FINAL REPORT - ELECTRON BEAM X-Y DEFLECTION SYSTEM

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June 1971

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

CONTRACT NAS8-26662

WESTINGHOUSE RESEARCH LABORATORIES
PITTSBURGH, PENNSYLVANIA 15235

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Abstract: An electron beam X-Y deflection system designed and fabricated for retrofit on the welding guns developed under contracts NAS8-20678 and NAS8-26350 is described in detail and test results are presented.

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CONTENTS

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I. INTRODUCTION

This report describes in detail an electron beam X-Y deflection system designed and fabricated for George C. Marshall Space Flight Center. This deflection system is defined by Westinghouse Design Specification D763688 entitled "Beam Deflection System." The system has been developed for retrofit on the electron beam welding guns developed and built under contracts NAS8-20678 and NAS8-26350.

The purpose of this deflection system is to provide a means of correcting for angular or lateral deviations of the electron beam from the electron gun axis. The necessity for having the capability to make such corrections is discussed in part II of this report.

A detailed electrical, magnetic, and mechanical description of the X-Y deflection system constitutes part III; retrofitting the X-Y deflection system to the existing electron gun is discussed in part IV. Part V presents the electrical requirements of the deflection system coils and part VI presents some comments which, it is hoped, will be of use in the operation of the deflection system. Part VII contains some comments useful in trouble-shooting the system should operational difficulties arise. Part VIII presents the results of certain neccessarily limited tests performed on the system at Westinghouse. The self-contained welding gun, for which this deflection system was built, was not available for these tests. Conclusions and recommendations are presented in part IX. Finally, drawings of the deflection system are included as part X.

II. NEED FOR X-Y DEFLECTION SYSTEM

The existing electron beam welding gun developed under contract NAS8-20678 contains an electron gun which produces a 20 keV, 100 mA electron beam. This beam travels through a "zig-zag" deflection coil system which causes the beam to bend through a certain angle away from the initial direction of travel and, after traversing a short region in this new direction, bend again through the same angle back toward the original direction of travel, so that the beam leaving the "zig-zag" deflection system is travelling in a straight path parallel to the original direction of travel but displaced transversely by about 1.27 cm (.5 in.). The beam then passes through a magnetic lens which can be adjusted to cause the beam to come to a focus at the weld specimen or work area. The final beam path lies roughly along the central axis of the magnetic lens but may be displaced laterally from this axis and/or exhibit some small angular deviation from the desired path. (The reasons for these deviations are discussed in a later paragraph.) In the existing electron optical system no device exists for correcting these small displacements and/or angular deviations and returning the beam to the desired path.

The zig-zag deflection system was incorporated to produce a lateral beam displacement that would eliminate any line-of-sight path from the work area to the high voltage region of the electron gun, to prevent contamination or damage to the electron gun which could be caused by metal droplets or splatter produced at the work under zero-gravity conditions. The magnetic fields produced by the zig-zag system are precisely adjusted (by adjusting the coil currents) to bend the 20 keV electron beam through the required angles. The magnetic flux density is determined by the electron gun accelerating voltage and the required angular deflection and once established, need not (and should not) be adjusted.

This electron-optical system was conceived, developed, and fabricated for the specific task of bead-on-plate welding in a series of experiments to be performed in an orbiting laboratory. Precise alignment of the beam was not required to perform these experiments. Between the time of the original development and fabrication of the electron-optical system and the present time, the scope of the experimental program has been enlarged considerably. Present plans call for the electron beam to be used to make at least one joint weld and also to be used to melt metal targets in a sphere-forming experiment. In the first case the beam must strike a point on the magnetic lens central axis a distance of approximately 4.76 cm (1.88 in.) from the end of the existing lens nozzle; and in the second case a defocused beam must irradiate a small area centered on the magnetic lens axis a distance of approximately 15.2 cm (6.0 in.) from the end of the existing lens nozzle.

Clearly in both cases precise alignment of the electron beam on the point of interest is required to obtain meaningful (and reproducible) experimental results. As previously stated, the existing electron optical system does not provide any means for systematically centering the beam or steering the beam to some desired point. Of course the question arises as to why it should be necessary to correct the beam alignment; or, stated differently, why doesn't the existing electron beam welding system produce a beam which is on axis with no displacements or deviations, and remains on axis? This question can be answered by considering how the electron beam is formed and what factors influence the beam trajectory both in the region where it is formed (within the electron gun) and also in the region between the electron gun and the weld specimen or workpiece.

The electron beam is formed from electrons emitted by a tungsten filament which has been heated to about 2800 to 2900°K. This filament is maintained at -20 kV with respect to the gun anode; thus electrons emitted from the filament experience a force which accelerates them toward the anode. A grid cup held at -400 V with respect to the filament helps control the electron emission from the filament and, together with the anode, shapes the electric field lines (between the grid and anode) in such a way as to force the electrons into a narrow beam which passes through a hole in the anode and travels along a path already described to the workpiece. The path of the electron beam from the region where it is formed to the workpiece is influenced primarily by the following factors:

1) Alignment of the gun filament on the gun axis;

2) Magnetic fields present within the gun or external to the gun;

3) Electrostatic fields internal and external to the gun.

Let us consider each one of these in more detail.

1) Alignment of the gun filament on the gun axis -- The centering of the filament on the gun axis is extremely critical in determining whether or not the electron beam will travel along the gun axis or at some small angular deviation. The actual centering adjustments involve observation and judgments by experienced personnel, which at first would seem to be a crude method to employ for such a critical step. However it must be pointed out that any more precise alignment is probably not justified because of the tendency of the filament to move slightly or change position each time it is heated. Formation of the filament from flat tungsten ribbon produces unrelieved stresses in the filament, especially where sharp bends have been made. When the filament is heated, especially the first time, some of the stresses are relieved, causing the filament to twist or warp slightly from its original position. For this reason the final filament centering is not carried out until after the initial heating ("flashing"). Heating also produces differential thermal expansion of the filament with respect to its relatively cool support posts, thus introducing additional stresses. The filament can still be expected to shift slightly on subsequent heating cycles, thus contributing to angular deviation of the electron beam.

2) Magnetic fields present within the gun or external to the gun -- The forces exerted upon charged particles by magnetic fields are very well known and well understood. It is also well known that magnetic fields are produced by electric currents; thus the electron beam itself produces a magnetic field whose flux density is about 2×10^{-6} T (.02 G) at a distance of 1 cm (.394 in.) from the beam. The electron gun filament current is about 16 A. This current creates a magnetic field which is quite strong near the surface of the filament.

Electrons emitted from the filament surface are acted upon by this field, resulting in changes in the electron trajectories. Clearly this effect can produce angular deviations of the beam electrons from the gun axis. Furthermore as the filament current is changed (to vary the beam current) the strength of the magnetic field changes, thus altering the beam deviation.

Considering now the magnetic fields external to the electron gun we must first discuss the fields which are external to the gun itself but still part of the electron-optical system, namely the magnetic lens field and the fields of the "zig-zag" deflection system. It is well known that the lateral deflection of an electron beam passing through a uniform transverse magnetic field is inversely proportional to the square root of the voltage used to accelerate the beam. It follows that any variation in the accelerating voltage will produce a variation in the lateral displacement of the beam as it traverses the zig-zag deflection system. Additionally, any variation in the zig-zag deflection coil current will also produce variation in the lateral displacement of the beam, although in the existing system the coil current is regulated to .1%.

It is also well known that the focal length of the magnetic lens is directly proportional to the voltage used to accelerate the beam. Thus variations in the accelerating voltage produce variations in the lens focal length, changing the axial position of the beam focus or crossover. There is an additional effect if the beam does not enter the lens exactly on-axis. If, for example, the entering beam is off-axis but parallel to the axis, then the crossover is produced off-axis and the diverging beam no longer travels parallel to the axis. In this case variations in the accelerating voltage not only change the axial position of the beam crossover, but produce variations in the lateral displacement of the crossover from the lens axis.

In addition to the known magnetic fields which are part of the electron-optical system there may be other magnetic fields in the region of the beam path. These fields may or may not have a significant effect on the beam path, depending on their direction and magnitude. For 20 keV electrons the field-curvature constant $H\rho$ is 481.5 Oe-cm (equivalent to 4.815×10^{-2} T-cm or 481.5 G-cm).* It is interesting to estimate the influence of the earth's field on the electron beam. The magnitude of the earth's field is approximately 5.5×10^{-5} T (.55 G). Thus over the entire 24 cm path from the electron gun to the workpiece, the variation in the lateral displacement of the beam that can result depending on whether the beam is travelling parallel to or perpendicular to the field of the earth is about .33 cm (.13 in.). This one effect in itself is sufficient cause to require the use of an alignment system if the beam is to be steered to a given point to better than .33 cm (about 1/8 in.) accuracy.

Much stronger fields than the earth's field may be present near the beam. Some obvious sources of fields are permanent magnet motors, structural members made of iron or any magnetic alloy, magnets on discharge vacuum gauge tubes, weld specimens containing iron, nickel, steel or some other magnetic material, etc. For this reason it is obvious that great care must be taken to map the magnetic fields in the region of the beam to make certain that the effects of whatever fields are present can be counteracted with the X-Y deflection system.

3) Electrostatic fields internal and external to the gun -- It is also well known that the trajectories of electrons (and all other charged particles) are influenced by electrostatic fields. In fact the electron gun itself employs an electrostatic field to shape the electron trajectories and accelerate the electron beam to 20 kV. No other electrostatic fields are used as part of the electron optical system but there are at least two ways in which electrostatic fields detrimental to the operation of the electron gun can appear. The first type of problem is associated with the use of silicon-based vacuum pump oils, lubricants, greases, etc. The vapor from such materials can be deposited on surfaces near the beam or even within the gun itself. Under the

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*Electron Physics Tables, L. Marton, C. Marton, and W. G. Hall, National Bureau of Standards Circular 571, March 30, 1956.

action of bombardment by stray electrons and/or x-rays such deposits will break down chemically into compounds such as SiO_2 (silicon dioxide), an excellent electrical insulator. Further stray electron bombardment causes these insulating coatings to acquire a charge and thus establish an electrostatic field which deflects the beam. Such fields are usually very unstable and lead to extremely poor beam stability. This type of situation cannot be corrected using an X-Y deflection system, for the fields and the forces on beam electrons are erratic. The other possibility is that more stable electrostatic fields can be established by stray electrons on insulating materials near the beam such as ceramics, teflon, wire insulation, glass, etc. It is possible (but unlikely) that the perturbing effects of such fields can be counteracted with the X-Y deflection system.

In summary, then, there are many factors which can influence the electron trajectories and some of these will always be present, thus necessitating the use of some beam alignment system for guiding the beam to a preselected location. As we have explained, for stable beam operation all electrostatic fields except that generated within the gun itself should be eliminated. External magnetic fields must be kept small enough that the beam can be brought to the desired location using the X-Y deflection system.

III. DESCRIPTION OF ELECTRON BEAM X-Y DEFLECTION SYSTEM

A. Electrical and Magnetic Parameters

The electron beam X-Y deflection system functions by establishing a static, reasonably uniform magnetic field perpendicular to the beam axis. This magnetic field exerts a resultant force F on each electron, where the magnitude of F is

$$F = evB_T$$

(e is the electronic charge, v the electron velocity, and B_T the net transverse magnetic flux density). This force is exerted in a direction perpendicular both to the electron path and also to the magnetic field.

While traversing the region where the magnetic field is present the electron moves in a curved path whose radius can be readily calculated. Upon leaving the region of magnetic field the electron resumes a straight-line trajectory; the final trajectory is bent at some angle relative to the initial trajectory. The angle between initial and final trajectories can be varied by varying the magnetic flux density. Our present system will provide deflection of the electron beam through an angle of at least $\pm 10°$.

This deflection system consists of two sets of electromagnets, one set being situated along an "X-axis" and producing a magnetic field B_x along the X-axis, and the other set being situated along a "Y-axis" (which is perpendicular to the X-axis) and producing a magnetic field B_y along the Y-axis. Both X and Y axes are perpendicular to the electron beam axis. The magnetic field B_x acts to deflect the beam along the Y-axis and B_y deflects the beam along the X-axis. Thus it is necessary that the "X-coils" be connected to the Y-axis control system and the "Y-coils" to the X-axis control system so that (for example) an operator expecting the beam to move along the Y-axis as he varies the designated Y-axis control will see his expectations come about. In general both B_x and B_y field components will be required to return the beam to the preselected location, in which case the magnitude of the net transverse field B_T acting on the beam electrons is given by

$$B_T = \sqrt{B_x^2 + B_y^2}$$

A schematic diagram showing the manner in which the coils are connected is presented as Fig. 1 on page 9. The two X-coils are wired in series in such a manner that the current circulates in the same sense, either clockwise in both or counterclockwise in both. Similarly the two Y-coils are series-connected. One lead from each coil leads to the Amphenol connector provided for hookup to the coil control system.

Each coil consists of 2800 turns of "Heavy Enameled Polythermaleze 2000" copper magnet wire, AWG #32, on an aluminum bobbin.

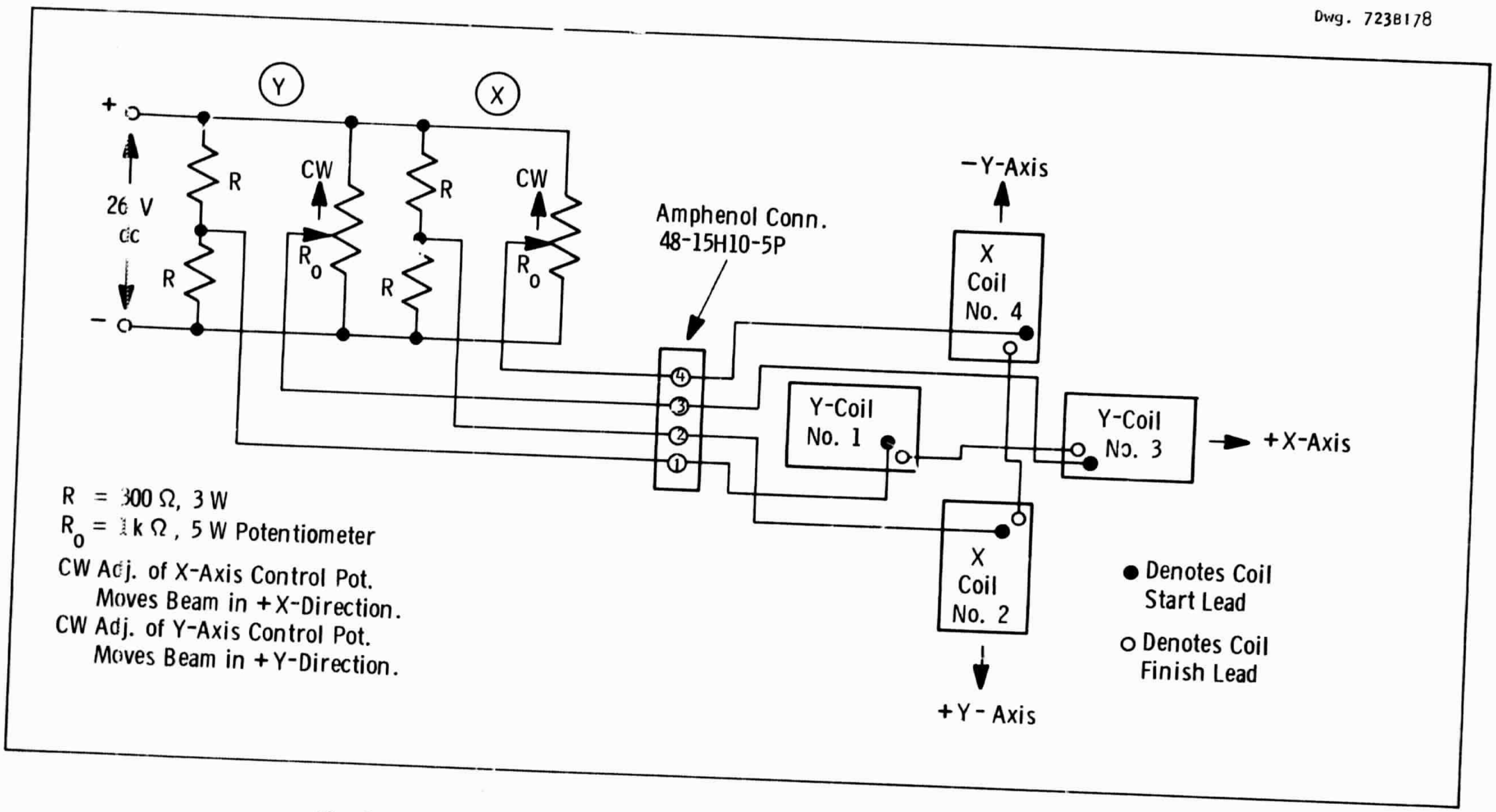


Fig. 1—Electrical connections to X-Y deflection coils and proposed control circuits

The dc resistance of each coil is about 75 Ω at 293 K (68°F); thus the total resistance of two coils in series is about 150 Ω. The maximum current through each set of series-connected coils is about 43 mA in the bridge circuit also shown in Fig. 1. Thus the total number of ampere-turns available to establish the magnetic field is about 240. This should be sufficient to deflect the electron beam by at least ± 10°. It must be pointed out, however, that the limitation on the available ampere-turns (and hence the maximum available field) is in the control circuit and not inherent in the coil design. The coils could be operated safely with currents as high as 100 mA for periods of 15 to 20 minutes, thus increasing the available ampere-turns to about 560 and greatly increasing the maximum deflecting field. If this were done a current regulator would be required to maintain constant coil current in the face of increasing coil resistance due to internal heating. Since these coils are located in a high vacuum (as is the whole deflection system) heat dissipation is a more serious factor than for coils operating in a gas which can provide some cooling.

It is expected that the voltage to ground from any point on the winding of any of the coils will not exceed 26 V dc during operation. However, for short periods of time (dielectric testing) it is permissible to apply up to 200 V dc from any part of the winding to the bobbin.

Some magnetic field mapping has been done to determine actual field contours within the gap between the pole pieces. These results are presented and discussed in part VIII.

A. Electrical and Magnetic Parameters

The most important part of the X-Y deflection system is the "iron circuit" consisting of the four pole pieces and iron ring (Dwg. 254C569). The magnetic field which deflects the beam is established in this iron and in the gap between the pole pieces by the four coils, one mounted on each pole piece. Armco magnetic ingot iron is used for all iron parts because of its high permeability and known magnetic properties when properly annealed. The four pole pieces make a zero-clearance fit over the center tube (Dwg. 722B959) to insure that they are held tightly in the desired positions and will not move under conditions of shock or vibration. This center tube fits precisely on the existing magnetic lens (Dwg. 181C847) and thus assures alignment of the deflection system on the nominal beam axis. In addition the center tube helps shield the coils from stray electrons and splatter from the work and acts as a heat sink to absorb beam energy if the beam should stray too far off-axis. It is made of high-thermal-conductivity silver copper, grade 116-60, which is anneal-resistant and maintains its strength at temperatures which soften ordinary copper. (Supplier: Copper Range Company, New York, New York 10020.)

The assembly of center tube, iron ring, pole pieces, and coils is attached to an aluminum support flange (Dwg. 254C572) with eight stainless steel screws. This support flange rests on the end face of the existing magnetic lens but centers on the center tube. A thin sheet-metal shroud covers the iron ring, pole pieces and coils, protecting the most critical parts of the assembly from metal vapor and splatter from the work. This shroud has four dimples which key into slots on the support flange. Four stainless steel screws hold the conical end of the shroud to the center tube. This arrangement holds the shroud securely in place but prevents undue stress from being exerted on the deflection coil assembly should the shroud become very hot and warp or otherwise distort. The shroud is made from molybdenum and will not be damaged by direct impingement of molten metal droplets from the work.

For electrical connection to the X-Y deflection system control circuitry an Amphenol connector (type 48-15H10-5P) is provided on a bracket mounted to the main support flange. Thus the entire assembly consisting of iron ring, pole pieces, coils, center tube, connector and bracket, support flange, shroud, and associated hardware can be installed or removed as a unit without any disassembly of the component parts. This assembly attaches to a mounting band/clamp (Dwg. 254571) with six or eight stainless steel screws, depending on the orientation of the support flange relative to the existing gun. The two-section aluminum band is keyed into existing slots in the magnetic lens housing and, when clamped in position around the lens, provides a rigid platform for mounting the deflection system. The system is locked against both axial movement and rotation.

The weight of the entire deflection system including the mounting clamp and Amphenol connector with its mating plug is 1.374 kg (3.03 lb). Fig. 2 on page 13 is a composite photograph showing three views of the X-Y deflection system.

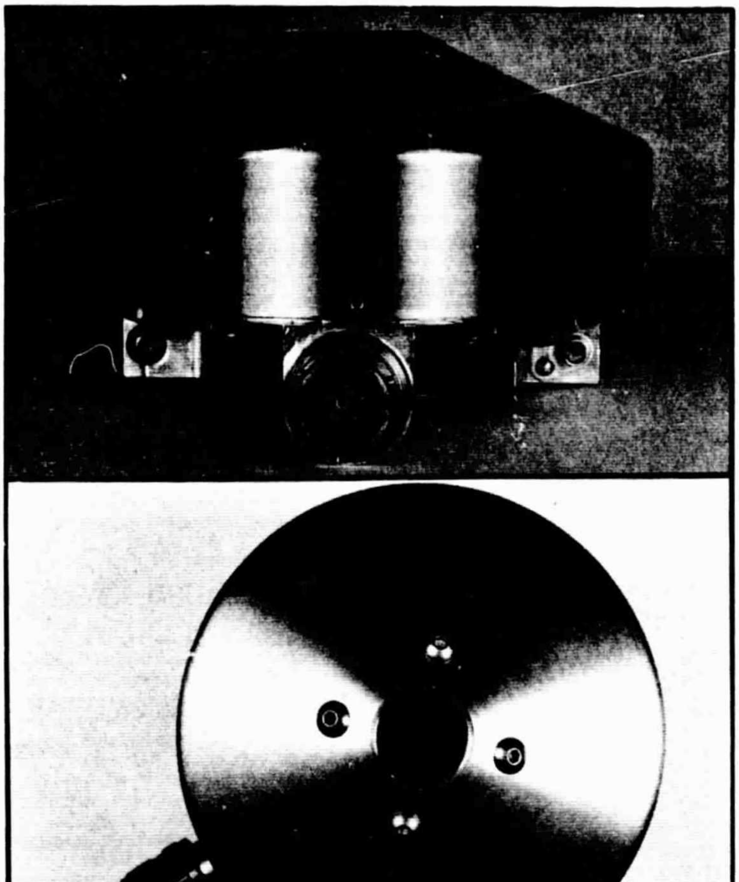
IV. MOUNTING AND ORIENTATION

A. Mounting

Mounting the X-Y deflection system to the existing welding gun is carried out by performing the following two steps:

1) Install the two section clamp (Dwg. 254C571) on the existing magnetic lens by slipping each section down along the side of the lens until the bottom tabs lock into the existing slots on the lens housing. The clamp must be oriented such that a plane lying along the magnetic lens axis and falling between the two sections of the clamp lies at an angle of 60° counterclockwise (as viewed from the workpiece toward the lens) from the short leg of the three-legged flange that supports the magnetic lens (It. 1, Dwg. 181C791). Secure the clamp with two 8-32 x .50 stainless steel button-head socket cap screws. Tighten these screws only until the clamp fits snugly against the lens, making certain that the clamp is pulled out as far as possible toward the end of the lens (away from the lens support). <u>Do not exceed .564 Nm (5 in.lb) torque on the two mounting screws</u>. <u>Overtightening these screws may deform and damage the lens housing</u>.

2) Slide the deflection system down against the magnetic lens, taking care to push the bundle of wires to the Amphenol connector into the appropriate slot on the mounting clamp. Use six or eight (depending on orientation) 8-32 x .62 stainless steel button-head socket cap screws with #8 flat stainless steel washers to hold the deflection system to the mounting clamp. Tightening these screws



Side View

End View

End View
Without Shroud

Fig. 2 THREE VIEWS OF X-Y BEAM DEFLECTION SYSTEM

each a little at a time (thus distributing the load on the flanges uniformly around the circumference), continue until the deflection system fits snugly against the magnetic lens housing. A gap of .62 ± .62 mm (.025 ± .025 in.) is expected between the support flange and the mounting clamp. Overtightening these screws may deform and damage the deflection system, mounting clamp and/or lens housing.

B. Orientation

Two orientations of the mounting clamp in the magnetic lens are possible, 180° apart. Either of these orientations is acceptable for mounting this item.

The deflection system is to have the following orientation on the mounting clamp: position the deflection system such that the Amphenol connector lies in a plane through the gun axis and the center of the short leg of the three-legged flange that supports the magnetic lens. The connector should be rotated 180° from the short support leg. In this orientation the connector and one pair of coils and pole pieces lie along what is defined to be the X-axis, with the connector in the -X direction. The connector thus lies on a line which is 178° 43' clockwise from a line which extends from the beam axis through the center of the main viewing port.

In the event that experimentation with the electron beam shows that this orientation is not satisfactory, nine other orientations are possible with no change in the parts. Referring to the position of the Amphenol connector relative to a line from the lens axis through the center of the short leg of the three-legged lens support flange, the preferred orientation is 180°. The other possible orientations are (as viewed from the work toward the lens) 30°, 60°, 90°, and 150° clockwise; 30°, 90°, 120°, and 150° counterclockwise; and 0°. In the 30° clockwise and 150° counterclockwise orientations eight screws and washers are used to fasten the deflection system assembly to the mounting clamp. In all other orientations only six screws and washers are used.

VI. ELECTRICAL REQUIREMENTS AND OPERATING TIME LIMITS

The electrical specifications of the electromagnetic deflection coils are presented in part III, A. The dc resistance of each coil is 75 ± 1 Ω at 293 K(68°F). Thus the resistance of each pair of coils is nominally 150 Ω. In the bridge circuit shown in Fig. 1 in which the coils will function, the maximum coil current is 43.3 mA. Since this constitutes a maximum wire cross-sectional loading of 1400 circular mils/ampere and since the power dissipation (at 43.3 mA) in each coil is only about 142 mW maximum, the coils may be operated continuously under these conditions. Internal coil heating is sufficiently low that coil current can be maintained constant (which is required for constant deflection) by maintaining coil voltage constant. The actual voltage requirement for two coils in series at this loading is about 6.5 V.

If ever necessary the coils may be operated at currents as high as 100 mA but for a maximum of only 15 minutes, after which at least three hours cooling must be allowed before again operating the coils. The coils heat rapidly with this high current, especially when they are operating in vacuum. As coil temperature increases, coil resistance also increases, thus increasing the power dissipation if the coils are being operated from a constant-current source, which causes the temperature to increase even further. Internal coil temperature must not be permitted to exceed 398 K (257°F). The average winding temperature can be determined by measuring the increase in coil resistance as the coil heats, the decrease in coil current if the coil is operating from a constant-voltage source, or the increase in coil voltage if the coil is operating from a constant-current source. A change in winding temperature from 293 to 398 K (68 to 257°F) will produce a 40% increase in coil resistance (from 150 Ω to 210 Ω for two coils in series), a 40% increase in coil voltage required to maintain constant current, or a 40% decrease in coil current if coil voltage is held constant.

VI. USING THE X-Y DEFLECTION SYSTEM - PRECAUTIONS AND INTERACTIONS

When using the electron beam X-Y deflection system there are certain precautions that must be taken by the operator to assure safe and reliable operation of the system. There are also interactions that can occur with other components of the electron-optical system. These items are discussed in the following paragraphs.

The most important precaution to be exercised is to avoid letting the electron beam strike the inside wall of the X-Y deflection system. If the beam is badly off-axis coming through the magnetic lens, very little deflection may be required to cause the beam to strike the inside wall of the deflection system, possibly damaging the system. Also at high coil currents a beam which is initially on-axis may be deflected sufficiently to strike the inner wall of the deflection system. Thus care must be taken that the operator knows where the beam is impinging and always visually follows the beam as he adjusts the coil currents. All adjustments should be made slowly and smoothly. If at any time the point of beam impingement on the work is not visible, it should be assumed that the beam is impinging on the wall of the deflection system and immediate corrective action must be taken or the beam turned off. Quantitative limits for deflection angles and coil currents based on actual test experience are presented in part VIII.

Interactions can occur especially between the magnetic lens and the X-Y deflection system for the following reasons:

The electron beam is focused by axial magnetic fields but deflected by transverse magnetic fields. On the axis of the magnetic lens the lens field has only an axial component, but off-axis there is a net transverse field component. Thus a beam entering the magnetic lens off-axis will experience not only focusing forces but also deflecting forces, and the amount of deflection will change as the lens current is changed.

The field of the X-Y deflection system is primarily a transverse field; but because of the unavoidable proximity of the magnetic lens to the X-Y system and the resultant flux linkage to the iron in the lens housing, a small axial field component is present in the region between the lens and the X-Y deflection system. This axial field component has its maximum value at a radius of about 1 cm (.394 in.) from the beam axis. Thus the X-Y deflection system can exert undesired focusing forces on the beam, particularly if the beam is some distance off-axis.

As an example of these interactions take the case where the beam path coincides with the magnetic lens axis and the X-Y deflection system is used to move the beam off-axis. If the beam is focused at a given axial location and then the deflection system is used to move the beam, the beam focus will not stay on a plane perpendicular to the axis and at the original focus position; in fact, the beam spot will even become elliptical (astigmatic). The lens current will have to be decreased to keep the beam focused on the original plane as the beam is moved off-axis. Furthermore, the peak power density in the beam will decrease as the beam is moved off-axis due to the astigmatism of the X-Y deflection system.

Another case of interest is that in which the beam is off-axis in the magnetic lens and the X-Y deflection system is used to bring the beam back on-axis, the situation which the X-Y deflection system is specifically designed to correct. In this case varying the lens current to achieve optimum beam focus will produce, in addition, a deflection of the beam. The X and Y coils must then be trimmed again to return the beam to the axis. The lens current may then need to be readjusted to maintain optimum beam focus. Because of this interaction it is clear that both lens and deflection coils must be adjusted in an iterative process to arrive at the final optimum focus and centering. It is also clear that a considerable level of operator skill and practice is required to carry out this alignment quickly and accurately.

It should be noted here that this interaction can only be avoided by assuring that the beam is precisely on-axis in the magnetic lens and by separating lens and deflection coils by a large enough distance to reduce flux linkage from one unit to the other to a very small level. This could be accomplished by placing two additional sets of four X-Y deflection coils between the magnetic lens and the zig-zag deflection system, each set spaced 3 to 5 cm (1.18 to 1.97 in.) from the lens, zig-zag coils, or adjacent deflection coils. The purpose of these two sets of coils would be to return the beam to the lens axis and to align the electron beam precisely on this axis. Of course such an arrangement is not possible within the size and weight limitations of the existing package.

VII. TROUBLE-SHOOTING AND MAINTENANCE

This brief section is included as a guide should difficulties be encountered in the operation of this system.

The only required maintenance is to keep the center hole of the X-Y deflection system free of particles and debris from the work. The system should be inspected and cleaned (if necessary) each time the vacuum (work) chamber is opened. In addition splatter should not be allowed to build up on the shroud; the shroud should be removed periodically and cleaned.

If at any time it is observed that the X-Y deflection system appears to have no effect on the beam, shut down the electron beam immediately. The difficulty can probably be found among those listed below:

1) Coil control circuit malfunction--check the coil control system to make certain that voltage is present at the coils and that the control circuits are capable of supplying current to the coils.

2) Short circuit in wiring or in one or more coils/open circuit in wiring or in one or more coils--measure the dc resistance of each pair of coils. Each pair should be 150 ± 3 Ω. If the resistance is less than this value for either pair of coils, that pair has a short in the wiring or shorted turns in the winding. If the resistance is much greater than this value for either pair of coils, that pair has an open circuit. In either case the shroud must be removed and the cause of the short circuit or open circuit must be searched out to isolate the defective coil (or coils).

3) Insulation breakdown in one or more coils--measure the insulation resistance from each pair of coils to the deflection system structure, or some other metallic structure electrically connected to the deflection system components (the deflection system must be disconnected from the control circuits for this measurement). Do not apply more than 200 V dc from the windings to case or ground. The insulation resistance should be at least 1000 MΩ at room temperature if made through no more than two 48-series Amphenol connectors. If the measurement is made after disconnecting the coils from the Amphenol connector, the insulation resistance should be at least 100,000 MΩ with 200 V dc applied at room temperature. If less than these figures, isolate the defective coil (or coils) and repair or replace.

4) Distortion of magnetic field by magnetic splatter, dirt or debris in deflection system--visually inspect the inner bore of the deflection system and remove any dirt or debris present there. Using a Hall effect dc gaussmeter, measure the magnetic flux density at the center of the gap between the pole pieces, energizing only one pair of coils at a time. With 25 mA coil current the field should be at least 4.8×10^{-3} T (48 G).

VIII. TEST RESULTS

A. Coil Resistance

The resistance of each of the four coils has been measured using a Biddle wheatstone bridge, Cat. 601106-1, at a temperature of 23.5°C (74.3°F). Values are shown in the table below:

COIL #	LOCATION	RESISTANCE
1	-X	74.27 Ω
2	+Y	74.32 Ω
3	+X	74.03 Ω
4	-Y	74.11 Ω

B. Insulation Resistance

The insulation resistance of each of the four coils has been measured at both 50 V dc and 500 V dc using a General Radio type 1862-B megohmmeter. The results are shown below:

COIL #	INSUL.RES. AT 50 V DC	INSUL.RES. AT 500 V DC
1	∞	∞
2	∞	10^6 MΩ
3	∞	∞
4	∞	2×10^6 MΩ

C. Magnetic Field Measurements

The magnetic flux density developed in the gap between the pole pieces has been measured as a function of position in the X-Y plane and as a function of coil current. The Z-axis (beam axis) variation of one component of the flux density has also been determined at one value of coil current. All flux density measurements were made with an F. W. Bell Model 610 Hall effect gaussmeter and a transverse probe Model T-6111.

At any point in the region between the pole pieces there is some magnetic flux density B(X,Y,Z). This flux density can be separated into components parallel to the mutually orthogonal X, Y, and Z axes: B_x, B_y, and B_z. The transverse field components B_x and B_y produce beam deflection and the axial field component B_z produces beam focusing. In the presentation of test data and the discussion that follows we will ignore B_z; B_z is very small in the X-Y plane which passes through the center of the gap (the plane defined by Z = 0) and along the Z-axis, and only becomes significant off-axis at values of Z larger than ± .25L to ± .5L, where L is the length of a pole piece.

One quantity of interest is the flux density at the center of the gap (X=Y=Z=0). If the Y-coils alone are energized then the flux density at the gap center has only one component, B_x; and if the X-coils alone are energized the flux density has only the component B_y. The direction of B_x or B_y depends upon whether the coil current circulates in a clockwise or counterclockwise sense. Both B_x and B_y have been measured at the gap center for the conditions stated above; the results for B_x are shown in Fig. 3 on page 22. The data points are very nearly the same for B_y. Fig. 3 indicates that the data points fit a straight line quite closely. Examination of the data reveals the following approximate relationships:

$$B = 2.00 \times 10^{-4} T \qquad 0 \leq I \leq 18 \text{ mA}$$

(where B is either B_x or B_y and is in Tesla with I in milliamperes) fits the data to within $\pm 10^{-4}$T ($\pm$ 1 G). And

$$B = 2.05 \times 10^{-4} T \qquad 18 \text{ mA} < I \leq 50 \text{ mA}$$

fits the data to within $\pm 2 \times 10^{-4}$T ($\pm$ 2 G).

In the initial design, calculations indicated that about 195 ampere-turns would be required to establish a field of 4.55×10^{-3} T (45.5 G) at the center of the gap (with one pair of coils energized). Fig. 3 indicates that only about 124 ampere-turns are required. Some of the discrepancy is due to the low value of permeability used for the Armco iron in the calculations, and the remainder is the result of an overestimation of the decrease in flux density at the gap center caused by flux linkage to adjacent orthogonal pole pieces (see Fig. 5).

Another quantity of interest is the axial variation of the transverse field. To obtain this measurement the Y-coils alone were energized to produce a B_x transverse field component. The Hall effect probe was moved along the Z-axis and the flux density recorded as a function of Z. The results are shown in Fig. 4 on page 23, where B_x is plotted against Z. Note that the flux density decreases by 20% from the center (Z = 0) to a value of Z corresponding to one edge of the pole piece (Z = .91 cm). It is notable also that even at Z = 3 cm the flux density is still 14% of the peak Z-axis value (50 G). (An iron work-piece, when moved into the Z = 3 cm position, will therefore influence the position of the beam spot.)

Curve 642147-A

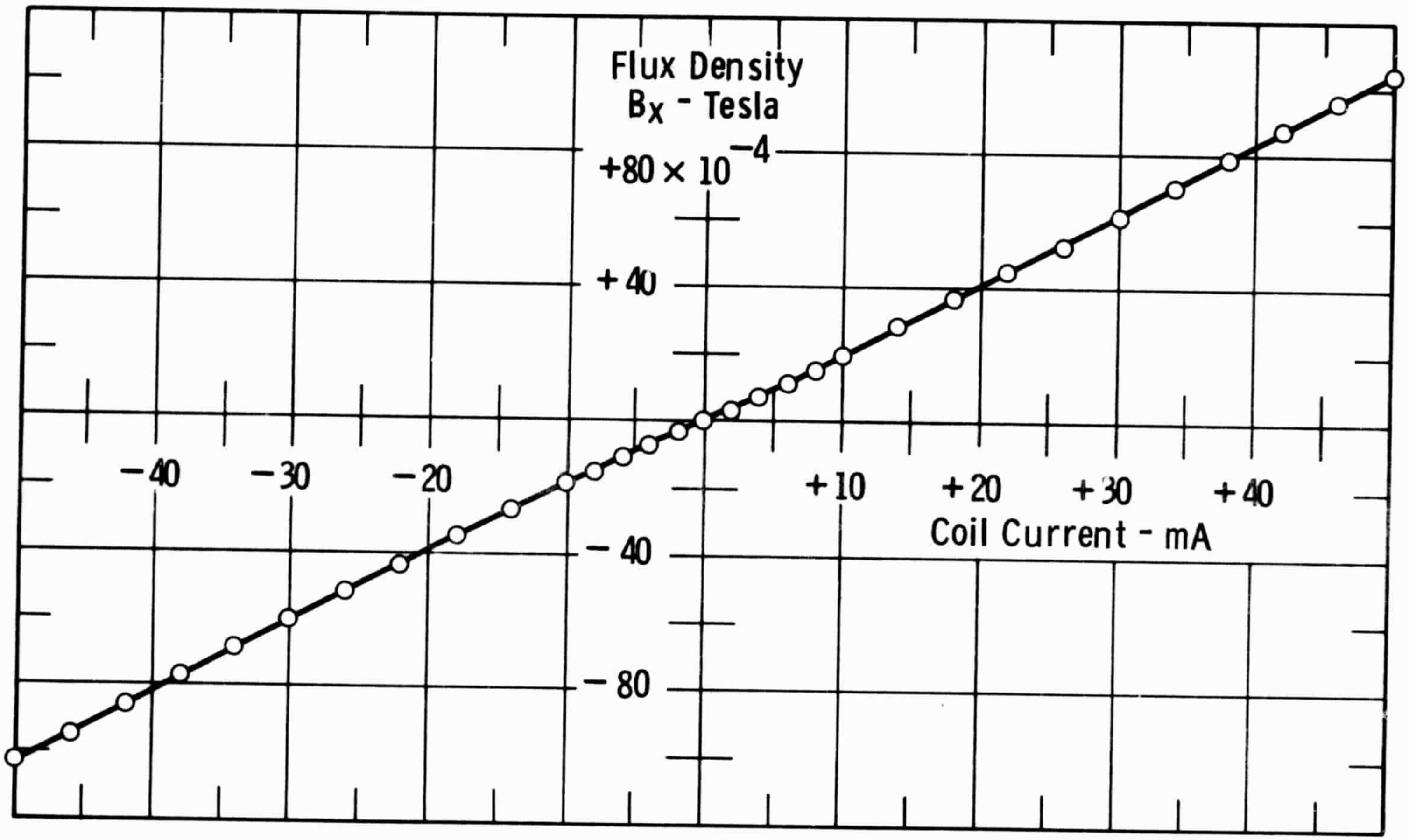


Fig. 3 Flux density B_x at Gap Center vs coil current

Curve 642148-A

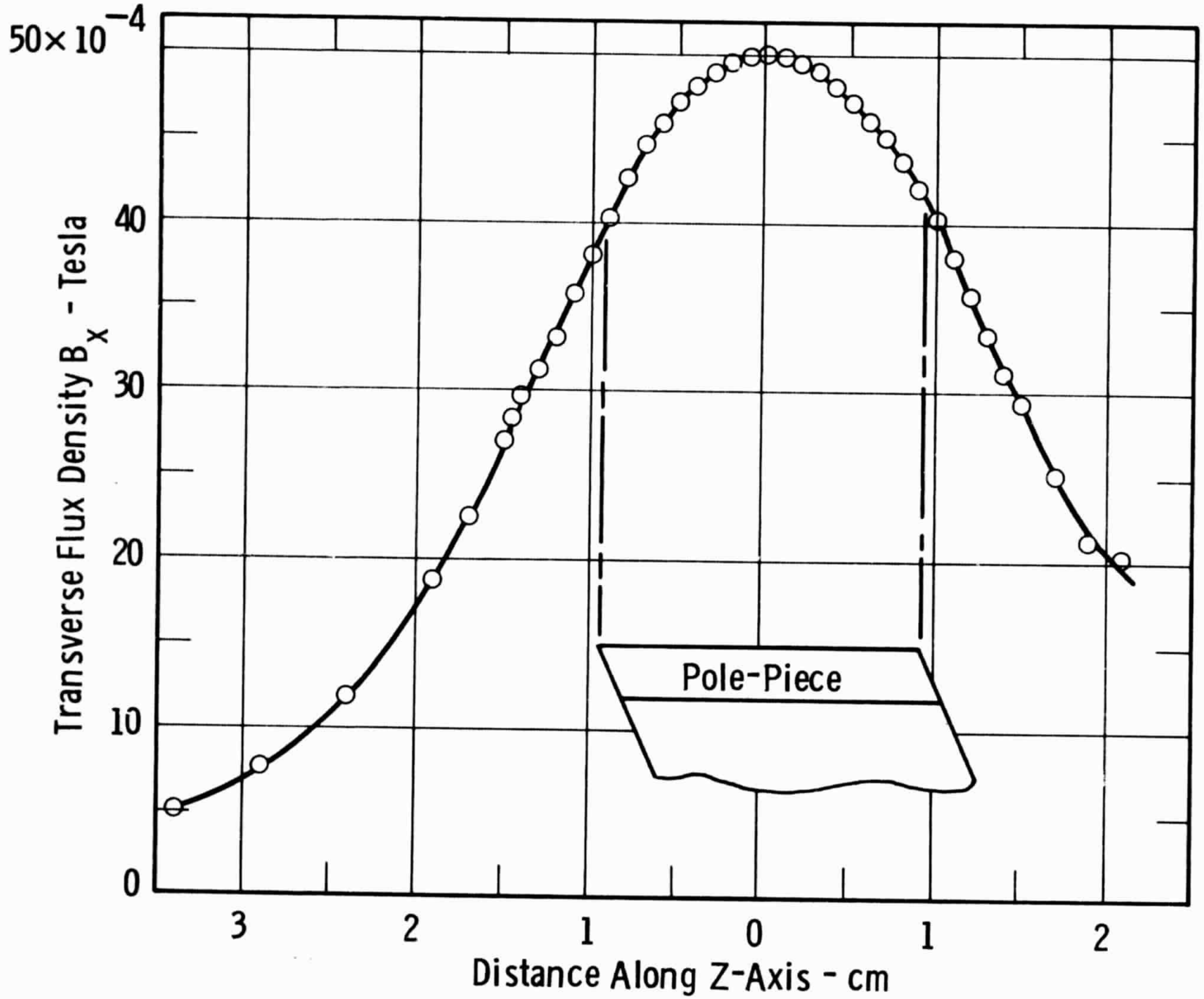


Fig. 4 Z-axis variation of transverse flux density B_x

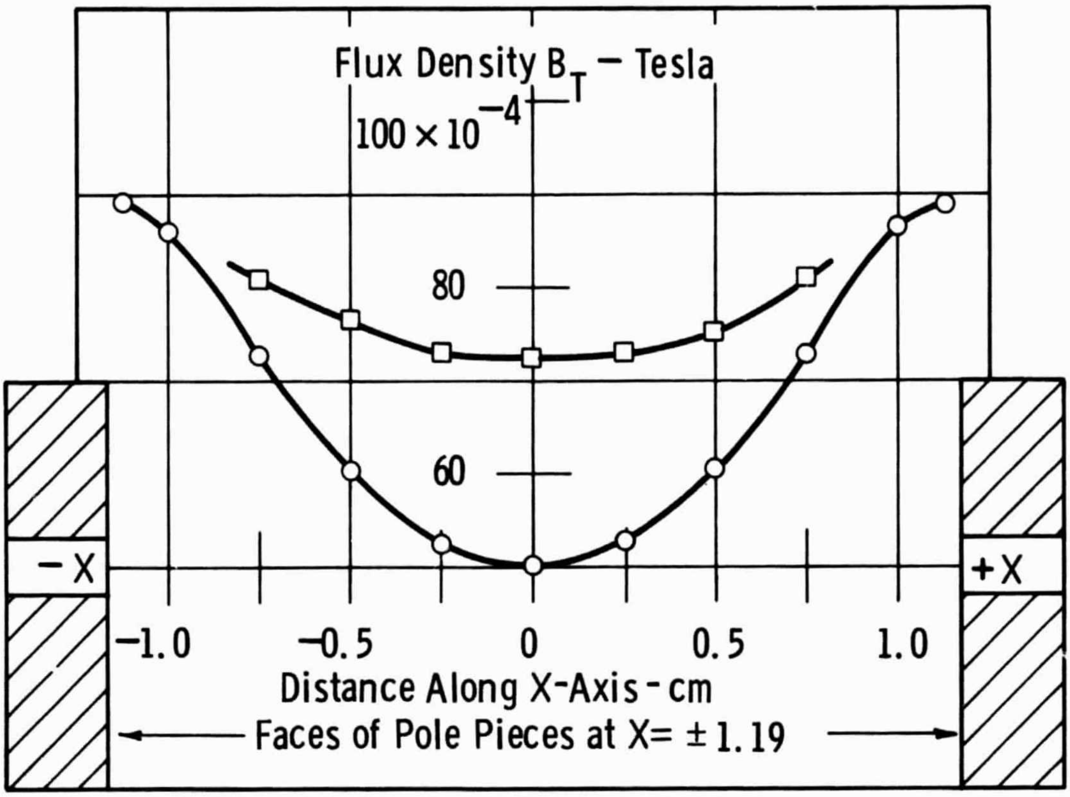
The variation of the flux density along the X and Y axes with coil current held constant has been determined and the results are presented in Fig. 5 on page 25 and Fig. 6 on page 26. The lower curve in Fig. 5 is the magnitude of the net transverse field $B_T = \sqrt{B_x^2 + B_y^2}$ along the X-axis when only the two coils on the X-axis (the Y coils) are energized with 25 mA. In this case B_y is negligibly small, and $B_T \sim B_x$. It is of interest to note that B_T decreases from about 89×10^{-4}T (89 G) near the pole pieces to 50×10^{-4}T (50 G) at the center of the gap; in the initial design calculations decrease by a factor of two was assumed. The upper curve in Fig. 5 is the magnitude of the net transverse field along the X-axis when both pairs of coils are energized with 25 mA. At the gap center $B_x = B_y$ and $B_T = \sqrt{2}\, B_x$. In this case the X-axis variation of B_T is much smaller than when the Y-coils alone are energized.

The lower curve in Fig. 6 is the magnitude of the net transverse field along the Y-axis when only the two coils on the X-axis are energized with 25 mA. Again B_y is negligibly small, and $B_T \sim B_x$. The upper curve in Fig. 6 is the magnitude of the net transverse field along the Y-axis when both pairs of coils are energized with 25 mA. Again $B_x = B_y$ at the gap center and $B_T = \sqrt{2}\, B_y$. Comparing this curve with the upper curve in Fig. 5 it should be noted that they are very nearly the same, as is to be expected.

D. Deflection Measurements

As a final test of the X-Y deflection system the ability to deflect a 20 keV electron beam was determined as follows. A Beam Deflection System Test Stand defined by Westinghouse Drawing 4865D18 was fabricated; the X-Y deflection system (it. 12 on Dwg. 4865D18) was mounted on the end of a magnetic lens (it. 11) externally identical to those used on the electron beam welding units delivered under contracts NAS8-20678 and NAS8-26350, and the test system was installed over a water-cooled beam collector (it. 14) in a vacuum bell jar.

Curve 642146-A

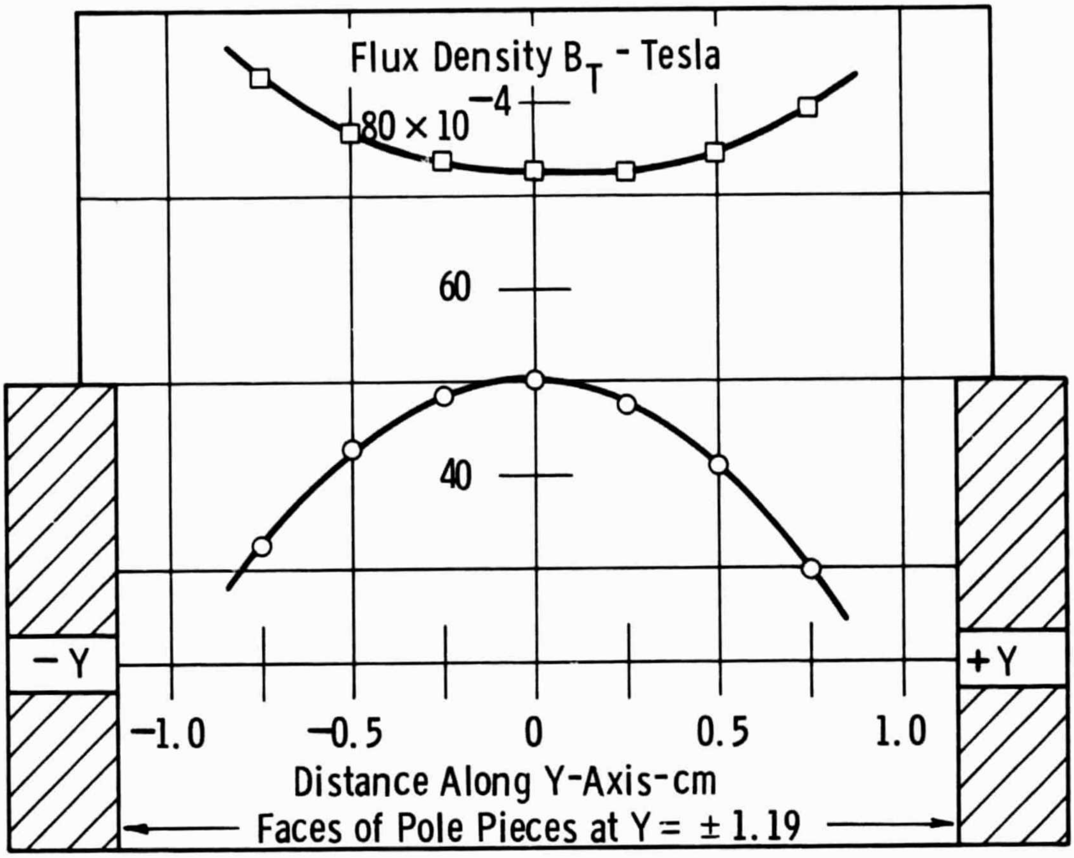


□ Magnitude of Net Transverse Field $B_T = \sqrt{B_x^2 + B_y^2}$ Along X-Axis Due to Both Pairs of Coils Being Energized with 25 mA.

○ Magnitude of Net Transverse Field $B_T = \sqrt{B_x^2 + B_y^2}$ Along X-Axis Due to Only Coils Along X-Axis Being Energized With 25 ma; $B_y << B_x$ So that $B_T \approx B_x$.

Fig. 5 X-axis variation of net transverse flux density B_T

Curve 642149-A



□ Magnitude of Net Transverse Field $B_T = \sqrt{B_x^2 + B_y^2}$ Along Y-Axis Due to Both Pairs of Coils Being Energized with 25 mA.

○ Magnitude of Net Transverse Field $B_T = \sqrt{B_x^2 + B_y^2}$ Along Y-Axis Due to Only Coils Along X-Axis Being Energized with 25 mA; $B_y \ll B_x$ So that $B_T \approx B_x$

Fig. 6 Y-axis variation of net transverse flux density B_T

In operation a 20 keV, 15 to 20 mA electron beam is produced in the electron gun (it. 1) and passes through a deflection system consisting of four mutually perpendicular deflection coils and pole pieces (it. 10), through the magnetic lens (it. 11), through the X-Y deflection system (it. 12), and into the beam collector (it. 14). The distance from the electron gun to the magnetic lens is the same as that used in the units already delivered. The deflection system located between the electron gun and the magnetic lens is used to align the electron beam on the axis of the test system so that the beam pssses through the small hole in the cover plate (it. 13) on the beam collector.

The collector cover serves as a test plate to record beam deflections produced with the X-Y deflection system. As either one pair or both pairs of coils are energized the beam moves away from the central axis, leaving a track as it melts a strip of metal on the top surface of the plate. Let the length of this track be L_T. Then the deflection angle α produced by a given coil current is given by

$$\alpha = \tan^{-1} \frac{L_T}{D}$$

where D is the distance from the top of the coverplate to a plane defined by $Z = 0$ through the centers of the four pole pieces of the X-Y deflection system. (The assumption is made that all the beam deflection is produced at the plane $Z = 0$, whereas in reality the deflection is produced gradually over an axial region whose length is several times the length of the pole pieces; but since the magnetic field is nearly symmetrical across the plane $Z = 0$, this is a reasonable approximation.)

The deflection angle α has been measured at coil currents from 5 to 20 mA, with just one pair of coils energized and also with both pairs energized. The resulting data points have been found to fit a straight line whose equation is (approximately)

$$\alpha = .41\ B_T$$

where α is in degrees and B_T is the net transverse magnetic flux density in gauss. The net transverse flux density at the center of the gap, $B_T(0,0)$, can be related to the coil current as discussed in the preceding section, but the exact nature of the relationship depends upon whether one pair or both pairs of coils are energized. For example, if just the Y-coils are energized to 10 mA, then $B_T \sim B_x = 20$ G, and $\alpha = 8.2°$; but if both pairs of coils are energized to 10 mA, then $B_T = 28.3$ G and $\alpha = 11.6°$. These quantitative results apply to a beam which is already on-axis and are only approximately correct when the beam is off axis.

It is a contractual requirement of this X-Y deflection system to deflect a 20 keV electron beam ten degrees. With just one pair of coils energized, ten degrees of beam deflection can be obtained at a coil current of about 12 mA. Since this value of current is well within the capabilities of both the coils and the coil control circuits, the deflection requirement is easily met.

The coil control circuits can provide over 40 mA for each pair of coils. Thus deflection angles in excess of 30° can be produced even with just one pair of coils energized. This apparently exceeds the contract requirement and indicates the possibility of weight reduction in the system; a discussion of these points is presented in part IX. Of utmost importance, however, is the fact that deflection of the electron beam through such large angles could result in damage to the work chamber or hardware within the chamber and even to the beam deflection system itself. Consequently, strict limits must be placed on allowable deflection coil currents. We shall consider any beam requiring corrective deflection of more than fifteen degrees to be grossly misaligned, requiring repair or adjustment in some part of the electron-optical system before proceeding. With one pair of coils energized, fifteen degrees of beam deflection can be achieved with about 18 mA or less. Thus we strongly advise that coil currents be limited to 18 mA maximum and that this limiting be effected by a "stop" on the current control potentiometer or by some other positive method which does not permit even inadvertent operation of either pair of coils above this limit. Experience gained in using the system may indicate some further reduction (or possibly increase) in this limit.

IX. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

Based on the test results discussed in the preceding section, the electron beam deflection system performs according to all design goals and meets all contract requirements.

B. Recommendations

Based on Westinghouse experience with the X-Y deflection system the following recommendations are made:

1) To gain experience in operating the system it is recommended that an electron gun (including magnetic lens) be set up on a laboratory vacuum bell jar and operated using laboratory power supplies, permitting the beam to be operated continuously into a water-cooled collector or onto a tungsten block. The operator could thus acquire a "feeling" for the interactions that occur between lens and deflection coils and learn how to align and focus the beam accurately and quickly.

2) It is recommended that deflection coil current be limited to 18 mA for each pair of coils, at least until further experience is gained with the deflection system; this limit should be effected by some positive method which prevents even inadvertent operation of either pair of coils at currents above the limit. Even with this restriction great care must be taken not to deflect the beam into areas where damage would result from direct beam impingement. It must also be remembered that the beam is "reflected" to some extent by metallic surfaces and that the beam trajectory can be drastically (and catastrophically) altered by external electrostatic and/or magnetic fields.

3) It is recommended that possible design improvements not be considered until after the deflection system is thoroughly tested under all possible operational conditions. Based on the presentation and discussion of test results in the preceding section (part VIII, C

and D), it is clear that the required ten degrees of deflection can be obtained at coil currents well below the capabilities designed into the system. This is due in some part to the reasons discussed in the fourth paragraph of part VIII, C, but is due primarily to the shape of the axial variation of the transverse field as discussed in the fifth paragraph of part VIII, C, and illustrated in Fig. 4. In the initial design calculations it was thought that the field would fall off very rapidly beyond the ends of the pole pieces; consequently the field was assumed to act only over the length of the pole pieces. But Fig. 4 indicates that significant flux density is present over an axial region on the order of three pole piece lengths (5.5 cm or 2.16 in.). Thus deflection of beam electrons begins well before they pass through the deflection system pole pieces and continues for some distance after leaving the region of the pole pieces.

The net result is that it should be possible to decrease the amount of Armco iron and copper wire in the deflection system with a consequent weight reduction, and still obtain ten degrees of beam deflection. But if this were done the net weight reduction would probably not be more than 250 to 300 gm (8.8 to 10.6 oz) for the reasons that follow. It would be inadvisable to decrease the pole piece length or separation, and locating the pole pieces closer to the magnetic lens would increase the flux linkage from deflection system to lens and result in more serious interactions between the two devices. Thus the deflection system should retain its present shape and dimensions. Some weight savings could be realized by reducing the amount of Armco iron in the ring that joins the four pole pieces (Dwg. 254C569, it. 2), but probably at the cost of increased complexity and machining expense. Also weight could be saved by reducing the number of turns on the four coils, but this would reduce the coil resistance and require compensating changes in the coil control circuitry; the coils could be wound with fewer turns of a smaller-diameter wire (AWG #33 or higher), but at the cost of increased fabrication time and expense and probably reduced reliability.

But the most important reason for making this recommendation is that the ten degree beam deflection required by this contract is a somewhat arbitrary figure based on limited experience in using the electron gun for welding. It is not difficult to think of situations in which more than ten degrees of corrective deflection could be required, for example a joint weld performed near the end of the X-Y deflection system. Another important consideration involves the effects of magnetic materials on the electron beam. Weld specimens or hardware within the work chamber consisting wholly or even partly of magnetic material (iron, nickel or cobalt) may possess an external magnetic field which could greatly alter the beam trajectory. Considerable corrective deflection could then be required to return the beam to the desired location. In addition, deposition of magnetic metal vapor onto the shroud and center tube could significantly decrease the magnetic flux density within the gap, requiring greatly increased coil currents to maintain the required deflection.

X. DRAWINGS

All the drawings that are a part of this contract are listed in Westinghouse Design Specification D 763688 entitled "Beam Deflection System" and presented on the next page. The drawings themselves follow; the first group of drawings defines the X-Y deflection system and the second group defines the setup used for testing the deflection system.

ROUTING					
FIREPROOF VAULT					

DRAWING LIST

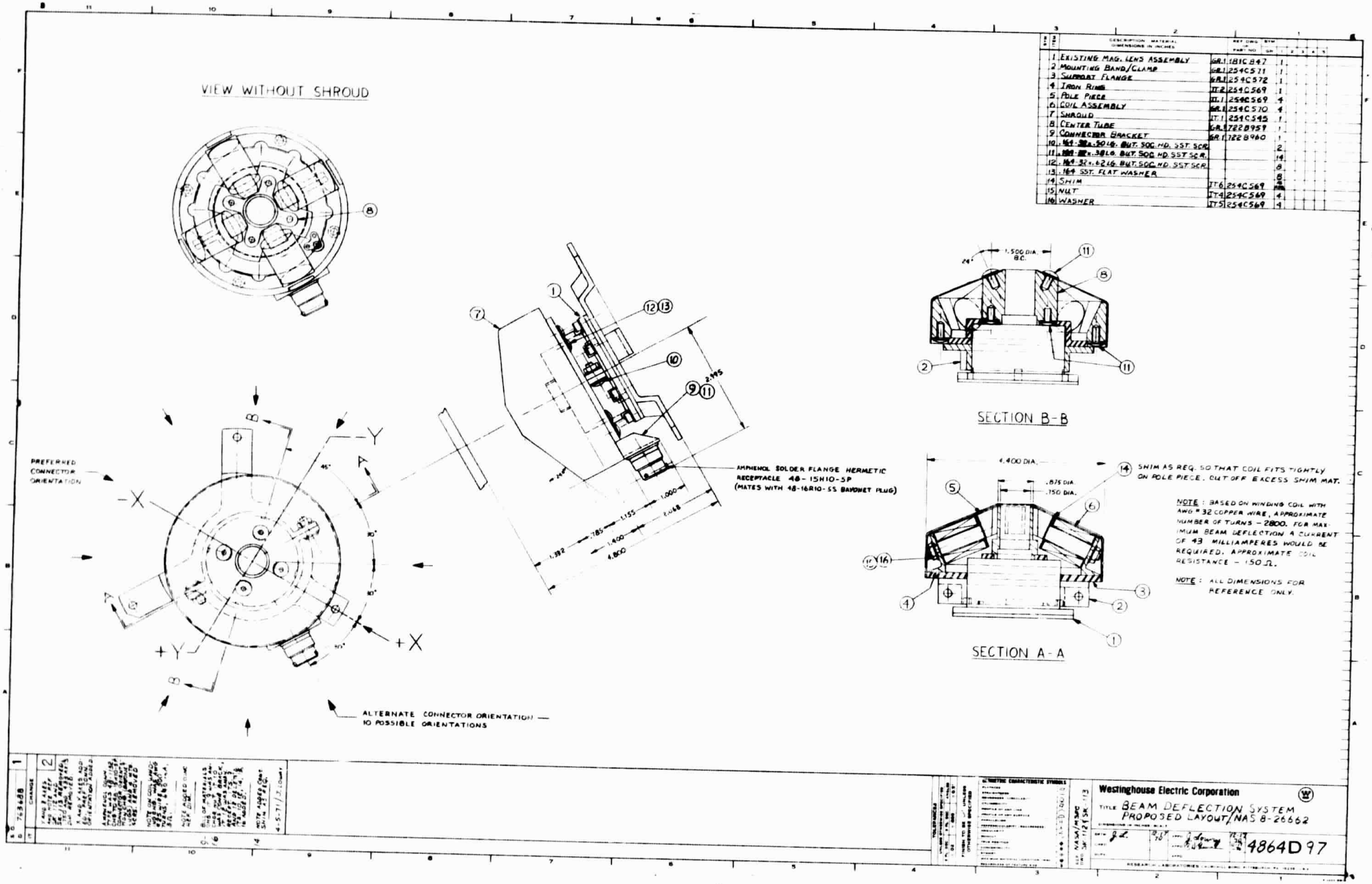
INDEX	LINE	TITLE OF DRAWING	DRAWING NO.	MULTI-PLIER	ITEMS OR STYLE NO.	CHECKED	DATE CHECKED
	1						
	2	Beam Deflection System					
	3	Layout	4864D97				
	4	Pole Pieces & Supp Ring					
	5	Dets & Ass'y	254C569				
	6	Bobbin Det	254C570				
	7	Mtg Band Clamp Det	254C571				
	8	Support Flange Det	254C572				
	9	Shroud Det	254C545				
	10	Ctr Tube Det	722B959				
	11	Conn Brkt Det	722B960				
	12						
	13						
	14						
	15						
	16						
	17	Test Stand Layout	4865D18				
	18	Mtg Flange Det	4865D17				
	19	Electron Gun Supp Flange					
	20	Det	254C567				
	21	Magnetic Lens Supp Flange					
	22	Det	254C568				
	23	Deflection Coil Ring Det	2937A22				
	24	Collector Cover Plate Det	2937A23				
	25						
	26						
	27						
	28						
	29						

STOCK ORDER (1ST S.O. ON WHICH INF. HAS BEEN SENT TO SHOP) | IDENTIFYING DATA: IN SPECIFYING THIS D NO. ON A STOCK ORDER THE ENGINEER MUST GIVE: —

NAME OF APPARATUS: BEAM DEFLECTION SYSTEM

J. Lowry

CHECKED BY AND DATE	1-12-71				
DESIGN SPEC. D 763688	SUB. LETTER A	SUB. LETTER	SUB. LETTER	SUB. LETTER	SUB. LETTER
WESTINGHOUSE FORM 6541 J — PAGE 1 OF 1	SUB. LETTER	SUB. LETTER	SUB-LETTER	SUB. LETTER	SUB. LETTER



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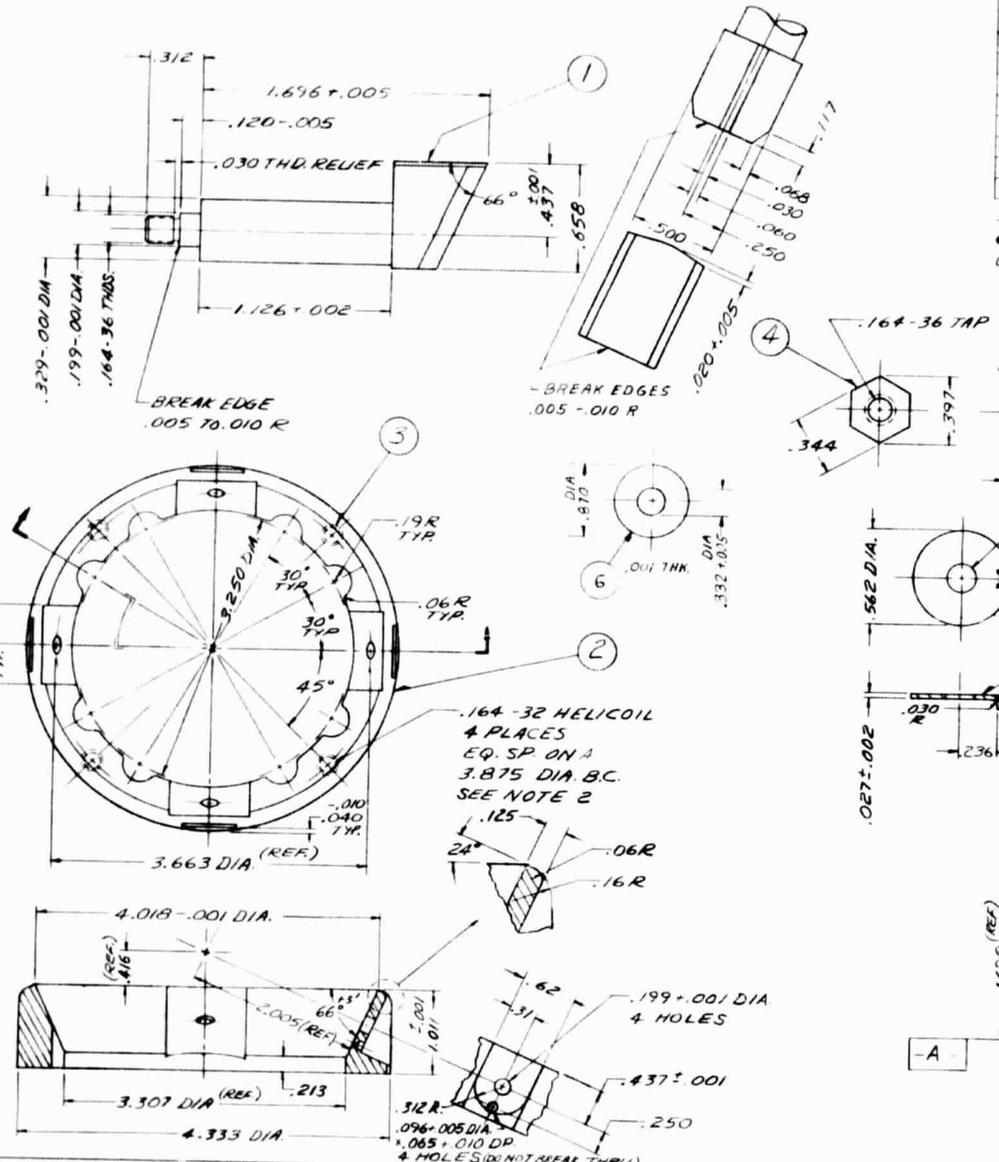
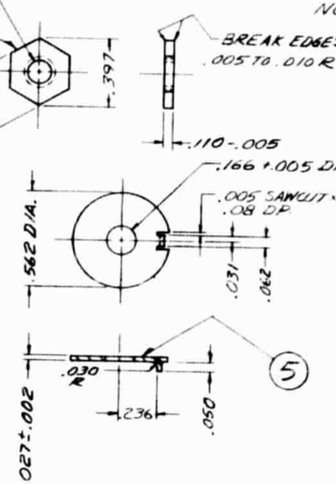
1	EXISTING MAG. LENS ASSEMBLY	GR.1 181C847	1
2	MOUNTING BAND/CLAMP	GR.1 254C571	1
3	SUPPORT FLANGE	GR.1 254C572	1
4	IRON RING	IT.2 254C569	1
5	POLE PIECE	IT.1 254C569	4
6	COIL ASSEMBLY	GR.1 254C570	4
7	SHROUD	IT.1 251C545	1
8	CENTER TUBE	GR.1 722B959	1
9	CONNECTOR BRACKET	GR.1 722B960	1
10	#4-32 x .50 LG. BUT. SOC. HD. SST. SCR.		2
11	#10-32 x .38 LG. BUT. SOC. HD. SST. SCR.		14
12	#4-32 x .62 LG. BUT. SOC. HD. SST. SCR.		8
13	#4 SST. FLAT WASHER		8
14	SHIM	IT.6 254C569	
15	NUT	IT.4 254C569	4
16	WASHER	IT.5 254C569	4

SYM	ITEM	DESCRIPTION MATERIAL DIMENSIONS IN INCHES	REF DWG PART NO.	SYM GR	1	2	3	4	5
*	1	MAKE FROM ARMCO MAGNETIC INGOT IRON			4				
*	2	MAKE FROM ARMCO MAGNETIC INGOT IRON			1				
●	3	.164-32 SCR. LOCK INSERT # 3585 2CN0246			4				
*	4	MAKE FROM ARMCO MAGNETIC INGOT IRON			4				
*	5	MAKE FROM ARMCO MAGNETIC INGOT IRON			4				
O	6	1.00 DIA OF .001 THK HEAVY DUTY AL FOIL			1				

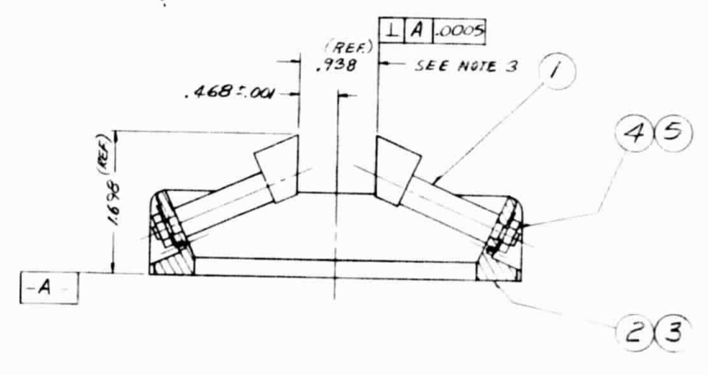
* - COREY STEEL CO, CICERO, ILL. 60680
● - HELI-COIL CORP., SHELTER ROCK LANE, DANBURY, CONN. 06810
O - ALUMINUM CO. OF AMERICA, 1501 ALCOA BLDG., PGH., PA 15219





NOTES:

1. ALL EDGES MUST BE SHARP & FREE OF BURRS UNLESS OTHERWISE SPECIFIED.
2. INSTALLATION OF HELICOILS
   - A. .177 +.003 DIA. x .375 +.015 DP.
   - B. .190 +.030 DIA. x 120° CSK.
   - C. .164-32 UNC-2B SCR. THD. INSERT BOTTOM TAP TO .320 +.020 DP. (BOTTOM TAP # 44187-2)
   - D. PITCH DIA. .184 +.003
   - E. INSTALL SCREW-LOCK INSERT # 3585-2CN0246, .023 TO .047 BELOW TOP SURFACE. USE INSERTING HAND TOOL # 7551-2
   - F. BREAK OFF DRIVING TANGS WITH AUTOMATIC BREAK-OFF TOOL # 3695-2
3. FINISH MACHINE TO FIT .938 ±.001 DIMENSION OF CENTER TUBE, DWG. 722B959, WITH ZERO CLEARANCE.
4. AFTER MACHINING, ANNEAL PER CURVE 581838-A



S.O.	D 763688	1
IT	CHANGE	

TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL. DEC. .02 | 3 PL. DEC. .005 | ANGLES 0.5°
FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

Westinghouse Electric Corporation

TITLE BEAM DEFLECTION SYSTEM POLE PIECES & SUPPORT RING DET. & ASSY.

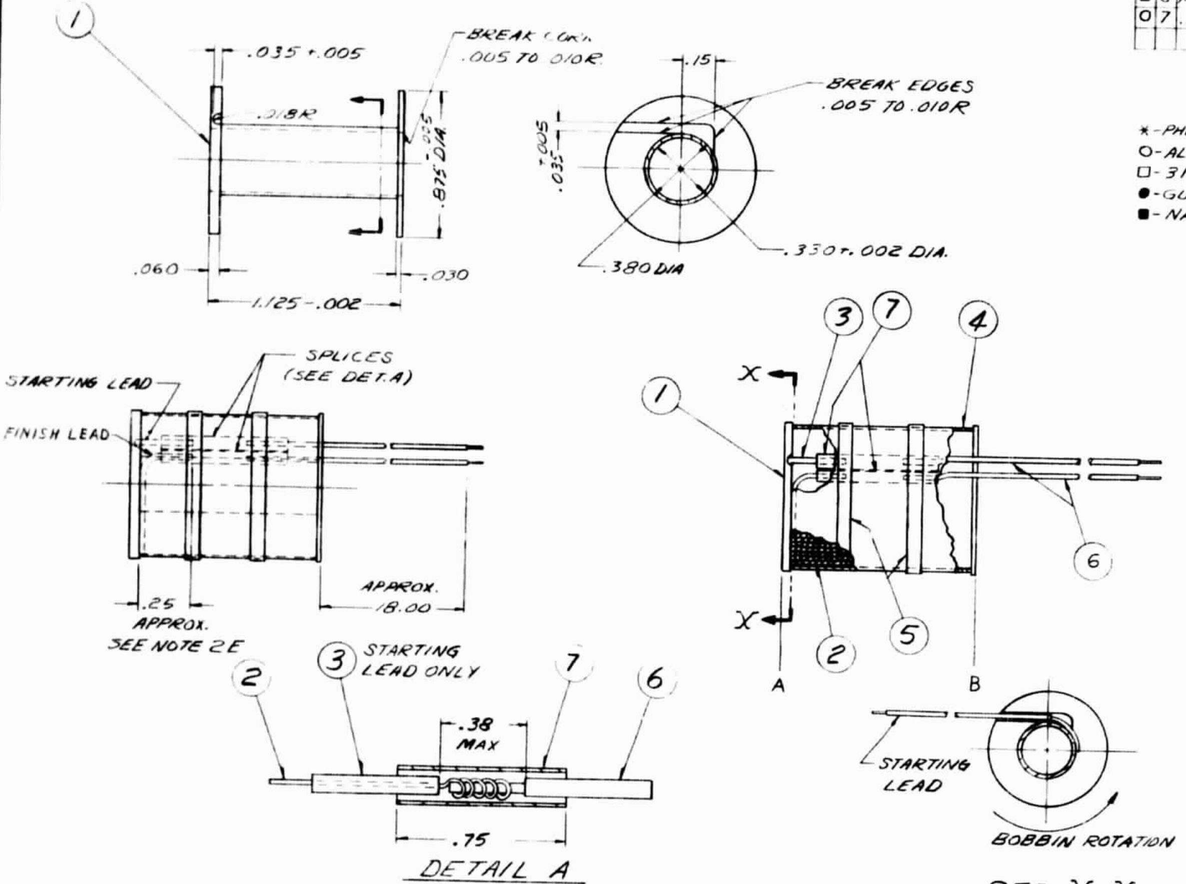
DIMENSIONS IN INCHES - SCALE NTS

DFTM. D. Yanuaidy 1-4-71 | APPD. J. Lowry 1-20-71 | 254 C569

RESEARCH LABORATORIES, CHURCHILL BORO, PITTSBURGH, PA 15235 U.S.A.

SYM	ITEM	DESCRIPTION · MATERIAL DIMENSIONS IN INCHES	REF DWG PART NO	SYM GR	1	2	3	4	5	R/L TR. NO
	1	1.25 OF 1.000DIA AL. ROD 2024 T351		1						0129
*	2	AWG.32 HVY ARMD POLY-THERMALEZE 2000ENAM MAG. WIRE								
O	3	AWG.30 ALPHLEX THIN WALL TEFLON TUB #TFT 200/30 (NAT)								
□	4	.50 WIDE TFE TAPE # 63								
●	5	BRAIDED NYLON LACING TAPE STYLE 22H, .06 WIDE (BLK)								
■	6	AWG.22 INS. CU. WIRE MSFC. SPEC. 40M39513/7								
O	7	.15 LG KYNAR SHRINK TUB FIT-350 .062		1						

*-PHELPS DODGE ELECTRONIC PRODS. CORP., NORTH HAVEN, CONN.
O-ALPHA WIRE MFG. INC., ELIZABETH, N.J.
□-3M CORP., DIELECTRIC MATERIALS DIV., ST. PAUL, MINN.
●-GUDEBROD BROTHERS SILK CO. INC., PHILADELPHIA, PA.
■-NASA MSFC, HUNTSVILLE, ALA.



REMOVE .30 TO .35 INSULATION FROM IT. 6 AND STRIP 1.25 OF ENAMEL FROM IT. 2. TIGHTLY WRAP IT. 2 AROUND IT. 6 (4-5 TURNS) AND SOFT SOLDER. CLEAN AWAY FLUX RESIDUE AND COVER SPLICE WITH IT. 7.

Notes:

1. All Edges Must Be Sharp & Free of Burrs Unless Otherwise Specified.
2. Coil Winding Procedure
   - A. Apply Teflon Coating as Per Dwg. 722B246 to Bobbin, It. 1. Do Not Coat Bore or End Faces A and B.
   - B. Slide Tubing, It. 3, on Starting Lead as Shown in Sect. X-X for Start of Winding.
   - C. Wind Wire, It. 2, on Bobbin. Wire Must Be Uniformly Layer-Wound and Tightly Packed. Lay on 105-106 Turns Per Layer Minimum, 26 or 28 Layers (an even number of layers is required to have finish lead on same end of coil as starting lead). Minimum Number of Turns Required is 2800. Build-Up (including tape and lacing) Must Not Exceed .875 Dia. Except at Splices.
   - D. Wrap One Width of Tape, It. 4 on Finish End of Coil to Secure Final Turns of Winding.
   - E. Cut Start Lead 1.50 in. From Point of Entry into Coil and Remove 1.25 in. of Tubing, It. 3, Taking Care Not to Pull Tubing Out of Coil. Cut Finish Lead 1.50 in. From Point of Entry into Coil. Splice Insulated Lead Wire, It. 6, to Coil Start and Finish Leads as Shown in Detail A.
   - F. Route Insulated Leads Along Coil Body and Secure to Coil With Tape, It. 4, and Lacing Tape, It. 5, as Shown.
   - G. Resistance of Finished Coil Must Be 74.2 ± 1 Ω at 20°C.

TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL. DEC .02; 3 PL. DEC ± .005; ANGLES ± 0.5°

FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

REF DWG

Westinghouse Electric Corporation

TITLE BEAM DEFLECTION SYSTEM BOBBIN DET

DIMENSIONS IN INCHES SCALE 2:1

DFTM D. SPINAZZOLA 1-12-71 APPD J. Sbury 1-11

CHKD

SUPV

254C570

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

S.O. D 763688 — CHANGE 1

IT

SYM	ITEM	DESCRIPTION - MATERIAL DIMENSIONS IN INCHES	REF DWG PART NO.	SYM GR	1	2	3	4	5	R & D STK NO.
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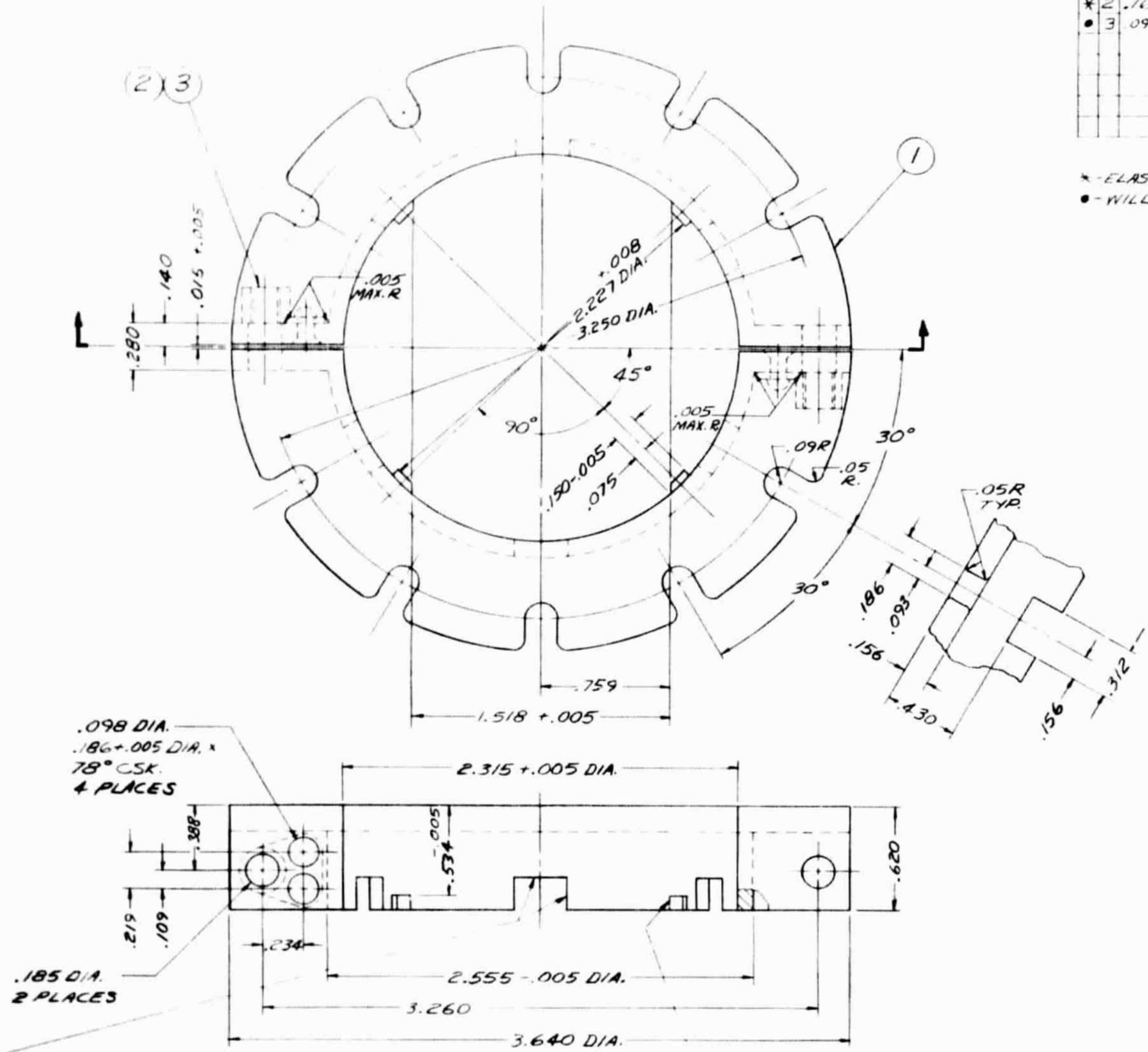
*	2	.164-32 ANCHOR NUT CAT # LHTA-75M	2860-82	2						
●	3	.093 DIA x .31 LG 78° CSK HD 1100F AL RIVET		4						

*-ELASTIC STOPNUT CORP OF AMER, 2330 VAUXHALL RD, UNION, NJ 07083
●-WILLIAMS & CO INC., 901 PENNSYLVANIA AVE., PGH, PA 15233



BREAK ALL INSIDE AND OUTSIDE EDGES AND CORNERS .015-.020R - 6 SLOTS

BREAK ALL EDGES .015-.020R 4 TABS

NOTES:
1. BREAK ALL EDGES .005 TO .010 R UNLESS OTHERWISE SPECIFIED.

S.O. D 763688 — 1 — CHANGE

TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL DEC .02; 3 PL DEC ±.005; ANGLES ±0.5°. FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

Westinghouse Electric Corporation

TITLE BEAM DEFLECTION SYSTEM MOUNTING BAND CLAMP DET.

DIMENSIONS IN INCHES - SCALE 2:1

DFTM D. Spinazzola 7/71 — APPD J. Lowry 7/30/71

CHKD — APPD

SUPV — APPD

254C571

RESEARCH LABORATORIES CHURCHILL BORO, PITTSBURGH, PA 15235 U.S.A.

SYM	ITEM	DESCRIPTION MATERIAL DIMENSIONS IN INCHES	REQ'D	STK NO
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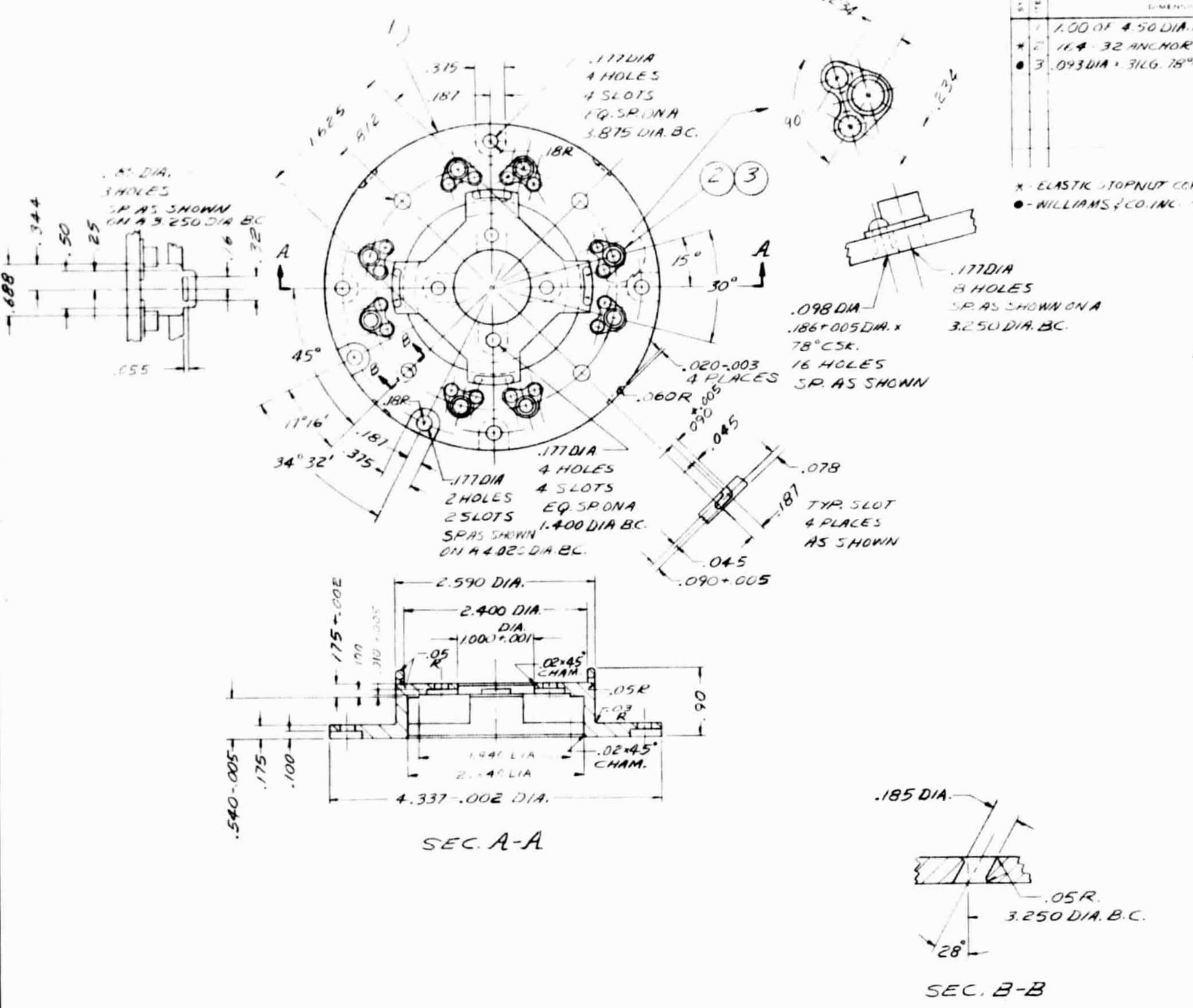
*	2	164-32 ANCHOR NUT AT #LHTAS MZ86D BC	8	
●	3	.093 DIA x 31LG. 78° CSK HD 1100 F AL RIVET	16	

* - ELASTIC STOPNUT CORP. OF AMER. 2330 VAUXHALL RD, UNION, N.J. 07083

● - WILLIAMS & CO. INC. 901 PENNSYLVANIA AVE., PGH, PA 15233



NOTES:

1. BREAK ALL SHARP EDGES .005 MAX R

TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL DEC .02; 3 PL DEC .005; ANGLES 0.5°

FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

Westinghouse Electric Corporation

TITLE BEAM DEFLECTION SYSTEM SUPPORT FLANGE DET.

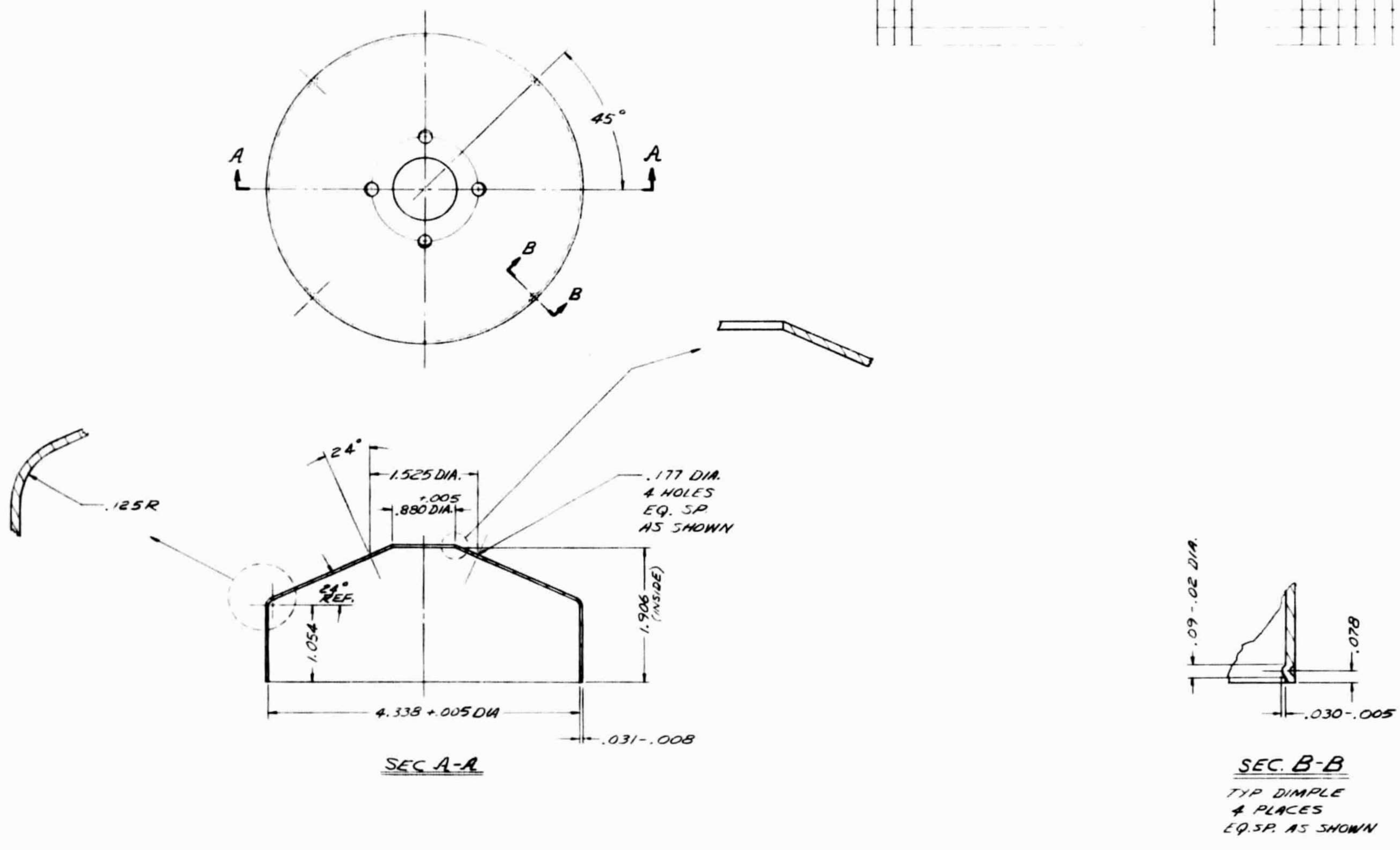
DIMENSIONS IN INCHES SCALE 1:1

254C572

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

S.O.	IT	CHANGE
D 763688	1	

SYM	ITEM	DESCRIPTION - MATERIAL, DIMENSIONS IN INCHES
	1	SPIN FROM MOLYBDENUM SH.



TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL DEC .02; 3 PL DEC .005; ANGLES 0.5°

FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

Westinghouse Electric Corporation

TITLE BEAM DEFLECTION SYSTEM SHROUD DET.

DIMENSIONS IN INCHES SCALE NTS

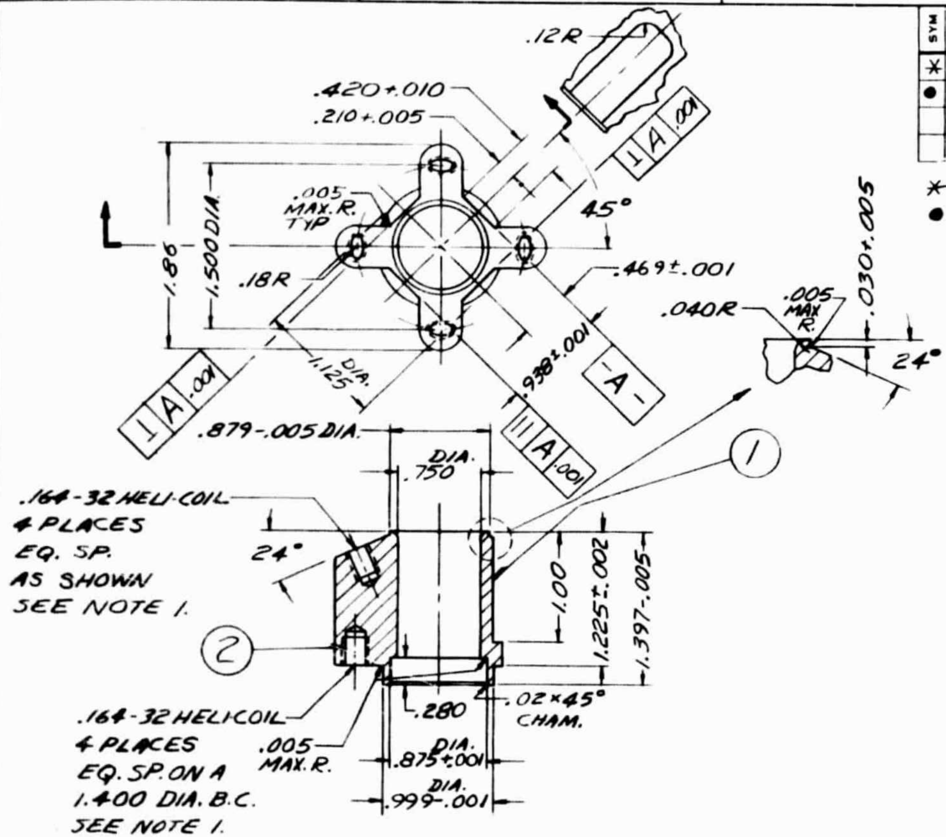
DFTM D.SPINAZZOLA 2/28/78 — APPD J.T. Lowry 12/29/70

CHKD — SUPV — APPD

254C545

RESEARCH LABORATORIES PITTSBURGH, PA. 15235 U.S.A.

S.O. D 763688 — CHANGE 1



SYM	ITEM	DESCRIPTION – MATERIAL DIMENSIONS IN INCHES	REF DWG OR PART NO	SYM GR	1	2	3	4	5
*	1	1.50 OF 2.00 DIA. SILVER COPPER ROD	GR. 116-60		1				
●	2	.164-32 SCR. LOCK INSERT # 3585-2CN	0246		8				

* - COPPER RANGE CO., 630 FIFTH AVE., NEW YORK, N.Y. 10020

● - HELI-COIL CORP., SHELTER ROCK LANE, DANBURY, CONN 06810

NOTES:

1. INSTALLATION OF HELICOILS
   - A. .177 +.003 Dia × .375 +.015 DP.
   - B. .190 +.030 Dia × 120° CSK
   - C. .164 – 32 UNC – 2B SCR. Thd. Insert Bottom Tap to .320 +.020 DP. (bottom tap # 44187-2)
   - D. Pitch Dia. .184 +.003
   - E. Install Screw-Lock Insert # 3585–2CN 0246, .023 to .047 Below Top Surface Use Inserting Hand Tool # 7551-2
   - F. Break Off Driving Tang with Automatic Break-Off Tool # 3695-2
2. BREAK ALL OUTSIDE EDGES .005 TO .010 R.

S.O.	D. 763688
IT.	CHANGE
1	

TOLERANCES

UNLESS OTHERWISE SPECIFIED

2 PL DEC	3 PL DEC	ANGLES
.02	.005	0.5°

FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

FLATNESS · STRAIGHTNESS · ROUNDNESS (CIRCULARITY) · CYLINDRICITY · PROFILE OF ANY LINE · PROFILE OF ANY SURFACE · PARALLELISM · PERPENDICULARITY (SQUARENESS) · ANGULARITY · RUNOUT · TRUE POSITION · CONCENTRICITY · SYMMETRY · MAXIMUM MATERIAL CONDITION (MMC) · REGARDLESS OF FEATURE SIZE

REF DWG

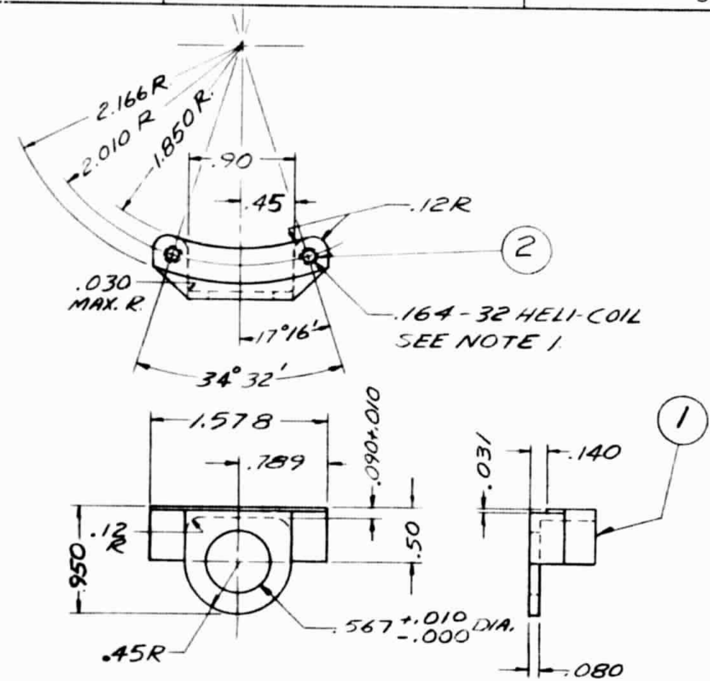
Westinghouse Electric Corporation

TITLE BEAM DEFLECTION SYSTEM CENTER TUBE DET.

DIMENSIONS IN INCHES—SCALE 1:1

DFTM D. Spinazzola 1-6-71	APPD J. Sowry 1-20-71	722 B959
CHKD	APPD	
SUPV	APPD	

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.



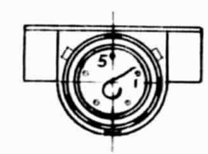
SYM	ITEM	DESCRIPTION – MATERIAL DIMENSIONS IN INCHES	REF DWG OR PART NO	SYM GR	1	2	3	4	5	R&D STK NO.
	1	1.75 x 1.12 of .75 THK. SST. PL. TYPE 304			1					3711
●	2	.164-32 SCR. LOCK INSERT # 3585-2CN0246			2					
*	3	SOLDER FLANGE HERMETIC (BAYONET) RECEPTACLE # 48 +5H10 5P			1					

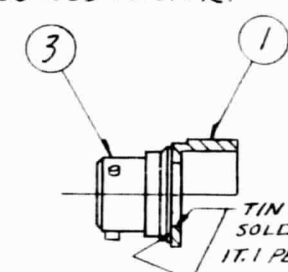
*-AMPHENOL CONNECTOR DIV., 2801 So. 25TH AVE., BROADVIEW, ILL. 60153

●-HELI-COIL CORP., SHELTER ROCK LANE, DANBURY, CONN. 06810

NOTES:

1. INSTALLATION OF HELICOILS
   - A. .177 + .003 Dia. × .375 + .015 DP.
   - B. .190 + .030 Dia. × 120° CSK.
   - C. .164 – 32 UNC – 2B SCR. Thd. Insert Bottom Tap to .320 + .020 DP. (bottom tap #44187-2)
   - D. Pitch Dia. .184 + .003
   - E. Install Screw-Lock Insert #3585 – 2 CN0246, .023 to .047 Below Top Surface Use Inserting Hand Tool #7551-2
   - F. Break Off Driving Tang with Automatic Break-Off Tool #3695-2
2. BREAK ALL OUTSIDE EDGES .005 TO .010R.





TIN THIS AREA & SOLDER IT. 3 TO IT. 1 PER INSTRUCTIONS IN AMPHENOL 48 SERIES APPLICATION MANUAL #1 NOTE PIN ORIENTATION

S.O. D. 763688 — 1 — IT — CHANGE

TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL DEC ± .02; 3 PL DEC ± .005; ANGLES ± 0.5°

FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS: FLATNESS; STRAIGHTNESS; ROUNDNESS (CIRCULARITY); CYLINDRICITY; PROFILE OF ANY LINE; PROFILE OF ANY SURFACE; PARALLELISM; PERPENDICULARITY (SQUARENESS); ANGULARITY; RUNOUT; TRUE POSITION; CONCENTRICITY; SYMMETRY; MAXIMUM MATERIAL CONDITION (MMC); REGARDLESS OF FEATURE SIZE

REF DWG

Westinghouse Electric Corporation

TITLE BEAM DEFLECTION SYSTEM CONNECTOR BRACKET DET.

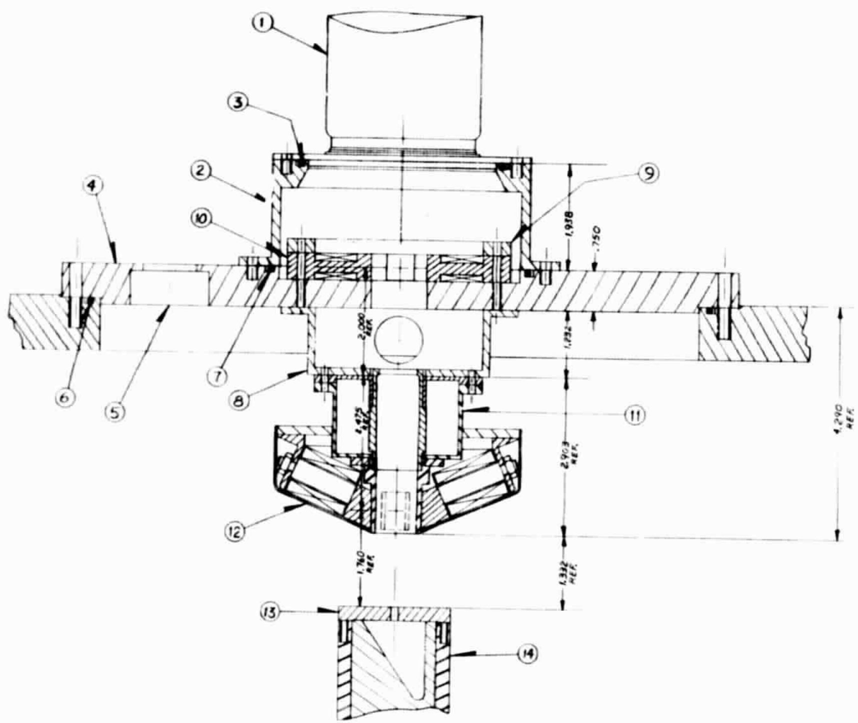
DIMENSIONS IN INCHES—SCALE 1:1

DFTM D. Spinazzola 1-12-71 — APPD J. Lowry 1-20-71 — CHKD — APPD — SUPV — APPD

722 B960

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

ITEM	DESCRIPTION - MATERIAL DIMENSIONS IN INCHES	REF DWG OR PART NO	GR 1
1	EXISTING ELECTRON GUN ASSEMBLY	181C849	1
2	ELECTRON GUN SUPPORT FLANGE		1
3	VITON O-RING #2-238 (3.50 I.D. x 3.75 O.D. x .12 WALL)		1
4	MOUNTING FLANGE		1
5	AMPHENOL HERMETIC RECEPTACLE # 49-03H12-12P		1
6	SILICON O-RING #2-276 (11.00 I.D. x 11.25 O.D. x .12 WALL)		1
7	VITON O-RING #2-246 (4.50 I.D. x 4.75 O.D. x .12 WALL)		1
8	MAGNETIC LENS SUPPORT FLANGE		1
9	DEFLECTION COIL RING		1
10	EXISTING DEFLECTION COIL		4
11	EXISTING MAGNETIC LENS ASSEMBLY	181C847	1
12	BEAM DEFLECTION SYSTEM	4864D97	1
13	COLLECTOR COVER PLATE		1
14	EXISTING BEAM COLLECTOR/DISSIPATOR		1



Westinghouse Electric Corporation

TITLE BEAM DEFLECTION SYSTEM TEST STAND LAYOUT

REF. DWG. 4864D97

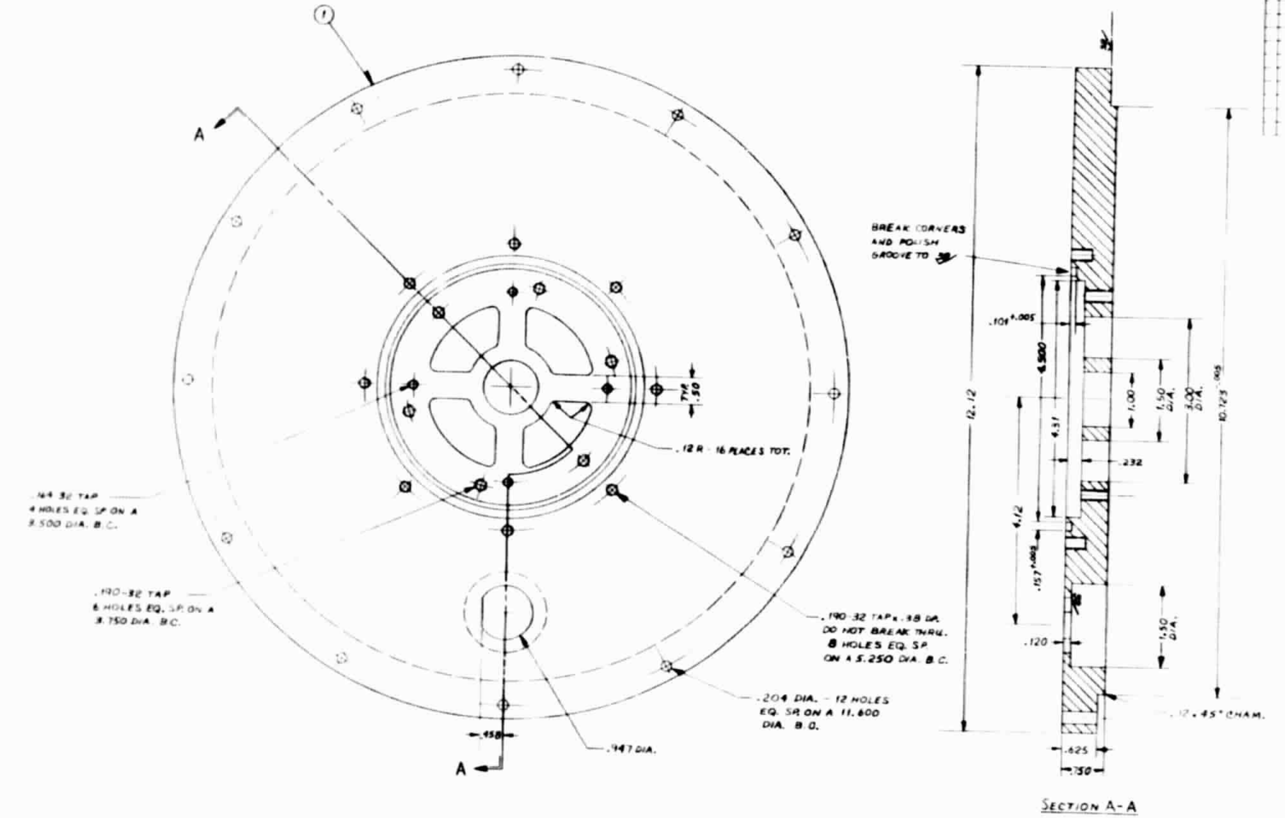
J. Lowry 1-11-71

4865D18

RESEARCH LABORATORIES

CHANGE: 765038

ITEM	DESCRIPTION, MATERIAL, DIMENSIONS IN INCHES	REF DWG PART NO.	SYM	REQ'D	STK. NO.
1	12.38 DIA. OF .875 THICK 2024-T351 ALUMINUM PL.				0271



SECTION A-A

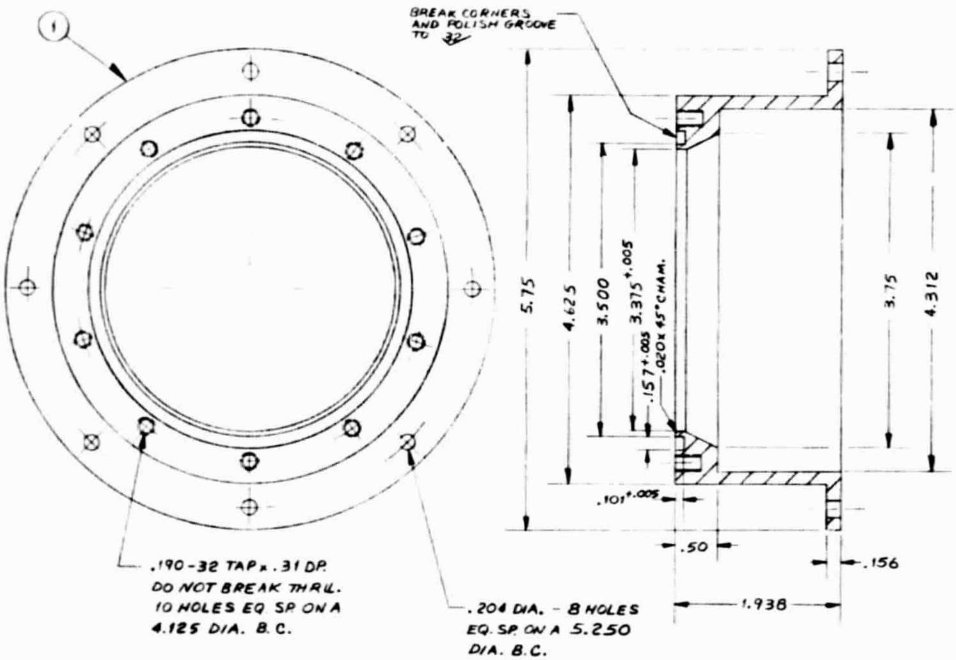
NOTE: REMOVE ALL BURRS AND BREAK ALL OUTSIDE EDGES .005 - .010 R.

Westinghouse Electric Corporation

TITLE: BEAM DEFLECTION SYSTEM TEST STAND
MOUNTING FLANGE

4865D17

SYM	ITEM	DESCRIPTION MATERIAL DIMENSIONS IN INCHES	REF DWG OR PART NO	SYM GR	1	2	3	4	5	REQ'D STK NO.
	1	2.12 OF 6.00 DIA. 2024-T351 ALUMINUM ROD								0153



REMOVE ALL BURRS AND BREAK ALL OUTSIDE EDGES .005-.010 R.

TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL DEC ±.02; 3 PL DEC ±.005; ANGLES ±0.5°

FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

Westinghouse Electric Corporation

TITLE BEAM DEFLECTION SYSTEM TEST STAND ELECTRON GUN SUPPORT FLANGE

DIMENSIONS IN INCHES—SCALE

DFTM J. Lowry 1-7-71 APPD

CHKD APPD

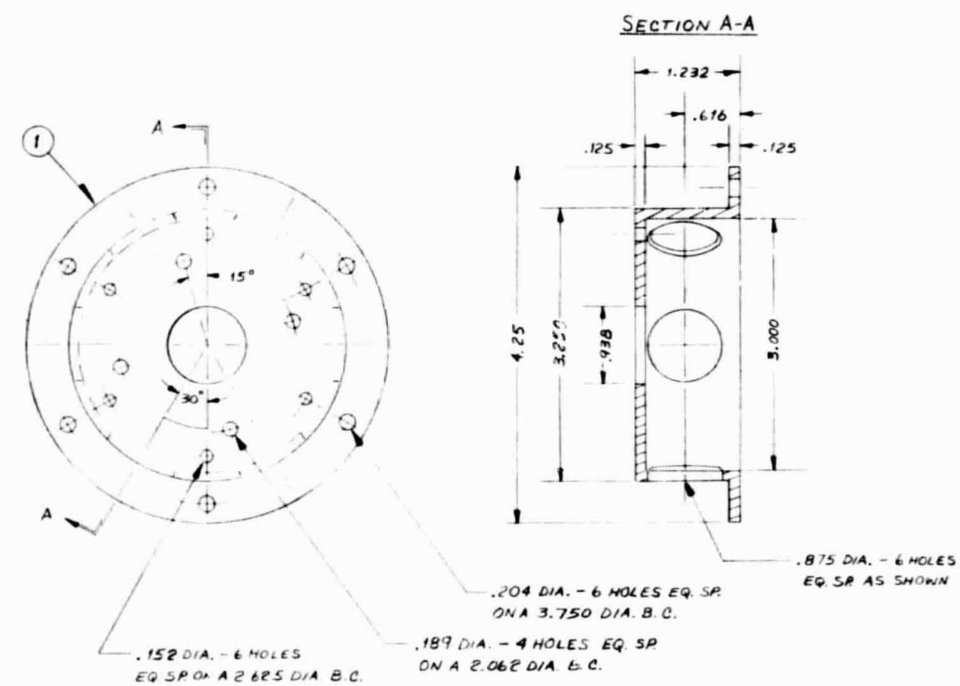
SUPV APPD

254C567

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

S.O. D 763688 — 1 — CHANGE

SYM	ITEM	DESCRIPTION - MATERIAL DIMENSIONS IN INCHES	REF DWG OR PART NO	SYM GR	1	2	3	4	5	REQD STK. NO.
	1	1.31 OF 4.50 DIA. 2024-T351 ALUMINUM ROD								0151



NOTE: REMOVE ALL BURRS AND BREAK ALL OUTSIDE EDGES .005-.010 R.

S.O. 763688 — CHANGE 1

TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL DEC .02, 3 PL DEC .005, ANGLES ±0.5°
FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

Westinghouse Electric Corporation

TITLE BEAM DEFLECTION SYSTEM TEST STAND MAGNETIC LENS SUPPORT FLANGE

DIMENSIONS IN INCHES - SCALE

DFTR G. Lowry 1-7-78

254 C568

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

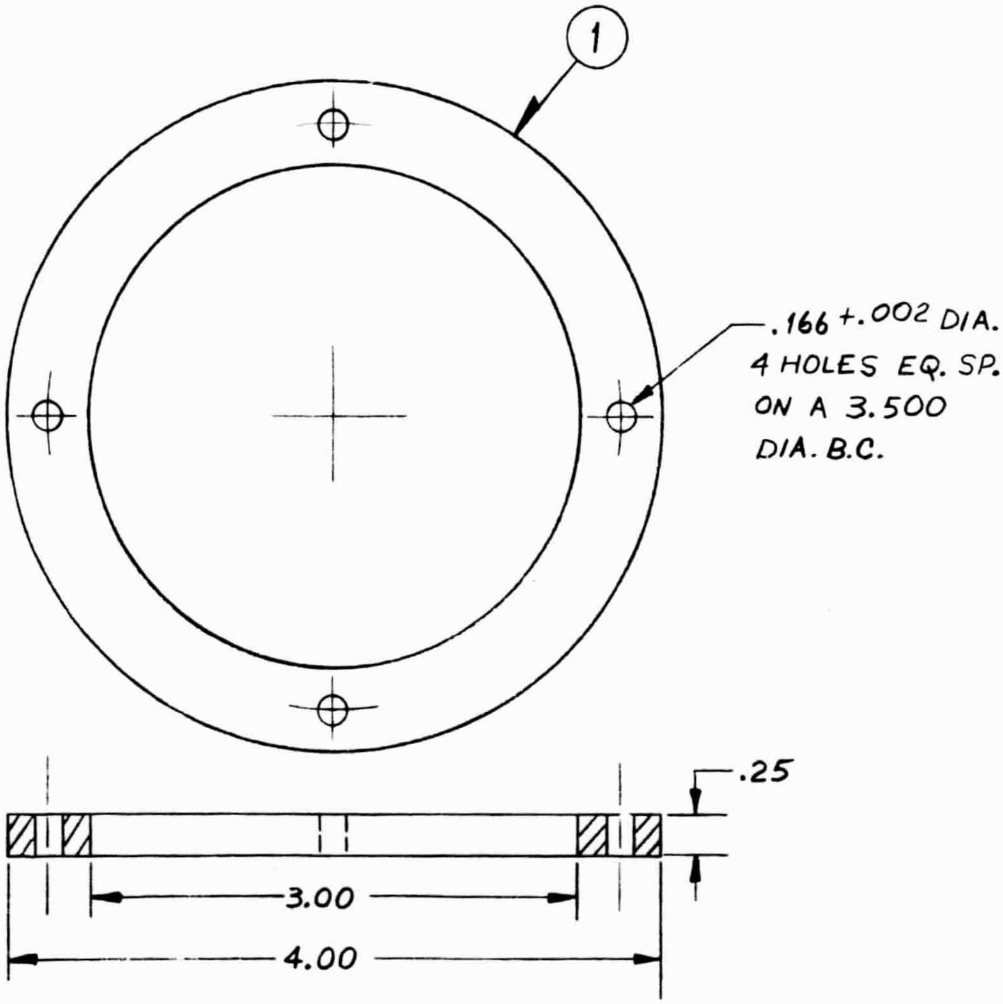
SUB.	S.O.
1	D. 763698
1-7-1	J. L.

WESTINGHOUSE ELECTRIC CORPORATION RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH 35, PA., U.S.A.

TITLE DEFLECTION COIL RING

DWG. A SUB. 1 FINISH CHART

SYM.	ITEM	DESCRIPTION — MATERIAL DIMENSIONS IN INCHES	PAT. NO. OR REF. DWG.	FIN. CH. LINE NO.	STYLE NO.	SYM. GR.	1	2	3	4	5	
	1	4.25 DIA. X .30 THK. ARMCO	MAGNET	INGOT	IRON							



TOLERANCES		
UNLESS OTHERWISE SPECIFIED		
2 PL. DEC.	3 PL. DEC.	ANGLES
±.02	±.005	±0.5°

2937 A 22

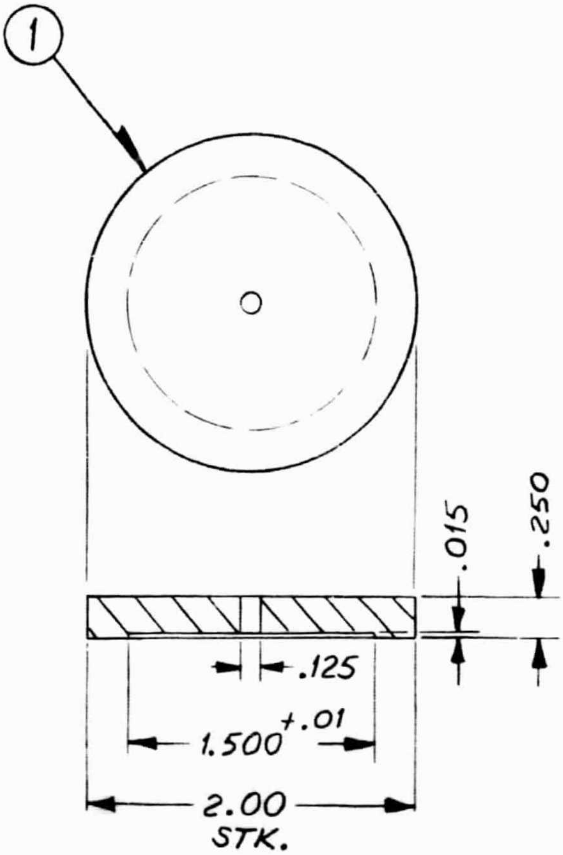
SUB	S.O.
1	D.7636688
1-11-71	J.L.

WESTINGHOUSE ELECTRIC CORPORATION RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH 35, PA., U.S.A.

TITLE BEAM DEFLECTION SYSTEM TEST STAND
COLLECTOR COVER PLATE

DWG. A SUB. 1 FINISH CHART

SYM.	ITEM	DESCRIPTION – MATERIAL DIMENSIONS IN INCHES	PAT. NO. OR REF. DWG.	FIN. CH. LINE NO.	STYLE NO.	SYM. / GR.	1	2	3	4	5	RED STK.	NO.
	1	.31 OF 2.00 DIA. 304 STAINLESS STEEL ROD										35	41



TOLERANCES		
UNLESS OTHERWISE SPECIFIED		
2 PL. DEC.	3 PL. DEC.	ANGLES
±.02	±.005	±0.5°

2937 A 23