THEORY AND CONSTRUCTION OF A ROTARY CONVERTER
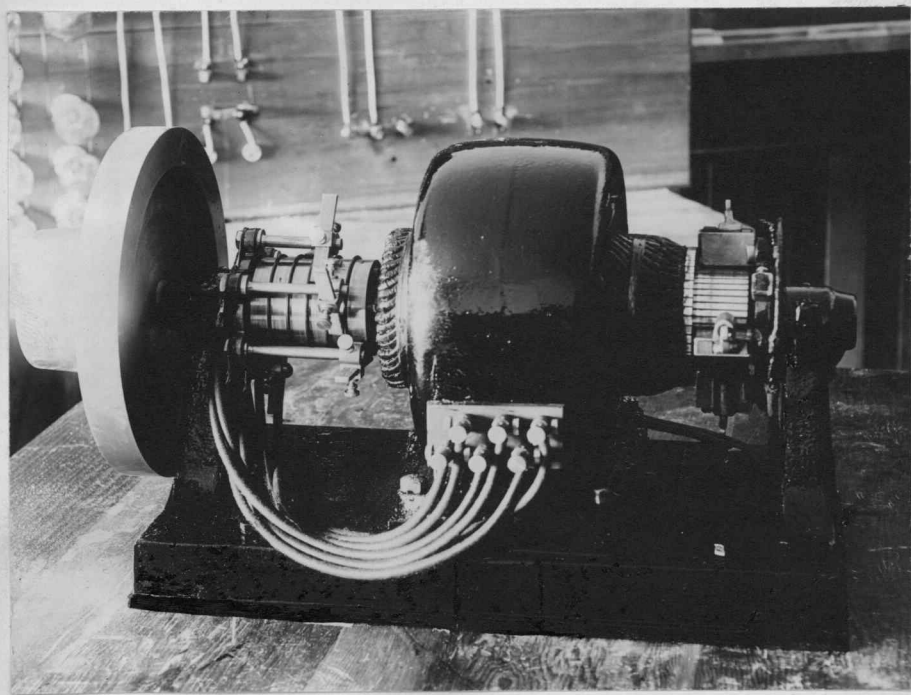

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The Theory and Construction of a Four Kilowatt Rotary Converter.

For the sake of simplicity we will take a special case
and extend it to the general. Suppose we have a closed coil bipolar
direct current generator. If we connect three leads to the com-
mutator at equidistant points around its circumference, i.e. 120
mechanical degrees apart and these in turn be connected to three
slip rings, disregarding the commutator and supposing the machine
to be separately excited, we will have a simple three phase closed
delta connection. Now if this were driven by external power it
would generate three phase current. Taking the current to excite
the field from the commutator will have no effect on this connection.
If alternating current be impressed upon the slip rings the machine
will operate as a synchronous motar but as stated before we started
with a direct current generator and as the armature is revolving
in a field if a load were connected across the brushes it would
operate as direct current generator. This is the principle upon
which all rotary converters are based. If the numbers of poles
were increased. the construction would have to be altered by tapp-
ing at every 120 electrical degrees instead of mechanical degrees.
These are to be connected in the proper order to the original
three slip rings. Thus for an N pole converter, where N is the
number of poles, therewould be three taps for every pair of poles
or $3N/2$ taps. Again in the case of a bipolar machine if two taps
were placed 90 degrees apart we would have a two phase converter.
Thus a converter can be made from a direct current generator of
any number of poles by locating the number of taps corresponding
to the phase desired and duplicating for every 360 electrical
degrees.

There would be some difficulty however in operating a
converter made from a common direct current generayor. In the
first place the alternating current voltage is equal to

$\dfrac{D.C \text{ voltage}}{\sqrt{2}} \sin \pi/N$. This is obtained by integrating the instan-

taneous values of the voltage in each coil for both direct current

and alternating current between the positive and negative maximum of
E as given by the angle of rotation as limits. Equating the express-
ion thus found and solving for the alternating currentvoltage we
will get the expression given above which is constant for any
machine.

The speed of a shunt motar varies with the voltage, while
the speed of a synchronous motor is the synchronous speed of the
supplying generator irrespective of the voltage. This seems to be
a paradox, i.e. the voltages have a constant ratio but when consid-
ering the speed, have no relation whatever. A rotary converter made
as described above, when run as an inverted converter or supplied
with direct current, it would give a frequency to low to be used
to an advantage while if run as a direct converter or supplied
with alternating current the speed would be to high to give spark-
less commutation and in some cases would even cause buckling of the
commutator bars. This can only be overcome by designing the machine
so as to give a synchronous speed that will generate an alternating
current voltage that will be $\frac{1}{\sqrt{2}}sm\frac{\pi}{n}$ times the direct current voltage
required.

Another important point in designing a converter is the
frequency. It is found that large machines operate most satisfact-
orily on a low frequency being limited to frequencies below 50 cycles.
Although small machines can be operated on 120 cycles. Owing to the
fact that most rotary converters either have some lights on the cir-
cuits which they supply or are themselves supplied from lighting
circuits the frequency has to be as high as possible as incandescent
lamps are not very satisfactory on low frequencies.

The speed in large machines is limited by the safe periph-
eral speed of the commutator and as the synchronous speed is a sub-
multiple of the frequency it will be seen that the frequency is
limited. The most satisfactory frequency used in practice is 40
cycles.

The power delivered by a rotary is equal to the input minus
the losses. Owing to the neutralizing effect of the two

opposing currents in the armature coils, the armature reactions are almost nil which makes the commutating plane almost constant with the neutral plane for all loads and eliminates the disadvantage of the skewing of the field which causes over saturation of the pole horns.

In a converter of more than two taps much of the current finds its way by the shortest path from the commutator to the slip rings or vica versa. In this way the capacity of a rotary is greater than the capacity of the same machine when used as a motar or generator. The capacity increases as the number of taps per pair of poles is increased or in other words with an increase in the number of phases.

The regulation of a converter is an important point to be considered in the design. If the machine is run as an inverted converter this is not so difficult, as the speed must be constant to give the proper frequency and this is accomplished by properly compounding the field as in any shunt motar. The compounding being less however, with the lower armature reactions. When run as a direct converter it is more complicated as the converter is generally used in a way so as to regulate the current that it receives. In a line having reactance and resistance the drop due to varying loads is quite noticable and the converter is so designed that it receives a constant or nearly constant voltage at all loads. To do this use is made of the property of an under excited field to produce a lagging current in the converter and an over excited field to produce a leading current. Thus in a converter that supplies power to a direct current system with varying loads the compound field is so arranged that when a lightload is on the line the fields are under excited and the voltage drop in the line is high. At about three fourths load the compound winding gives the field excitation which gives unity power factor. This cuts out the inductance drop and the voltage is still constant. Then at full load the field is over excited the machine takes a leading current which makes the voltage impressed

across the collecter rings greater than the generated voltage and will give the correct voltage relation. In this way the rotary can be compounded to compensate for any line drop or to give a higher voltage on an increased load, but the compound winding must be designed for one particular case and must be changed if any change occurs in the construction of the line.

As noted above a weak field produces a lagging current in the converter. Though this is to be utilized when running as a direct converter, it is very detrimental when running as an inverted converter. A weak field causes a lagging load, a lagging load will react in such a manner as to weaken the field and as the converter is running as a shunt motor this weakening of the field will cause an increase of speed. The frequency varies directly as the speed and the reactance due to inductance of a load varies directly as the frequency; this increase of speed will make a still greater lag in the load and will cause a still greater increase in speed which will continue to increase until the circuit is broken or the armature raced to destruction.

This makes it very undesirable to use a rotary converter to supply an induction motor as these machines take a heavy lagging current from the line when starting.

When running as a direct converter any change in load taken from the direct current brushes causes an oscillation of the synchronous motor from one side to the other of the synchronous speed. This is termed hunting and is dis advantageous. In large machines this is overcome by so designing the armature as to have a large moment of inertia or a large fly wheel capacity. In small machines a fly wheel is some times placed on the shaft; this tends to keep the speed constant during a change of load and gives the motor time to adjust its phase.
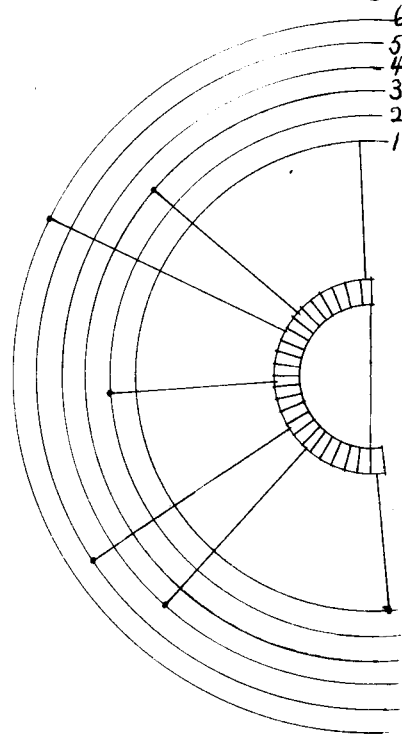
Construction.

Broadly speaking this machine consists of three parts, a base, an armature, and a field. The base is 17 5/8" long by 13" wide and stands about 2" high. It consists of a cast iron shell the space underneath containing the starting device. It also has two bearing supports cast integral with the base. The bearings are of the ring oiling type and consist of a brass tube surrounding the shaft which is held in place by Babbit's Metal. The shaft is carried by these bearings about 8" from the base. The bearing supports are machined on the inner ends and carry the collars that support the brush holders. These collars are made in halves being fitted together after being placed. The collar on the direct current side carries four brush holders which are made of brass containg carbon brushes set radially and held in place by springs. The collar on the alternating current side is supplied with six studs of varying lengths to which are fixed the alternating current brush holders. These brushes are of brass gauze and are set at an angle.

The field consists of the pole pieces and the yoke. The yoke which is of cast iron is about $4\frac{1}{2}$" wide and 11" high. The pole pieces are made of No. 20 sheet iron cast into the yoke. They are machined down so that they have an inside diameter of 5 5/8". Although the machine is a four pole converter it has eight pole pieces, two adjacent poles being of the same sign. The field coils are made of No. 23 double cotton covered wire with 14 layers or approximately 620 turns, each coil being made in two sections and designed to carry .75 amperes. These coils are well taped and the terminals carried into the chamber in the base.

The armature, commutator, and slip rings are mounted on a steel shaft which is 25 $\frac{3}{4}$" long. The diameter at the bearings is 7/8", at the commutator 1", and at the slip rings 1". The armature core is made of soft iron disks No. 27 gauge with an external diameter of $5\frac{1}{2}$" and an internal diameter of $2\frac{1}{2}$". These are mounted upon two three arm spiders which in turn are mounted on the shaft

being held in place by two hexagon nuts one on each side. It has
two spacings for ventilation ducts and the spiders are so constructed
that the air has free access to the inner surface of the core. The
core has 48 slots, 3/16" x 1/2" milled into it. The commutator is
composed of rolled copper bars. It is 3½" in diameter and has 1½"
rubbing surface. The bars are insulated from each other and from
the supports by mica. T he slip rings are of brass. They are 7/16"
wide and have 1/12" of hard rubber insulation between them and 1/16"
of asbestos insulation between them and the shaft. The commutator
and slip rings are mounted on opposite sides of the core and are con-
nected to each other by wires running between the spider legs.
As the machine is a four pole machine, then will there have to be
two taps for each phase. This is done by simply making connections
back of the commutator and running only one lead per phase through
the spider to the slip rings. The machine is designed for a six
phase current but being built for laboratory work it is so constructed
as to give either single phase, two phase, three phase, or six phase.
This will be explained by the aid of the accompaning diagram which
represents one half of the commutator or 360 electrical degrees.

The two inner circles
represent the commutator, while
the outer circles represent the
six phases as numbered. It will
be noticed that ring No.1 has two
taps but this is because the com-
mutator being shown in half the
second tap is the same as the
first if it were a full circle.
As there are 24 bars each bar re-
presents 15 degrees. As there
are 12 bars between 1 and 2 which is 180 degrees, single phase can
be obtained by connecting across these two brushes. The same is true
of 3 and 4. There are 6 bars and 90 degrees between 1 and 3, 2 and

3, 3 and 4, 4and 1 which gives the correct connections for two phase current. There are 8 bars or 12C degrees between 1 and 3, 3 and 5, 5 and 1 which gives the correct connections for three phase current. The connections for six phase is only approximate as the connections run as follows; 90 degrees, 30 degrees, 60 degrees, 60 degrees, 30 degrees, and 90 degrees, while a true six phase connection is tapped uniformly 60 degrees apart.

In the winding of the armature, formed coils are used. These are made of No. 17 double cotton covered copper wire and are wound three conductors wide and four layers deep. These are shellacked and well tapped and driven into the slots of the armature. The terminals of the coils are soldered to the commutator bars, one terminal of one coil connecting to the second terminal of the next coil and so on, forming a closed coil winding. After the armature coils are in place, the armature is banded with hard drawn brass wire to keep the coils from shifting. This band is made of No.24 wire and is about 3/8" wide, there being five spaced equally along the armature. The completed turns are sweated together with solder. This completes the construction of the armature proper but a fly wheel and pully are fixed to the end of the shaft which diminishes the tendency to hunt and also affords a means of driving the machine as a generator when desired.

All the details of the machine have been given except the starting switch. This is intended to be used to start the machine when operated as a direct converter running on a single phase current. It consists of a hard wood roller with two rows of contacts and a strip of fiber to which 38 fingers are attached,to the leads from the field coils 32 of these are connected; two fingers are leads from the alternating current mains and two are connected to the direct current brushes of the machine. The switch has only two positions "start" and "normal running notch". When the handle which is attached to the hard wood roller is turned toward "start" the fingers rest on one row of contacts. These contacts are arranged in two sets one set

being connected together and also connected to the contact which corresponds to one of the alternating current leads, the second set being connected together and to the other lead. So when the switch is in this position all the field coils are divided in halves and these halves are connected in multiple across the alternating current leads in series with the armature. This gives a torque sufficient to bring the machine nearly to synchronism. As the machine approaches synchronism, the handle is thrown over to the "normal running notch". Here the fingers rest on the second set of contacts. These contacts are all connected in series and the two end contacts are connected to the contacts corresponding to the direct current fingers. Thus the field coils are all connected in series across the direct current brushes which is the normal running notch of the machine.
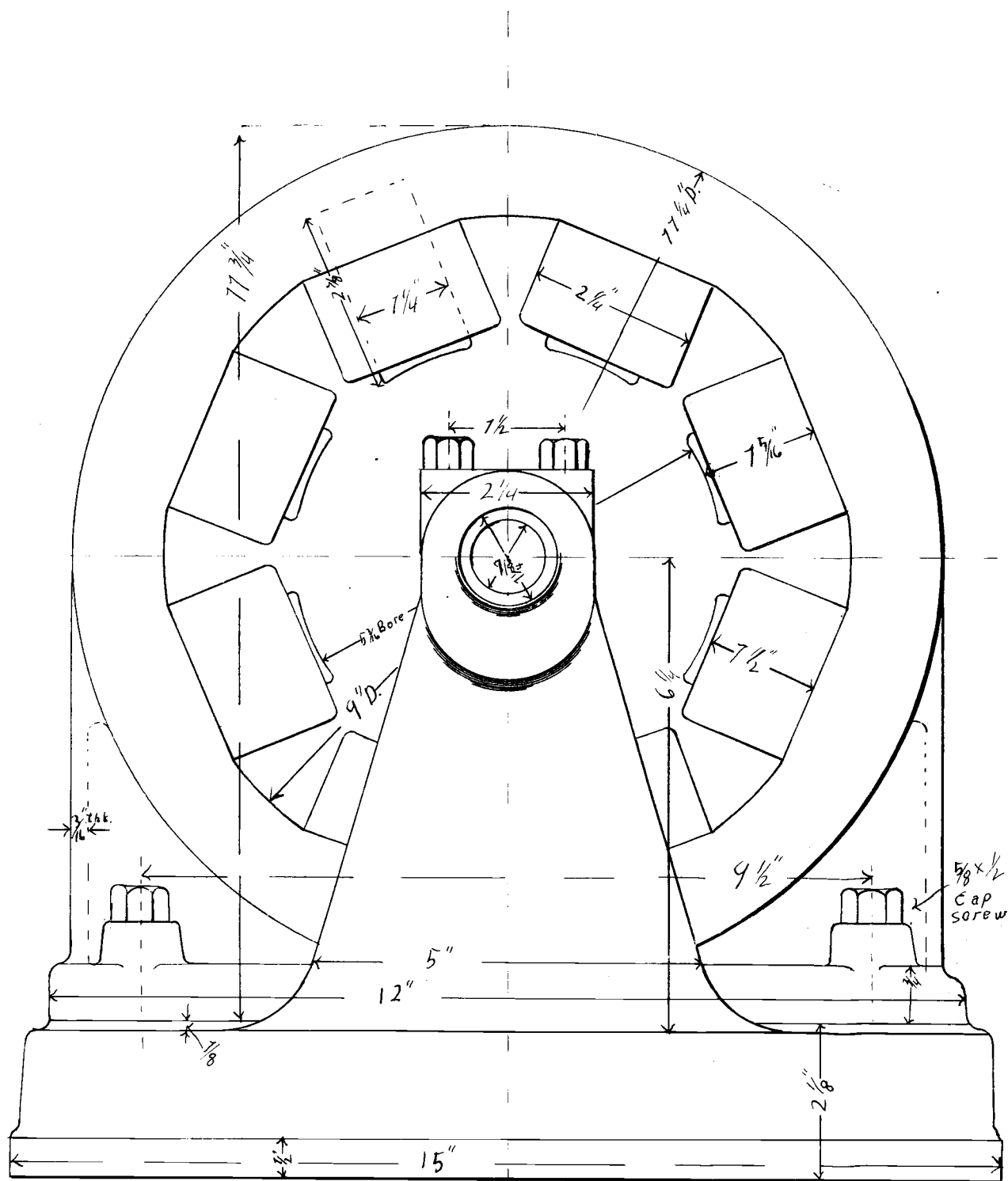
End Elevation of Field Magnet Frame and one Pedestal.

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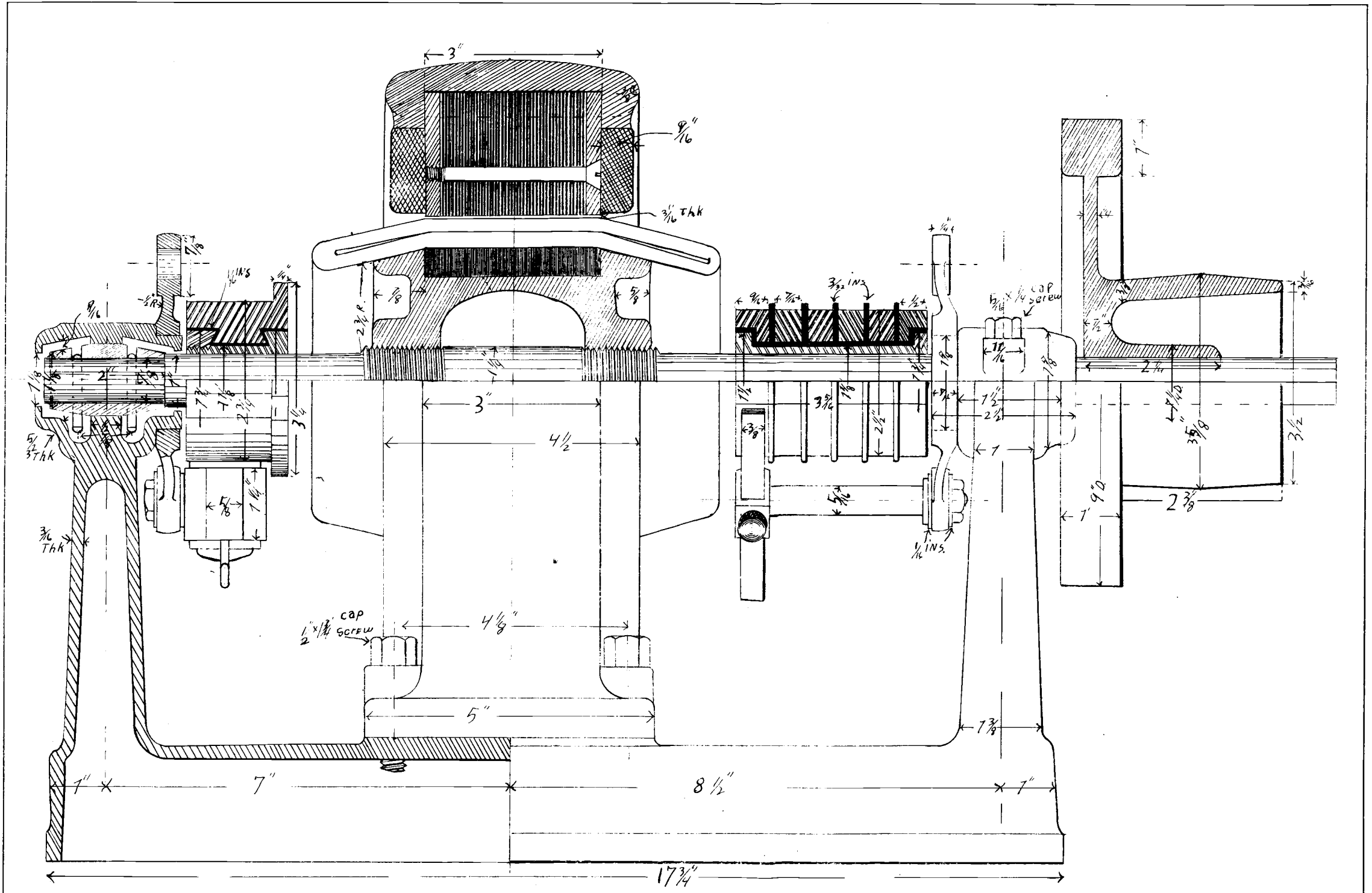
Longitudinal Elevation, One half in Cross-section, Scale ½.

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