DESIGN AND CONSTRUCTION OF A VACUUM SPECTROGRAPH

by

JAMES FRANCIS LUBZINSKI

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October 12, 1950.

Dr. L. W. Dunlap,
Librarian,
University of British Columbia.

Dear Dr. Dunlap:

This letter will certify that the thesis of Mr. James F. Lubzinski has been carefully studied by the undersigned, and that the thesis meets the required standards and an abstract has been approved by the Department.

Yours sincerely,

G. M. Shrum
Head of the Department

A. M. Crooker
Professor of Physics

GMS:lc

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ABSTRACT

A vacuum spectrograph is designed to cover from the visible to the far ultraviolet. The general path equation is expanded as a power series to the fourth power. Conditions for minimizing this path are given to the third power. There are two different settings in the visible region -- a grating of 576 lines per millimetre is used and the slit is set at normal incidence of 20°; in the far ultraviolet, a grating of 1152 lines per millimetre is used and the slit is set at glancing incidence of 80°.

The housing and vacuum system difficulties are explained and figures are given showing how some of these are overcome.

The optical parts were designed to facilitate in focussing, stress being made on designs which are free from machining difficulties. Although the grating and plate holders are different from those previously used, the slit design is such that it is completely free from mechanical difficulties usually encountered. A plate diaphragm is used to increase the number of exposures.

The complete set of drawings used in the construction of this apparatus are given in the appendix.

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J.F. Lubzinski

The University of British Columbia
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INTRODUCTION

The objective, to measure precisely certain wave lengths in the far-ultra-violet, brought about the need to build a vacuum spectrograph which is capable of producing results at least comparable in accuracy to that of previous investigators. Before deciding on any design in particular not only were the instruments of previous workers investigated but also the facilities at our disposal were studied. With these findings in mind the plans in some cases had to deviate from the more standard types of design.

The reasons for using a concave diffraction grating vacuum spectrograph are rather obvious. To determine wave length to a greater degree of accuracy, the index of refraction for air must also be known to a greater degree. With a vacuum spectrograph this can either be determined or entirely neglected. The second important factor is the high absorption of short wave length by air which reduces the intensity. Furthermore, in order to eliminate the determination of index of refraction of any substance, it is necessary to have the entire light path in free space. This fact automatically eliminates the use of prisms and source windows.

This spectrograph was designed with two alternative positions for a source, thus giving scope for a wide range helpful in setting up the instrument by making it possible to start in the visible region.

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CHAPTER I

THE CONCAVE GRATING THEORY

Since the wave lengths to be measured are very short, and also in order to get high dispersion, large angles of incidence will have to be used. To be able to work in this region a complete understanding of the concave grating theory is essential. Various references were consulted and checked for the length and width of grating and the size of slit to be used. Of the many articles read and evaluated, Zernke's was found to be mathematically complete and straightforward. Therefore his theory, being the most applicable to this work, is here developed and expanded to the degree deemed necessary for the size of angles used in this spectrograph.

Fermat's principle of least time is applied to a general path of light of any order M; that is, the conditions that must be applied to make a general path an extremum.

Take the origin of a cartesian system at the center of the grating so that the radius of curvature is at $x = R$ and the ruled lines are parallel with Z so that a plane parallel with X and Z cuts the sphere of radius R at the ruled lines. The co-ordinates of the three points being the source A(x,y,z), a point P on the grating P(, ,), and the image B(x',y',z'). The center of the circle is then (R,0,0). The optical path length for the central or zero order image is equal to AP **plus** PB. From grating theory the increase in path between rulings is (d sine $\varphi = m\lambda$) for image of the mth order is $m\lambda$. Hence increase in path length in centimeters is Nm where N is number of lines per centimeter. Hence a general path is

$$V = AP + PB + Nm\lambda\rho$$

where the rulings are equally spaced by P.

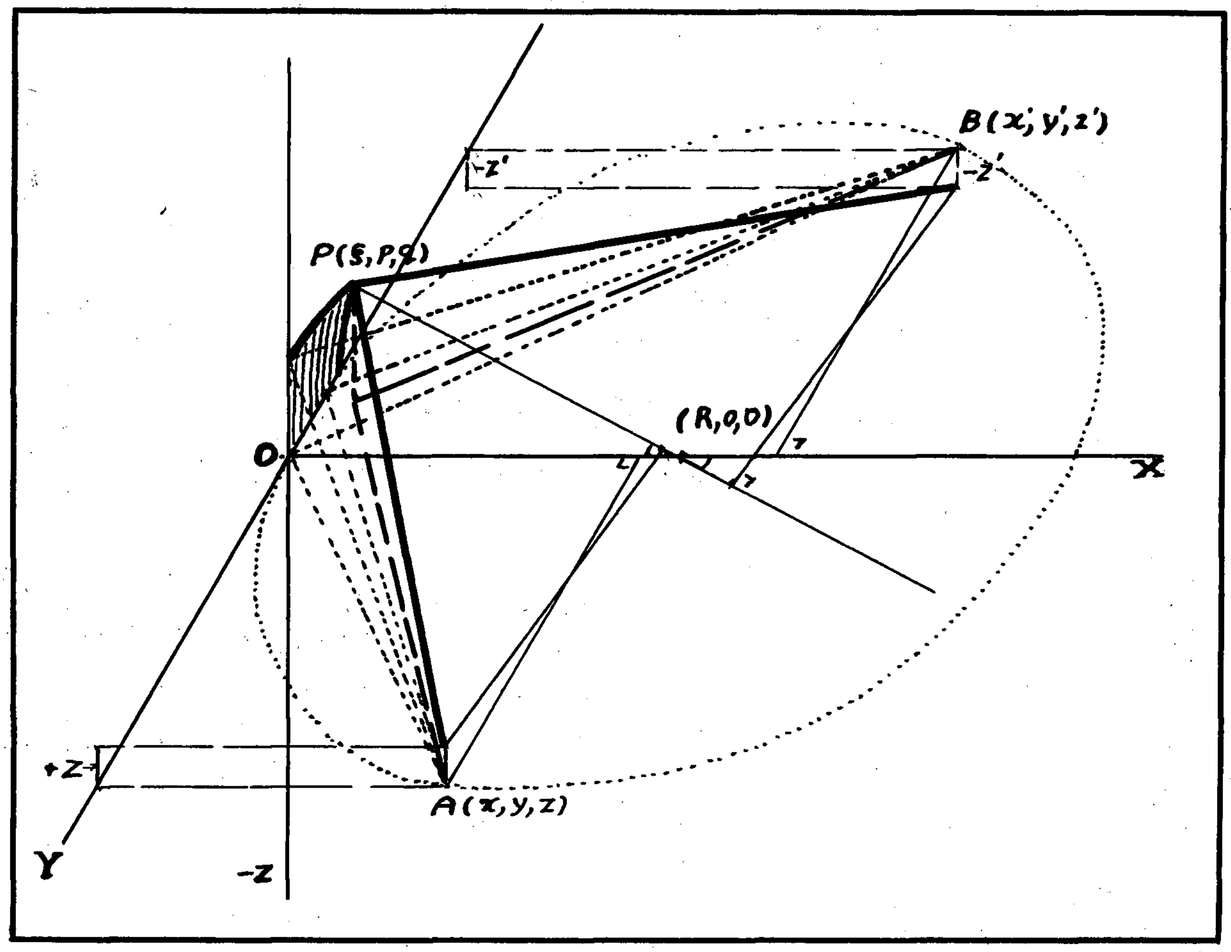


Figure 1 (a)

That is

$$V = \left[(x-\xi)^2 + (y-\rho)^2 + (z-\zeta)^2\right]^{\frac{1}{2}} + \left[(x'-\xi)^2 + (y-\rho)^2 + (z'-\zeta)^2\right]^{\frac{1}{2}} + Nm\lambda\rho$$

Since we are interested in finding the minimum path for a fixed grating then the function "V" must be expanded in powers of the variables of the grating p and q, the height of the slit z, and the image z'.

Let : $x = r \text{ cosine } \varphi \qquad y = r \text{ sine } \varphi$

$x' = r' \text{ cosine } \varphi' \qquad y' = r' \text{ sine } \varphi'$

and since P lies on a circle of radius R then the condition $(R - \xi)^2 + p^2 + q^2 = R^2$ may be used; but since ξ is small then ξ^2 may be neglected whereby we have

$$\xi = \frac{1}{2R}(p^2 + q^2)$$

making this substitution into the general path equation we have the following

$$V = r\left[1 + \frac{p^2 + q^2}{r^2} - \frac{\cos\varphi}{R}(p^2+q^2) + \frac{}{r^2} - 2\frac{\sin\varphi}{r}p - 2\frac{q}{r^2}\right]^{\frac{1}{2}}$$

$$+ r'\left[1 + \frac{p^2 + q^2}{r'^2} - \frac{\cos\varphi'}{R}(p^2+q^2) + \frac{'^2}{r'^2} - 2\frac{\sin\varphi'}{r'}p - 2\frac{'q}{r'^2}\right]^{\frac{1}{2}}$$

$$+ Nm\lambda p$$

which when expanded in ascending powers of p, q, z, and z' is

$$V = r + r' - (\sin\varphi + \sin\varphi' + Nm\lambda)P$$

$$+ \frac{1}{2}\left(\frac{1}{r} + \frac{1}{r} + \frac{\cos^2\varphi}{r'} + \frac{\cos^2\varphi'}{r'} - \frac{\cos\varphi}{R} - \frac{\cos\varphi'}{R}\right)p^2$$

$$+ \frac{1}{2}\left(\frac{1}{r} + \frac{1}{r'} - \frac{\cos\varphi}{R} - \frac{\cos\varphi'}{R}\right)q^2$$

$$+ \frac{1}{2}\left(\frac{z^2}{r}\right) + \frac{1}{2}\left(\frac{z'^2}{r}\right) - \frac{qz}{r} - \frac{qz'}{r'}$$

$$+ \frac{1}{2}\left(\frac{\sin\varphi\cos^2\varphi}{r^2} + \frac{\sin\varphi'\cos^2\varphi'}{r'^2} - \frac{\sin\varphi\cos\varphi}{rR} - \frac{\sin\varphi'\cos\varphi'}{r'R}\right)p^3$$

$$+ \frac{1}{2}\left(\frac{\sin\varphi}{r^2} + \frac{\sin\varphi'}{r'^2} - \frac{\cos\varphi\sin\varphi}{rR} - \frac{\cos\varphi'\sin\varphi'}{r'R}\right)pq^2$$

$$+\frac{1}{2}\left(\frac{\sin\varphi}{r^2}\right)pz^2 + \frac{1}{2}\left(\frac{\sin\varphi'}{r'^2}\right)pz'^2$$

$$-\left(\frac{\sin\varphi}{r^2}\right)pqz - \left(\frac{\sin\varphi}{r'^2}\right)pqz'$$

$$-\frac{1}{8}\left(\frac{1}{r^3}+\frac{1}{r'^3}+\frac{r\cos^2\varphi}{R^2}+\frac{r'\cos^2\varphi'}{R^2}-\frac{\cos\varphi}{rR}-\frac{\cos\varphi'}{r'R}-6\frac{\sin^2\varphi}{r^3}-6\frac{\sin^2\varphi}{r'^3}\right.$$

$$\left.+6\frac{\sin^2\varphi\cos\varphi}{rR}+6\frac{\sin^2\varphi'\cos\varphi'}{r'R}+5\frac{\sin^4\varphi}{r'^3}+5\frac{\sin^4\varphi'}{r'^3}\right)p^4$$

$$-\left(\frac{1}{8r^3}+\frac{1}{8r'^3}+\frac{r\cos^2\varphi}{8R^2}+\frac{r'\cos^2\varphi'}{8R^2}-\frac{\cos\varphi}{4rR}-\frac{\cos\varphi'}{4r'R}\right)q^4$$

$$-\frac{1}{8r^3}z^4 - \frac{1}{8r'^3}z'^4$$

$$-\left(\frac{1}{4r^3}+\frac{1}{4r'^3}+\frac{r'\cos^2\varphi'}{4R}+\frac{r\cos^2\varphi}{4R^2}-\frac{\cos\varphi}{2rR}-\frac{\cos\varphi'}{2r'R}\right.$$

$$\left.-\frac{3}{4}\frac{\sin^2\varphi}{r^3}-\frac{3}{4}\frac{\sin^2\varphi'}{r'^3}+\frac{3}{4}\frac{\sin^2\varphi\cos\varphi}{rR}+\frac{3}{4}\frac{\sin^2\varphi'\cos\varphi'}{r'R}\right)p^2q^2$$

$$-\left(\frac{3}{4r^3}-\frac{1}{4}\frac{\cos\varphi}{rR}\right)q^2z^2 - \left(\frac{3}{4r'^3}-\frac{1}{4}\frac{\cos\varphi}{r'R}\right)q^2z'^2$$

$$-\left(\frac{1}{4r^3}-\frac{3}{4}\frac{\sin^2\varphi}{r^3}\right)p^2z^2 - \left(\frac{1}{4r'^3}-\frac{3}{4}\frac{\sin^2\varphi}{r'^3}\right)p^2z'^2$$

$$+\left(\frac{1}{2r^3}-\frac{1}{2}\frac{\cos\varphi}{rR}-\frac{3}{3}\frac{\sin^2\varphi}{r^3}\right)p^2qz + \left(\frac{1}{2r'^3}-\frac{1}{2}\frac{\cos\varphi}{r'R}-\frac{3}{2}\frac{\sin^2\varphi}{r^3}\right)p^2qz'$$

$$+\left(\frac{1}{2r^3}-\frac{1}{2}\frac{\cos\varphi}{rR}\right)q^3z + \left(\frac{1}{2r^3}-\frac{1}{2}\frac{\cos\varphi'}{r'R}\right)q^3z'$$

$$+\left(\frac{1}{2r^3}\right)qz^3 + \left(\frac{1}{2r'^3}\right)qz'^3$$

Applying Fermat's principle, the points A and B' lie on conjugate rays if the function of the distance is a minimum with respect to the variables p and q. That is $\frac{\partial v}{\partial p} = \frac{\partial v}{\partial q} = 0$ Since here we are interested in the action of the grating - the variation of the path given by the function "V" with respect to the variables p and q of the grating - so the object and image points A and B are taken in the plane of symmetry XOY ($Z = Z' = 0$). Therefore the two partial differential equations are :

$$
\begin{aligned}
\frac{\partial V}{\partial p} = {} & (-\sin\varphi - \sin\varphi' + Nm\lambda) + \Big(\frac{1}{r} + \frac{1}{r'} + \\
& \frac{\cos^2\varphi}{r} + \frac{\cos^2\varphi'}{r'} - \frac{\cos\varphi}{R} - \frac{\cos\varphi'}{R}\Big)\, p \\
& + \frac{3}{2}\Big(\frac{\sin\varphi\cos^2\varphi}{r^2} + \frac{\sin\varphi'\cos^2\varphi}{r'^2} - \frac{\sin\varphi\cos\varphi}{rR} - \frac{\sin\varphi'\cos\varphi}{r'R}\Big)\, p^2 \\
& + \frac{1}{2}\Big(\frac{\sin\varphi}{r^2} + \frac{\sin\varphi'}{r'^2} - \frac{\cos\varphi\sin\varphi}{rR} - \frac{\cos\varphi'\sin\varphi'}{r'R}\Big)\, q^2 \\
& - \frac{1}{2}\Big(\frac{1}{r^3} + \frac{1}{r'^3} + \frac{r\cos^2\varphi}{R^2} + \frac{r'\cos^2\varphi'}{R^2} - \frac{\cos\varphi}{rR} - \frac{\cos\varphi'}{r'R} - 6\frac{\sin^2\varphi}{r^3} - 6\frac{\sin^2\varphi'}{r'^3} \\
& 6\,\frac{\sin^2\varphi\cos\varphi}{rR} + 6\,\frac{\sin^2\varphi'\cos\varphi'}{r'R} + 5\,\frac{\sin^4\varphi}{r^3} + 5\,\frac{\sin^4\varphi'}{r'^3}\Big)\, p^3 \\
& - \Big(\frac{1}{2r^3} + \frac{1}{2r'^3} + \frac{r'}{2}\,\frac{\cos^2\varphi'}{R^2} + \frac{r}{2}\,\frac{\cos^2\varphi}{R^2} - \frac{\cos\varphi}{rR} - \frac{\cos\varphi'}{r'R} \\
& - \frac{3}{2}\,\frac{\sin^2\varphi}{r^3} - \frac{3}{2}\,\frac{\sin^2\varphi'}{r'^3} + \frac{3}{2}\,\frac{\sin^2\varphi\cos\varphi}{rR} + \frac{3}{2}\,\frac{\sin\varphi'\cos\varphi'}{r'R}\Big)\, pq^2 \\
& = 0
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial V}{\partial q} = {} & \Big(\frac{1}{r} + \frac{1}{r'} - \frac{\cos\varphi}{R} - \frac{\cos\varphi'}{R}\Big)\, q \\
& + \Big(\frac{\sin\varphi}{r^2} + \frac{\sin\varphi'}{r'^2} - \frac{\cos\varphi\sin\varphi}{rR} - \frac{\cos\varphi'\sin\varphi'}{r'R}\Big)\, qp \\
& - \Big(\frac{1}{2r^3} + \frac{1}{2r'^3} + \frac{r\cos^2\varphi}{2R^2} + \frac{r'\cos^2\varphi'}{2R^2} - \frac{\cos\varphi}{rR} - \frac{\cos\varphi'}{r'R}\Big)\, q^3 \\
& - \Big(\frac{1}{2r^3} + \frac{1}{2r'^3} + \frac{r'\cos^2\varphi'}{2R^2} + \frac{r\cos^2\varphi}{2R^2} - \frac{\cos\varphi}{rR} - \frac{\cos\varphi'}{r'R} \\
& - \frac{3}{2}\,\frac{\sin^2\varphi}{r^3} - \frac{3}{2}\,\frac{\sin^2\varphi'}{r'^3} + \frac{3}{2}\,\frac{\sin^2\varphi\cos\varphi}{rR} + \frac{3}{2}\,\frac{\sin^2\varphi'\cos\varphi'}{r'R}\Big)\, p^2q
\end{aligned}
$$

To further simplify the problem consider a ray where P is at the origin ($x = 0$)

$$\frac{\partial V}{\partial p} = -\sin\varphi - \sin\varphi' + Nm\lambda$$

$$\frac{\partial V}{\partial q} = 0$$

Thus the first condition is that

$$\sin\varphi + \sin\varphi' = Nm\lambda$$

which gives the relation between the angle of incidence and the angle of diffraction (the well-known diffraction grating formula). If the above condition is to be fulfilled, focussing (all rays from A pass through to B') is only possible by varying r and r'. Therefore the condition for all points along p (horizontal focussing) which satisfy $\frac{\partial V}{\partial p} = 0$ is found by letting the coefficient of p vanish

$$\frac{\cos^2\varphi}{r} - \frac{\cos\varphi}{R} + \frac{\cos^2\varphi'}{r'} - \frac{\cos\varphi'}{R} = 0$$

that is, if

$$r = R\cos\varphi$$

$$r' = R\cos\varphi'$$

the conditions of the Rowland circle, as shown by the diagram, and likewise the conditions for all points along q (vertical focussing) which satisfy $\frac{\partial V}{\partial q} = 0$ are found by letting the coefficient of q vanish.

$$\left(\frac{1}{r} + \frac{1}{r'} - \frac{\cos\varphi}{R} - \frac{\cos\varphi'}{R}\right) q = 0$$

For a stigmatic image, both the horizontal and the vertical conditions, coefficients of p and q, must be simultaneously satisfied. This is only possible if $r - \propto$ and $\varphi' = 0$; known as the Wadsworth collimator mount.

Since we are interested in resolving distances in the horizontal direction it is not a serious disadvantage if the image of a point source is a vertical line. However, if the defocussing is too great, a serious loss of intensity may result. To examine this matter the simplification of taking the points A and B on the plane of symmetry will not suffice since the first degree terms in q, $\frac{z}{r}$ and $\frac{z}{r'}$ are missing. Adding these two terms to the above equation we have:

$$\left(\frac{1}{r} + \frac{1}{r'} - \frac{\cos\varphi}{R} - \frac{\cos\varphi'}{R} \right) q - \frac{z}{r} - \frac{z'}{r'} = 0$$

Simplifying this equation, since each point of the slit produces a vertical image, the inverse is here considered - or that each point of the image is produced by a part of the length of the slit. Thus, for the relation between the slit, the grating rulings and the image length, we have

$$z = hq - \frac{r}{r'} z'$$

where $h = \cos\varphi\,(\sin\varphi\tan\varphi + \sin\varphi'\tan\varphi')$

as h denotes the vertical spread here it serves as a measure of astigmatism. The following figure shows the relation between the angles of incidence and diffraction and the degree of astigmatism.

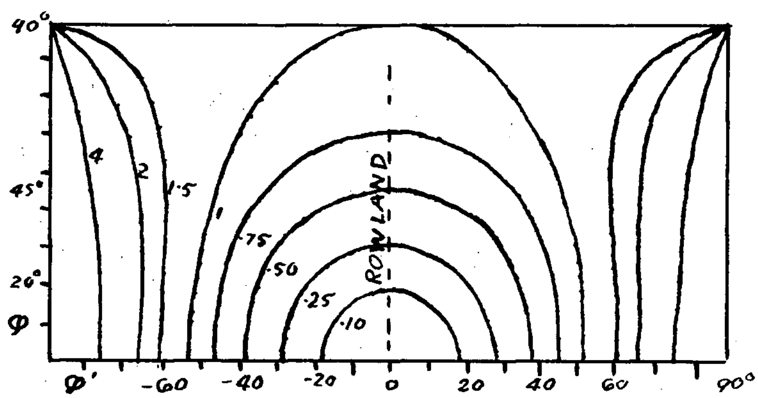


Figure 1 (b) : Plot of the function "h"

From the foregoing diagram it is seen that for large angles where $h > I$, to keep vertical astigmatism to a minimum, $h = I$ The angle of diffraction should not be greater than $45°$; hence from first order considerations, it appears that the slit length should be about the same length as the rulings on the grating.

In consideration of the high power terms in p and q, if $\frac{\partial V}{\partial p} \neq 0$ and $\frac{\partial V}{\partial q} \neq 0$ then the normal to the wave front, $V = \text{const}$ is at an angle to the line AB which was determined by the foregoing conditions. The vertical displacement is given by

$$z = r' \frac{\partial V}{\partial q}$$

The horizontal displacement is given by

$$t = \frac{r}{\cos \varphi'} \quad \frac{\partial V}{\partial p}$$

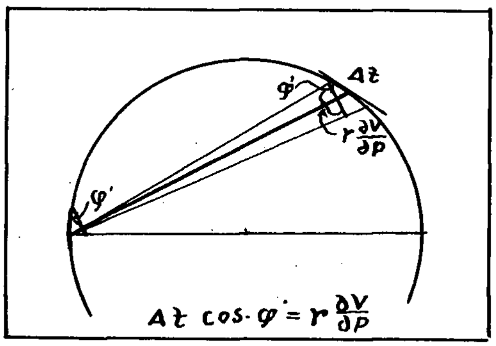


Figure 1 (c)

Since the vertical displacements here are much smaller than those discussed before, seeing that all factors are of a higher order will therefore be negligible.

The terms which will produce shifts in the horizontal direction are proportional to p^2 and q^2 and hence lop-sided comas. The coefficient of the first is called the horizontal coma as in analogy to the vertical coma, the coefficient of second.

The horizontal coma is given by

$$\Delta t = \frac{r'}{\cos\varphi'} \quad \frac{3}{2}\left(\frac{\sin\varphi\cos^2\varphi}{r^2} + \frac{\sin\varphi'\cos^2\varphi'}{r'^2} - \frac{\sin\cos\varphi}{rR} - \frac{\sin\varphi'\cos\varphi'}{r'R}\right)p^2$$

$$= \frac{3r'}{2\cos\varphi'} \quad \cos\varphi\left(\frac{\sin\varphi}{r} - \frac{\sin\varphi'}{r'}\right)\left(\frac{\cos\varphi}{r} - \frac{1}{R}\right)$$

and vanishes for the entire spectrom if the slit is placed on the Rowland circle;

$r = R\cos\varphi$.

Before proceeding to investigate the vertical coma directly, since the variables q, z, and a' are related, so all the terms of the 2nd order must be considered together.

$$\Delta t_2' = \frac{r'}{2\cos\varphi'} \left[\left(\frac{\sin\varphi}{r^2} + \frac{\sin\varphi'}{r'^2} - \frac{\cos\varphi\sin\varphi}{rR} - \frac{\cos\varphi'\sin\varphi'}{r'R}\right) q^2 - \frac{\sin\varphi}{r^2}(2qz - z^2) - \frac{\sin\varphi'}{r'^2}(2qz' - z'^2)\right]$$

Take the case, $z > hq$, where the slit length is longer than that which is required by that length of grating rulings; hence z may be eliminated. In order that the condition for eliminating the horizontal coma be preserved substitute the values $r = R\cos\varphi$ and $r' = R\cos\varphi'$

$$\Delta t_2' = \frac{1}{2R}\left(\sin\varphi'\tan^2\varphi' + \sin^2\varphi'\tan^2\varphi\sin\varphi - \sin\varphi'\tan\varphi'\sin^2\varphi - \sin^3\varphi\right)q^2$$
$$- \frac{1}{R\cos\varphi'}\left(\tan\varphi' + \sin\varphi'\tan\varphi'\sin\varphi - \tfrac{1}{2}\sin^2\varphi\right)qz'$$

So the first term is that which defines the vertical coma and when written as

$$\Delta t = \frac{f}{2R}q^2$$

one can see that this may be reduced by masking the grating but, due to loss of intensity, the degree of masking has to be considered from the plot of the function f

$$f = \sin\varphi'\tan^2\varphi' + \sin^2\varphi'\tan^2\varphi\,\sin\varphi - \sin\varphi'\tan\varphi'\sin^2\varphi - \sin^3\varphi$$

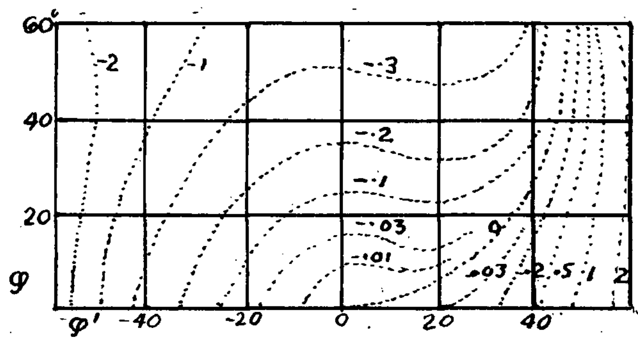


Figure 1 (d) : Plot of the function "f"

Hence it is easily seen that the angle of diffraction should be kept small.

In the case where $z < hg$ here the slit is the restricting element and each point of the image receives light from the whole slit length: thus q may be neglected.

$$t = \frac{fr'}{2\cos\varphi'}\left(\frac{\sin\varphi}{r^2}\right)z^2 - \frac{r'}{2\cos\varphi'}\left(\frac{\sin\varphi'}{r'^2}\right)z'^2$$

The first term being proportional to z^2, this equation may be written as:

$$\frac{1}{2} = \frac{f'}{2Rh^2}z^2 - \frac{1}{Rh^2}\,\frac{\sin\varphi\sin\varphi'}{\cos^2{}'}\,(\sin\varphi + \sin\varphi')2z'$$

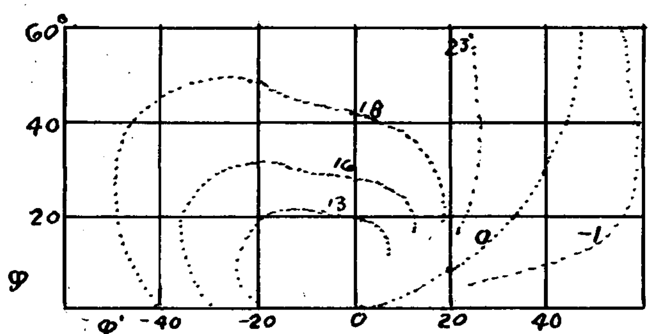


Figure 1 (e) : Plot of the function "$\frac{f'}{h^2}$"

So for large angles of incidence a short slit should be used. The error proportional to zz' is the tilt error and is zero in the middle of a spectral line.

FOCUSSING TEST

Since the image is astigmatic, a horizontal slit is used in front of the focal plane and short spectral lines are then produced in the focal plane. Because of different angles of inclination the light rays must come from a definite part of the slit - the short spectral lines are then automatically stigmatic. If the source slit image is then reduced to about 1/50 vertically and, being the same in the horizontal position, the errors are then magnified to about 50 times (as in the case where either the grating or the slit is not perpendicular to the plane of the Rowland circle) so the reduction is helpful in lining up this apparatus.

Since the vertical coma which produces a horizontal shift proportional to z^2 appears in the focal plane in the same manner as curvature of the slit, therefore the vertical coma may be reduced by the right slit curvature.

Now as the horizontal slit is moved perpendicular to the plane (Z'-) then the tilt error proportional to zz' appears as the inclination of the spectral lines.

CHAPTER II

SPECTROGRAPH DESIGN

To cover a wide range, from the visible to the far ultra-violet, two gratings were available. An ultra-violet grating of 1152 lines per millimetre and, in the visible region, a grating of 576 lines per millimetre. To make the most use of these, i.e. to get a high dispersion, two source or slit positions are used.

In these two cases the angle of incidence is in the ultra-violet at glancing incidence, and in the visible at normal incidence. The two grating equations are

$$m\lambda = b(\sin\varphi_1 - \sin\varphi')$$

for glancing incidence

$$m\lambda = b(\sin\varphi_2 + \sin\varphi')$$

for normal incidence.

The major problem in selecting these two angles of incidence is to determine the minimum angle of diffraction that will be required in order that some spectral lines will occur in both settings. The selection of this minimum diffraction will determine the size of apparatus necessary.

Taking 80° as the largest permissible angle of incidence, and using the 1152 lines per millimetre and 2000 mm diameter grating, we consider $m\lambda$ for five different angles of diffraction:

$\varphi' = 40$	$m\lambda = 2970$ Å
50	1900
60	1025
70	392
80	0

$m\lambda$ increases as φ' decreases.

Then taking an angle 20° from the normal and using the 576 lines per millimetre and 2000 mm diameter grating, m is given for the same five angles:

$\varphi' = 40$	$m\lambda = 5200$ Å
50	7350
60	9100
70	10380
80	11150

$m\lambda$ increases as φ' increases.

The spectral lines considered are the H, D and He lines which occur in the vacuum grating region with their higher orders in the region 2400–5000

H	D	He
	1215.7	1085.0
1641	1215.1	1025.6
1636.5		921.6

The reciprocal dispersion, or plate factor, in A per millimetre

$$\frac{d\lambda}{ds} = \frac{b\cos\varphi}{mR} \qquad \text{where} \quad ds = Rd\varphi$$

$$= \frac{bd}{mR^2} \qquad \text{where} \quad d = R\cos\varphi \quad \text{is the}$$

distance from the pole of the grating, is given for the above selection of diffraction angles.

When incident angle is 80° dispersion is :

		1152 lines/mm grating	576 lines/mm grating
φ =	40	6.650	13.300
	50	5.580	11.160
	60	4.340	8.680
	70	2.969	5.938
	80	0.0	0.0

When incident angle is 20° dispersion is :

		1152 lines/mm grating	576 lines/mm grating
φ =	40	6.650	13.300
	50	5.580	11.160
	60	4.340	8.680
	70	2.969	5.938
	80	1.507	3.015

In the following diagram are marked : the two angles, the two slit pole lengths, the plate length and the angle which was selected between the common normal to the grating and the center line of the apparatus.

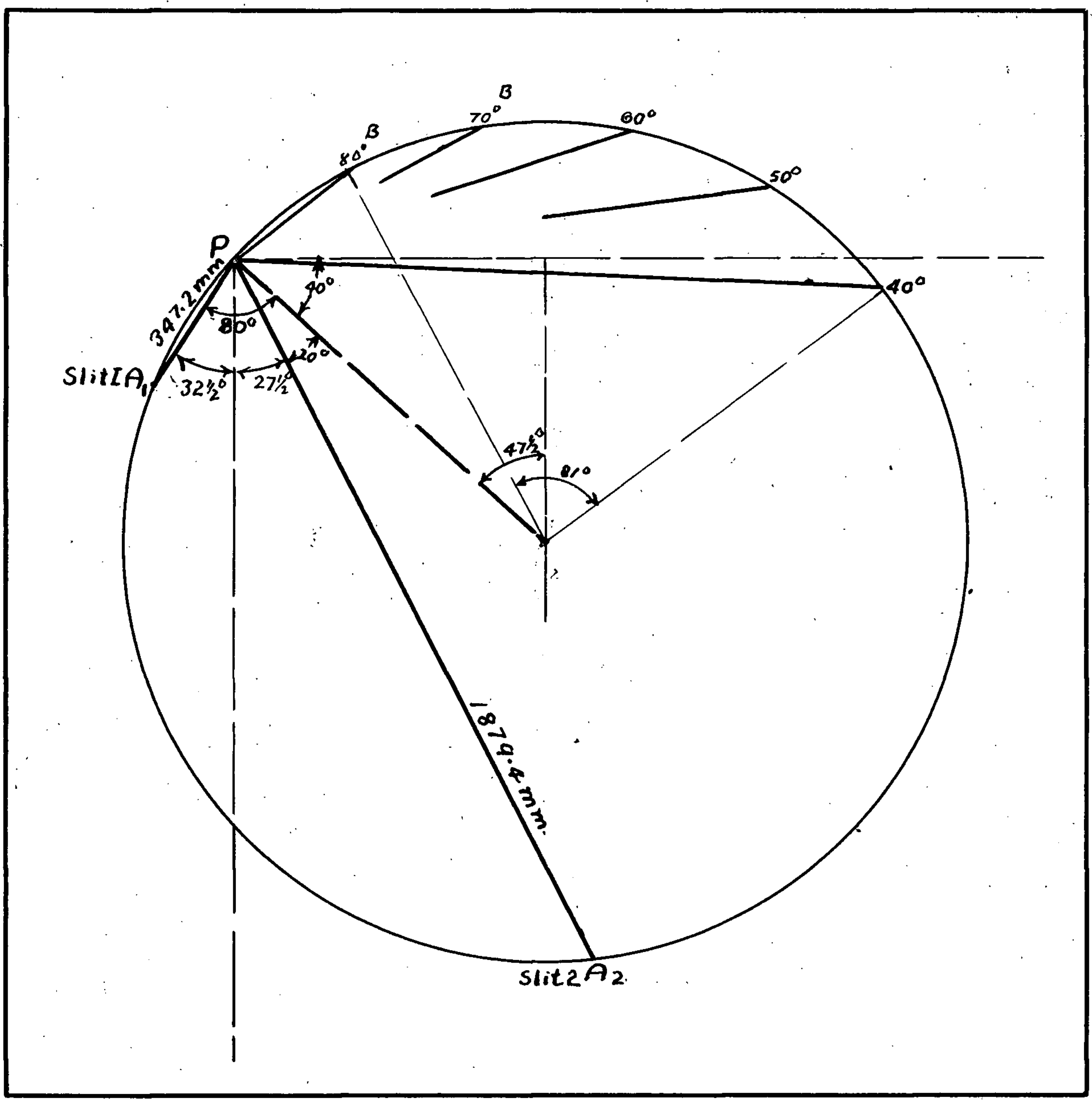
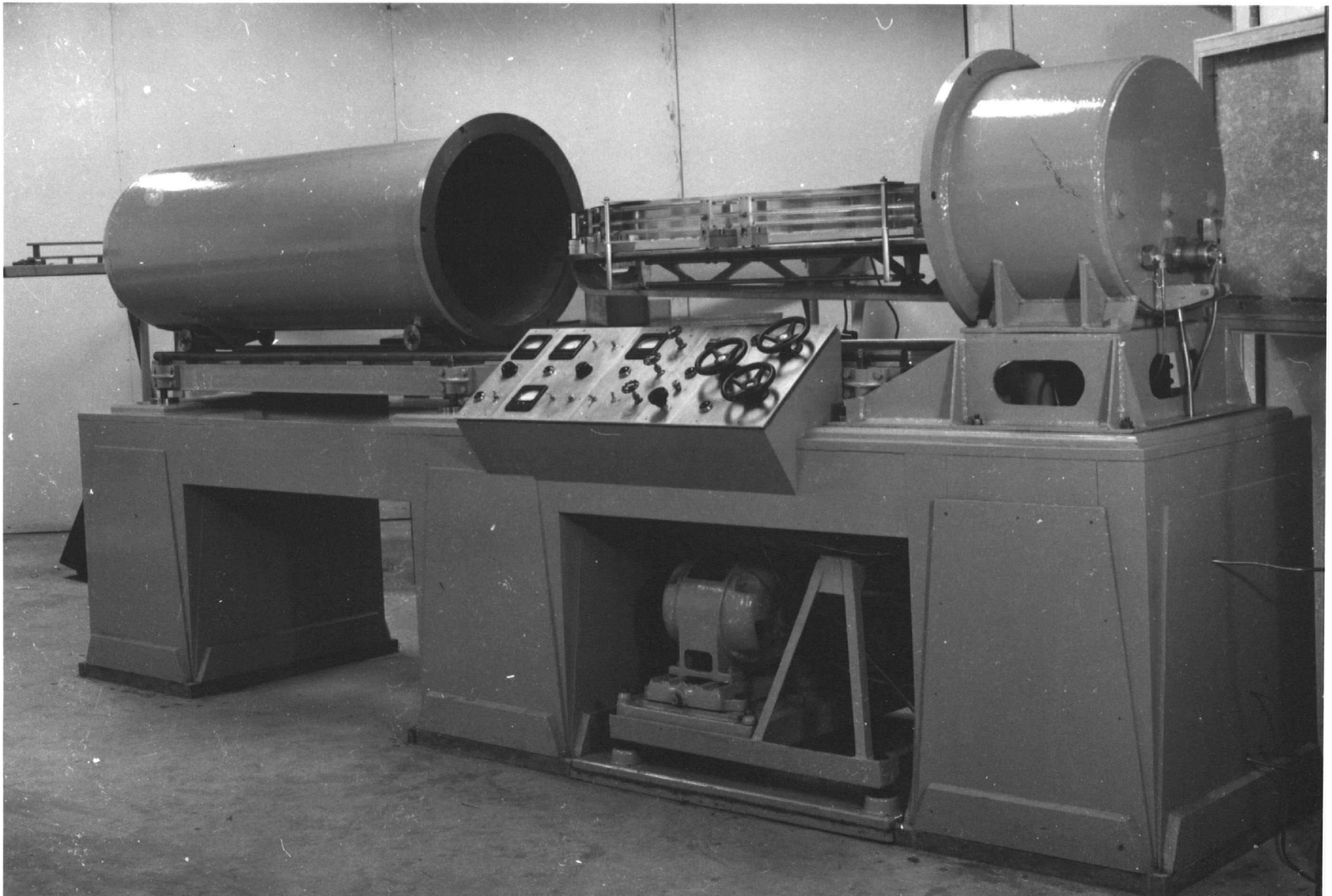


Figure 2 (a)

P L A T E   I

The Vacuum Spectrograph showing opening for loading plate and setting up apparatus in general



CHAPTER III

DESIGN OF THE SPECTROGRAPH HOUSING

To illustrate the main points to be considered in designing the housing for the vacuum spectrograph, the following diagram is a schematic illustration showing the three principal parts : the slit, the grating and the plate.

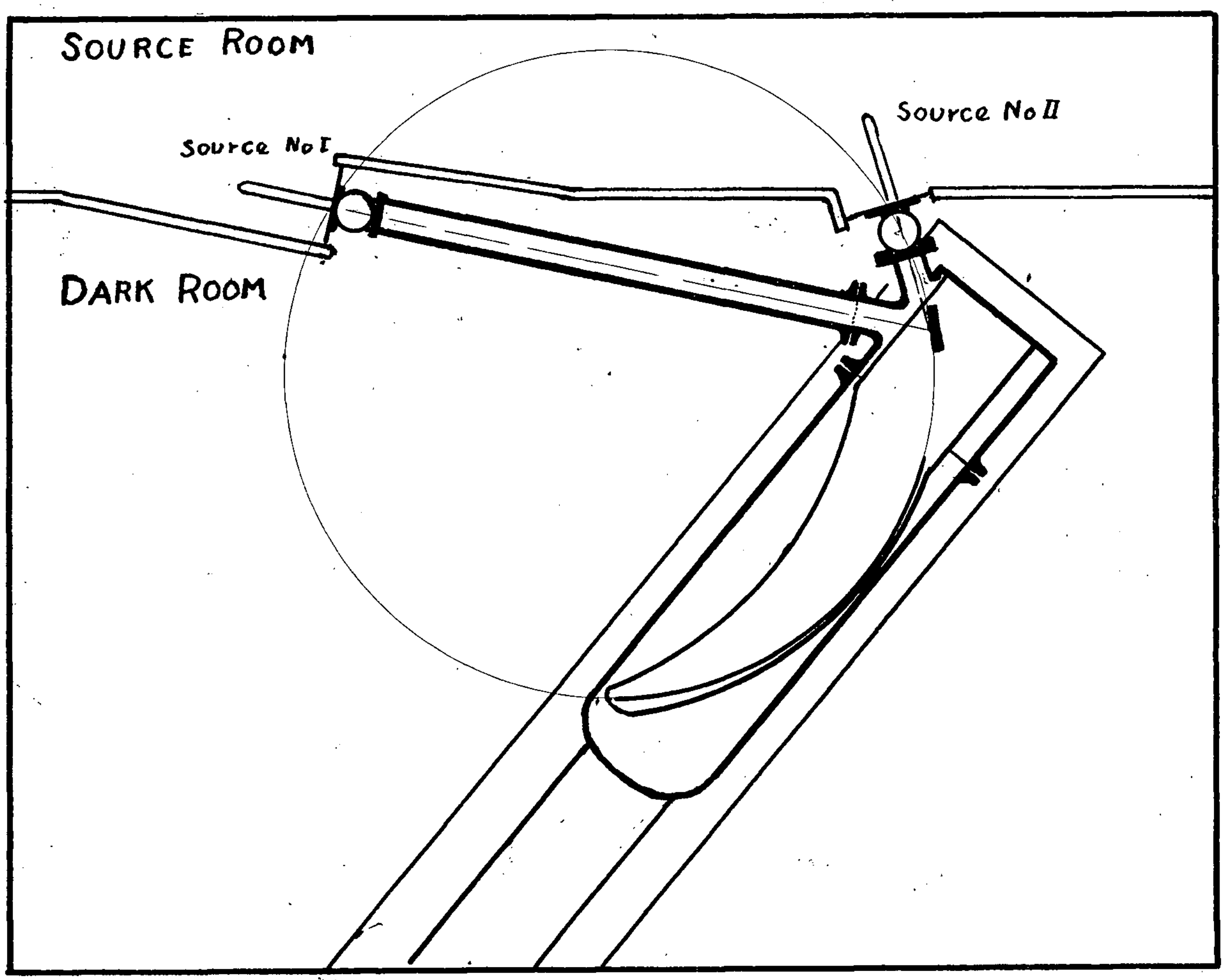


Figure 3 (a) : Spectrograph plan

Since it is desirable to get as much as possible of the perimeter of the Rowland circle on the photographic plates that are to be placed inside the vacuum, the plane of the Rowland circle is therefore placed in the center of the tubular housing. A tubular housing is used to avoid reinforcing which would be necessary to withstand the outside pressure if a flat chamber were used. It is readily seen from the diagram that this factor determines the volume and hence the size of the pumping equipment that is necessary to maintain a vacuum.

The second major problem is to provide access to the vacuum chamber to set up the spectrographic apparatus without impairing the rigidity of the spectrograph mounting.

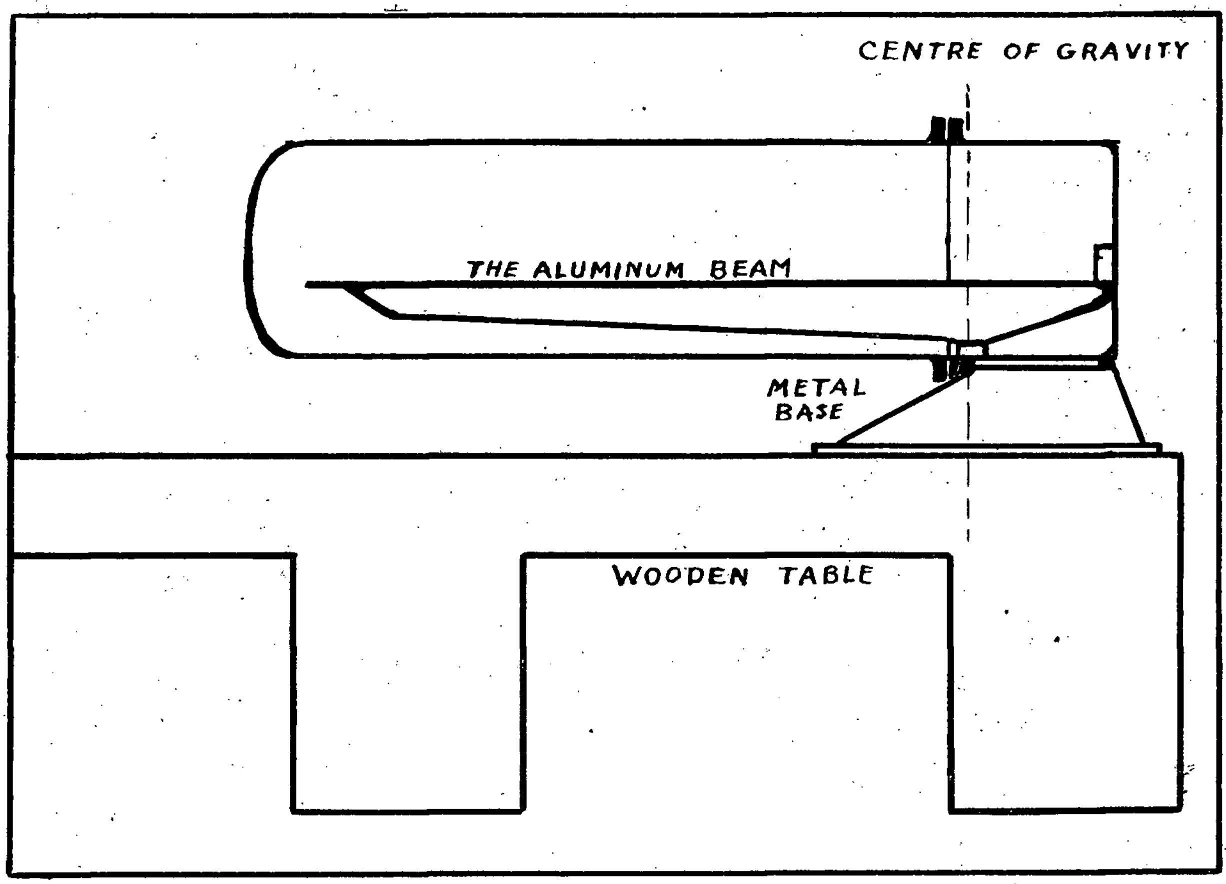


Figure 3 (b) : Spectrograph elevation

Cutting the tank horizontally would provide an excellent mounting base for the spectrograph but the sealing flanges would have to be faced on a milling machine and such an oval seal is very difficult to do. Splitting the tank in any other direction, except in the circular cross section, involves difficult and costly machining of the sealing flanges. Manholes are undesirable, as it is very difficult to set up apparatus through these unless the manholes are large enough, in which case only more seals are introduced. Conceding that the above is the more logical choice, one finds that the two requirements mentioned at first are of a conflicting nature. That is, to get as much of the plate holder outside as possible does not allow enough cross sectional area of the base for a very rigid mount. Likewise, the inverse - or using a very large base - does not permit the plate holder to be sufficiently out in the open.

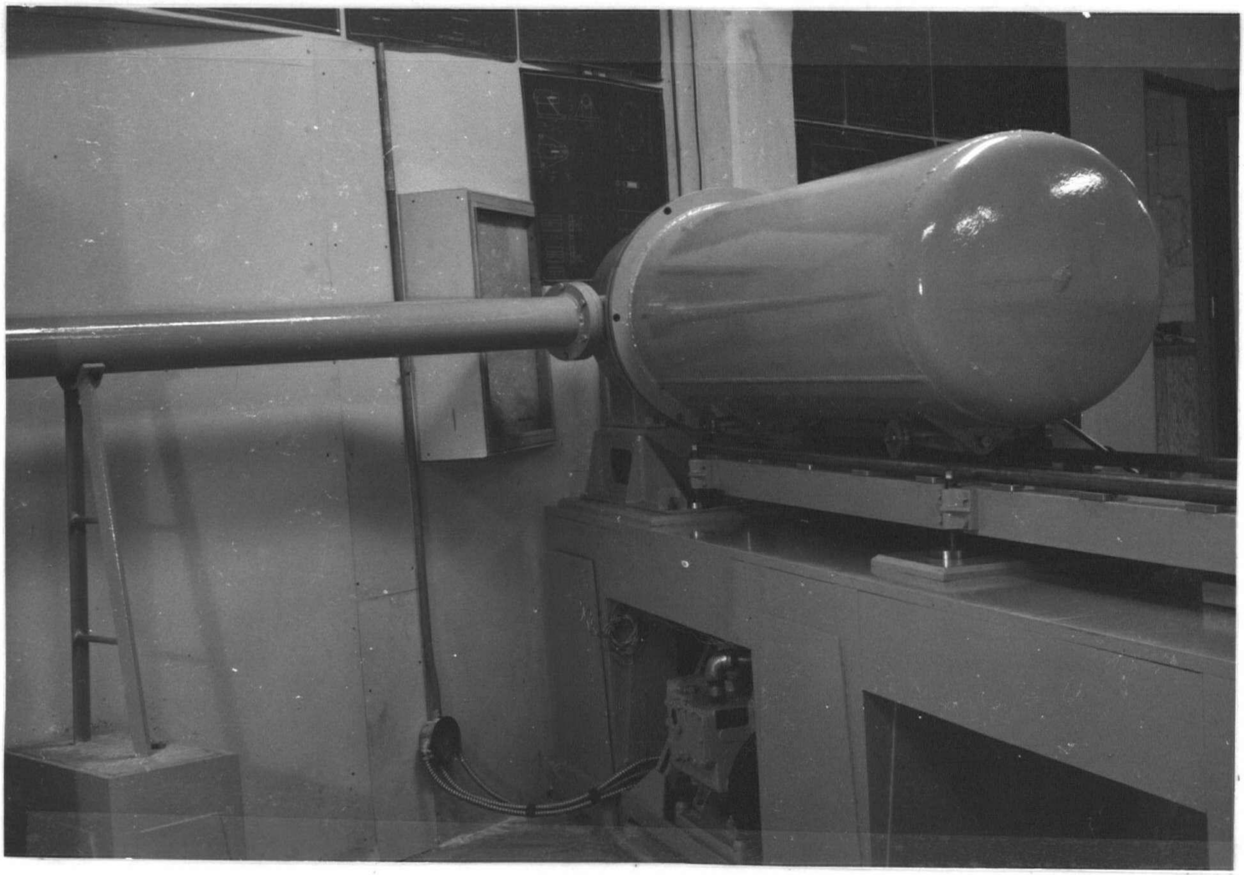


Figure 3 (c) : Slit Connection

In deciding where the cut should be made the first consideration is to avoid interference with the two side tubes which support the slits and the sources: these should obviously be rigid with the main part of the system. The ring is therefore cut just in front of these, so the size of base was calculated by finding where the center of gravity is for the beam and for the head and then by letting this be the central position of the metal base. In this way, the load on the wooden table is then only in a downward direction and hence eliminates any side stress in the wooden table below.

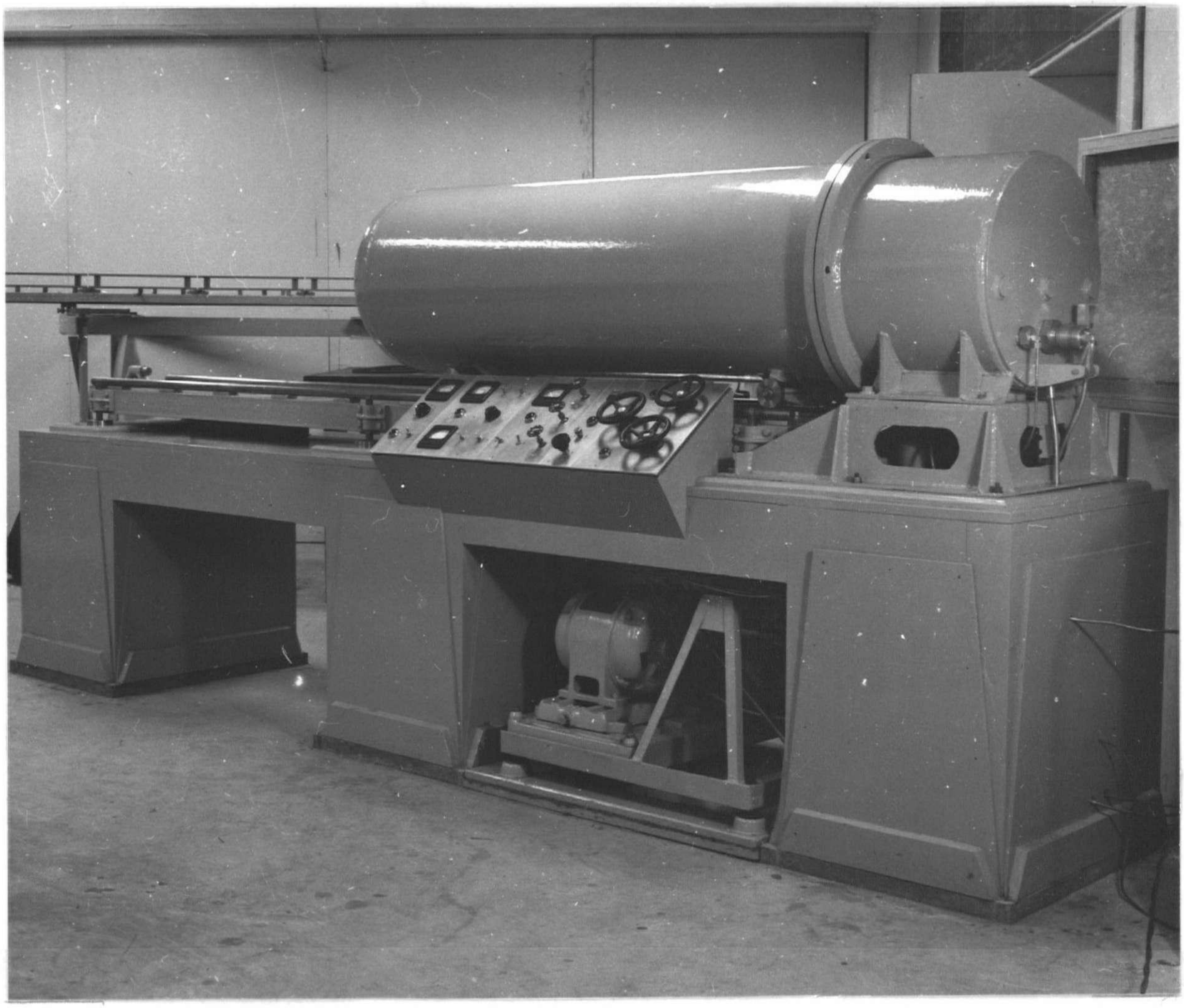


Figure 3 (d) : Operating position of the Spectrograph

The wooden table is so designed that the points of load rest on the solid frame and not on the panel work of the surface. All joints are by mortise and tenon and each set of four legs is laced together with panels making three pedestals. These are then set in concrete so that all the legs will be firm and evenly loaded.

The steel base had to be broken just below the tank, solely for the purpose of machining the flanges, as otherwise it would be impossible to turn this piece on a lathe with the base extending in the forward direction.

Figure 3 (e) : The main internal member

The main internal member is an aluminum casting mounted on a single point of support at the edge of the head as a cantilever, and held down at the back of the head by two levelling screws which facilitate levelling the beam. Since both the plate holder and the grating are mounted on this beam it is therefore rigidly fixed to the spectrograph head by three Allen head cap bolts at the back and two such bolts at the base. These bolts do not hold the load but act as lock bolts to prevent shifting of the beam. At both these points of contact lead pads are used to form a proper fit and to act as damper for vibrations.

The removable part of the shell is moved back by an adjustable track system. In order to be able to line up the movable tank with the fixed

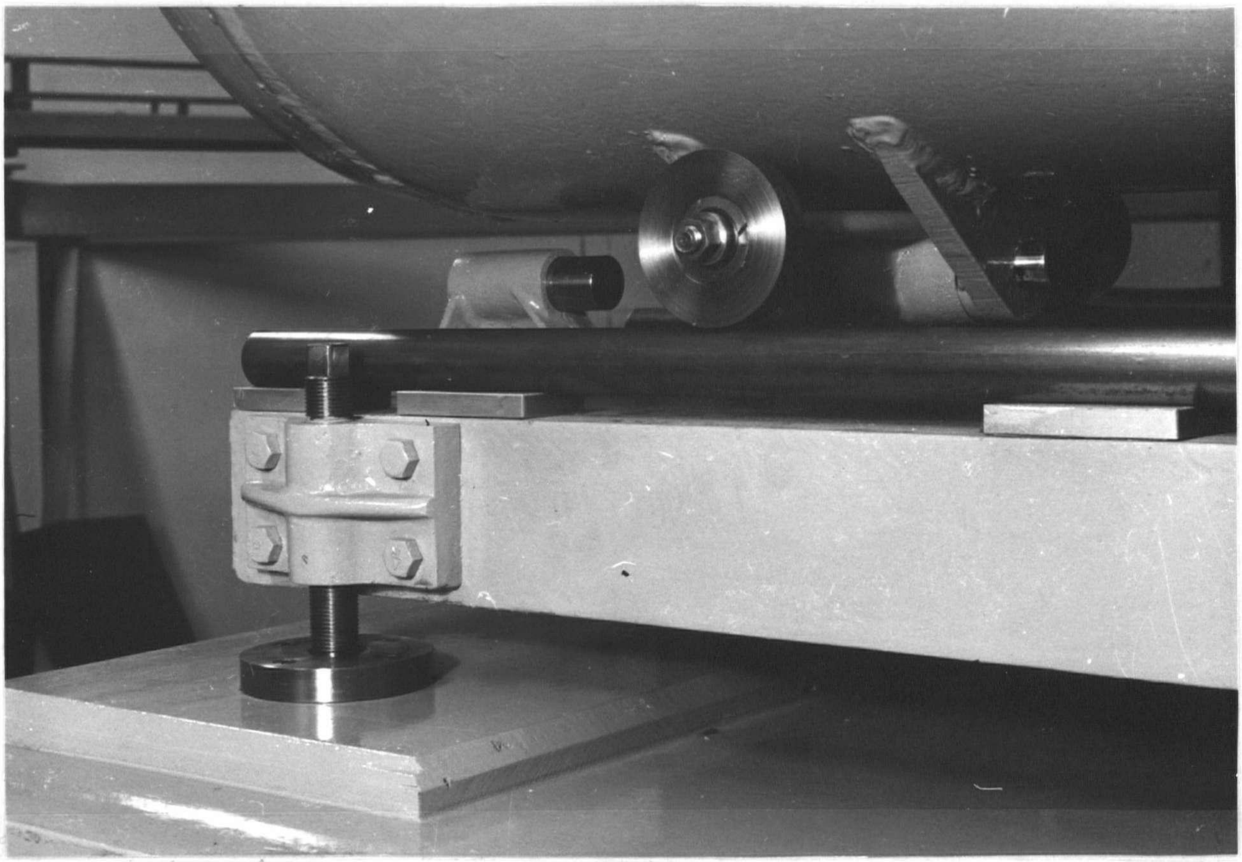


Figure 3 (f) : Levelling gear and recoil mechanism

head, two degrees of freedom at right angles to the direction of travel are necessary. The vertical movement is accomplished by raising and lowering the track by means of six levelling screws. The horizontal movement of the tank is obtained by mounting it on the two axles by a single bearing or pinion at the mid point of each axle, both these being in line with each other and the line passing through them being at right angles to the face of the sealing flanges. This permits the tank to rock in an arc of a circle, but since the movement necessary is very small the tangential motion is sufficiently horizontal. The position of the tank is then rigidly fixed by means of two set screws in the front axle which are on each side of the afore-mentioned bearing. The rear axle, having no such set screws, is free to swivel about the mounting bearing and allows the tank to ride as if on a three point suspension.

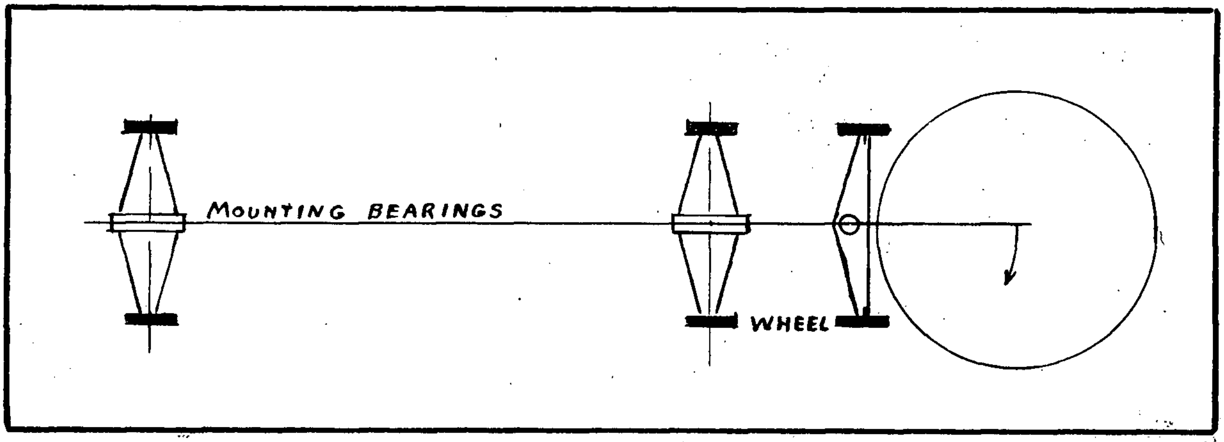
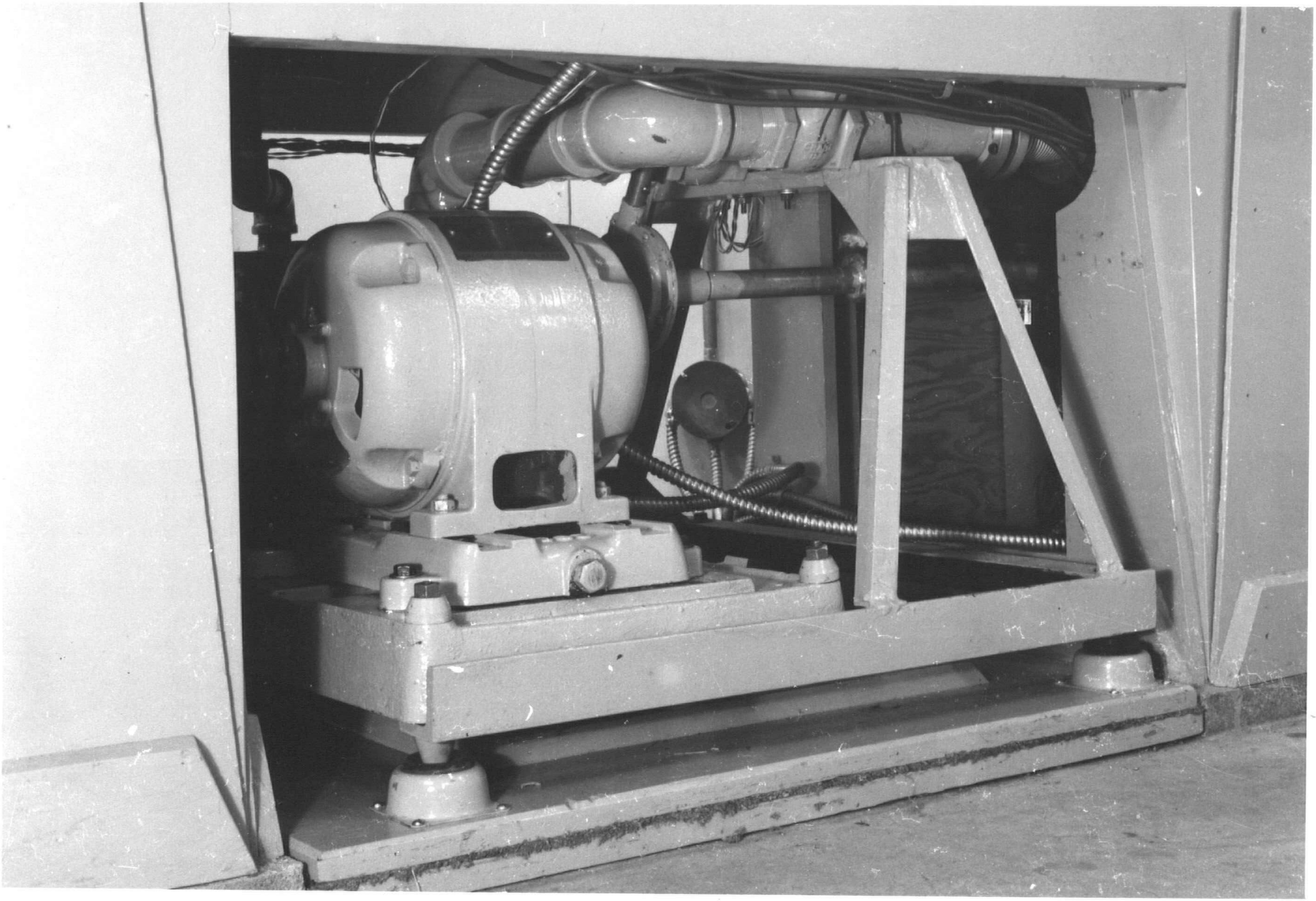


Figure 3 (g) : Under carriage plan

P L A T E I I

The Vacuum Pump showing sylphon connections
and anti-vibration mountings



CHAPTER IV

THE VACUUM SYSTEM

A very high pumping speed is desirable for this type of apparatus where the vacuum system has to be opened rather frequently to adjust and load new plates. Besides using fairly large pumps, a by-pass system, using two modified steam valves and a trap valve, has been incorporated to eliminate the need of shutting off the pumping system when a vacuum seal has to be broken.

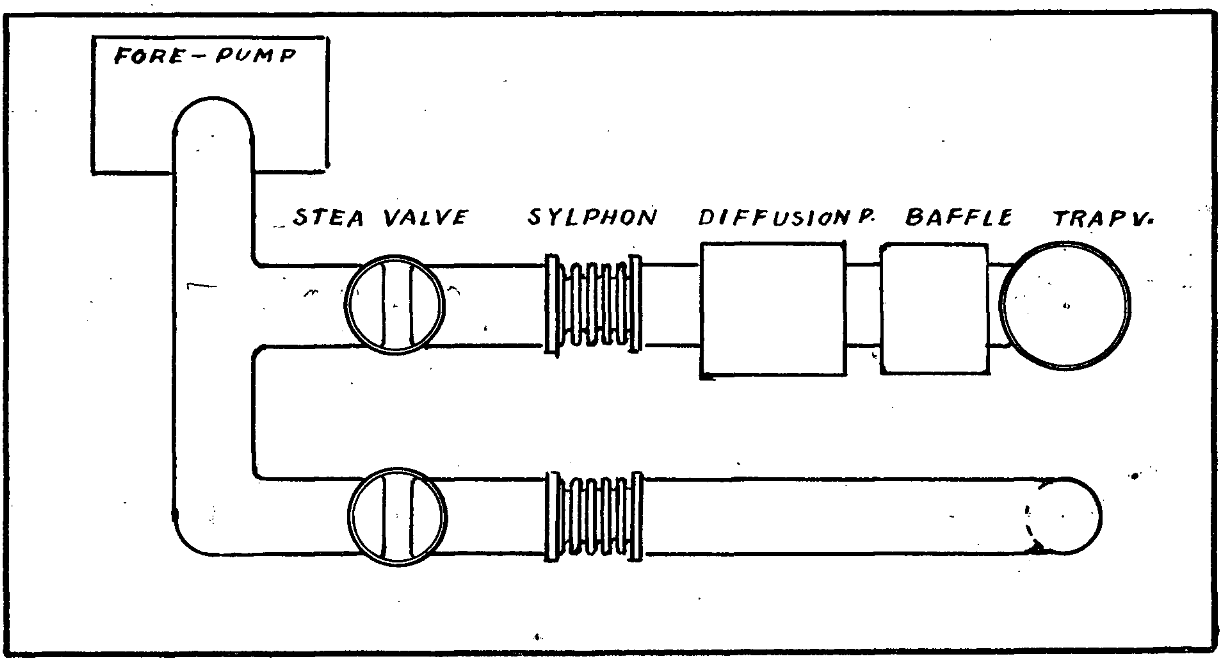


Figure 4 (a) : Pumping system diagram

The schematic diagram on the previous page shows the elements of the of the two channels. The direct fore-pump connection or the by-pass has first a flexible sylphon link so that the vibratory motion of the fore-pump is not transmitted to the spectrograph and, second, a modified 260 crane steam valve. The other path starts off with a trap valve: the reason for such a valve will be explained later. Next there is a water baffle to condense oil vapor that might tend to enter the spectrograph chamber. Directly below this is the 250 Cenco diffusion pump; the path then goes through a similar flexible connection and valve as the by-pass to the fore-pump.

With the above system, it is not only possible to leave the pumping system operating when the tank is open but also possible to cut in either the fore-pump or the diffusion pump at will. It should be understood that when the fore-pump alone is hooked up, the valve between the fore-pump and the diffusion pump is shut off as there would be back pressure on the diffusion pump. Also it should be understood that when the diffusion pump is hooked in, this valve is opened before the trap valve, otherwise back pressure in the diffusion pump would build up very fast. This eliminates the time needed for cooling off and heating up again when shutting down and starting up. If all the air had to pass through the diffusion pump this would be necessary.

Thus, after reloading the plates, it is easily pumped down by means of the by-pass to where the diffusion pump can take over.

The trap valve was designed to stay closed or close itself, due to its weight, if conditions require it, even though it has to be opened manually: a worm gear is used so that any desired opening may be set.

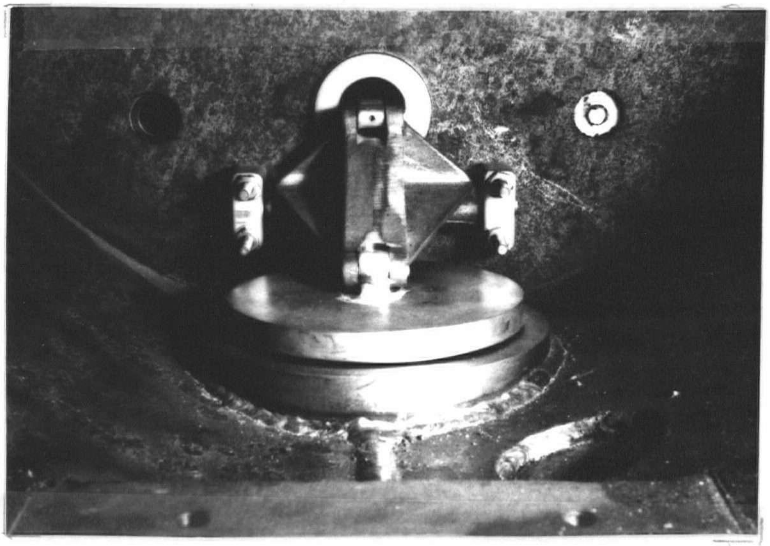


Figure 4 (b) : The trap valve

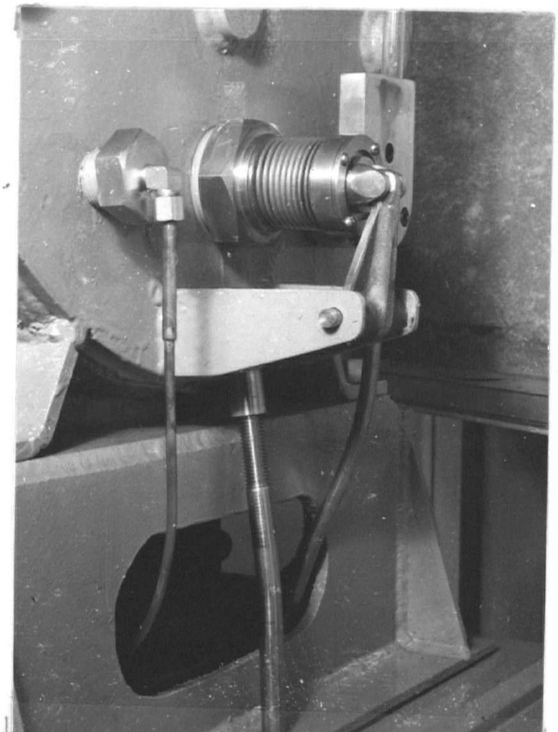


Figure 4 (c) : The trap valve activator

Since the engaging pin which locks together the rotating stem and the external bell-crank is held in position by a D C powered solenoid, the D C contact points are held together by an A C powered relay. This relay does not close until the pressure inside the vacuum chamber is low enough for the diffusion pump to take over: this does not allow the whole volume of air to pass through the diffusion pump which would break down some of the oil. The A C relay that feeds power to the heating coil of the diffusion pump being a double poll also feeds power to the previously mentioned relay; but this relay does not close, even though the diffusion pump switch is thrown, until the baffle water is turned on. This interlocks the pump and the valve with the water supply and acts as a safety

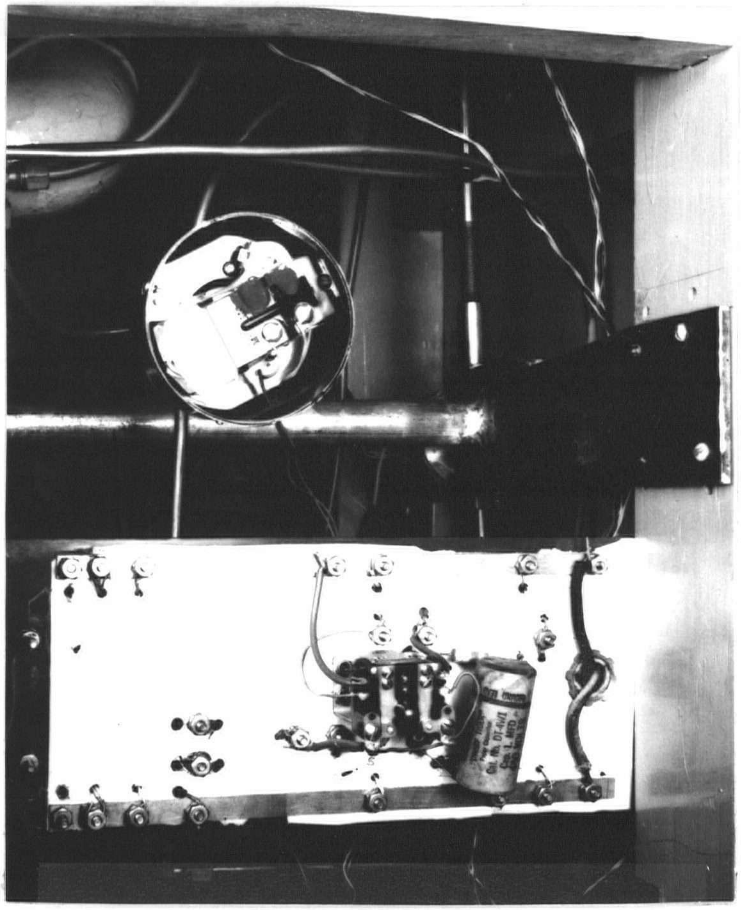


Figure 4 (d) : The interlock system

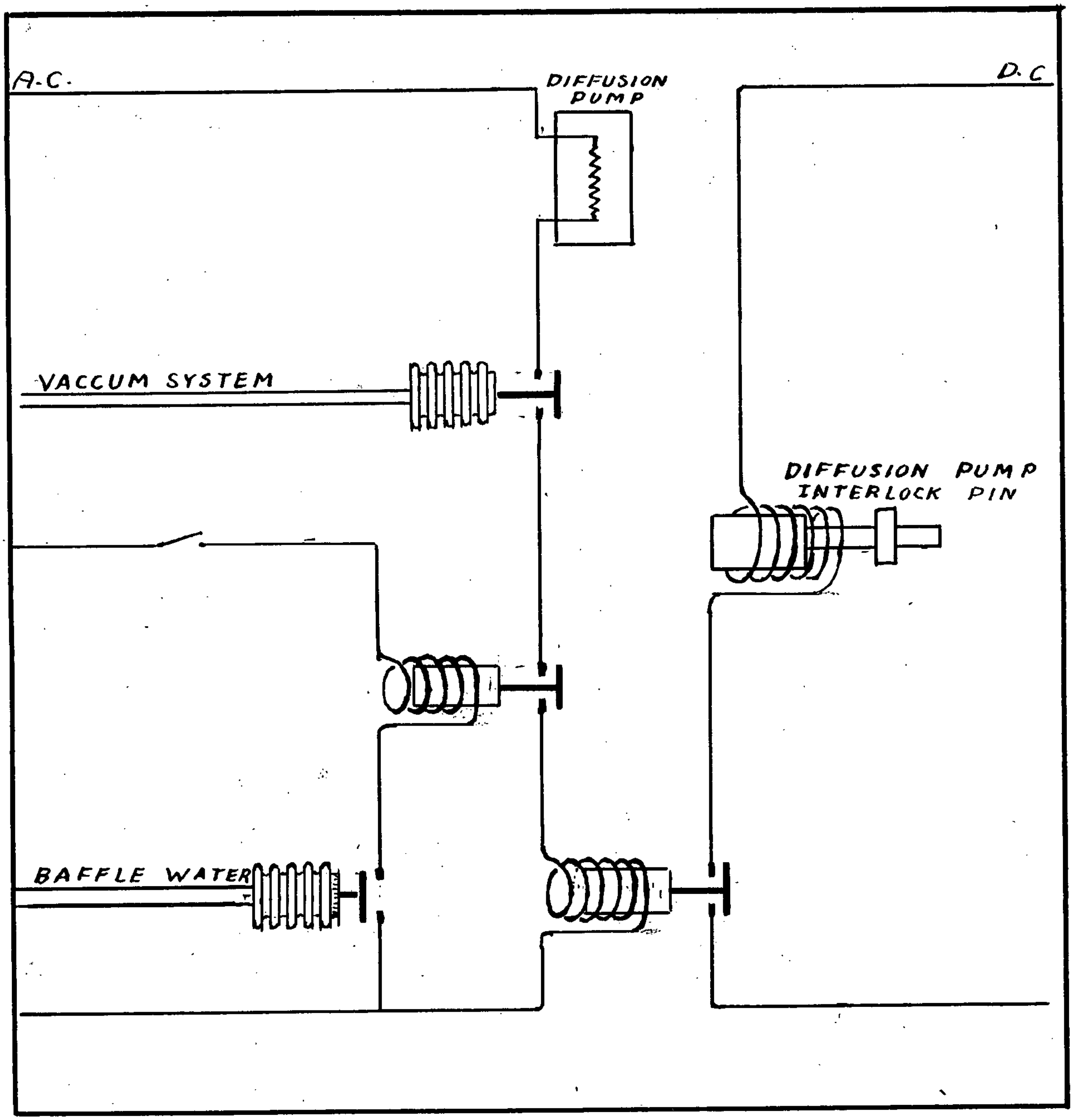


Figure 4 (e) : Wiring diagram of interlock system measure, shutting off the spectrograph from the pumping system, which stops oil vapours from entering if the water pressure fails and stops the rush of air through the diffusion pump should a large leak develop.

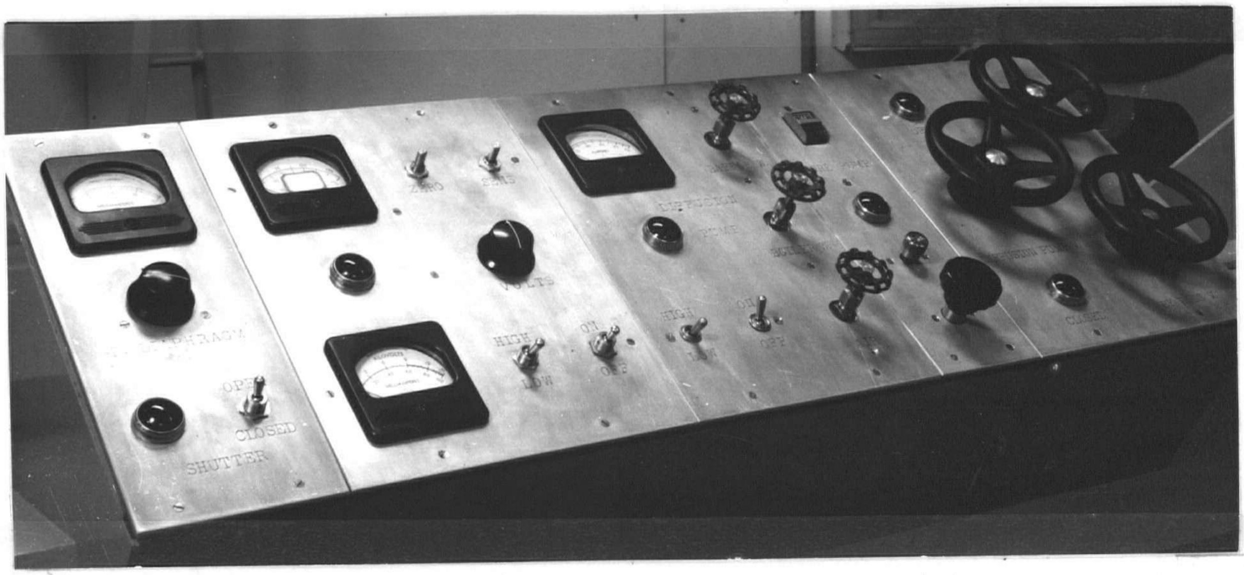


Figure 4 (f) : Control panel

Section one of the above panel contains the three valves: fore-pump valve, by-pass valve and the diffusion pump valve. The diffusion pump valve has green and red light indicators for open and shut positions, while the other two have rising stems which indicate their positions. The second section has the fore-pump switch, a pressure indicator which turns on the green pilot light on the panel and makes the circuit for the diffusion pump valve. Below this is the inlet to the tank itself. The third section is the diffusion pump control. The top valve is the baffle water, the second is for cooling the boiler in cases where the pump has to be turned off quickly, the last tap is for blowing out the water from the boiler cooling coil which has to be free from water before starting the heating coil. The ammeter measures the current through the filament. The red pilot light is the indication whether the heating coil is on the high or low range as set by the lower left switch, or if the heater coil has been turned on without turning on the baffle water. In the latter case, not only is the pilot light red but, also, the heater does not go on till the water has been turned on. If the baffle water is not turned on, neither will the diffusion pump valve open. The fourth section is the pressure gauge. The two top knobs are the zero setting and the sensitivity; the center is the voltage control; while the bottom two are the off and on switch and the high and low switch. The top meter is the supply voltage while the bottom meter is the pressure gauge. The following are a circuit diagram and calibration charts for the high and low ranges.

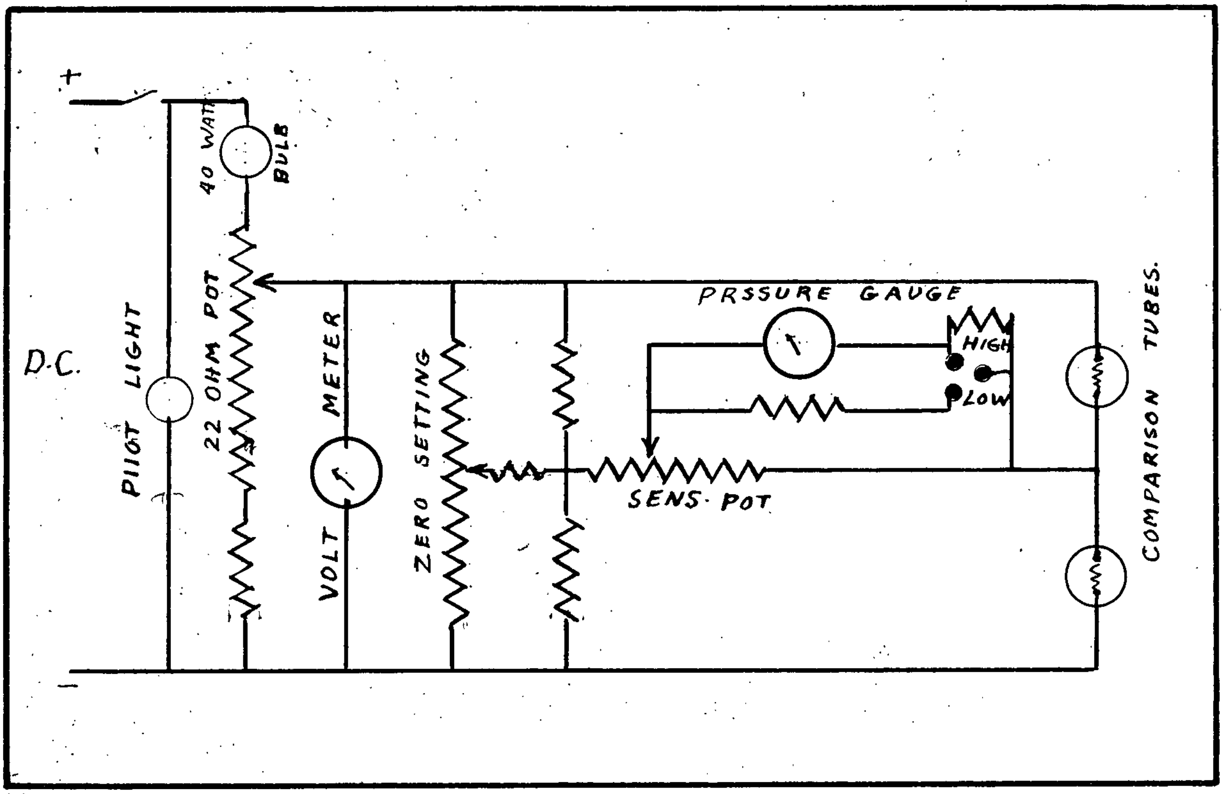


Figure 4 (g) : Pressure gauge circuit diagram

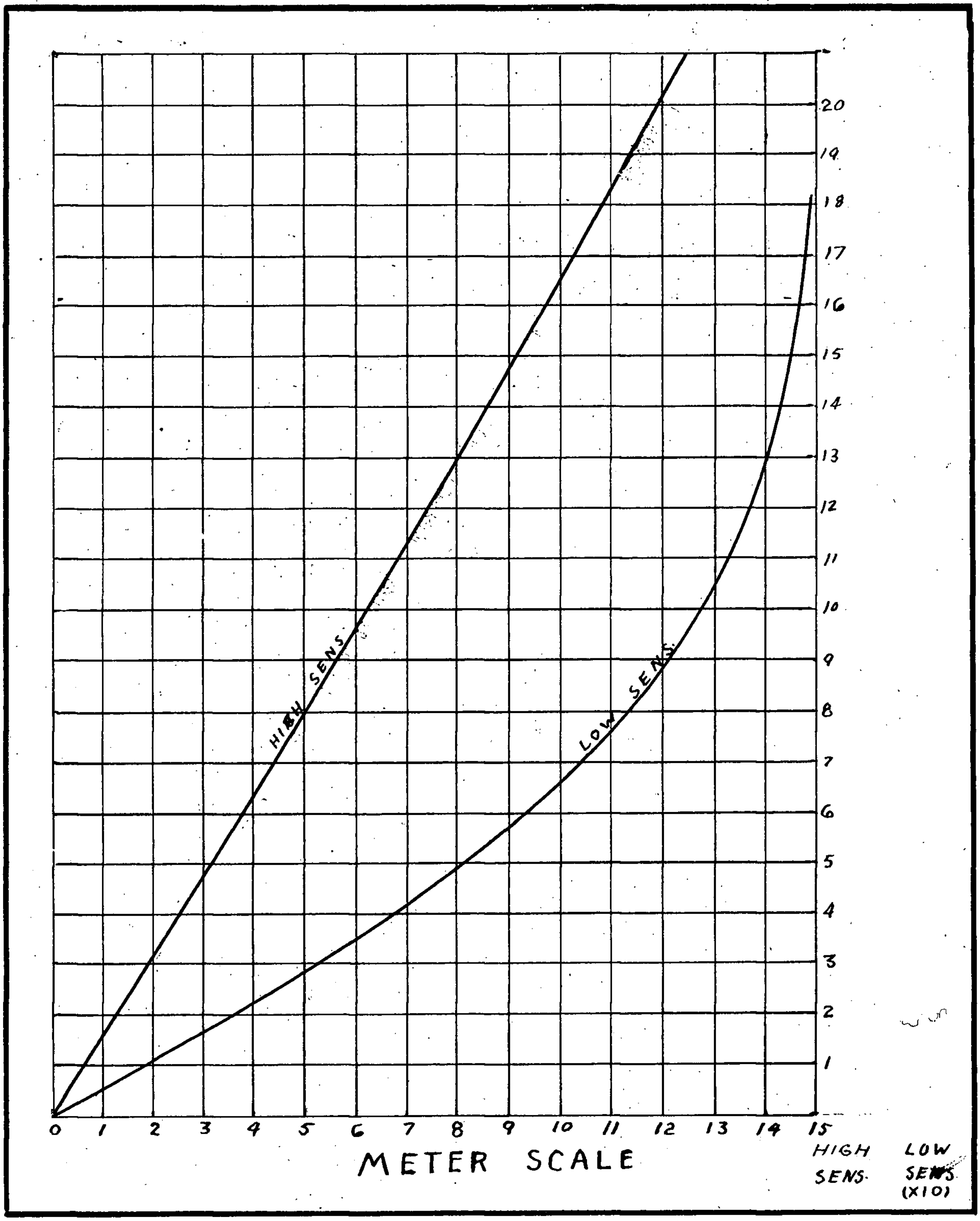


Figure 4 (h) : Pressure gauge calibration

The fifth and last section is for adjusting the plate diaphragm which will be discussed later.

The fore-pump mounting had to be slightly different from that used in other cases, due to the fact that the openings are in a horizontal direction. There is a net torque of about 95 foot-pounds tending to tip the pump over. This is overcome by setting the pump back a sufficient distance from the front shock absorbers, in this way producing a counter acting torque. This is analytically shown in the diagram below.

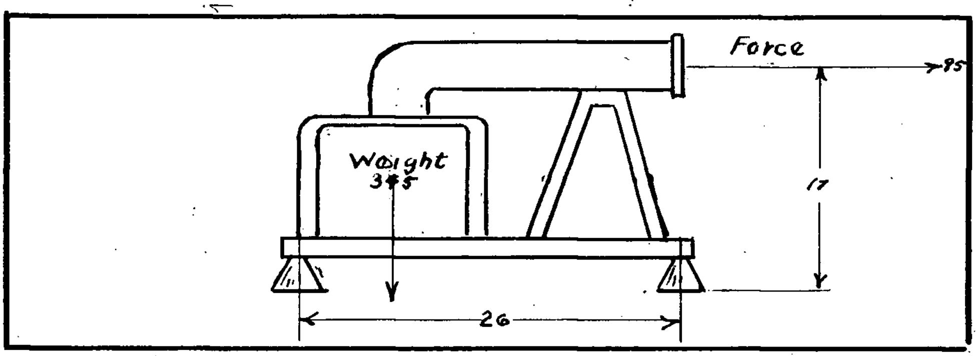


Figure 4 (i) : Fore-pump mounting

To absorb as much of the vibration as possible a double shock system was used. The major vibration is absorbed in the rubber suspension, but its natural frequency which is transmitted is absorbed by a layer of kem-pack. To prevent the pump being dragged across the floor, a socket fit is employed as illustrated below.

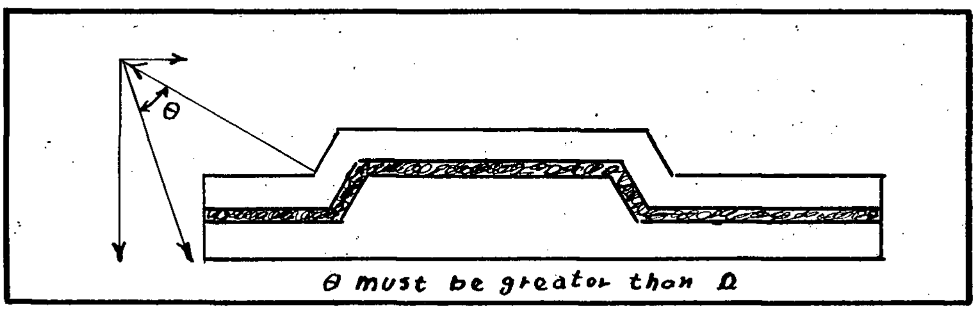


Figure 4 (j) : Shock absorbing system

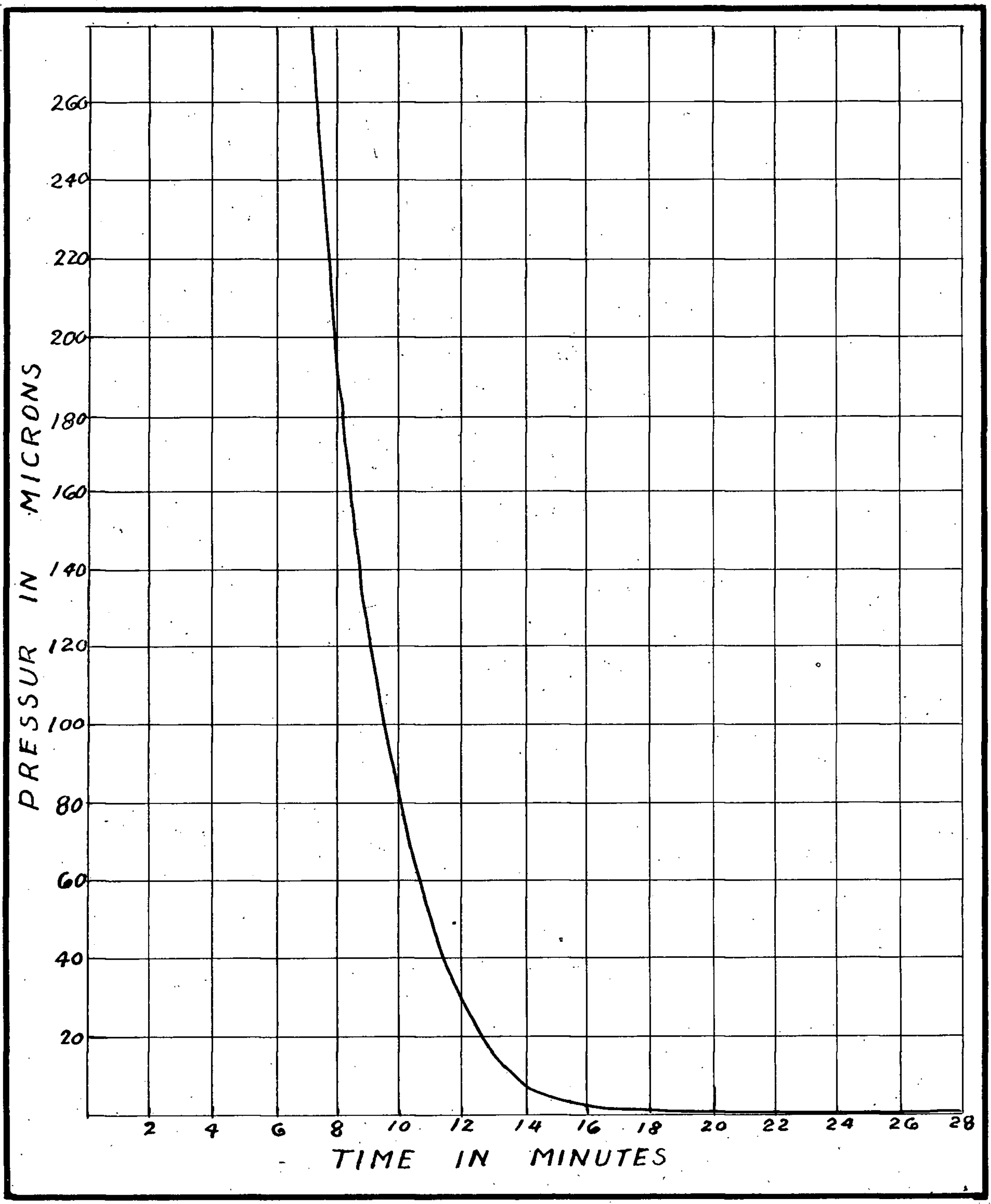
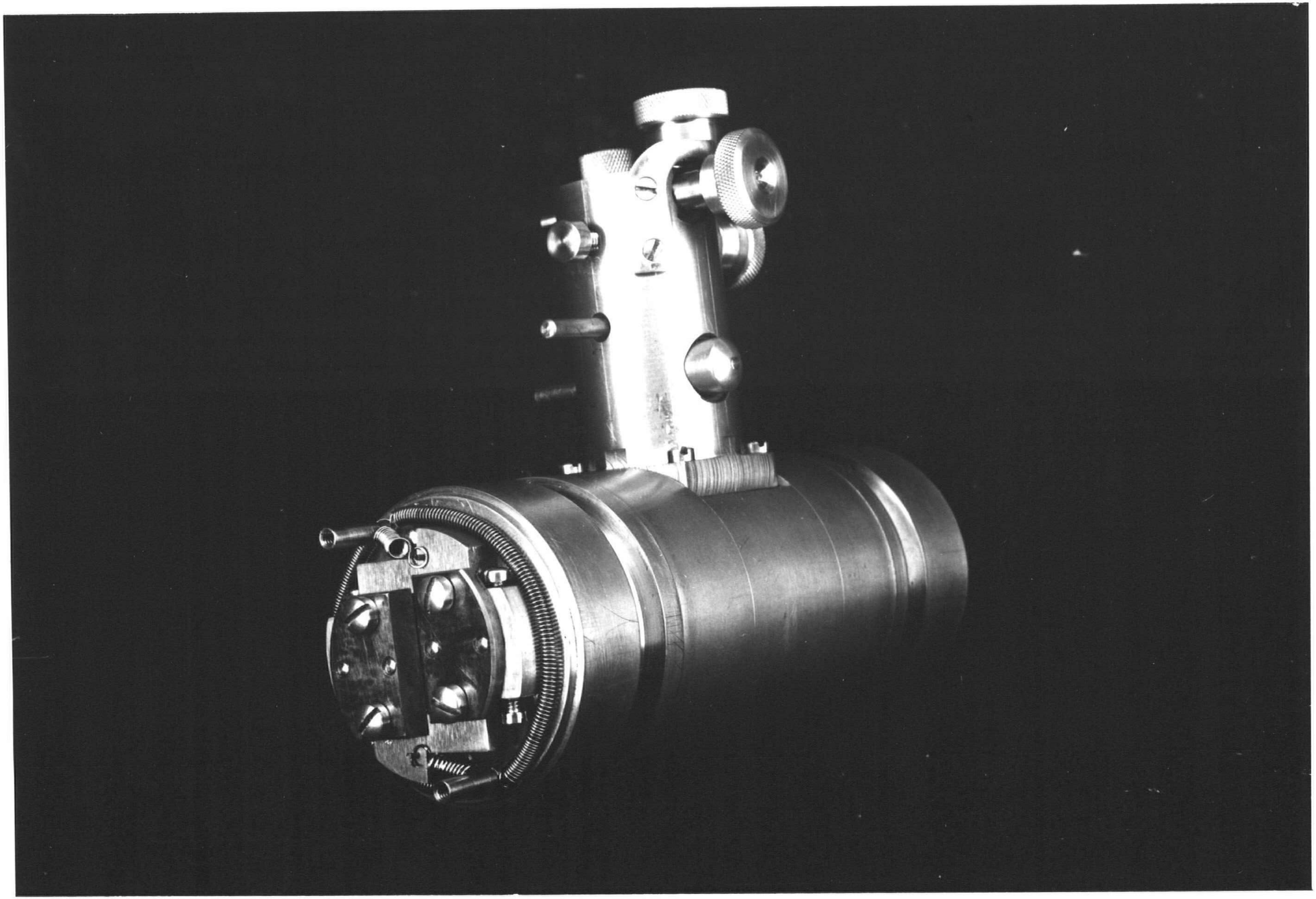


Figure 4 (k) : Rate of pumping

P L A T E   I I I

The Spectrograph Slit
removed from its housing



C H A P T E R V

DETAIL DESCRIPTION OF SOME OF THE PRINCIPAL PARTS

Some of the spectrograph parts had to be specifically designed because they could not be obtained; in other cases different requirements were necessary, and in some cases it was felt that better results could be obtained if differently built equipment were used.

THE SPECTROGRAPH SLIT.

There are two distinct problems in developing a slit for this type of spectrograph. The most important point is the age-old difficulty of keeping the two sides of the slit parallel at all times when setting the width of the slit. Solution of this difficulty was attempted by trying to

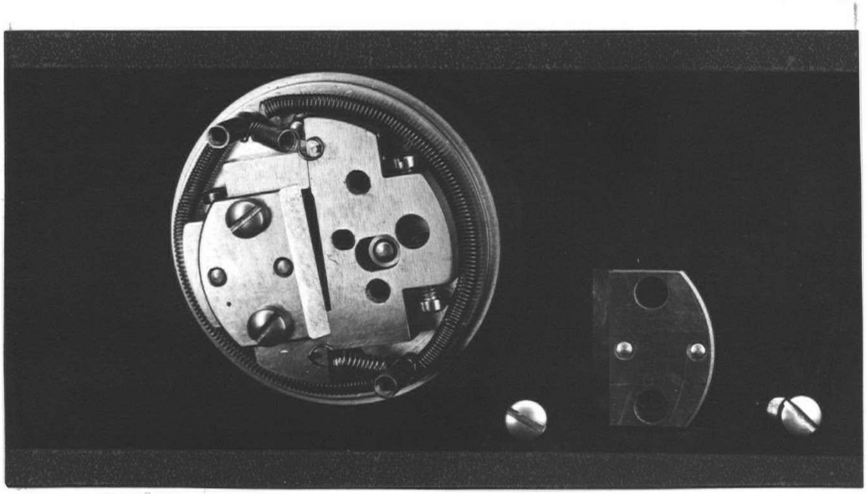


Figure 5 (a) : The Slit Mechanism

design a slit, the accuracy of which would be independent of the accuracy of machining. The type of mechanism that will probably give absolute accuracy and still be relatively easy to produce is shown in detail in the photograph on the previous page, and is explained by the schematic diagram below.

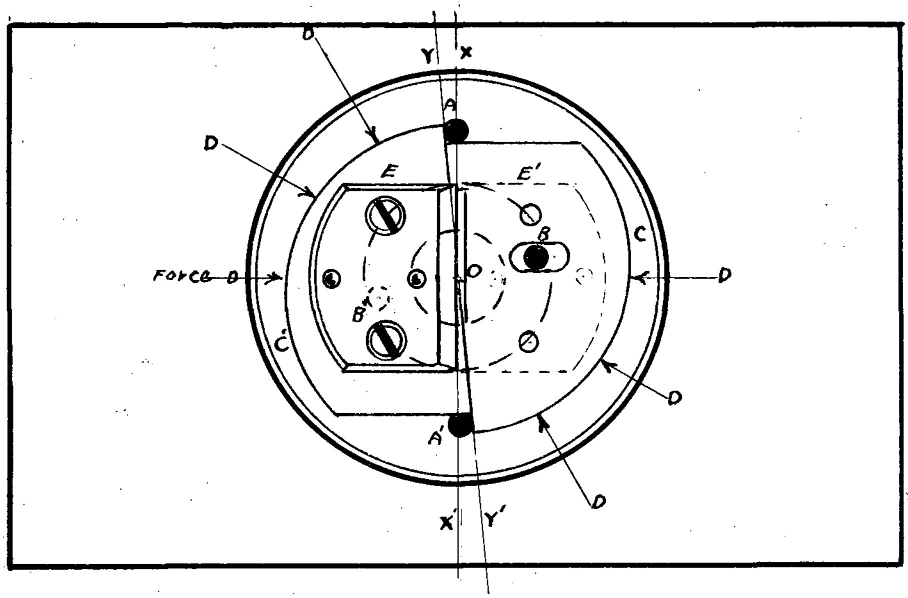


Figure 5 (b) : Schematic diagram of slit mechanism

Pivots A and A' are fixed to the outer frame, while pivots B and B' are fixed to the inner cam which is free to rotate with respect to the outer frame. The two semicircles C and C' are held together by means of a garter spring D which exerts a force in the direction as indicated by arrows: on these two semicircles are mounted the shutters E and E'. The knife edge X and X' is adjusted to be perpendicular to the plane of the Rowland circle and is at a very small angle to the line Y and Y' which just passes the two pivots A and A'. Now, as the inner cam with pivots B and B' rotates with respect to A and A', the semicircles C and C' move parallel to the line Y and Y', while the slit opens as the sine of the angle XOY. One can easily see that the accuracy is independent of the accuracy of the bearing on which the inner cam rotates and on the position of any of the pivots, but depends only on the accuracy of the one surface between the two semicircles, since this is a plane surface it is the easiest operation that can be performed; moreover, the fact is these surfaces increase in accuracy with use.

The second major problem is to be able to set the slit exactly on the Rowland circle. One readily sees the advantage of having all controls independent of each other - the varying of one should not in any way alter the setting of any other. In plate III is shown the main bearing by which the adjustments making the slit perpendicular to and on the perimeter of the Rowland circle are made.

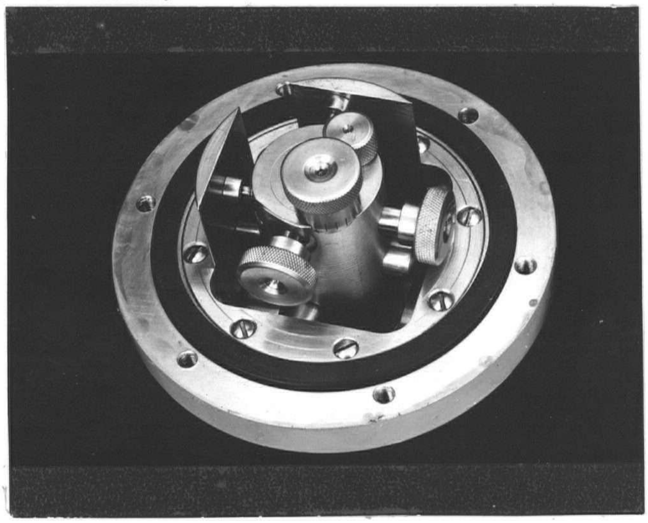


Figure 5 (c) : Slit Controls

This main bearing is moved back and forth along a chord of the circle by means of the thumb screw M and held under tension by returning spring M'. Perpendicularity is adjusted by means of thumb screw N and spring N' which rotates the slit mechanism on the same bearing as above. In this case, since each movement depends on the accuracy of the surface on which the seat of the other thumb screw rides, these adjustments can not be said to be independent of each other but, when making adjustment with both these controls at the same time (that is when both settings approach the correct position at the same time) the degree of movement in each of the two directions becomes smaller and approaches zero as the position is approached; thus the error that may enter into one setting due to the movement of the other also approaches zero. Therefore it is not necessary to have these two controls independent as once they are set there is no more need to vary them.

The adjustment of the slit width which is accomplished by means of thumb screw O and held under tension by spring O' is entirely independent of the other two adjustments. This is very necessary as the slit is adjusted very frequently.

The entire slit mechanism is built out of rolled brass in order to avoid pores. More important than this, however, is the fact that to get a smooth surface the metal must not have any sand in it that would damage the machining tool.

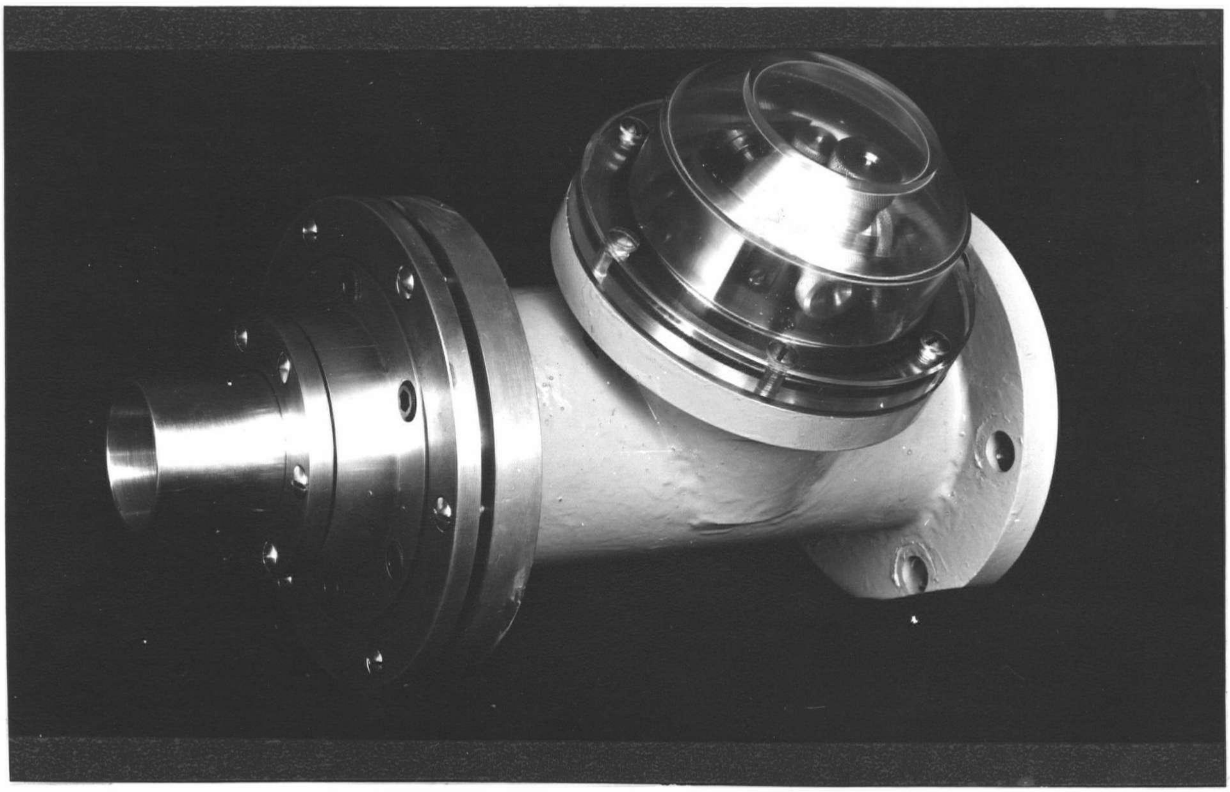


Figure 5(d) : Slit Housing

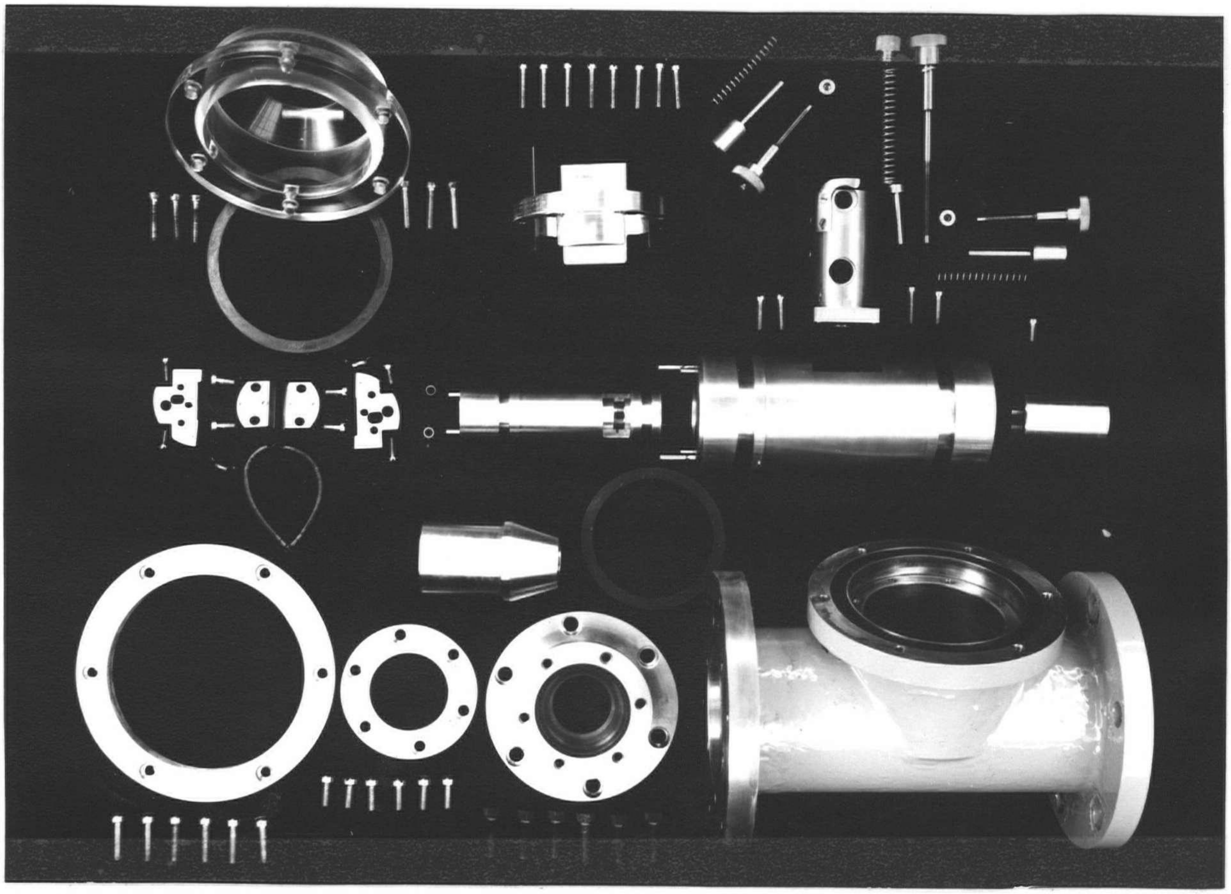


Figure 5 (e) : The component parts of the slit

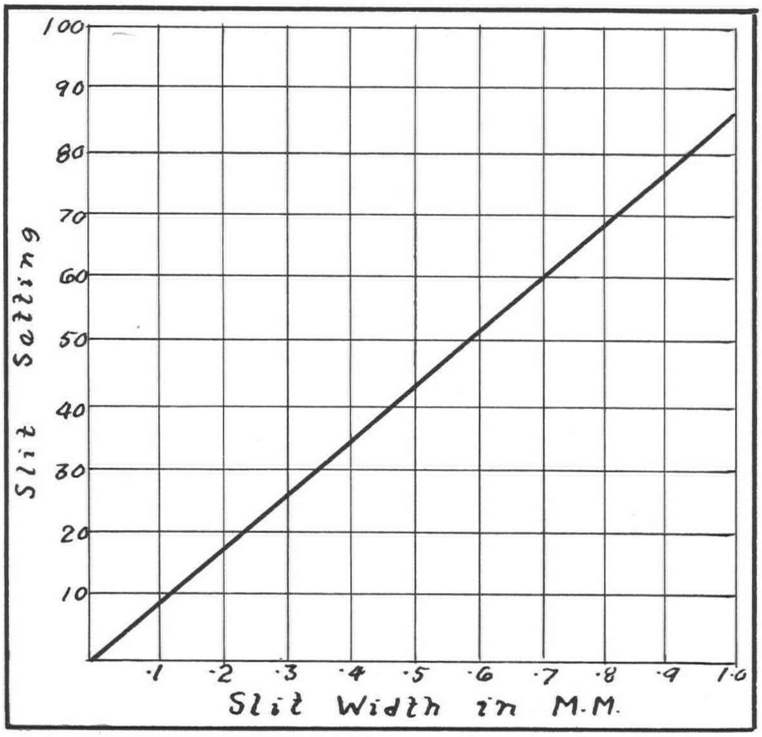
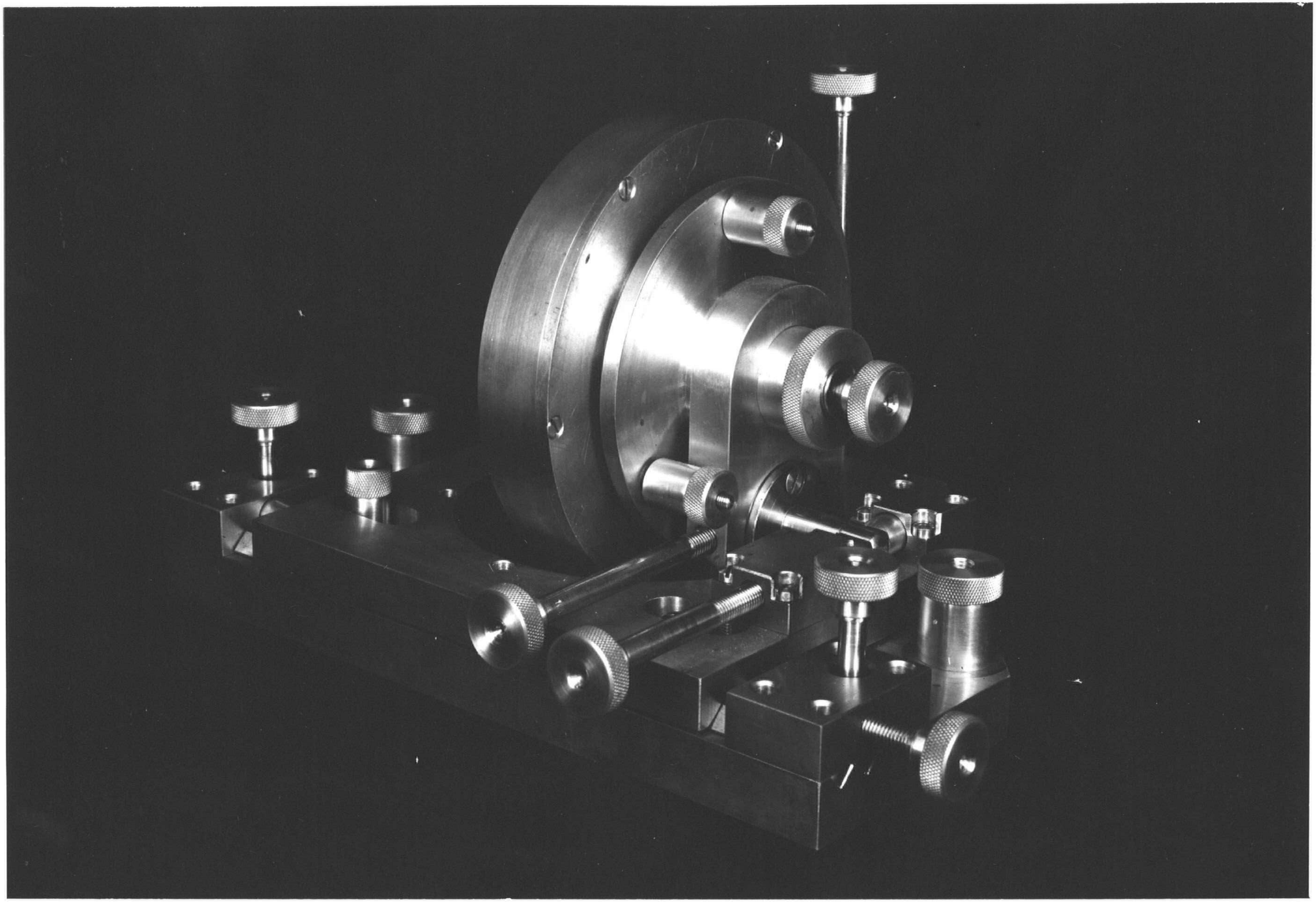


Figure 5 (f) : Slit calibration

PLATE IV

The Spectrograph Grating Holder
in operating position



THE GRATING HOLDER

The main purpose of the grating holder is to be able to line the grating so that it is at the focal point which makes the image and object distance a minimum. Four degrees of freedom are necessary - two translational and two rotational. The grating center has to be raised up to the plane of the Rowland circle and it has to be moved along a radius so that it is set on the perimeter. Rotation in the horizontal plane is necessary to face the grating to the center of the circle,while rotation in the vertical plane is necessary to bring the ruled lines perpendicular to the plane. Actually more adjustments are necessary than just those to accomplish the above movements. In the cases of rotation the central point of the grating has to be brought to the axis of rotation.

Just as in the case of the slit there is the advantage of having independent control. In the following discussion reference will be made to plate IV showing the grating holder as in operating condition and the following figure where the component parts are shown dismantled.

The three thumb screws A raise the main base in such a way that the central point of the grating is in the plane of the Rowland circle. Moreover, since it is a three point mounting, it is possible to level the base so that the axis of rotation of the horizontal motion is perpendicular to the plane. Thumb screw B moves the grating along a radius of the circle, hence is locked in position by means of lock screws B'. Thumb screw C rotates the grating in the plane of the circle and is locked in position by lock screw C'. Thumb screw D rotates the grating in a vertical plane and is locked in position by lock nut D'. All the above movements are returned by compression springs which eliminate a great deal of back lash. All lock nuts are also spring loaded so that, when loosened, tension of the spring still holds the various parts in position. The thumb screw adjusts the grating so that it is directly above the axis of rotation in the horizontal plane and the three cap nuts line up the grating with the movements of the mounting.

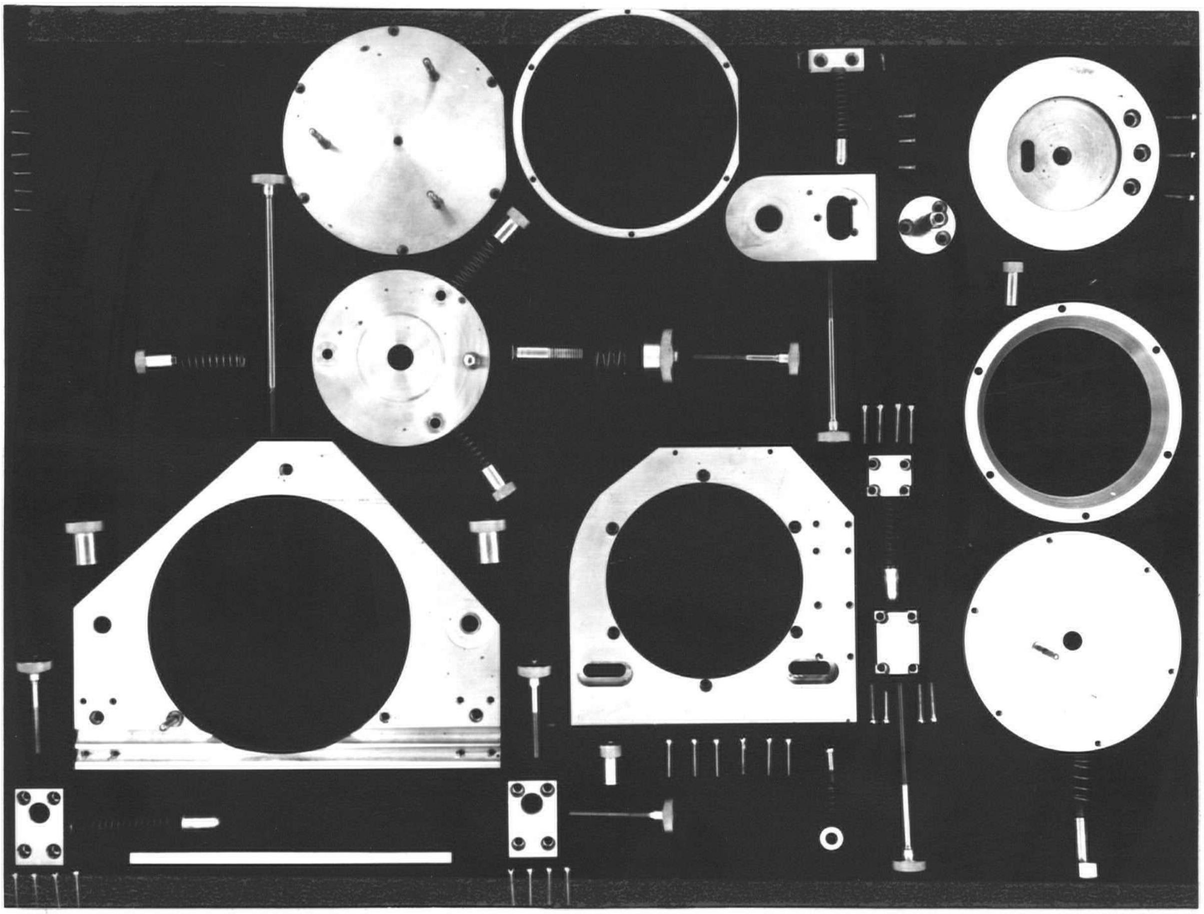
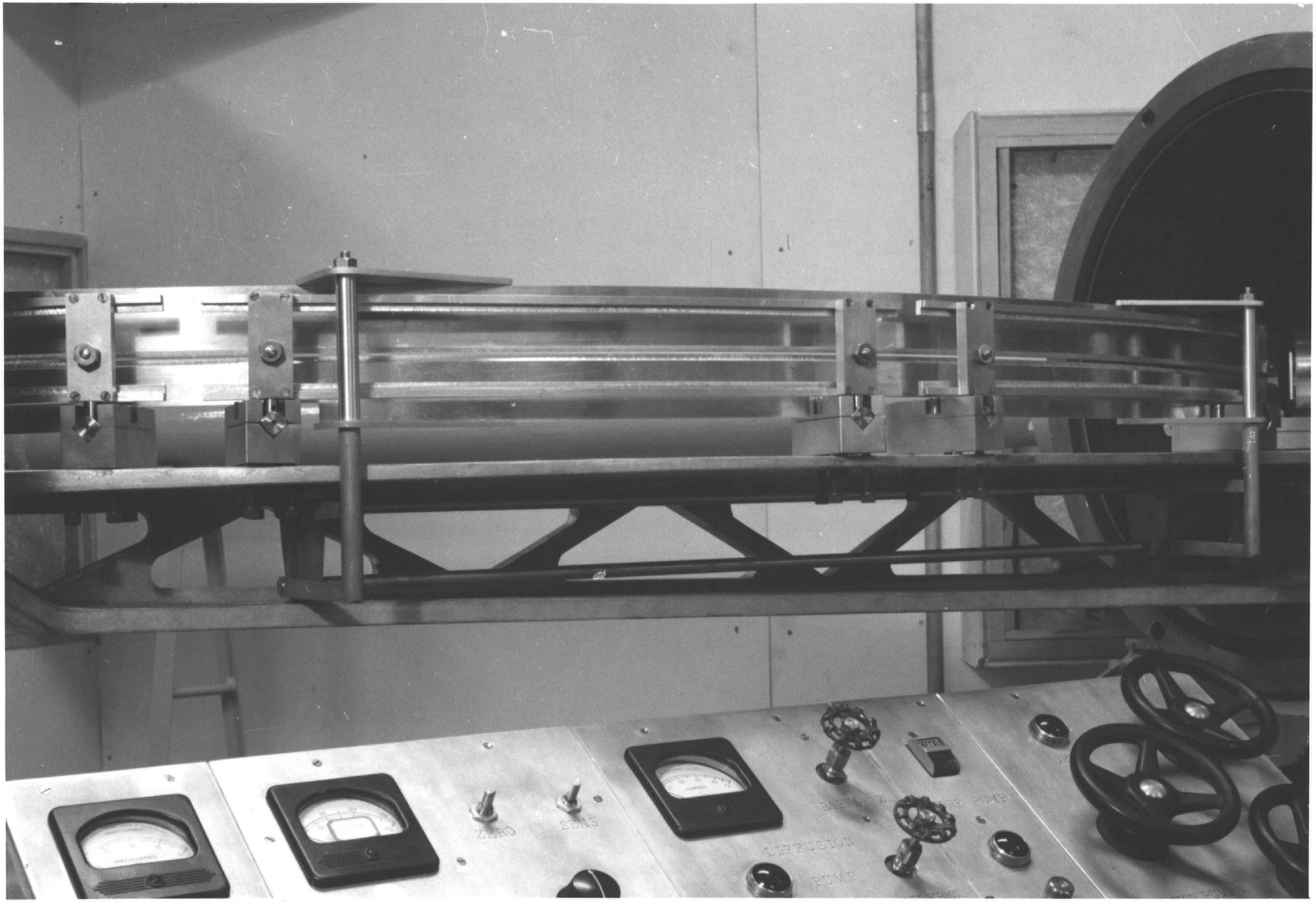


Figure 5 (g) : Component parts of the grating holder

PLATE V

The Spectrograph Plate Holder shown from the side from which plates are inserted


ZERO
SENS
DIFFUSION
PUMP

THE PLATE HOLDER

To line the plate so that it is at the image point of the optical system requires only one degree of freedom. It is necessary to line the plate in a horizontal direction only - i.e. in the plane of the Rowland circle. Vertical movement is unessential as the photographic plates are sufficiently wide to allow a shift of image on it.

The plate holder, as shown in plate V, is made by bending two aluminum rails to a one metre radius. They are then laced together at each end. By means of the lacing bars the holder is moved along a mean radius on a dual track system: this is to avoid distortion of the holder rails.

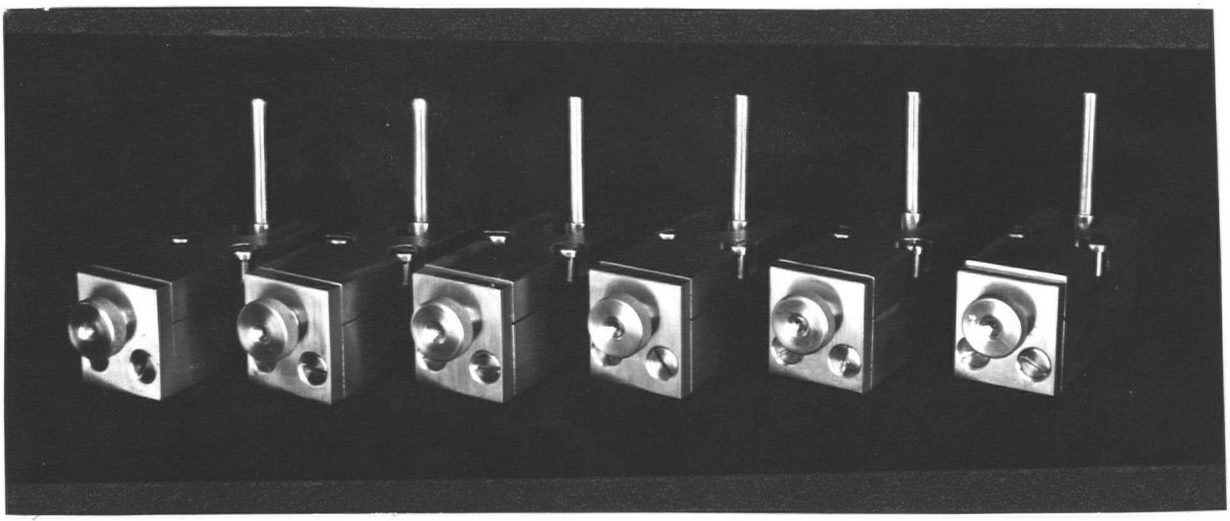


Figure 5 (h) : Plate holder adjusting blocks

The following figure shows one of the adjustable tracks dismantled. The base A is mounted on three points and held down by a central bolt. In it is milled a single "V" track. The square bar B rides in this groove and is held down by Cap C which was milled at the same time as the base.

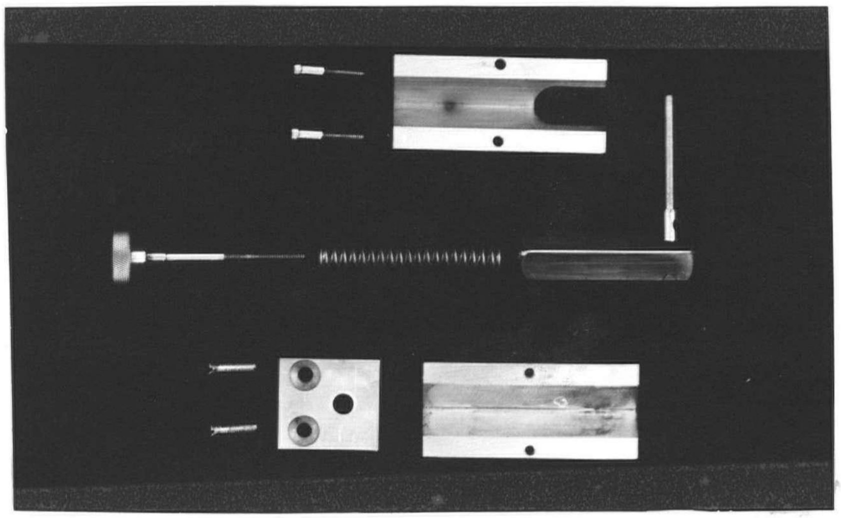
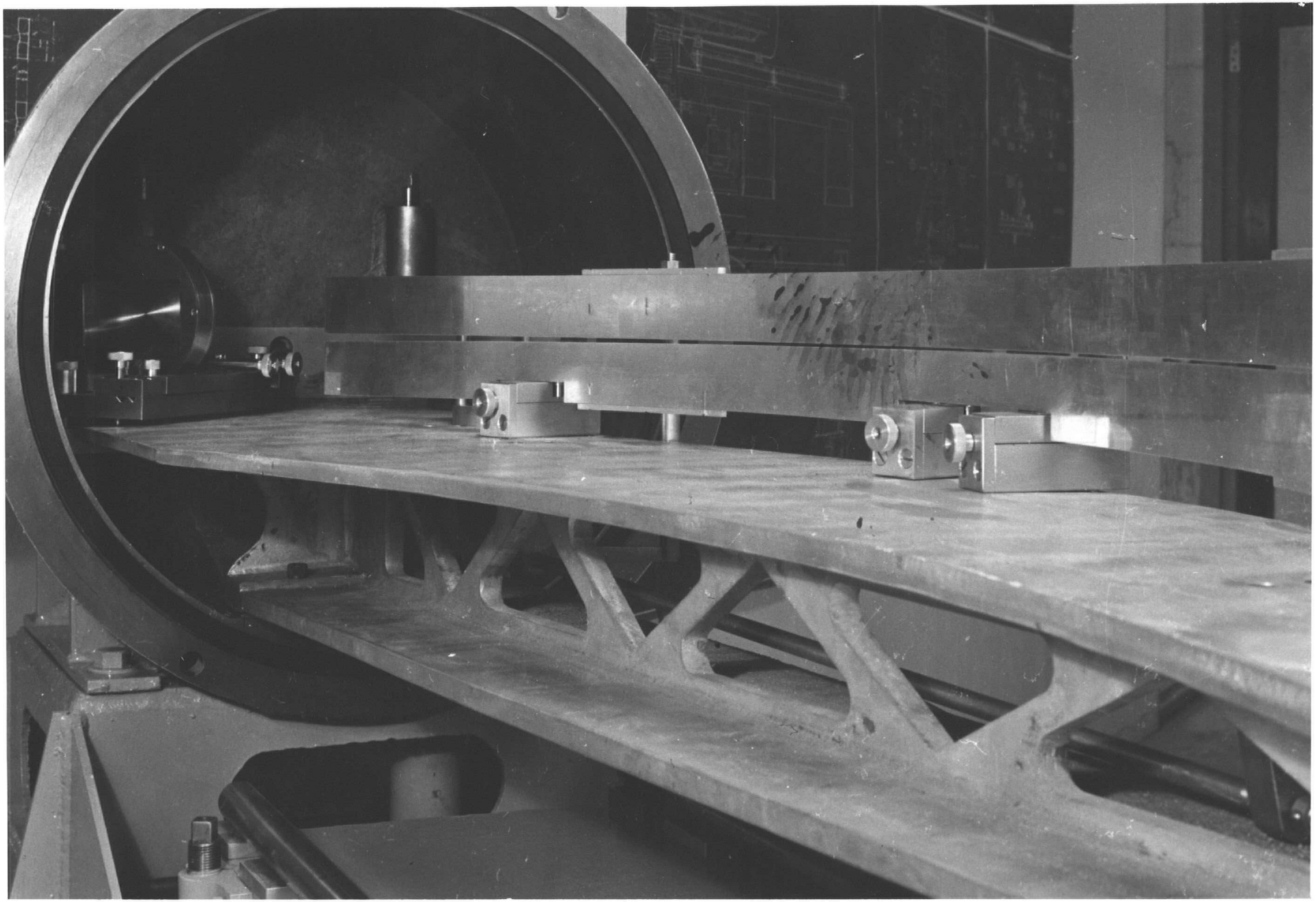


Figure 5 (i) : Component parts of an adjusting block

P L A T E   V I

The Plate Diaphragm



THE PLATE DIAPHRAGM

In order to increase the number of exposures without having to break the vacuum seal a plate diaphragm is moved vertically across the plate. This mask covers most of the plate except for a narrow strip of about one millimetre in the center and, when moved its full length, will alow about five exposures on the same plate. The diaphragm is mounted in front of the plate by means of parallel linkages which are moved together by two torsion bars powered by a synchronous motor. The generator is mounted under the last panel. A reduction gear system is used so that at least one turn is necessary to move the diaphragm one place: the amount of movement is indicated by a voltmeter.

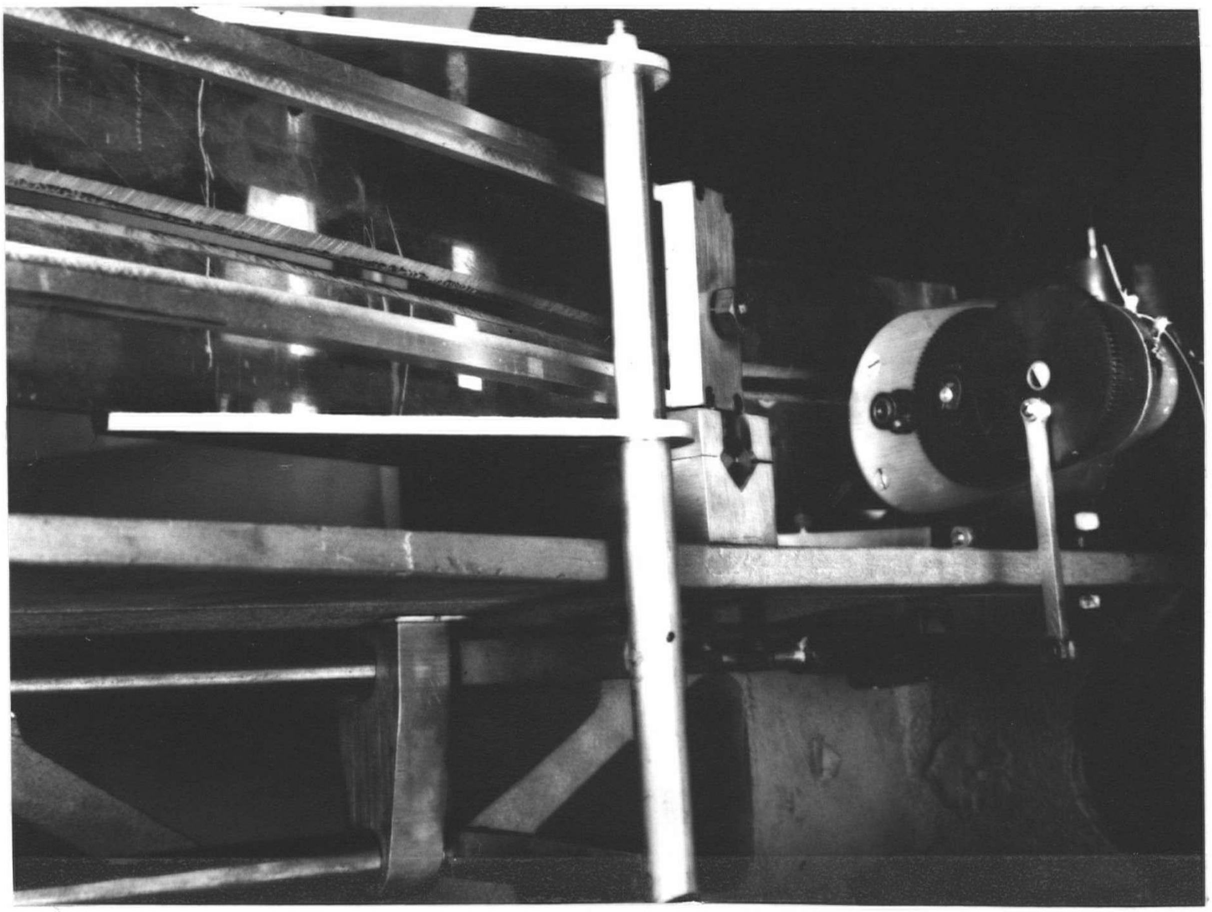


Figure 5 (j) : Diaphragm lifting mechanism

B I B L I O G R A P H Y

ANDERSON, R.C. and MACK, J.E. On Compensating for the Aberrations of the Concave Grating, J. Opt. Soc. Am., Nov. 1934, 24, 11, 292.

BELL, E.E., NOBLE, R.H. and NIELSEN, H.H. A Recording Vacuum Grating Spectrometer for the Infra-Red, Rev. Sci. Instr., Jan. 1947, 18, 1, 48.

BEUTLER, H.G. The Theory of the Concave Grating, J. Opt. Soc. Am., May 1945, 35, 5, 311.

BOYCE, J.C. Spectroscopy in the Vacuum Ultraviolet, Rev. Mod. Phys., Jan. 1941, 13, 1, 1.

ESTERMANN, I. and FONER, S.N. Vacuum Valve, Rev. Sci.Instr., Jan. 1947, 18, 1, 64.

KAYSER, Heinrich, G.J. Handbuch der Spectroscopie, Vol.1, 533-539, 1905, Leipzig, S. Hirzel (1901..)

KURIE, Franz N.D. Vacuum Systems, Seals, and Valves, Rev. Sci. Instr., Aug. 1948, 19, 8, 485.

MACK, J.E., STEHN, J.R. and EDLEN, Bengt. On the Concave Grating Spectrograph, Especially at Large Angles of Incidence, J. Opt. Soc. Am., May 1932, 22, 5, 245.

MACK, J.E. and STEHN, J.R. On the Concave Grating, Especially at Large Angles of Incidence: Addendum, J. Opt. Soc. Am., May 1933, 23, 184.

MACK, J.E. and ANDERSON, E.E. A 21-Foot Multiple Range Grazing Incidence Spectrograph. Rev. Sci. Instr. Feb. 1944,15,2,28.

WILSON, Robert R. A Vacuum-Tight Sliding Seal, Rev. Sci.Instr. Feb. 1941, 12, 2, 91.

ZERNIKE, F. von (Groningen), Die Abbildungsfehler Des Konkavgitters und Ihre Hebung, Verhandelingen, Op.25 Mei 1935 Aangebaden Aan Prof. Dr. P. Zeeman, 1935, 'S-Gravenhage, Martinus Nijhoff.

APPENDIX A

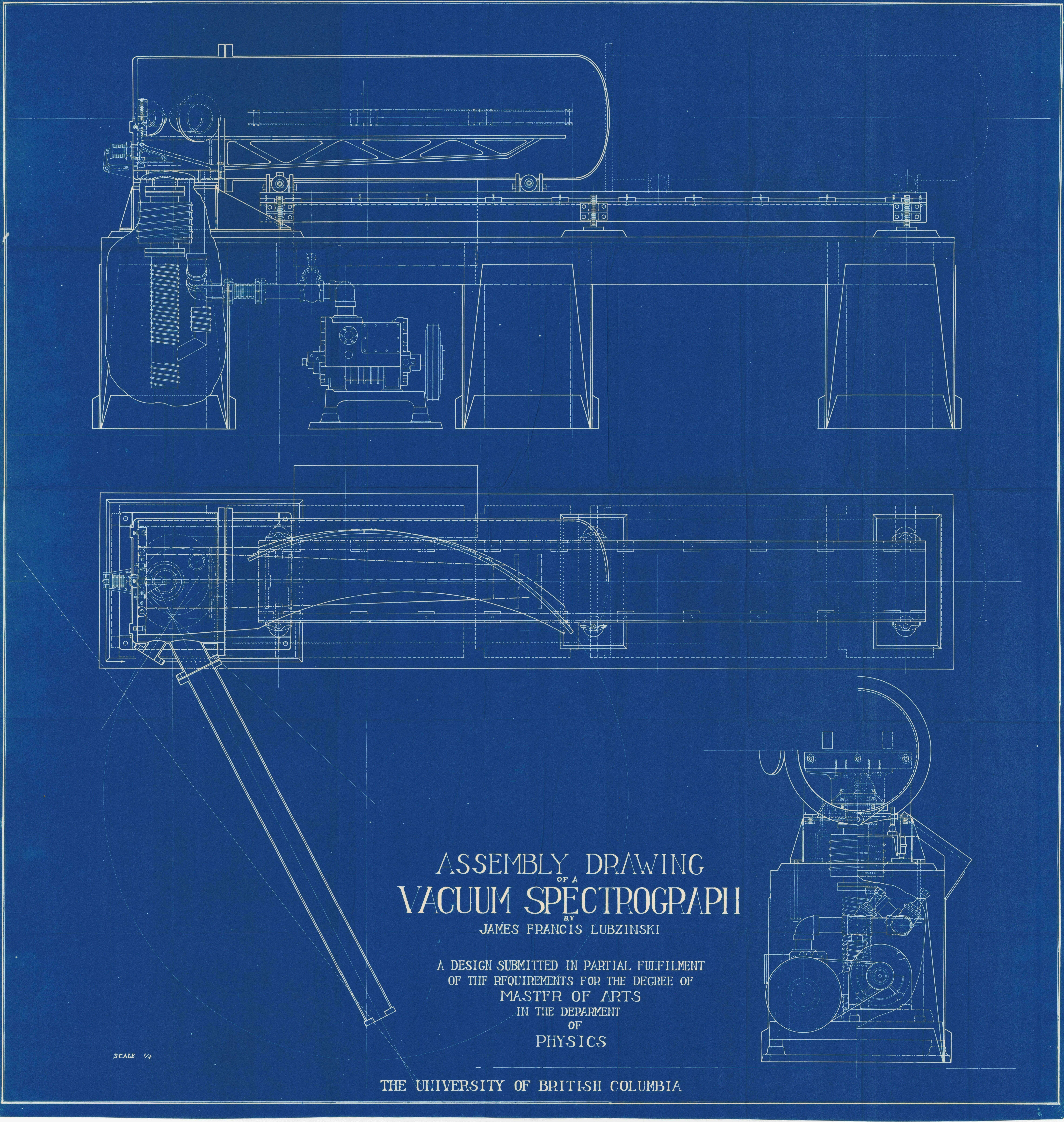
LIST OF WORKING DRAWINGS

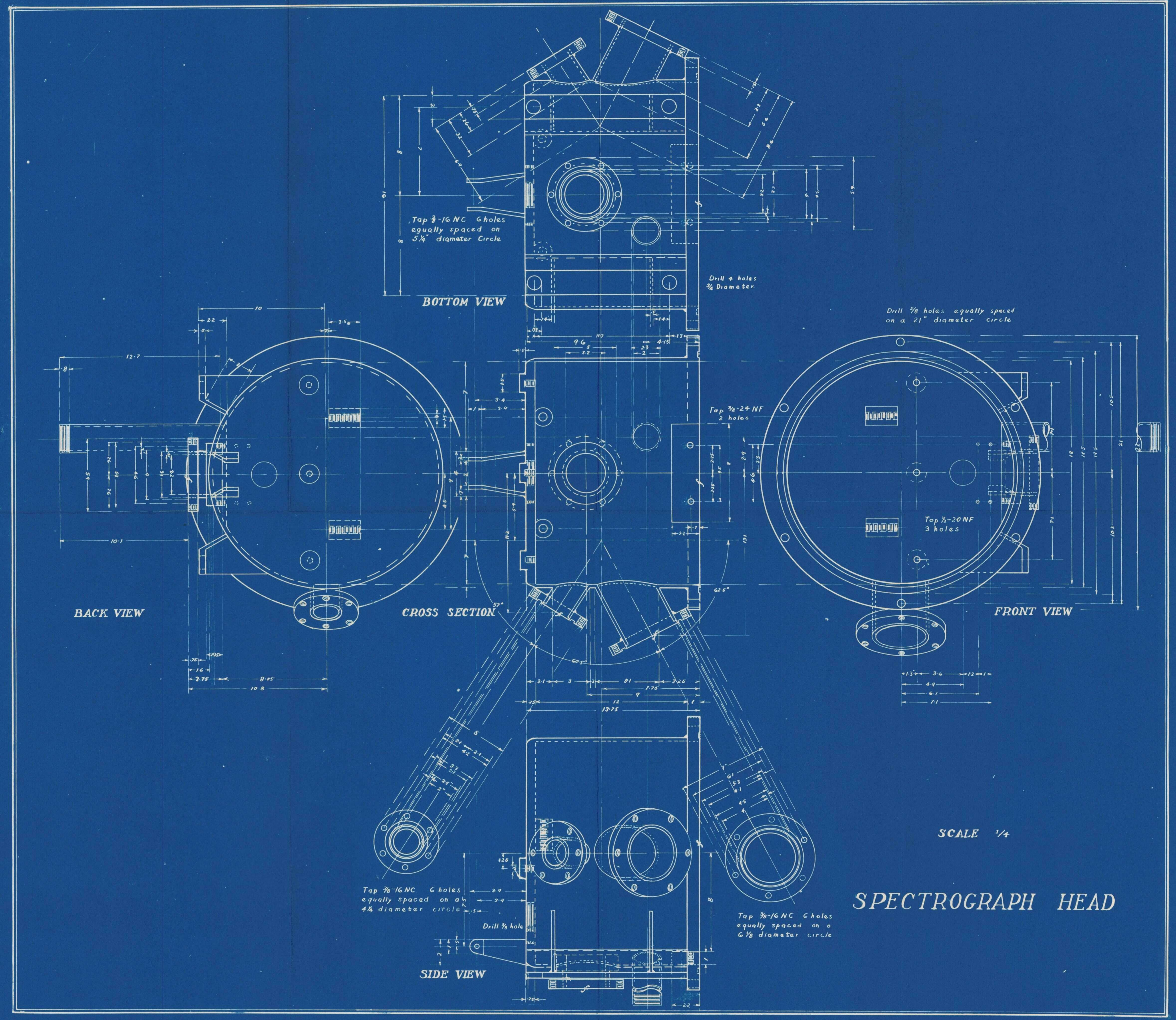
1. Spectrograph assembly drawing.
2. Spectrograph head.
3. Spectrograph housing
4. Slit tube; vacuum connections; sylphon fittings; beam support.
5. Beam.
6. Levelling screws; wheels and axle.
7. Mount and track.
8. Table.
9. Panel.
10. Recoil mechanism; cover plate; track levelling blocks; lead pads.
11. Trap valve mechanism; bell cranks.
12. Diffusion pump locking pin.
13. Assembly drawing of slit.
14. Slit housing.
15. Slit cover and source connection.
16. Detail slit mechanism.
17. Assembly drawing of grating holder.
18. Detail base plate; sides and bearing.
19. Detail of screws.
20. Assembly and detail of plate adjusting blocks.
21. Assembly of plate diaphragm.
22. Detail of diaphragm bearing.
23. Torsion bars.

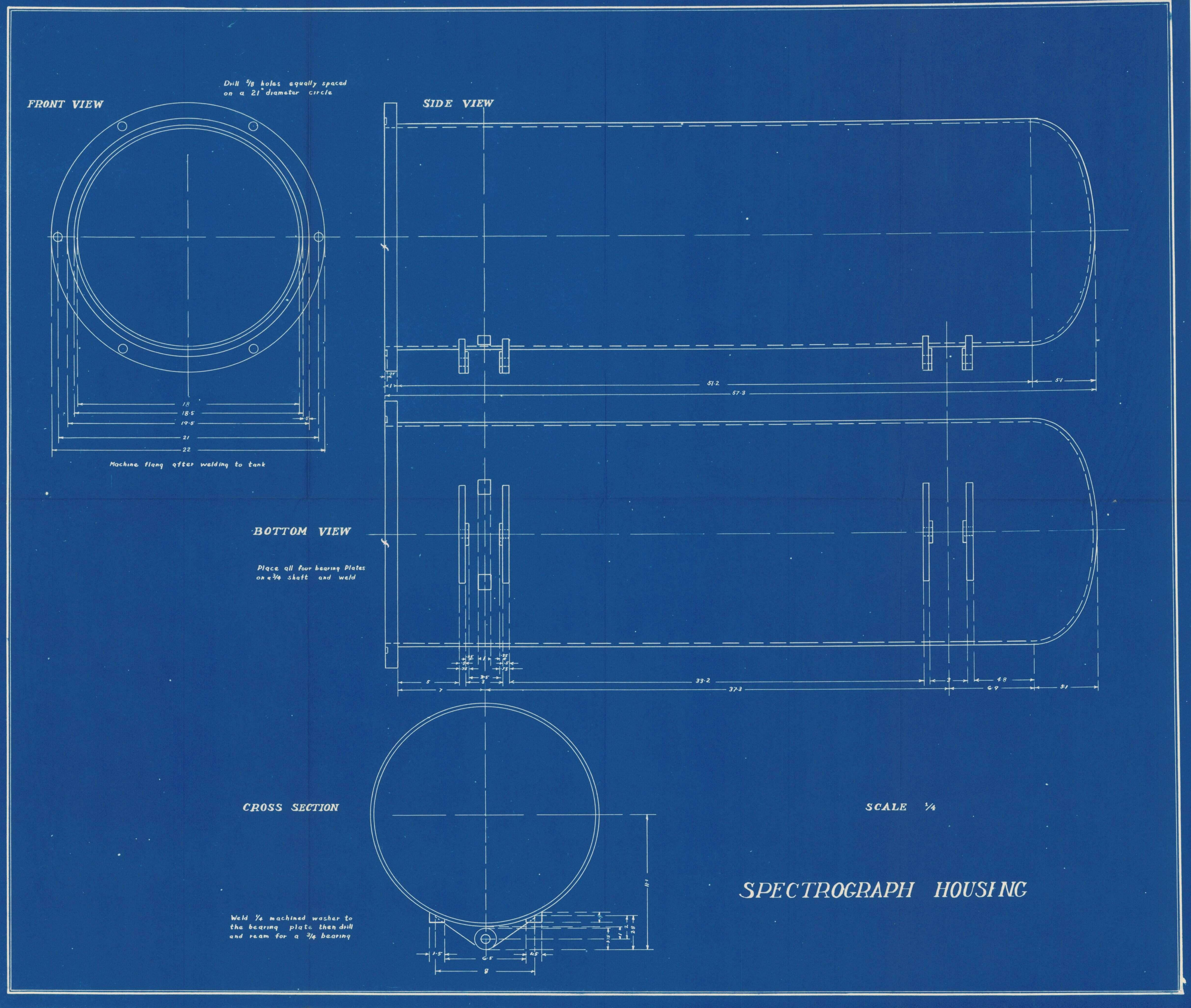
VII.

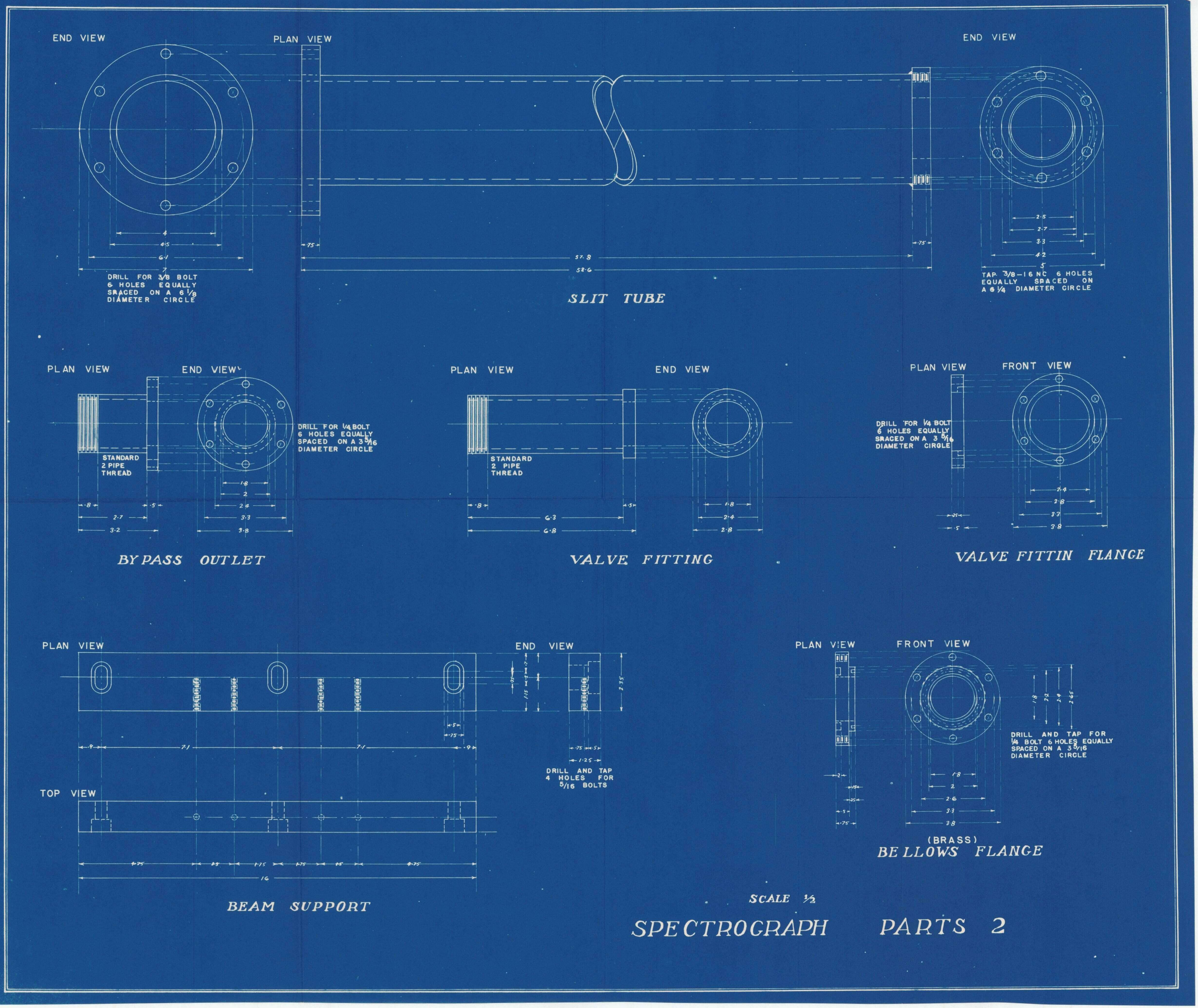
A P P E N D I X B

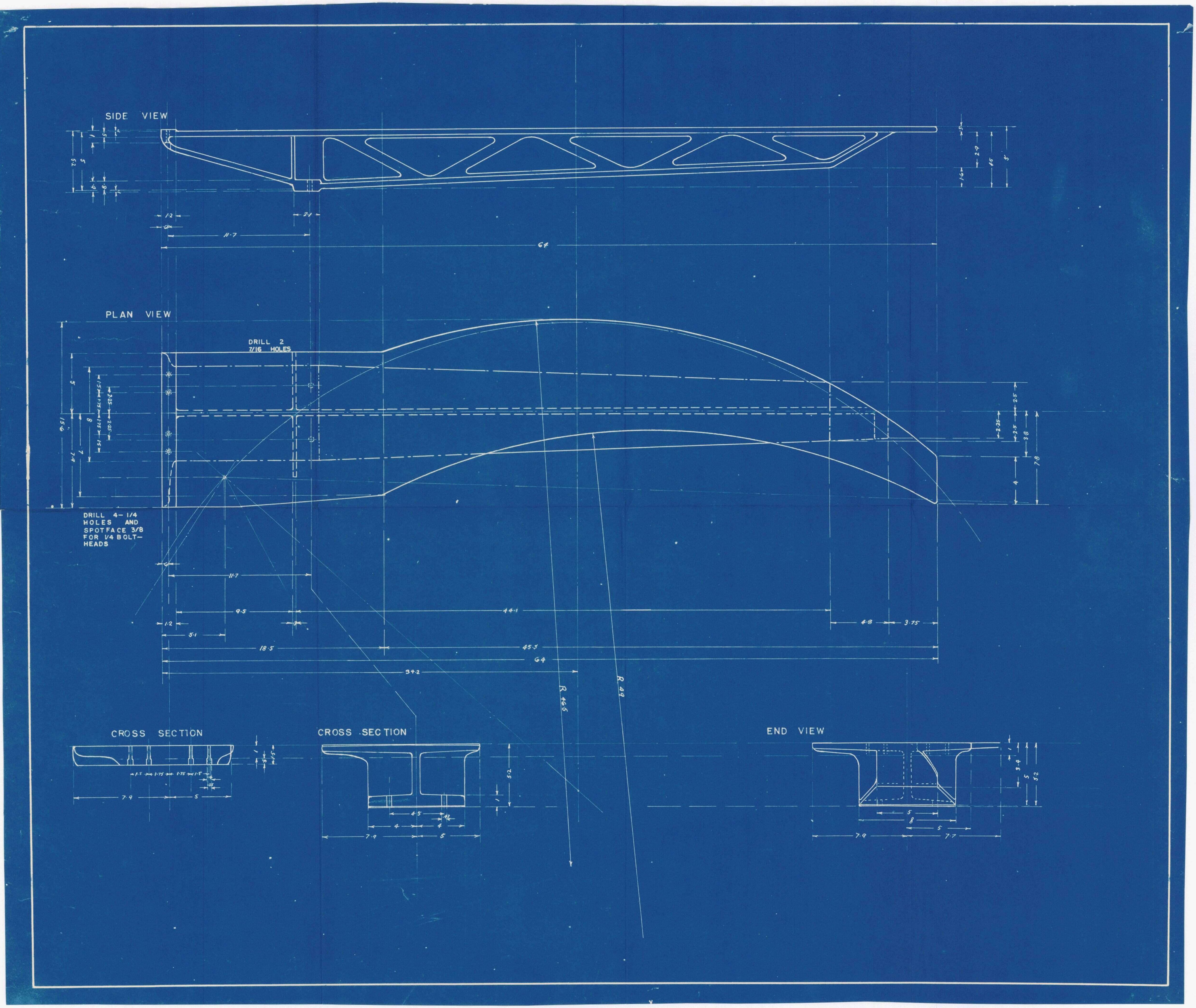
WORKING DRAWINGS USED IN THE CONSTRUCTION OF THE SPECTROGRAPH

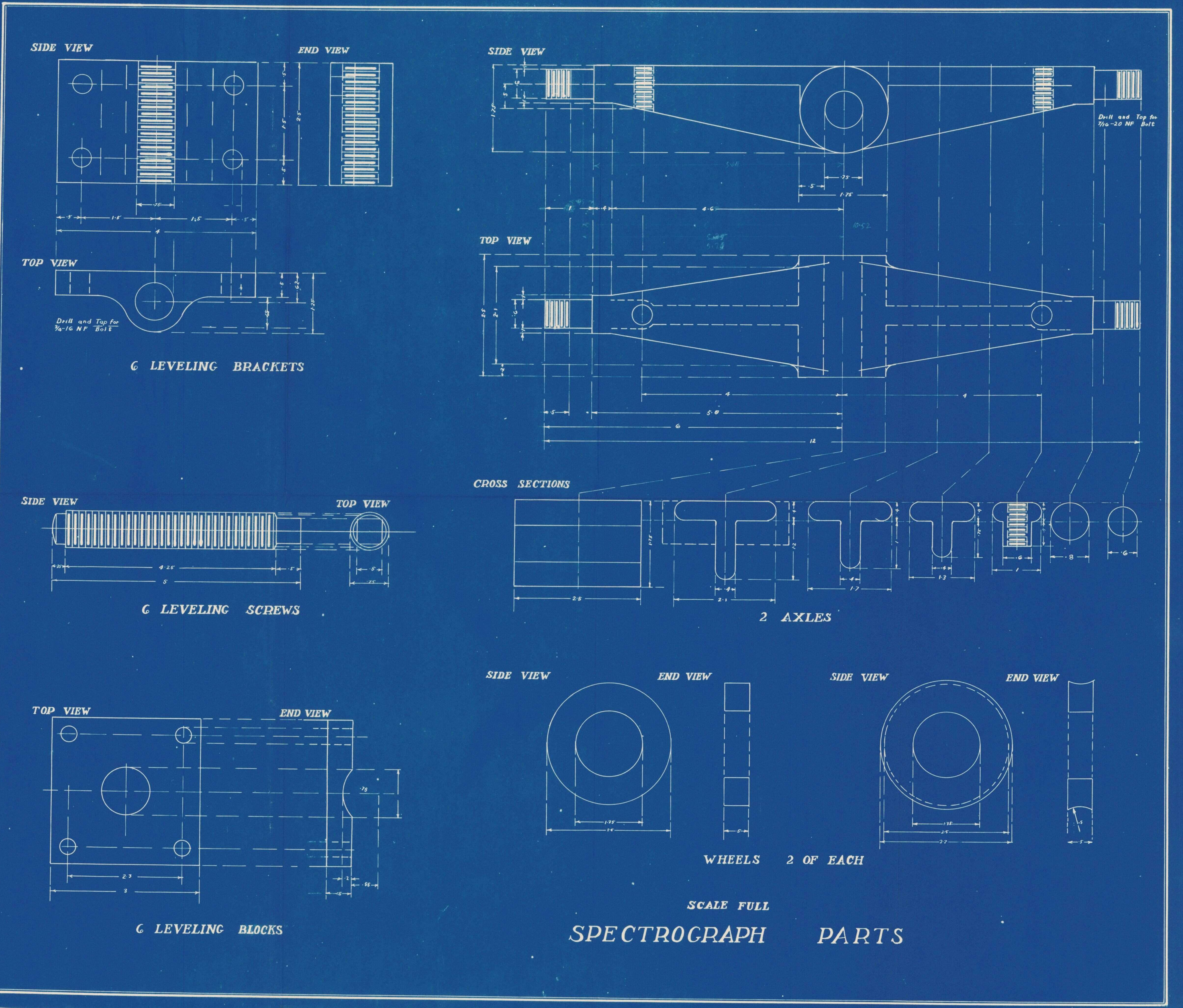

ASSEMBLY DRAWING
OF A
VACUUM SPECTROGRAPH
BY
JAMES FRANCIS LUBZINSKI
A DESIGN SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS
IN THE DEPARMENT
OF
PHYSICS
SCALE 1/4
THE UNIVERSITY OF BRITISH COLUMBIA


SPECTROGRAPH HEAD
SCALE 1/4
BOTTOM VIEW
BACK VIEW
CROSS SECTION
FRONT VIEW
SIDE VIEW
Tap 3/8-16NC 6 holes equally spaced on 5 1/4" diameter circle
Drill 4 holes 3/4 Diameter
Drill 5/8 holes equally spaced on a 21" diameter circle
Tap 3/8-24 NF 2 holes
Tap 1/2-20NF 3 holes
Tap 3/8-16NC 6 holes equally spaced on a 4 1/4 diameter circle
Drill 3/8 hole
Tap 3/8-16NC 6 holes equally spaced on a 6 1/8 diameter circle


FRONT VIEW
Drill 5/8 holes equally spaced on a 21" diameter circle
18
18·5
19·5
·5
21
22
Machine flang after welding to tank
SIDE VIEW
51·2
57·3
5·1
BOTTOM VIEW
Place all four bearing Plates on a 3/4 shaft and weld
·25
·5
·75
1
2·5
3
5
7
33·2
37·3
3
4·8
6·9
5·1
CROSS SECTION
Weld 1/4 machined washer to the bearing plate then drill and ream for a 3/4 bearing
11·1
2·8
2
1
1·75
1·5
6·5
1·5
8
SCALE 1/4
SPECTROGRAPH HOUSING

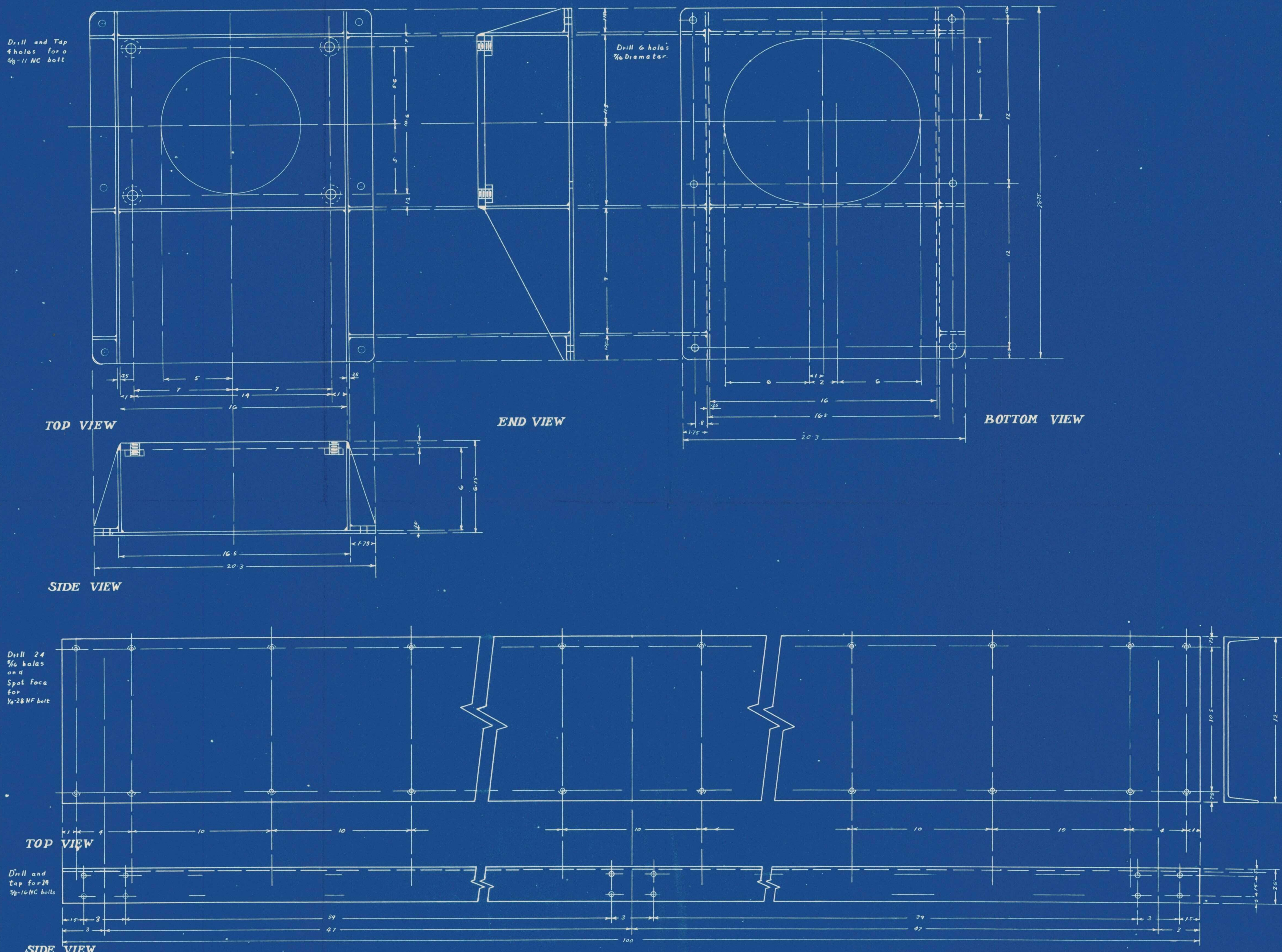

END VIEW
PLAN VIEW
END VIEW
DRILL FOR 3/8 BOLT 6 HOLES EQUALLY SPACED ON A 6 1/8 DIAMETER CIRCLE
TAP 3/8-16 NC 6 HOLES EQUALLY SPACED ON A 6 1/4 DIAMETER CIRCLE
SLIT TUBE
PLAN VIEW
END VIEW
DRILL FOR 1/4 BOLT 6 HOLES EQUALLY SPACED ON A 3 5/16 DIAMETER CIRCLE
STANDARD 2 PIPE THREAD
BY PASS OUTLET
PLAN VIEW
END VIEW
STANDARD 2 PIPE THREAD
VALVE FITTING
PLAN VIEW
FRONT VIEW
DRILL FOR 1/4 BOLT 6 HOLES EQUALLY SPACED ON A 3 5/16 DIAMETER CIRCLE
VALVE FITTIN FLANGE
PLAN VIEW
END VIEW
DRILL AND TAP 4 HOLES FOR 5/16 BOLTS
TOP VIEW
BEAM SUPPORT
PLAN VIEW
FRONT VIEW
DRILL AND TAP FOR 1/4 BOLT 6 HOLES EQUALLY SPACED ON A 3 5/16 DIAMETER CIRCLE
(BRASS)
BELLOWS FLANGE
SCALE 1/2
SPECTROGRAPH PARTS 2


SIDE VIEW
PLAN VIEW
DRILL 2 7/16 HOLES
DRILL 4-1/4 HOLES AND SPOTFACE 3/8 FOR 1/4 BOLT-HEADS
CROSS SECTION
CROSS SECTION
END VIEW
R 46.5
R 49



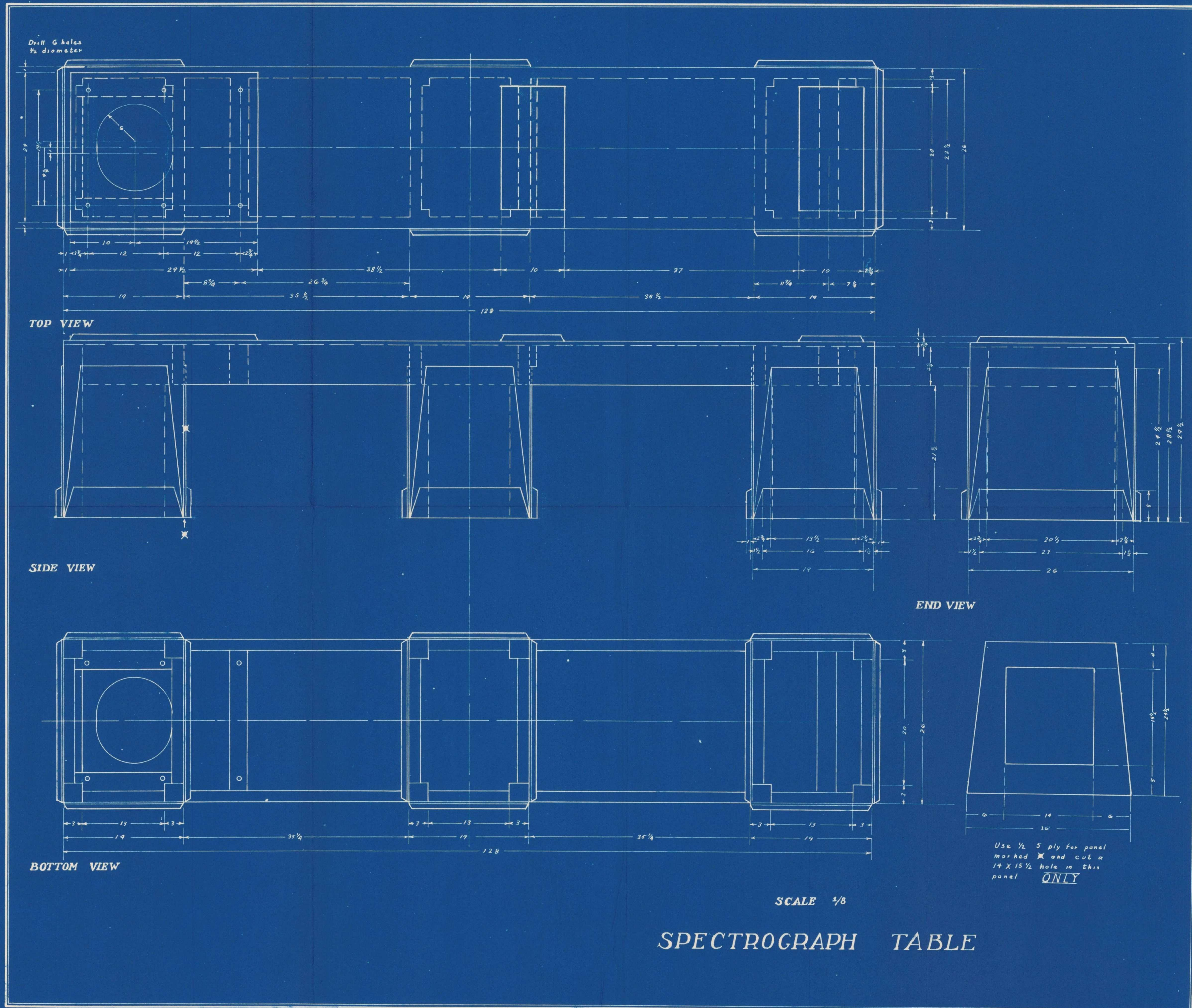
SCALE FULL

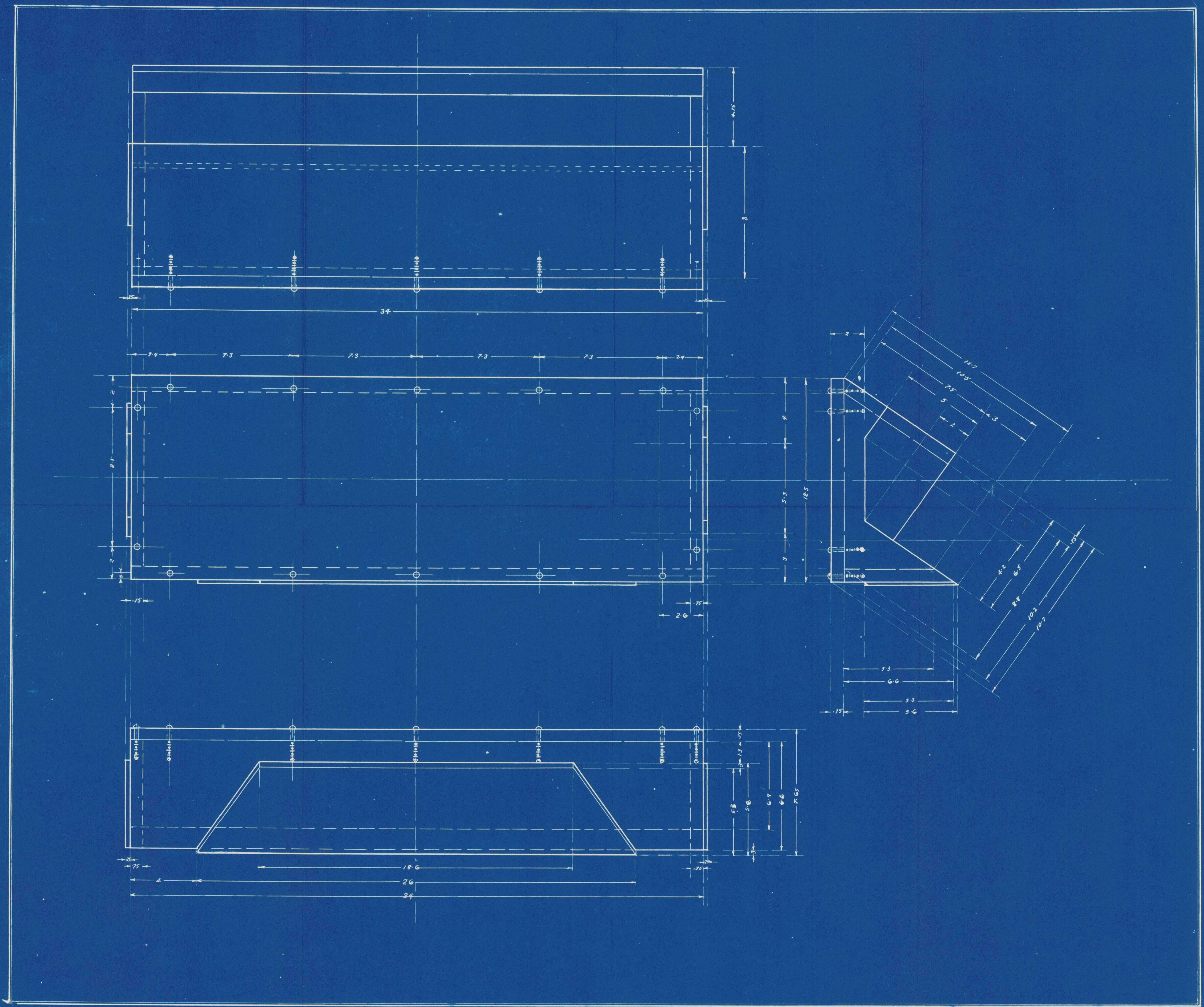
SPECTROGRAPH PARTS



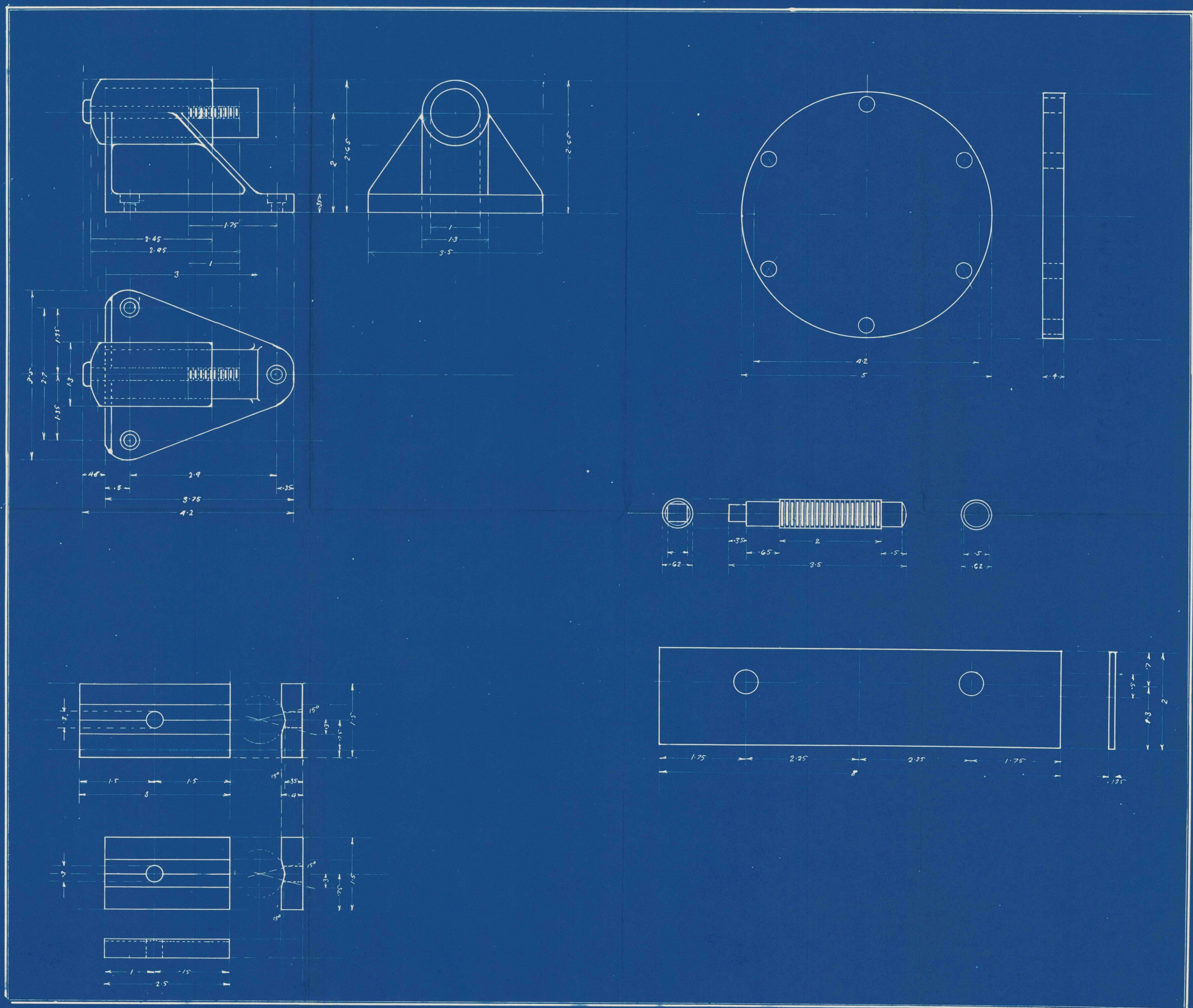
SCALE 1/4

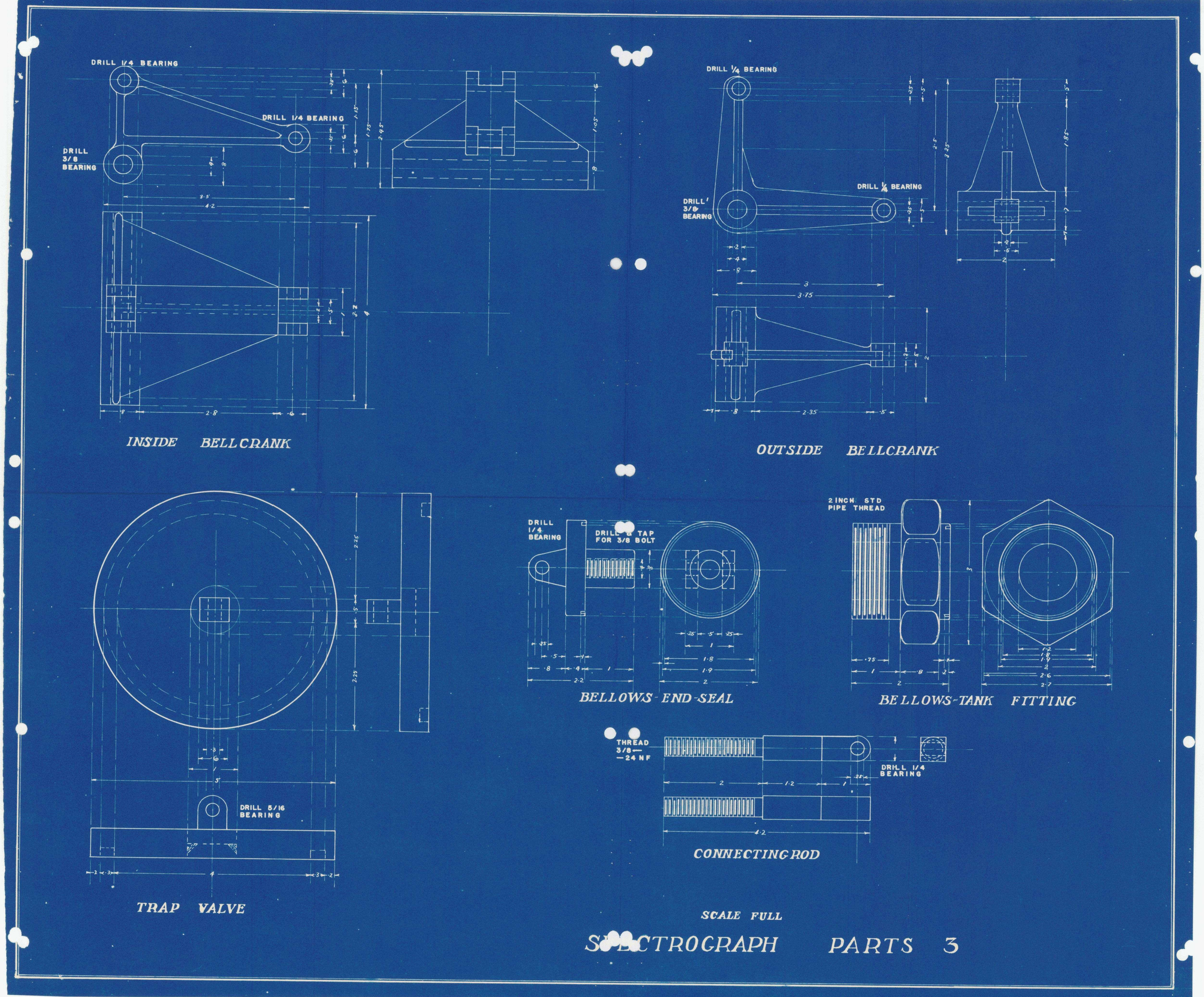
SPECTROGRAPH MOUNT AND TRACK

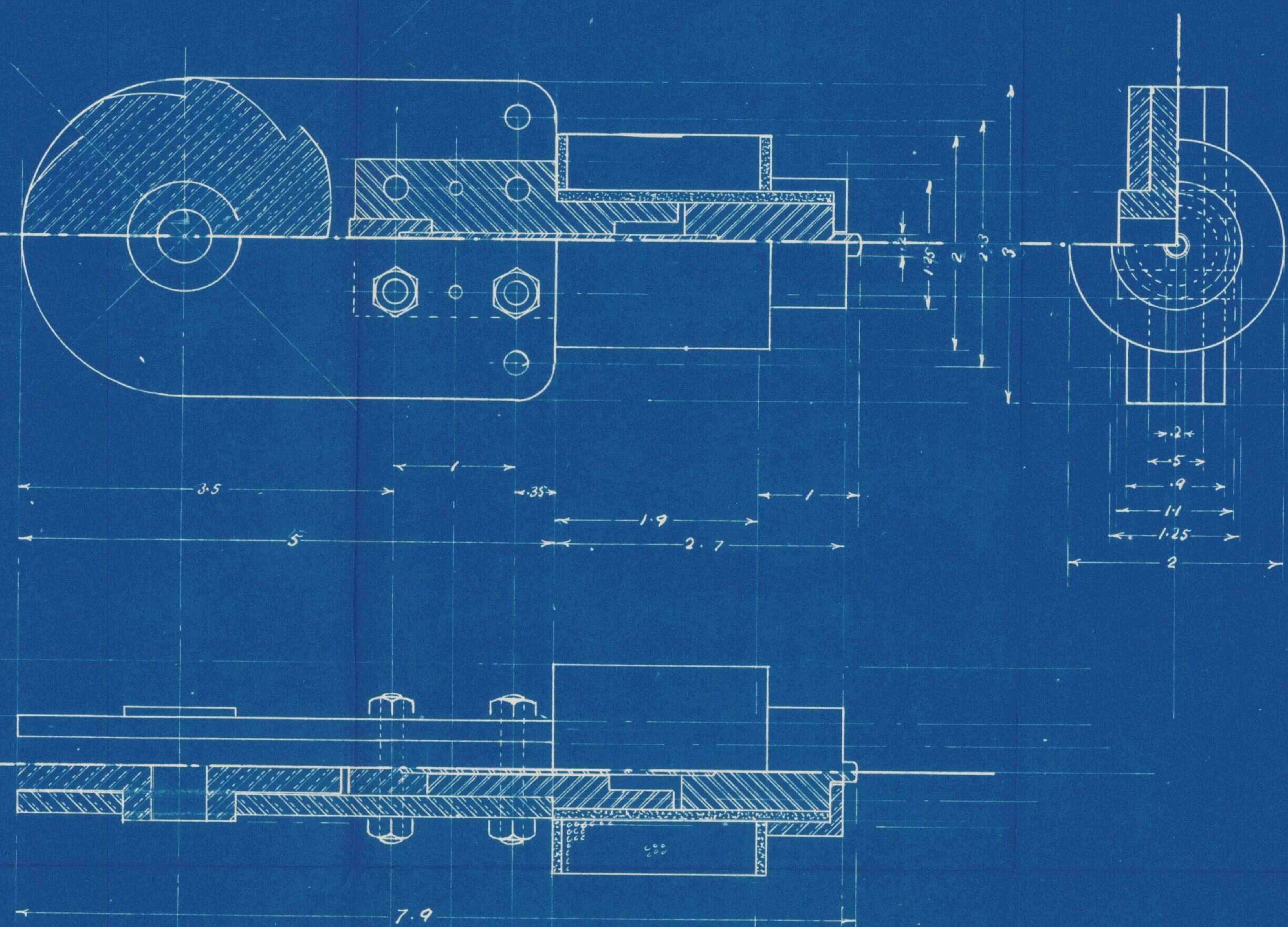

Drill 6 holes ½ diameter
TOP VIEW
SIDE VIEW
END VIEW
BOTTOM VIEW
Use ½ 5 ply for panel marked ✱ and cut a 14 X 15½ hole in this panel ONLY
SCALE 1/8
SPECTROGRAPH TABLE



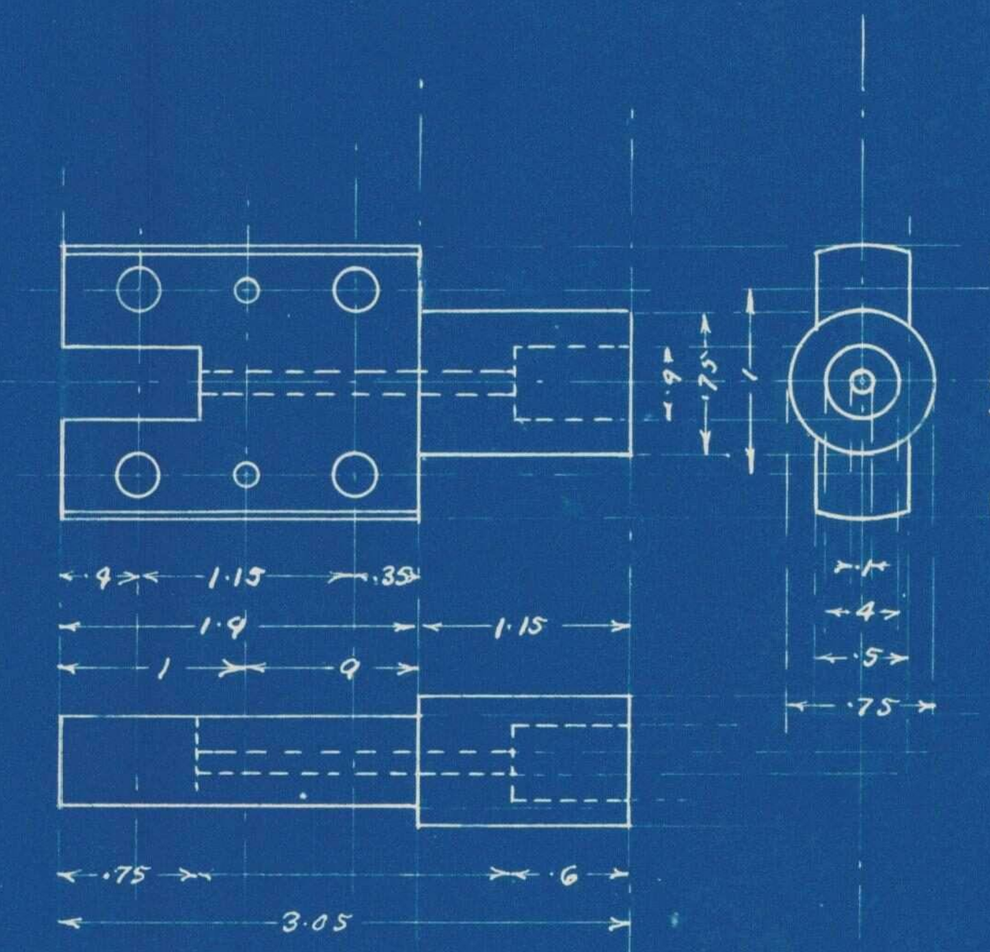
34
7·4
7·3
7·3
7·3
7·3
2·4
2·6
·75
12·5
8
18·6
26
4
5·3
6·6
5·3
5·6
12·7
10·5
7·5
5
3
2
4·2
6·5
8·8
10·2
10·7
7·65
6·6
6·4
5·8


1·75
2·45
2·95
1
3
2
2·65
1
1·3
3·5
2·9
·5
3·75
4·2
4·2
5
·4
·35
·65
2
·5
3·5
·62
1·75
2·25
2·25
1·75
8
2
·125
1·5
1·5
3
15°
·35
·4
1
·15
2·5

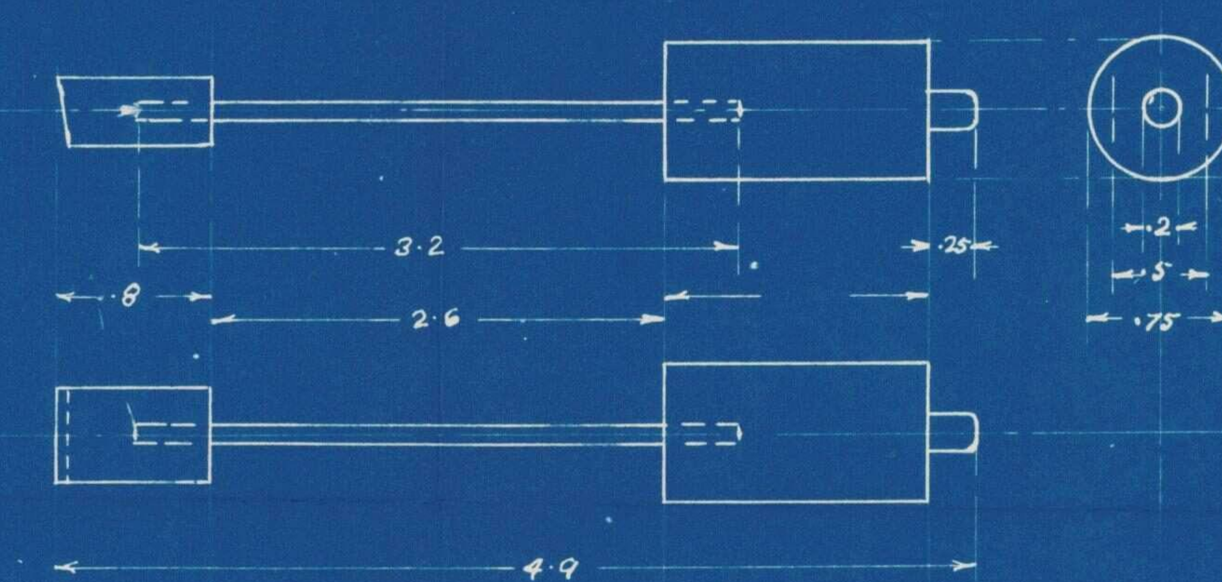

DRILL 1/4 BEARING
DRILL 1/4 BEARING
DRILL 3/8 BEARING
INSIDE BELLCRANK
DRILL 1/4 BEARING
DRILL 1/4 BEARING
DRILL 3/8 BEARING
OUTSIDE BELLCRANK
TRAP VALVE
DRILL 5/16 BEARING
DRILL 1/4 BEARING
DRILL & TAP FOR 3/8 BOLT
BELLOWS-END-SEAL
2 INCH STD PIPE THREAD
BELLOWS-TANK FITTING
THREAD 3/8—24 NF
DRILL 1/4 BEARING
CONNECTING ROD
SCALE FULL
SPECTROGRAPH PARTS 3



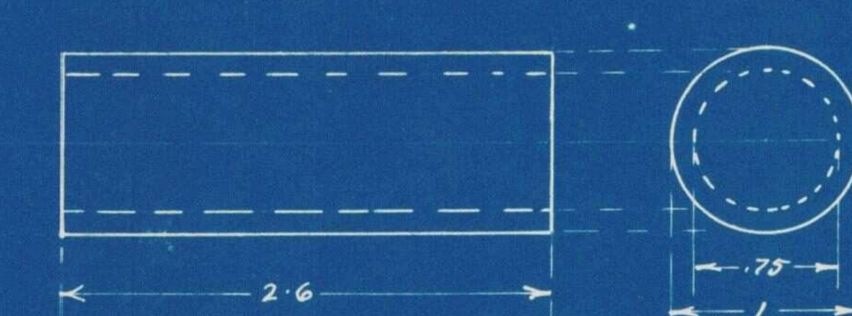
ASSEMBLY DRAWING



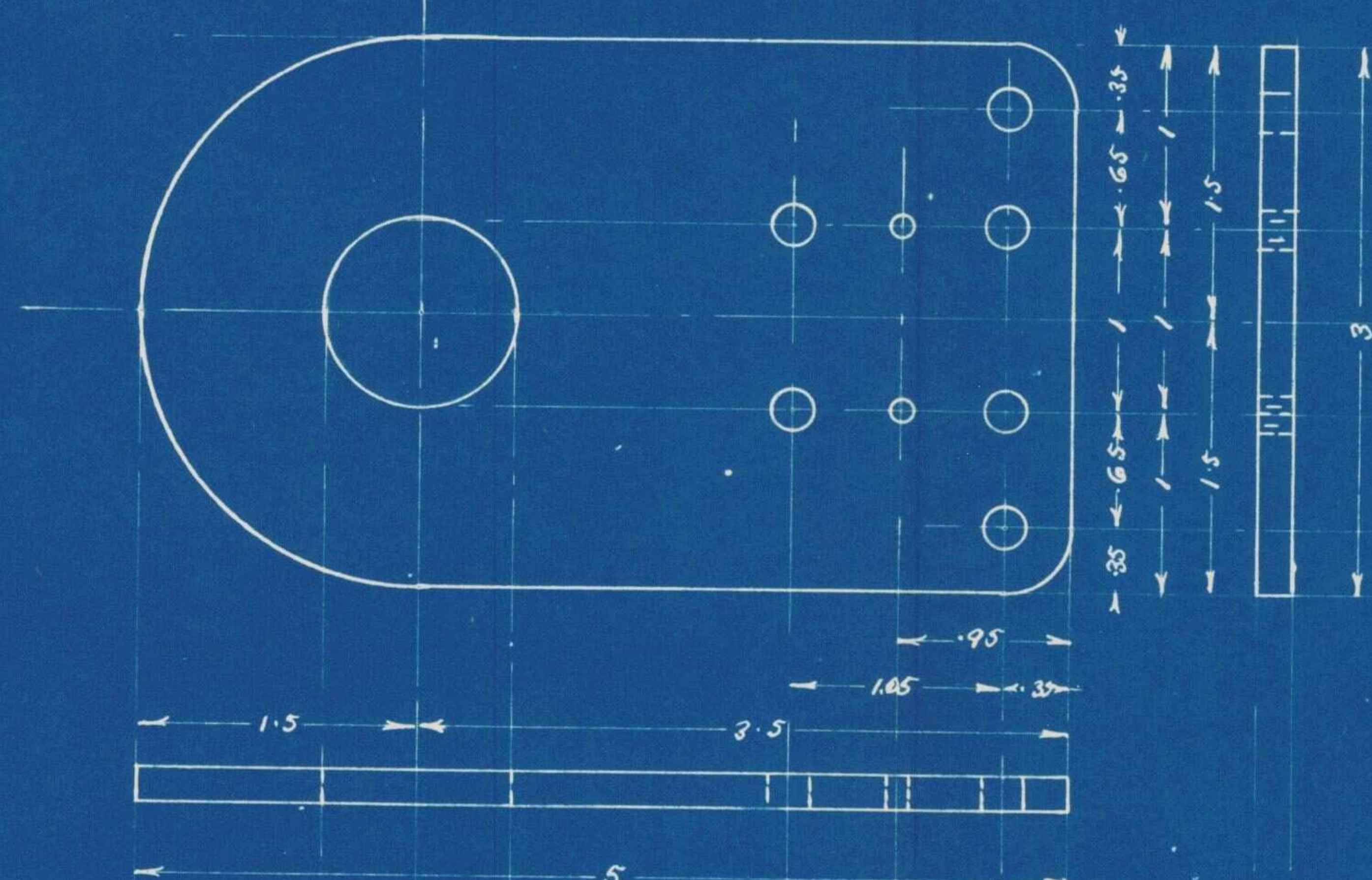
PART C



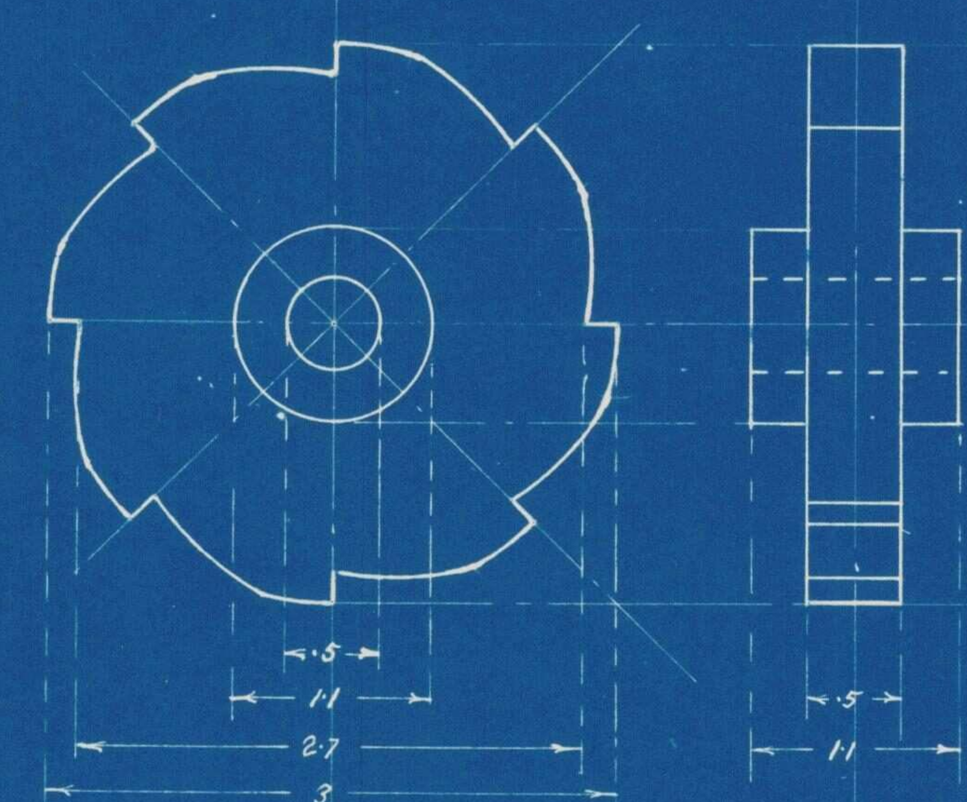
PART D



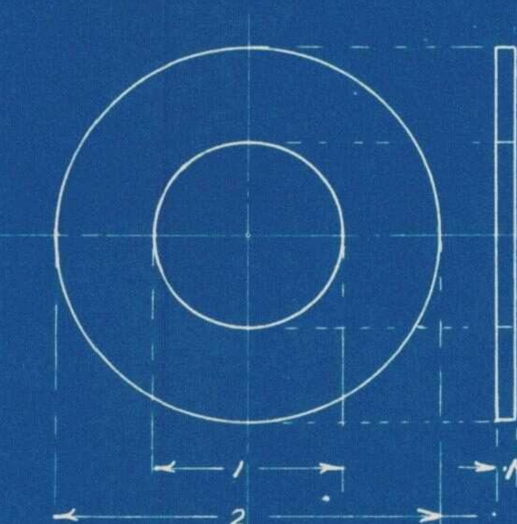
PART E



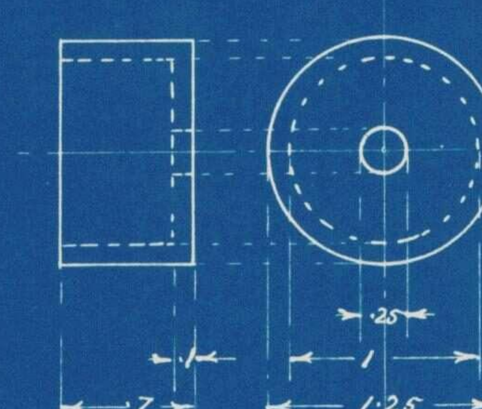
PART A



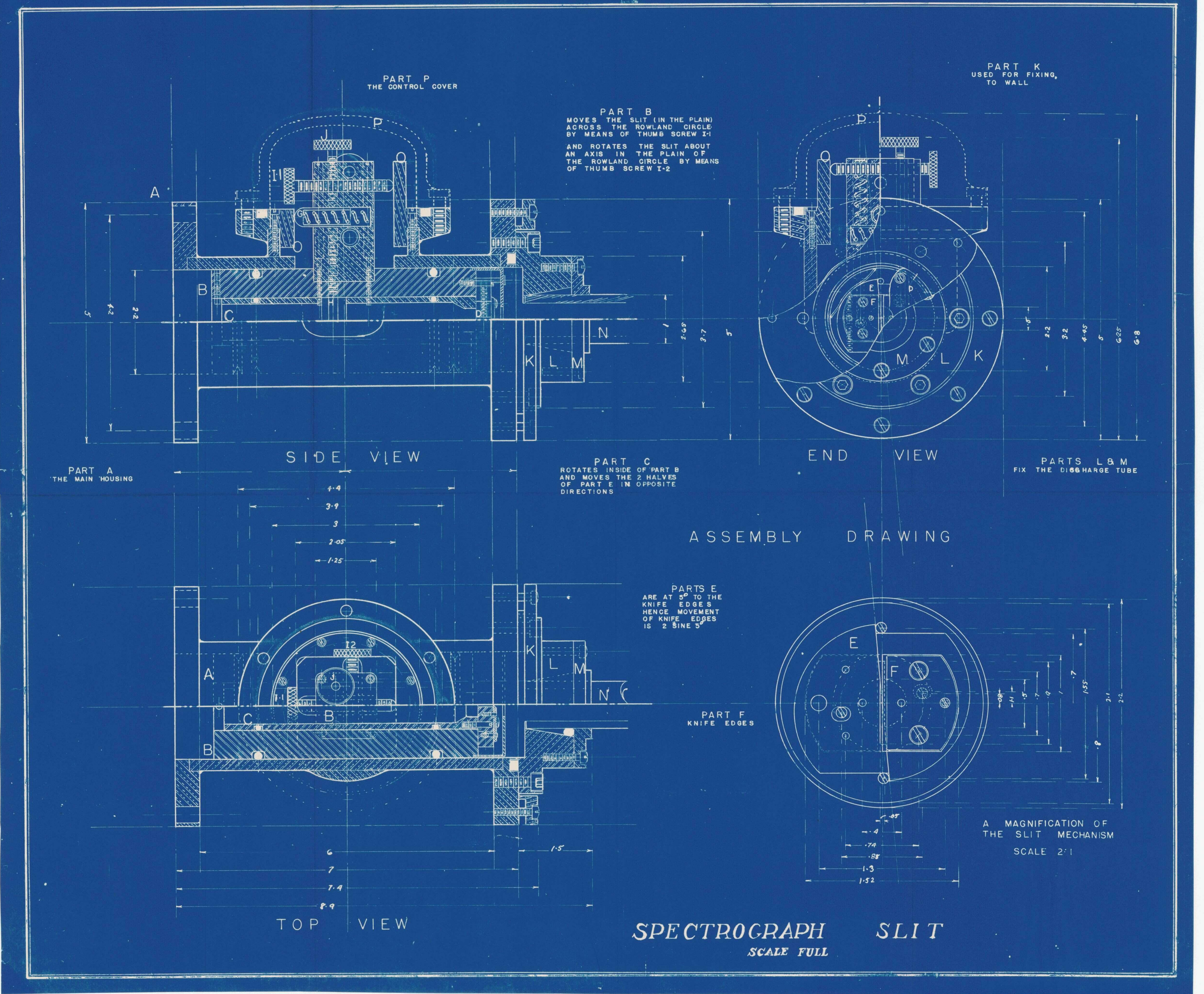
PART B



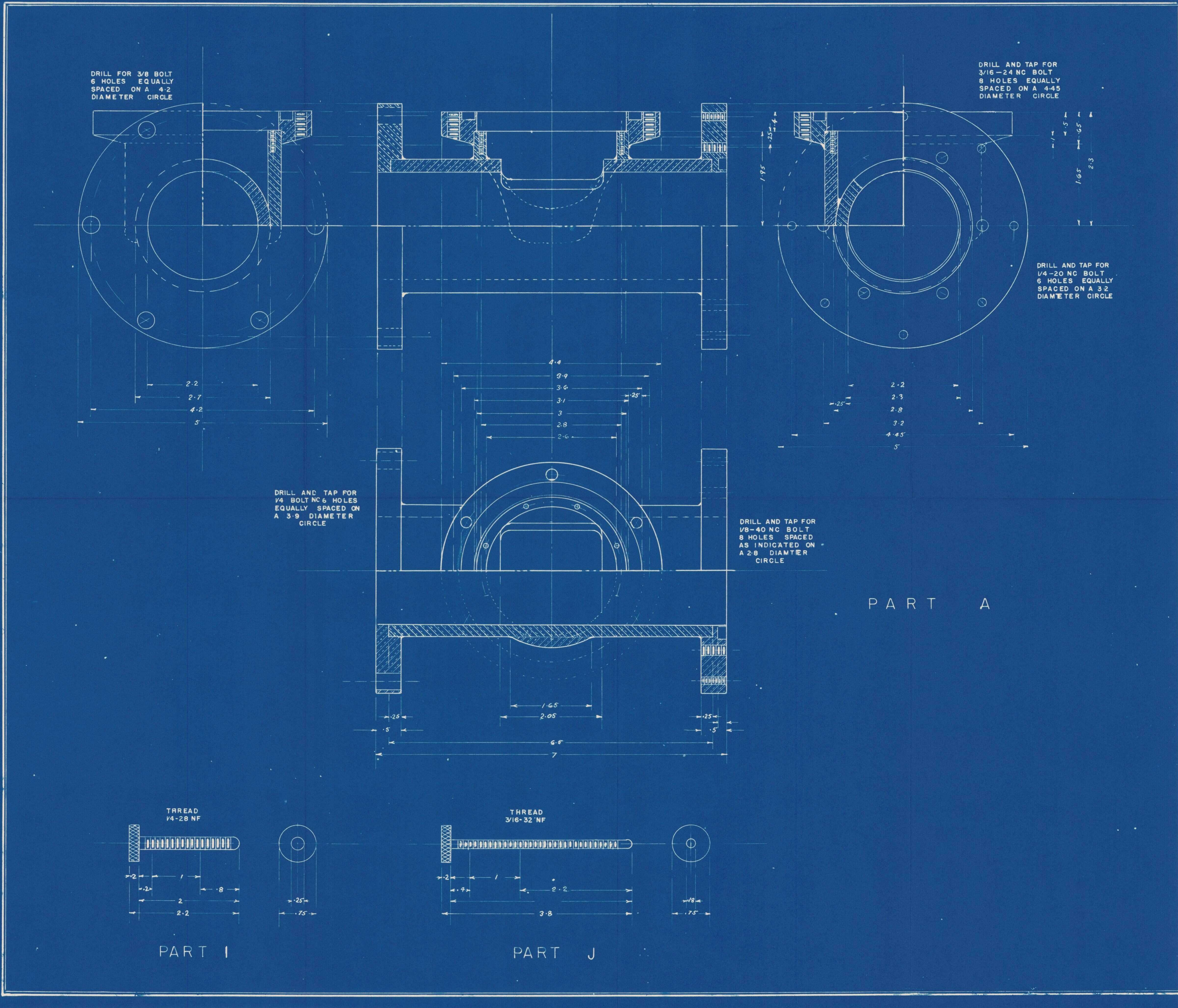
PART F



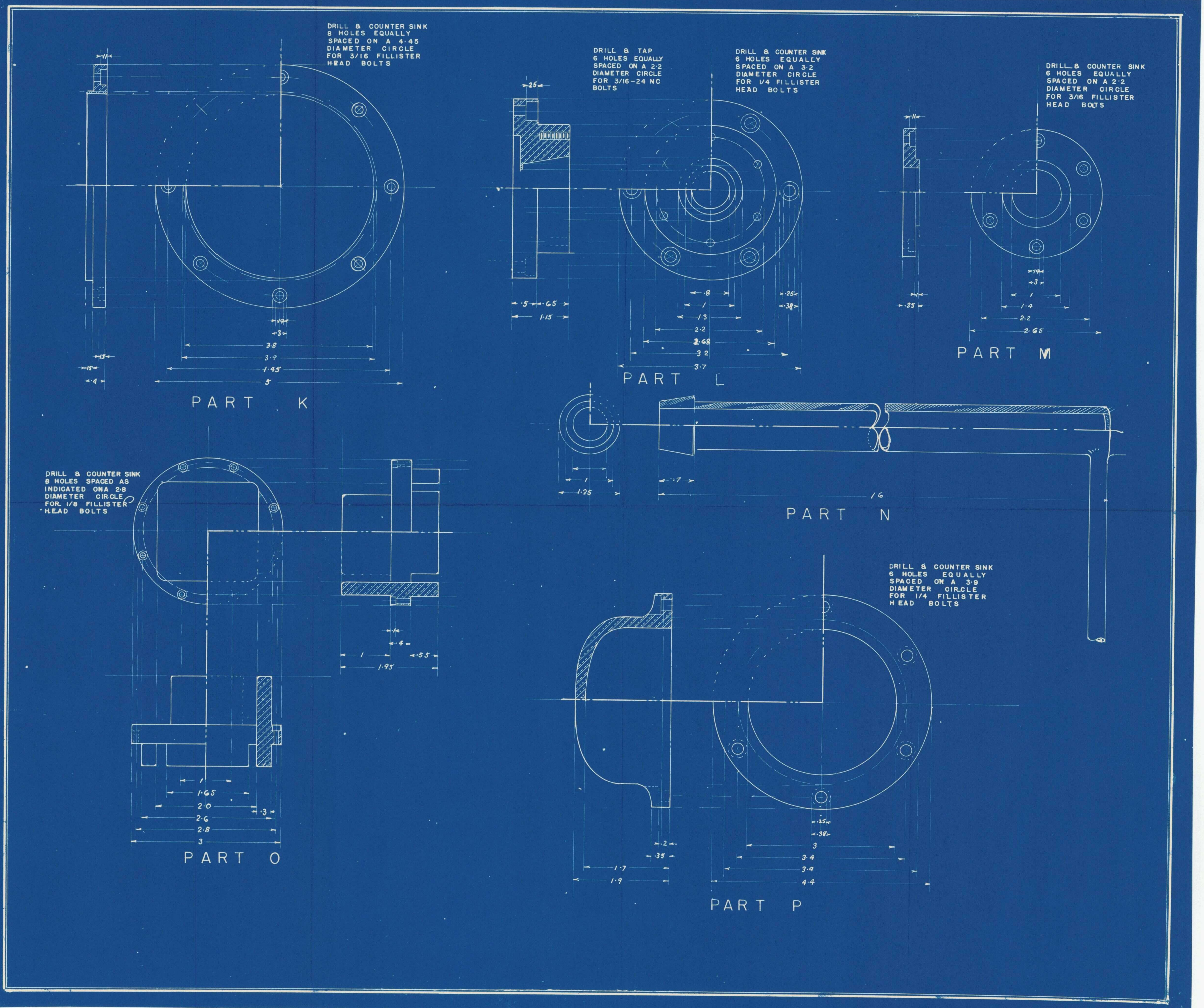
PART G

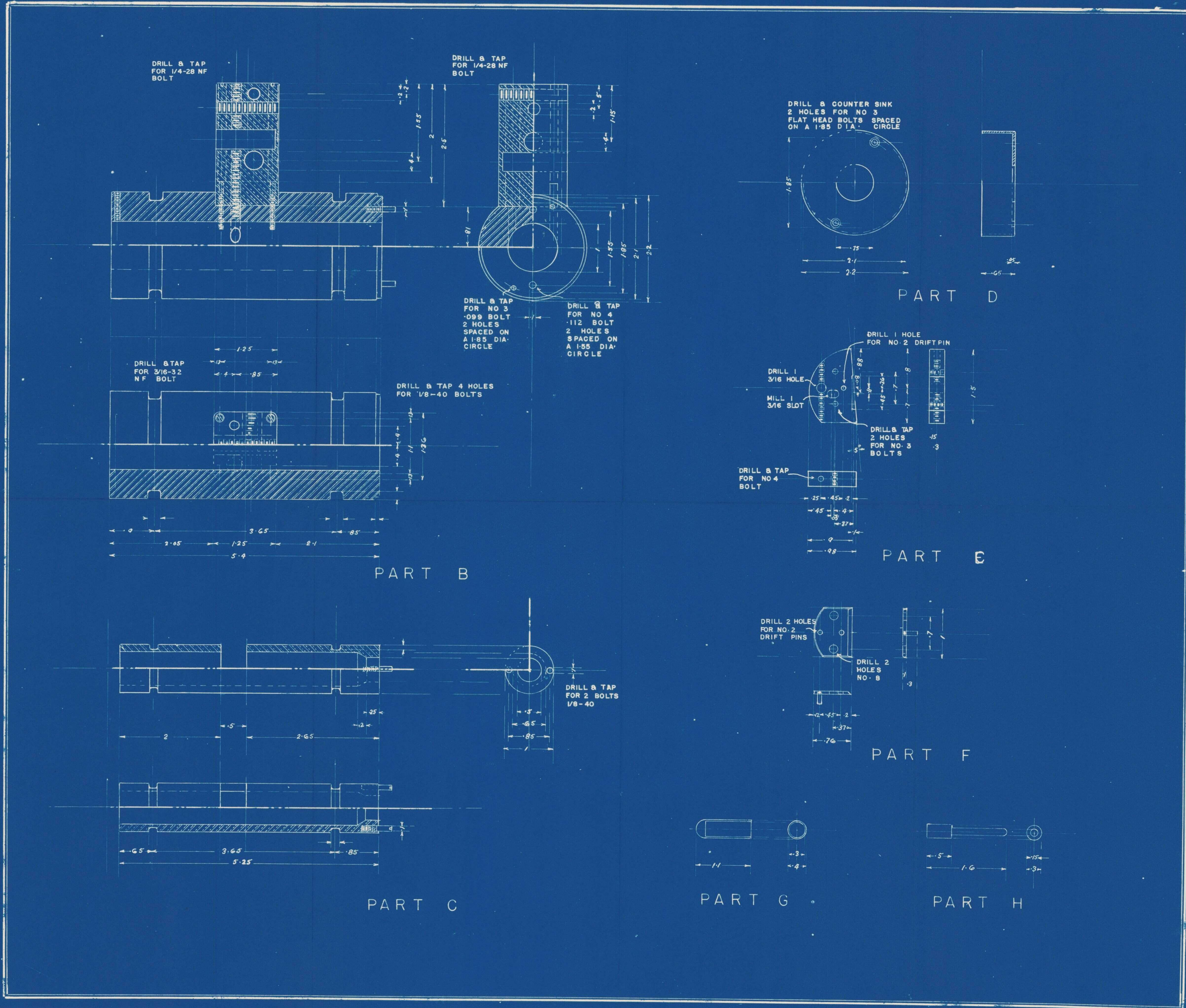


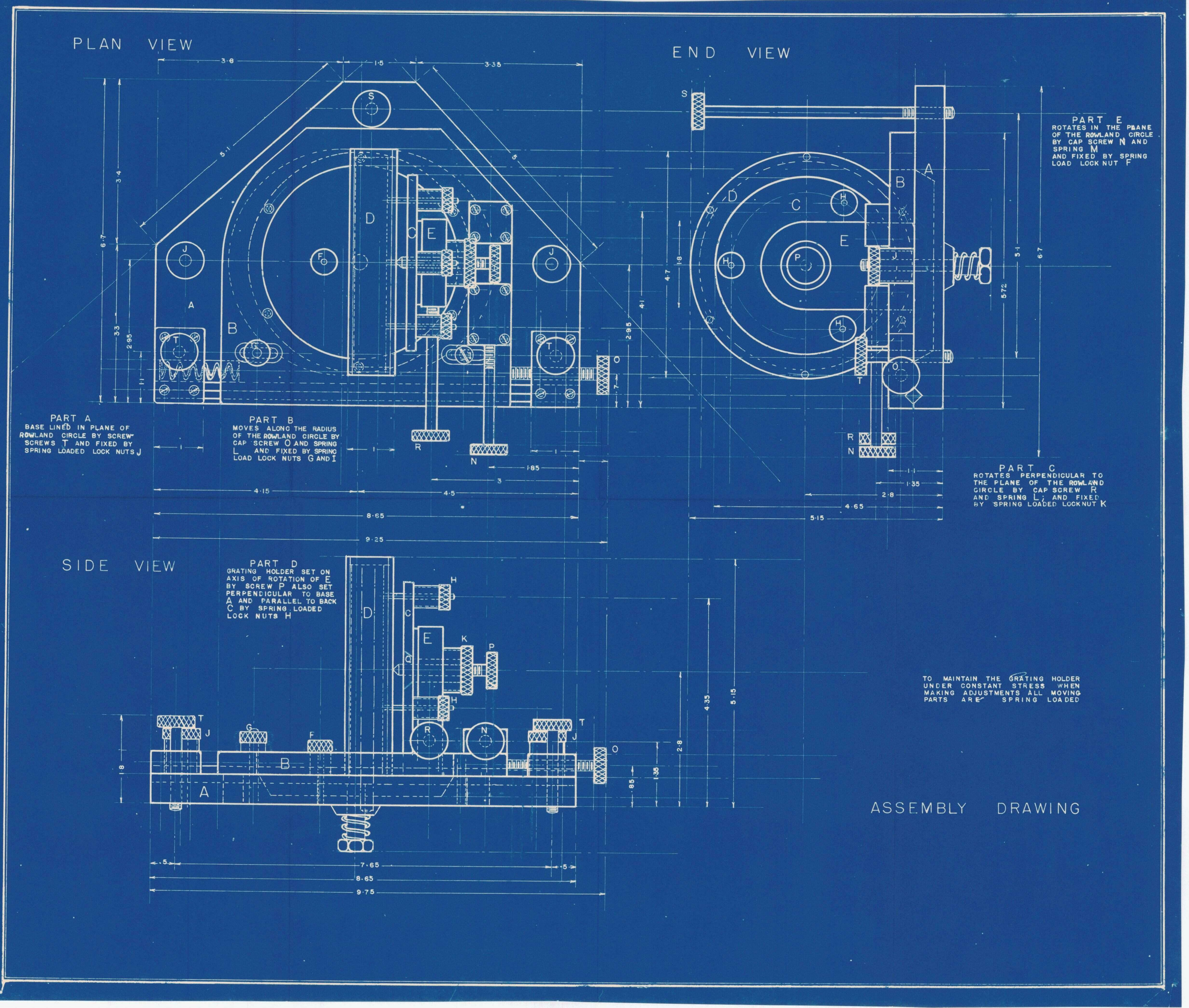
PART P
THE CONTROL COVER
PART B
MOVES THE SLIT (IN THE PLAIN) ACROSS THE ROWLAND CIRCLE BY MEANS OF THUMB SCREW I-1
AND ROTATES THE SLIT ABOUT AN AXIS IN THE PLAIN OF THE ROWLAND CIRCLE BY MEANS OF THUMB SCREW I-2
PART K
USED FOR FIXING, TO WALL
SIDE VIEW
PART A
THE MAIN HOUSING
PART C
ROTATES INSIDE OF PART B AND MOVES THE 2 HALVES OF PART E IN OPPOSITE DIRECTIONS
END VIEW
PARTS L & M
FIX THE DISCHARGE TUBE
ASSEMBLY DRAWING
PARTS E
ARE AT 5° TO THE KNIFE EDGES HENCE MOVEMENT OF KNIFE EDGES IS 2 SINE 5°
PART F
KNIFE EDGES
TOP VIEW
A MAGNIFICATION OF THE SLIT MECHANISM
SCALE 2:1
SPECTROGRAPH SLIT
SCALE FULL

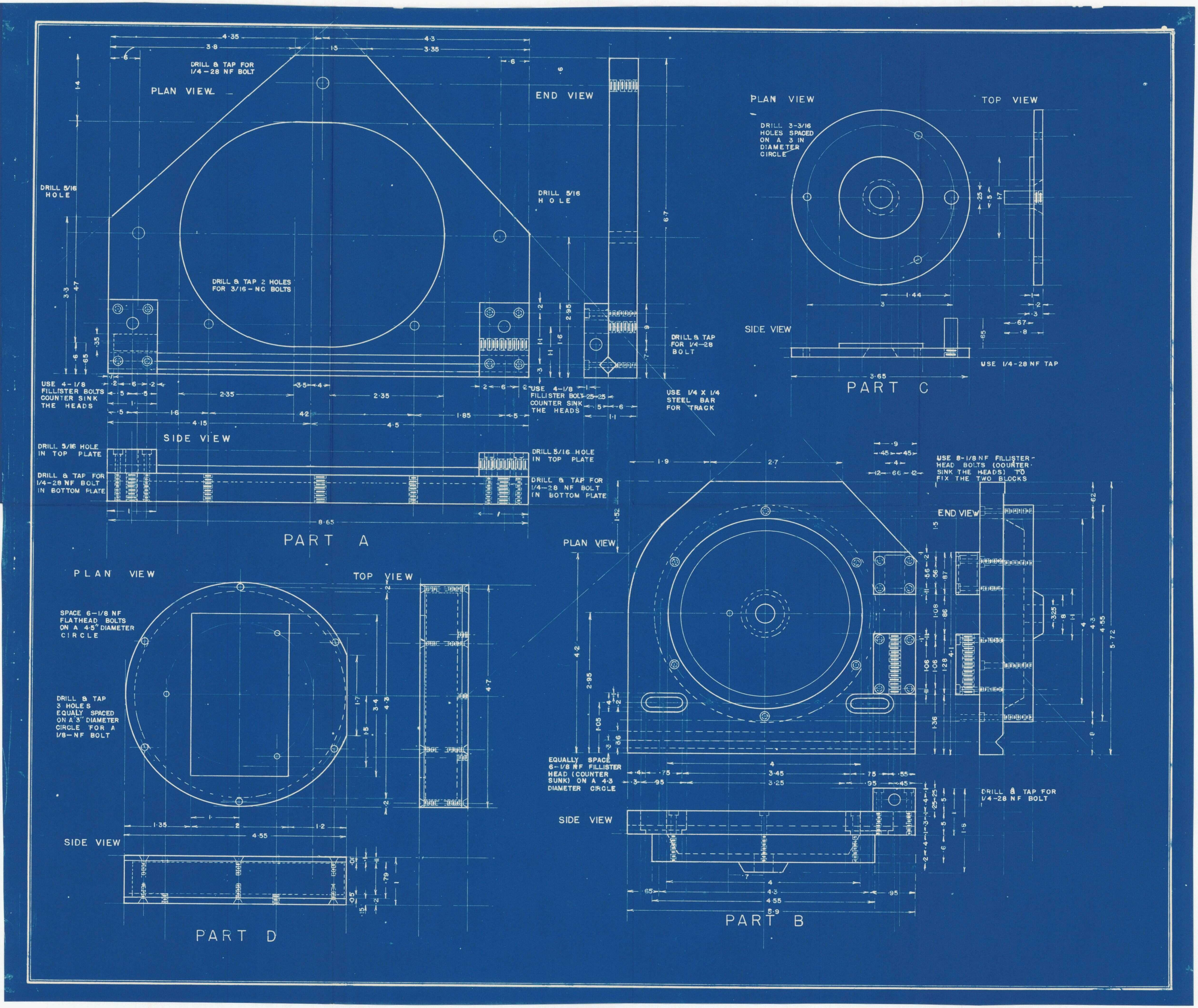


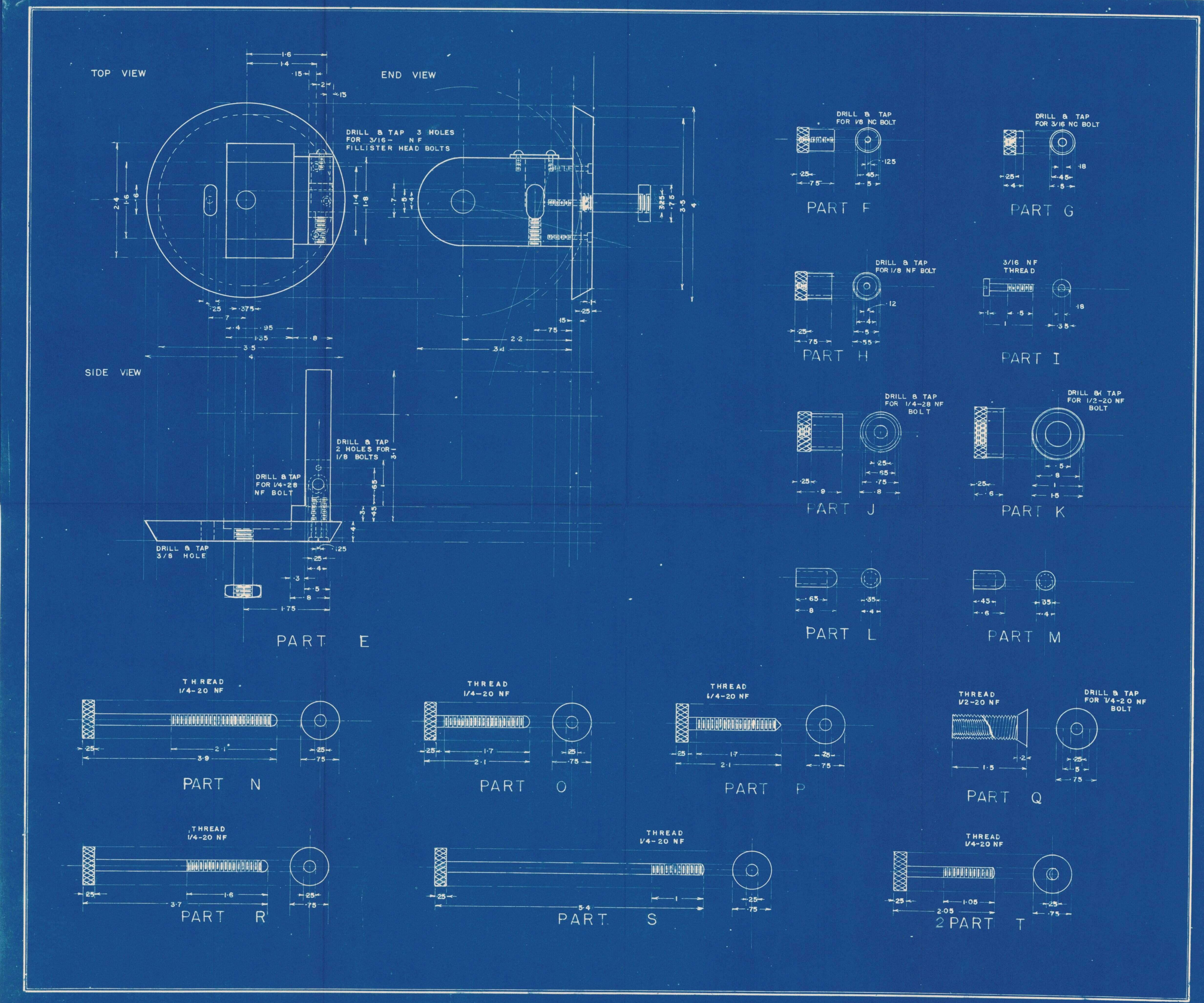
DRILL FOR 3/8 BOLT
6 HOLES EQUALLY
SPACED ON A 4·2
DIAMETER CIRCLE
DRILL AND TAP FOR
3/16—24 NC BOLT
8 HOLES EQUALLY
SPACED ON A 4·45
DIAMETER CIRCLE
DRILL AND TAP FOR
1/4-20 NC BOLT
6 HOLES EQUALLY
SPACED ON A 3·2
DIAMETER CIRCLE
DRILL AND TAP FOR
1/4 BOLT NC 6 HOLES
EQUALLY SPACED ON
A 3·9 DIAMETER
CIRCLE
DRILL AND TAP FOR
1/8-40 NC BOLT
8 HOLES SPACED
AS INDICATED ON
A 2·8 DIAMTER
CIRCLE
PART A
THREAD
1/4-28 NF
THREAD
3/16-32 NF
PART I
PART J

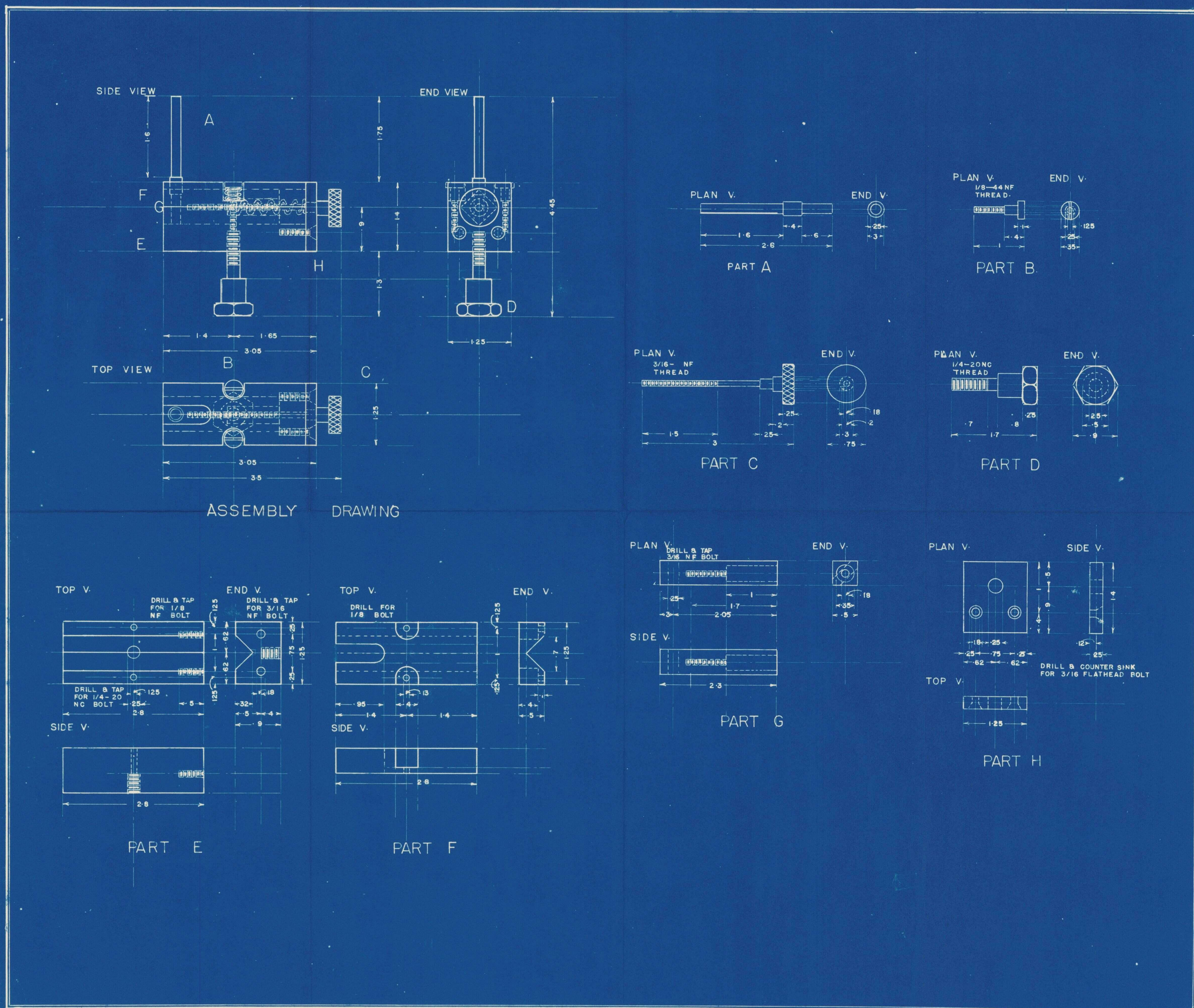

DRILL & COUNTER SINK 8 HOLES EQUALLY SPACED ON A 4·45 DIAMETER CIRCLE FOR 3/16 FILLISTER HEAD BOLTS
PART K
DRILL & TAP 6 HOLES EQUALLY SPACED ON A 2·2 DIAMETER CIRCLE FOR 3/16–24 NC BOLTS
DRILL & COUNTER SINK 6 HOLES EQUALLY SPACED ON A 3·2 DIAMETER CIRCLE FOR 1/4 FILLISTER HEAD BOLTS
PART L
DRILL & COUNTER SINK 6 HOLES EQUALLY SPACED ON A 2·2 DIAMETER CIRCLE FOR 3/16 FILLISTER HEAD BOLTS
PART M
PART N
DRILL & COUNTER SINK 8 HOLES SPACED AS INDICATED ON A 2·8 DIAMETER CIRCLE FOR 1/8 FILLISTER HEAD BOLTS
PART O
DRILL & COUNTER SINK 6 HOLES EQUALLY SPACED ON A 3·9 DIAMETER CIRCLE FOR 1/4 FILLISTER HEAD BOLTS
PART P

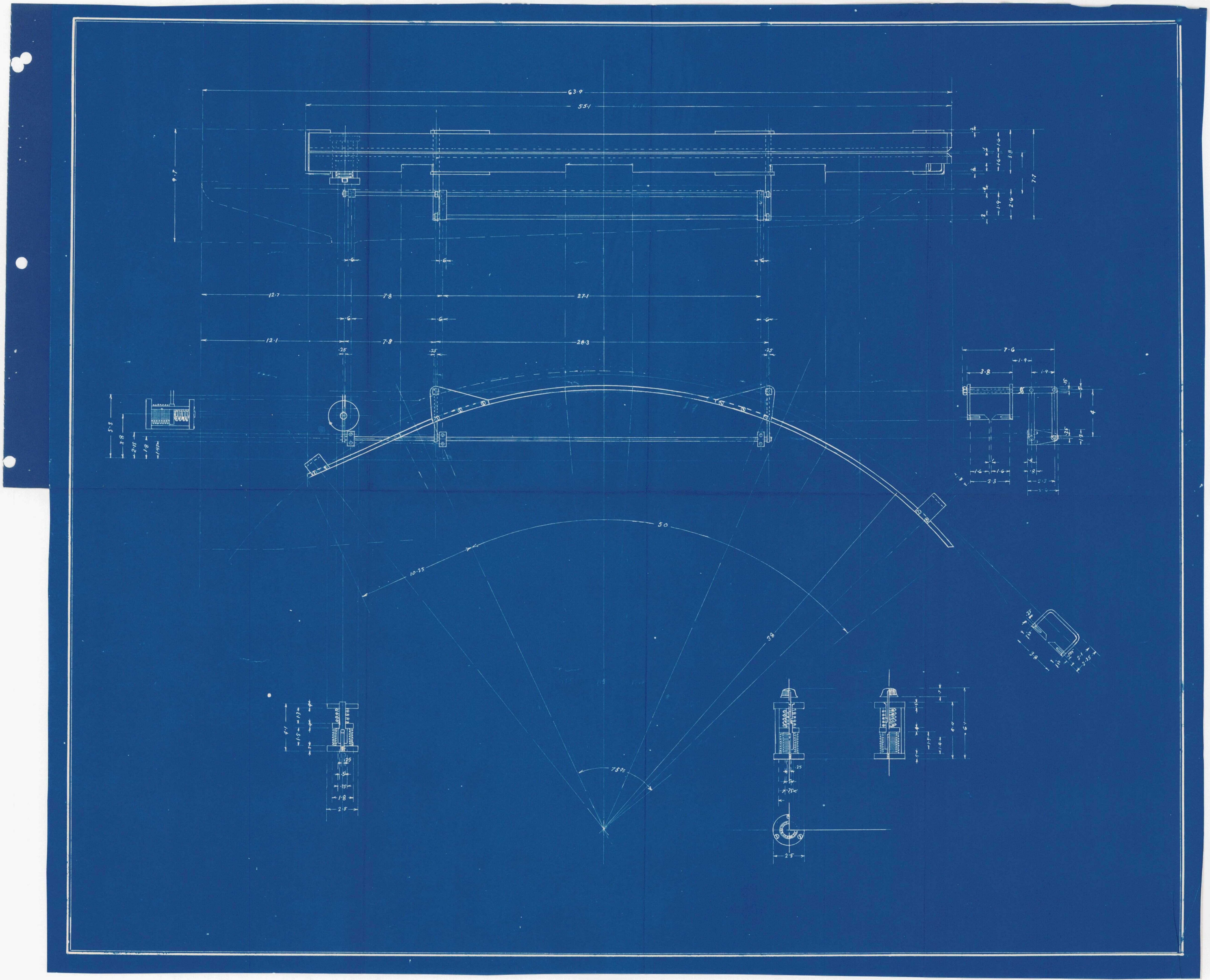

DRILL & TAP FOR 1/4-28 NF BOLT
DRILL & TAP FOR 1/4-28 NF BOLT
DRILL & TAP FOR NO 3 ·099 BOLT 2 HOLES SPACED ON A 1·85 DIA· CIRCLE
DRILL & TAP FOR NO 4 ·112 BOLT 2 HOLES SPACED ON A 1·55 DIA· CIRCLE
DRILL & TAP FOR 3/16-32 NF BOLT
DRILL & TAP 4 HOLES FOR 1/8-40 BOLTS
PART B
DRILL & COUNTER SINK 2 HOLES FOR NO 3 FLAT HEAD BOLTS SPACED ON A 1·85 DIA· CIRCLE
PART D
DRILL 1 HOLE FOR NO· 2 DRIFT PIN
DRILL 1 3/16 HOLE
MILL 1 3/16 SLOT
DRILL & TAP 2 HOLES FOR NO· 3 BOLTS
DRILL & TAP FOR NO 4 BOLT
PART E
DRILL & TAP FOR 2 BOLTS 1/8-40
PART C
DRILL 2 HOLES FOR NO· 2 DRIFT PINS
DRILL 2 HOLES NO· 8
PART F
PART G
PART H


PLAN VIEW
END VIEW
PART E
ROTATES IN THE PLANE OF THE ROWLAND CIRCLE BY CAP SCREW N AND SPRING M AND FIXED BY SPRING LOAD LOCK NUT F
PART A
BASE LINED IN PLANE OF ROWLAND CIRCLE BY SCREW SCREWS T AND FIXED BY SPRING LOADED LOCK NUTS J
PART B
MOVES ALONG THE RADIUS OF THE ROWLAND CIRCLE BY CAP SCREW O AND SPRING L AND FIXED BY SPRING LOAD LOCK NUTS G AND I
PART C
ROTATES PERPENDICULAR TO THE PLANE OF THE ROWLAND CIRCLE BY CAP SCREW R AND SPRING L; AND FIXED BY SPRING LOADED LOCKNUT K
SIDE VIEW
PART D
GRATING HOLDER SET ON AXIS OF ROTATION OF E BY SCREW P ALSO SET PERPENDICULAR TO BASE A AND PARALLEL TO BACK C BY SPRING LOADED LOCK NUTS H
TO MAINTAIN THE GRATING HOLDER UNDER CONSTANT STRESS WHEN MAKING ADJUSTMENTS ALL MOVING PARTS ARE SPRING LOADED
ASSEMBLY DRAWING

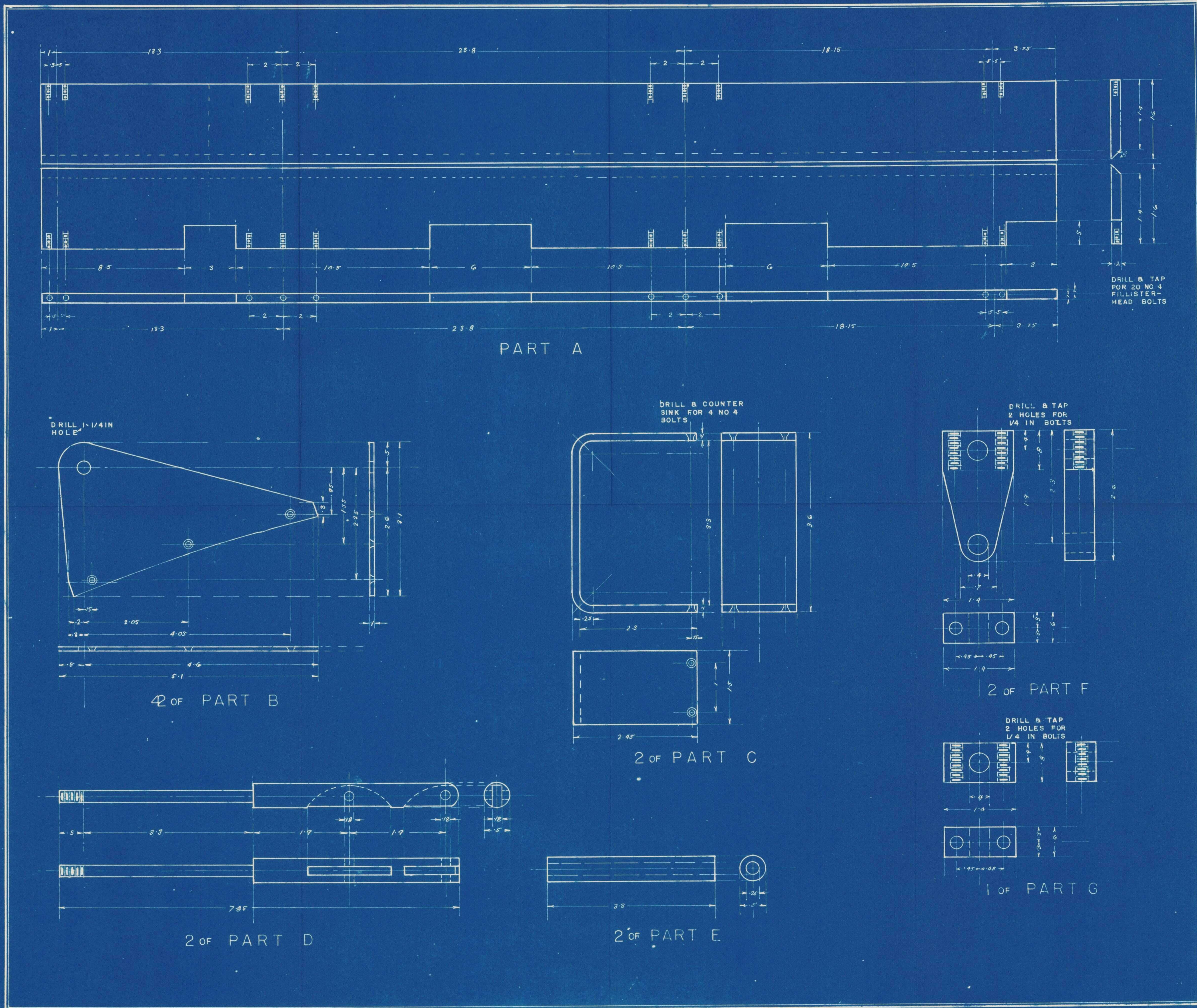

PLAN VIEW
DRILL & TAP FOR 1/4-28 NF BOLT
END VIEW
DRILL 5/16 HOLE
DRILL 5/16 HOLE
DRILL & TAP 2 HOLES FOR 3/16-NC BOLTS
DRILL & TAP FOR 1/4-28 BOLT
USE 4-1/8 FILLISTER BOLTS COUNTER SINK THE HEADS
USE 4-1/8 FILLISTER BOLTS COUNTER SINK THE HEADS
USE 1/4 X 1/4 STEEL BAR FOR TRACK
SIDE VIEW
DRILL 5/16 HOLE IN TOP PLATE
DRILL & TAP FOR 1/4-28 NF BOLT IN BOTTOM PLATE
DRILL 5/16 HOLE IN TOP PLATE
DRILL & TAP FOR 1/4-28 NF BOLT IN BOTTOM PLATE
PART A
PLAN VIEW
TOP VIEW
DRILL 3-3/16 HOLES SPACED ON A 3 IN DIAMETER CIRCLE
SIDE VIEW
USE 1/4-28 NF TAP
PART C
PLAN VIEW
TOP VIEW
SPACE 6-1/8 NF FLATHEAD BOLTS ON A 4·5" DIAMETER CIRCLE
DRILL & TAP 3 HOLES EQUALY SPACED ON A 3" DIAMETER CIRCLE FOR A 1/8-NF BOLT
SIDE VIEW
PART D
USE 8-1/8 NF FILLISTER-HEAD BOLTS (COUNTER-SINK THE HEADS) TO FIX THE TWO BLOCKS
END VIEW
PLAN VIEW
EQUALLY SPACE 6-1/8 NF FILLISTER HEAD (COUNTER SUNK) ON A 4·3 DIAMETER CIRCLE
SIDE VIEW
DRILL & TAP FOR 1/4-28 NF BOLT
PART B

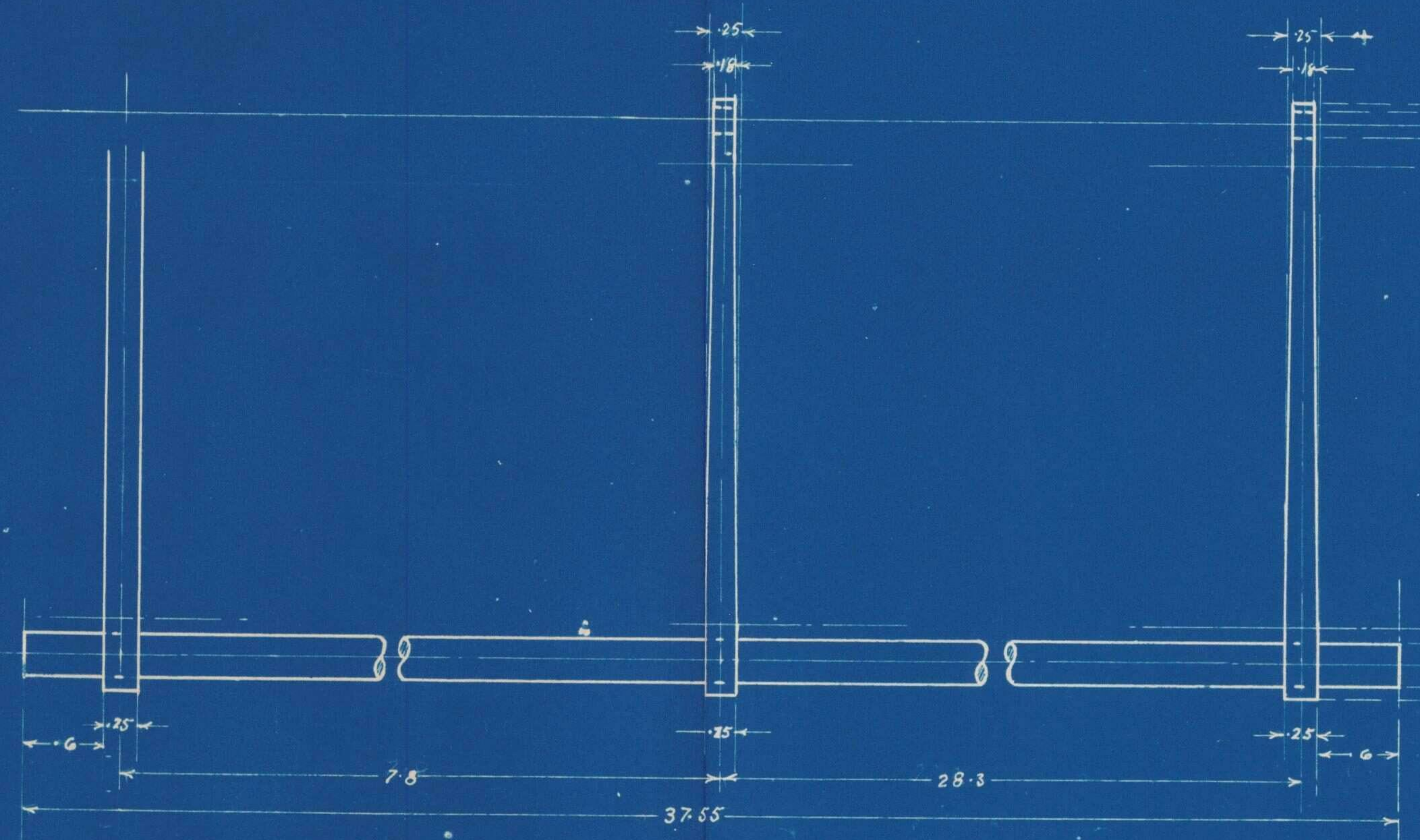

TOP VIEW
END VIEW
DRILL & TAP 3 HOLES FOR 3/16- NF FILLISTER HEAD BOLTS
SIDE VIEW
DRILL & TAP 2 HOLES FOR 1/8 BOLTS
DRILL & TAP FOR 1/4-28 NF BOLT
DRILL & TAP 3/8 HOLE
PART E
DRILL & TAP FOR 1/8 NC BOLT
PART F
DRILL & TAP FOR 3/16 NC BOLT
PART G
DRILL & TAP FOR 1/8 NF BOLT
PART H
3/16 NF THREAD
PART I
DRILL & TAP FOR 1/4-28 NF BOLT
PART J
DRILL & TAP FOR 1/2-20 NF BOLT
PART K
PART L
PART M
THREAD 1/4-20 NF
PART N
THREAD 1/4-20 NF
PART O
THREAD 1/4-20 NF
PART P
THREAD 1/2-20 NF
DRILL & TAP FOR 1/4-20 NF BOLT
PART Q
THREAD 1/4-20 NF
PART R
THREAD 1/4-20 NF
PART S
THREAD 1/4-20 NF
2 PART T


SIDE VIEW
END VIEW
A
F
G
E
H
D
1·6
1·75
4·45
1·4
·9
1·3
1·4
1·65
3·05
1·25
TOP VIEW
B
C
1·25
3·05
3·5
ASSEMBLY DRAWING
PLAN V.
END V.
1·6
·4
·6
2·6
·25
·3
PART A
PLAN V.
END V.
1/8—44 NF THREAD.
·1
·4
1
·125
·25
·35
PART B.
PLAN V.
3/16— NF THREAD
END V.
·25
·2
·25
1·5
3
·18
·2
·3
·75
PART C
PLAN V.
1/4—20 NC THREAD
END V.
·7
·8
·25
1·7
·25
·5
·9
PART D
PLAN V.
DRILL & TAP 3/16 NF BOLT
END V.
·25
1
1·7
·3
2·05
·18
·35
·5
SIDE V.
2·3
PART G
PLAN V.
SIDE V.
·5
·9
·4
1·4
·18
·25
·25
·75
·25
·62
·62
·12
·25
DRILL & COUNTER SINK FOR 3/16 FLATHEAD BOLT
TOP V.
1·25
PART H
TOP V.
DRILL & TAP FOR 1/8 NF BOLT
END V.
DRILL & TAP FOR 3/16 NF BOLT
·125
·62
·62
·125
·75
1·25
·25
DRILL & TAP FOR 1/4-20 NC BOLT
·125
·25
·5
2·8
·32
·18
·5
·4
·9
SIDE V.
2·8
PART E
TOP V.
DRILL FOR 1/8 BOLT
END V.
·125
·125
·7
1·25
·95
·13
·4
1·4
1·4
·4
·5
SIDE V.
2·8
PART F

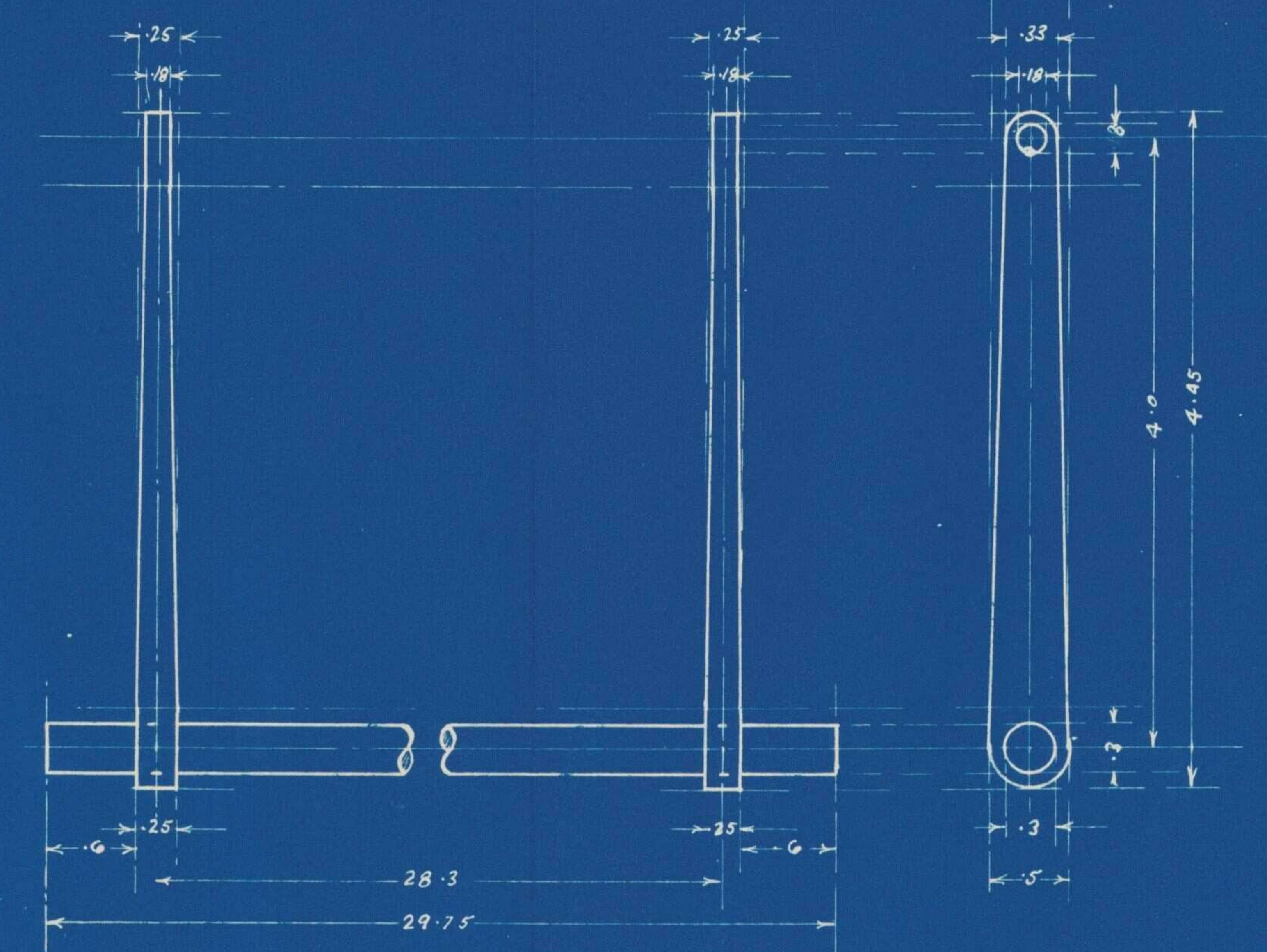


63·9
55·1
9·7
7·7
12·7
7·8
27·1
12·1
7·8
28·3
·6
·25
5·3
3·8
7·6
1·9
3·8
1·9
3·3
50
10·25
38
4·1
1·8
2·5
2·5

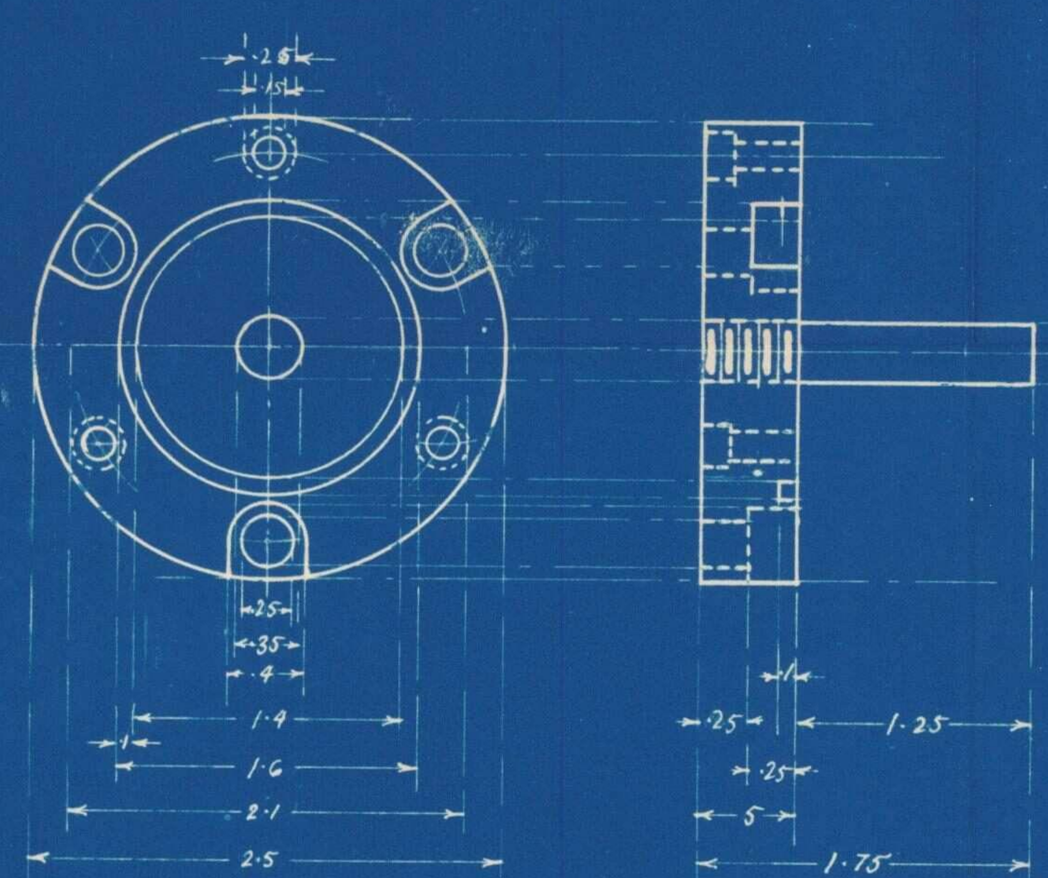

DRILL & TAP FOR 20 NO 4 FILLISTER-HEAD BOLTS
PART A
DRILL 1-1/4 IN HOLE
42 OF PART B
DRILL & COUNTER SINK FOR 4 NO 4 BOLTS
2 OF PART C
DRILL & TAP 2 HOLES FOR 1/4 IN BOLTS
2 OF PART F
DRILL & TAP 2 HOLES FOR 1/4 IN BOLTS
1 OF PART G
2 OF PART D
2 OF PART E



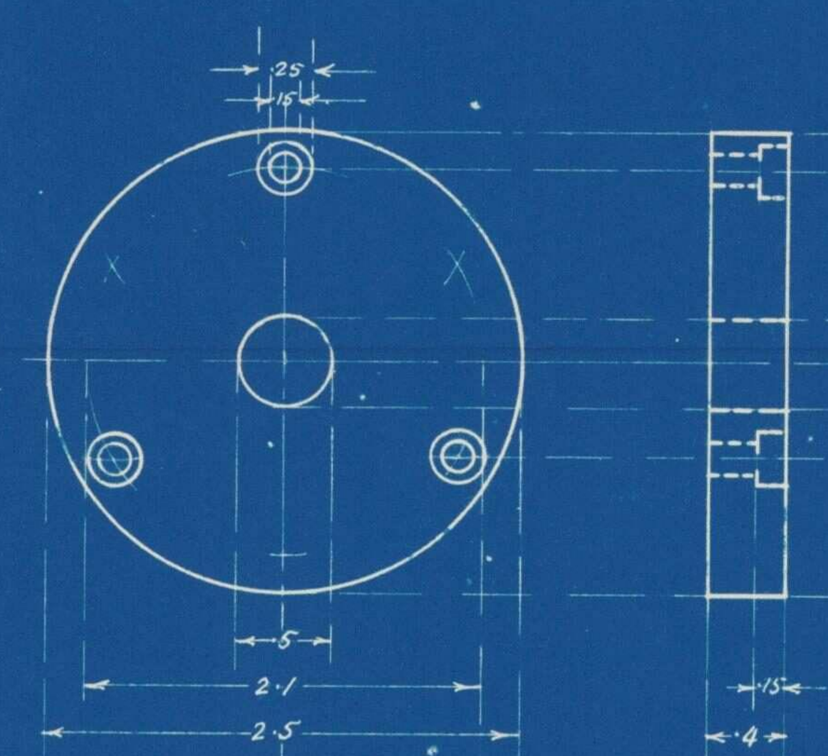
PART H



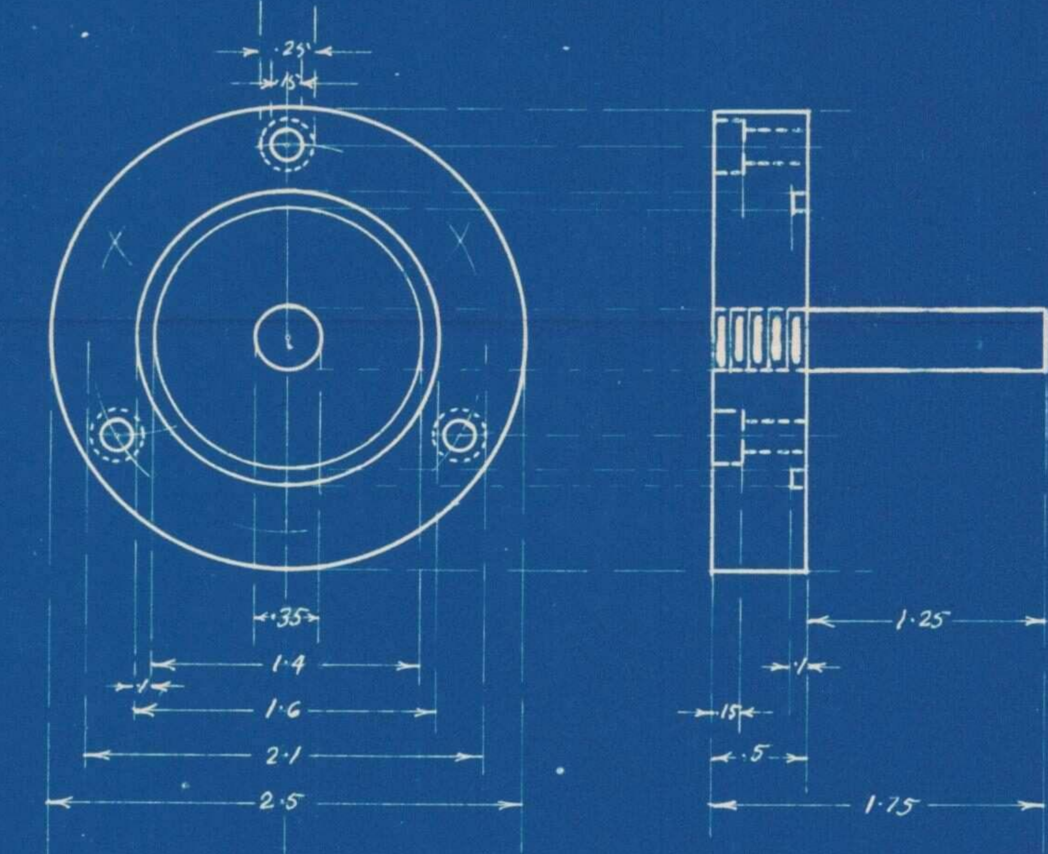
PART I



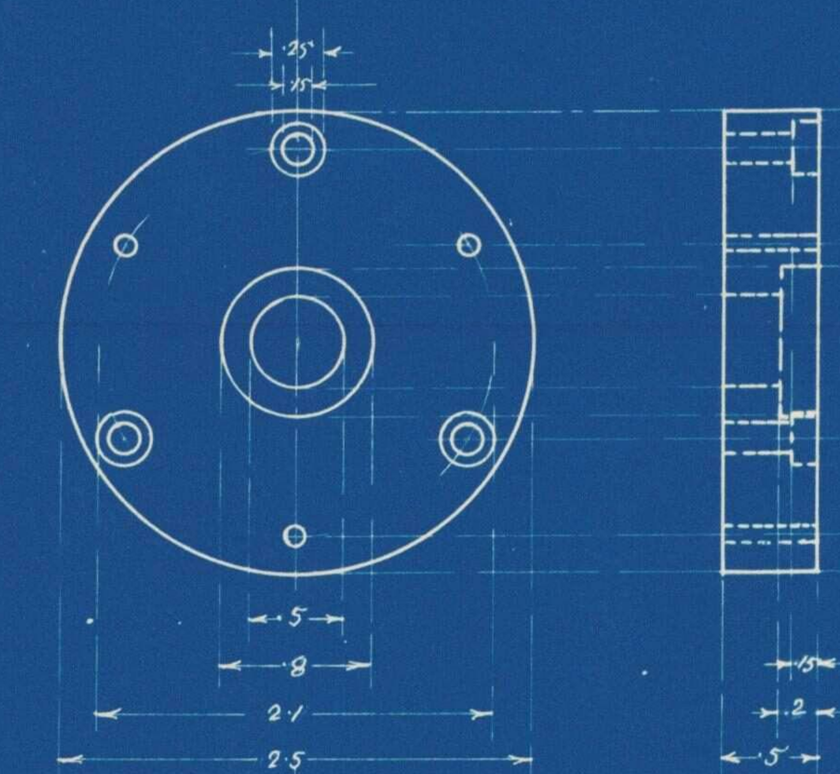
PART J



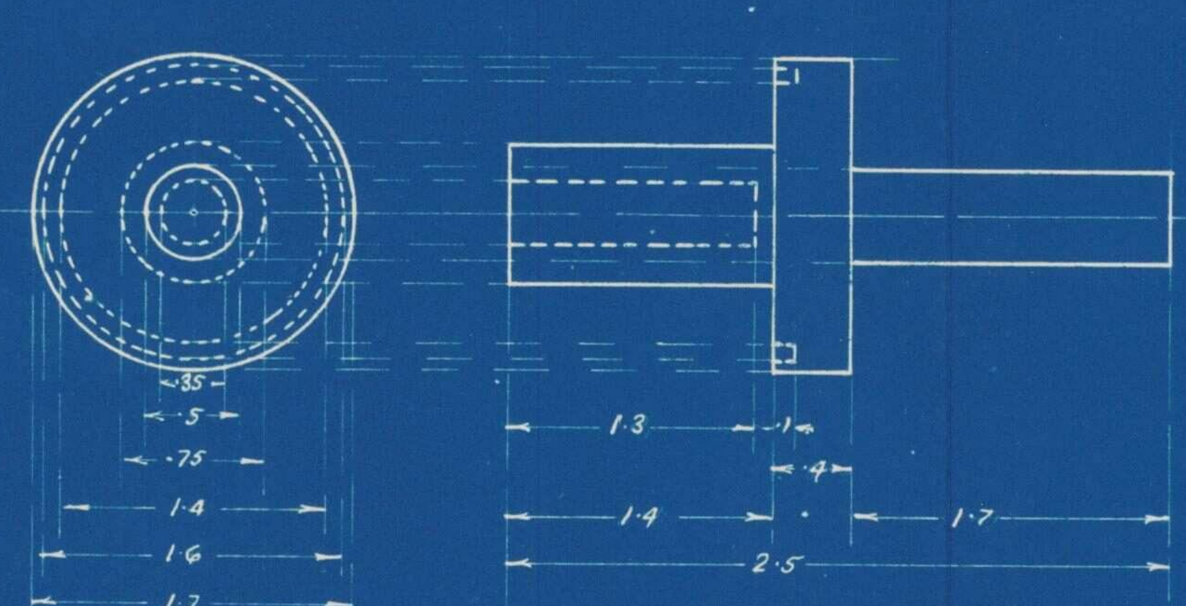
PART K



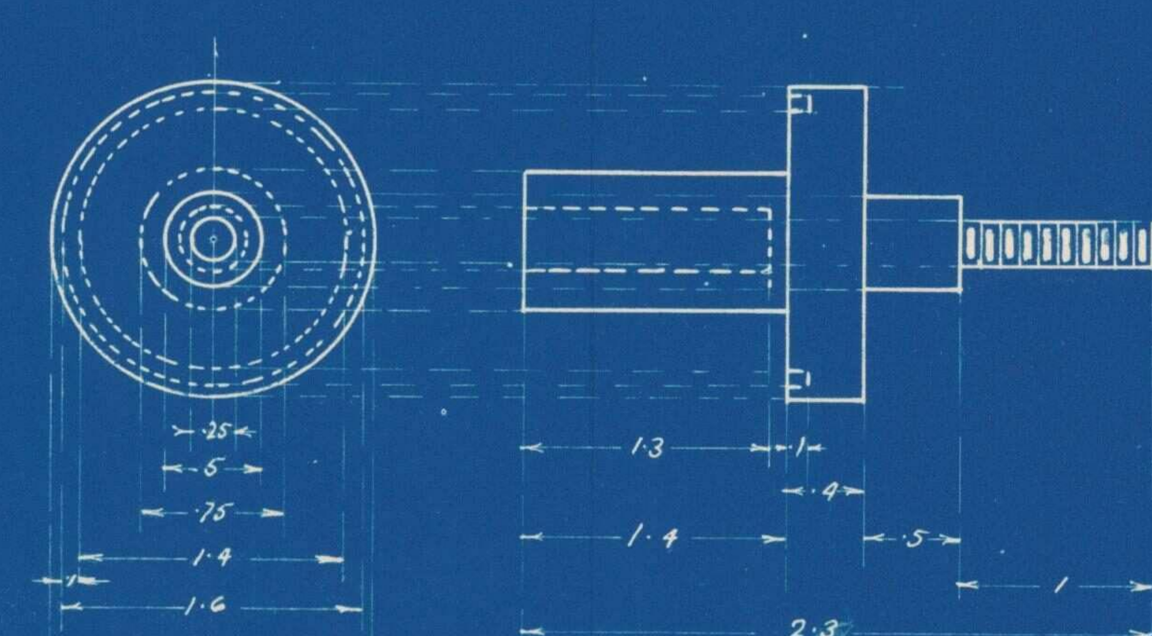
PART L



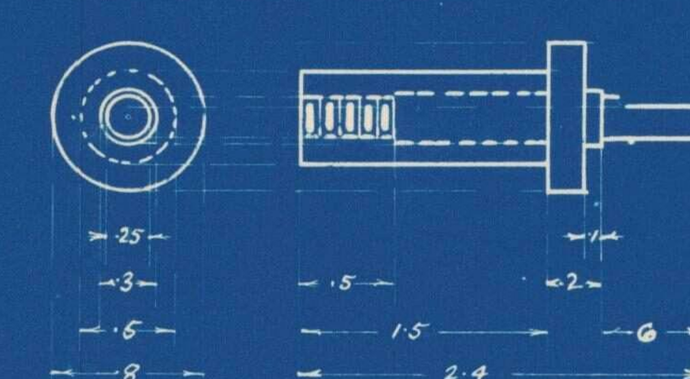
PART M



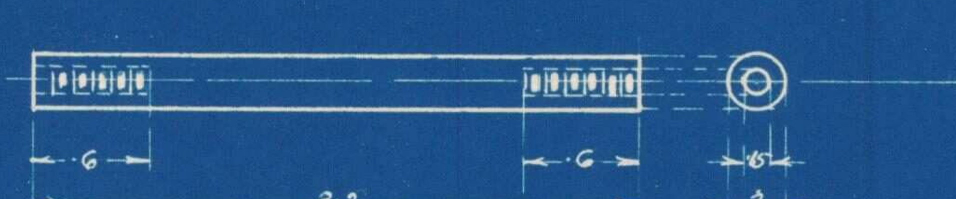
PART N



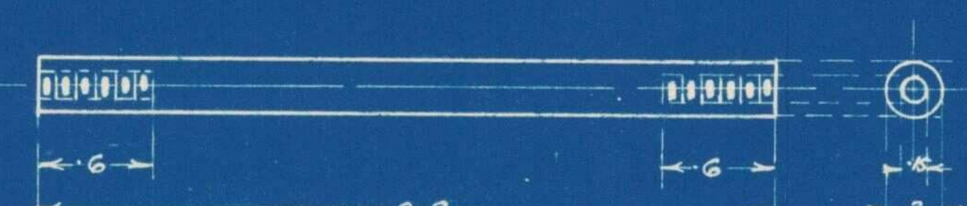
PART O



PART P



3 OF PART Q



3 OF PART R