THESIS

on

THE THEORY, DESIGN, AND CONSTRUCTION OF A 5 K.W., 125 VOLT, COMPOUNDED, DIRECT CURRENT GENERATOR.

Submitted to the faculty

of the

O R E G O N A G R I C U L T U R A L C O L L E G E

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by

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INTRODUCTION

It has been a standing problem among the scientists of the past and will perhaps be puzzled-over for many centuries to come; namely the most efficient method of transmitting power from one point to another. The nearest solution at present, and a very satisfactory one, is electricity. By means of generators, transformers, transmission lines, and motors, power can be transmitted for a considerable distance with quite high efficiency.

There are many possibilities in the field of electrical transmission of power, for electricity is comparatively in its infancy, and new features are being developed along this line almost daily. Think of the startling discoveries and wonderful inventions by such men as Lord Kelvin, Steinmetz, Edison, and Marconi; the three latter are still living with power to add to their wonderful achievments.

Few are the towns that do not boast of electric lights, and thousands are the factories that use electric power. Countless miles of street car systems are operated by electricity, and quite recently the railroads are adopting electric traction thus opening another very extensive field for this ideal form of power.

The fuel supply of this country, tho of enormous quantities, will not last for ever. Ultimately we will be forced to use water power for the greater portion of our industries; which can only be satisfactorily accomplished by the means of electricity.

The dynamo is a mysterious piece of mechanism to the people who know nothing of the theory upon which it is constructed. They view it with awe, for they see no visible means by which that curious machine can transmit so much energy, nor how it can cause such woeful disturbance to the nervous system of the human body. They believe a man is a wizard possessed with world wide knowledge who can operate this silent medium of power. They do not realize that thousands of incandescents and numberless horse power for factories are supplied thru two or three metallic wires. Yet to one who has investigated the theory of this wonderful invention , there is nothing complicated about it. The public at large does not get enough information about the construction of electrical machinery. A dynamo is not as complex as an ordinary steam engine , and almost any American boy, with any mechanical intuition whatever, can easily explain the operation of the ordinary steam engine.

The large companies seem to have secured the manufacturing of all kinds of electrical apparatus; and every thing pertaining to the various steps of their manufacture is kept secret in order to keep their rivals from gaining any detrimental information; thus the public does not obtainany of the details of the construction of these world wide utilities.

Electrical energy is produced by the cutting of lines of force by inductors, these inductors are tapped by a collecting device which is commected to the mains. The lines of force are produced by magnets diametrically opposite each other and of opposite polarity. These may be either permenant or solenoid magnets; the latter being almost exclusively used in the manufacture of electrical generators.

Either the magnetic field of the inductors may be rotated so as to allow the latter to cut lines of force. In direct current machines the inductors are rotated in the magnetic field while in some alternators the field is revolved. Exitation may be had from an external source or by current taken from the armature.

The inductors are generally wound on a drum shaped core of laminated wrought iron called the armature. This is fastened to a shaft which is rotated by a prime mover.

The commutator is the part which facilitates the collection of the energy. It consists of a number of copper bars of equal size, each insulated from the remainder and fastened together in the shape of a cylinder. Copper or carbon strips are used to collect the current from the rotating commutator; these are called brushes and are placed in the neutral plane.

DESIGN

We will now deal with the design of a 5 K.W., 125 volt, compounded, direct current generator.

ARMATURE

The number of volts per foot of active conductor.

$$E' = \frac{45,000 \times 12^2 \times 10}{10^8} \times 31 \times .75 = 1.506 \text{ volts.}$$

Then the number of feet of inductor $= \frac{125}{1.506} = 83.4$ ft.

We assume an angular velocity of 1450 R.P.M. and a peripheral velocity of 40.3 ft per second. Then the diameter, d, $= 40.3 \times 60 / 1450\pi = .531$ feet $= .531 \times 12 = 6.375$ inches or the mean diameter to which we add the length of the tooth making a total diameter of 7.25 inches. The number of slots of this diameter of armature is 30 and the depth 7/8 inch, and we find the width to be 3/8 inch.

The capacity of the machine being 5 K.W., and the voltage 125; the current will be 5,000/125 = 40 amperes. Choosing a double winding in order to secure a better distribution, the current in each inductor will be $40/(2\times2) = 10$ amperes.

Assuming 1,000 circular mils per ampere, a cross-section of 10,000 circular mils is required, which is equivalent to one #11 B.&S. or two #13 in parallel. We find that 24 #13 wires can be fitted into each slot with the proper insulation, making 6 inductors. The length of solid iron in the armature = 83.4 x 12/(30x6) = 5.5 in.

COMMUTATOR

The commutator diameter is .6 the diameter of the armature or 4.35 inches and as we have chosen two windings in parallel there will have to be 60 segments thus making the width of two segments with the proper insulation between them equal to .5 inch.

Allowing 32 amperes per square inch of contact surface we obtain 1.25 sq.in. of contact surface. And as the width of two segments with their insulation is .5 inch; the length of contact surface will be 1.25/.5 = 2.5 inches. Allowing one inch for connections and shifting of brushes; the commutator will be 3.5 inches long.

As 2.5 inches is too long for one brush, we will make two brushes each 1.25 inches long. As this is a bi-polar machine;two sets will be required.

SHUNT FIELD

Assuming a density in the air gap of 45,000 lines per square inch; then as the area of the pole tip is 64 sq.in. the total effective flux is 64 x 45,000 = 2,880,000 lines. This times the leakage factor(1.28) gives 3,580,000 lines, the number to be used in computing the cross-section of the parts of the magnetic circuit.

Assuming a density of 85,000 lines per sq.in. in the core; then the cross-section of the came will be 3,580,000/85,000 = 42.2 sq.in. this will give a diameter of 5.375 inches.

Assuming a density of 85,000 in the yoke; this will give a cross-section of 1,780,000/85,000 = 21.1 sq.in., as the magnetic circuit divides into two branches. This is obtained, approximately, by making the yoke of a rectangular section having the dimensions of 9.75 x 2.1875 inches.

From a sketch of the armature and field parts, the lengths of the parts of the magnetic circuit are measured. Then from data taken from Wiener's Dynamo Electric Machinery; we find that the number of ampere turns required to force the given flux thru the magnetic circuit is as follows;

Parts	Density	length	unit M.M.F.	amp turns
Air gap	45,000	.25"	14,100	3,525
Arm body	45,000	5.00	8.5	42
Teeth	90,000	1.75	50.7	100
Core & Yoke	85,000	32.00	44.0	1,410
	Total amp turns required			5,077

Best usage allows from two to three % of the full load current to circulate thru the shunt field of a machine of this size. Assuming 2.5 % , the shunt field current will be .025 x 40 = 1 ampere.

The resistance of the shunt coils must cause about 90 % of the drop in the shunt circuit and the field rheostat must cause the other 10 %. This would make the resistance of the shunt coils about 110 ohms and the number of turns would be 5,077/1 = 5,077. Allowing 1,000 circular mils per ampere we find from the table that the wire required is about #20 B.& S.

We find in winding on the wire that 28 pounds fills up the winding space very well and makes 5,820 turns. Also the resistance of this wire is 92 ohms. The ampere turns required are 5,077 and the number of turns on the field are 5,820; thus the shunt current required is 5,077/5,820 = .89 ampere. Then to obtain this current we must have a resistance of 125/.89 = 140 ohms. The resistance of the field, cold, is 92 ohms and thus the field rheostat must have a maximum resistance of 140 - 92 = 48 ohms. The resistance of the field hot (50°) is 130 ohms, in which case the resistance in series with the field must be at least 10 ohms.

SERIES FIELD

Series coils for flat compounding must compensate for back ampere turns and for the IR drop

in the armature. The back ampere turns = the number of slots between the pole tips times the turns in each slot times the current flowing in those turns.
The back ampere turns, therefore, = 24 x 4 x 5 = 480; multiplying by the leakage factor (1.28) gives 615, the number of series ampere turns to be added to the field to compensate for the back ampere turns.
Allowing 50 % of the full load current to flow thru the series field; then the number of turns required is 615/20 = 30.7; dividing by two gives 15 turns, the number for each pole.

The resistance of the armature is .029 ohms and the full load current is 40 amperes, thus the IR drop at full load is only 40 x .029 = 1.16 volts. This drop is so small in proportion to the voltage of the machine that correction gor it may be neglected. Thus the number of series turns are 30 or 15 for each pole. Allowing 2,000 circular mils per ampere, we find from the table that the wire required is #4 B.& S. The mean length of a turn is 22.6 inches and, therefore, the amount of wire required is 30x 22.6/12 = 59 ft. or 7.5 pounds.

EFFICIENCY

Loss due to hysteresis = $\frac{1}{10^7} npB_a^{1.6} \frac{V}{60} v$ in watts.

Substituting values in this formula gives P_h = 179 watts.

The loss due to ohmic resistance in the armature = I^2R_a = 46 watts.

The loss in shunt field = I^2R_f = 112.5 watts.

Total losses at full load = 338 watts.

Thus the efficiency at full load is 5000/5338 = 93.5 %

Efficiency at 3/4 full load is 3750/4076 = 91.8 %

Efficiency at 1/2 full load is 2500/2814 = 89.0 %

Efficiency at 1/4 full load is 1250/1553 = 80.5 %

CONSTRUCTION

The castings for the yoke and brackets were received from the foundry and finished to the dimensions shown in the drawings. They were too large for the largest lathe to handle with its maximum capacity, so it became necessary to raise the head stock about five inches, which was done with small cast iron blocks.

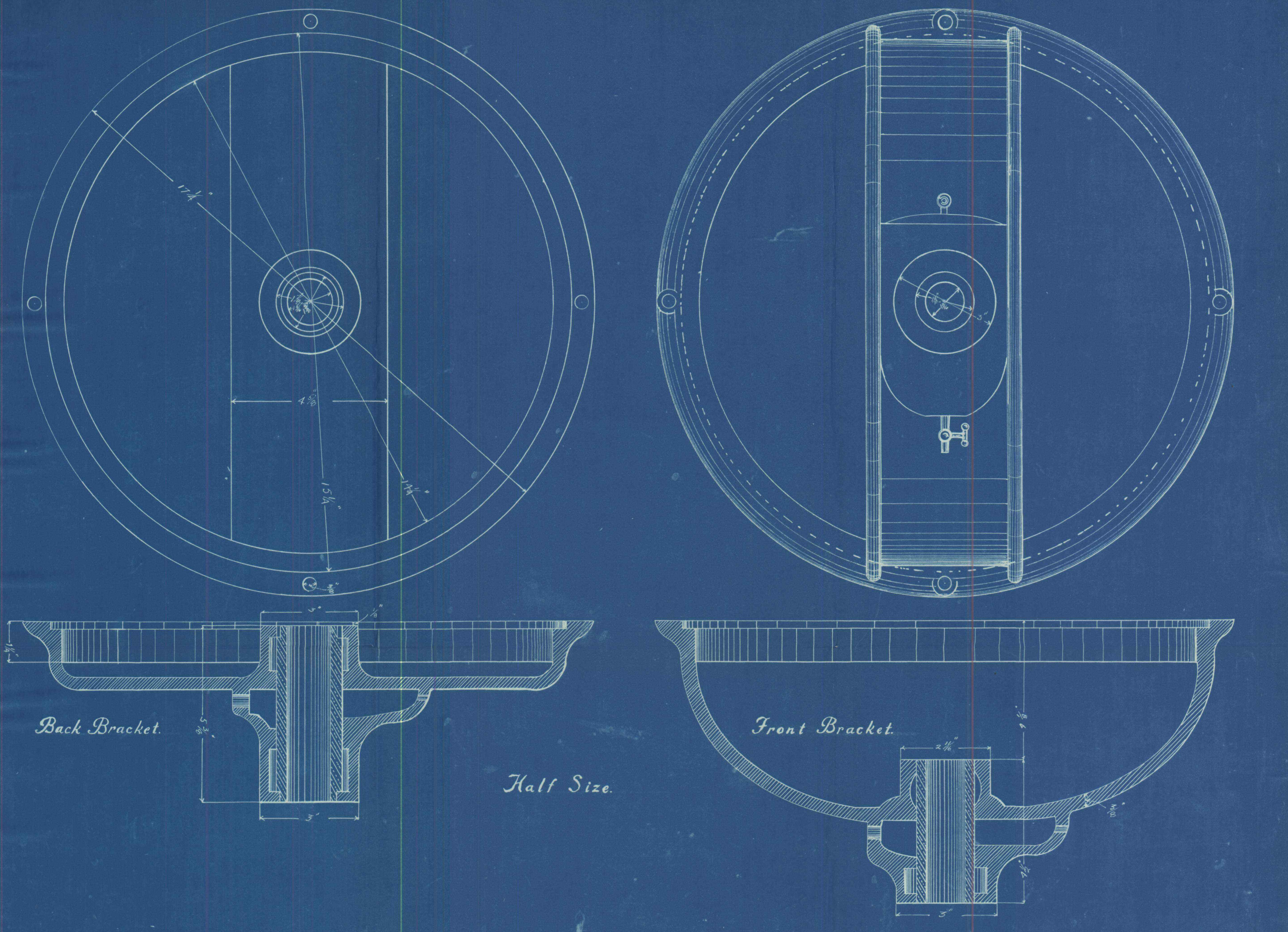
The shaft for the armature was received roughly machined, with the key for the armature discs in position. We smoothed it up, turned oil grooves in the portions adjoining the bearings, and placed the discs and commutator in position.

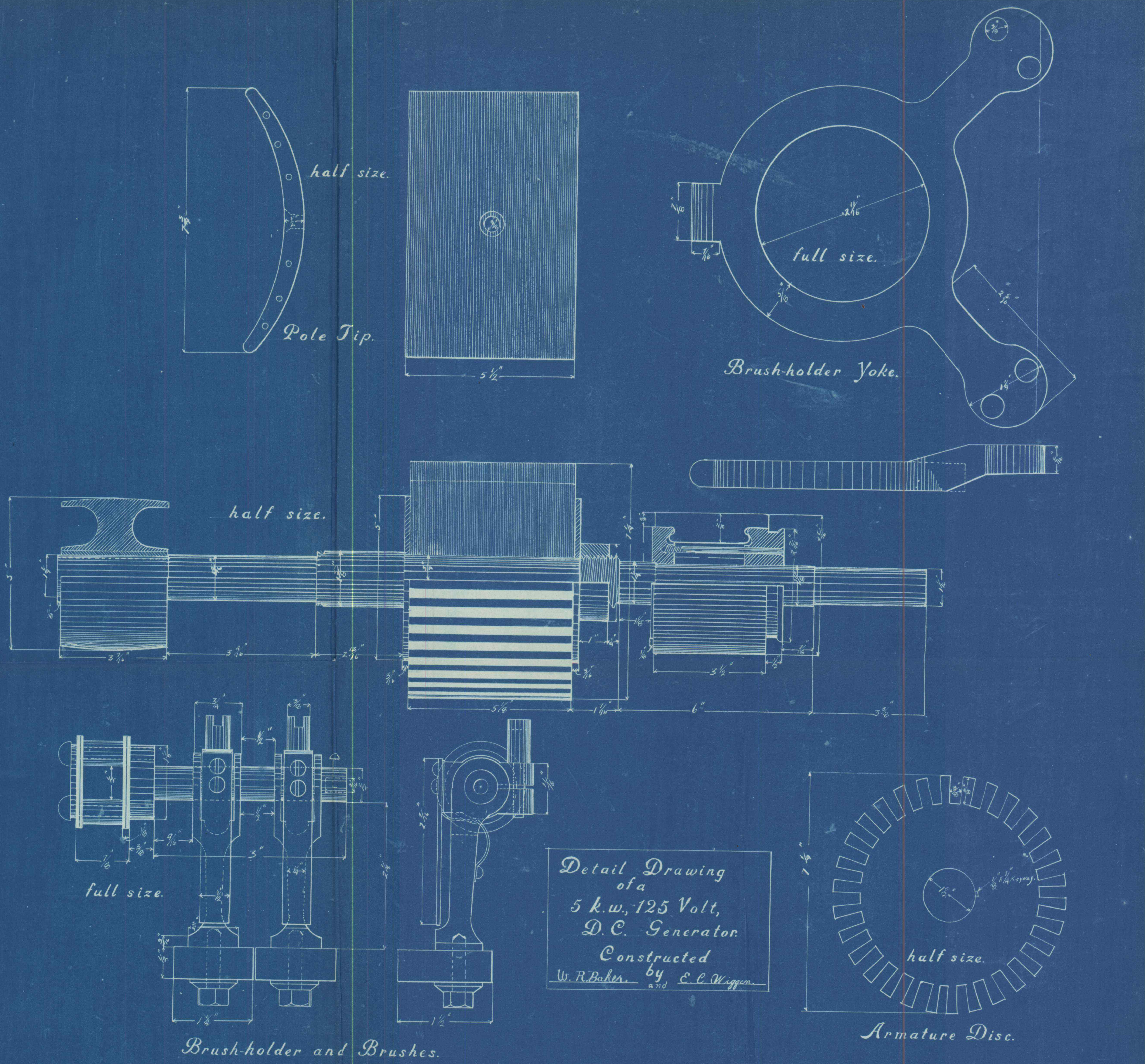
The discs were found to have been punched by a defective machine, as certain parts of each had the edges turned under, necessitating the hammering of each to flatten them properly. They were pressed together by the testing machine; this method was also employed in pressing the commutator into position. When the discs were in position the slots were filed out to the proper size.

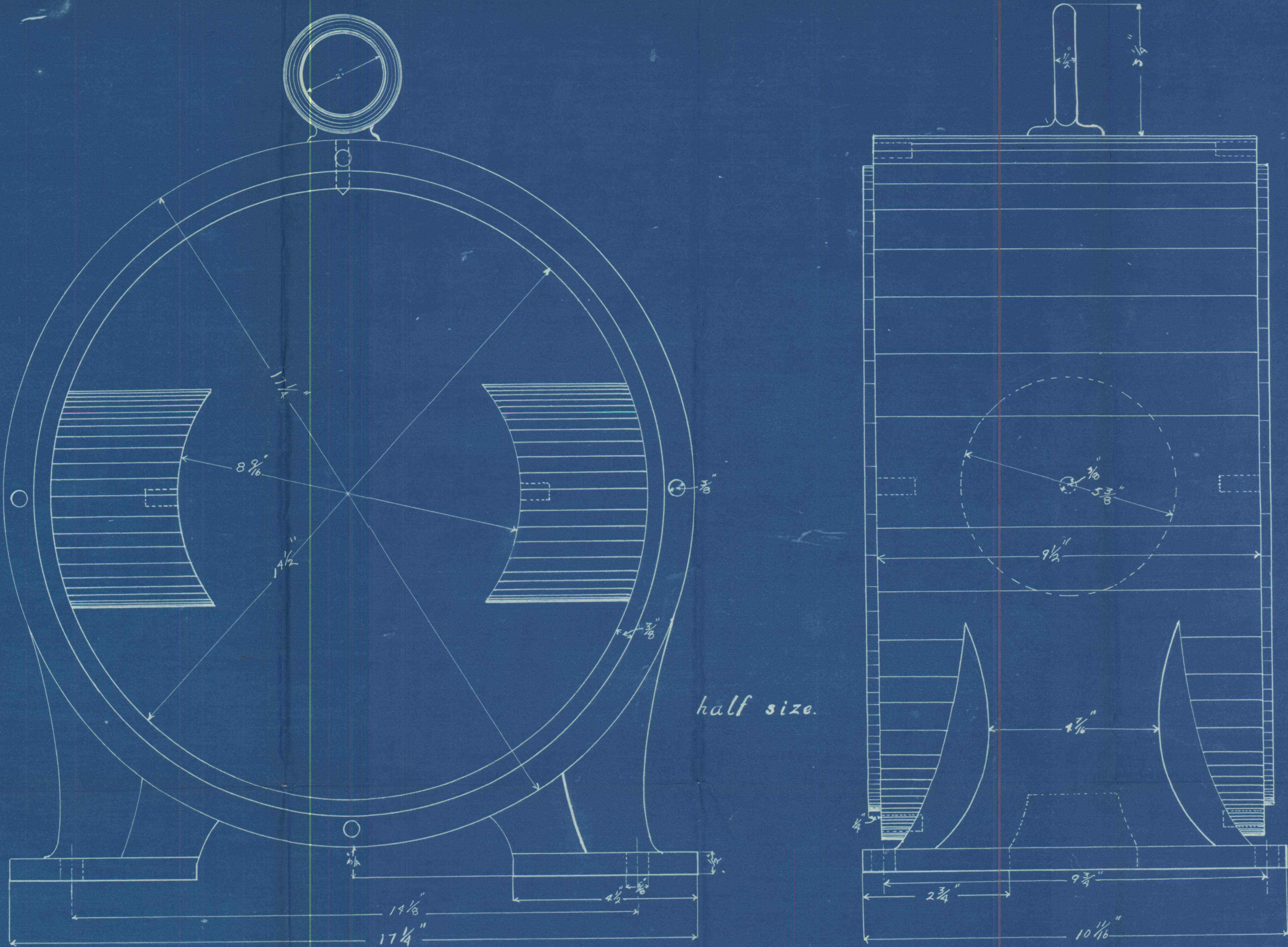
The commutator was finished with the exception of turning down. Slots for lead connections were cut in the ends of each segment by the milling machine.

The field and armature coils were would on wooden forms, taped, and covered with an insulating compound.

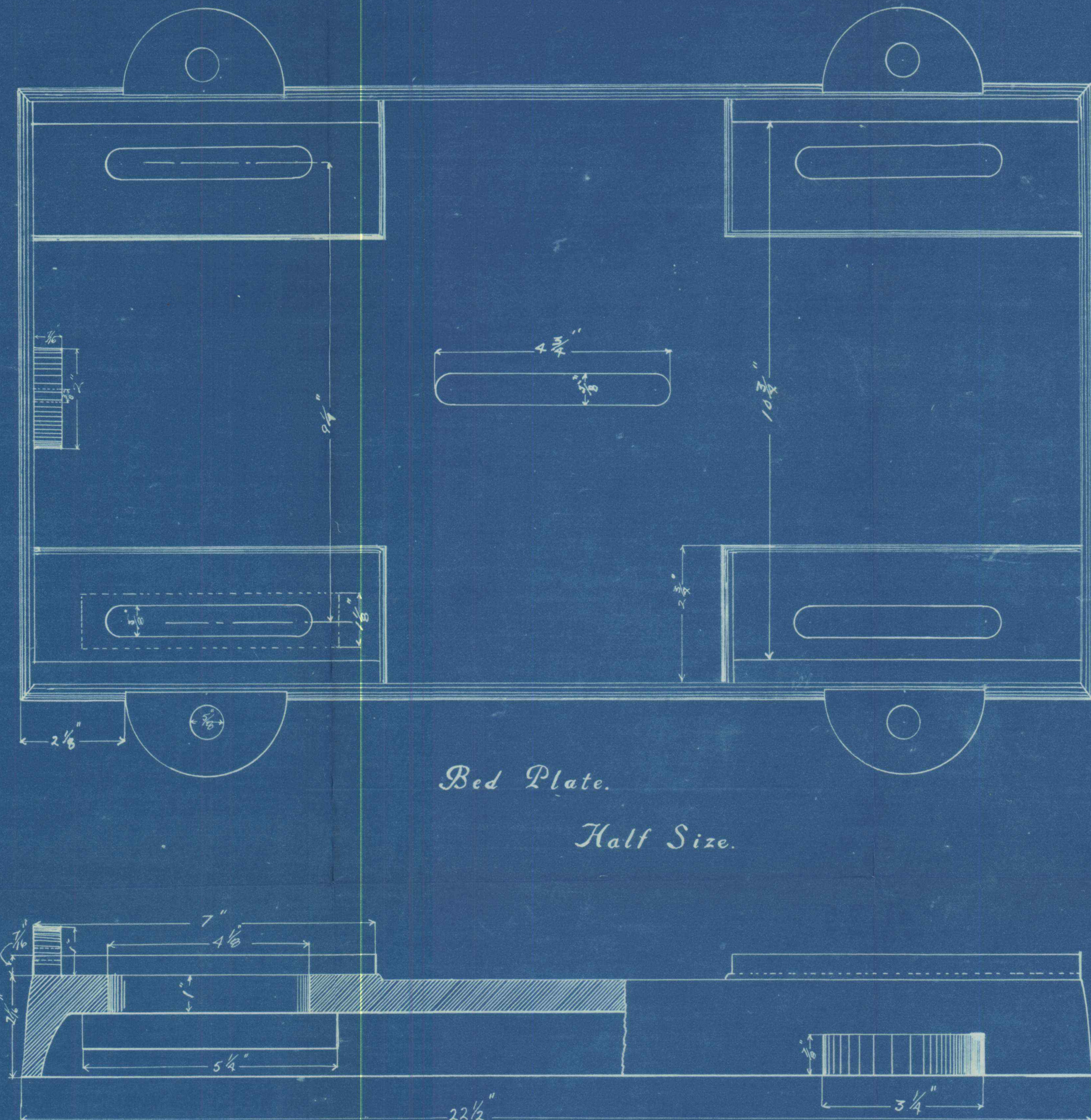
The small fixtures of the machine; such as brushes, binding posts, drain cocks, bolts, etc.; came ready to be attached. All of the machine work necessary was of minor importance and it is needless to mention it here.


Back Bracket.
Front Bracket.
Half Size.
3"
3"


half size.
Pole Tip.
5 1/2"
full size.
Brush-holder Yoke.
half size.
full size.
Brush-holder and Brushes.
Detail Drawing
of a
5 k.w., 125 Volt,
D.C. Generator.
Constructed
by
W. R. Baker. and E. C. Wiggen
half size.
Armature Disc.


11 1/4"
8 9/16"
1 1/2"
3/8"
3/8"
half size.
14 1/8
4 1/2"
17 1/4"
1/2"
3 1/4"
5 3/8"
9 1/2"
7/16"
9 3/4"
2 3/4"
10 11/16"

Magnet Yoke.



Bed Plate.

Half Size.