THESIS

Design of an Electric Furnace
for a Brass Foundry

by

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of the

Class of Nineteen Hundred Twenty
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Pasadena, California
1920

REFERENCES

1. Rodenhouser, Schoenawa, Von Baur: "Electric Furnaces in the Iron and Steel Industry"

2. Stanfield: "The Electric Furnace"

3. Iron Age, Ji. 26, 1919.

4. Electrical World, Vol. LV, No. 24 June 16, 1910.

5. Electrical World, Dec. 20, 1919.

6. Met. and Chem. Eng. 17:461 Oct. 15, 1917.

Design of an Electric Furnace for a Brass Foundry

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I The Problem to be Solved

It was necessary to choose a design that would be practicable and economical in handling small quantities of brass or aluminum castings. The attempt was made to cut down the almost prohibitive initial cost and at the same time to offer a design that was efficient and comparatively simple in its mechanical and electrical details. Other details of the problem were rapid handling of the furnace and its contents, and easy access to these.

II Selection of Type

The Qualifications of Electric Heating

The general characteristics which make the study of the application of electricity to foundry, a practical and promising undertaking are of great value. High temperatures which are not possible with any system of gas heating, are obtained in a short period of time with the use of electricity. A positive control of the temperature of the bath is made possible through electric operation and any definite temperature may be sustained throughout the time required by the particular demands of the process in question.

With the use of gas or oil as fuel in the process of melting the charge, foreign and other harmful substances are introduced into the original mixture. Electricity offers the cleanest heating agent thus far known so that all the deleterious effects which other heating processes have are entirely eliminated. Electric furnaces operate entirely without the need of a supply of air, which makes possible operation in any atmosphere and prevents reactions which may be caused by elements in the air, gases, or the products of combustion.

The requirements which a practical furnace must possess:

We found that the requirements of any furnace which shall give maximum results are as follows:

(1) The ability to use any prevailing alternating current at any voltage and frequency.

(2) The avoidance of any sudden change in the load.

(3) Ease of regulating the incoming current.

(4) High Electrical Efficiency.

(5) The ability to reach any desired uniform temperature in all parts of the bath, and at the same time avoiding any local under or over-heating.

(6) Complete uniformity of the material in all parts of the molten metal and consequently a sufficient circulation in the bath.

(7) The ready adaptability of the furnace to intermitters service.

The Selection of the Type of Furnace Best Suited to any Conditions.

In selecting the type of furnace we compared the merits of each with the standard described above, that is, the ideal furnace and the type which satisfied the larger number of the requirements was adopted as a working basis. All of the various furnaces devised operate on the simple principle that when an electric current flows through any conductor a certain work is is done which manifests itself as heat, the principle still being fixed the only work to be done resolved itself into two main divisions. One was concerned with the question as to how the large currents required are to be produced; the other was concerned with the question as to the resistance through which these currents be passed to produce the necessary heat with the maximum efficiency.

The two questions which arose were fully investigated by independent workers; all the possible combinations were worked out and developed. Three well defined combinations were established, upholding methods entirely separate, but fundamentally identical. These combinations are:

(1) The induction type of furnace.

(2) The resistance type of furnace.

(3) The arc type of furnace.

1. Rodenhauser
Schoenawa — Electric furnaces in the Iron and Steel
Von Baur — Industry.

Each has been investigated and compared with theoretical standards in order that the one best suited to the conditions required might be selected.

1. The Induction Type of Furnace

When an electric current flows in a conductor a magnetic field is generated around the conductor, and if the alternating current be made to flow the magnetic field will be in phase with the current and alternate from zero to a maximum, depending upon the frequency of the impressed voltage. A conductor which lies in the field will have a current induced upon it and this current will be proportional to the number of lines of force cut in unit time. Upon this principle is built the type of induction furnace. The heat is produced when the induced current is made to flow through a resistance, which in this case is that of the metal to be melted. The only problem is the determination of the amount of current necessary to produce the required heat and the overcoming of the destructive forces which are introduced by the excessive heat.

The general features of an induction furnace are as follows:

An induction furnace is a transformer having only one turn for the secondary winding, which is formed by the molten metal. The primary winding, P (see fig. 1.) is wound on an iron core consisting of one or two legs and having the bath of metal in the form of a circle around the iron core. The current in the primary coil, P, generates lines of force, which travel in the iron core. The induced current in the secondary turn generates lines of force which take a path in the iron in the opposite direction, ϕ_1''. The current strength in the metal can be varied through very wide ranges

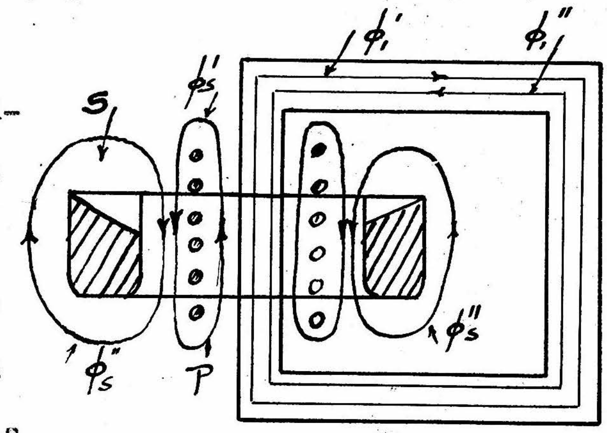

Fig. 1

by increasing or decreasing the number of turns in the primary winding and by changing the voltage applied to the primary.

Special provisions must be taken to protect the primary winding from the intense heat of the bath and a water cooling system is used to keep the iron of the core at a low temperature.

Comparison With Standard Furnace

This furnace fulfills the first requirement since it can be built for single or three phase current and at any voltage obtainable.

The operation of the furnace cannot take place if the charge of metal is cold scrap since a complete ring is not formed, and therefore the secondary winding is not short-circuited. For this reason all of the metal cannot be poured, but a small quantity forming a ring is left to provide for the resumption of the operation with the next charge. This process is objectionable, since the removal of all of the slag is made impossible.

The second requisite is only partly complied with. The incoming current can be easily regulated, since all that is needed is a variable rheostat which varies the voltage applied to the primary coil.

The high efficiency of the furnace is due to the absence of electrode losses and also to the fact that the losses which take place in the transformer occur in the form of heat, and since the purpose of the furnace is to produce heat, these losses are utilized.

Requirements five and six are satisfied by means of the same peculiar conditions which are caused by the influence of the magnetic fields generated by the primary and secondary.

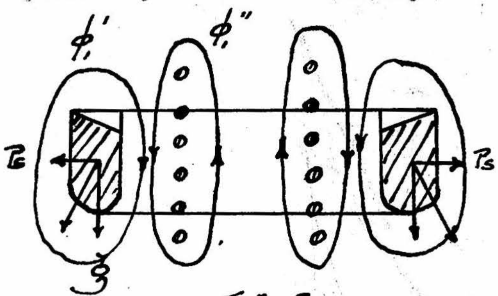

Fig. 2

The primary and secondary are not in direct contact but have an air space intervening. Some of the lines of force will not interlink the coils but form closed paths around the coil, generating the flux ϕ' and ϕ''. These flux paths are in directions opposite to each other but from the accompanying diagram it can be seen that the opposite direction of these lines of force makes the direction of current flow the same between the primary winding and the bath. Since lines of force of the same direction repel each other, forces must appear which repel the molten metal from the primary to the outside. This repulsion does take place in practice and the level of the metal is that produced by the combinations of the gravity force (g) and the repelling force (P_s) at right angles to each other. The level of the bath is at right angles to the resultant of the combination of the two forces. At the same time a flow of the metal takes place from the outside edge towards the inner lower one providing for a uniform and intimate temperature and mixture of the bath.

The last requirement is not fully met, since either some part of a previous charge must be left in the furnace, in which case a different composition of metal cannot be melted, or separate rings must be provided, made of the metal which it is desired to fuse.

While the fundamental principles are more or less fulfilled, another condition must also be considered : This is the power factor of the system. Experiments show that with the same frequency the power factor decreases with an increased amount of metal charged. This is explained when the conditions that go to make up the quantity representing the power factor are examined.

$$\cos\theta = \frac{r}{Z}$$

$$Z = \sqrt{r^2 + Z^2}$$

$$r = \rho\frac{l}{A}$$

$$x = 2\pi f L$$

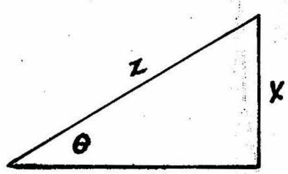

Fig. 3

Therefore, for a certain furnace l, ρ and L are fixed quantities.

The value of r decreases with increase in charge or cross-section of metal; therefore the only way to increase the power factor is to decrease the value of Z or (Fig. 3.) decrease the frequency. This means that a different frequency would have to be used for different quantities of charges, so as to make the change quite impossible.

Conclusions

While this type of furnace has many good features, yet it is not adapted for a brass foundry, because in a brass foundry different mixtures of metal are poured every day, necessitating new lining for every charge. The present frequency of the city system is sixty cycles, which is much higher than is required to give a good power factor at maximum charge for the furnace. The depreciation on a small furnace is much higher per ton of metal produced because of the small amount of metal charged at every run, while the whole apparatus is submitted to the extreme heat to which a large furnace would be subjected that produced many times the amount of metal. For these various reasons this type of furnace was not adopted.

The Resistance Type of Furnace

When an electric current flows in a conductor, heat is developed and the quantity is:

$$Q = 0.24\, i^2 r t \text{ calories}$$

From this it is evident that if a large current is passed through a small resistance, as for example, a large volume of molten metal, a high temperature is obtained. In order to maintain the current at a reasonably small value, the resistance of the bath must necessarily be increased. The resistance of any material is expressed by the formula:

$$r = \rho \frac{l}{a}$$

l = length

ρ = specific resistance

a = cross-sectional area

It is evident that the only terms which can be varied are l and a; therefore the resistance is increased by making the area smaller and making the length greater.

In Fig. 4, a is the electric contact to the metal; b indicates the channels in which the metal is confined; c is the pouring spout; d is the external electrical connection to the furnace; e is the refractory material making up the furnace.

Comparison With Standard Furnace

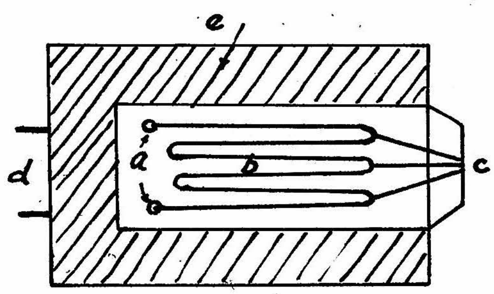

Fig. 4

The first requirement is met, inasmuch as any prevailing current can be used with proper external resistance which is varied according to the cross section of the bath.

The second requirement is partly fulfilled, since with a charge of scrap metal poor contacts are established, so as to cause fluctuations of power input.

The third requirement is easily satisfied with the help of external resistances.

The electrical efficiency is very high, since no losses are encountered; but this is offset by the large radiation losses which are brought about by the very long exposed bath.

The fifth requirement is fulfilled by the simple adjustment of the impressed voltage. The heating produced is entirely uniform throughout the bath.

Circulation of the metal is not produced without the aid of external methods.

The furnace is adapted to intermittent service, since operation can be resumed with cold scrap metal.

Conclusions

The good points of this furnace are the uniform heating of the bath and the positive control, within very narrow limits.

The disadvantages of the temperature desired are quite serious. In order to produce the best electrical conditions, long and narrow channels must be constructed. These channels expose large surfaces of metal and therefore cause excessive thermal heat losses which must be counteracted by a larger power input. It is impossible to remove the slag from the small channels and therefore a uniform mixture of the metal is made impossible.

Because of those serious faults, this type of furnace was not adopted.

The Arc Type of Furnace

When the ends of two conductors carrying current are brought in contact and slightly separated, the current continues to flow, forming an arc. When the arc is formed the current is not carried across the gap by the intervening air but by the gases which emanate from the metal constituting the conductors. The theory of the way in which the arc occurs is very simple. At the instant when the conductors are slightly separated, a high resistance is offered to the flowing current. This generates an intense heat which gasifies the metal and fills the gap. Although the current can pass from one conductor to the other with the aid of the small metal particles, it is opposed by a very high resistance, and this is the cause of the high temperatures produced by the arc. The carbon arc gives the highest temperature so far reached, about 3,500 C, this being the temperature at which carbon gasefies; and this is the one used in the arc type of furnace.

One of the simplest arc furnaces consists of a hearth (a), a bath of metal (b) and the carbon electrodes forming the arc, (c).

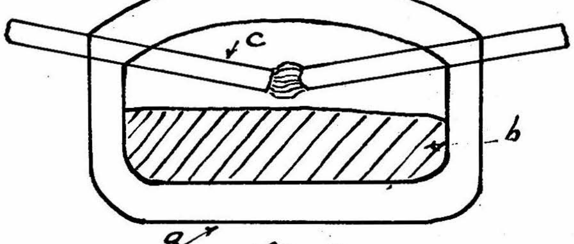

Fig. 5

Comparison with Standard Furnace

This type of furnace can use any current with any number of phases.

Since the metal does not come in contact with the arc, the operation of the arc is not disturbed by the process of melting large pieces of scrap.

The incoming current is easily regulated by varying the gap between the electrodes, and this adjustment can be made within narrow limits.

The electrical efficiency is high, since the only loss encountered is that due to electrode losses.

With mechanical modifications the heating of all the parts of the bath can be made uniform. With the same improvement the metal is mixed thoroughly into a homogeneous mass.

Because of the simple construction of this furnace the lining can be cleaned so that different mixtures of metal may be placed in the furnace in successive runs.

Conclusions

With the mechanical modifications that must be made, the arc type of furnace fulfills all of the requirements specified. This type was therefore adopted as a working basis, and a part of the task of the thesis consisted in the working out of the mechanical features of this furnace.

Design of Furnace

The requirement was for a design of furnace suitable to accommodate small amounts of brass metal frequently and rapidly. The mechanical details therefore, had to be designed with these objects in view. The design was expected to combine simplicity and economy with ease and rapidity of handling.

Size of Furnace

The size of the furnace, it was agreed upon, should be large enough to hold 250 lbs. of molten brass or copper. Since a charge of copper requires B. T. U. per pound to produce a melt than brass the amount of current required was calculated taking the value of B. T. U. required to melt a charge of 250 of copper. Since 85 watt-hours are required to melt one pound of copper;

$250 \times 85 = 21250$ watt-hours

The electrode loss is;

$400 \times 2.2 = 880$ watts per electrode

$880 \times 2 = 1760$ watts total

Therefore the amount of electrical energy required is 23010 watt-hours.

Assuming a total efficiency of 75%

$$\frac{23010}{.75} = 30800 \text{ watt-hours.}$$

This amount of energy will meet 250 lbs. of copper in one hour. The time required for each melt was desired to be cut to 45 minutes and the amount of energy must necessarily be increased.

$$\frac{30800}{.75} = 41000 \text{ watt-hours.}$$

400 amperes at 110 volts = 44 Kw. hours.

Dimension of Electrode

Table of Electrode Constants. Carl Hering.

Temp.	Drop.	Section S		C	Current i	
C	F	Sq. in.	Sq. cu	Volts	in. Units	cm. Units
		Copper				
800	1472	.000014	.000036	0.18	70,300	27,700
1000	1832	14	35	.22	71,800	28,300
1200	2192	14	35	.26	72,800	28,700
1400	2552	14	35	.30	73,400	28,900
1600	2912	13	34	.34	73,900	29,100
1800	3272	13	34	.38	74,300	29,300
2000	3632	.000013	.000034	.42	74,600	29,400
		Iron				
800	1472	.000100	.00026	.29	10,000	3900
1000		100	25	.30	10,000	3900
1200		.000099	25	.43	10,100	4000
1400		99	25	.49	10,100	4000
1600		98	25	.56	10,200	4000
1800		98	25	.63	10,200	4010
2000		.000098	25	.70	10,200	4010
		Graphite				
1000		.00025	.00063	1.3	4100	1600
1200		23	59	1.4	4300	1690
1400		22	57	1.5	4500	1760
1600		22	55	1.5	4600	1810
1800		21	54	1.5	4700	1860
2000		21	53	1.5	4800	1890
2500	4532	20	51	1.5	5000	1960
3000	5432	.00020	.00050	1.5	5100	2010

Temp drop		Section S		C	Current i	
C	F	Sq. in	Sq. cu	Volts	Units	Units
			Carbon			
1000		.00074	.00187	1.9	1360	530
12		64	.00162	2.1	1570	620
14		57	.00145	2.3	1750	690
16		52	132	2.5	1920	750
18		48	123	2.7	2070	810
20		45	115	2.9	2200	870
25		40	102	3.3	2500	980
3000		.00037	.00093	3.7	2700	1080

The current required, the temperature difference between the arc-end and the cool part of the electrodes and the length of the electrode must be predetermined by the requirements of the furnace. For the drop in temperature required the value of (S) is found in the table for the material which is to be used. This number (S) is the specific section for that drop in temperature, it is analogous to specific resistance that is, to ohms per cubic inch or per unit-foot, etc., at a high temperature; it represents the section per ampere and per unit or centimeter length. The proper size for the electrode is then found by multiplying this factor (S) by the amperes required and the length in inches or centimeters. Circulating the cross -section for the various materials which may be used the comparative cost of each is found and a selection made relatively simple. The dimensions of the electrode thus forced will be so that the heat lost through connection by the electrode will be the minimum in conjunction with the minimum loss due to the resistanc of the eléctrode. To determine the loss due to the resistance of electrode the value of (C) from the table is found which corresponds to the conditions decided upon. Multiplying the value of (C) by the current will give the loss due to each electrode. If it is required to find the proper current value for existing condition and size of electrode, the value of as taken from the table corresponding to the temp. drop. This value is again a specific quantity, being the current per square inch section for an inch length. Thus number is multiplied by the existing cross section and divided by the length. In this particular case the current required is 400 amps. and since the melting temperature of copper is 1083° C a temperature of 1400° C may be taken for the arc temperature. The temperature of the cold end of the electrode is kept at 100° C giving a temperature drop at 1300° C. Carbon was chosen as the material for the electrodes and from the table the value of "S" corresponding to a 1300° temp. diff. is .000675.

The proper cross-section is:

.000675 x 400 x 20 5.4 sq. in.

or 2.6 in. diameter.

A standard size is chosen 2.5. The electrode is therefore 2.5 in. by 30 in.

The Design of Furnace Electrode by Carl Hering

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June 16, 1910

General Features

The furnace is cylindrical in form, the axis of the cylinder being horizontal. The furnace revolves about this axis. The cylinder is supported by rollers which transmit the motion to the furnace, the rollers being in turn revolved by friction contact with a pulley fastened to a motor shaft.

There is a door at either end of the furnace. The carbon electrodes pass through the center of each door. Power is transmitted to the furnace by means of copper shoes which slide along a copper band around the furnace. This band is electrically connected to the electrodes. The electrodes are cooled by water coils surrounding them, there being a steady circulation of water kept up at all times when the furnace is in operation.

The Furnace Proper

The furnace proper is made up of a steel cylinder. This cylinder is lined with fire brick 5 inches thick, the brick growing thicker toward the ends to give the inside surface a more nearly spherical form. The inside of the furnace is 18 inches in diameter and 20 inches in length. The ends of the cylinder are closed with cast iron plates which are riveted to the steel cylinder. The end plates are lined with 4 inch fire brick, except at the openings for the doors. The doors are of cast iron lined with brick. The doors swing on one large hinge, which is bolted to the end plates. The doors are fastened by means of a lever catch.

Through one end plate and the fire brick back of it, a hole is drilled. This hole opens at the inner edge of the inside. of the furnace. The outer opening is plugged with a movable fire clay stopper. Around this hole, on the outside, a metal spout is bolted to the end plate. To empty the furnace of its bath, the furnace is stopped so that the spout is at the lowerside of the cylinder. When the slug is removed it leaves a free path for the metal bath to run out.

Around each end of the cylinder a circular ring of 4 inch channel steel is bolted. These rings are entirely insulated from the rest of the furnace by placing heavy press board insulation material between the rings and the cylinder. Every bolt is also insulated from the ring and the cylinder. The weight of the furnace is carried by these rings, which rest upon two parallel rollers. These rollers are driven by a friction pulley on a motor shaft and they in turn transmit the movement to the furnace by bearing friction with the channel rings around the cylinder.

Power Transmission and Commutation

Around the inside of the outer flange of each channel ring, a band of copper is fastened, but this band is insulated from the rings. Copper shoes are suspended and held against the copper band by slight spring pressure. These shoes are connected by wires through the proper switches to the transformer. The current from the copper bands is carried by wires to metal clamps which surround the carbons. Thus the current comes from the positive lead of the transformer, through the switches to the shoes, which are in contact with the band of copper around the furnace. From the band the current travels by wire to the positive electrode, arcs over to the negative electrode and on back to the transformer by a similar path.

The Electrode Carriage

The carbons are perpendicular to the plane of the doors. Three equally spaced rods extend from the doors for a distance of about 2 feet. These rods are also perpendicular to the plane of the doors. At the ends of these rods an iron plate is bolted. The whole structure is strengthened by six braces. A pair of braces to each rod. These braces are bolted to the plate, each pair diverges to the outer edge of the doors, where they are bolted.

Along these three rods slides a spider, but it can be clamped in any position. Through the center of this spider passes the carbon and above that a threaded shaft. The shaft is held in position laterally with respect to the spider by cotter pins. The threaded part of the shaft screws into a clamp which can readily be fastened to the carbons. At the other end of the shaft there is a crank. By turning this crank, therefore, the carbon is moved in or out at will. If a greater and quicker change of the carbon is desired; all that is necessary is to unclamp the spider and slide it and the carbon in either direction and clamp again in the new position. To remove the carbon entirely all that is necessary is to unclamp the threaded clamp which holds the carbon.

The Cooling System

At the point where the carbons pass through the doors, they are surrounded by a coil of pipe which is cast in a block of metal that fits in the center of the doors. The carbons are insulated from this block by a thin graphite sleeve. The water comes into one coil, passes through it and is carried out by a flexible hose to a pipe which runs horizontally along the outside of the cylinder to the other side. At the other end of this pipe another flexible hose connects it to one end of the coil surrounding the other electrode. The other end of the coil is connected to a pipe which runs along the electrode carriage.

At the ends of each carriage the water pipes are connected by flexible hose to elbows which are held on pivots, the pivots being fastened to the end plates of the carriages. The centers of one side of the elbows exactly coincide with the center axis of the furnace, when the elbows are pivoted into position. The elbows are pivoted so that they may be swung out of the way when a carbon is being removed from the carriage.

It must be remembered that the furnace is revolving and that the pipes and other attachments are revolving with it. Thus it was necessary to bring the two water pipes out with their centers coinciding with the axis of revolution. After this was accomplished it was necessary to connect pipes which would be revolving with others which were stationary.

This was done by designing a short piece of pipe which screws into the revolving elbow. The outside of this pipe was to be polished to a shafting finish. Unions were threaded to the stationary pipes. Over the revolving pipes packing rings were placed. The stationary pipes were brought up until their ends almost touched the ends of the revolving pipes. The packing rings were then screwed into the unions, which were on the ends of the stationary pipes, until tight. The revolving pipes were then free to revolve, and yet the water would pass from the stationary to the revolving pipes, and vice versa, with little or no leakage.

The stationary pipes are held in place by braces which run slantingly down to the stationary hose of the furnace. Hose or other pipes may be attached to these stationary pipes of the furnace. The water goes into one of these pipes to the revolving pipe, on to one coil, out, and over to the other coil. The water passes out of this coil and on to the revolving pipe on this side. From here it passes to the stationary pipe and is carried away wherever desired.

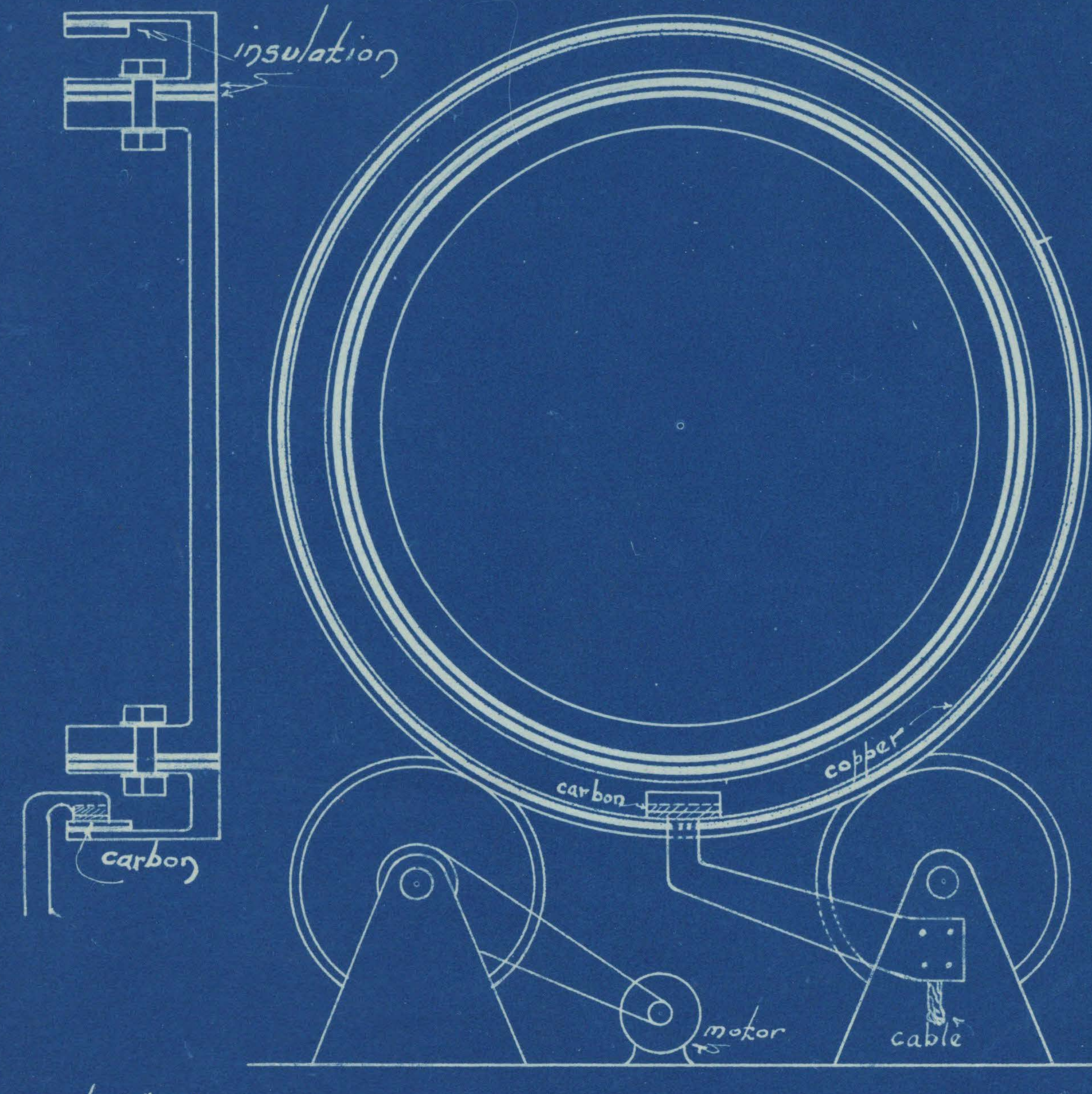
Conclusions:

The outstanding features of the furnace are:

(1) The complete rotation of the furnace gives a longer life to the lining because the bath absorbs the excess heat which the lining absorbs when it is exposed to the heat and not covered by the bath.

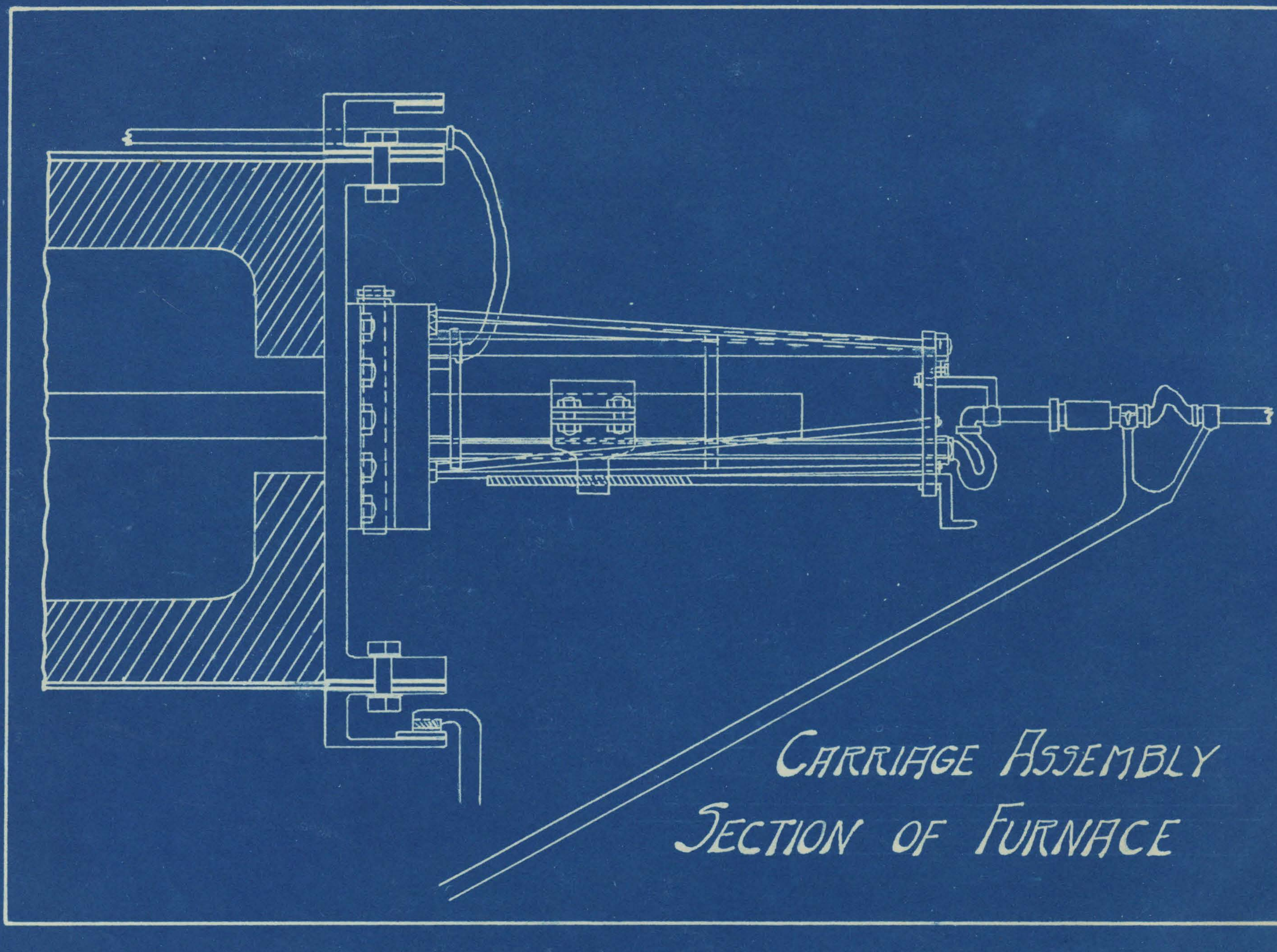
(2) The lining is evenly consumed and a longer life made possible, since only two joints are present and these can be filled with cement.

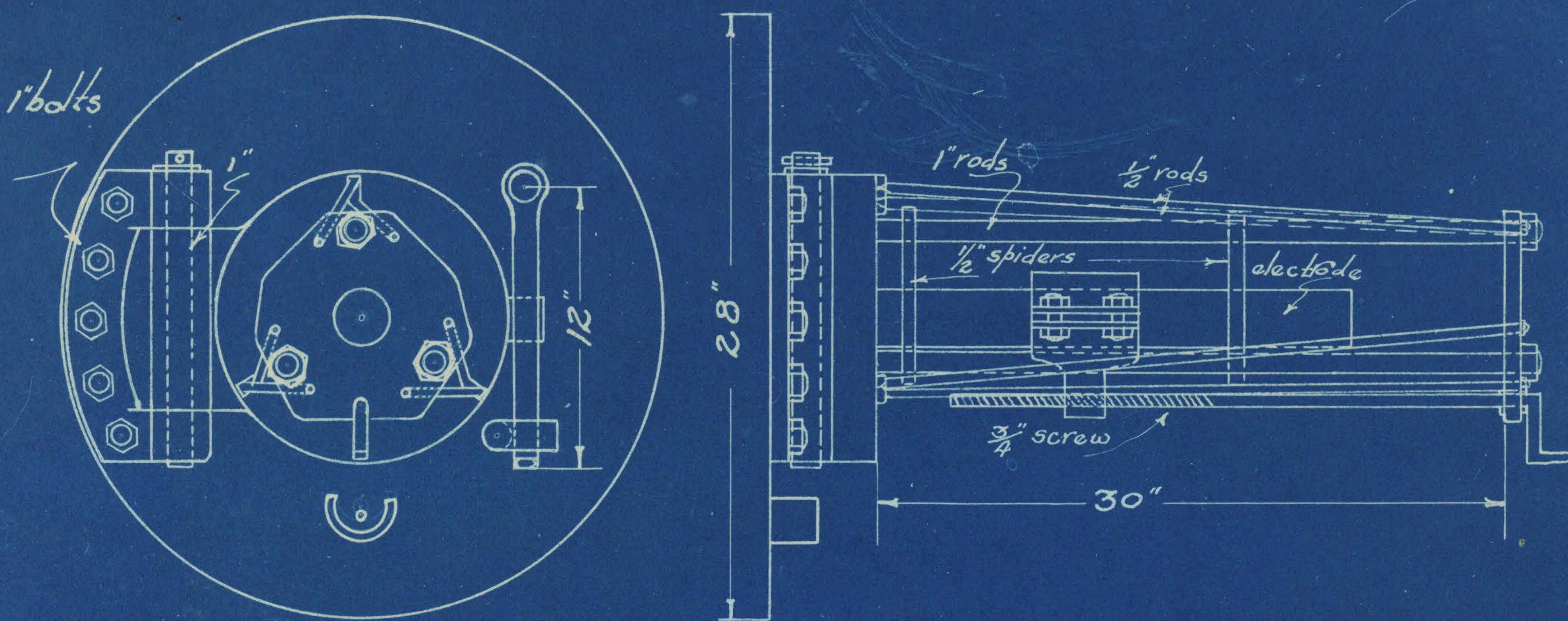
(3) The electrodes can be moved out quickly, and in this way the doors can be opened with little delay.



Scale $\frac{1}{8}'' = 1''$

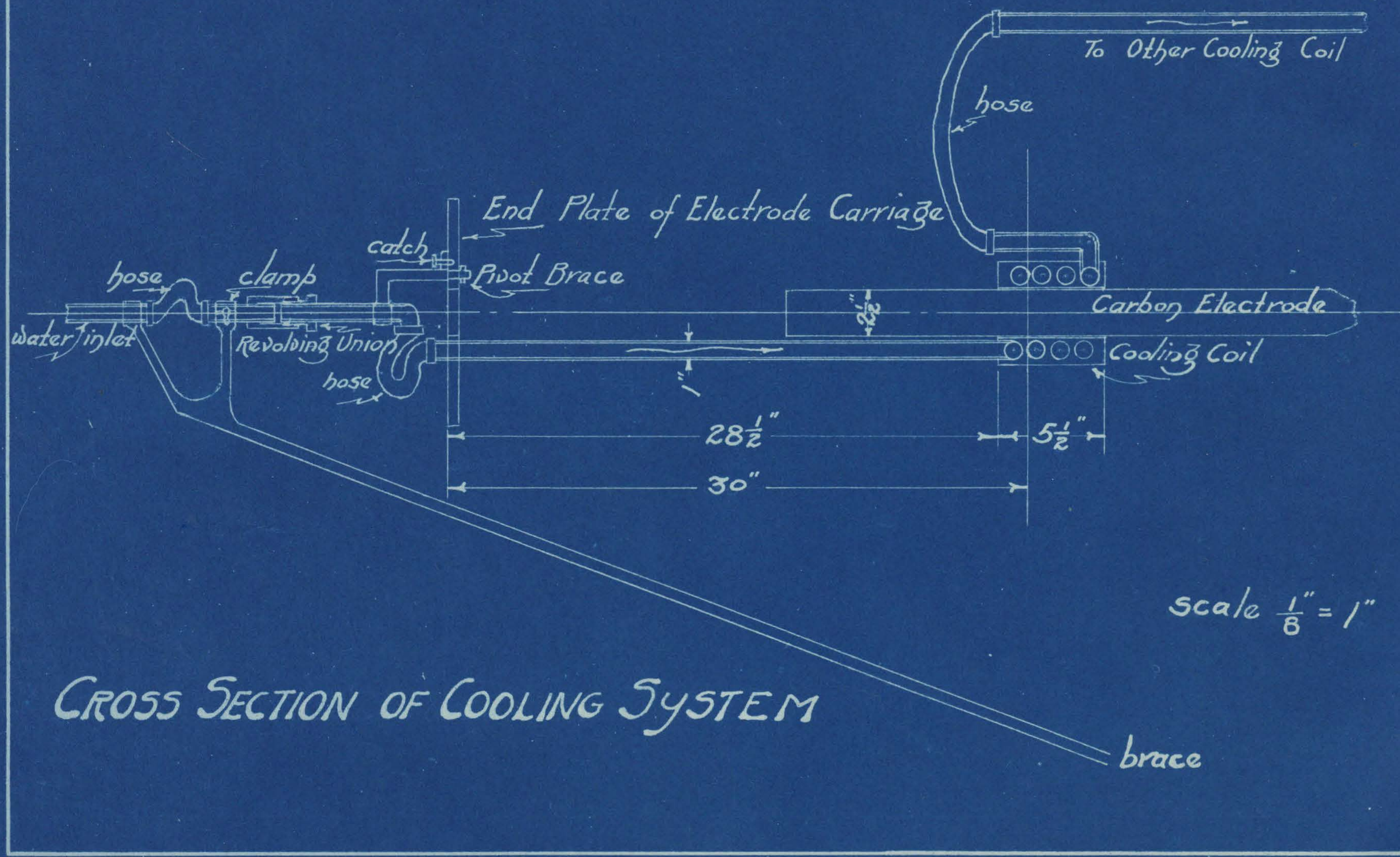
DETAIL OF ROLLERS


CARRIAGE ASSEMBLY
SECTION OF FURNACE



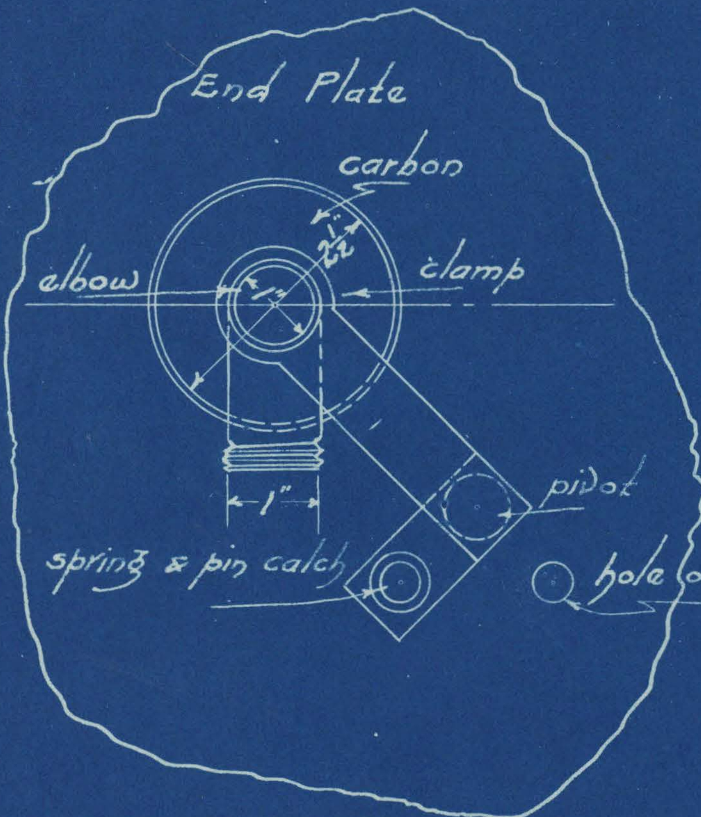
Scale ⅛" = 1"

ELECTRODE CARRIAGE

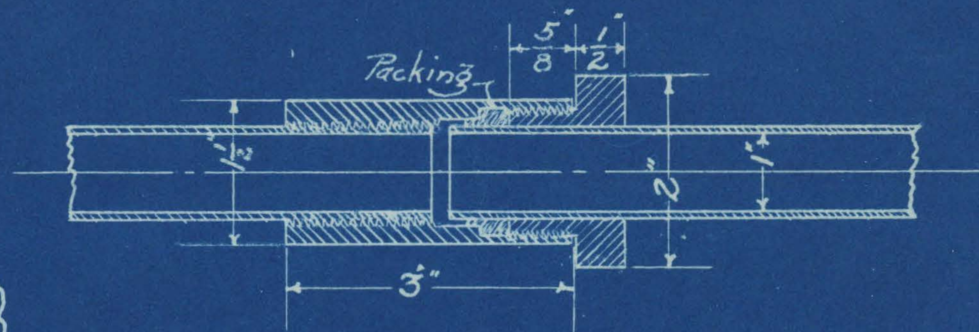


CROSS SECTION OF COOLING SYSTEM

DETAIL DRAWINGS



Pivot Brace



Cross-Section Revolving Union

Scale $\frac{1}{2}$" = 1"

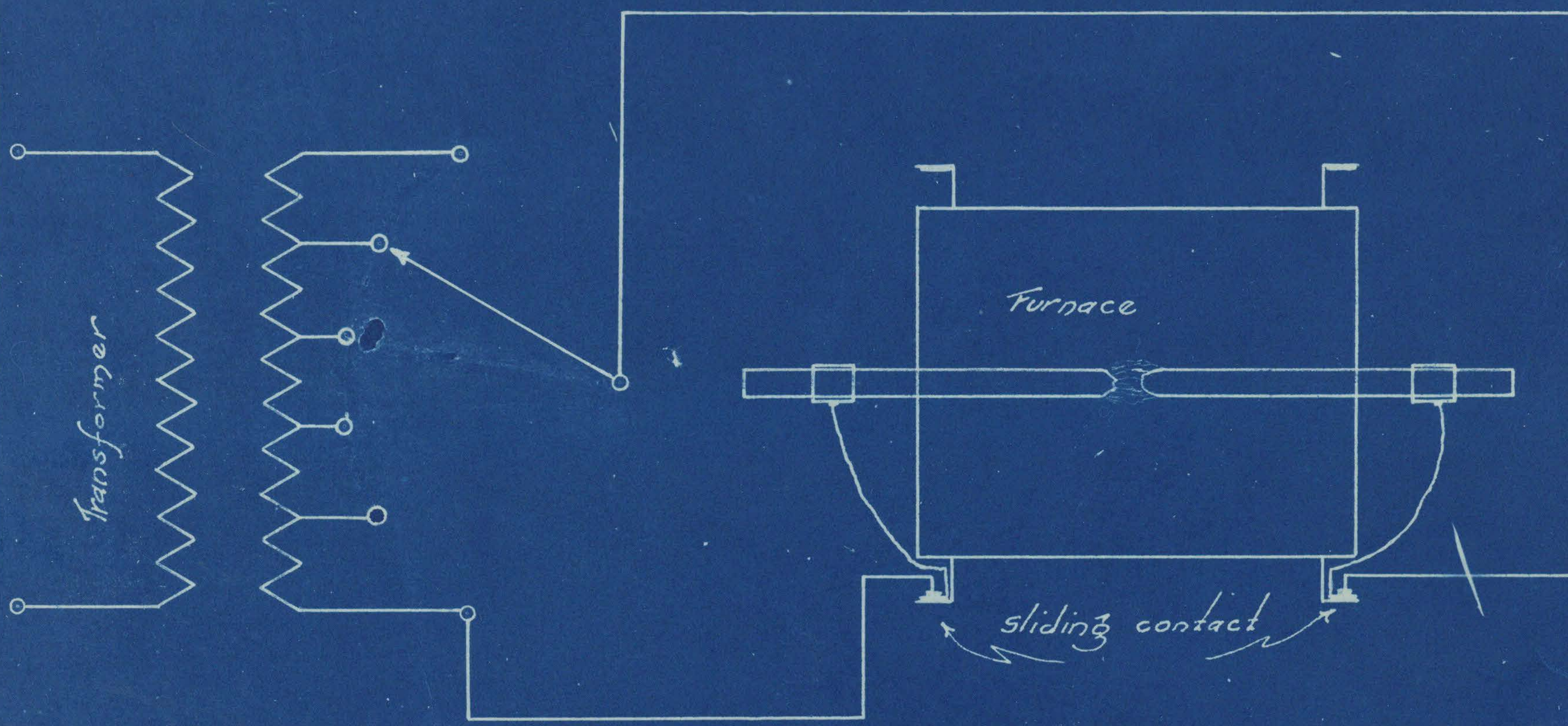


DIAGRAM OF CONNECTIONS