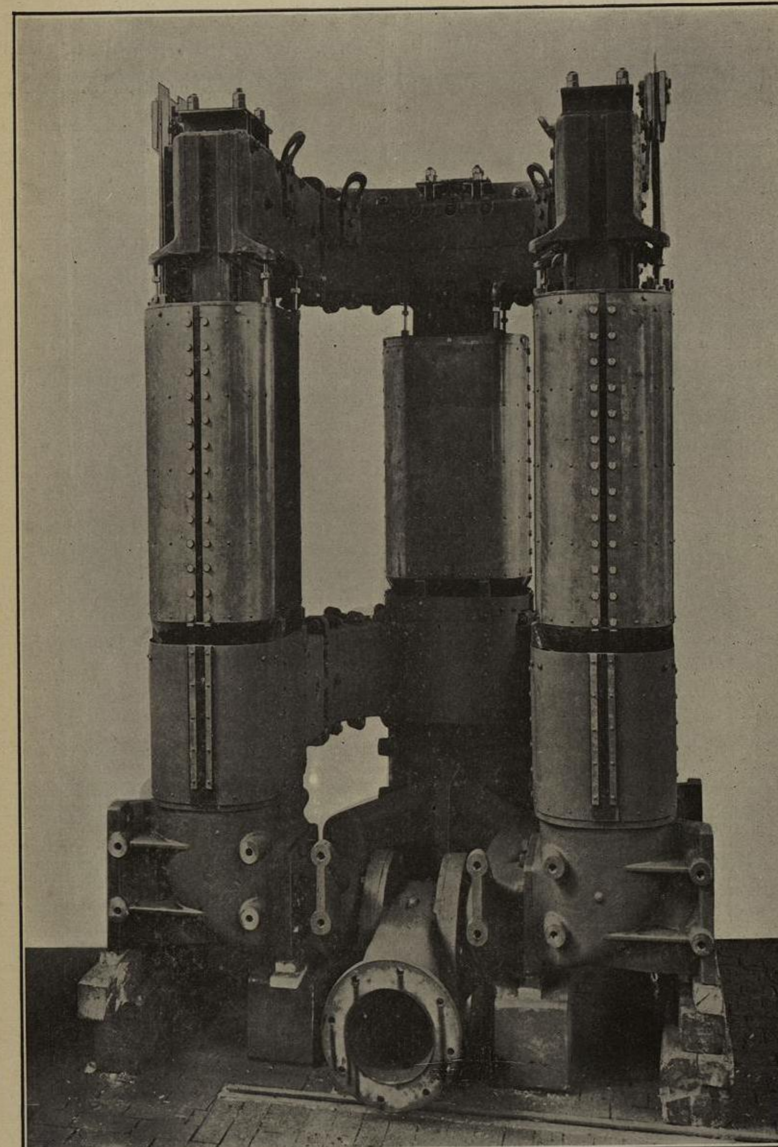

FIG. 59.—Details of Transformer Construction for Röchling-Rodenhauser Three-phase Furnace.

Fig. 57 shows a 736-kilowatt transformer coil, designed for the original form of Kjellin furnace. The transformer core was built up of laminated sheet iron, and the coil consisted of hundreds of turns of insulated wire. This transformer was designed to take current at 4,500 to 4,900 volts pressure. The

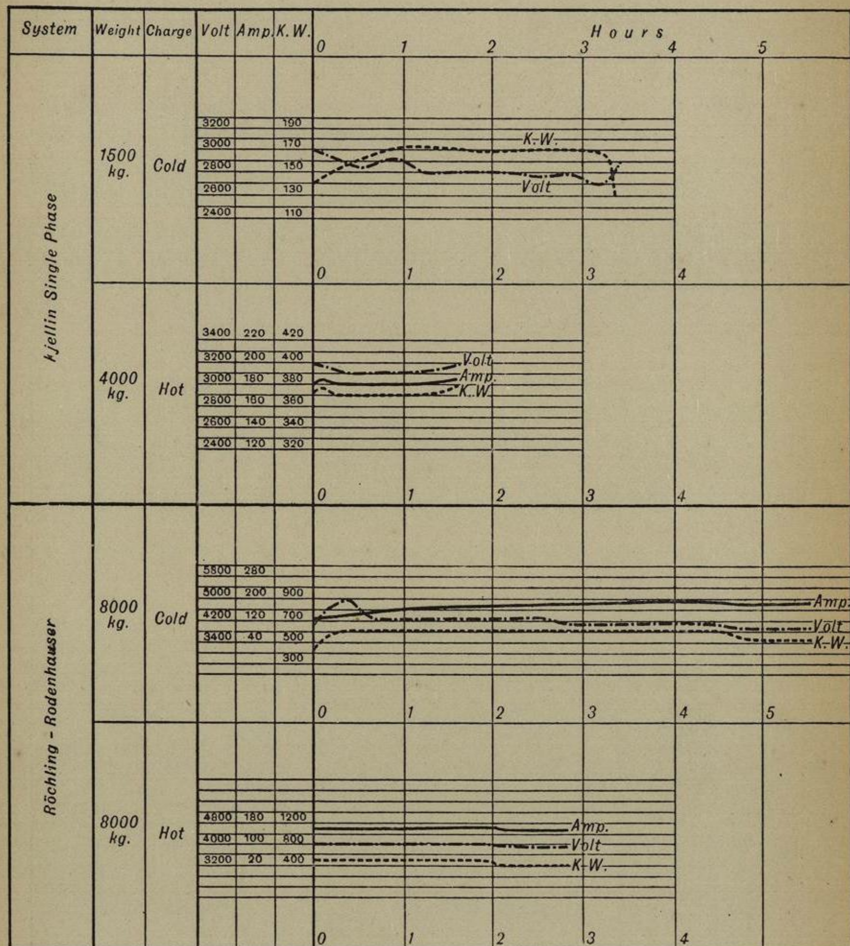

FIG. 60.—Graphic Representation of Power Requirements of Kjellin and Röchling-Rodenhauser Furnaces.

coil was 5 ft. in diameter and 2¼ ft. in depth; the whole frame and coil weighed 35 tons.

Fig. 58 shows details of the transformer construction for a Röchling-Rodenhauser induction furnace designed for three-phase

current. This transformer is provided with three cores and with three coils, attached above and below to a horseshoe-shaped form of yoke, to give the requisite rigidity. The method of building up the cores and winding the coils is similar to that employed for the single-phase furnace.

Fig. 59 shows this transformer enclosed and provided with the requisite pipes for air cooling. One of the special advantages expected from this type of construction was, that the three electro-magnetic fields produced in the furnace would lead to better mixing of the molten metal. This effect was certainly produced, but the greatly increased wear and tear upon the lining of the furnace was found to more than balance this gain, and the author is informed that owing to the heavy cost of repairs this type of furnace construction, for use with three-phase current, has not been further developed.

Fig. 60, giving the current and voltage curves for several runs with Kjellin and Röchling-Rodenhauser furnaces, charged with both solid and liquid raw material, shows that these furnaces operate with remarkable steadiness, especially when charged with molten metal, and that the variations in the power consumed are so slight that they can be worked directly from an ordinary electricity supply without the installation of special generators. This is a feature of these induction furnaces which should render them specially suitable for installation in large ironworks, where the present-day tendency is for the whole power supply of the works to be generated as three-phase current from large gas engines, operated by the hitherto wasted gases from the coke ovens and blast furnaces. The special feature of these "curves" is their resemblance to straight lines rather than to curves. No power engineer who has had the charge of a generating plant supplying current for electro-metallurgical purposes can fail to appreciate the significance and advantages of this "straight line" form of power curve.