Final Report No. IITRI V6034-24

DEVELOPMENT OF A CONTINUOUS SCANNING LAMINOGRAPH

to

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama 35812

Attention: PR-RC

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DEVELOPMENT OF A CONTINUOUS SCANNING LAMINOGRAPH

June 20, 1966 through June 30, 1968

Edited by

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Submitted by

IIT RESEARCH INSTITUTE
Technology Center
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to

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FOREWORD

This is the final report under NASA Contract NAS8-20640, covering the period of June 20, 1966 through June 30, 1968. Principal contributors to the work described in this report were Dr. Robert B. Moler (Project Leader), Dennis L. Riley, Robert C. Pape, Romas Kasparas, Blaine E. Arneson, Richard H. Hagedorn, Paul C. Gregg, and Harold F. Bennett. Numerous others made significant contributions in a variety of ways. The cooperation, generous assistance, and continual great interest of J. F. Blanche is also acknowledged.

Respectfully submitted
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ABSTRACT

The design of a X-ray laminograph for the inspection of multilayered printed wiring boards is presented. The design is based on the use of a closed circuit television system in conjunction with an optical derotation system to form a motionless image. Three magnifications are provided, 0.2X, 1X, and 4X, to allow either coarse or detailed inspection. The X-ray source and television camera may be programmed to scan the sample automatically in depth (Z-axis) and area (X and Y axes). The resolution is limited by the optical system to about 0.001 in. Vertical (layering) resolution is 0.002. Any volume of the sample may be selected for inspection. A manual mode is also available which allows complete operator control of the inspection.

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I. INTRODUCTION

The inspection of multilayer printed circuit boards is a matter of considerable concern especially in cases where the board must be space qualified. A variety of techniques are employed for 100 percent inspection; however, the limited knowledge of the nature, occurrence,and appearance of the defects makes the choice of an inspection technique somewhat ambiguous.

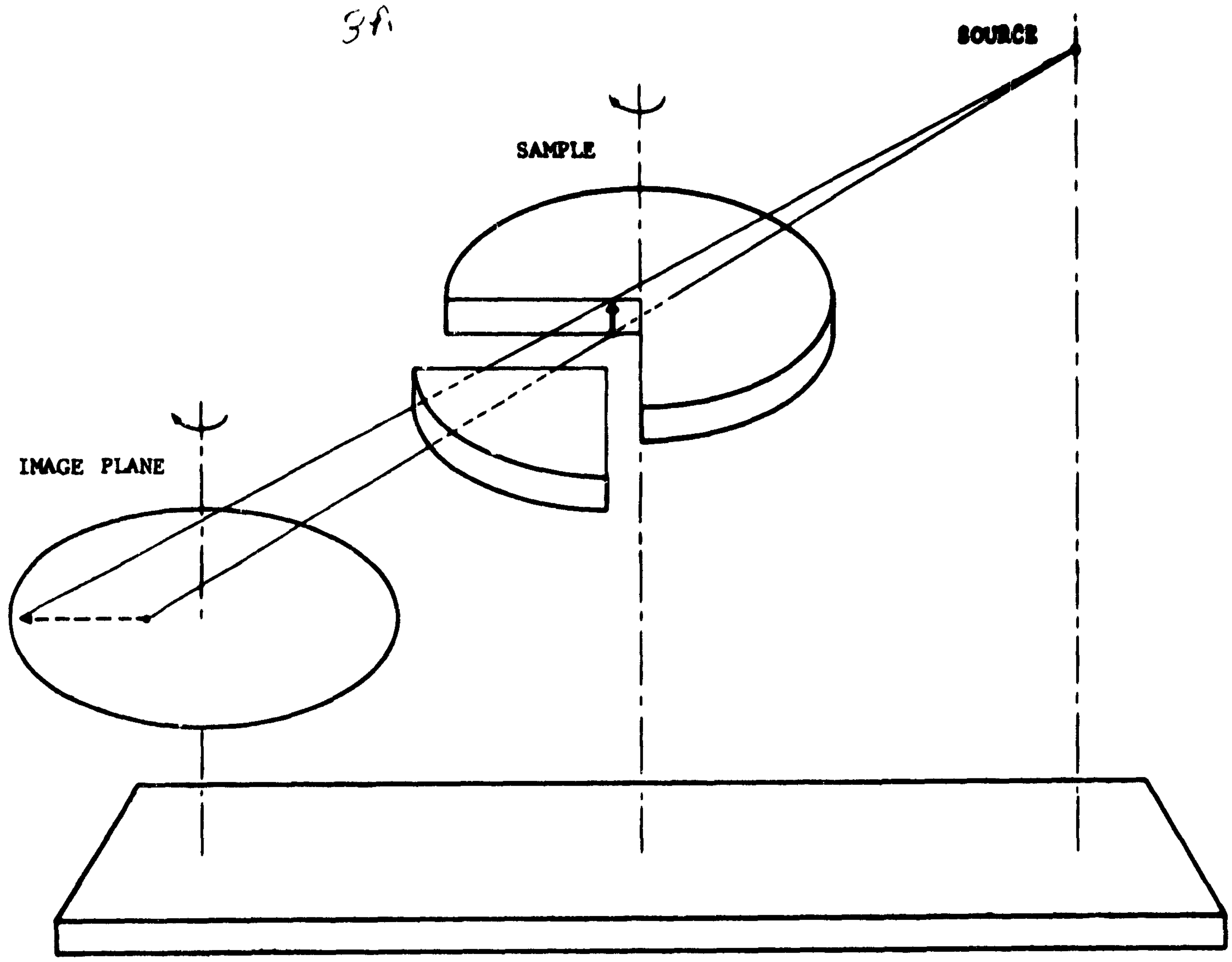
The goals of this program were to design, construct, and test an instrument which would be capable of producing cross-sectional views of a multilayer printed circuit board using the technique of laminography. The instrument was to have the following specific characteristics: detail resolution of 0.001 in. or better, layering resolution of 0.004 in. or better, and the capability to inspect a printed board of maximum dimensions 12 in. by 12 in. by 0.5 in; operation was to be semiautomatic and a real time display of the layer area being inspected was to be provided, a magnification range of 10 to 1 was desired to allow either detailed or gross inspection; scanning of the sample was to be programmable so that continuous scanning could be performed. This report describes the design of an instrument to achieve these goals, albeit certain compromises in terms of ease of operation and rapidity of inspection were necessary.

Radiography is well known as a nondestructive testing tool and has been in common use for many years. One of its principal drawbacks is its inability to locate flaws in depth in a sample without making multiple exposures followed by careful analysis. In a previous program[(1)] a technique called laminography was explored and found to be very promising. This technique is capable of producing cross-sectional radiographs with high resolution and very close interplane spacing. The technique was fully described in the previous report[(1)] and will be discussed only briefly in the following paragraphs.

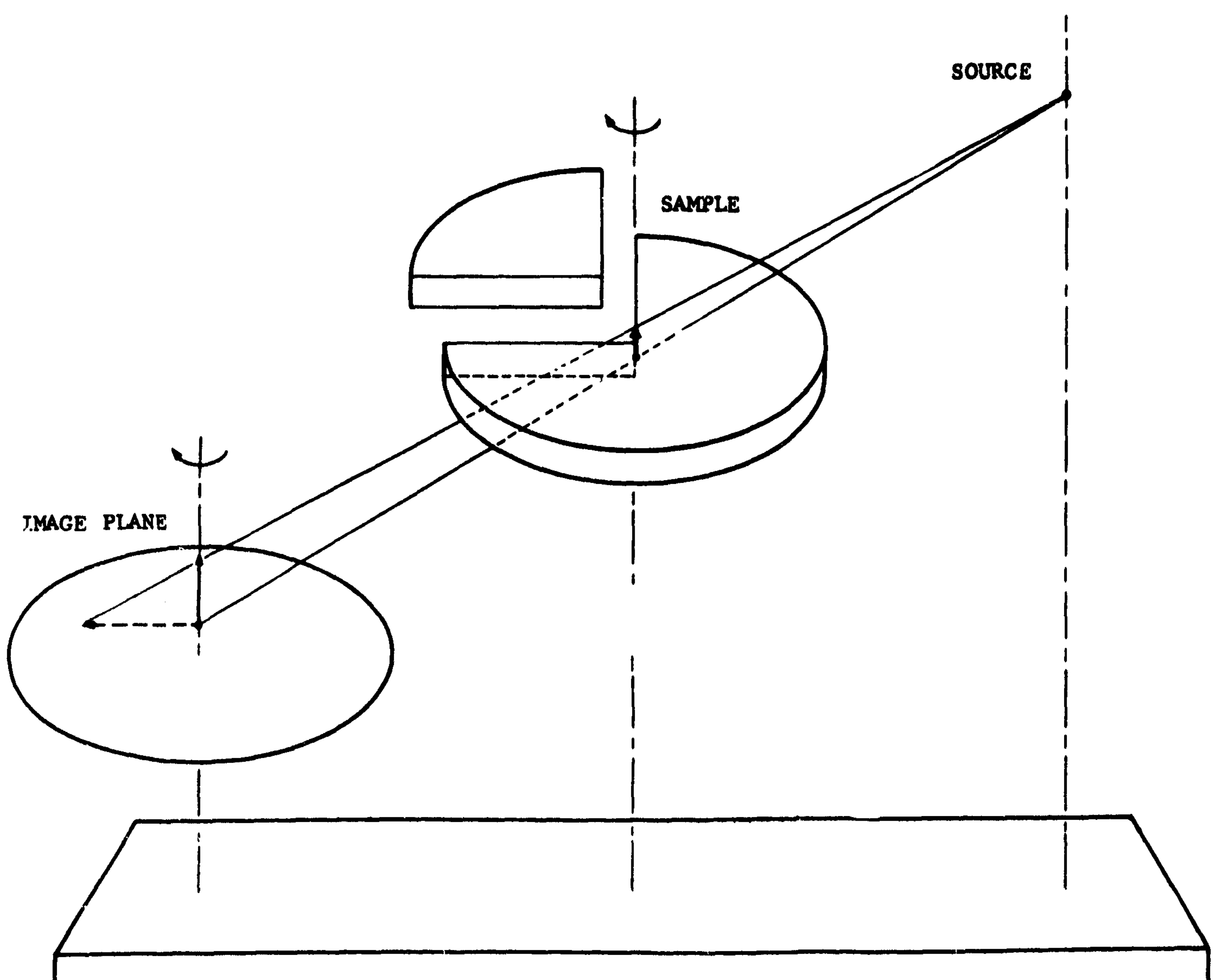
The laminography technique is based on the fact that if the sample and the image-forming plane rotates synchronously, the source-sample-image plane geometry will determine a plane in the sample whose image remains fixed in the rotating image-forming surface. Other planes in the sample result in images which describe epicycles in the image-forming plane, and therefore no sharp image can be observed. This more or less uniform smearing of the images of planes in the samples is the essential mechanism which accounts for the operation of the technique. Figures I-1 and I-2 illustrate the technique in one of its simpler forms: that of a rotating sample and film.

A variety of motions are available, all of which produce essentially the same results. For example, the source and film may be coupled to perform linear motion, planetary motion, or some more complex motion; the sample and film may describe rotary, linear, or precessional motion, or yet more complex motion. Most of these variations have been well described by Takahashi.[2] In essence, all of these variations achieve the same fundamental result and the choice of any one of them depends on the particular application; for example, if a person is to be laminographed, it is practically dictated that the film and source carry out the requisite motion.

In all of these variations, an essential feature is the use of X-ray sensitive film as the image-forming medium. This at once has the major disadvantages of being relatively slow as well as incurring an unavoidable delay between the time the sample is laminographed and when the developed film is inspected. It was the purpose of this program to explore means to remove these limitations and to develop an instrument based on the optimum technique. The most important of these techniques as well as the chosen approach are discussed below.

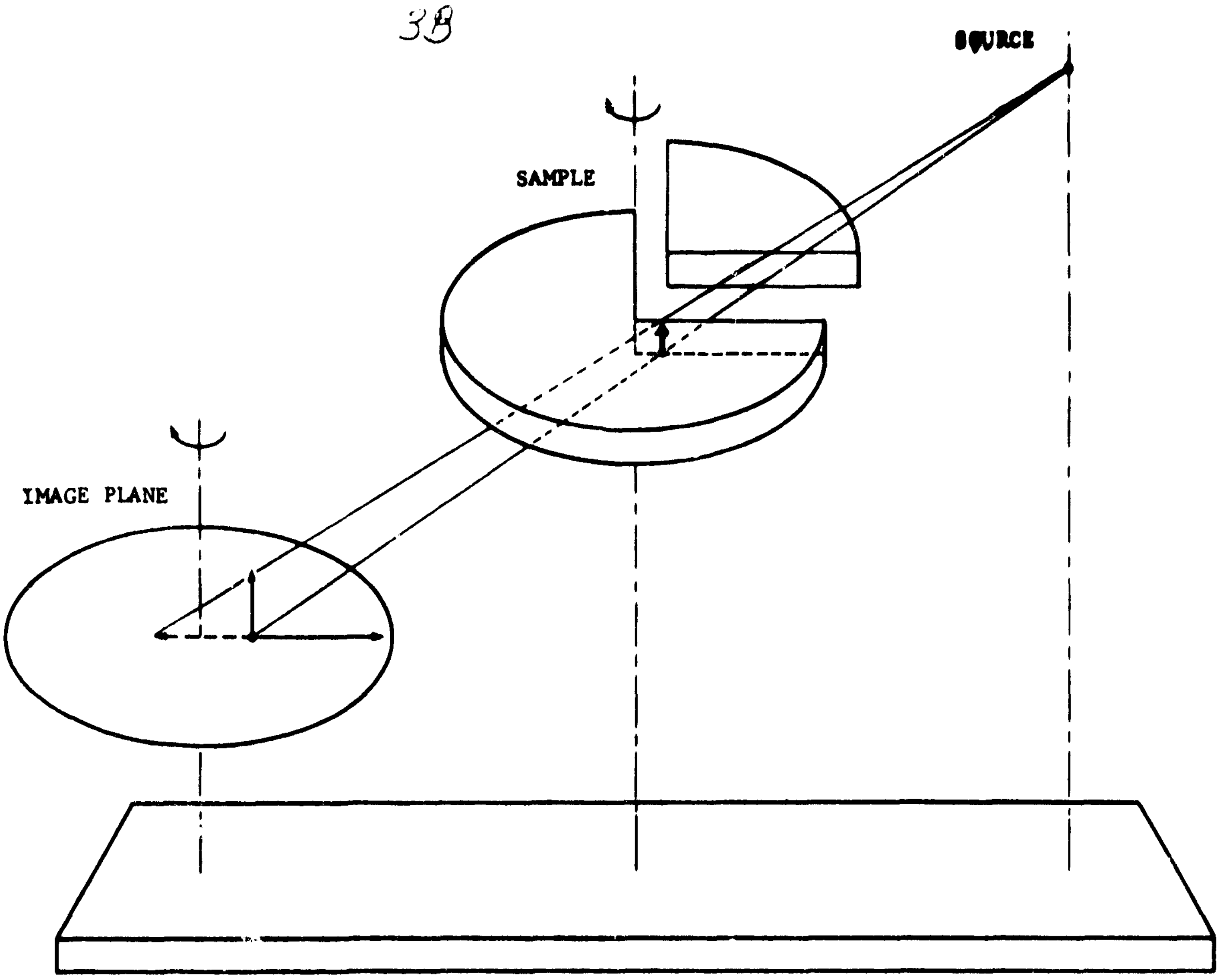


a. Initial Position and Image

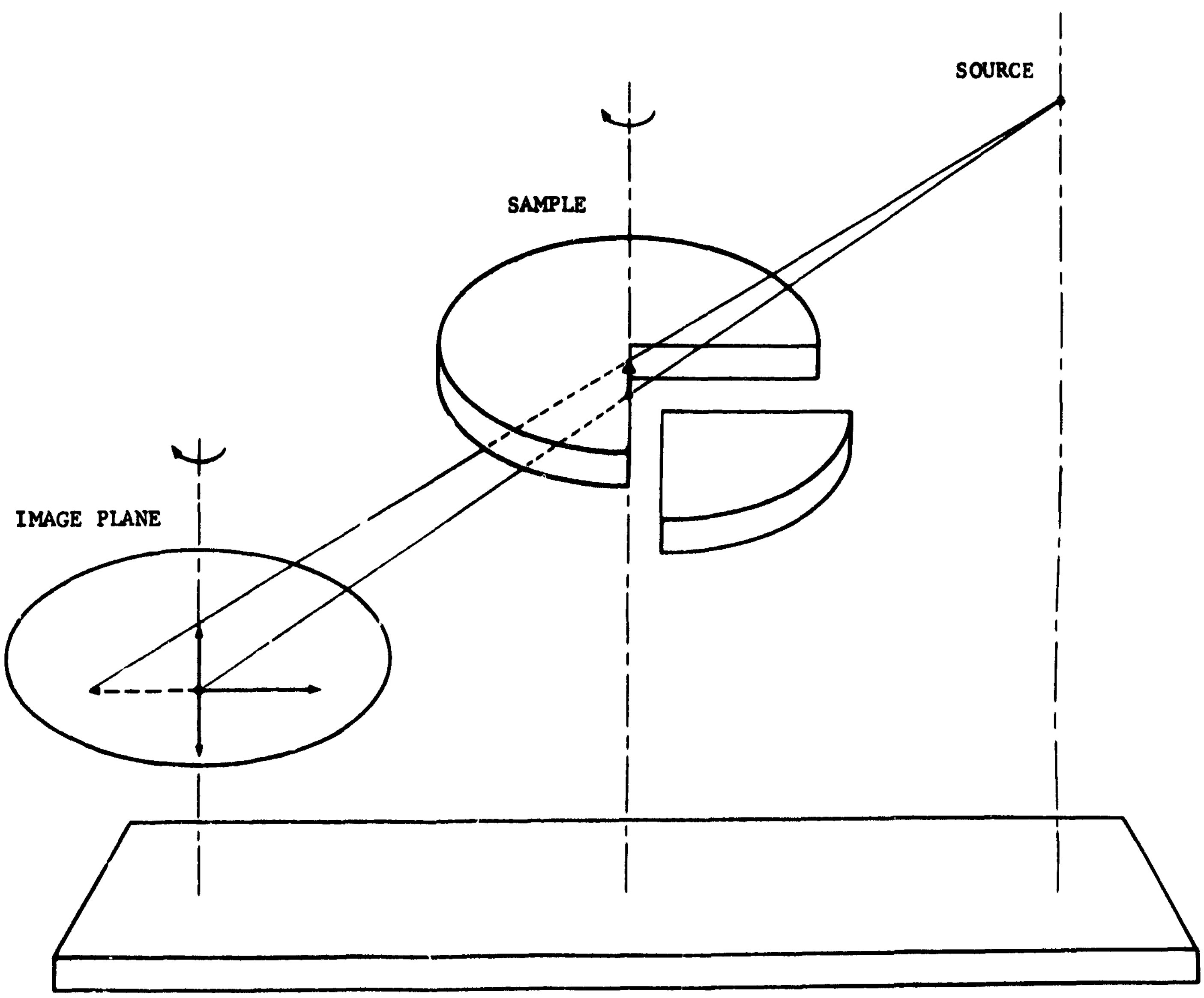


b. Position After 90° Rotation Showing Old and New (Dashed Line) Images

3B



c. Sample and Images After 180° Rotation



d. After 270° Rotation Showing 4 Images

Figure I-1 LAMINOGRAPHY GEOMETRY SHOWING THE DEVELOPMENT OF A FIXED AND SMEARED IMAGE. THE PLANE OF SHARP FOCUS IS THE BOTTOM OF THE SAMPLE. THE BOTTOM OF THE ARROW PRODUCES A FIXED POINT ON THE IMAGE PLANE.

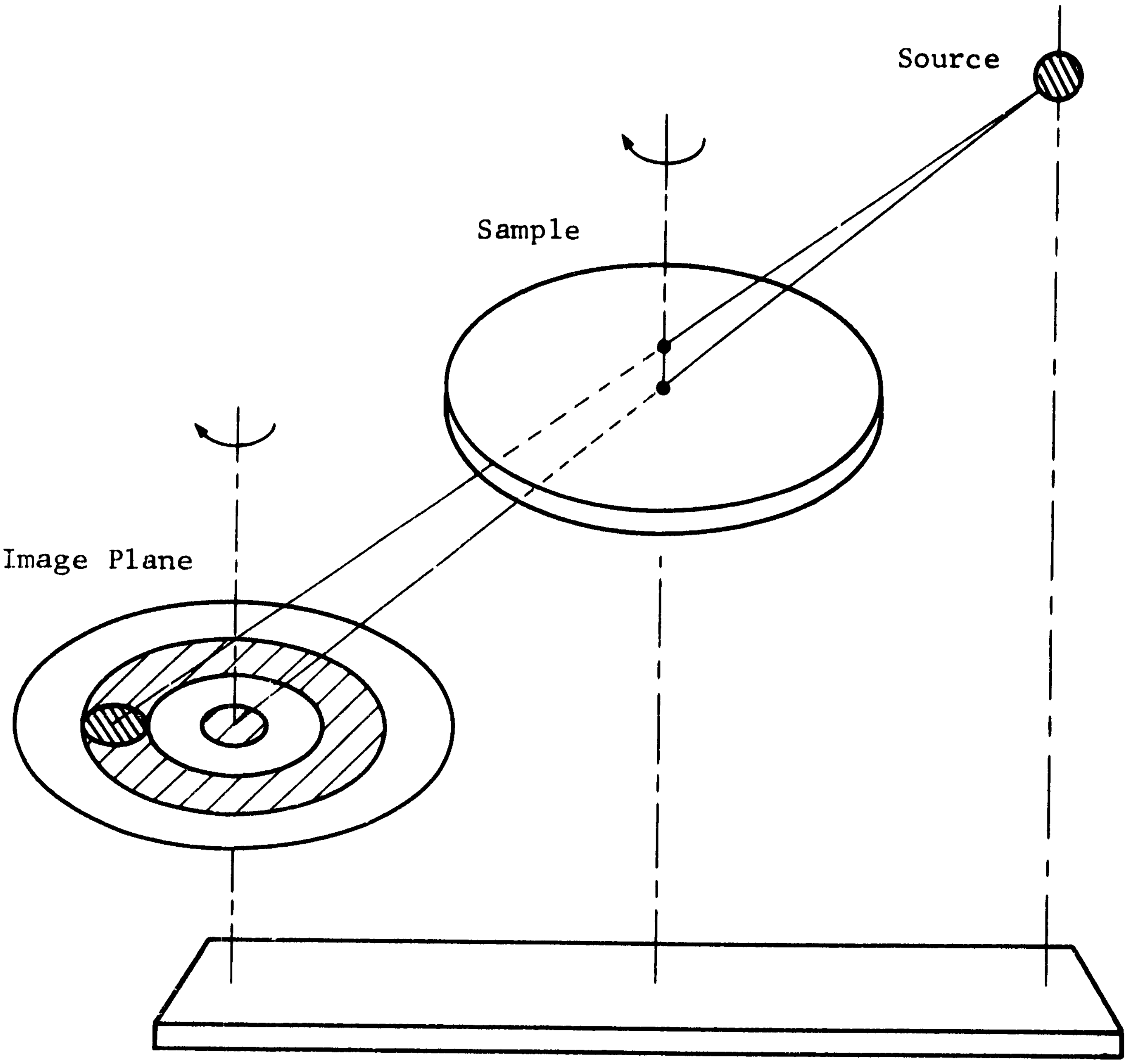


Figure I-2 SCHEMATIC DRAWING SHOWING A REINFORCED POINT AND A SMEARED POINT AFTER 300° ROTATION

One of the advantages of the ordinary film technique is that a permanent record is obtained, but this becomes a liability when the total number of exposures which must be made is twenty or more,as it is in most cases of interest. Since any two exposures contain all the information necessary to reconstruct the internal details of the sample, it is possible to produce, with a limited number of exposures, a permanent record of the sample. The exposures, if properly taken and subsequently displayed, will recreate in a volume of space, a three dimensional image of the sample. Any plane within this image can be viewed when an appropriate screen is placed into the image volume. This technique of projective laminography, while it has obvious advantages, still suffers from an inherent time delay. It is also difficult to view magnified sections of the image. These two disadvantages in addition to the fact that no prototype equipment of this type had been used at the time, led to the elimination of this technique from further consideration. The technique deserves further study and experimental verification. Because of the inherent time delay, all techniques using film were eliminated subsequently and only those techniques which could produce real time viewing were considered. Systems which were considered to have promise were systems which replaced the X-ray film with a fluorescent screen, and systems which replaced the X-ray film with an X-ray sensitive vidicon.

The use of an X-ray sensitive vidicon has obvious advantages based on simplicity, reliability, and cost; however, the major disadvantage of rotation of the camera (or vidicon tube) was found to be too great to make this technique practical. The major problem arises as a result of the limitation on resolution inherent in all TV systems. To achieve acceptable resolution with even the best available vidicon, the area of the sample viewed by the vidicon photocathode must be magnified by at least a factor of two. This would involve some separation between the sample and vidicon and a problem of scattered X-rays; but more importantly, it would require that the vidicon rotate off axis, and be programmable in two dimensions (radius and angle) to cover the area of a sample undergoing inspection. The problems of moving the vidicon in this manner were sufficiently serious to rule out the technique. Other serious problems were encountered as well. The required separations between source, sample, and photocathode impose requirements on the X-ray source that cannot be met at present. The resolution sensitivity of the vidicon is also a problem since the decreased sensitivity as a result of the resolution requirement increases the required source intensity. Future improvements in vidicons and X-ray sources may change this situation and the method deserves a reevaluation at that time.

The chosen technique involves replacing the X-ray film with a fluorescent screen, and replacing direct viewing with a closed circuit television system. In any system using film the integration required to produce the effective single layer imaging is performed in the film itself. An obvious way to achieve the same effect is to use a fluorescent screen with a long decay time, derotate the image optically, and observe the derotated image with a standard television system. A large variety of phosphors were investigated, none of which were available in a form suitable for our purpose. In general, no phosphor with a sufficiently long decay time was available in the form of a fluorescent screen which would have detail resolution adequate for the design goals. Some attempts were made to produce high quality screens by vacuum deposition. This effort met with limited success although the results were sufficiently encouraging to predict that such screens could be produced. ther developments made the consideration of this effort unnecessary.

In considering the integration of the image which results in the single layer image, it became obvious that integration could take place at the photocathode of the image tube as well as in the primary converter, the fluorescent screen. When this is realized, the requirement of the screen is altered and a screen having a short decay time is desirable. If the decay is sufficiently short, rotation of the screen is no longer required, with a consequent simplification of the system. An appropriate phosphor is $CaWO_4$ which is a very efficient converter for X-rays in the 50 to 150 keV region and has a short decay time. Screens made from this material have a long history of development and can be produced having properties tailored to the desired use. Typically such screens are made by deposition of $CaWO_4$ particles in a binder onto an appropriate substrate. Particle sizes are usually a few microns or less. The measurement of the light output of several such screens is discussed in Appendix A.

After careful study of the various alternatives, a preliminary design was developed which consisted of a fixed X-ray source and fluorescent screen, a rotating sample and a rotating optical system to form a fixed image on the photocathode of the image tube. The elements of this preliminary design are shown in Figure I-3.

This preliminary design resulted in nearly as many problems as it solved. The limited resolution of available image tubes meant that magnification of the image would be required. Since only a portion of the board could be viewed, the image tube must be moved in the X-Y plane to scan the full image a portion at a time. Because of the magnification light levels would be low, a problem compounded by the optical derotation system which was found to have low light gathering efficiency when designed for high resolution. These difficulties resulted in a series of compromises in the design. The details of the design and the compromises will be discussed in the following section; however, it is appropriate here to discuss the advantages and limitations of the design without going into details.

R1 X-Ray Source and Z Traversing Mechanism
R2 Base Table
R3 Optics Rotary Table
R4 Optics Drum and Housing
R5 Mirror Mount Structure
R6 0.2 X Movable Optics System
R7 Fluorescence Screen
R8 Support for Auxiliary Lens System
R9 Lens Turret for TV Camera
R10 Sample Rotary Table
R11 X-Y Traversing Mechanism
R12 Support Structure for X-Y Mechanism
R13 Main Support Structure
R14 Television Camera

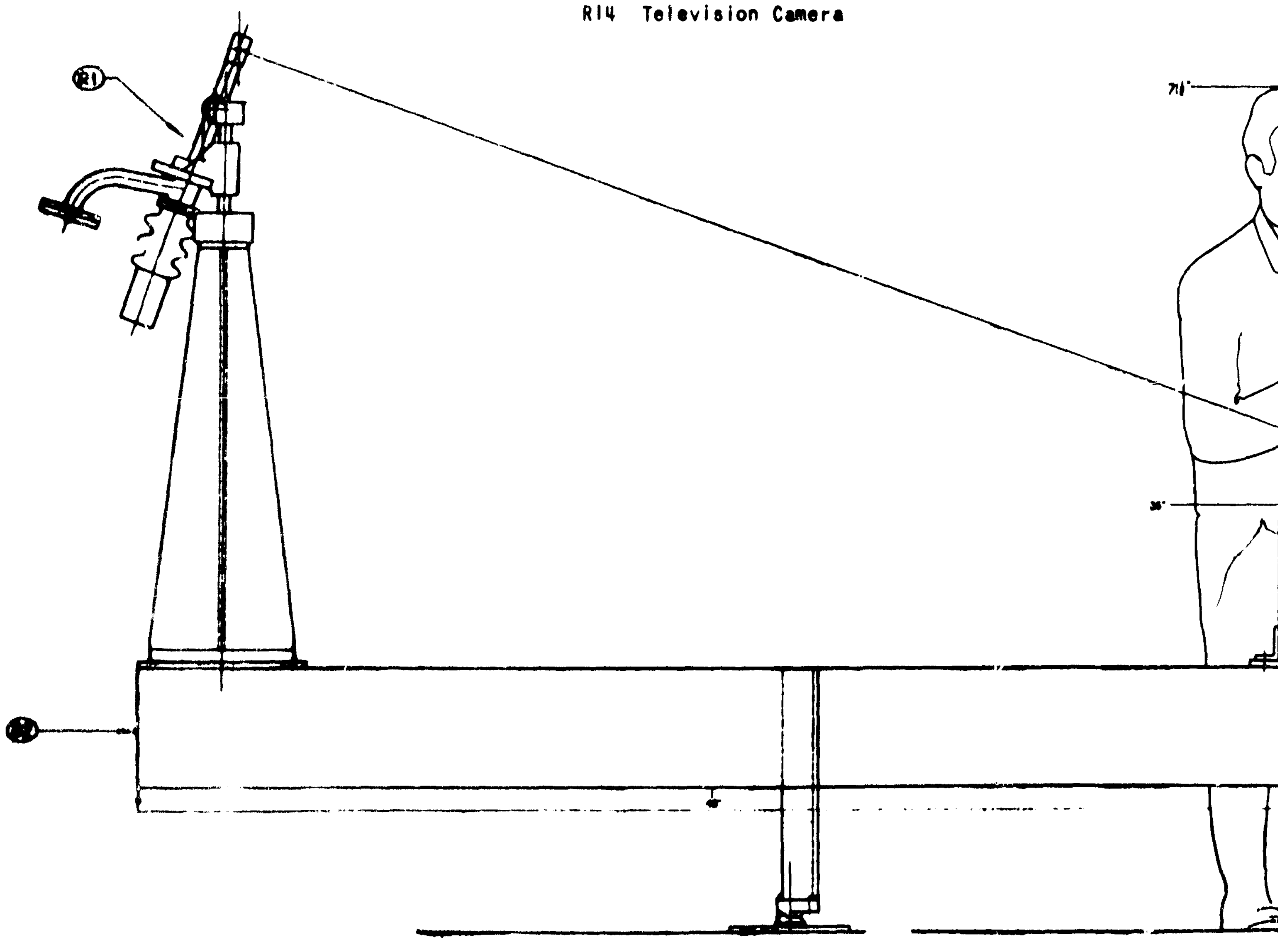
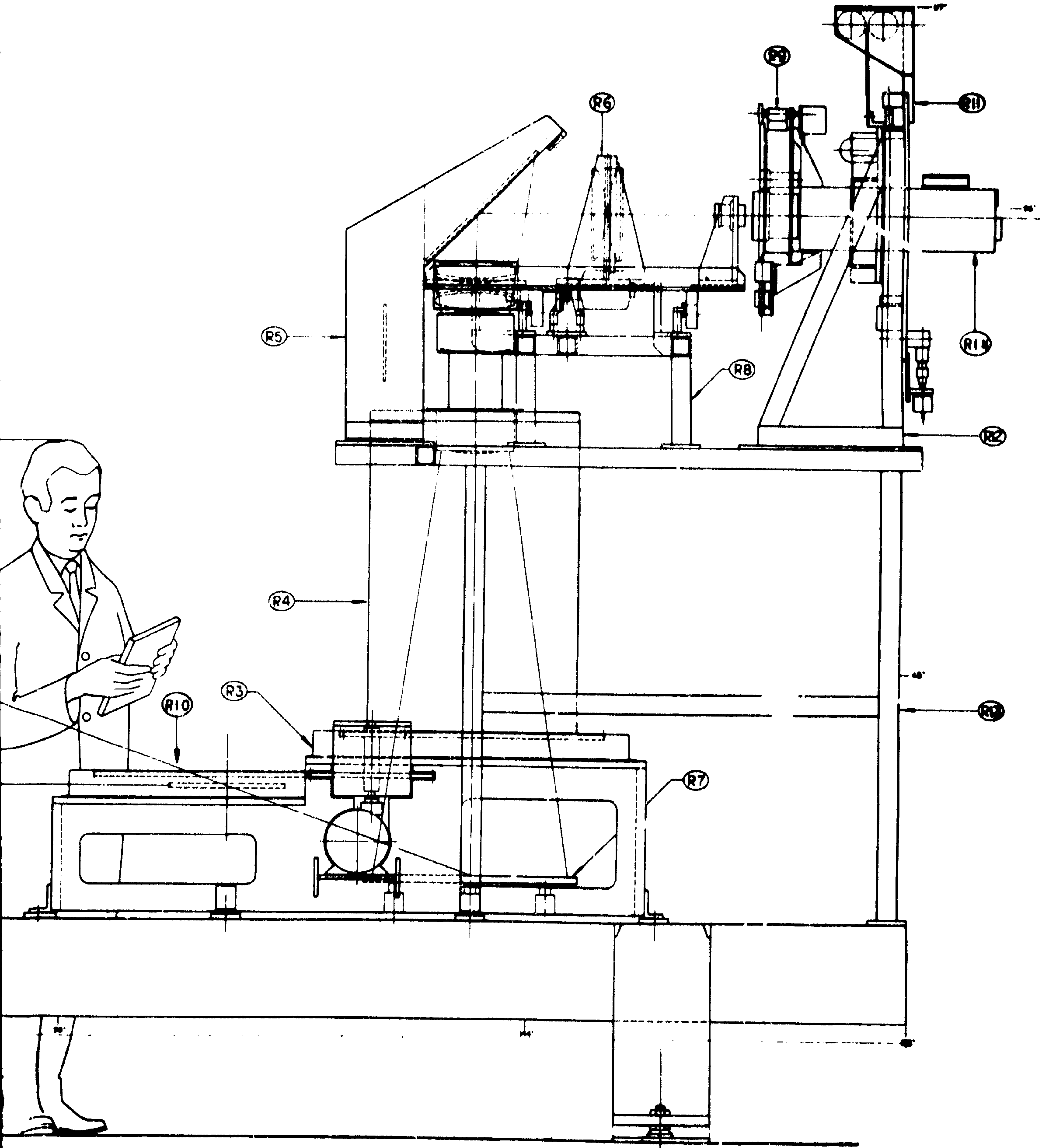


FIG. I-3 MAJOR COMPONENTS



NTS OF THE LAMINOGRAPH

Briefly, the laminograph will inspect any printed circuit board with maximum dimensions of 12 in. by 12 in. by 0.5 in. Three magnifications are provided: 0.2X, 1X, and 4X. At the smallest magnification a large area (~ 1/4 of the board) of the printed circuit board can be viewed. The resolution of the system in this mode is severely limited by the television resolution and only gross detail can be observed. In the 1.0X mode, reasonable detail is available but only an area 1.24 x 1.24 in. is viewed. In the 4X mode, the viewed area is only 0.3 x 0.3 in., but the resolution is about 0.001 in. This small viewed area represents the most serious compromise which had to be made in the design, and was dictated by the requirement of 0.001–in. detail resolution. State-of-the-art image orthicons achieve a resolution of about 250 line-pairs/in., a factor of 4 less than required. Had the available resolution been equivalent to 1000 line-pairs/in., a viewed area of at least 1 in. x 1 in. would have been possible, materially reducing the complexity of the instrument, greatly increasing the speed and ease of inspection, and virtually assuring that an eminently useful instrument could be developed. Individual layers are selected by moving the X-ray source in a vertical direction. Scanning is achieved by programming the X-ray source and television camera movements through a logic control unit. Any selected volume of the sample may be inspected and the scanning will be performed automatically. The display unit is a high resolution 14-in. monitor. The scan sequence can be manually overridden if a longer view of a given area is required. A completely manual mode is available in which scanning is controlled by the operator. Readouts for each of the position encoders are provided so that return to a previous position is achieved readily. Permanent recording of the inspection is achieved by making use of a Polaroid camera attached to an auxillary 7-in. monitor which is also used for initial setup and fine focusing.

Although the system is very versatile in its operation, it achieves this at the expense of considerable complexity. The control requirements are extensive and operation will require some skill for efficient utilization.

One of the major goals of this design effort was the replacing of some presently used inspection techniques by a much faster 100-percent inspection tool. This goal has been achieved although the solution is not an ideal one. The major limitation is the fact that inspection still involves the human factor, and as yet no completely satisfactory definition of flaws has been formulated.

A limitation is still present because of the limited speed of inspection. This limitation is imposed, in large degree, because of the necessity of visual inspection, but it also is a result of the design itself. This design limitation imposes a time lag of a minimum of 2 sec on the movement of the scan from one position to the adjacent position. For a board of maximum size to be inspected at 4X magnification, the time for a complete scan would be several hours. Clearly an inspection time of several hours is meaningful only if the inspection is capable of achieving nearly 100 percent quality assurance, or if this time is substantially shorter than the time involved in applying conventional methods. In general, the latter is true while the former is not. It is known that there are flaws incapable of being observed by laminography which would lead to failure of the printed circuit boards.

The two areas in the laminographic technique where improvement would greatly increase its usefulness is in detail resolution and in inspection time. Both of these objectives could be achieved if an image tube having a resolution of 5000 lines were developed. Much of the present optical system could then be discarded and more area would be displayed on the monitor. Inspection would be much faster. Such an image tube does not appear to be in the offing in the near future.

II. SYSTEM REQUIREMENTS

The requirement which dictates all other system requirements is the resolution. The laboratory prototype equipment achieved a resolution of about 0.002 in. during its initial evaluation; however, it was considered that a resolution of 0.001 in. could be achieved. Later work carried out on this program demonstrated a resolution significantly better than 0.001 in. on samples which were more representative of the types to be encountered. With these results as a demonstration of what could be achieved, the preliminary design of a continuous scanning laminograph was initiated with the goal of an 0.001-in. resolution.

The initial effort was confined to developing a conceptual system which would achieve the desired results with existing hardware or at least readily obtainable hardware. The only area in which relatively well defined requirements could be stated was in the mechanical motions and alignment of the interacting subsystems. An analysis of these aspects of the laminographic technique had been carried out previously and could be applied to the design directly. These minimum requirements for the mechanical design are summarized in Table I-1.

Table I-1

Rotational Synchronism	$\delta\theta < 5$ min.
Axial Parallelism	$\delta\phi < 0.5$ min.
Deviation of Source from the Plane of the Axes	< 0.002 in.

The design of the mechanics to meet these requirements is discussed in Section III-E.

The next area which required consideration was the optics-TV system interaction. Since the resolution of this combination must be 0.001 in. or better, several alternatives need consideration. Initially, a standard television system was considered in conjunction with a 10X magnification of the image to be viewed. Using this system the light levels appeared to be a problem, and the size of the viewed image is so small that an excessive time requirement is imposed on the inspection of a full-size board.

The major requirements of the optics could be defined as follows:

1. The derotation optics must have a resolution of 0.001 in. or better as a one-to-one system.
2. The optics must provide some magnification (4 to 10 times) with a resolution equivalent to 0.001 in.
3. The magnification must be such that the resolution is determined by the optics rather than the television system.

To meet the requirements of No. 3 above, a television system using a 945 line scan in conjunction with a 4X magnification was chosen.

The light level which must be achieved was completely unknown since no data were available which gave resolution-sensitivity figures for television cameras using other than light from a 2870°C blackbody radiator (white light). Measurements of the output of fluorescent screens as a function of X-ray energy and intensity were not available and had to be made. The requirement here is deceptively simple: the X-ray source must have an intensity such that the light from a suitable fluorescent screen is sufficiently intense when viewed through an optical system to achieve an effective resolution of 0.001 in. on a closed circuit television system.

There are conflicting requirements imposed in this set of requirements. For the optical system any increase in light gathering ability will make the achievement of the required resolution more difficult if not impossible. A higher output fluorescent screen can be chosen only at the expense of resolution. As one increases the power of the X-ray source, the spot size increases. The system which was finally achieved effected a compromise among these conflicting requirements which was quite successful, although the most advanced systems and techniques presently within the state-of-the-art had to be employed.

Having chosen an X-ray source, fluorescent screen, optical system, and television system, the problem remained of determining the overall system operation to achieve efficient scanning. A known requirement was that scanning be automatic and that the scan pattern be such that operation would be simple, require little manipulation on the part of the operator, and be of such a nature that defects could be easily located. After consideration of the requirements, the system actually designed has great flexibility, although after an initial setup operation it would require little manipulation on the part of the operator. The flexibility allowed for a variety of operating modes and the ability to return to a given area for a more leisurely inspection.

A number of other operational refinements are included. The scan limit can be set to conform to the size board undergoing inspection and the dwell time at each inspection site is variable. Also, provision is made for photographing the view seen by the camera. Each of these abilities was dictated by the fact that little was known about how such a system would operate in practice,and for the purposes of a first design, a number of capabilities which might prove unnecessary were incorporated. The detailed considerations which led to the final design are discussed in the following section.

III. DESIGN CONSIDERATIONS

A. Introduction

In this section the final design will be discussed in some detail. This includes the results of the parametric study and any other considerations which led to the actual design.

Somewhat arbitrarily, the discussion is broken into several subsections dealing with the X-ray source and fluorescent screen, the optical system, the electrical systems, and the mechanical systems. In many cases, the interaction among these various systems is strong and a more unified approach might be considered; however, the complexity of the laminograph makes such an approach unnecessarily cumbersome.

B. The X-Ray Source and Fluorescent Screen

1. X-Ray Source

The X-ray source was one of the areas which received early attention. Its choice was dictated by the requirement of maximum spot size. The apparent spot size is related to the actual source size and the ratio of distances from the source to sample and sample to image. In the laboratory prototype instrument the source size was about 40 microns in diameter and the above ratio was 4 to 1. This produced an apparent source size of 10 microns. Early measurements using a 100-micron-square source verified that no observable image quality degradation was produced by this larger source. This observation is confirmed by analytical studies reported earlier.(1)

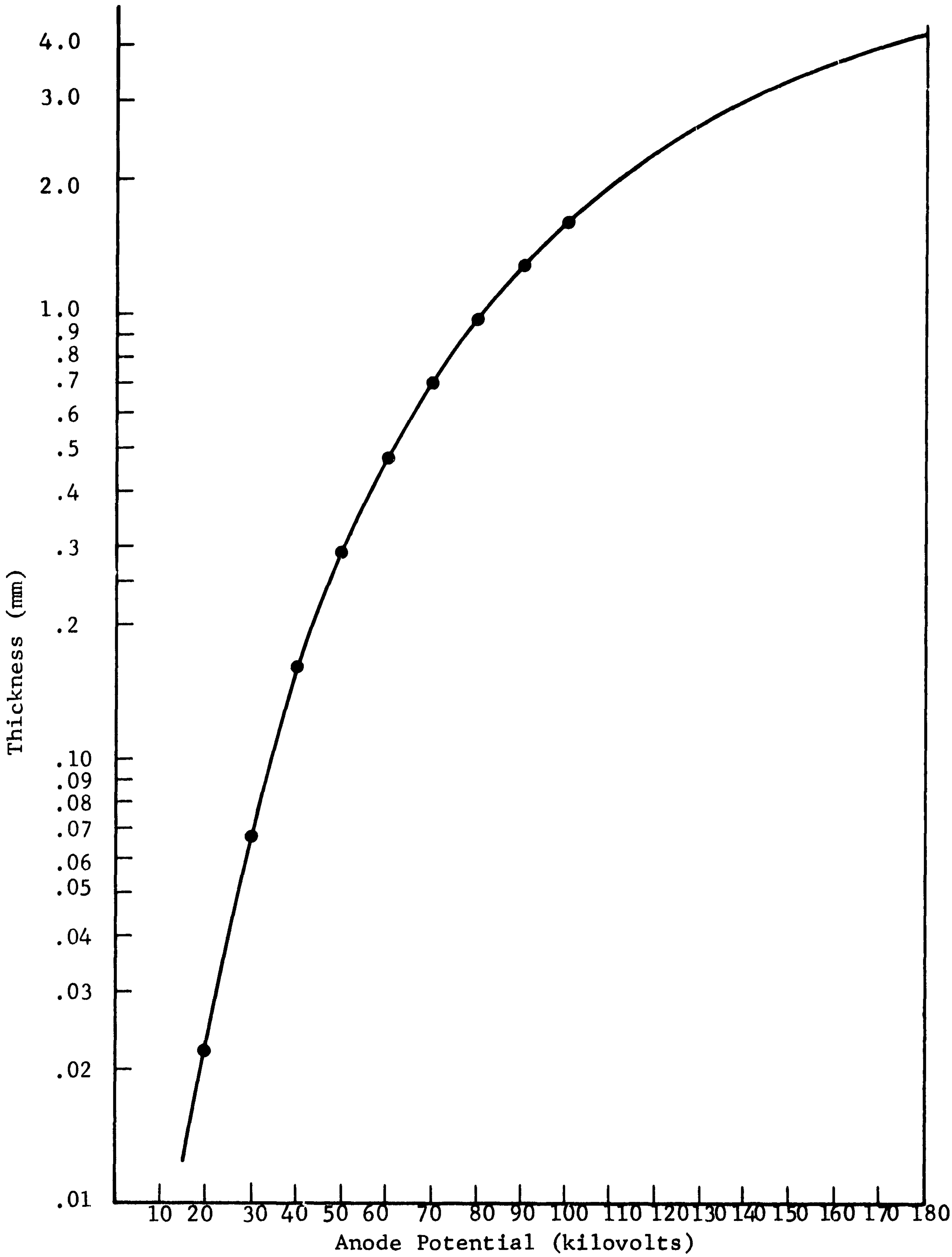
X-ray machines which have source sizes in this range are available from several manufacturers. In general they have similar characteristics. The current which they can sustain at the anode is limited to a value which is below that level, resulting in sputtering and rapid pitting. This level is essentially fixed by the anode material, especially its melting point temperature and heat conductivity. In the case of tungsten, the power dissipation is limited to 6000 w/mm^2, assuming adequate cooling. For a 40-micron spot, present designs are at this limit and no significant improvement is likely. This imposes a limit of 0.5 ma at a potential of 50,000 V. It appeared obvious that such a tube would not be adequate for the purpose of the continuous scanning laminograph. To improve the current capacity the 100-micron source was investigated. This source is a filament with dimensions of 0.125 mm x 6 mm. Focusing of the electrons from this filament onto the anode produces an X-ray source of dimensions 0.1 x 0.8 mm. When seen from the center of the image plane, this source has an apparent size of 0.1 x 0.1 mm since its long dimension is within 7° of being parallel to the line of sight. The total anode area is 0.08 mm^2, and hence the power loading could be as high as 500 w. Cooling limits it to about 250 watts for a tungsten target. Based on consideration of the fluorescent screen, which will be discussed later, the available current of 5 ma at 50 kV appeared to be adequate.

The choice of the X-ray source above is far from optimum in terms of use in the laminograph. To a fair approximation the output I of an X-ray source is given by

$$I = K\, i\, V^2 Z, \qquad (1)$$

where K is a constant, i and V are the beam voltage and current, respectively, and Z is the atomic number of the anode material. It is clear from this expression that for constant power dissipation, trading current for voltage is advantageous. A second advantage occurs because the increased voltage results in an increase in average X-ray energy and a consequent increase in penetrability.

Using these qualitative results as a guide, the best X-ray source would be a modification of the commercial microfocus units. It would have a source diameter of about 100 microns and a maximum current of 3 ma at 50 kV. The maximum potential should be 150 kV. At 150 kV the current would be limited to 1 ma. Compared to the 40-micron standard, the available X-ray intensity would be a factor of 20 greater. It would also be a factor of 2 greater than the 50 kV, 0.1 mm x 6 mm line source, with the advantage of greater penetration. Figure III-B-1 shows the 1/e thickness of copper as a function of X-ray energy. The thickness for equal transmission increases by a factor of 20 as the X-ray energy increases from 30 keV to 90 keV, the approximate average X-ray energies for anode potentials of 50 kV and 150 kV. No tube commercially available meets these specifications. The tubes which are closest have a 0.3-mm diameter and will have a maximum current and voltage of 5 ma and 150 kV, respectively. The spot size on several of these tubes has just recently been reduced from 0.5-mm diameter to 0.3-mm diameter. The larger diameter led to their not being considered initially; however, with a spot size of 0.3 mm, they should be given additional consideration. Results obtained using an 0.4-mm source diameter and a 60° angle of incidence produced results indicative of a resolution of 0.001 in. Although these results could not be expected at an angle of 20°, a compromise using 30° and a source size of 0.3 mm should give excellent results at a slight sacrifice in layering resolution.



FigureIII-B-1 THE 1/e X-RAY TRANSMISSION THICKNESS OF COPPER AS A FUNCTION OF ANODE VOLTAGE

2. Fluorescent Screen

A suitable fluorescent screen must have a variety of conflicting characteristics; on the one hand, it should have the high light output achieved by using large grain size, and on the other, it must have excellent resolution, better than the optical resolution achieved by using grains whose average size is 20 microns or less. A secondary characteristic is the thickness of the fluorescent material layer, which must be about 0.001 in. or less to be consistent with the desired layer resolution (compare for example, the thickness of the emulsion of a typical X-ray film). Finally, the time decay of the emitted light has a significant bearing on the achievable resolution. In the scheme proposed originally, the light decay of the phosphor had to be very slow since integration was to be performed at this point. The decay time constant had to be at least 1 sec for proper operation. Although this could be achieved, several characteristic effects which accompany this long decay time were undesirable. The change to integration at the photocathode resulted in a much simpler and more efficient (for light utilization) system.

The characteristics of the fluorescent screen were changed drastically by the system change. A desirable characteristic now was a very short decay time since the screen itself was fixed. Another desired characteristic was high light output. A variety of materials meet these requirements; in general, however, the two found to be most suitable are $CaWO_4(W)$ and ZnCdS(Ag). These two have a peak output near the maximum sensitivity of most photocathode materials. They also have short decay times with no afterglow and high X-ray to visible light conversion efficiency.

The fluorescent screen will have a 20-in. diameter. The sample will be rotating 360°/sec (2π radians/sec). The light decay time must be sufficiently short that no smearing occurs during the time required for the sample to rotate an amount $\theta = 10^{-3}/\pi(18) \times 360°$. This results in a time

$$T = \frac{0.001 \times 1.25}{\pi \times 1.8} = 2.2 \times 10^{-5} \text{ sec.} \qquad (2)$$

Within one decay time 63 percent of the light will be emitted. This is sufficient to eliminate any significant smearing due to motion. The light decay time for $CaWO_4$(W) phosphor is 3×10^{-7} sec, much smaller than necessary. The ZnCdZ(Ag) phosphor is not so short ($\sim 10^{-5}$ sec), but still much shorter than necessary.

One aspect of the stationary fluorescent screen not previously dealt with concerns the resolution. In a system where the fluorescent screen and sample rotate synchronously, the grain size must be much smaller than the desired resolution size. In the case where the image moves with respect to the screen, a notable improvement in image quality is achieved at the photocathode. This is due to the averaging of the image over several grains as the image rotates. An analogous effect is observed with a ground-glass screen which is vibrated to improve the image quality. This improvement occurs when the observable resolution is nearly equal to the grain size. This effect has the useful effect of allowing the use of a screen with a much higher light output without a sacrifice in resolution. In practice little is gained since the phosphor grain size for the brightest screen is much less than 0.001 in.

C. Optical System

1. Design Approach

The optical system has been designed to receive light from a 20-in.-diameter fluorescent screen upon which the X-ray source casts a shadow of a rotating object. The optical system consists of a derotation lens assembly, which forms a stationary one-to-one image of the rotating shadow, and auxiliary lenses for magnifying to 4X and reducing to 1/5X. A portion of the image is received upon an image orthicon tube in a TV camera, and the camera is movable laterally and vertically to examine the entire image.

Figure III-C-1 shows the effective operating spectral distribution of the light for the system. This distribution takes into account the fluorescent screen emission, the sensitivity of the image orthicon tube, and the transmission of the optical glass elements as a function of wavelength, for which curves are also shown. The F, g, and h (Fraunhofer) wavelengths are among the standard wavelengths for which refractive indices are supplied in the optical glass catalogs. These spectral lines were found to fit the effective spectral distribution of this system and were used in the design calculations.

The fabrication tolerances of the lenses and prism were partly computed and partly estimated, in general accordance with the rules of W. J. Smith, pages 414-426 of "Modern Optical Engineering." The element thickness tolerances were computed on the design program. Each lens element in turn was made 0.024-in. thicker (in the computer input) and the object and image distances recomputed. The recomputed spot sizes were compared, and the most sensitive thickness was found to be that of the cemented doublet. The computed thickness tolerance for this doublet seemed so stringent that the cost of fabrication

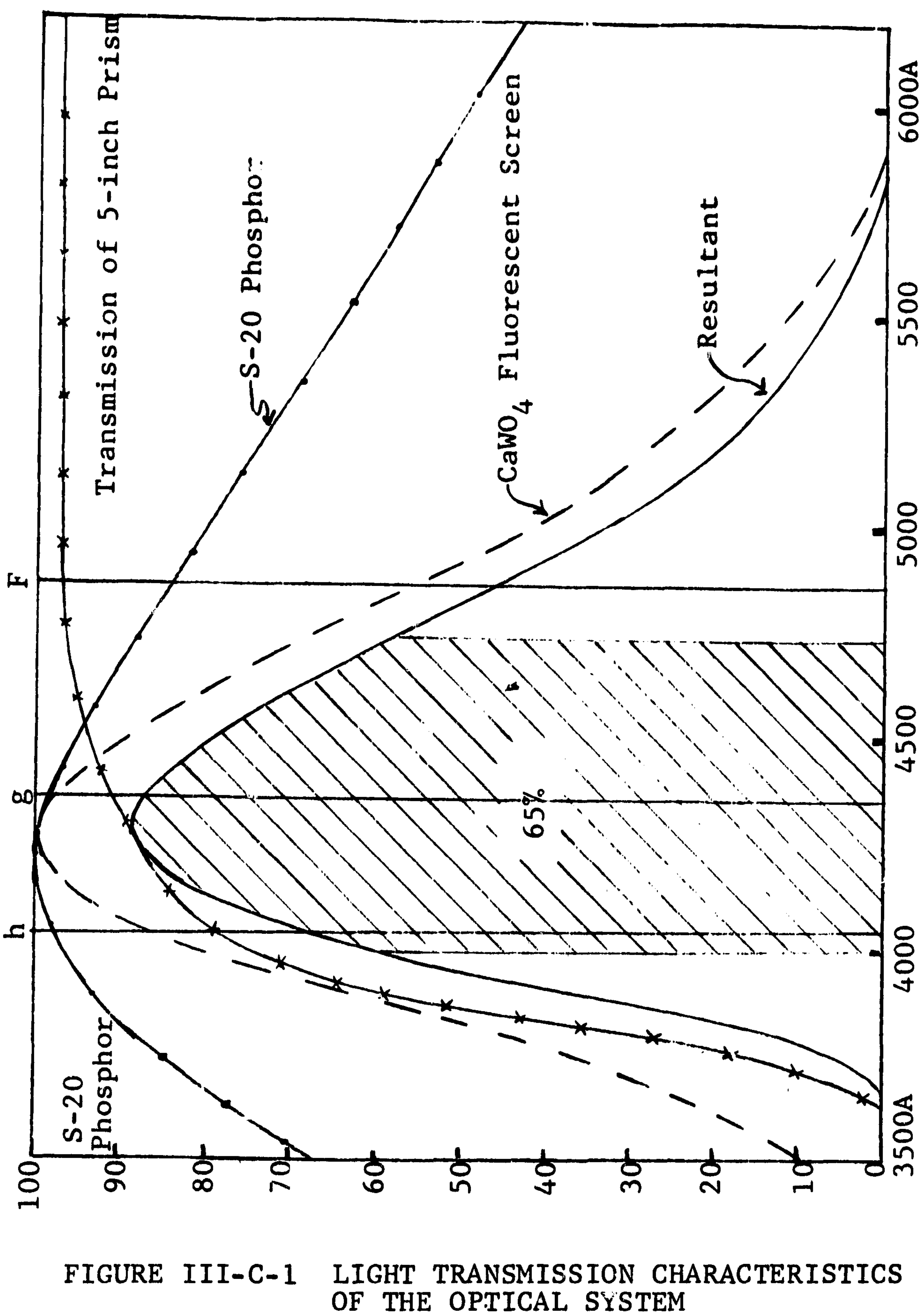


FIGURE III-C-1 LIGHT TRANSMISSION CHARACTERISTICS OF THE OPTICAL SYSTEM might be high. An alternative fabrication approach was considered whereby the cemented doublet is to be made first and its error in thickness compensated by re-optimizing the rest of the lens. A four-page discussion of tolerances is included in Appendix C.

The optical design calculations were done on an IBM 7094 computer. Two computer programs were used, the ALEC program and the Los Alamos Lens Design program, Version 2.2 (LASL). The ALEC program was developed by Gordon Spencer at Scientific Calculations, Inc., Rochester, N. Y. and the LASL program was developed by the late Dr. C. A. Lehman and based on an earlier program, by Dr. John Holladay, also of Los Alamos Scientific Laboratory. As a final design check, an independent evaluation of the derotation lens and of the 4X system, described below, was made by Mr. Urban Ludwig, Physicist (Optical) Code 283, Goddard Space Flight Center, Greenbelt, Maryland. This design check utilized the GOALS program on an IBM 360 computer. This lens design program is a recent development by Gordon Spencer.

The ALEC program is based in part on third-order aberrations and was used for preliminary designing. It was found during this project that it is usually best to start with data for a series of plane surfaces and one spherical surface chosen to correct focal length. In many cases a fairly well corrected lens resulted in about two minutes of computing time. In the case of a one-to-one lens, half of the lens was computed with object at infinity, and the data were then used in setting up the complete lens and prism system data for the LASL program.

The LASL program is based entirely on tracing rays of light through the lens system and computing the scatter of the rays or spot size of the image at a specified image plane. This spot size is defined as twice the root mean square scatter. This is computed by finding the centroid of the ray positions and the distance r of each ray from the centroid and then evaluating $\frac{\Sigma r^2}{\text{number of rays}}$. The diameter of the circle enclosing half the rays is roughly twice the rms scatter computed by this program.

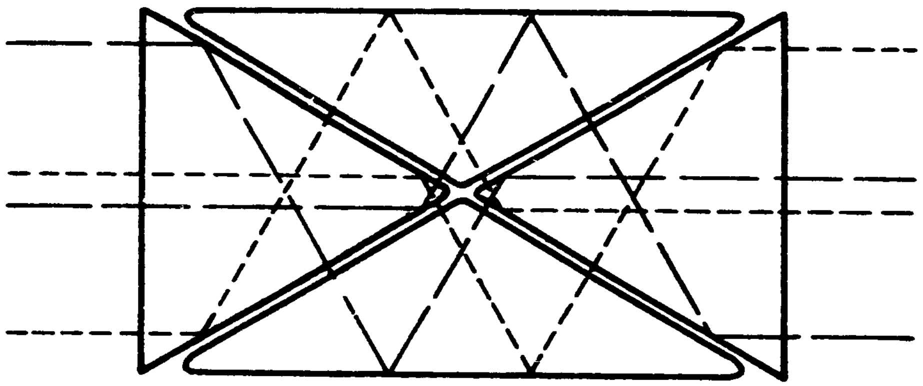
During the design process, three object points were usually used, located at (0, - 7.1), (0, + 1.3), and (0,+9.7) inches. The program automatically sets up a series of equally spaced object points, and (reversing one sign) this particular selection approximates the 0 percent, 70 percent, and 100 percent generally favored by lens designers.

2. The Derotation Optics

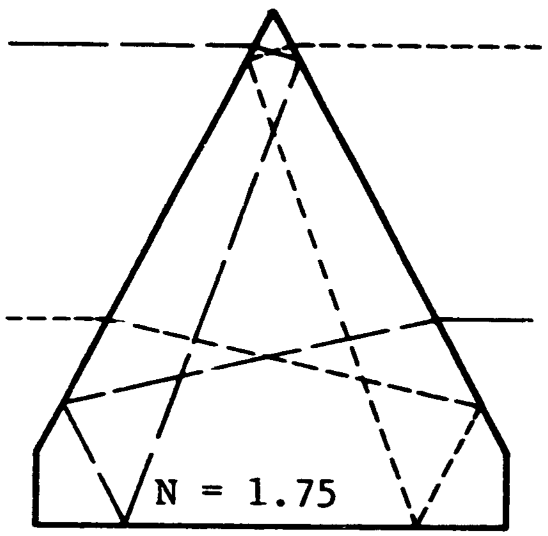
The principle of rotation or "derotation" of an optical image is well known and has long been used in submarine periscopes and elsewhere. The basic requirement for image rotation is a prism or mirror system in which the beam of light is reflected an odd number of times (in one plane) and emerges coaxial with its original path. This prism or mirror system is inserted in the optical system, and as it is rotated the image rotates at twice the speed.

Figure III-C-2 shows four types of prisms that were considered for this project. The Koenig prism and the Pechan prism can be used in convergent light if the lens system is designed to allow for the aberrations introduced by the prisms. All four types can be used in collimated (parallel) beams. However, the double Dove is the only one that will cover the required field of view (about ± 16°). In the other types, the optical path through the prism is excessively large and the unvignetted field too small. The two halves of the Dove prism have to be made and mounted very precisely, but this is within the state-of-the-art.

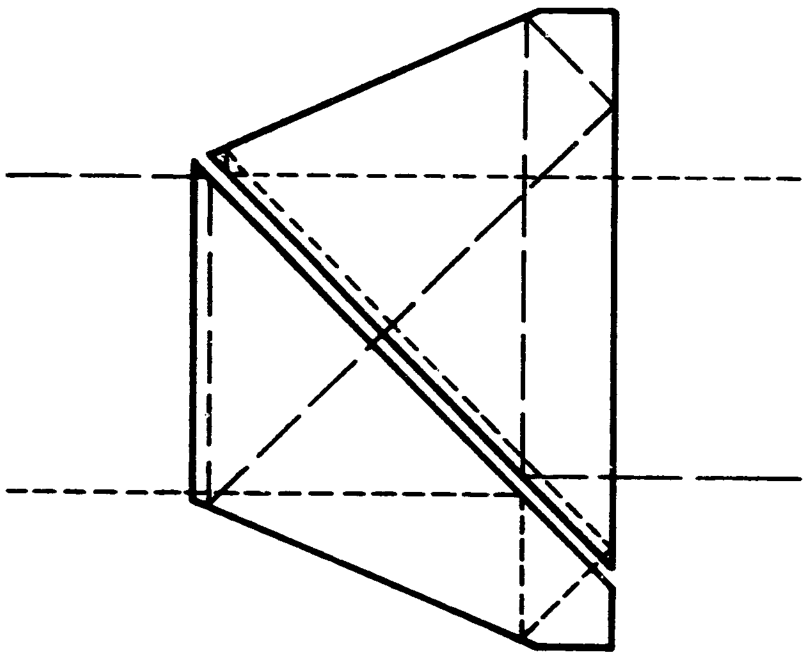
Figure III-C-3 shows the final design configuration of the one-to-one lens, enclosing the derotation prism between two symmetrical lens halves. Each half of the lens operates at



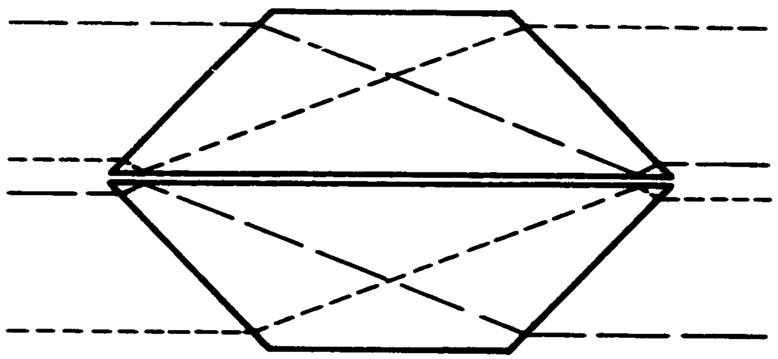
a. Double Koenig or Hastings Prism



b. "V" Prism



c. Pechan Prism



d. Double Dove Prism

Figure III-C-2 TYPICAL DEROTATION PRISMS

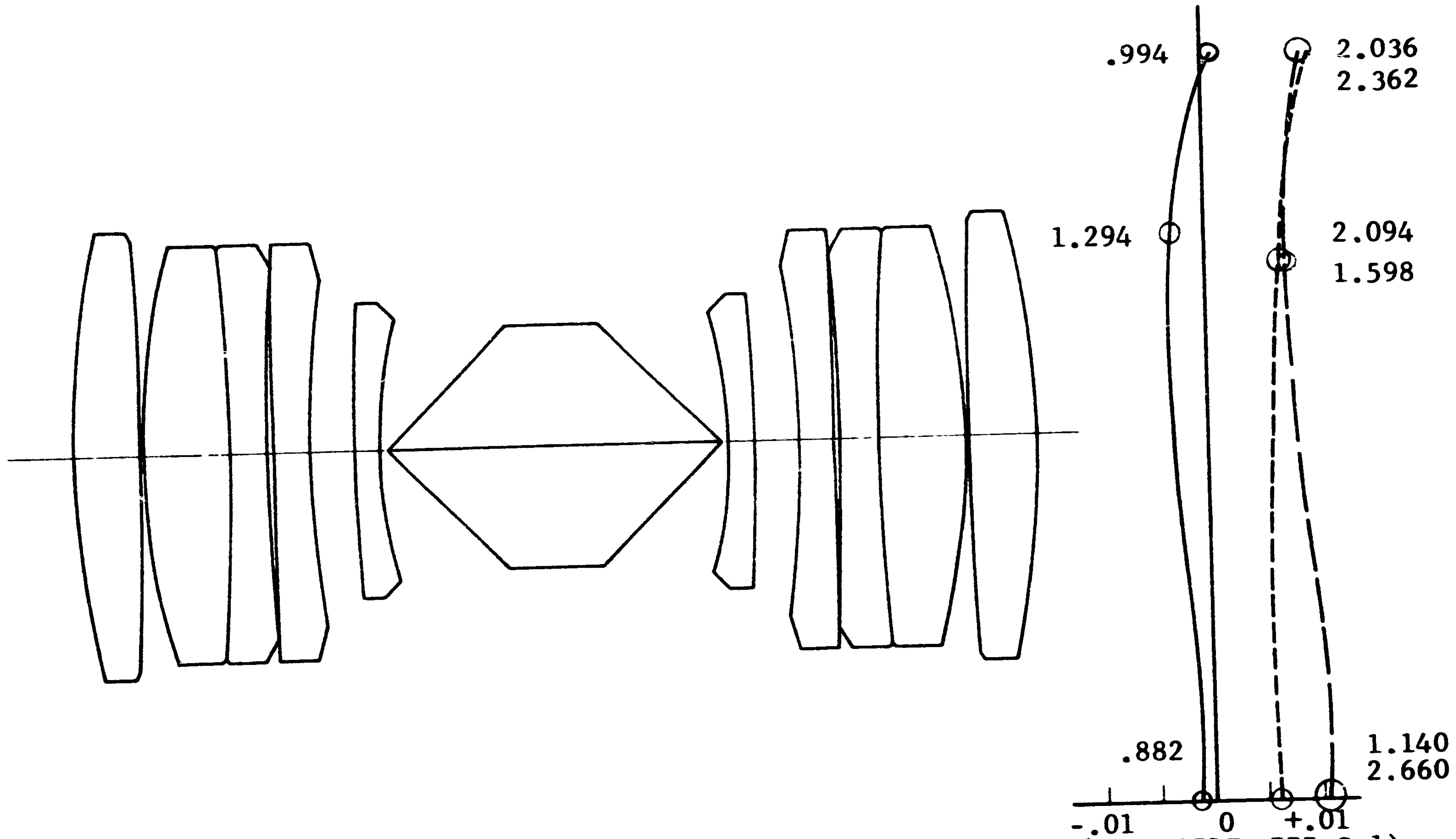


Figure III-C-3 DEROTATION LENS, SHOWN IN AXIAL SECTION (SEE TABLE III-C-1)
AND GRAPH OF IMAGE CURVATURES

about f/11. Initially an f/16 lens was designed consisting of three elements in each half, but a study of the brightness of the fluorescent screen and the sensitivity of the TV tube indicated that a larger aperture is needed. A four-element f/11 half-system was then designed but the color correction was not considered acceptable. The images formed by F and h light were about 0.065 in. beyond that formed by the g light, thus giving a spot size of about 0.006 in. for these colors (representing about 30 percent of the effective energy). Several other selections of glass were used in a further preliminary design phase, and the five-glass combination shown in the figure was selected as most promising for final designing. The out-of-focus distance was reduced to about 0.004 in. at the g focal plane.

Figure III-C-3 also shows the image curves for the three colors and the rms spot diameters at three image points and for the three colors at their respective best foci.

Table III-C-1 shows the lens prescription in the conventional way. The radii of curvature R of the lens surfaces numbered from the front of the lens are given in the first column. The distances d from each surface to the next are given in the second column, and the refractive indices of the respective glass types for the F, g, and h wavelengths as well as the manufacturer's designation of glass type are given in the remaining columns. The + and - signs on the radii indicate surfaces respectively convex and concave to the front. The data are given for only the front half of the derotation lens; the rear half is symmetrical to the front half.

TABLE III-C-1 DEROTATION LENS (INCHES)

Radii	Distances	N_F	N_g	N_h	Glass Type
R_1 = +16.081	1.095	1.64737	1.65306	1.65778	LaK-01 (OHARA)
R_2 = -85.65	0.053				
R_3 = +12.563	1.450	1.71022	1.71834	1.72525	LaF-01 (OHARA)
R_4 = -42.06	0.640	1.62153	1.62915	1.63561	Borate F1 (CHANCE)
R_5 = +47.11	0.100				
R_6 = +1105.	0.590	1.75866	1.77449	1.78852	SF-3
R_7 = +18.365	0.744				
R_8 = +35.803	0.430	1.46938	1.47317	1.47628	FK-3
R_9 = +8.231	0.100				
Prism	5.56	1.70448	1.71789		SF-52 (SCHOTT)

Note 1. Rear Half Symmetrical to Front Half.

Note 2. Object Plane: Diagonal = 19.8 Distance from First Surface: 42.725

Note 3. Entrance Pupil: Diam. 4.610 Distance behind First Surface: 8.8

3. Magnification Modes

To provide different magnifications for viewing the circuit board image, three interchangeable optical arrangements have been designed, operating at one-to-one, 4X magnification, and five-to-one reduction, respectively.

The one-to-one (or 1X) system consists simply of the derotation lens and a 45° mirror to project a 14 in. by 14 in. image positioned in a vertical plane. The face of the image orthicon tube is positioned in the same plane for examining a 1.27 in. by 1.27 in. section of the image. The entire area is examined by mechanically traversing the TV camera in the X and Y directions.

Figure III-C-4 is an optical diagram of the 4X system. The one-to-one image of the fluorescent screen is shown as a dotted line. A divergent lens, sometimes called a Barlow lens, is removably mounted on the TV camera. It intercepts the rays directed toward a 0.32 in. by 0.32 in. area and refocuses them onto a plane about 0.9 in. farther back. The standard TV camera (with slight modification) has means for moving the tube back to refocus the magnified image, and the 14 in. by 14 in. image area is traversed as before except that the camera is moved in smaller steps.

Table III-C-2 gives the lens prescription for the divergent (Barlow) lens. It is understood, of course, that the derotation lens forms a part of the system.

Figure III-C-5 is an optical diagram showing the five-to-one reduction (0.2X magnification) system which is to provide an overall view of about a quarter of the fluorescent screen. In this case the 4X Barlow lens is removed from its operative position and a complex lens system is moved into place. This system consists of a supplementary lens assembly immediately above the derotation lens, a field lens assembly roughly half way between the derotation lens and the TV camera,

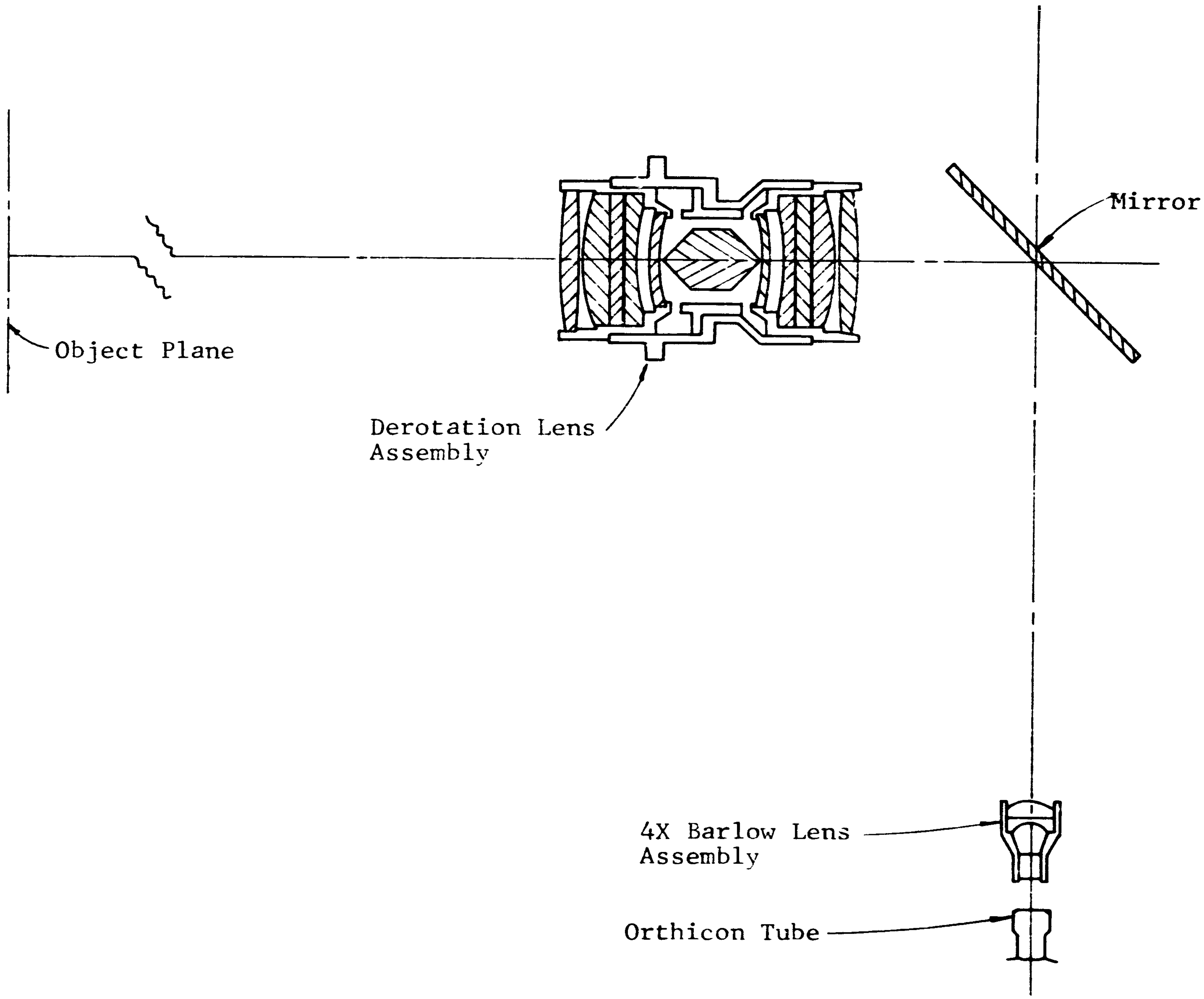


Figure III-C-4 OPTICAL SYSTEM FOR 4X MAGNIFICATION

TABLE III-C-2

BARLOW LENS

Radii	Distances	N_F	N_g	N_h	Glass Types
R_{21} = +1.832	1.049	1.61592	1.62286	1.62871	BaF-5
R_{22} = -6.91	0.180	1.59146	1.59964	1.60667	LF-5
R_{23} = +1.13	1.722				
R_{24} = -1.369	0.200	1.61248	1.62159	1.62946	F-14
R_{25} = -0.270	0.150	1.49230	1.49597	1.49900	FK-5
R_{26} = +1.046	0.326				
R_{27} = -0.7115	0.150	1.65934	1.66538	1.67039	LaK-7
R_{28} = +0.750	0.400	1.59933	1.60759	1.61470	LF-2
R_{29} = -2.12	1.47				

Note: Axial distance from R_{20} (last surface of derotation lens) = 37.90

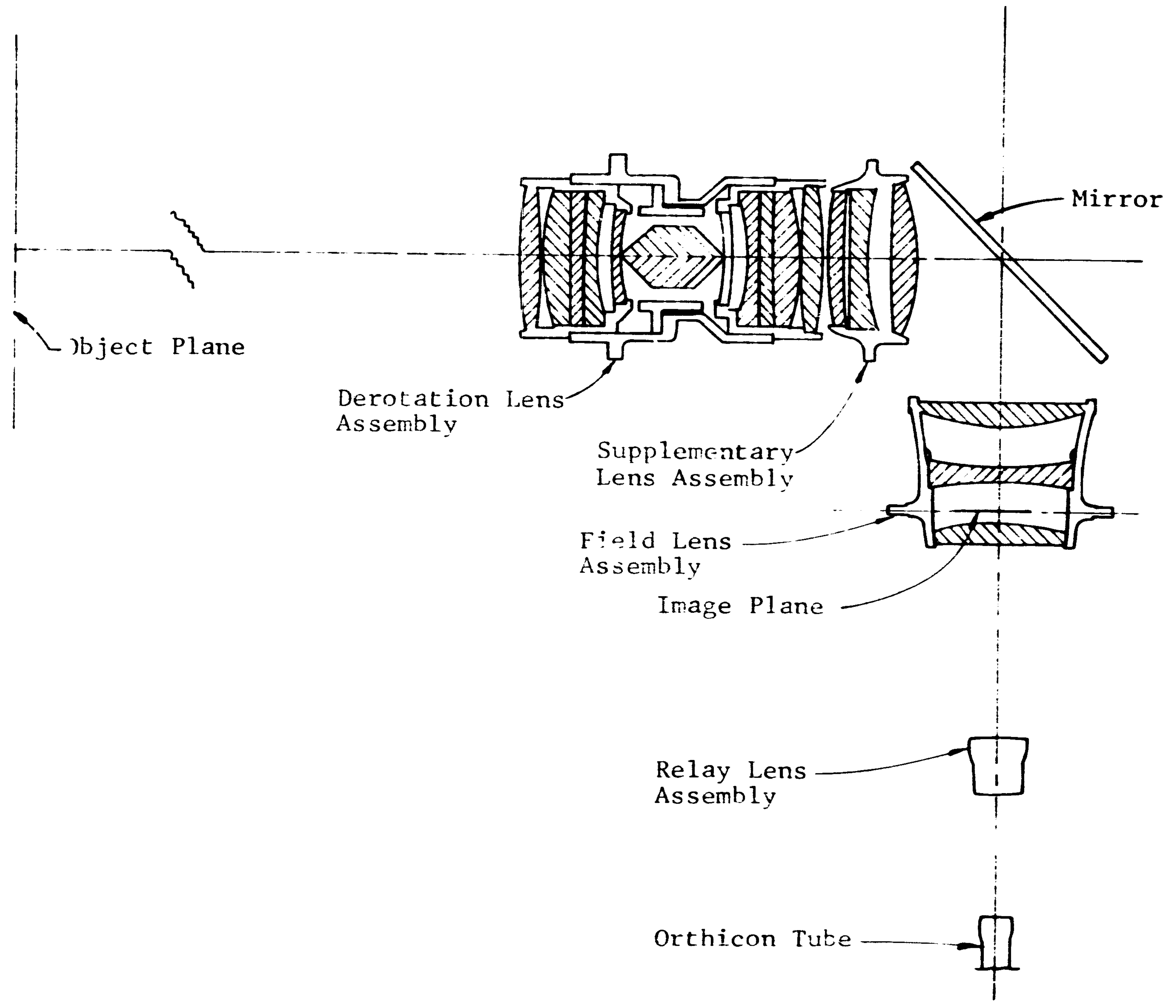


Figure III-C-5 OPTICAL SYSTEM FOR 5 TO 1 REDUCTION (0.2 MAGNIFICATION) and a relay lens assembly. The supplementary lens assembly acts substantially like a close-up attachment on a camera (only in reverse) and forms an intermediate image (0.34X) between the 45° mirror and the TV camera. This image is reimaged at a further reduction by the relay lens onto the plane in which the orthicon tube face is located. A field lens in the vicinity of the intermediate image is required in order to redirect the light rays toward the relay lens. The field lens is made up as an assembly of two positive lenses and a negative lens to aid in flattening the image. (This image naturally tends to be concave toward the 45° mirror.) A commercially available lens (Kodak C.R. Tube EKTAR lens, 50 mm f/2.0, Formula M-236) was chosen as the relay lens, adjusted to 1.7-to-1 reduction.

The 0.2X system projects a 2.8 in. x 2.8 in. image, about a quarter of this image falls onto the orthicon tube at any one time. The camera housing is moved in X and Y directions to examine the area.

Table III-C-3 gives the lens prescription for the removable portion of the 0.2X system except for the commercial relay lens. The derotation lens (lens surfaces R_1 to R_{20}) is part of the 0.2X system, and its prescription is given in Table III-C-1.

If a special relay lens were designed (with overcorrected curvature) instead of using a commercially available lens, the field lens would probably require only the two positive lenses.

Table III-C-3 REMOVABLE 5X REDUCTION SYSTEM

Radii	Distances	N_f	N_g	N_h	Glass Type
	0.125				
+16.90	0.8	1.70542	1.71214	1.71771	LaK-24
+52.18	0.15				
∞	0.9	1.66384	1.67521	1.68514	SF-17
+ 9.27	1.665				
+40.70	1.296	1.62756	1.63312	1.63774	SK-16
-11.14	4.427				
Mirror	7.292				
+175.8	1.3	1.68749	1.69983	1.71064	SF-5
-11.0	2.165				
-29.22	0.8	1.50755	1.51239	1.51647	K-10
-24.80	2.0				
+11.83	1.2	1.68749	1.69983	1.71064	SF-5
+95.4	10.				

Eastman Kodak, 5 inch f 2.5 cathode ray tube Ektar lens, focused at 1.7 to 1.0.

4. Independent Design Check

Table III-C-4 gives the results of the independent check of the one-to-one (derotation) lens and the 4X system. The first column gives the height (in inches) of the object point as computed. The second column gives the orientation of the leading edge of the prism (vertical, 45° diagonal or horizontal). Of course the orientation makes no difference at 0-object height. The third column gives the color in which the spot size was computed. (No. 1 is N_g, the main color, No. 2 is N_h, and No. 3 is N_F.) A blank indicates a total of all three colors weighted equally. The next four columns give the spot sizes in mils (0.001 inch) for the respective systems, the 50-percent spot includes half the rays and the 100-percent spot all the rays. The GOALS program (by Gordon Spencer) was used and gives the radius (semidiameter) of the spot.

Each spot was generated by computing about 90 to 100 rays, and the values tabulated are for a best average plane with equal weighting for the three colors. The computed spot size would doubtless be somewhat smaller if a different plane had been selected and the weighting factor had been doubled for the main color, No. 1, as seems reasonable. Moreover, it is likely that something can be gained by slight refocusing in different parts of the image plane.

An optimistic note is that the spot sizes for the 4X system average considerably less than four times the corresponding values for the 1X system. This is not due to additional vignetting, and seems to be a windfall in that the two parts of the 4X system were designed separately and not as a complete combination.

Table III-C-4 IMAGE SPOT SIZES COMPUTED BY "GOALS" PROGRAM (SEMI-DIAMETERS OF SPOTS, IN MILS).

Object Height	Prism Position	Color	One-to-One Lens 50% Spot	One-to-One Lens 100% Spot	4X System 50% Spot	4X System 100% Spot	RMS Spot 1-to-1	RMS Spot 4X
0	---	1	1.52	3.9	1.52	4.8*	0.461	1.669
		2	1.32	2.5*	2.41	5.3*	0.659	2.577
		3	1.42	1.8*	7.82	9.6	1.834	7.374
			1.40	3.9	2.53	9.6	0.854	3.322
5 in.	Horiz.	1	1.26	4.3	2.54	6.0*	0.859	3.105
		2	1.15	3.7*	4.00	8.2*	1.215	4.799
		3	1.17	2.2*	5.07	9.1	1.416	5.893
			1.19	4.3	4.02	9.1	1.087	4.226
	45°	1	1.05	2.9	2.09	4.3*	0.613	2.310
		2	1.15	2.7*	2.69	6.8*	0.889	3.435
		3	1.16	1.9*	4.31	8.6	1.163	4.690
			1.13	2.9	2.74	8.6	0.820	3.186
	Vert.	1	1.74	4.2	1.87	5.4*	no	2.320
		2	1.41	3.1*	3.19	4.7*	out-	3.178
		3	1.20	2.1*	5.06	8.1	put	5.528
			1.34	4.2	3.05	8.1		3.337
7.5 in.	Horiz.	1	1.45	4.3	2.45	6.5*	0.834	3.050
		2	0.94	3.4*	5.14	10.9	1.527	6.327
		3	0.85	2.6*	3.90	7.4*	1.034	4.540
			1.00	4.3	3.89	10.9	1.057	4.242
	45°	1	1.27	3.1	2.20	5.6*	0.664	2.475
		2	1.29	3.0*	3.02	8.7	1.007	3.914
		3	1.10	2.0*	3.12	7.0*	0.848	3.514
			1.12	3.1	2.58	8.7	0.796	3.094

*Because of an error in programming the computer output, these values had to be extrapolated from the 90% and 95% spot sizes.

Table III-C-4 (Continued

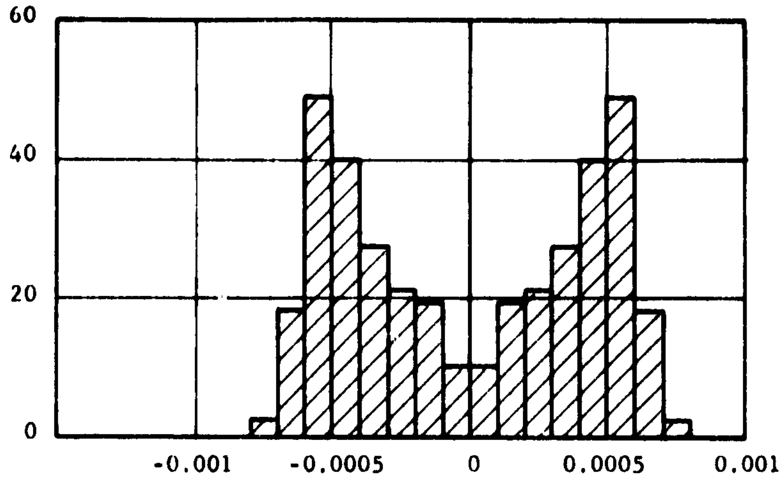
Object Height	Prism Position	Color	One-to-One Lens 50% Spot	One-to-One Lens 100% Spot	4X System 50% Spot	4X System 100% Spot	RMS Spot 1-to-1	RMS Spot 4X
7.5 in.	Vert.	1	1.99	4.4	2.11	7.0*	0.675	2.180
		2	1.36	2.8*	3.24	8.0*	0.840	3.564
		3	1.19	2.4*	3.27	9.4	0.921	4.084
			1.35	4.4	2.77	9.4	0.778	3.002
9.9 in.	Horiz.	1	1.45	3.7*	1.72	4.3*	0.558	2.116
		2	1.07	2.9*	7.99	12.9	1.964	8.005
		3	1.44	4.0	5.10	9.7*	1.310	5.476
			1.24	4.0	3.79	12.9	1.097	4.428
	45°	1	1.12	2.4	1.52	5.1*	0.425	1.802
		2	1.28	2.4	3.13	9.5	1.153	4.546
		3	1.13	2.0*	3.07	6.7*	0.892	3.529
			1.14	2.4	2.34	9.5	0.724	2.920
	Vert.	1	1.66	4.0	1.14	5.0*	0.497	1.754
		2	1.18	2.6*	4.00	15.6	1.332	5.370
		3	1.17	3.3*	2.71	14.6*	1.156	4.454
			1.24	4.0	2.22	15.6	0.870	3.333

*Because of an error in programming the computer output, these values had to be extrapolated from the 90% and 95% spot size.

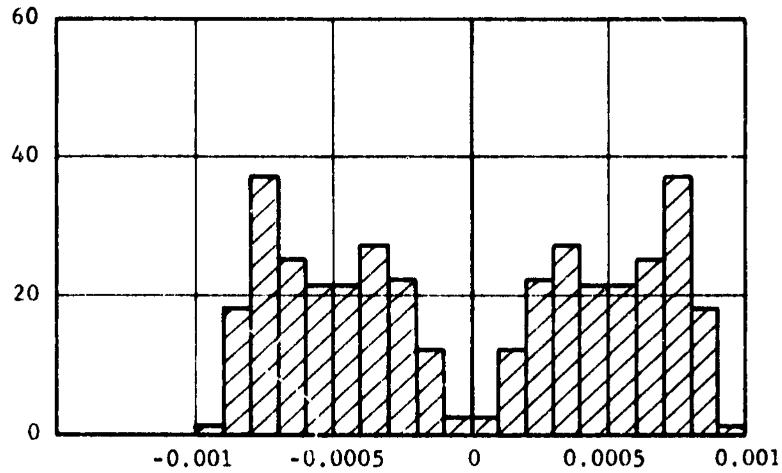
Two columns have been added to Table III-C-4 to give a more realistic spot size, since the 50 percent and 100 percent energy evaluation was not carried out at the best focal plane. The rms spot sizes, on the other hand, were computed on 25 planes spaced 0.005 inch apart. From these, a best plane was selected. This was 0.04 inch closer to the 1-to-1 lens and 0.035 inch closer to the 4X lens. Moreover, the average was weighted 50 percent for color No. 1 and 25 percent each for No. 2 and No. 3 instead of using equal weighting, as was done in computing the 50 percent spots. These rms values are given in the last two columns.

Figure III-C-6 shows the point spread function at three image heights for the derotation lens. They were computed using the LASL program. These plots indicate that the effective resolution varies from approximately 0.002 to less than 0.001 inch, depending upon the position of the object and image. They also indicate the tendency of the image to split into two small images, especially if the lens is not exactly focused for collimated light at the Dove prism.

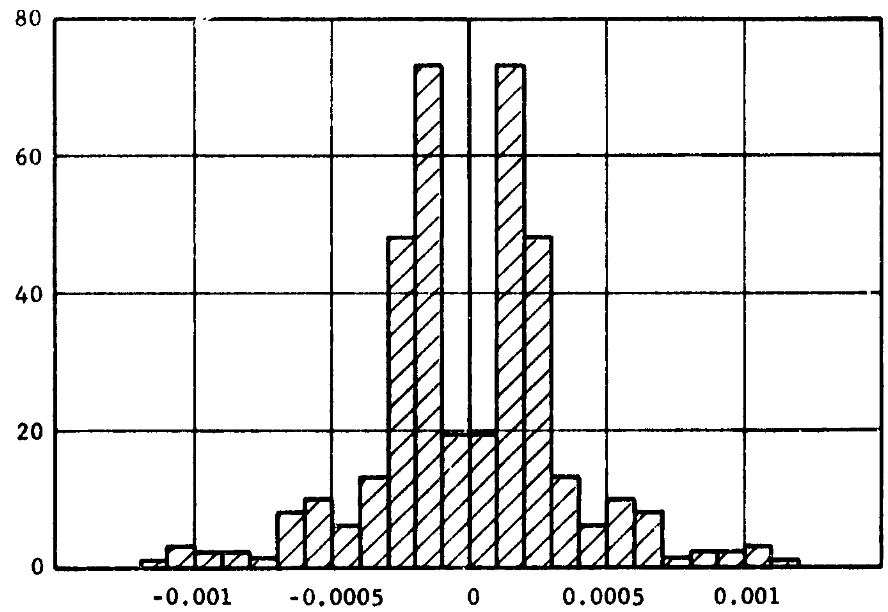
Although a resolution of 0.001 inch has not been achieved for all object-image heights, we are confident that further optimization (using actual melt indices) would achieve this end.



a. Image Height 1.30 in.



b. Image Height 7.1 in.



c. Image Height 9.7 in.

Figure III-C-6 DEROTATION OPTICS POINT SPREAD FUNCTION

D. Electrical and Electronics Systems

1. Introduction

The electrical and electronics portion of the laminograph system consist of three principal subsystems: (1) the television subsystem including the high sensitivity TV camera, a 17-in. TV monitor, and an 8-in. TV monitor, (2) the automatic TV camera X and Y coordinate position control along with the automatic X-ray source Z coordinate position control subsystem, and (3) the X-ray emission control subsystem. The former two subsystems are interdependent to a certain extent, while the X-ray emission control is independent of the other electrical subsystems.

Locations of the respective units of these subsystems are shown on the system block diagram drawing 0-0-A(1). The chassis 3-3, called "Optics Position Control", is a part of a separate minor subsystem not included in any of the three principal subsystems already described. This subsystem controls the effective optical magnification of the laminograph optical system. The chassis 1-4, called "AC Power Control," simply turns the 115-V ac line power on and off for all chassis which require it; it is involved in this way with all electrical systems (major and minor) except for the X-ray emission control. The details of the functional elements of each major and minor electrical subsystem, with regard to the number and interrelation of the elements, and their fabrication, are presented on a subsystem basis in the next seven sections.

2. Television Camera and Monitor System

a. TV Camera and Controls

The television camera and control system selection was determined by size, versatility, and accuracy. Although a number of cameras are available, the availability and quality as well as the willingness of the manufacturer to make several substantial modifications to the unit made the Ortho VIB, manufactured by Maryland Telecommunications, Inc., the camera of choice. This unit incorporates a 945-line scan. Earlier a 1023-line scan was specified but this was modified in consultation with the manufacturer. This change occurred when it was realized that the 1023-line scan could not be used effectively as a result of the limitation of light and the resolution of the image orthicon tube. An additional factor influencing the change is the fact that the 1023-line scan is not standard while the 945-line scan is.

The camera system is housed in two separate units; the camera (chassis 4-3), and the camera control unit (chassis 1-1). In the laminograph system the camera will be installed on the laminograph structure while the control unit will be mounted in the control console. A single cable (cable J) interconnects the two.

Several modifications necessary in the camera must be specified. These include provision for remote optical focusing image orthicon beam blanking, and limit switches associated with the image orthicon positioning mechanism.

The modifications required are specified on drawings 4-4-D(1) and 4-4-D(2). In response to a request for quotation wherein these specifications were presented, MTI responded with a quotation included in Appendix D.

One additional modification is required in the camera control unit. This entails tapping into the synchronizing circuits to provide a pulse at the field rate. This pulse is used in the blanking control logic to control the timing of the blanking signals for the monitors and the image orthicon. A convenient point for obtaining this signal is at the output of the "industrial synchronizing module," (MTI No. 04-3400). The signal designated as Vertical Drive is a 10-V, negative-going pulse which establishes the field rate. This is available at terminal 17 of the module connector. The manufacturer would provide the wiring from this point to a BNC cable connector on the rear panel.

A special low-light-level image orthicon has been specified for the camera. This is the GE type 6967. This tube has a spectral response which peaks very close to the peak of the fluorescent screen emission. A detailed analysis of the sensitivity of this tube to the fluorescent screen emission is given in Appendix A. Some of the pertinent characteristics are given here.

Based on the measurement of light levels produced by irradiating various fluorescent screens, a sensitivity of 1.6×10^{-5} ℓ/ft^2 is required. This value is based on a light output of 2.5×10^{-2} ℓ/ft^2 from the screen under typical conditions, an optical attenuation of 1.6×10^3, and a contrast of 50 percent or better. To achieve the required sensitivity the most sensitive image orthicon available was required. Even with this tube integration of the light striking the photocathode was necessary. An integration time of 2 sec was chosen to achieve the required sensitivity.

Table III-D-1 gives some of the pertinent characteristics of the tube as it will be operated in the laminograph.

Table III-D-1

IMAGE ORTHICON CHARACTERISTICS

Illumination - $CaWO_4$ fluorescence radiation 4400A (50% at 3800A & 4900A)	
Contrast - 100 percent	
Integration time - 1/30 sec	
Resolution - 800 TV lines	
Sensitivity - 3×10^{-6} ℓ/ft^2	

Refer to Figure VIII-B-3, which shows the resolution of this tube for various light levels, integration times, and contrasts.

b. TV Monitors

Two monitors have been selected for this system. The main monitor is a 17-in. rack-mounted unit manufactured by Miratel. The model number is HLB17R. It is designated as chassis 1-5, and is located in Unit 1, the operator's station outside the laminograph room. This is a high-resolution, all solid-state unit. The monitor is to be supplied with a long persistence CRT to maintain the image over the two-second integration period. A special blanking circuit must be added to this monitor to blank the E-beam of the CRT except during the one active frame (2 fields), which is swept every two seconds. The blanking circuit is shown in Drawings No. 1-5-A(1). It is envisioned that this circuit would be fabricated on a small printed circuit board located near the CRT socket. The +300 V supply is available within the monitor.

The 8-in. monitor is a Conrac CNB8/RC rack mount monitor and is designated as chassis 1-3. It is located at Unit 1, the operator's station outside the laminograph room. This monitor is intended primarily for optical focusing of the TV camera and for obtaining photographs of selected areas during actual laminograph operation.

The camera selected for this system is a Polaroid Cu-5. The camera and its associated accessories are used primarily for copy work. The camera mount is modified to provide a light-tight seal between the camera and the 8-in. monitor. The camera is to be equipped with a Tektronix Model 3 Camera Actuator. The component parts which make up the entire camera system are:

Polaroid	Cu-5 Land Camera
Polaroid	88-1 Pack Film Body
Polaroid	88-5 5-in. Lens
Polaroid	88-65 Universal Mount
Polaroid	88-53 6-in. x 7 3/4-in. Framing Kit
Tektronix	016-0218-01 Camera Actuator
Tektronix	016-0230-01 Power Supply

A Tektronix camera activator is required for use with this monitor so that shutter operation may be synchronized to the blanking signal. The shutter and blanking logic is shown in Drawing No. 1-6-A(10). (See Section VIII-D.) The blanking circuit for this monitor appears on Drawing No. 1-3-A(1). Fabrication and mounting considerations for this monitor are the same as for the Miratel unit. Note that this blanking circuit includes a switch to inhibit its operation. This switch is to be installed on the front panel of the monitor and is used only while focusing the TV camera.

3. <u>TV Camera and X-Ray Source Positioning Control</u>

a. <u>Purpose</u>

Positioning of the TV camera and X-ray source are controlled remotely from the main control console. Positioning may be manual or may follow a preset programmed sequence. The latter mode is necessary because of the large number of areas to be examined in a routine inspection operation. The positioning systems are of the digital servo type employing stepping motors for drive.

b. <u>General Description</u>

The TV camera can be moved either horizontally or vertically with a total allowable traverse of twelve inches on either axis. Digital position encoders are geared to the drive shaft for each axis to provide signals for the position indicators and for servocontrol. Three-character displays are used with a resolution of 0.1 in.

The X-ray source may be positioned on the vertical axis only. Total traverse is approximately 2.6 in. This corresponds to a displacement of 0.5 in. when referred to the sample. The position encoder for the X-ray source position is geared such that displacement relative to the sample is read-out. Calibration resolution is 0.001 in.

Throughout this report the TV camera motion is referred to as X-or Y-axis motion, and the X-ray source as Z-axis motion. The outputs of the position encoders include straight decimal coded signals for the display units and binary coded decimal signals for the control logic.

The position encoders require a 16-V power supply (chassis 3-4). This supply is located in the equipment rack to be installed in the laminograph room (see Drawing 0-0-A(1)).

The control logic for routing the drive pulses to the motor drive amplifiers (chassis 3-2) and for determining the scan sequence is contained on two chassis. These are designated as the Motor Drive Logic (chassis 3-3) (installed in the laminograph room), and the Scan Control Logic (chassis 1-6) (located in the control console). The Motor Drive Logic performs two key functions: the actual selection and routing of drive pulses to the appropriate windings of a selected motor (one of three located at 4-1), and selection of a set of BCD signal lines from one position encoder (4-2). Only one position encoder is connected into the servo loop at one time. This reduces the logic complexity considerably but imposes the limitation that positioning is restricted to one axis at a time. This limitation is significant only in the setup operation. Since the setup time is very short compared to the inspection time, the reduction of logic components and complexity outweighs the small increase in setup time.

In a typical inspection operation the operator would first position the printed circuit board in its support jig. Since it is unlikely that the majority of boards will require the total available viewing area capabilities of the TV system, thumbwheel switches are included on the scan control panel (chassis 1-6) for the purpose of defining the boundaries of the area to be inspected. Refer to drawing 1-6-B(1) for location and identification of controls described in the following paragraphs. The overall viewing area may be represented by a 14 in. x 14 in. grid, with major divisions 0.5 in. x 0.5 in., and with minor divisions every 0.1 in. If it were desired to inspect a board 3 in. x 2 in., centered on the grid pattern, the left edge (X_1) would be located 4.5 in. from the X origin, and the right edge, 7.5 in. The X_1 selector switch would be set to 045 and the X_2 selector, to 075 (recall that the resolution is 0.1 in.). Similarly the Y_1 selector would be set to 050 and Y_2 to 070. If the board was 0.25-in. thick and the first layer of interest was located on the bottom surface, the Z_1 selector would be set to 000 and Z_2, to 250. If the first layer were not on the bottom surface the Z_1 selector would be set accordingly. System power would then be turned on and after the laminograph drive was up to speed and stabilized, the "Start" button on the control panel would be actuated. Approximately 5 seconds after "Start," the "Ready" light will come on. This time delay is included for the purpose of resetting certain critical elements within the logic. When the "Ready" light is on, the "Search" push button may be actuated. The TV camera then moves automatically to X_1. When X_1 is reached, it will move to Y_1. When Y_1 is reached,the X-ray source will move to the position designated as Z_1. When this occurs the system will automatically switch to the Automatic Scan Mode. These are XYZ Scan and ZXY Scan. For this example the XYZ mode will be considered.

After transfer to Automatic Scan has occurred, the camera will remain at location X_1, $Y_.$, and Z_1 for a period of time determined by the setting of the Dwell Control, typically 10 to 30 seconds. At the end of the Dwell period the camera will move right to the next 0.5-in. scale division and dwell at this point as at the origin. The boundaries established by the thumbwheel selector switches need not correspond to major scale divisions; however, when automatic scan begins, the dwell points will be at the major scale divisions. The sequence of Scan and Dwell will continue until the digital comparator indicates that $X = X_2$. The camera will then move vertically to the next major division. The sequence again starts except that scan motion is to the left. When $X = X_1$ the camera will move half an inch on the vertical axis and resume scanning. This line-to-line scan process will continue until the end of the top line. At this point the X-ray source will reposition to select a new layer and the process will repeat.

At any time during the scan, the operator may interrupt the automatic program by pressing the Vernier Scan button. The automatic scan will stop and the X, Y, or Z levers may be operated to center a desired region in the TV presentation. To recenter the Automatic Scan mode it is necessary to return to the point at which the system was stopped. The pilot lamp, associated with each positioning level indicates the direction that the camera, or X-ray source, must be moved to return to this point. When all Position Indicator lamps are out, the "Auto" button may be pressed. The system will then resume automatic scan.

Full manual operation of the system is also possible. This mode of operation may be entered only after the start Command and while the Ready light is on. Controls are interlocked in such a way that either scan mode may not override the other. To change from Automatic to Manual, it is necessary to press Stop, followed by Start, then Manual. In addition, entering any combination of commands will not damage or overload any portion of the system. In Automatic Scan the manual positioning levers have no effect.

4. <u>Automatic Lens System Selection and Orthicon Positioning Control</u>

a. <u>Lens Selection</u>

The optical subsystem of the laminograph instrument has been designed so that the image of the object under scrutiny can be viewed by the TV camera at three different magnifications. Viewing can be done on a one-to-one basis ("1X" magnification), optically magnified four times ("4X" magnification),or optically reduced five times in size ("0.2X" magnification) so that the view of the TV camera is over a much larger cross-sectional area of the object. These three discrete magnification settings of the optical system are achieved by the insertion of certain optical elements into the optical path of the system, accompanied by removal of other optical elements and the movement of the TV camera image orthicon tube to accommodate an axial movement of the focal plane.

Automatic selection of any of the three discrete magnifications is initiated by the operator pressing one of three pushbuttons. Indication of the status as to which of the three magnifications is established in the system is also required. Table III-D-2 gives the respective positions of the three movable optics "elements" for the three required magnifications.

Table III-D-2

OPERATING MODE - LENS SELECTION

Element / Operating Mode	0.2X	1X	4X
0.2 X Lens	in	out	out
4 X Lens	out	out	in
Camera Tube	back*	forward*	back

*back is away from derotation lens and forward is toward lens.

The mechanical drive associated with the 4X lens is called the "turret," and the mechanical drive associated with the 0.2X lens is called the "slide," when discussed elsewhere in this report.

b. Optical Focusing of TV Camera

Optical focusing of the TV camera actually involves the fine positioning of the image orthicon tube along the optical axis. Since the lens system optics automatic control (described in Section III-D-4) has no provision for actual final focusing of the optical image on the TV camera image orthicon tube, this must be done in nonautomatic fashion by the operator. The operator has two pushbuttons for this purpose located on the front panel of the scan control chassis (chassis 1-6), located at the operator's station outside the laminograph room (unit 1). When one of these manual slow pushbuttons is pressed and held down, the image orthicon drive moves the tube slowly forward at the fine manual slewing speed which is approximately 1/10 of the speed used in the fast course positioning of the "optics position control." Pressing and holding the other pushbutton causes the image orthicon tube to be moved slowly backward at the fine manual slewing speed. There are mechanical stops provided to set a limit on the ultimate amount of movement in either direction, so that if either of the buttons is held down for an extreme period of time, no damage can be done.

The operator depresses the buttons in arbitrary sequence while observing the result on the screen of the 8-in. Conrac monitor. During this operation, the rotation of the laminograph sample table is stopped, so that a true radiograph image is produced to be used for focusing purposes. The sample table drive motor is switched on and off at the front panel of the ac power control chassis (chassis 1-4). Electron beam blanking in the 8-in. monitor is switched off while focusing. When the image is in focus according to the judgment of the operator, he ceases manipulation of the manual slew pushbuttons, and normal operation of the laminograph may resume. If at any time in the operator's judgment, the acutal position of the image orthicon photosensitive surface is far from the true focal plane, he may activate the "optics position control" to reposition the image orthicon tube to either of its "nominal" positions which are close (but not at) the two true focus positions.

The MTI camera will be supplied by the manufacturer with provisions for remote focus adjustment as specified in Appendix D.

5. X-Ray Control System

a. Purpose

An integral part of the laminograph system is the X-ray source monitoring and control subsystem. Due to the special nature of the X-ray source, a vacuum pumping system is employed, and a vacuum gage is required for monitoring the vacuum level. The maintenance of a specified maximum low pressure is essential for proper operation of the X-ray source; in addition to this, certain electrical parameters of the X-ray source need to be monitored, and adjustments must be made to insure a suitable source of X-rays for the purpose of laminography. The tube filament current, anode voltage, and the tube current all must be monitored, as well as controllable, either directly, as with filament current and anode voltage, or indirectly, as with tube current by adjustment of the "bias" or X-ray tube series load resistance. In addition to these continuous control functions, an on-off control of the anode voltage is necessary to allow complete turn-off of the X-ray source, without complete shutdown of the X-ray unit.

The usage of the X-ray unit in the laminograph system requires a dual-station monitoring and control capability, the latter to at least a partial extent. The X-ray source electrical parameters must be monitored and controlled from the operator's station outside the laminograph room, but the bulk of the equipment required for the X-ray source (in particular the vacuum pumping system) must be located adjacent to the actual X-ray source in the laminograph room. This equipment, as normally supplied by the manufacturer (Jarrell-Ash), is fully operable from a single large console unit which includes all vacuum pumping equipment as well as all electrical equipment. The routing of many of these leads to the operator's station. Chassis 1-2 control interface chassis (chassis 3-1) was created to be located within the laminograph room, and contains all the necessary relays which are added in the dual-station modification of the X-ray unit. The actual duplicate controls themselves, such as the anode voltage variable autotransformer, are,of necessity located on the front panel of the X-ray control chassis (chassis 1-2) at the operator's station, so that some lines with 230 V ac potentials do go to this place.

b. <u>System Description</u>

The modifications to the Jarrell-Ash X-ray unit (unit 2) and the added control components which together constitute the complete dual-station X-ray control system, were made to fulfill the following performance criteria:

1. All control and monitoring functions provided as part of the Jarrell-Ash main console (unit 2) are to be duplicated at the operator's station, with the exception of the switch controls for the vacuum system. The vacuum gage monitoring function is to be duplicated at the operator's station.
2. Monitoring functions are to be simultaneous as much as practicable. Control functions are to be of automatic switchover type, with lock-out

of the "unused" station, to prevent conflict of control inputs from two sources, as might otherwise occur during service operation of the X-ray source by a person in the laminograph room (who is fully cognizant of the X-ray hazard), with an operator attempting to operate the X-ray source from the unattended operator's station which is not in sight of the person in the laminograph room.

3. The automatic switchover shall be controlled by the opening of the door to the laminograph room and by turning on the laminograph room lights. Partial opening of the door to the laminograph room shall cause X-ray source control to transfer to the control station located at unit 2 (in the laminograph room), and if the laminograph room lights are turned on, subsequent closure of the laminograph room door does not alter this transfer, control is maintained at unit 2.

4. The laminograph room lights cannot be turned on until the laminograph room door is at least partially opened.

5. The TV camera on the laminograph machine (unit 4) shall be interlocked with the laminograph room door and the laminograph room lights so that partial opening of the laminograph room door shall blank the TV camera. If the laminograph room lights are turned on, subsequent closure of the laminograph room door does not alter this condition, the TV camera remains blanked. This criterion is imperative, because even low light levels in the laminograph room will cause permanent damage to the unblanked image orthicon tube in the TV camera.

6. Provision shall be made to operate the X-ray source from the control station located at unit 2 (in the laminograph room), with the laminograph room door fully closed, with the laminograph room lights turned off, and with the TV camera automatically turned off. This is necessary to perform certain X-ray tests which require visual observation of the equipment at very low light levels. This shall be known as the "Defeat" mode.
7. Transfer of X-ray source control from either station to the other, neglecting to turn off the X-ray source anode voltage and filament current, shall cause them to be turned off automatically.
8. The Jarrell-Ash X-ray unit (unit 2) shall be physically modified in such a way that its internal wiring can be easily restored to the original schematic state, as by the addition of a dummy or test plug.
9. No additional safety interlocking for equipment or personnel protection shall be provided beyond that provided by the Jarrell-Ash main console before modification and as normally supplied by the manufacturer. All existing safety interlocking features shall be retained.
10. An audible alarm shall sound in the laminograph room when the X-ray source is turned on with filament current and anode voltage applied.

These design criteria are mainly for operator and equipment safety during all conceivable conditions of normal modes of laminograph operation and maintenance, with a few provisions for operator or equipment protection during abnormal or careless operation. It is recommended that the operator's manual for the

Jarrell-Ash Multifocus X-ray unit be studied carefully to become aware of the correct operating procedures and precautions required.

E. Mechanical Systems

1. General Description

Referring to Assembly Drawing V6034-R-000, the laminograph system is composed of a number of mechanical subassemblies or modules. The basic unit assembled will be approximately 183-in. (15.25 feet) long, 48-in. (4 feet) wide, and at its highest point, 120 in. (10.0 feet) from the floor. The weight of this entire unit will be approximately 3200 pounds.

In order to obtain a complete and clear understanding of the mechanics involved in the laminograph system, the description of the mechanics will be described by modules.

There are ten main modules which when assembled make up the complete laminograph system.

1. X-ray Source (Mechanics and Support Structure)
   Drawing Number V6034-R-100.
2. Rotary Drive System (Sample and Optics)
   Drawings Number V6034-R-200 and V6034-R-300.
3. Derotation Lens and Support Structure
   Drawing Number V6034-R-400.
4. Mirror and Support Structure
   Drawing Number V6034-R-500.
5. 1/5 Lens Movable Carriage and Support Structure
   Drawing Number V6034-R-600.
6. TV Camera Housing and 4X Mounting Mechanism
   Drawing Number V6034-R-900.
7. "X-Y" Traversing Mechanism and Support Structure
   Drawings Number V6034-R-800 and V6034-R-1100.

8. Upper Support Structure
Drawing Number V6034-R-1200.
9. Base Table Support Structure
Drawing Number V6034-R-1000.
10. Fluorescent Screen Mounting Plate
Drawing Number V6034-D-700.

The following section discusses each of the modules.

2. X-Ray Source (DrawingsNumber V6034-R-100, and V6034-R-154)

The X-ray source consists of four submodules, namely: (1) Jarrell-Ash microfocus vertical X-ray tube, (2) precision vertical traversing mechanism, (3) positioning mechanism, and (4) support structure. This entire unit is fixed to a machined pad located at one end of the base table support structure (Drawing Number V6034-R-1000).

a. Jarrell-Ash X-Ray Tube

Refer to Section III-B for the description and specifications.

b. Vertical Traversing Mechanism

The traversing mechanism is designed to move the X-ray tube automatically in the vertical direction a distance of 2.605 inches in increments of 0.00521 inches allowing thus, to image planes at 0.001-in. intervals and scan samples up to 0.500-in. thick. The mechanism consists of three elements, namely: (1) a step-servo motor, (2) bidirectional locking clutch, and (3) a ballscrew assembly. The motor chosen is a Wright Number 25L, manufactured by Wright Machinery Company, Division of Sperry Rand Corporation. This motor will deliver approximately 60 oz-in. running torque, 120 oz-in. stall torque with response rates up to 250 pps bidirectionally in 15° increments. Actual stepping rate, however, is not to exceed 40 pps and it will be operated at the rate of 20 pps. Mounted in line with the motor and ballscrew assembly is a bidirectional locking clutch, manufactured by Formsprag Company, which will lock the X-ray tube in any given vertical position during the scan periods.

The ballscrew assembly is a precision built item, by Kidde Aerospace Division, and is designed specially for applications such as computers, X-Y plotters, etc.

The size of the ballscrew was dictated by operating load capacity and by the thread of lead which is 0.125 inches per revolution which lends itself to our application. The X-ray tube adapter plate which is connected to the vertically moving ballscrew nut then becomes the mobile part of the mechanism. This mobile part is guided by two vertically parallel hardened (58-63C) round guide bars. These bars also function as ways for the adjustable diameter ball bushings which are part of the vertical traversing carriage. The entire mobile section of the traversing mechanism is counterbalanced by 4 (four) negator springs. The exact size and load capacity of these springs will be determined during assembly.

c. <u>Positioning Mechanism</u>

The positioning mechanism will permit precise positioning of the X-ray tube in three directions: horizontal, vertical, and axial. All three adjustments are based on a differential screw adjusting method.

A differential screw is basically a stud with a 1/2-12UNC thread on one end and a 7/16-14NC thread on the opposite end. It is held in position by two pivoting nuts with corresponding threads. One of the nuts is designed to move away and around the stationary pivoting nut. By turning the stud in the desired direction a motion is produced which moves the "free" nut 0.00549 in. per revolution. The X-ray source will be assembled and placed as close as possible to its permanent position on the base table and the micrometer adjustments will only be used for final positioning.

(1) Horizontal Micrometer Adjustment. This adjustment is to allow alignment of the X-ray tube with the longitudinal axis of the entire laminograph system with the X-ray tube in a fixed vertical position. This may also be described as aligning the theoretical centerline of the X-ray beam with the centerline of the laminograph system.

(2) Vertical Micrometer Adjustment. This adjustment is to provide alignment with the longitudinal axis throughout the entire vertical traversing of the X-ray tube.

(3) Axial Micrometer Adjustment. This adjustment is to provide precise "aiming" capabilities of the X-ray beam toward the centers of the sample, fluorescent screen, and optics system.

d. Support Structure

The support structure is a welded steel plate construction. The base height of the structure is approximately 35.00 inches from the top of the base table.

3. Rotary Drive System (Drawings Number V6034-R-200, and V6034-R-300)

a. Initial Considerations

Three alternate drive methods were proposed for the laminograph -- namely, a standard nonmetallic timing belt/sprocket system, a perforated steel belt/sprocket system, and a two-mesh gear train system. Each of the three concepts proposed had relative advantages and disadvantages, but a basic analysis indicates that the gear system has the best chance to succeed among the three open-loop, simple mechanical systems.

b. Nonmetallic Timing Belt/Sprocket System

The severe angular error tolerance required for the laminograph, as translated into permissible speed ratio and backlash error, quickly rule out a flexible, nonmetallic element such as a timing belt. The belt tooth and tooth-to-tooth dimensional tolerances available in this type of product simply cannot meet the requirements of laminograph. The problem is compounded by the possibility of belt stretch or other longer time dependent dimensional instability.

c. Metallic Belt/Sprocket and Gear Train Systems

The first of these concepts represents a considerable improvement in system accuracy over the nonmetallic belt, but it has at least one inherent deficiency compared to the gear concept: for every speed change in a given drive system, there are two component interfaces with use of a belt as contrasted to only one with use of meshed gears. It is precisely at such interfaces that dimensional inaccuracies and dynamic disturbances come into play, hence speed ratio and backlash errors occur. For the particular laminograph drive line layout under discussion, the characteristic equation for angular error (or asynchronism) of the sample holder with respect to optics housing can be written as

$$\theta = \frac{2}{3} S \qquad \text{(metallic belts/sprockets)}$$

radians

$$\theta = \frac{1}{3} S \qquad \text{(meshed gears)}$$

where,

θ = maximum lead or lag (asynchronism) of sample holder with respect to optics housing, radians.

S = minimum circumferential dimension tolerance obtainable for the combination of contacting parts at <u>each</u> belt/sprocket interface or, minimum operating backlash obtainable at <u>each</u> gear mesh.

Therefore, for equal "backlash type errors" in each system, meshed gears will produce one-half the angular asynchronism compared to belts and sprockets. The difference exists because two belt loops and four sprockets act analogous to four gear meshes.

In any case, if the belt/sprocket system were to be further pursued, the required accuracy of the sprocket would place it in the "precision gear" category. A direction toward direct gearing is certainly indicated.

Although a gear train drive system appears most feasible, it will not be a simple task to obtain the desired minimum asynchronism. Assurance of the previously mentioned backlash tolerance is by no means the total requirement. Other dimensions that require precise control are: tooth-to-tooth spacing, pitch diameters, center distances, and concentricities. Better indication of gearing requirements are total composite error and overall speed ratio variation between input and output; calculations show that precision 3-in.-class or somewhat better gears will be needed.

Other system components-- bearings, housings, etc.,will require similar precision if the gears are expected to live up to their potential. For example "class 7" or better bearings will be needed. The laminograph drive requirement is a total system design problem. Preliminary designs with the gear concept indicate that such a total system is feasible.

The rotary drive system incorporates four basic areas. These areas are (1) sample rotary table, (2) derotation lens rotary table, (3) drive pinion assembly, and (4) main housing.

(1) Sample Rotary Table. The sample rotary table consists of a modified Kaydon Turntable Bearing Number KH-275 which will be seated into the main housing. This bearing will be supplied by:

Kaydon Engineering Company
Muskegon, Michigan
Kaydon Drawing Number - C-10213001

The turntable bearing specifications are as follows:

- o Ball pitch diameter - 27.500 inches
- o Outside race diameter - 31.700 inches
- o Bore diameter (inner race) - 23.40 inches min.
- o Width of bearing - 2.500 inches
- o Width of individual race - 2.000 inches
- o Offset of races - 0.500 inches
- o Outside diameter (inner race) - 27.250 inches
- o Bearing type - 4-point contact
- o Ball preload - 0.000 to 0.0005
- o Bearing runout - 0.0002 maximum

Machined into the inner race of the bearing is the drive gear. The gear specifications are as follows:

- o Pitch diameter runout to bearing runout (concentricity) - 0.0002 maximum
- o A.G.M.A. quality 16
- o Total composite error - 0.0002 maximum
- o Tooth-to-tooth error - 0.00015
- o Diametral pitch - 32

- o Pitch diameter - 27.187
- o Number of teeth - 870
- o Pressure Angle - 20°

A 25.00-in.-diameter counterbore is also machined into the inner race. This counterbore will serve as a seat for the sample supporting plate.

The sample supporting plate is 25.00 in. in diameter and 0.125-in. thick. It will be held into position by a ring with 24-1/4, 20UNC screws located around its periphery. This sample support plate is fabricated from pure beryllium. Deflection of the plate under its own weight should not exceed 0.00025 in. and the deflection based upon an evenly distributed load of ten pounds should not exceed 0.002 in.

A simple means of retaining the sample on the beryllium plate will be the use of double-back masking tape. If this method is not satisfactory an alternate method of vacuum cups with attached brackets could be used. A description of this bracket is as follows.

The vacuum cup is a standard molded rubber cup with a protruding screw. Tests conducted in order to establish the holding capabilities show that polished edge and glycerine-treated vacuum cups will adhere almost indefinitely to a good polished metal surface.

The vacuum cup shield is a steel cup covering the vacuum cup in order to protect the latter from the X-rays. The clamp is a formed beryllium part. Beryllium is used here again due to its permeability to X-rays. Various types of clamps would be used depending on the size, shape, thickness, and general condition of the sample. Two such clamps are illustrated in this report. (See Figure III-E-1.)

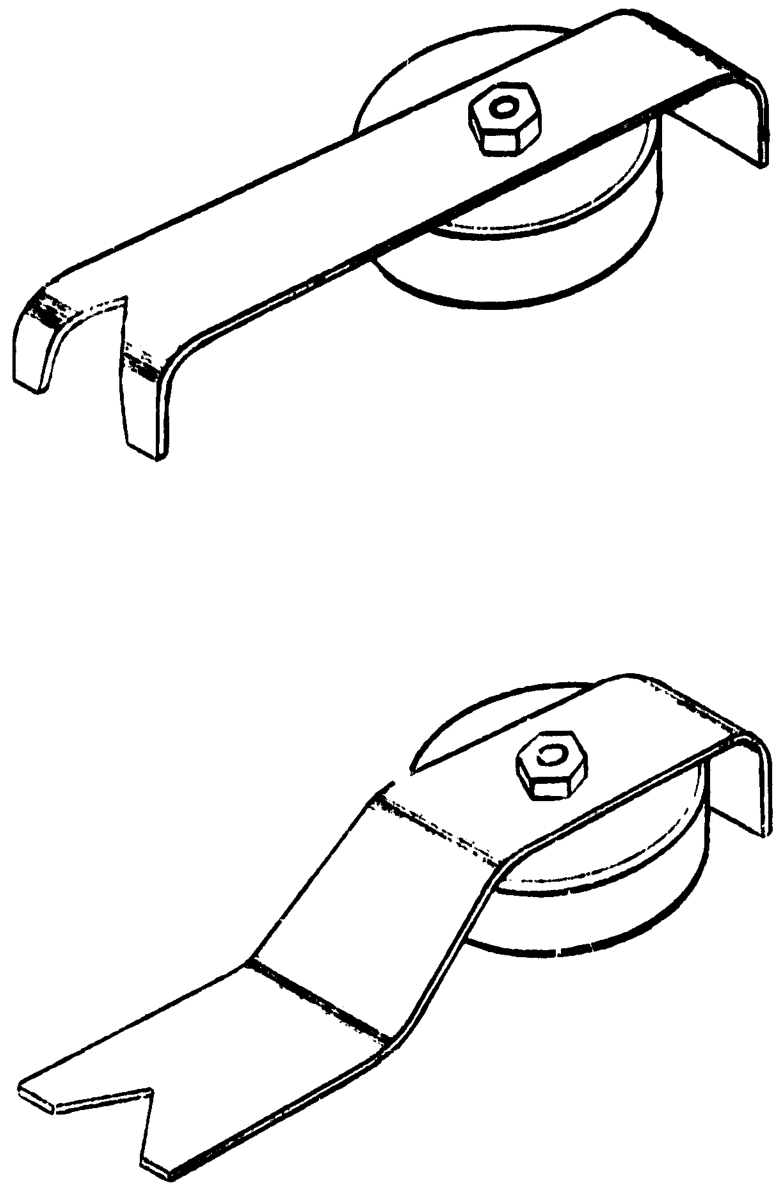


Figure III-E-1

VACUUM CUP CLAMPS

(2) Derotation Lens Rotary Table. The derotation lens rotary table will also consist of a modified Kaydon Turntable Bearing Number KH-275. This bearing will be fabricated identical to the sample rotary table bearing.

The 25.00-in.-diameter counterbore will incorporate the derotation lens mounting structure.

(3) Drive Pinion Assembly. The drive pinion will be fabricated from one piece (probably a welded structure) and incorporate a 12.500-in. pitch diameter, and a 6.250-in. pitch diameter gear (see Drawing Number V6034-R-200). The tolerance specifications for the drive pinion gears will be identical to the rotary table gears. The drive power source is a "Winsmith Gearmotor," Unit Number IMCVRW, Assembly LD, single reduction, input speed - 1725 rpm, output speed - 115 rpm, (15:1) reduction, single phase - 115 volts ac, 1/2 hp dripproof. This speed reducer is connected inline thru a Torrington one-direction (overunning) clutch (cat. number RCB-121616) to the drive pinion.

The speeds of the sample and optical rotary tables will be as follows:

Sample drive unit

- Sample rotary table gear (driven) - 27.187 pitch diameter
- Pinion gear (driver) - 12.500 pitch diameter
- Ratio - 2.175:1
- Table speed $\frac{115}{2.175}$ = 53 rpm approx.

Optics drive unit

- Optics rotary table gear (driven) - 27.187 pitch diameter
- Pinion gear (driver) - 6.250 pitch diameter
- Ratio - 4.32:1
- Table speed $\frac{115}{4.35}$ = 26.5 rpm approx.

The pinion will rotate about two preloaded, class 7, angular contact bearings which will be seated in the pinion gear housing. Once the pinion is properly located in the relation to the two rotary table gears (centerline variation should not exceed 0.001 in.), the pinion housing will be pinned and bolted.

(4) Main Housing. The housing which will support the bearings and the derotation lens support structure will be a steel fabrication utilizing 0.625-in. plates and be a combination welded and bolted construction. The side and end plates will have sufficient cutouts to reduce the overall weight of the structure and also allow a means for the X-rays to escape. Six machined pads located on the bearings centerlines will serve as datum planes for Kaydon Engineering to locate the housing in their grinding machine, and they will also serve as the mounting brackets when the housing is fixed on the base tables support structure. All machining operations will be done with reference to the machined surfaces on the pads. The housing will have overall dimensions of 61.00-in. long, 36.00-in. wide, and 16.500-in. high.

The weight of the unit which shall include: (1) housing structure, (2) bearings, and (3) optics housing and support structure, will be approximately 1000 pounds. Eye bolts will be fixed to the housing so that a lifting mechanism can be utilized in shipping and assembly.

4. Derotation Lens Mounting Structure (Drawing Number V6034-D-400)

The derotation lens housing is fixed to an adjustable plate that can be leveled (3-point support) and aligned (4-screw adjustment) with the axis of the optics rotary table.

This tube will be fabricated from aluminum in order to reduce its weight and will be dynamically balanced. The balancing is to avoid any offset of weight while rotating. This balancing is necessary because of the precision alignment tolerances and also to avoid any vibrations.

This tube will be fixed to a retaining ring which will be located in the 25.00-in.-diameter counterbore in the optics rotary table bearing inner race.

Alignment of the derotation lens housing in relation to the housing centerline is anticipated to be a tedious operation. Refer to Alignment Techniques, Section IV-B of this report.

5. <u>Mirror and Support Structure (Drawing Number V6034-R-500)</u>

The mirror used is a rectangular 12 in. x 16 in. x 3/8 in. thick glass plate. It is held flat in a metal frame at 45° in relation to the derotation system centerline. The metal frame is supported by three leveling screws that will permit angular, level, and slight distance adjustment of the mirror (distance mentioned here is from the derotation lenses). The mirror structure itself has been considerably redesigned as compared to the preliminary design structure. This is due to the addition of the 1.5X lens system. The present support structure, while supporting the mirror directly over the derotation and supplementary lenses when the latter is in position "in", is designed to clear the 1.5X lens system carriage when it is being transferred from position to position. The basic structure consists of two 1/4-in.-thick steel plate sides connected by a welded crossbar The bottom is machine finished and holes are provided for direct mounting of this structure.

6. Mechanics of the 1.5X System (Drawing Number V6034-R-600)

This description of the 1.5X system is concerned with the mechanical aspects only. For the description of the function and of optical elements of this system, refer to the optics section of this report.

The mechanical end of this system consists of three main subdivisions: (1) frame, (2) positioning mechanism, and (3) carriage.

a. The Frame (Drawing Number V6034-R-661)

The 1.5X system support frame is a compact, square tube, welded structure. It is located on top of the top support structure and is secured there by means of bolts. The bottom and top pads are machine finished for parallelism of planes involved. Tapped and clearance holes are provided for the carriage and the positioning mechanism mounting. No assembly drilling or fitting is required.

b. The Carriage and the Positioning Mechanism (Drawing Number V6034-R-600)

The carriage is built to move on machined rails via cam followers and is guided in two directions-- vertically and horizontally. It carries the supplementary lens, the field lenses, and the relay lens. The supplementary lens is vertically mounted on the bottom plate of the carriage. It has provisions for fine three-point axial, vertical, and level positioning and adjustments. The field lenses are horizontally mounted on a stand that is adjustable along the optical and TV system axis for large increment adjustment. Fine adjustment capabilities are provided so that the field lens housing can be further adjusted horizontally and leveled by three-point support and positioned axially by two-point support. The two-point mounting support for the axial adjustment is due to the horizontal mounting of these lenses. The relay lens is mounted in a manner very similar to that of the field lenses and has basically the same positioning and adjustment capabilities.

The function of the positioning mechanism is to transfer and to maintain the 1.5X lens system in one of the two required positions - IN or OUT. When the 1.5X lens system is in the "in" position, its center axis is aligned, horizontally and vertically through the entire length of the system, with the optical and TV camera axis. In the position "out" the carriage is stopped in any predetermined position so that the lines of "vision" of the other magnification systems are unobstructed. In order to clear the lines of "vision" the carriage must travel a distance not less than 13 inches. This is accomplished by a motor driven fixed position screw and a nonrotating nut that is attached to the system carriage. The nut is placed in a slot and is spring-tensioned in one direction. When moving in the direction "in" the carriage is stopped in the required position by two solid stops while the nut, at this point against the spring tensions, begins its travel within the slot and moves until a cam which is part of the nut assembly reaches a limit switch and stops the motor. At this point, the nut is stationary on the screw and the carriage is held against the solid stops by the spring tension. The two stationary stops are adjustable and serve as carriage positioners in the horizontal direction. The spring holding tension can also be varied by changing the limit switch position in a slotted mounting bracket. To reach the "out" position, the motor is activated and the carriage is allowed to travel 13 inches in the opposite direction until another limit switch is reached and the carriage is stopped. There are no stops for this position and the springs do not perform any function here. The "out" position is determined, as mentioned before, by the lines of "vision" of the other magnification system and can be varied by the location of the limit switch.

The motor used to position the carriage is a 1/2-hp, 115-volt, 60-cycle, single-phase, reversible-from-standstill RATIOMOTOR. The output shaft, 350 rpm, is connected in-line via electric clutch, to the fixed position screw. The screw is a standard Acme 5/8-diameter, 8-threads-per-inch screw. The time required to transfer the carriage 13 inches is 17.8 seconds, approximately.

7. Television Camera Housing and 4X Lens Mounting Mechanism (Drawing Number V6034-R-900)

The television camera housing will consist of a welded construction incorporating 0.250-in. steel plates. The housing will be fabricated in a (⊔) channel construction. The top and back will be open to allow proper air circulation. The housing will incorporate a series of 8 alignment pads which will be used for precision positioning of the centerline of the image orthicon tube in relation to the 4X lens centerline. The positioning of the television camera will be done after the 4X lens mounting mechanism is located and fixed to the housing.

With this alignment technique the television camera has a freedom of movement of approximately 10 degrees in any direction once placed in the housing.

Located in each side of the housing are the mounting brackets which will be secured to the X-Y traverse mechanism.

On operator command, the 900 to 1 reduction capacitor start gear motor rotates the counterbalanced lens mounting arm from its rest position (30° BTDC) to a horizontal operating position against an adjustable stop. (Total rotation 120° in 10 seconds.)

The lens mounting arm is mounted in two precision antifriction ball bearings and is driven through an adjustable (0 to 64 in. oz) continuous duty slip clutch. The arm is initially detained in its rest position by a magnetic stop requiring 20 in. oz. torque on the drive shaft to release, and the unbalanced mass of the lens system requiring an additional 10 in. oz. torque for movement or a total of 30 in. oz. torque. This torque is less than half the output of the slip clutch. The gear motor produces 100 in. oz. torque. As the arm approaches the horizontal operating position it activates a limit switch which turns the motor off after a 5-second time delay. This switch can be adjusted for actuation from 0 to 60° before the arm reaches its operating position to provide a smooth stop without banging.

The arm is held in its operating position by the unbalanced mass of the lens and by a magnetic stop,and requires a total of 30 in. oz. torque for movement.

On operator command the lens arm is returned to its rest position by the reversible gear motor. This operation is the reverse of the operation above except that the rest stop is not adjustable and the stop switch has a smaller range of adjustment.

In the operating position the system will remain in alignment when subjected to 1 1/2-G vertically downward acceleration and is unaffected by upward or horizontal acceleration.

In the rest position the system will retain its position under 3-G downward and 2 1/2-G horizontal acceleration, and is unaffected by upward acceleration.

8. X-Y Traversing Mechanism and Support Structure (Drawings Number V6034-R-800, and V6034-R-1100)

The television camera traversing mechanism incorporates the use of two traversing tables, one for the X, or horizontal movement, and one for the Y, or vertical movement. Both tables are to be guided by two 0.750-diameter hardened steel rods which will ride in a set of rolling and floating "V" bearings. These bearings are made especially for traversing carriages. Because of the low torque required to move the table in the horizontal direction (approximately 2 oz-inches), this table will be powered by a single ballscrew, driven by a stepping motor.

The ballscrew and nut assemblies will be supplied by Walter Kidde and Company, Inc., Belleville, New Jersey, and have a 0.625 diameter with a 0.100 lead. The ballscrew ends will be gound down and the ends will be fixed and preloaded in a set of angular contact bearings. The nut assembly will consist of two flanged preloaded nuts. Preloading of the nuts is utilized to minimize deflections in the system when subjected to operating loads. The stepping motor will be supplied by Wright Machinery Co., Durham, North Carolina, Number 25L. The specification for this motor is as follows:

- Stall torque - 120 oz-inches
- Running torque - 60 oz-inches (approximately)
- Step angle - 15°
- Stepping rate - 250 steps per second (specified)
- Bidirectional shaft.

Due to the weight of the television camera and housing, the horizontal table, and the 4X lens mounting mechanism, the vertical table will utilize two ballscrew drives. These ballscrews will be driven through a series of miter gears and powered by a single Wright Machinery Company stepping motor. Both sets of ballscrews will incorporate a bidirectional clutch which will be used to lock the ballscrews when the table is stopped.

In order to reduce excess loading of the stepping motor, the vertical table will incorporate a set of counterbalancing negator springs. These springs will be attached to the vertical table and the negator spring housings will be fixed to the support structure.

Full traversing movement will be 13 inches in either the X or Y direction. In order to minimize a cantilever effect and to eliminate the possibility of chatter when the television camera is moving, the complete television camera assembly will be mounted to the horizontal table at its center of gravity.

The X-Y traversing mechanism will be mounted to a welded angle iron frame which is fixed to the upper support structure.

9. Upper Support Structure (Drawing Number V6034-R-1200)

The upper support structure consists of a welded 2 in. x 0.187 wall square tubing construction. Located on the top and bottom of this structure are welded mounting pads.

The top pads are for mounting the mirror and its support structure, the 1.5X lens carriage support structure, and the X-Y traversing mechanism support structure. The bottom pads are used for the mounting of the entire frame to the base table. A number of square tubes will be welded diagonally across the frame to eliminate twisting effects.

10. Base Table Support Structure (Drawing Number V6034-R-1000)

The base table consists of a "U" channel welded structure supported on three legs. Welded to this structure are parallel machined pads which will serve as mounts for the rotary drive housing, upper support structure, and the X-ray support structure.

An overall analysis of the base table was conducted to determine the proper location of the three legs for overall balance of the entire system, and ascertain the stress level in the base table to be a very low value. This is to assure perfectly linear stress-strain relationships for any additional loading of the frame. The frame was treated as a wide beam on two supports (in the longitudinal plane). Center of gravity of the structure in the transverse plane can be assumed on the longitudinal centerline. The legs were positioned so that no matter where, a load has to be more than that of the weight of the table to tip. Also fixed to each support leg will be an adjustable foot pad. When leveling the table only two pads will be used. The third pad will act as a solid column. In order to distribute the loads produced by the three mounting pads into the floor, each pad will rest on a 12-in.-square by a 0.50-in.-thick plate. The overall dimensions of the base table are: 183-in. long (15.25 feet) by 48 in. (4 feet) wide by 22 in. (1.83 feet) high. The weight of the table will be approximately 1000.0 pounds. A cover for the base table was not designed as no real need of one was anticipated.

If a cover is required it could be fabricated from stock plywood or sheet steel and fixed to the flange of the channels by screws.

Once the table is properly placed in position and leveled, the table should be bolted to the floor by means of the clearance holes provided in the 12-in.-square plates welded to the leveling pads.

11. Fluorescent Screen Mounting Plate (Drawing Number V6034-D-700)

In order to utilize the full viewing areas of the sample, the fluorescent screen was changed from a 14-in. square to 20.00 in. in diameter. The fluorescent screen will be bonded to a 22.00-in. diameter by 0.750-thick plate. The top surface of this plate will be machined and ground flat to within 0.0005 in. maximum. The plate will reset on (by its own weight) three micrometer adjusting screws. These screws will be used to position the plate (fluorescent screen) parallel with the sample. Two screws will be used for the adjustment while the third will act as a rigid support. Deflection of the plate under its own weight should not exceed 0.003 in.

IV. ALIGNMENT TECHNIQUES

A. Optical Alignment

The derotation lens and prism have to be aligned with extreme care. The 4X Barlow lens and the 0.2X system are less critical and can be mounted by ordinary optical shop techniques.

As previously mentioned, the derotation lens is to be mounted at the center of a rotating table. The 14 in. x 14 in. fluorescent screen is to be 50.7 in. below the center of the lens assembly. The X-ray shadow image rotates on this fluorescent screen and is to be derotated by rotating the table (with the lens) at one-half speed. A target value of 0.001 in. effective spot size is desired. Each half of the derotation lens has a focal length of about 32 in., so this spot subtends an angle of 0.1 minute. The principal optical problems are: (1) obtaining the desired image quality under static conditions, and (2) aligning the axis of the lens and prism with the static center point of the rotating X-ray shadow image. Under No. (1), surface and thickness tolerances and especially the alignment should be held with more than usual care, as discussed under "Tolerances" in Section VIII-C.

The next alignment test is that of the prism itself. The assembled prism is to be capable of being placed between two aligned collimators as indicated schematically in Figure IV-A-1 without disturbing the optical alignment by more than 0.1 minute and without splitting the image by more than 0.05 minute. The displacement in the vertical plane as shown in elevation depends upon the exact leveling of the prism and need not be proven at this stage. Displacement and image splitting in the horizontal direction are caused by pyramid errors and must be measured with the prism parallel to the axis and also with the prism rotated 16° in each direction. The rotation in one direction is indicated by dotted lines in the plan view. Vertical image splitting is caused by lack of parallelism of the two individual

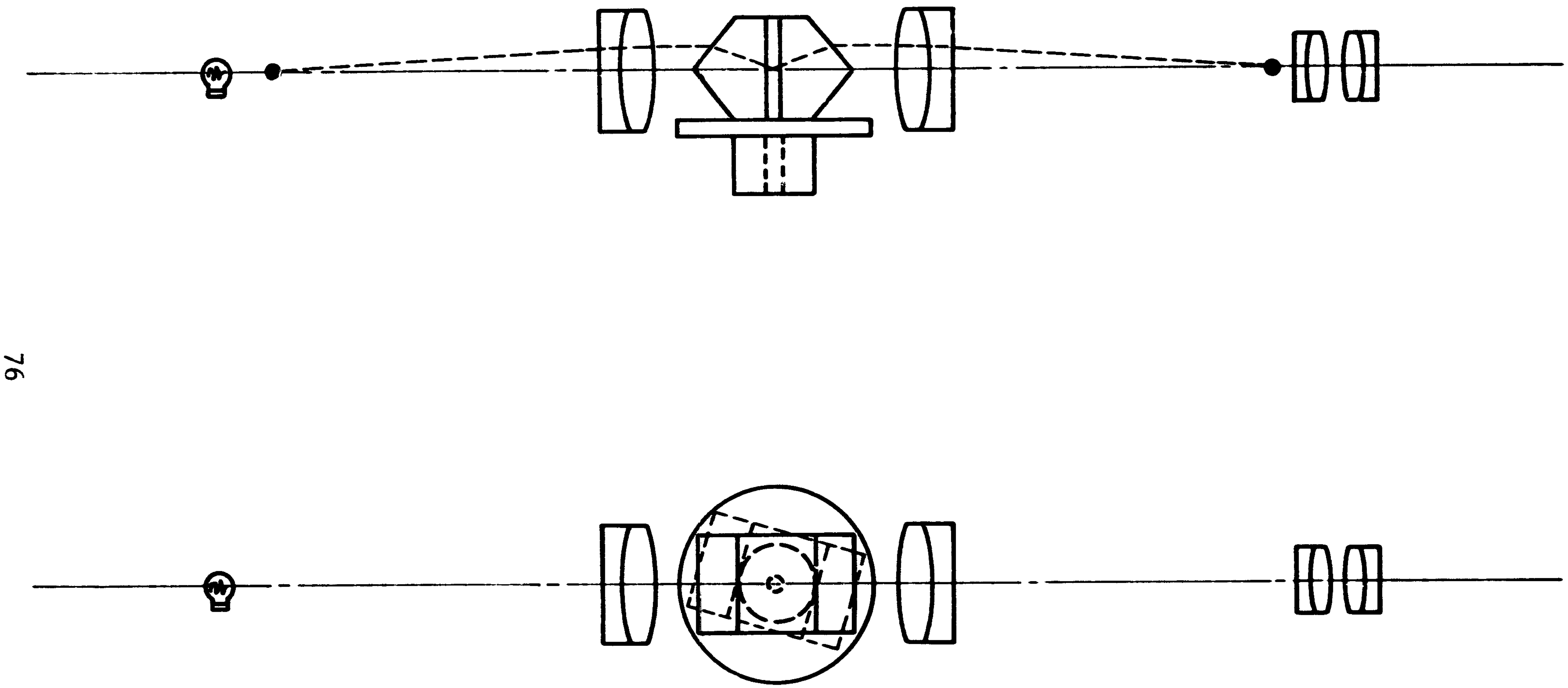


Figure IV-A-1 PRISM ALIGNMENT

prisms or by inaccuracies of the 45° angles. To a small degree these two types of errors can be balanced against each other.

Under No. (2), it is required that an axis of reference be defined, and this is assumed to be the axis of the outer surface of the lens barrel, determined by a run-out gage when the barrel is mounted on a rotatable fixture.

The rear lens assembly, already accurately aligned in its mount by standard methods, is next mounted in the barrel as shown in Figure IV-A-2 and tested with a standard run-out test, A--B. A test object, such as an illuminated pinhole P, is then adjusted in position so that the emerging beam is collimated, as tested by a prefocused collimator C, and so that the image is stationary when the barrel is rotated.

The prism, mounted in its cell, is next inserted into the barrel. The lateral positioning of the prism is comparatively uncritical. The tilting, however, is the most critical parameter of all and must be adjusted so that the image is stationary again when the assembly is rotated.

Finally, the collimator is to be removed and the front lens assembly is to be inserted and checked for run-out by reflection. The image of the pinhole is again to be examined by a low power microscope and should be stationary within the stated limits.

When the derotation lens is mounted in the final instrument and adjusted so that the barrel runs true, it establishes the center point of the shadow image, and this center point is to be matched by critical adjustment of the position of the X-ray source. This must be done by actual operation of the system with some test target in the sample stage and the X-ray position adjusted to the point of minimum image motion.

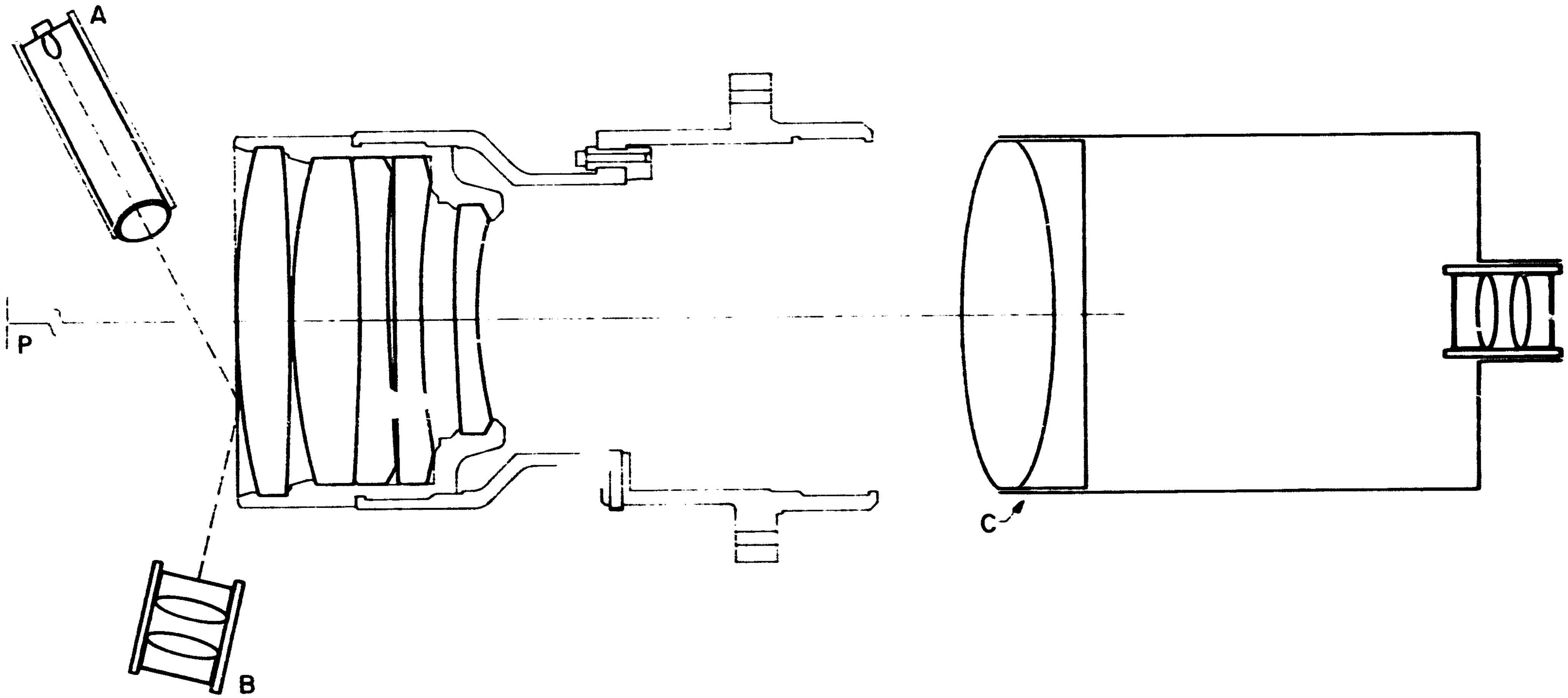


Figure IV-A-2 METHOD OF ALIGNING DEROTATION LENS IN BARRELL

B. Mechanical Alignment

There are two areas in which mechanical alignment is critical. These are the meshing of the pinion gears with the outer gears of the rotating tables and the parallelism of the sample table and fluorescent screen.

The alignment of the gears will be achieved by aligning two surfaces, one on the gear and one on the pinion. These two surfaces will have to be made with the gears and pinion and held to the same tolerances. A precision block gage will then allow precise meshing of the gears for minimum backlash.

The second area is of greater importance, since the conditions that must be met are that the axes of rotation are parallel to within 0.5' of arc, and perpendicular to the fluorescent screen within 0.5' of arc. These alignments are to be made using optical techniques. The fluorescent screen is to be used as one reference surface and the surface of the sample table as the second. A light beam can then be split, transmitted to, and reflected from these surfaces. The angle of divergence of the two beams can be measured accurately, and the alignment adjustments made with great precision.

C. X-Ray Source Alignment

The proper alignment of the X-ray source is essential to the achievement of the resolution of the system. In the earlier report on laminography, the requirement for this alignment and its achievement were discussed. In essence, the alignment that is required is three fold: vertical movement must be parallel to the plane of the axes of rotation, the source must be within 0.002 in. of the plane of the axes of rotation, and the source must illuminate the sample uniformly.

The last of these requirements is met quite easily by providing two degrees of freedom for the source. Observation of the fluorescent screen will be an adequate means of determining when proper alignment has been achieved.

The achievement of the former two types of alignment requires considerably more effort and care. The technique developed earlier, although somewhat tedious, has proven to be very accurate and would be adapted to the alignment of this unit. A special cross-hair sample is required. The cross-hairs are made of 0.0005-in.-diameter tungsten. One is placed perpendicular to the X-ray beam, the other parallel to, but displaced from the center of the beam. A Polaroid camera would view the fluorescent screen at the image plane (1 to 1 magnification). A double exposure is made, the sample and optics rotated 180° and 90°, respectively. The separation of the two images is equal to twice the distance the source is displaced from its correct position. The sign of the displacement is not known, and can only be found by trial and error. It is also necessary that the image of the wire perpendicular to the beam be either a single or a very closely spaced double image. If this is not the case, vertical motion must be used to bring these images together. Once the source is aligned at one vertical position, the process is repeated, after changing the vertical position of the cross-hairs by 0.5 in. A displacement of the image of the parallel wire indicates that the source vertical motion is not parallel to the rotation axes. Again a trial and error analysis must be made to determine the sense of the required tilt correction.

Previous experience has shown that this alignment can be made to an accuracy considerably better than actually required.

V. ROOM REQUIREMENTS

Because of the nature of the laminograph as an instrument, there are a variety of special requirements for the room in which it is to be placed. These generally are related to three areas: personnel safety, machine stability (temperature, vibration), and camera light sensitivity.

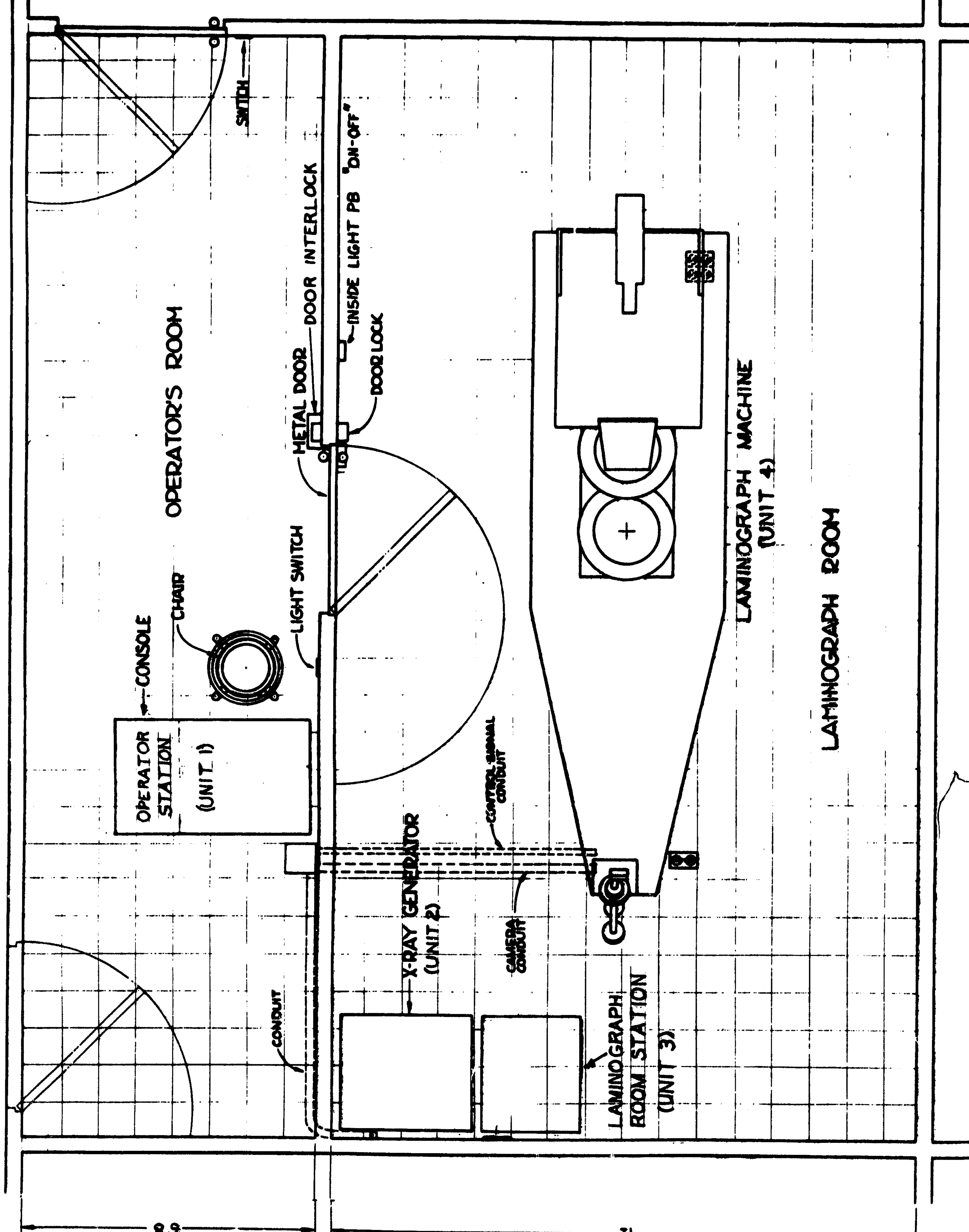
For the first of these, personnel safety, two requirements must be met: (1) the room must have adequate shielding to insure that personnel in the vicinity will not receive excessive radiation and (2) the room must have interlocks that will turn off the X-ray source if the room is entered during operation. The first requirement is easily met by the usual cement block wall and windowless metal door in a steel jamb. This requirement would change considerably if a more energetic source were used. If a 150 KV machine were used, considerable additional shielding would be required. This could consist of lead sheets placed over the walls and ceiling. Alternatively, the room could be constructed originally with poured concrete walls and ceiling approximately 6 inches thick. The door would then have a lead sheet for shielding.

The room should be at grade or basement level for stability, preferably the latter. The room should have minimum dimensions of 24 x 12 x 12 ft. The control room could be as small as 24 x 8 x 12 ft. Since there are several critical dimensions in mechanical assemblies the room must have a temperature that is constant within 2°C. Controlled humidity is desirable although not essential. The room must have provisions for 220 and 115 VAC power, water for cooling and a drain. Ordinary room lighting is required. The room must be light tight.

The remaining area of camera light sensitivity is such that relatively elaborate interlocking of the room door, room lighting, and camera control system is necessary. This interlocking is such that the camera beam current will be completely blanked for excessive ambient light levels as noted by a photomultiplier sensor located near the camera. The door and room lights interlock circuits are also to be connected to the beam blanking circuits so that opening the door will blank the beam. Turning on the room lights will also blank the beam. The lights and door are further interconnected so that opening the door is required before the room lights may be turned on. There is a defeat mode which allows control of the X-ray source from the laminograph station with the lights off and the door closed, but this does not allow operation of the camera. The lights must be turned off and the door closed after the defeat mode is deactivated before X-ray control can be transferred to the control room and the camera turned on.

There is a possibility that a person could be inadvertently left in the laminograph room; we consider this a very small hazard since the lights must be off and an audible alarm would sound when the X-ray source is turned on. Turning on the lights, opening the door, or switching to the defeat mode would shut down the X-ray source.

Figure V-1 shows the room requirements and a suggested equipment layout.


SWITCH
DOOR INTERLOCK
INSIDE LIGHT PB "ON-OFF"
DOOR LOCK
METAL DOOR
OPERATOR'S ROOM
LIGHT SWITCH
CHAIR
CONSOLE
OPERATOR STATION
(UNIT 1)
CONTROL SIGNAL CONDUIT
X-RAY GENERATOR
(UNIT 2)
CAMERA CONDUIT
CONDUIT
LAMINOGRAPH ROOM STATION
(UNIT 3)
LAMINOGRAPH MACHINE
(UNIT 4)
LAMINOGRAPH ROOM
6.8'
12'

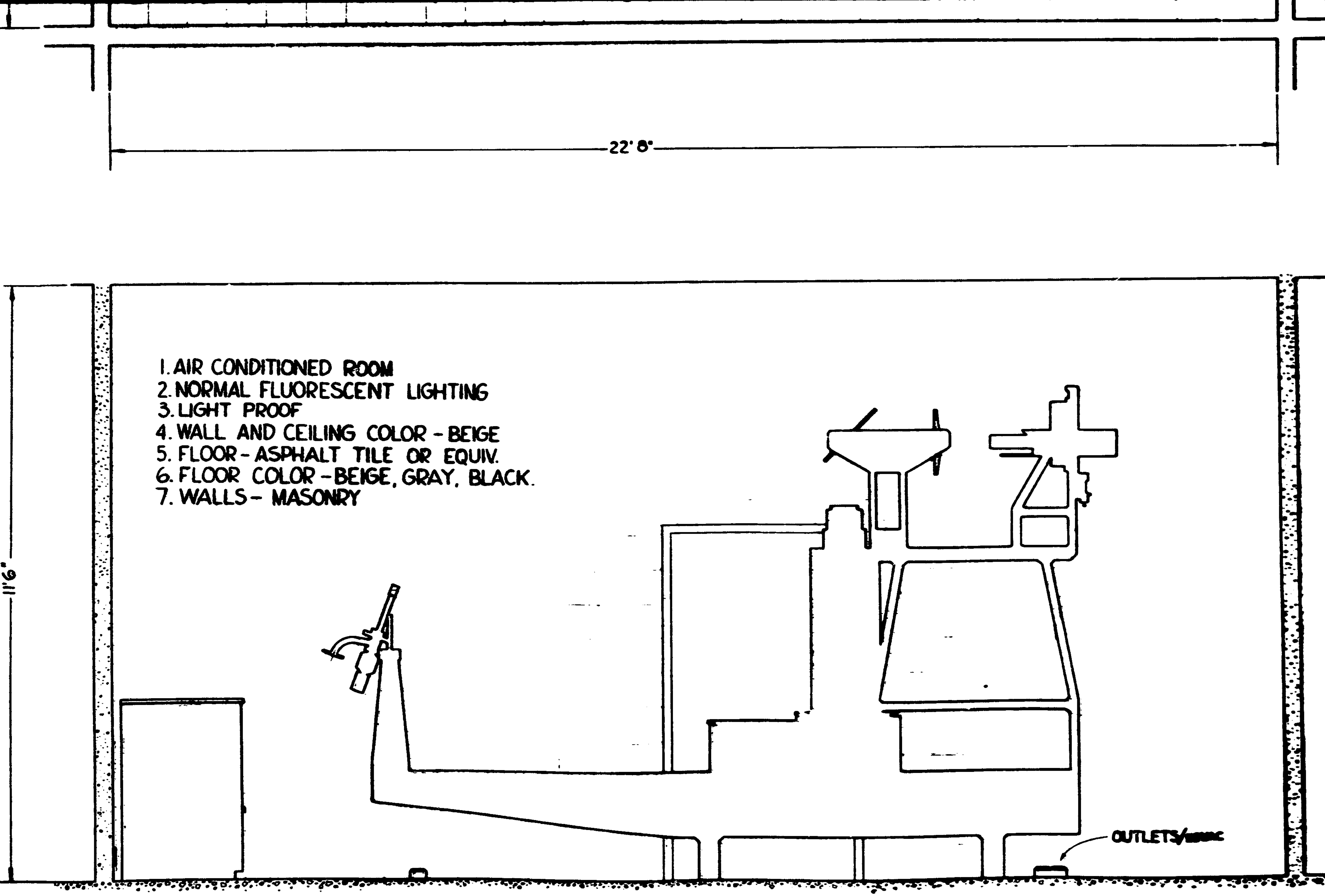


Figure V-1 ROOM REQUIREMENTS AND SUGGESTED EQUIPMENT LAYOUT

VI. OPERATIONAL REQUIREMENTS

The general operating requirements of the laminograph have been discussed in the preceeding sections; however, no unified discussion of the operating procedure which would be required for routine operation has been presented so far. It is the purpose of this section to make such a presentation.

The elements of the laminograph which require specific consideration during any operation are the following:

1. X-ray source vacuum system
2. X-ray source controls
3. TV camera and monitor
4. Rotation mechanism
5. Scanning mechanism
6. Automatic scan controls

The subsystems would be considered in the order shown during actual operation and the following is, in some sense, a paraphrase of how the operation would be carried out.

Prior to any other steps in the operation, the vacuum system must be checked and the system pressure reduced to 10^{-5} Torr. This is achieved by turning on the roughing pump and allowing it to operate for 10 to 15 minutes. This pump will become very quiet in operation when a pressure of 10^{-3} Torr is reached. If the vacuum gage is one with the system at high pressure (greater than 10^{-3} Torr) it will be damaged or ruined. After the 10 minute period it may be operated briefly to observe the pressure. If the pressure is 10^{-3} Torr or less, the diffusion pump may then be turned on. It will require several hours for the system to pump down to a base vacuum of 10^{-5} Torr. In normal operation the roughing pump and diffusion pump will operate at all times and the above procedure will not be required except in the event of unscheduled or planned shutdown.

When the X-ray source is at operating pressure the X-ray source may then be operated. The Jarrell-Ash manual for this instrument should be used, but briefly, operation is as follows: turn on the filament and increase its current to about 2 amp, energize the high voltage and increase it to about 20 KV (the current control should be a minimum), increase the current to 4 ma; if the current will not increase to this value the filament current should be increased until a current of 4 ma is reached. With the current reduced to 1 ma the voltage is increased to 55 KV and the current increased to 4 ma. The fluorescent screen should now be fluorescing brightly. The current is reduced to 0 and a test sample placed on the sample holder.

The room is now closed and the TV camera may be operated. The lens system is placed in the 1X position, and the camera turned on. The X-ray source current is increased to 4 ma. An image of the sample should now be visible on both monitor screens. The camera and monitors can be adjusted for optimum results. The lens system is changed to the 4X position and the TV camera readjusted for best results. The mechanical drive can be activated and an image should still be visible, although not necessarily very good since the Z-axis position may be incorrect. The scan control for the Z-axis (X-ray source) is activated and the optimum Z-position is located. The manual X-Y scan controls are operated and the test sample scanned. The automatic scan is set up for the test sample and a test scan made. The size of the board must be known and it must be positioned approximately correctly on the sample holder for correct scanning. The scan limits and zero position for X, Y, and Z may be set into the controls via the six thumbwheel switches. The setup pushbutton is depressed and causes the scan circuits to seek the X_o, Y_o, and Z_o position. Automatic scanning can now commence. Some dwell time should be selected as well as the magnification. Scanning is stopped during a change in magnification.

The scan-start pushbutton is depressed to begin the scan. Normally the scan pattern will be ZXY; however, XYZ is available. During automatic scan, the scan may be manually overridden and advanced or reversed at will in any direction any time during the scan.

If after the setup and complete test procedure has been carried out and no difficulties have been encountered, routine inspection of boards may commence. The X-ray source must be turned off before a new board may be placed in the sample holder. This is a disadvantage, but since most boards will require an hour or more for inspection, it is not serious.

VII. SUMMARY

This report has described a continuous scanning laminograph for the inspection of multilayer printed wiring boards. The device uses a 50-KV X-ray tube having a source size 0.1 mm x 0.1 mm. The imaging system consists of a high resolution, high brightness fluorescent screen and a high sensitivity image orthicon.

Since by nature the laminograph technique requires precision motion between the sample and imaging system, a highly precise mechanical system was designed. This system holds system composite errors to less than 0.002 in.

A complex optical system was designed to meet the requirements of image viewing of a magnified and derotated image. This optical system produces a stationary image of the view formed on the fluorescent screen. It has three magnifications of 0.2X, 1X, and 4X, the latter of which allows high resolution (~ 0.001 in.) viewing of the sample to be achieved using the television system.

The required time integration which produces the laminographic effect is achieved by integrating the light at the photocathode of the image orthicon. A logic and control system has been incorporated which will automatically scan a given sample throughout its three dimensional structure. Variable limits can be placed on the extent of the scan and the dwell time can be varied from about 1 sec to 30 sec. This scan can be overridden at will by the operator-inspector who may elect to carry out a manual scan if desired. Boards as large as 12 in. by 12 in. up to 0.5-in. thick may be scanned completely. Larger boards can be accommodated but cannot be scanned in a single operation.

The total system has been engineered to be as safe and foolproof as possible. Elaborate interlocking of the X-ray source, television camera and room lights and door, have been provided to prevent exposure of personnel or damage to the image orthicon.

VIII. APPENDICES

A. Analyses of Mechanical Systems

1. Introduction

The purpose of this study is the investigation of vibrations that may adversely affect the operation of the laminograph.

The laminograph is a precision instrument and all critical parts have been designed to extremely close tolerances using high quality materials and components. The design of the supporting members has been based upon rigidity requirements rather than strength. This rigidity requirement is necessary to maintain desired clearances and to minimize deflection. It should be pointed out that static deflections will not affect the instrument performance since all alignment will be done with respect to the statical positions. However deviations from these positions must be maintained within certain specified limits. The allowable displacement deviations for several critical points are shown on Figure VIII-A-1. These allowables are based upon a 1 mil resolution.

2. Vibration Sources

In order for components and subassemblies to vibrate at all, it is necessary that they be excited. Hence a discussion of possible source of vibration is in order. Four such sources are discussed.

a. Ground or Floor Motion

Perhaps the most important source of motion that could affect the performance of the laminograph is floor motion. The precise location of the laminograph installation is not

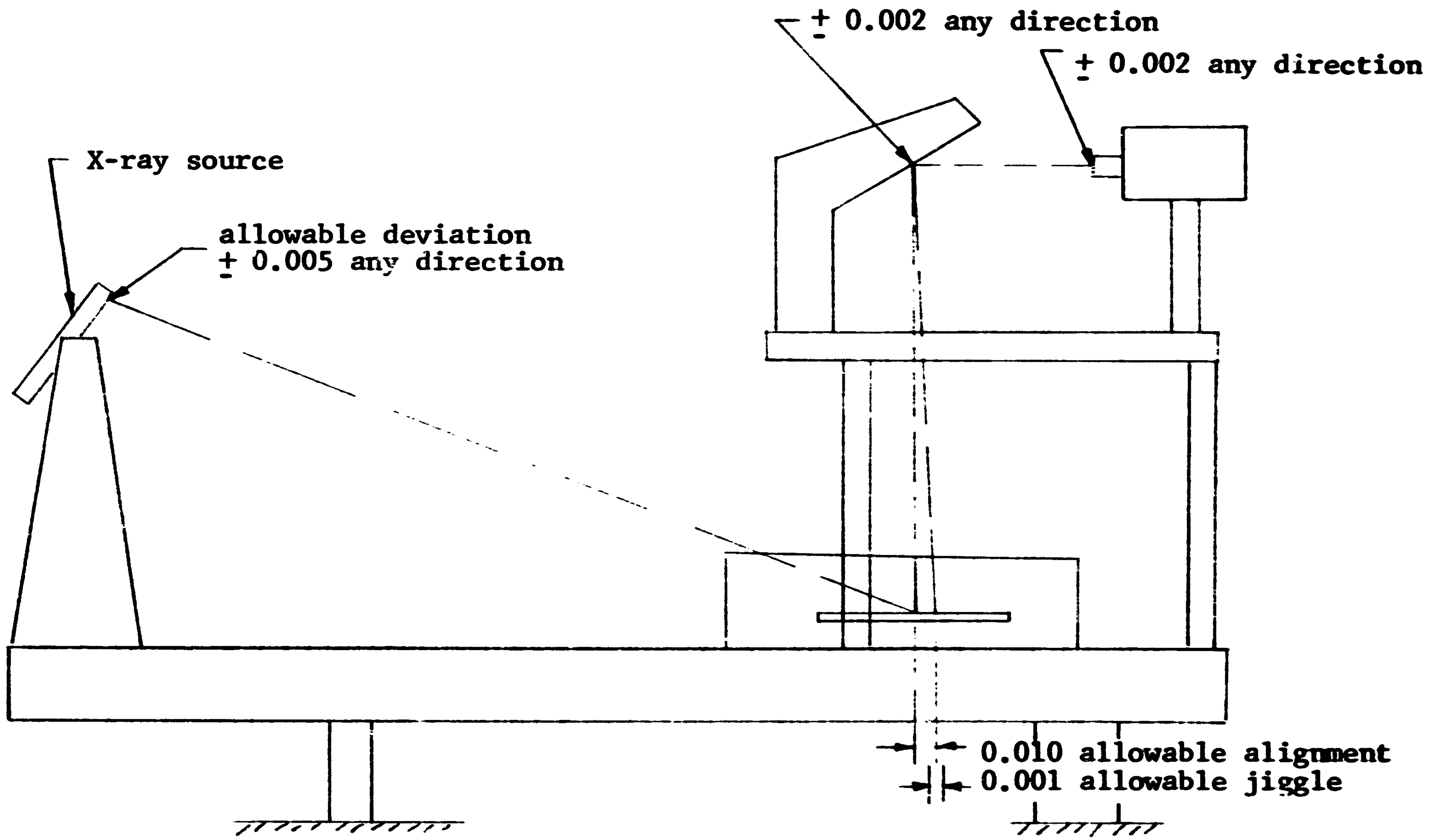


Figure VIII-A-1 ALLOWABLE DISPLACEMENTS

known and hence it is not possible to determine the floor motion. An estimate of the severity of ground shock however, can be made. For instance,* seismic measurements of vertical accelerations and frequencies at a point 50 ft. from a railroad, during the passing of a diesel powered unit, exhibit peak g-levels of approximately 0.04 g's at frequencies of 0 to 20 cps. A vertical displacement amplitude can be estimated by assuming a sinusoidal wave form, i.e.,

$$y = y_o \sin wt$$

$$\ddot{y} = y_o w^2 \sin wt$$

and

$$y_o = \frac{\ddot{y}}{w^2} = \frac{0.002(386)}{[2\pi(10)]^2} \cong 0.0002 \text{ in.}$$

Floor displacement amplitudes can also be estimated from Figure VIII-A-2.

b. Gears and Bearings

Precision spur gears will be operating during viewing. Studies of spur gears indicate that the predominate excitation is the result of gear tooth contact. Consequently the principal excitation frequency is the tooth frequency. This frequency is given by the product of the rotational frequency and the number of gear teeth, i.e.,

$$f_T = \frac{rpm}{60} N$$

*Shock & Vibration Handbook, C. M. Harris & C. E. Crede, Vol. 3.

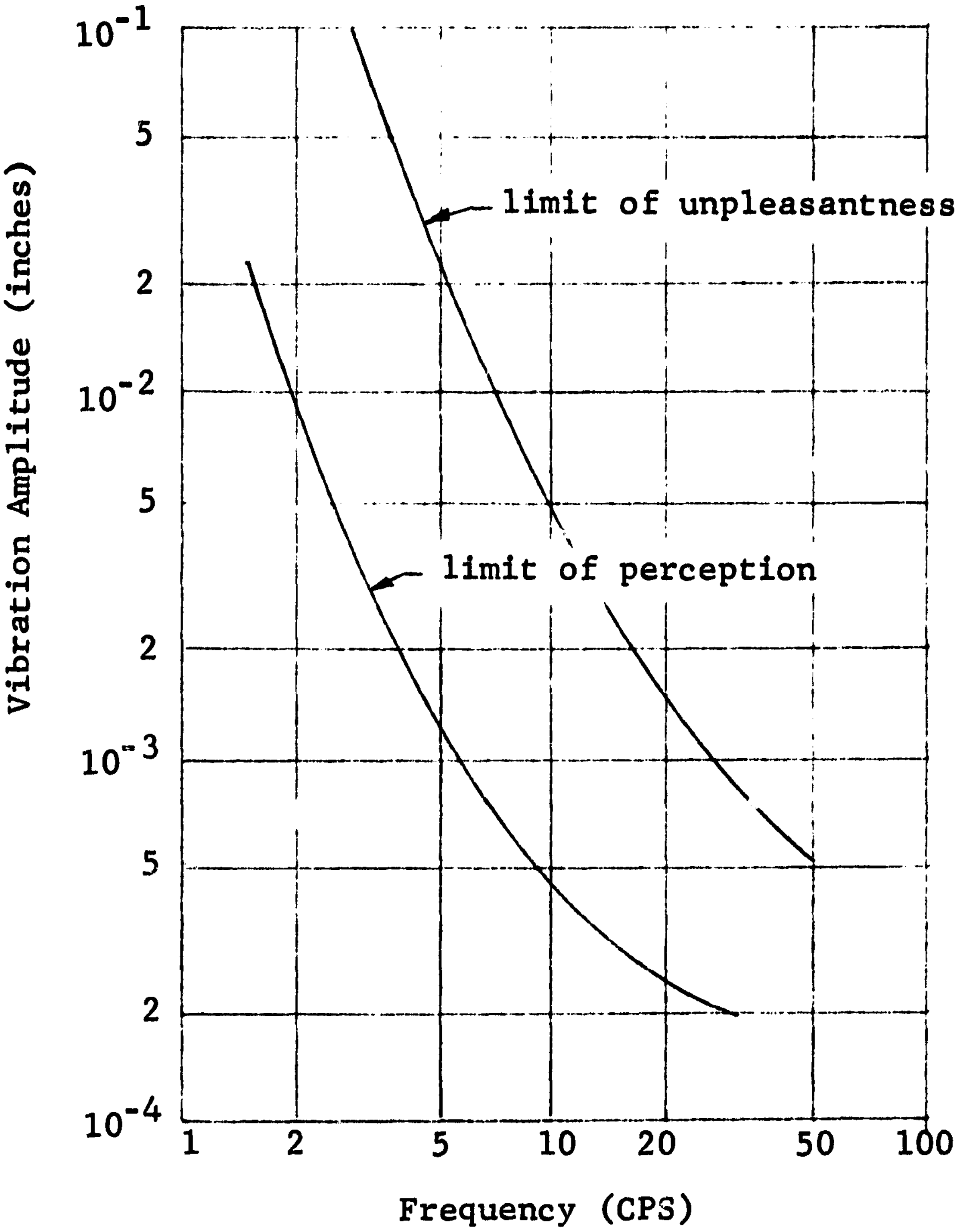


Figure VIII-A-2 HUMAN RESPONSE TO FLOOR VIBRATION

Hence, the gears on the laminograph would likely produce excitation frequencies as shown in the table below.

LAMINOGRAPH GEARS (4)

RPM	No. of Teeth	Tooth Frequency*
60	870	870 cps
30	870	435 cps
120	200	400 cps
120	400	800 cps

*Note all gears are 32 pitch.

Bearing frequencies are usually random and need not be considered.

c. Main Drive Motor

The main drive motor is a 1/3 hp d.c. motor operating at 1200 rpm. This motor is bolted directly to the frame. The principal excitation frequency of this motor would occur at the running speed and is 20 cps. Unbalance of the rotating parts could cause a shaking force. The magnitude of this force can be estimated from motor torque considerations. Hence:

Torque fluctuations, 17.5 in.-lb starting torque, 10 percent torque variation $\pm$ 2 in.-lb, 6 in. centers, 1/3 lb gives $\pm$ 5 oz. shaking force.

d. Rotating Parts Unbalance

The largest rotating part is the drum assembly. Unbalance of this assembly will cause an excitation force.

The magnitude of this force is calculated assuming two kinds of unbalance. The first is due to improper alignment of the rotational centerline, i.e.,

$$F_1 = \frac{m}{2} (r - \Delta r) w^2$$

$$F_2 = \frac{m}{2} (r + \Delta r) w^2$$

where m is the mass of the drum, r is the radius of the drum, Δr the displacement of the center, and w is the rotational frequency. The unbalance force ΔF is:

$$\Delta F = F_2 - F_1$$

$$\Delta F = \frac{m}{2} w^2 [(r + \Delta r) - (r - \Delta r)]$$

$$\Delta F = \frac{m}{2} w^2 [2\Delta r]$$

$$\Delta F = m\Delta r\ w^2$$

The total weight of the assembly is 352 lb. The allowable displacement of the centerline is 0.010 in. The rotational speed is 30 rpm, hence:

$$m = \frac{W}{g} = \frac{352}{386} = 0.912$$

$$\Delta r = 0.010 \text{ in.}$$

$$w = \frac{2\pi}{60} (30 \text{ rpm}) = \text{-rad/sec}$$

$$\Delta F = 0.912\ (0.010)\ (\pi)^2 = 0.090 \text{ lb} \cong 2 \text{ oz.}$$

The second way that unbalance may occur is for the tube assembly to be asymmetrical (see Figure VIII-A-3). The unbalance weight in the tube is approximately:

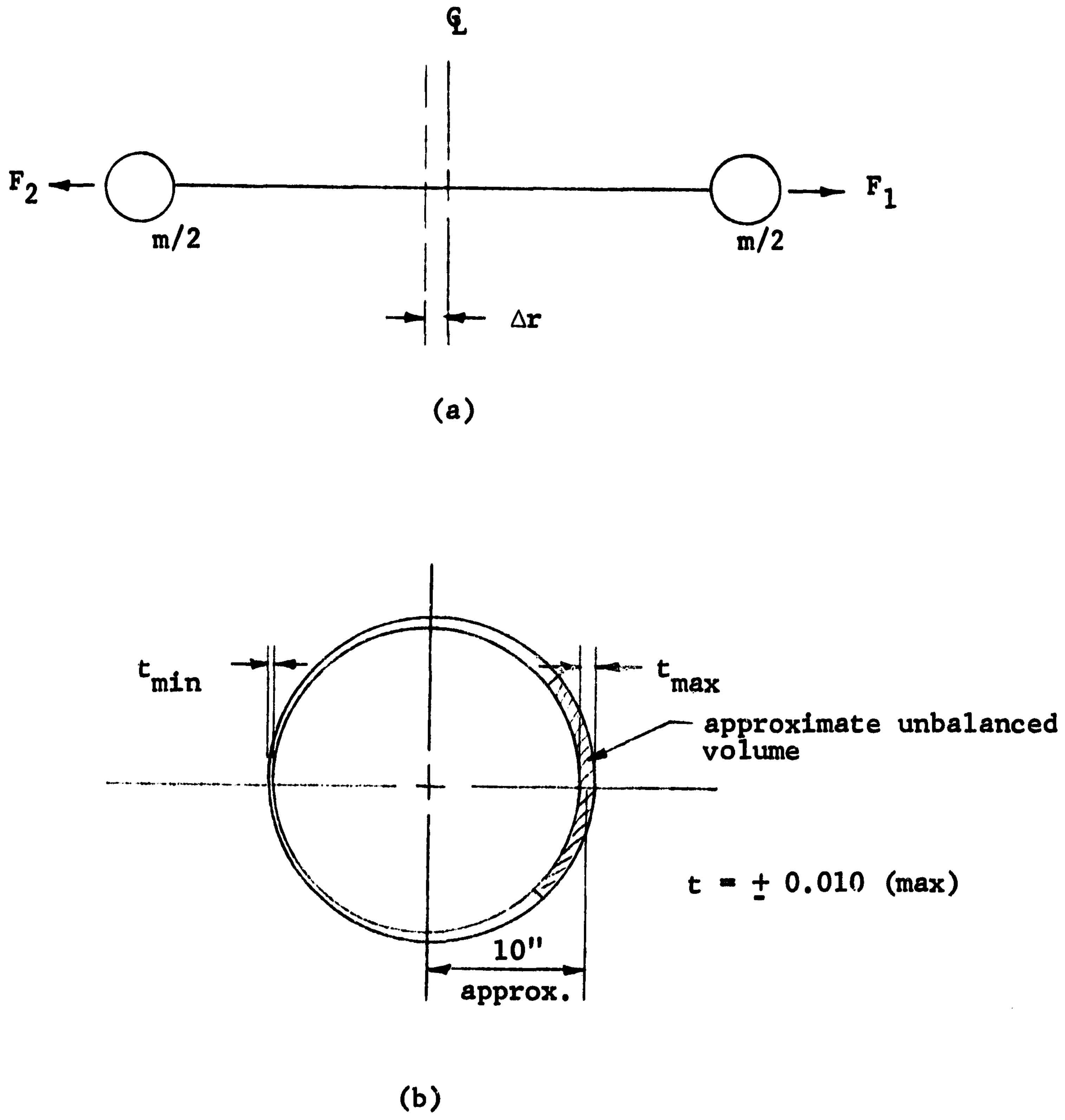


Figure VIII-A-3 DRUM UNBALANCE

$$w = 1/4\ (t_{max} - t_{min})\ \pi d\ell p$$

$$w = 1/4\ (0.020)\ (\pi)\ (20)\ (31)\ (1/10)$$

$$w = 0.973 \text{ lb.}$$

$$\Delta F = mrw^2$$

$$= \frac{0.973}{386}\ (10)\ (\pi)^2 = 0.248 \text{ lb} \cong 4 \text{ oz.}$$

3. <u>Vibration Effects on the TV Camera</u>

The possibility exists that horizontal ground motion will affect the TV camera. If the camera is assumed to be supported as a simple column (see Figure VIII-A-4), the critical stiffness of the column can be computed. For a stiffness greater than this value no motion amplification would be expected.

$$z = \frac{mw^2 x_o}{(k_{eq} - mw^2)}$$

$$k_{eq} = \frac{F}{\sigma} = \frac{3EI}{\ell^3}$$

$$z = \frac{mw^2}{\frac{3EI}{\ell^3} \cdot mw^2}\ x_o$$

Since $z = x_o$ for no amplification of base motion, then

$$\frac{mw^2}{\frac{3EI}{\ell^3} - mw^2} \leq 1.0$$

$$\frac{1}{\frac{3EI}{mw^2 \ell^3} - 1} \leq 1.0$$

$$\frac{3EI}{mw^2 \ell^3} > 2.0$$

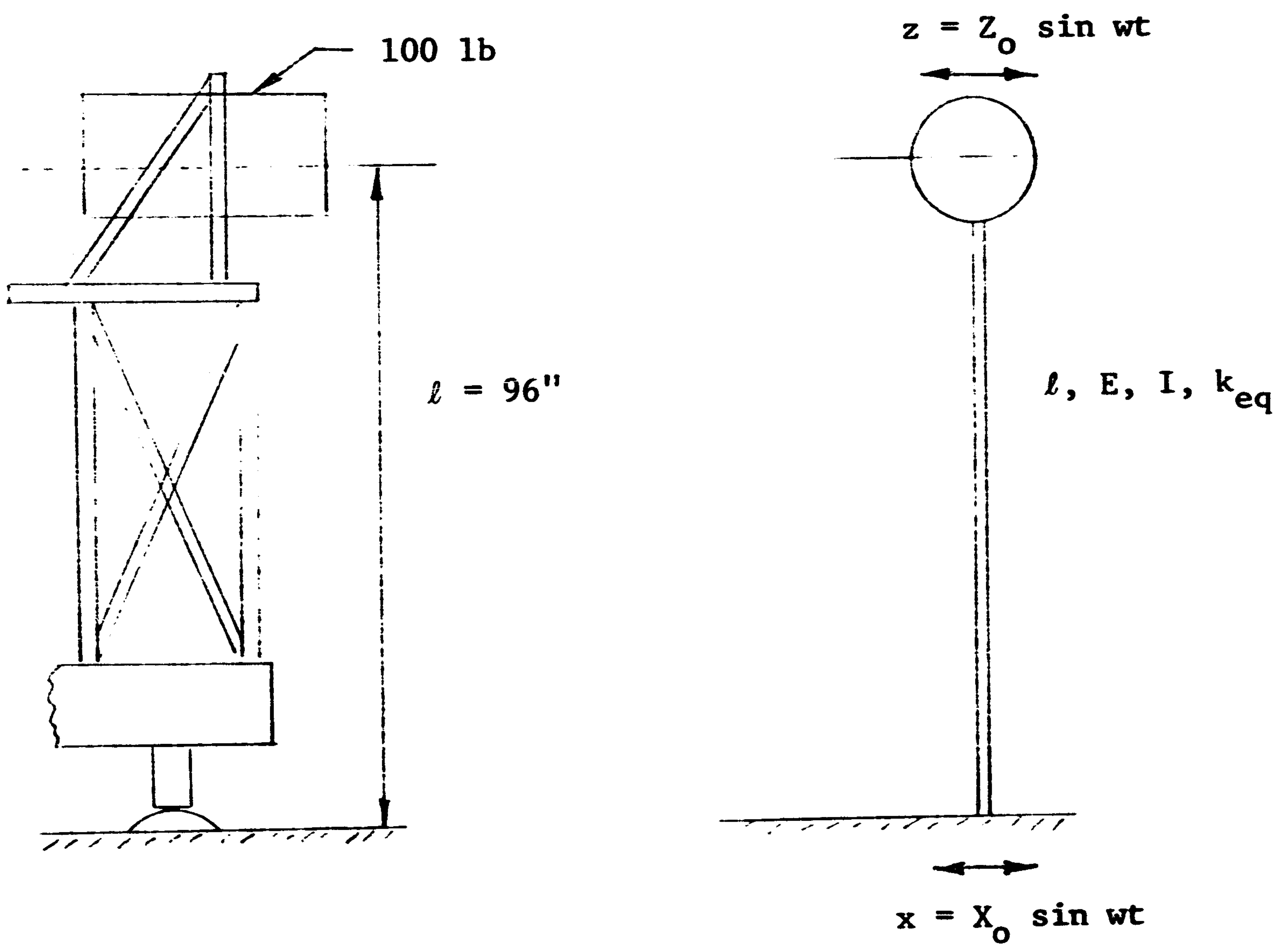


Figure VIII-A-4 CAMERA VIBRATION MODEL

Hence,

$$I > \frac{2}{3} \frac{m\ell^3}{E} w^2$$

$$I > \frac{2\ (100)\ \ \ \ \ (96)^3}{3\ (386)\ (12 \times 10^6)} w^2$$

$$I > 0.019\ w^2$$

Let w = 10 cps, then

$$I > 1.9\ in^4 \text{ (approx. 3 in. I-beam)}$$

The 2 in. x 2 in. aluminum tubes used in the upper frame structure are much stiffer than this, hence no amplification of base motion should occur.

4. Isolation of Vibration Sources

a. Ground and Floor Motion

Ground is a good absorber of high frequency vibration.
0 - 35 cps frequencies transmitted.
Isolated floor at IITRI lab approximately 7 - 8 cps.
Rubber pads under the feet of the machine would in all probability increase the motion amplitude.(Hard mount recommended.)

b. Gears and Bearings

Isolation not possible. Should present no problems.

c. Main Drive Motor

Quality motor (balanced armature).
Hard mount (provision for future soft mount).

d. Rotating Parts Unbalance

Recommend dynamic balancing of all critical rotating parts and assemblies.

B. Analysis of the X-Ray Source-Fluorescent Screen-Closed Circuit Television System

1. Introduction

This supplemental report presents results on the sensitivity characteristics of the laminograph design. It relates all major parameters to light output from the screen as a function of X-ray energy and beam current and to resolution of the television camera as a function of available light level. Since the actual operating conditions cannot be simulated precisely at this time, some extrapolations have been required. These extrapolations are generally in accord with previous experience and are considered to be conservative.

2. Image Orthicon Sensitivity

The resolution of the camera is related to available light and line scan as well as image contrast. The present system uses a 945 line scan system. The other factors have been measured by Maryland Telecommunications for IITRI. The results have been carefully evaluated and are presented here.

The resolution sensitivity of this camera has been measured for illumination with light having a color temperature of 2870°K. The intensity of this light was measured using a standard photometer; however, the S-20 photocathode has a response much different from the photometer (eye) response and the 2870° blackbody source has a large output at long wavelengths where the photometer does not measure. If all the light appeared in the visible region, the tube would appear to have greatly decreased sensitivity, but in reality, its sensitivity would be increased. Sensitivity figures have little meaning except for comparative purposes when all conditions are identical; however, meaningful results can be obtained if the data is treated properly.

For the 7689 image orthicon the absolute sensitivity to 2870°K blackbody radiation can be obtained by multiplying the rated sensitivity by the factor:

$$\int_{3000}^{8000} I_{2870}(\lambda) \qquad \int_{3000}^{8000} I_{2870}(\lambda) \cdot S_p(\lambda) d\lambda \qquad (1)$$

where $I_{2870}(\lambda)$ is the relative intensity of the 2870°K light source and S_p is the relative sensitivity of the photometer. Figure VIII-B-1 shows the $I_{2870}(\lambda)$, $S_p(\lambda)$, and the transmittance T_{W47} of a Wratten 47 filter. Figure VIII-B-2 shows the product of $I_{2870}(\lambda) \cdot S_p(\lambda)$ as well as some other relevant products. The limits of integration were chosen to correspond to the response limits of the S-20 photocathode. For these conditions the ratio of Eq. 1 is 4.39.

It was desired to measure the sensitivity of this image orthicon to light which simulated the light being emitted by the $CaWO_4$ phosphor. To achieve this end, a Wratten No. 47 filter was used in conjunction with a 2870°K blackbody source whose intensity had been measured with a photometer. Since all the light from this filtered source has a wavelength within the sensitive region of the photocathode, the measurement of sensitivity is somewhat less ambiguous. The intensity of the apparent source (I_{W47}) is related to the intensity of the 2870°K blackbody source, the photometer response, and the filter response by the following:

$$\int_{3000}^{8000} I_{W47} = O_{2870} \cdot \int_{3000A}^{8000A} I_{2870}(\lambda)\, T_{W47}(\lambda), \qquad (2)$$

where $T_{W47}(\lambda)$ is the fractional transmittance of the Wratten filter and O_{2870} is the total output of the 2870°K source within the 3000A to 8000A band. This output is obtained by

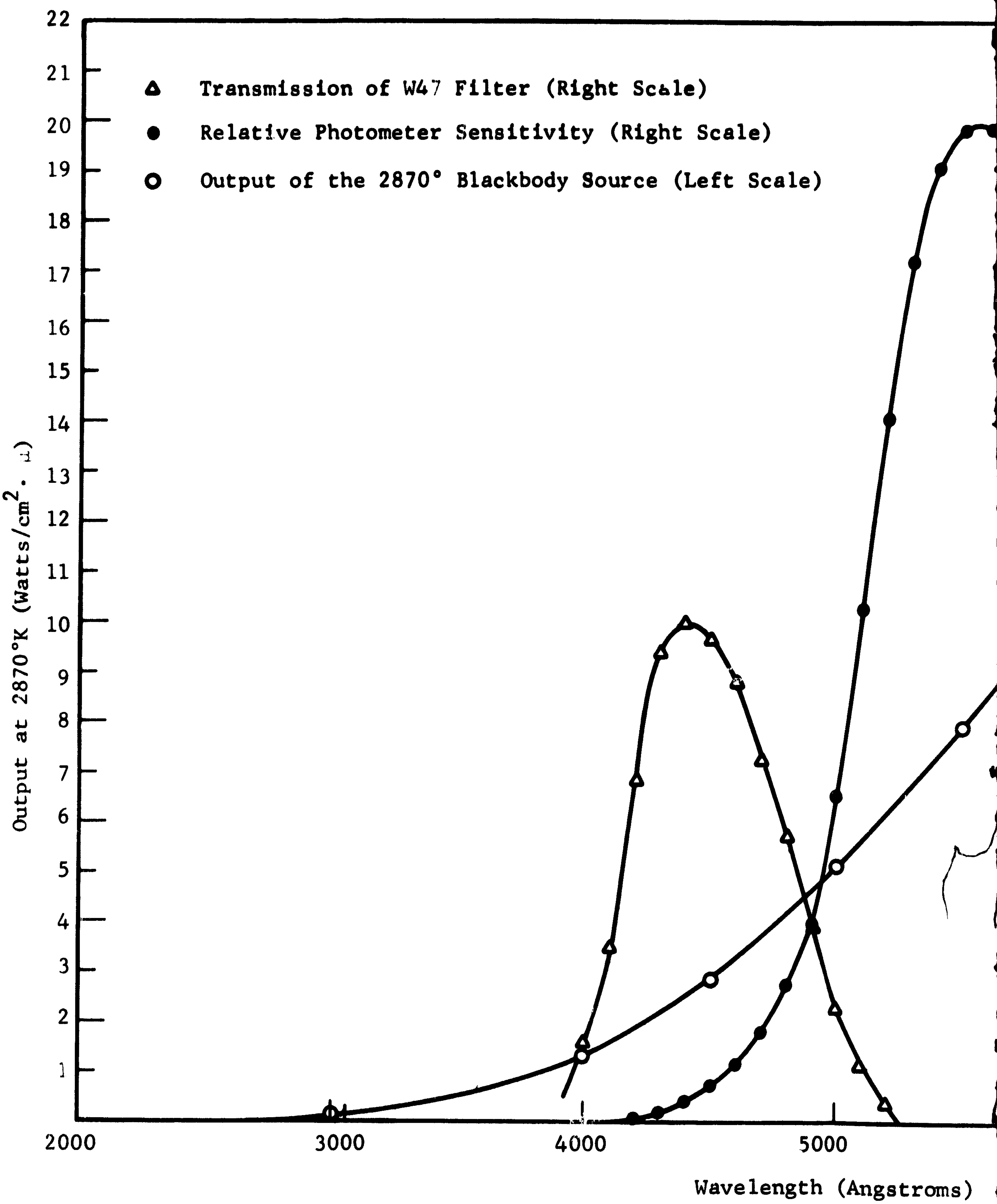
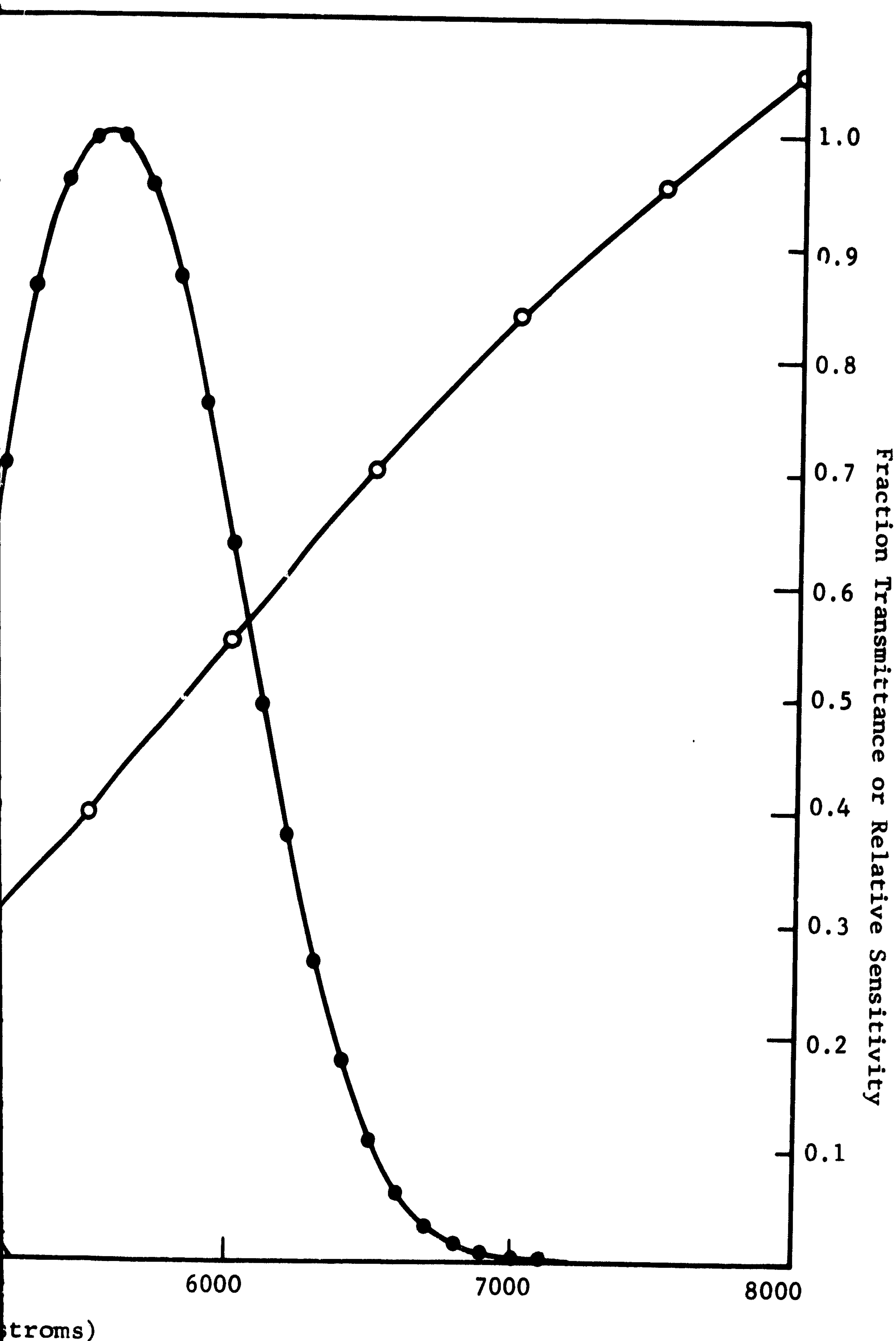


Figure VIII-B-1 OUTPUT OF THE 2870°K BLACKBODY SOURCE, TR
AND RELATIVE RESPONSE OF THE VISUAL PHOTO



URCE, TRANSMITTANCE OF THE W47 FILTER,
AL PHOTOMETER

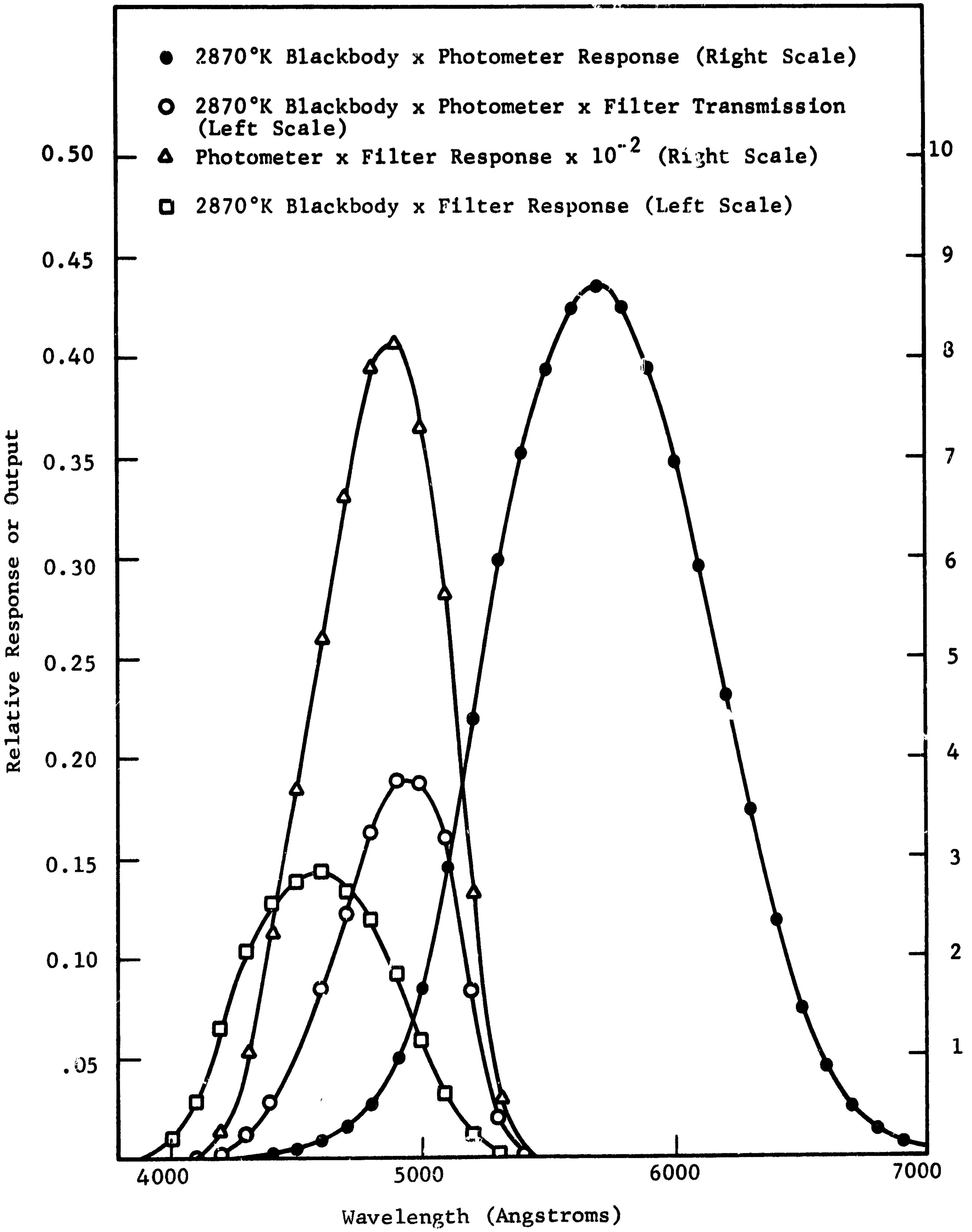


Figure VIII-B-2 RELATIVE RESPONSE OR OUTPUT FOR VARIOUS COMBINATIONS OF SOURCE, PHOTOMETER, AND FILTER multiplying the photometer measured output O_p by the ratio of equation (1). The above ratio is 0.117 so that the filtered source has an output of 0.117 of the output of the 2870°K source as measured by a photometer. Figure VIII-B-3 shows the resolution sensitivity of the image orthicon to this light. The image orthicon was operating as it would in the completed instrument except that integration time was 1/30 sec rather than 1 sec.

Since the sensitivity and resolution is also affected by image contrast, an additional set of measurements were made using a test pattern having a contrast of 60 percent (this figure corresponds closely to the contrast expected through the optical system at maximum resolution). This curve is also shown in Figure VIII-B-3. A curve for 60 percent contrast and 1 sec integration time has been included. This curve was interpolated from published data and these measurements. From this latter curve, a value of about 2×10^{-5} ℓ/ft^2 for the sensitivity of the camera under typical conditions is found.

3. Fluorescent Screen Light Output

The light output of a fluorescent screen is a function of the X-ray intensity as well as its quality (average energy). The type of screen most suitable for this application is composed of calcium tungstate. This material has a high efficiency in the 50 to 150 kV region.

Measurements of the light output of several screens, including the Radelin PF, TF-2, UD, and TL-2, have been made. Of these, the PF and TL-2 were most nearly suitable for this application. The spectral response of these two phosphors is shown in Figure VIII-B-4.

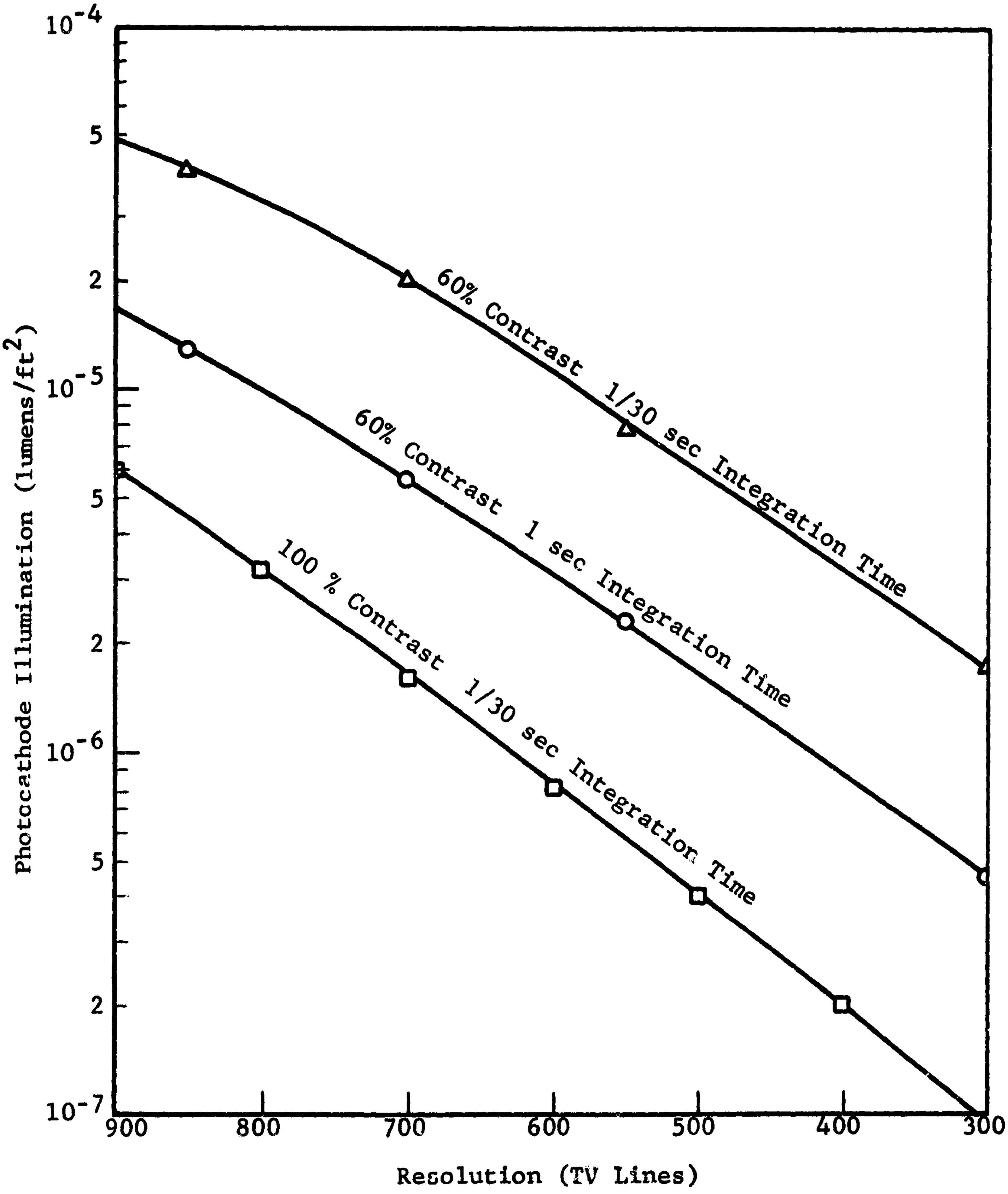


Figure VIII-B-3 RESOLUTION SENSITIVITY OF THE IMAGE ORTHICON FOR 1/30 SEC AND 1 SEC INTEGRATION TIME AND 100% AND 60% CONTRAST

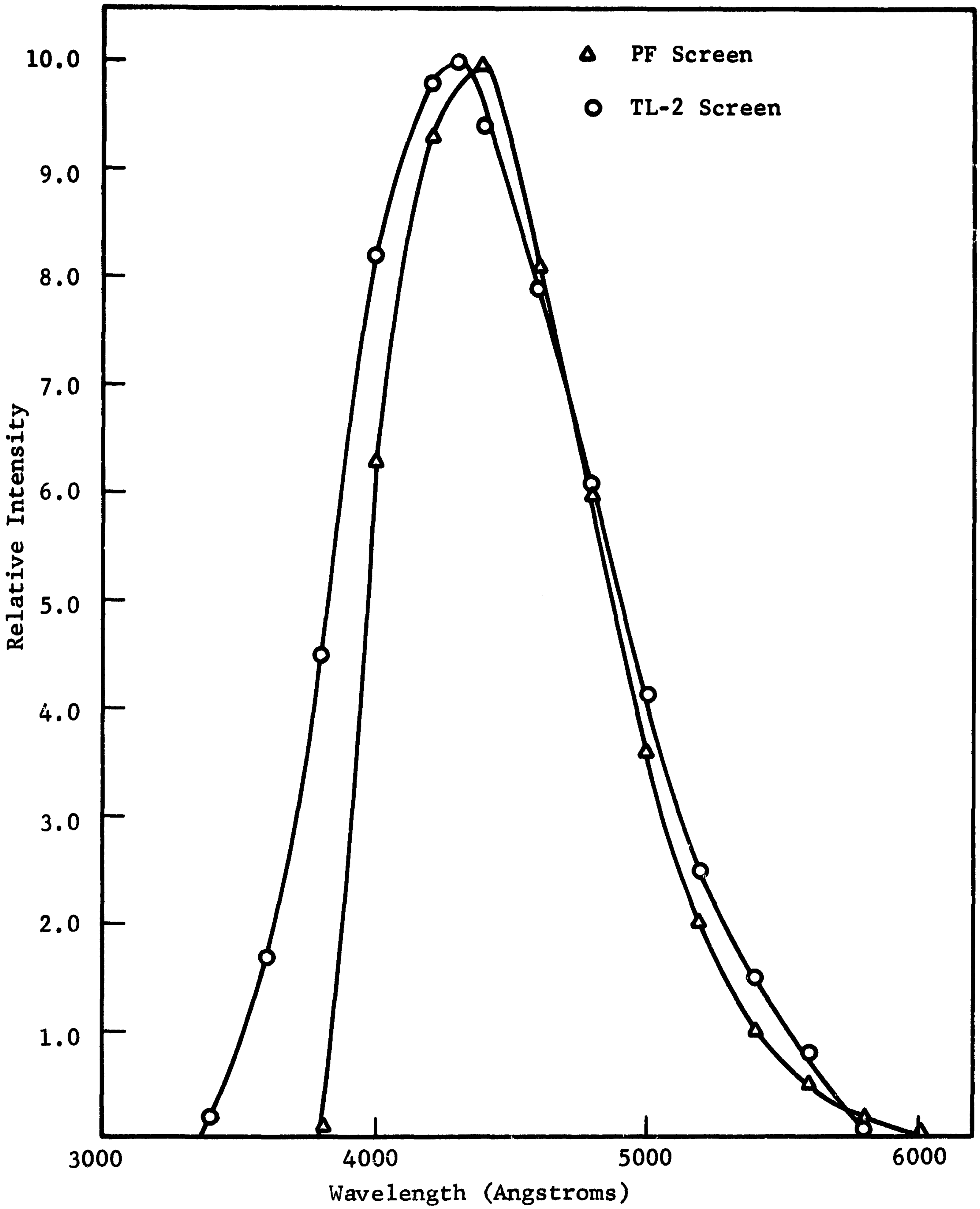


Figure VIII-B-4 SPECTRAL RESPONSE OF THE PF AND TL-2 FLUORESCENT SCREENS

As noted for the section on the resolution sensitivity of the image orthicon, it is not a straightforward problem to measure the absolute intensity of a source which has its major output outside the visible region, since most photometric devices are tailored to have an eye response and measure only the effective visible intensity. To make measurements of the output of the fluorescent screen which would be meaningful in terms of the measured sensitivity of the image orthicon, a somewhat circuitous route must be followed.

A tungsten filament light source was used as a standard. This source had a color temperature of 2540°C which, while somewhat lower than the 2870°K source used to measure the sensitivity of the camera, is not sufficiently different to cause any error if the spectrum is well known, which it is. A standard photometer was used to measure the output of this source. This measurement indicated a source strength of 97 candles. A W47 filter was placed over this source and the intensity remeasured using the same photometer, giving a value of 0.6 candles. It is desired to know the effective source strength of the W47-filtered source. Using the first measure, the output (O_{W47} - 2540°K),

$$O_{W47} - 2540°K = O_p \frac{\int T_{W47}(\lambda) \cdot I_s(\lambda) d\lambda}{\int S_p(\lambda) \cdot I_s(\lambda) d\lambda} . \qquad (3)$$

This result is 8.5 candles.

As a check, the second measurement can be converted to output as follows:

$$O_{W47} - 2540°K = O_{W47-p} \cdot \frac{\int T_{W47}(\lambda)\, I_s(\lambda) d\lambda}{\int I_s(\lambda)\, T_{W47}(\lambda)\, S_p(\lambda) d\lambda} . \qquad (4)$$

The result is 5.2 candles. This result is subject to serious error on two counts. First, the measurement made with the photometer was at very low level, nearly at the limit of sensitivity of the instrument; and secondly, the result depends sensitively on the overlap of the transmission of the filter and the spectral response of the photometer. The relevant curves are shown in Figure VIII-B-1 and the overlap is shown in Figure VIII-B-2. Since the photometer response may not be accurate in the overlap region, a large error can occur. This cannot happen in the first measurement because the overlap functions which are required do not have strong dependence on the tails of the response functions. The result of 8.5 candles will be used in subsequent calculations. The second result is looked upon as corroborative evidence of the essential correction of the method, although the error in it may be large.

The filtered source was used to illuminate a white reflective surface whose absolute reflectance was measured. The reflectance is shown in Figure VIII-B-5 along with the output spectrum of the filtered source. Knowing the output of the filtered source and the reflectance of the surface, the absolute brightness of the surface was calculated and used to calibrate a photomultiplier having an S-4 response. This calibrated photomultiplier was used to view the fluorescent screen under duplicate conditions of angle and separation. Since the spectral output of the fluorescent screen is slightly different from that of the filtered source, the screens were viewed by the photomultiplier through a W47 filter to eliminate any effect on the measurements resulting from the spectral sensitivity of the photomultiplier.

The output of the screen is calculated as follows:

$$O_{f.s.} = O_{pm} \frac{\int I_{f.s.}(\lambda) d\lambda}{\int I_{f.s.}(\lambda)\, T_{W47}(\lambda)} , \qquad (5)$$

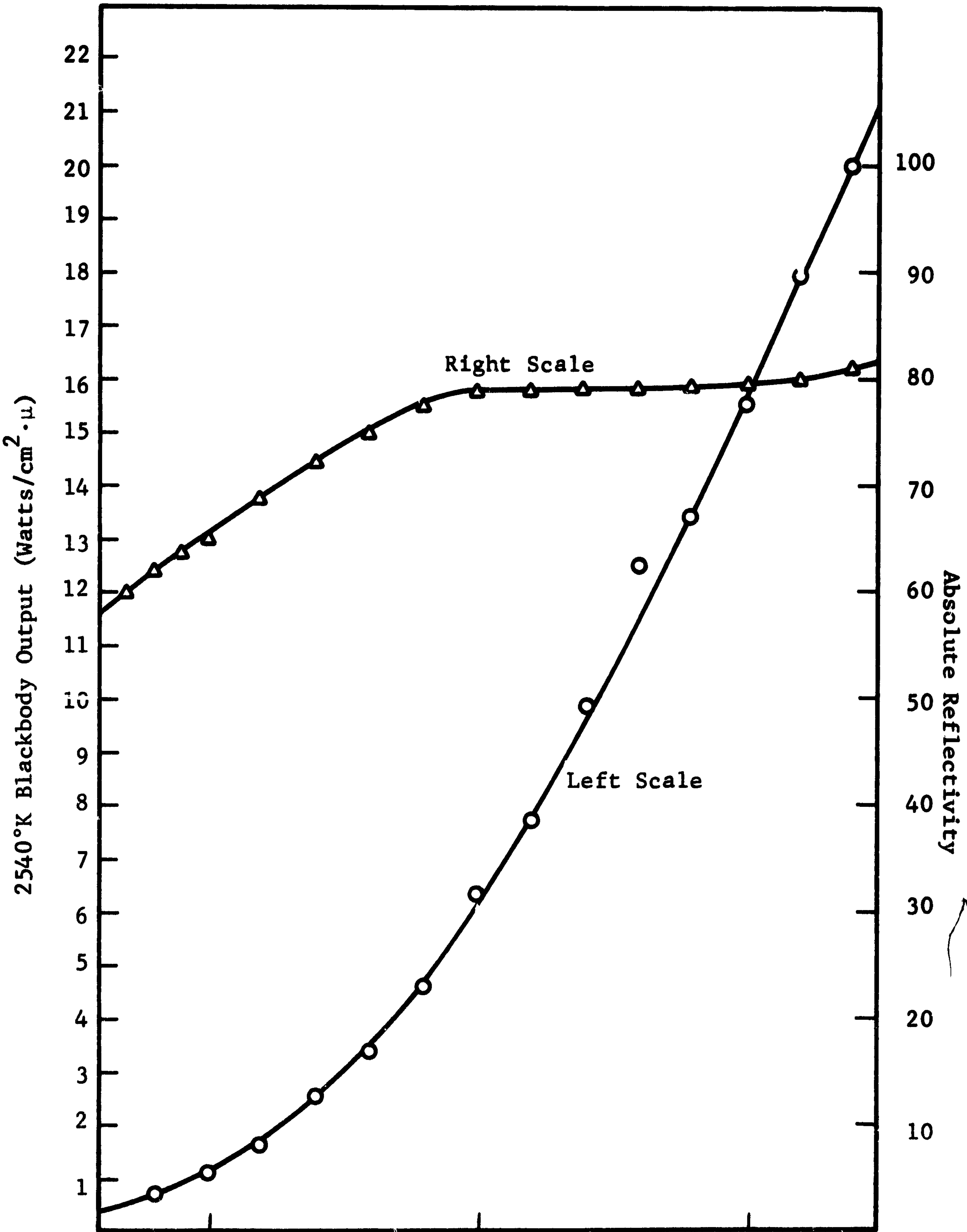


Figure VIII-B-5 OUTPUT OF THE 2540°K BLACKBODY CALIBRATION SOURCE AND ABSOLUTE REFLECTIVITY OF THE REFLECTOR where $O_{f.s.}$ is the output of the screen in lumens*, O_{pm} is the output measured by the photomultiplier and $I_{f.s.}(\lambda)$ is the output spectrum of the screen.

Figures VIII-B-6 and VIII-B-7 show the output of the PF and TL-2 fluorescent screens for various voltages and currents. The results were measured using a copper target in the X-ray machine and have been corrected for a tungsten target. This dependence is well established and little or no error is introduced in making this correction. The output of the PF screen at maximum voltage and current is 0.05 lumens/square foot for a 144 in. source to screen separation.

It should be noted that these light levels can be exceeded by a large margin if a different X-ray source were to be used. For example, use of the Norelco 150 kV machine would result in a light output increase factor of approximately 20.

Although the above figures represent the maximum available light, no account has been taken of the attenuation of the X-ray beam in the sample. For the 60 kV energy, the half thickness of copper is approximately 0.04 cm. The remaining material is negligible. The thickness of one layer of copper is about 0.0025 cm. The maximum continuous thickness of copper to be penetrated in a very thick (10 layer) board is about 0.025 cm. It is expected that the light output is unlikely to fall below 2.5×10^{-2} ℓ/ft^2.

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*The use of the term lumen should not be interpreted strictly since it is being used as an absolute intensity unit for a source which does not have a standard photometer spectrum. A better term might be "quasi-lumens." Better yet, all of these results could be converted to watts.

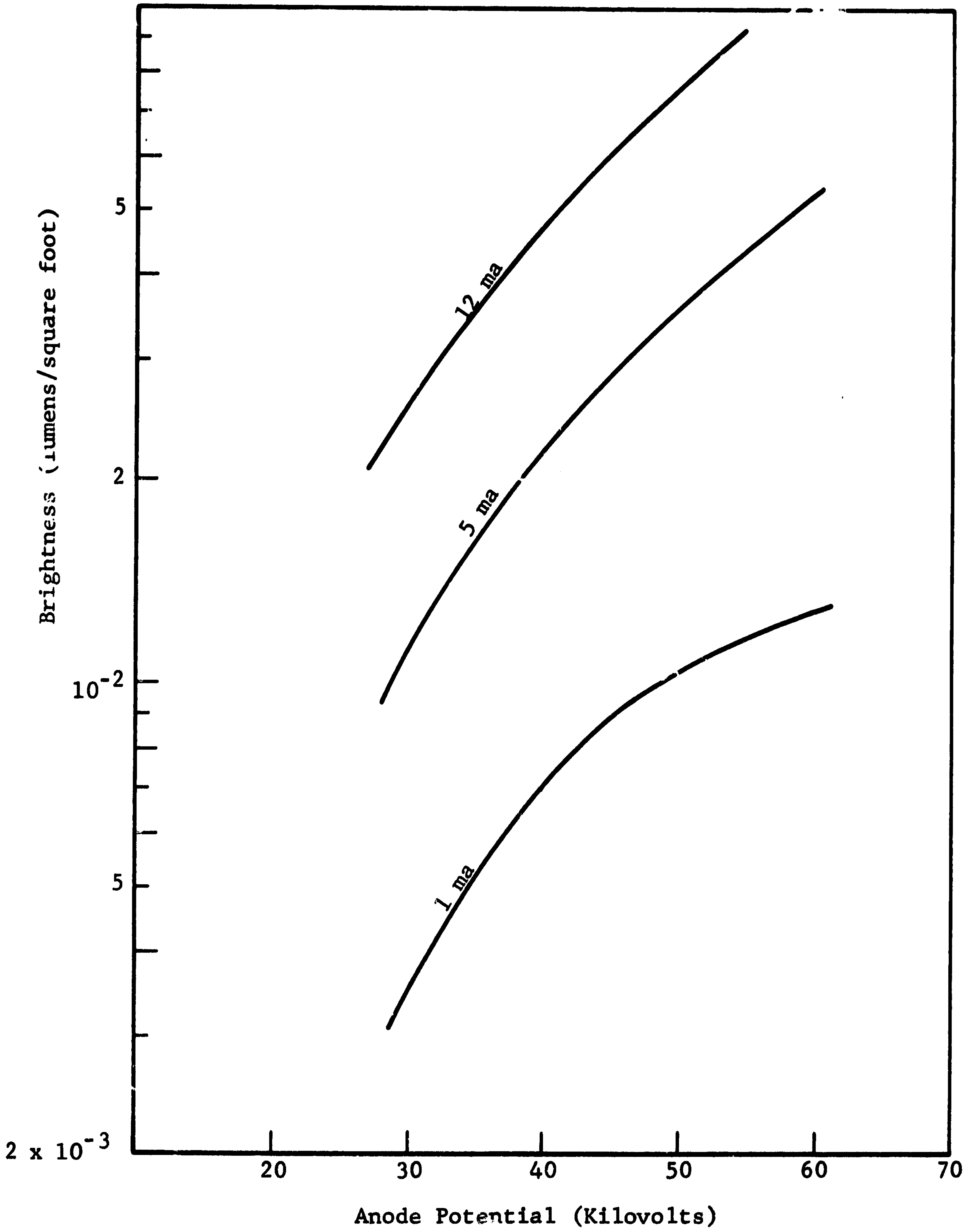

Figure VIII-B-6 BRIGHTNESS OF THE RADELIN PF FLUORESCENT SCREEN

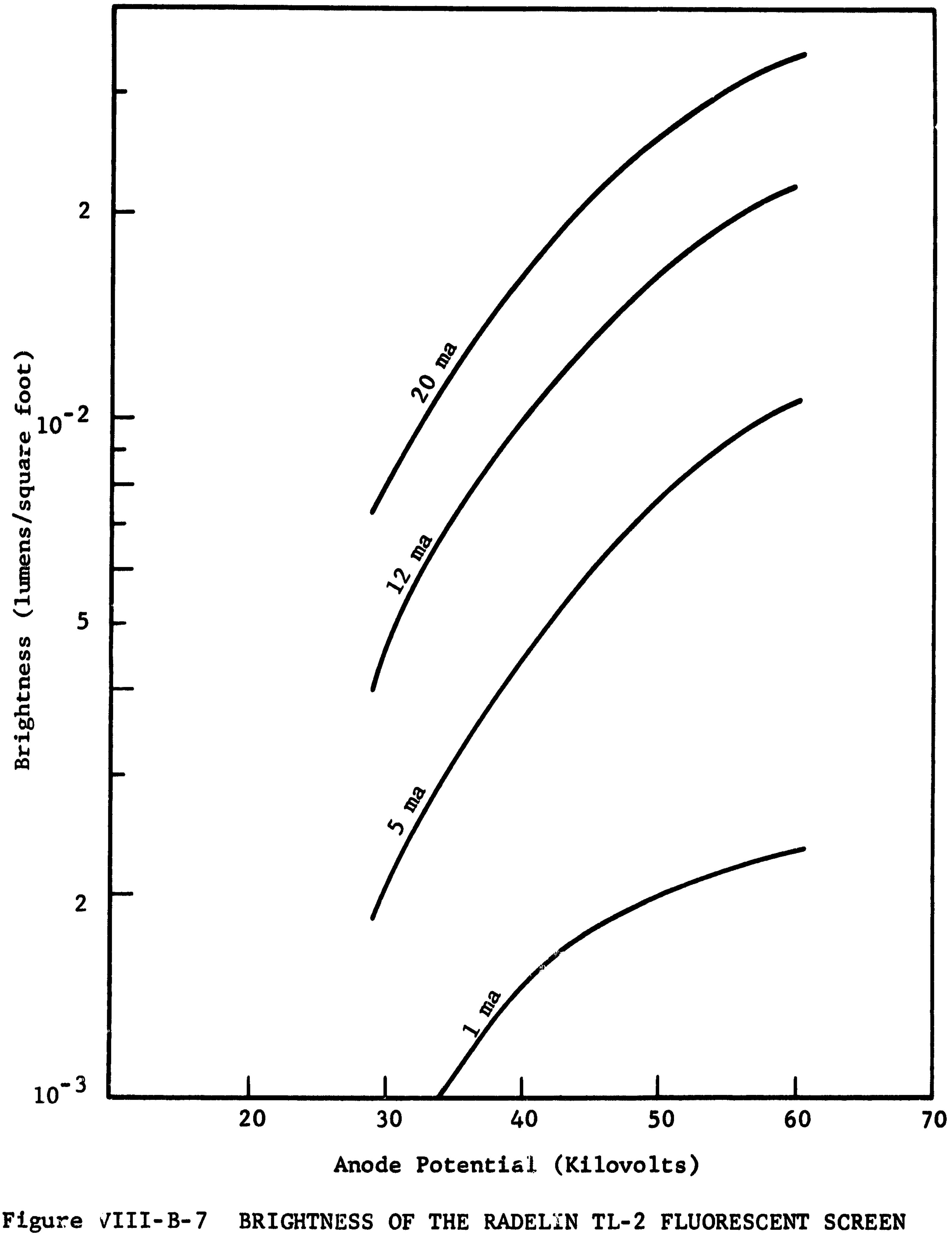

Figure VIII-B-7 BRIGHTNESS OF THE RADELIN TL-2 FLUORESCENT SCREEN

4. Resolution

There are three factors which influence the resolution of the system: vis; television camera resolution versus sensitivity, optics resolution, and a geometric factor which accounts for the magnification of the projected image.

The geometric factor may be evaluated readily by noting that the image is magnified by a factor of 1.25. This factor will be used subsequently in conjunction with the TV resolution to give a figure of resolution related to the sample. The resolution of the camera is related to available light as well as line scan. The present design employs a camera with a 945 line scan system.

For the 0.2X magnification the limiting resolution will occur in the television camera where 1 line pair will correspond to a separation of about 0.005 in. Since about 2 line pairs are required for simple "inspection"* the resolution is at best 0.007 in. In the 1.0X mode, the resolution limit is still in the camera, being 0.0014 for orientation. In this case the light level is reduced as a result of the aperture of the

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*The above usage is loosely based on the work of J. Johnson, "Analysis of Image Forming Systems," Proc. Image Intensifier Symposium, October 6-7, 1958, USAERDL, Fort Belvoir, Virginia. Johnson experimentally determined the number of line/pairs per target minimum dimensions for four levels of observational discrimination which he describes as follows:

a. "detection" - an object is present-1.0 ± 0.25 line pairs.
b. "orientation" - the object is approximately symmetrical or unsymmetrical and its orientation may be discerned 1.4 ± 0.35 line pairs.
c. "recognition" - the class to which the object belongs can be determined - 4.0 ± 0.8 line pairs.
d. "identification" - the object can be described to the limits of the observers knowledge-6.4 ± 1.5 line pairs.

It seems clear that this classification is not entirely relevant since for many flaws in a printed wiring board, improving from b to c above may provide virtually no additional relevant information. That this is true is documented by the earlier derotation lens system. Since the derotation lens is effectively a transfer lens the brightness of the image is equal to the brightness of the source divided by 100 (the square of the aperture of the system). The light level will be about 2.5×10^{-4} ℓ/ft^2. This is well above the minimum requirement of 2×10^{-5} ℓ/ft^2 as shown on Figure VIII-B-3.

When the optical magnification is increased to 4X the light reduction is an additional factor of 16, resulting in a minimum output of 1.6×10^{-5} ℓ/ft^2. The optical system in the 4X mode will produce an effective spot size (diameter in which one-half of the rays fall) of 0.004 in. Two spots (line pairs) in the sample with a separation of 0.001 in. between black lines will result in a separation of 0.00125 in. on the fluorescent screen because of the geometrical magnification. These two spots will be separated by 0.005 in. at the photocathode with a contrast of very nearly 50 percent and an average light level of 1.6×10^{-5} ℓ/ft^2.

The photocathode will be scanned by a raster which is 1.24 in. square. There will be 945 lines in a vertical direction. This corresponds to 764 lines/inch and hence a separation of 0.0013 in./line. Johnson* considers that 1.4 line pairs are required for "orientation" of an object. We are using the term "inspection" implying some details can be observed. Two line pairs are assumed to be necessary for "inspection." In the present case, there are very nearly the required 2 lines

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results using film. In these studies resolution ranged downward to 0.0005 in. or better and comparison of results of a given feature in which different resolutions were available indicated essentially no useful improvement was obtained for resolutions greater than that necessary for "detection." It seems reasonable, to assure, lacking additional information, that the resolution should be somewhere between that required for "orientation" and that required for "recognition." For lack of a better term we can describe this as "inspection" and assume that 2 line pairs per minimum target dimension are required.

*Op. Cit.

available for the inspection of the image. Considering the light level at the photocathode, according to Figure VIII-B-3, the resolution will be 880 lines, corresponding to 3.6 lines across an image to be resolved, or 1.8 line pairs. This is for the worst case and will improve for increased light availability.

5. Summary

The light output of a suitable fluorescent screen and the present X-ray source will be approximately 0.025 ℓ/ft^2. Maximum resolution of 945 lines/in. at a contrast of 60 percent at the image orthicon, requires a light level of 2×10^{-5} ℓ/ft^2. The optics will result in light reduction of 1.6×10^3. The available light at the photocathode will be 1.6×10^{-5} ft-candles resulting in a resolution of 880 TV lines. This corresponds to 3.6 TV lines or 1.8 line pairs spanning the width of an image pattern to be resolved. In general, this represents the worst case, since for most samples the available light will be somewhat higher.

C. The Optical Systems Design Details

1. General Considerations

The optical system is conveniently regarded as three separate interacting subsystems: vis; derotation optics; 0.2X magnification subsystem consisting of a supplementary lens, a field lens, and a reverse close-up lens; and 4X magnification subsystem consisting of a 4X Barlow lens. With the exception of the derotation subsystem and the Barlow lens these optical elements are quite standard and can be produced by standard techniques.

Since each manufacturer of optical parts tends to use his own method of mounting optical elements, only tilt, spacing and other relevant tolerances have been specified; however, the outer surface of the lens housing has been specified in detail (drawings V6034V3-2000 through V6034V3-2311).

Since the most difficult problems are to be encountered in the construction of the derotation optics this area will be dealt with in some detail.

2. Tolerances of the Derotation Lens Components

Because of some unusual features in the system of which this lens is a part, a rather detailed discussion of tolerances seems to be in order.

This lens, with its axis vertical, is to be mounted on a rotating table on bearings of highest obtainable accuracy. A rotating X-ray shadow image on a 20 inch diameter fluorescent screen is to be derotated by rotating this lens and prism assembly at one-half the rotation speed of the fluorescent screen image. A target value of 0.001-inch effective image spot size is desired. The rate of rotation is controlled by gears of the highest obtainable quality. The principal optical problems are (1) obtaining the desired image quality under static conditions and (2) aligning the axis of the lens and prism with the static center point of the rotating X-ray shadow image.

Under (1), the ordinary fabrication tolerances of surface curvatures and thickness should be held with more than usual care. Three fringes spherical and ± 1 fringe irregular seems adequate for glass-air surfaces. The thicknesses of the two cemented elements are many times more sensitive than that of the outermost element. One procedure that would relax the shop tolerances somewhat is to make the cemented doublet and the adjacent negative element first and to optimize the other thicknesses and airspaces again by computer.

For example, the nominal values given here in Line A, were arbitrarily changed as in Line B and upon reoptimization turned out as in Line C with spot sizes substantially as good as the original (some better, some worse):

A:	42.7255	0.053	1.45	0.59	0.7438	0.43	0.10
B:			1.426	0.614			
C:	42.7228	0.032	1.4362	(0.614)	0.72645	0.44367	0.11736

The R.M.S. spot sizes by the Los Alamos Lens Design program were:

Distance from axis	1.3"	7.1	9.7"
Before:	0.00049"	0.00062"	0.00059"
After:	0.00047"	0.00069"	0.00051"

Also, the lens should be optimized after obtaining refractive index values for the individual melts of glass. Therefore, this suggested procedure for thickness tolerances should not involve much additional computer work.

The prism receives two parallel bundles of rays at one end and is to deliver two parallel bundles at the other end. The prism angles at the two ends could be 44.75° or 45.25° without harm, but they must be equal to each other to a close tolerance. Because of the availability of special optical tests for 45° angles, it is probably easier to hold these angles individually to 45° ± 0.1' to gain the necessary equality between the two. If the two base angles differ by say 0.5' it may be possible to compensate by mounting the two reflecting faces at a slight angle (0.2'?) so that the two beams emerge parallel to each other, but this seems to be a more difficult procedure. However, pyramid errors can not be so compensated, and must be held within ± 0.12'. Otherwise the optical axes above and below the lens are not aligned with each other and difficulties of parallelism of object and image plane arise.

Rather surprisingly, there seems to be no necessity of holding the lengths of the two prisms equal within wavelength tolerances. If they are exactly equal, the two beams are out of phase anyway at certain off-axis angles and the fringe pattern around a point image is then noncircular. It does not seem to matter greatly whether this happens on-axis or somewhat off-axis.

If the assembled prism can be placed between two aligned collimators without disturbing the optical alignment by more than 0.1' minute and without splitting the image by more than 0.05 minute it should be considered to have met the specifications as to angles.

The second set of requirements, matching the mechanical axis of rotation, requires some definite set of coordinates as a basis of reference. The logical approach seems to be to assume that the outer surface of the lens barrel is a cylinder and consider its axis as the axis of the reference. If the front (lower) lens assembly is mounted coaxial with this axis, as tested by a collimator, and the prism is added and adjusted so as to maintain the alignment (as described above under prism tolerances), then the rear (upper) lens assembly can be added, and it substitutes for the collimator in the collimator test.

3. Prism Structure

As noted on the prism assembly drawing, theoretically the prisms should be mounted with the reflecting faces unsilvered and with a small airgap between them. However, there may be no reasonable way to mount and maintain them in proper alignment, and so the aluminizing and cementing is specified.

The natural aperture stop of the system is midway of the length of the prism. Conceivably, a slot could be cut with a diamond saw, but the danger of a fracture starting at the sharp edges would be too much. Accordingly, a nominal radius of 0.50 to 0.75 inch was specified.

D. The Electrical System Design Details and Specifications

1. Introduction

This appendix describes in detail all of the electrical subsystems, gives parts lists, presents details of procedure for modification to be carried out, and construction of non-commercial items, and attempts to document all that is presently known about the operation of these systems based on the design and experience with the laboratory prototype and experience with other complex instruments not directly comparable to this design.

2. Nomenclature for Unit, Chassis, Part, and Cable Identification

a. Unit Designations

A unit shall be a movable piece of the laminograph system, usually connected by cables to another unit or units.

Unit 1 - The operator's station (console) outside the laminograph room, which has the TV monitors, X-ray control, and scan control chassis among others.

Unit 2 - The modified Jarrell-Ash X-ray console located in the laminograph room, but not in the immediate proximity of the laminograph machine itself.

Unit 3 - The relay rack cabinet adjacent to the Jarrell-Ash X-ray console, also in the laminograph room. This cabinet contains the X-ray control interface chassis, the stepper motor drive chassis, and motor drive logic chassis, among others.

Unit 4 - The laminograph machine itself, which has mounted upon it the TV camera and immediately associated camera control, the stepper motors, and the optics control motors.

b. Chassis Designations

A chassis shall be the next largest component of a unit, usually occupying the space associated with a relay rack panel. It is a separate item removable from a unit by unscrewing the panel and disconnecting cables. All of the chassis for the various units are listed on the system block diagram, drawing 0-0-A(1). A chassis is identified by the unit number in which it is located, followed by the chassis number of that unit. For example, Chassis 1-6 (Scan Control) is located in Unit 1, and is the sixth of an arbitrary sequence of chassis.

c. Part Number Designations (Component Parts)

A part number shall be assigned to each item that is a functional electrical part of a chassis, such as relays, resistors, capacitors, Flip-Flops, NAND gates, etc. Purely hardware items shall be excluded, with the exception of connectors. In the case of the logic elements (NAND gates, inverters, etc.), since several are on a card, each element is not a unique physical entity as it is with the other component parts.

The different types of electrical component parts shall be designated by an alphabetic prefix of one or more characters, such as given in the following list:

R - Resistor
C - Capacitor
CR - Control Relay
T - Transformer

S - Switch, including toggle switches, pushbutton switches, limit switches, tap (rotary) switches
TB - Terminal Block
J - Connector Jack
P - Connector Plug
D - Diode
F - Flip-Flop
G - NAND Gate
I - Inverter (logic inverter)
SS - Surge Suppressor
VAT - Variable Autotransformer

Note: Connector plugs and jacks shall be associated with the chassis identification of the chassis to which they connect, thus a cable that connects two chassis of two different units will have different connector designations at the respective ends.

The serial part number for a given part of a given chassis shall be made up of first, the part type alphabetic designation followed immediately by a part number assigned in arbitrary sequence for that type of part for only that chassis, followed by a hyphen, followed by the complete chassis designation. For example, a relay number 3 in Chassis Number 3 of Unit 3 is:

CR3-3-3 - (part type)(number) - (unit) - (chassis)

Cable designations are made simply by assignment of alphabetic characters in arbitrary sequence.

3. Cable Lengths

The lengths of the cables shown on drawing O-O-A(1) are not specified in this or any of the individual cable drawings. The lengths of the cables which connect between chassis of a given cabinet rack depend upon the arrangement of the chassis within that rack. The recommended arrangements of chassis within the cabinet racks comprising Unit 3 and Unit 1 are given in drawings 3-O-B(1) and 1-O-B(1), respectively. The lengths of the cables which connect between chassis of different cabinet racks depend upon the arrangement of the units which comprise the laminograph system. A recommended arrangement is shown in drawing O-O-A(4), but, of course, actual dimensions are determined by the location or site available. It is suggested that after the chassis are all assembled, one can measure the required lengths of cables, allowing sufficient cable slack for correct dress after installation, and ready removal of individual chassis without requiring removal of an excessive number of cables not connecting to that chassis. (See Table VIII-D-1 for the parts list of cable connectors.)

Table VIII-D-1 SUMMARY PARTS LIST OF CABLE CONNECTORS

Cable	Reference Designation	Part Number	Description and Manufacturer	Quantity	Total Cost [1]
A	P3-3-1	MS 3106A 36-15P	Type MS, 35 pin, straight plug, male, Amphenol Corp.	1	$ 5.57
A	P3-3-1	MS 3057A-24	Cable clamp, for shell size 36, Amphenol Corp.	1	$ 3.58
A	P3-3-1	AN 3420-16	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.19
A	P6-1-2	MS 3106A 36-15S	Type MS, 35 pin, straight plug, female, Amphenol Corp.	1	$ 6.06
A	P6-1-2	MS 3057A-24	Cable clamp, for shell size 36, Amphenol Corp.	1	$ 3.58
A	P6-1-2	AN 3420-16	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.19
B	P1-2-0	MS 3106A 28-21P	Type MS, 37 pin, straight plug, male, Amphenol Corp.	1	$ 4.20
B	P1-2-0	MS 3057A-16	Cable clamp, for shell size 28, Amphenol Corp.	1	$ 1.18
B	P1-2-0	AN 3420-16	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.19
B	P2-3-1	MS 3106A 28-21S	Type MS, 37 pin, straight plug, female, Amphenol Corp.	1	$ 4.76

[1] Prices as of 3/68

Table VIII-1 (Continued)

Cable	Reference Designations	Part Number	Description and Manufacturer	Quantity	Total[1] Cost
B	P2-3-1	MS 3057A-16	Cable clamp, for shell size 28, Amphenol Corp.	1	$ 1.18
B	P2-3-1	AN 3420-16	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.19
C	P4-3-1	MS 3106A 28-2P	Type MS, 14 pin, straight plug, male, Amphenol Corp.	1	$ 3.11
C	P4-3-1	MS 3057A-16	Cable clamp, for shell size 28, Amphenol Corp.	1	$ 1.18
C	P4-3-1	AN 3420-10	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.15
D	P5-3-1	MS 3106A 20-7S	Type MS, 8 pin, straight plug, female, Amphenol Corp.	1	$ 2.23
D	P5-3-1	MS 3057A-12	Cable clamp, for shell size 20, Amphenol Corp.	1	$ 0.87
D	P5-3-1	AN 3420-4	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.09
D	P5-3-5	MS 3106A 20-7P	Type MS, 8 pin, straight plug, male, Amphenol Corp.	1	$ 2.07
D	P5-3-5	MS 3057A-12	Cable clamp, for shell size 20, Amphenol Corp.	1	$ 0.87

[1] Prices as of 3/68

Table VIII-D-1 (Continued)

Cable	Reference Designation	Part Number	Description and Manufacturer	Quantity	Total[1] Cost
D	P5-3-5	AN 3420-4	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.09
E	P1-4-1	MS 3106A 18-12S-X	Type MS, 6 pin, straight plug, female, X insert position, Amphenol Corp.	1	$ 1.70
E	P1-4-1	MS 3057A-10	Cable clamp, for shell size 18, Amphenol Corp.	1	$ 0.79
E	P1-4-1	AN 3420-6	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.10
E	P2-4-1	MS 3106A 18-12S-Y	Type MS, 6 pin, straight plug, female, Y insert position, Amphenol Corp.	1	$ 1.70
E	P2-4-1	MS 3057A-10	Cable clamp, for shell size 18, Amphenol Corp.	1	$ 0.79
E	P2-4-1	AN 3420-6	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.10
E	P3-4-1	MS 3106A 18-12S-Z	Type MS, 6 pin, straight plug, female, Z insert position, Amphenol Corp.	1	$ 1.70
E	P3-4-1	MS 3057A-10	Cable clamp, for shell size 18, Amphenol Corp.	1	$ 0.79

[1] Prices as of 3/68

Table VIII-D-1 (Continued)

Cable	Reference Designation	Part Number	Description and Manufacturer	Quantity	Total Cost [1]
E	P3-4-1	AN 3420-6	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.10
F	---	57-30140	57 series, "Micro-Ribbon™," 14 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 3.55
F	---	57-30140	57 series, "Micro-Ribbon™," 14 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 3.55
G	P1-4-4	MS 3106A 20-27S	Type MS, 14 pin, straight plug, female, Amphenol Corp.	1	$ 2.53
G	P1-4-4	MS 3057A-12	Cable clamp, for shell size 20, Amphenol Corp.	1	$ 0.87
G	P1-4-4	AN 3420-8	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.12
G	P2-4-4	MS 3106A 18-1S	Type MS, 10 pin, straight plug, female, Amphenol Corp.	1	$ 1.93
G	P2-4-4	MS 3057A-10	Cable clamp, for shell size 18, Amphenol Corp.	1	$ 0.79
G	P2-4-4	AN 3420-6	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.10

[1] Prices as of 3/68

Table VIII-D-1 (Continued)

Cable	Reference Designation	Part Number	Description and Manufacturer	Quantity	Total Cost[1]
G	P6-3-3	MS 3106A 28-12P	Type MS, 26 pin, straight plug, male, Amphenol Corp.	1	$ 3.63
G	P6-3-3	MS 3057A-16	Cable clamp, for shell size 28, Amphenol Corp.	1	$ 1.18
G	P6-3-3	AN 3420-10	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.15
H	---	57-30140	57 series, "Micro-Ribbon™," 14 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 3.55
K1	---	57-30140	57 series, "Micro-Ribbon™," 14 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 3.55
K1	---	57-30140	57 series, "Micro-Ribbon™," 14 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 3.55
K2	---	57-30140	57 series, "Micro-Ribbon™," 14 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 3.55
K2	---	57-30140	57 series, "Micro-Ribbon™," 14 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 3.55

[1] Prices as of 3/68

Table VIII-D-1 (Continued)

Cable	Reference Designation	Part Number	Description and Manufacturer	Quantity	Total Cost [1]
K3	---	57-30140	57 series, "Micro-Ribbon™," 14 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 3.55
K3	---	57-30140	57 series, "Micro-Ribbon™," 14 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 3.55
K4	P6-3-5	57-30240	57 series, "Micro-Ribbon™," 24 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 3.90
L	---	31-012	Type "BNC" plug, coaxial, male, for RG 59/U coaxial cable, Amphenol Corp.	1	$ 0.68
L	---	31-012	Type "BNC" plug, coaxial, male, for RG 59/U coaxial cable, Amphenol Corp.	1	$ 0.68
M	---	31-012	Type "BNC" plug, coaxial, male, for RG 59/U coaxial cable, Amphenol Corp.	1	$ 0.68
M	---	31-012	Type "BNC" plug, coaxial, male, for RG 59/U coaxial cable, Amphenol Corp.	1	$ 0.68

[1] Prices as of 3/68

Table VIII-D-1 (Continued)

Cable	Reference Designation	Part Number	Description and Manufacturer	Quantity	Total Cost[1]
S	P7-3-3	MS 3106A 18-1P	Type MS, 10 pin, straight plug, male, Amphenol Corp.	1	$ 1.78
S	P7-3-3	MS 3057A-10	Cable clamp, for shell size 18, Amphenol Corp.	1	$ 0.79
S	P7-3-3	AN 3420-6	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.10
T	---	57-30360	57 series, "Micro-Ribbon™," 36 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 4.77
T	---	57-30360	57 series, "Micro-Ribbon™," 36 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 4.77
U	---	57-30360	57 series, "Micro-Ribbon™," 36 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 4.77
U	---	57-30360	57 series, "Micro-Ribbon™," 36 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 4.77
V	---	57-30360	57 series, "Micro-Ribbon™," 36 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 4.77

[1]Prices as of 3/68

Table VIII-D-1 (Continued)

Cable	Reference Designation	Part Number	Description and Manufacturer	Quantity	Total[1] Cost
V	---	57-30360	57 series, "Micro-Ribbon™," 36 contacts, cable-to-cable plug, Amphenol Corp.	1	$ 4.77
W	P8-3-3	MS 3106A 20-27P	Type MS, 14 pin, straight plug, male, Amphenol Corp.	1	$ 2.51
W	P8-3-3	MS 3057A-12	Cable clamp, for shell size 20, Amphenol Corp.	1	$ 0.87
W	P8-3-3	AN 3420-6	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.10
W	P1-3-5	MS 3106A 20-27S	Type MS, 14 pin, straight plug, female, Amphenol Corp.	1	$ 2.54
W	P1-3-5	MS 3057A-12	Cable clamp for shell size 20, Amphenol Corp.	1	$ 0.87
W	P1-3-5	AN 3420-6	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.10
AD	---	31-012	Type "BNC" plug, coaxial, male, for RG 59/U coaxial cable, Amphenol Corp.	1	$ 0.68
AD	---	31-012	Type "BNC" plug, coaxial, male, for RG 59/U coaxial cable, Amphenol Corp.	1	$ 0.68

[1] Prices as of 3/68

Table VIII-D-1 (Continued)

Cable	Reference Designation	Part Number	Description and Manufacturer	Quantity	Total Cost [1]
AE	---	31-012	Type "BNC" plug, coaxial, male, for RG 59/U coaxial cable, Amphenol Corp.	1	$ 0.68
AE	---	31-012	Type "BNC" plug, coaxial, male, for RG 59/U coaxial cable, Amphenol Corp.	1	$ 0.68
AF	---	31-012	Type "BNC" plug, coaxial, male, for RG 59/U coaxial cable, Amphenol Corp.	1	$ 0.68
AF	---	31-012	Type "BNC" plug, coaxial, male, for RG 59/U coaxial cable, Amphenol Corp.	1	$ 0.68
AB	P3-1-4	MS 3106A 18-10P-Y	Type MS, 4 pin, straight plug, male, Y insert polarization, Amphenol Corp.	1	$ 1.75
AB	P3-1-4	MS 3057A-10	Cable clamp, for shell size 18, Amphenol Corp.	1	$ 0.79
AB	P3-1-4	AN 3420-4	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.09

[1] Prices as of 3/68

Table VIII-D-1 (Continued)

Cable	Reference Designation	Part Number	Description and Manufacturer	Quantity	Total[1] Cost
AG	P2-1-4	MS 3106A 18-10P-X	Type MS, 4 pin, straight plug, male, X insert polarization, Amphenol Corp.	1	$ 1.75
AG	P2-1-4	MS 3057A-10	Cable clamp, for shell size 18, Amphenol Corp.	1	$ 0.79
AG	P2-1-4	AN 3420-5	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.009

[1]Prices as of 3/68

4. AC Power Control (Chassis 1-4)

The ac power control chassis (chassis 1-4) controls all 115 v ac line power to the laminograph system, with the exception of the 115 v ac circuit to the laminograph room overhead lights (see subsection 10-c of this portion of the report). It does not control the 230 v ac line power to the X-ray subsystem (which enters at Unit 2); the reason for this is detailed in subsection 10-c of the electrical systems portion of the report. It has two illuminated legend pushbuttons; one is "Main Power On," which is illuminated whenever 115 v ac power is supplied to the laminograph system, and the other is "Main Power Off," which is illuminated when the 115 v ac power to the laminograph system is turned off, but obviously the 115 v ac power feed to this chassis 1-4 is connected and turned on. This chassis also has a high interruption capacity power toggle switch (S3-1-4) which independently turns the sample table drive motor on and off. It has no status indicator light. This chassis has no "main fusing" since each chassis of the laminograph electrical system which uses 115 v ac line power has its own line fuse. There are two fuses present in this chassis, accessible only from the rear. The one designated (F1-1-4) is a very low current fuse which protects only the pushbutton and light circuit in the chassis 1-4 itself. The other, (F2-1-4) is a fuse which protects the sample table drive motor, and is of the slow-blow type.

In order to construct this chassis, the following drawings are required:

1-4-A(1)	AC Power Control Chassis Schematic
1-4-B(1)	AC Power Control Chassis Panel Layout
1-4-C(1)	AC Power Control Chassis U-Bracket Chassis Layout, Mounting and Connector Detail

A parts list for the parts required to construct the ac power control chassis (chassis 1-4) is presented in Table VIII-D-2.

Table VIII-D-2 PARTS LIST FOR AC POWER CONTROL

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total[1] Cost
PR1, PR2-1-4	KRP14AG	Power relay, 3PDT contacts, gold-flashed silver, 10 A., 120 v AC coil, Potter and Brumfield	2	$16.40
---	77M1P11	Socket for KRP14AG relay, 11 pin, Amphenol Corp.	2	$ 0.58
---	9KR-15	Hold-down spring for KRP14AG relay, for horizontal mounting, Potter and Brumfield	2	$ 0.30
F1-1-4	3AG(Standard)	Type 3AG (standard blow) fuse, 1/16 A., 1/4 in. x 1-1/4 in., Littlefuse, Inc.	1[2]	$ 0.75
F2-1-4	3AG(Slo-Blo)	Type 3AG (slo-blo) fuse, 3 A., 1/4 in. x 1-1/4 in., Littlefuse, Inc.	1[2]	$ 0.75
---	HKP	Fuseholder for 3AG fuse, 1/4 in. x 1-1/4 in., Bussman Mfg. Co.	2	$ 0.74
S1-1-4	10EA1C1F1J4L (R)N1R1V13 Main Power, on	Panel indicator type momentary snap-action pushbutton switch, DPDT, illuminated legend, red, MAIN POWER ON, Master Specialties Co.	1	$20.00 (approx)
S2-1-4	10EA1C2F1J3L (G)N1R1V13 MAIN POWER OFF	Panel indicatory type momentary snap-action pushbutton switch, DPDT, illuminated legend, green, MAIN POWER, OFF, Master Specialties Co.	1	$20.00

[1] Current prices as of 3/68 [2] Price given for box of 5

Table VIII-D-2 (Continued)

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost[1]
S3-1-4	7501K13	Toggle switch, SPST, heavy duty 15 A., 125 v, Cutler Hammer Mfg.	1	$ 0.63
R1-4-1	RC42GF	Fixed composition resistor, 620 ohms ± 5%, 2 watts, Ohmite Corp.	1	$ 0.12
TS1-1-4	863	Terminal strip, lug type, 2 lugs, H. H. Smith Co.	1[3]	$ 0.30
J1-1-4	160-5	AC line power connector, flush mounting 2 pole grounding type receptacle, male, Amphenol Corp.	1	$ 1.25
J2-1-4	MS 3102A 18-10S-X	Connector, type MS, 4 pin, box receptacle, X polarized, Amphenol Corp.	1	$ 1.39
J3-1-4	MS 3102A 18-10S-Y	Connector, type MS, 4 pin, box receptacle, Y polarized, Amphenol Corp.	1	$ 1.39
---	5252	Duplex AC line outlet, 3 wire grounding type, parallel slots, Harvey Hubbell Co.	2[4]	$ 9.60

[1]Current prices as of 3/68

[3]Price given for quantity of 10

[4]Price given for quantity of 10

Table VIII-D-2 (Continued)

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost[1]
---	PA-1102	Relay rack panel, aluminum, 3-1/2 in. height, smooth gray finish	1	$ 1.65
---	827-228F3	On-off legend plate for toggle switch S3-1-4	1	$ 0.04

[1] Current price as of 3/68

Layout of the panel-mounting components is shown in drawing 1-4-B(1). The holes to mount the U-bracket chassis to the front panel are not shown. They must be located to suit the bracket. Flat-head machine screws should be used to mount the U-bracket to the front panel. The U-bracket shown on drawing 1-4-C(1) should be made approximately as shown. Aluminum may be substituted if appropriate corner reinforcing and "channel" reinforcing is added. Affix all required labels to the painted front panel, mount all components, assemble, and wire. Use No. 14 AWG wire where noted, and No. 12 AWG wire for the continuous chassis ground.

The 115 v ac power plug P2-1-4 which connects to J2-1-4 will carry two switched 115 v circuits (two circuits are used to distribute the load on two relay contacts) and will be the termination of a group of No. 14 AWG wires (which may be solid conductor building wire) which run inside a steel thinwall conduit which is a riser in both sides of the operator's station (Unit 1) of the laminograph system. At intervals along this conduit duplex outlets are placed, so that the line cords of the chassis to be switched on and off are plugged into these outlets. The arrangement of these conduits in the two cabinets shall be such as to divide the power load in the distribution as shown on drawing 0-0-A(3), for the "Control Station Room." These conduits and the outlets may be run along the sides (inside) of the cabinets which make up Unit 1. Caution: secure No. 12 AWG ground wire firmly to the frame of these cabinet racks, as well as having it run to the ground pins of all of the duplex line outlets.

The 115 v AC power plug P3-1-4 which connects to J3-1-4 will carry two switched 115 v circuits into a steel thinwall conduit which runs from the control station room into the laminograph room and terminates near the laminograph room station rack (Unit 3). These lines should solely occupy this conduit; do not run any other cables through this conduit. The circuit which goes from Pin C of J3-1-4 will continue and terminate in a duplex outlet box located physically near the sample table drive motor on the laminograph machine (probably on the floor, or near it). The other 115 v ac switched circuit will enter a conduit which is a rise inside the laminograph room station rack; a conduit with duplex outlets spaced on it periodically, into which the line cords of the chassis in this rack are plugged. Carry through and secure the No. 12 AWG ground wire to this rack, and to the X-ray unit (Unit 2-0) as well. The latter is imperative for personnel safety in case of a fault in the X-ray system with its high operating voltages. The No. 12 AWG wire should also connect to the ground pins of all of the duplex outlets mentioned, including the one for the sample table drive motor.

5. DC Power Supplies (Chassis 1-7 and 3-4)

The principal power supply for the integrated circuit card logic (EECologic™) used in the electronic subsystems of the laminograph system is a 5 v dc filtered and regulated power supply which is capable of an output current of 8 amperes. This power supply is chassis 1-7, and is a rack mount type with standard 19 inch panel width. It is available as a purchased item, and is an EECologic™ L Series Silicon System Supply - Rack Mount, available from the Engineered Electronics Company, 1441 East Chestnut Avenue, Santa Ana, California, 92702. It is a "Deltron" L Series Power Supply L5-8 and is listed at $264.00. It has no front panel meters, but does have internal continuous overload and short circuit protection of the output. The panel height of the unit is 3-1/2 inches. It has a line fuse, off-on switch, pilot light, voltage adjust, and current limit adjust on the front panel; the line terminations are on a terminal block at the rear.

The chassis 3-4 is a power supply principally for the position encoders and associated indicators. It is a standard rack mount unit with a 19 inch front panel width. It is a filtered and regulated nominal 16 v dc supply, and is a purchased unit available from Technipower, a Benrus subsidiary. The actual unit is an assembly of a Model P-15.8-3.0 Regulated Power Supply Module, mounted on a Rack Mount Model RM-5.25HD. The panel is 5-1/4 inches high, and the total price is $270.00. The unit is adjustable in voltage output over a 15.2 to 16.5 volt range, and has built-in protection for overload or short circuit of the output. It has no front panel meters, but does have a front panel mounted on-off switch, pilot light, and line fuse.

6. <u>Scan Control (Chassis 1-6)</u>

a. <u>General</u>

The scan control logic is best described by reference to its sub-elements; all of which are contained in the 1-6 chassis. The scan control chassis (1-6) is an EEClogic Taper Pin Circuit card drawer designated 22H-904-2-2 which has 22 inch drawer slides, a total card capacity of 60 and has type H-414 taper pin connectors already installed. A parts list of all the logic module cards which make up the scan control subsystem follows in Table VIII-D-3. Standard logic wiring methods should be used in the assembly of this chassis. To assist in wiring, a listing of all "Input-Output Designations for Scan Control Logic" interconnections is presented in tabular form as drawing 1-6-A(9). For component layout and designation refer to drawings 1-6-B(1) and 1-6-C(1). Individual component part numbers and manufacturers are given on the drawings referred to in the descriptions which follow or are identified in the text itself. The drawings referred to in this section include 1-6-A(1) through 1-6-A(11) in addition to those already mentioned.

Table VIII-D-3 PARTS LIST FOR SCAN CONTROL

ECCO Part#	Description	Quantity	Total Price
IRS-2216	Eight R-S Flip-Flops (Latch)	2	$ 63.20
IGF-0231	Four Gates Flip-Flops	9	$1061.00
INN-2202	Eight 2-Input NAND Gates	16	$ 396.00
INN-2203	Six 4-Input NAND Gates	11	$ 341.00
INN-2237	Four 4-Input NAND Gates with Two 4-Input Extenders	6	$ 190.20
IIC-2228	Sixteen Inverters	5	$ 185.00
ILD-0207	Ten Lamp Drivers, 50 ma at 28v	1	$ 45.00
IRD-0242	Eight 250 ma Relay Drivers	1	$ 37.15
IMC-2243	4-Bit Digital Magnitude Comparator	4	$ 235.80

The power supplies required by the control logic and auxiliaries are described in Section h. Details relating to the design of the scan control logic are contained in the subsections which follow.

b. BCD Selector Switch Commutator

The first portion of the scan control logic system to be discussed is the BCD selector switch commutator. As previously mentioned, the position encoders are switched into the logic system one at a time. This applies only to the BCD signal lines. The decimal outputs are left connected to the position indicators so that a continuous display of all three axis positions is presented.

The wiring diagram for the BCD selector switch commutator is shown in drawing 1-6-A(1).

The wiper contact of each switch* is connected to the armature of a single-pole, double throw relay. In the deenergized position these are connected to the logic supply (+5 volts). The output contacts of each selector switch is therefore either floating or at +5 volts. The outputs of the switches go to a set of NAND gates. Since a NAND gate does not respond to a logical ONE (+5 volts), or to an open input there will be no outputs from the gates. When a relay is energized, however, the switch contacts necessary to represent the BCD value of the number set in, are shorted to ground. When any input of a NAND gate is grounded, the output switches to the ONE state. The outputs of the NAND gates therefore correspond to the complement of the number set into the switch.

---

* Switches are EECo Switch, No. 702-L-10, Engineered Electronics Company, Santa Ana, California.

c. Comparater Logic

The outputs of the BCD selector switch commutator and the position encoder commutator are compared using a Digital Comparator, EECo Type IMC-2243. The complete wiring diagram is shown in drawing 1-6-A(2). Three identical cards are employed to obtain the necessary 11 bit capacity (the 800 bit never appears). The cards are completely prewired so it is only necessary to complete the interconnections. Inverters are used in each data line since the cards require both the True and the Complementary value for each bit. The cards provide outputs indicating the following input relationships, $A \leq B$, $A = B$, and $A \geq B$, as well as their complements.

d. Scan Start-Stop Logic

This portion of the system, shown on drawing 1-6-A(3), constitutes the first block of digital logic in the scan-control system.

During normal scan operation both the scan enable and scan inhibit are in the zero state. The first time that the scan enable drops from the one to the zero state, inverter I-26 is momentarily cut-off while the 1.0 mfd capacitor charges. The 10K resistor does not provide sufficient loading at the inverter input to hold it in the cut-off state but is included to provide a discharge path for the capacitor.

During the capacitor charging pulse the output of G-19 is in the zero state. This sets the Q output of F-1 to the one state providing the auto scan output signal as well as enabling G-22 and G-29. A zero output from G-19 may be initiated by pressing the "Auto" button at any time after the initial one to zero transition of the scan enable, providing that the scan inhibit remains in the zero state.

Gate G-12 will provide a zero output only for the following input combination,

$$\overline{8} \cdot \overline{4} \cdot \overline{2} \cdot \overline{1} = 1$$

which exists only for the BCD representation of decimal zero. Gate G-13 will provide a zero output only for

$$\overline{8} \cdot 4 \cdot \overline{2} \cdot 1 = 1$$

which is the BCD code for decimal five. Gate G-15 functions as an OR gate for either input equal to zero so a one state will appear at its output whenever the units decode from a selected position encoder is zero or five. This establishes the grid-pattern described in a previous section.

The $\overline{Z}$e-2 input is at a logical one level in both the X and Y scan operations so gates G-16 and G-17 are both disabled for these. The function of these gates will be discussed later in this section.

Proceeding with the discussion of system operation as it applies to X or Y scan assume that the Q output of Flip-Flops F-1, F-2, and F-5 are in the one state, while F-3, F-4, F-6, and F-7 are in the zero state. Flip-Flops F-3 through F-7 are connected as a binary counter but are inhibited from counting by the application of a logical zero to the direct clear inputs of F-3, F-4, F-6, and F-7 and to the direct set input of F-5. Note that this corresponds to pre-loaded count of 4 stored in the counter. When the counter is permitted to count, the last stage, F-7, will reverse state on the count of 12.

The clock enable line is held in the one state for the states assumed. This line controls a gated multivibrator which generates the pulses for the stepper motors. These clock pulses are also applied to the input of the binary counter (F-3).

The stepper motor selected by the scan control programmer is being pulsed and the output signals from the position encoder is changing as its shaft is rotated. When a major grid line is reached (units decoder equals zero or five), a one state occurs at the output of G-15. Since $\bar{Z}e\text{-}2 = 1$, gate G-18 responds and a stop scan A pulse occurs. This is coupled through G-22, G-26, and I-28 to the Toggle input of F-2. The Q output of F-2 drops to the zero state but the clock enable line remains in the one state since $\overline{Ze\text{-}2} = 1$ and $\overline{F\text{-}7\ Q} = 1$. The counter is now permitted to count clock pulses since the direct control lines have been released. At the count of 12, F-7 will change state and the clock enable line will drop to zero. The effect of the counter circuit in the system operation is to allow twelve additional clock pulses after the position encoder indicated the occurrence of a zero or five. Note that this occurs only in the X or Y scan mode since in Z scan the $\overline{Ze\text{-}2}$ line is zero. This provides an inhibit to G-30 so the clock enable line will drop when F-2 changes state.

The purpose of the added count of 12 is to correct for an ambiguity in position due to the combination of stepping motor characteristics and the drive system gear ratios for the X and Y axis. Twenty-four clock pulses are required to move the camera 0.1 inch. The occurrence of a one or five from the encoder indicates that the camera has reached the edge of an imaginary line 0.1 inch wide, but does not define which edge. Adding 12 counts always moves the camera to the center of this 0.1 inch line.

The Z axis operation differs only in the introduction of gates G-16 and G-17. The Z increment switch disables one gate or the other. In the "2" position of this switch G-16 is disabled. The encoder input to G-17 is from the $\bar{1}$-U line. This line alternates between zero and one as the digits alternate from odd to even. A scan stop A pulse will occur each time the units decoder contains an even number. Thus F-2 will be toggled every second digit rather than every fifth.

When the switch is set to the "5" position, operation is exactly as in the X or Y mode.

In any automatic mode, a dwell delay (variable) circuit begins when the clock enable line drops. At the end of this delay, an end of dwell (EOD) pulse is produced which sets F-2 and a new clock cycle begins. Once started the system will recycle at each EOD until the Vernier push-button is actuated. This clearsF-1 causing the auto scan signal to return to zero. Note that this control has no effect unless F-2 is in the set state. This coincides with the dwell period.

The gate G-14 functions only during the Vernier scan mode since G-23 is enabled only in this mode. The inputs to G-14 are differentiated pulses from the $\overline{T}$-U line. Since both the complement and true states of this line are used a toggle pulse is applied to F-2 for each digit change in the units decoder. In this mode the system will step one digit per scan.

The system may be returned to the automatic mode by pressing the auto button, providing the scan inhibit line is zero. This line originates in the Vernier scan memory portion of the logic and will be in the zero state only if the position of the TV camera and X-ray source correspond to the positions when the Vernier button was pressed.

Additional inputs to the scan start-stop logic are the dwell override (D-O), comparator output (Cx), inverted manual enable ($\overline{M}$), and set-up enable (S-O). The D-O signal permits F-2 to be set without an EOD signal; Cx = 1, whenever the position encoder BCD output matches the selector switch setting, $\overline{M}$ is zero in the manual scan mode, and S-U is aero during the initial origin search. The output of G-21 provides a scan-stop whenever a scan boundary is reached.

e. Scan Mode Control Logic

This portion of the scan control logic provides the routing of motor drive signals for each scan mode. The wiring diagram appears on drawing 1-6-A(4). Flip-Flops 8 through 11 control the starting sequence, F-12 and 13 the origin search, and 14 through 20 are used in both manual and Vernier scan.

When power is initially applied by pressing the start button, a time delay relay holds the line labeled delay relay at ground potential for approximately 5 seconds. This line clamps the clear inputs of F-10, F-11, F-9 through G-32, and both set and clear of F-8. The set input of F-8 is clamped directly while the clear is clamped through a diode. While the clamp line is down, both outputs of F-8 are in the one state. When released, the Q output switches to the zero state since the clear input is held down briefly by the 1.0 mfd capacitor. The ready light comes on at this time.

The set inputs of F-9 and F-11 are connected to F-8 through normally open push buttons. Pressing either one will set the associated FF, resulting in a set pulse at the input of F-8. The Q output of F-8 now switches to the one state and until power is removed and reapplied, neither the "auto" button or the "manual" button will have any effect. The primary purpose of this interlock arrangement is to prevent transfer to manual during automatic scan which would throw the scan program out of step.

In manual operation, the Q output of F-11 supplies a one to an input of G-54, the remaining input is controlled by G-49 which produces a logical one if any Flip-Flop in the group F-14 through F-20 is set. This results in a dwell override to F-2 in the start-stop logic resulting in a continuous clock enable.

In the automatic (auto) mode, F-9 is set. This provides an enable input to gates G-33 and G-34. The remaining inputs are from the comparator (drawing 1-6-A(2)). The A = B output is one when the position encodes matches the selector switch. The A $\leq$ B output indicates the relative position with respect to the BCD switch. This provides a "sense" signal during origin search. The camera, or X-ray source, will always start out in the proper direction, i.e., move toward the selected origin (X_1, Y_1, Z_1).

Flip-Flops F-12 and F-13 are connected as a two stage binary counter. The set inputs of these two stages are clamped initially by the delay relay, so the initial Q states are logical one. A truth table for F-12 and F-13 and gates G-35 through G-38 is presented below:

Trigger Pulse No.	F-12	F-13	G-35	G-36	G-37	G-38
	1	1	1	0	1	1
1	0	1	1	1	0	1
2	1	0	1	1	1	0
3	0	0	0	1	1	1

Before discussing the scan program selector logic in detail, a brief explanation of the motor control logic is necessary.

Only five command lines are required between the scan control logic and the position control logic. These are X enable (X_e), Y enable (Y_e), Z enable (Z_e), sign, and clock. The enable lines together with the sign are gated to route the clock pulses to the appropriate motor drive input. For example, for X_e = 1 and sign = 1, clock pulses would be routed to the motor drive input required to move the camera to its right. A similar gating arrangement is used for selecting the desired BCD switch. In the set-up mode the sequence is always the same; following activation of auto, the camera will seek X_1. This requires an X_e signal and a sign polarity such that the camera will move toward X_1, regardless of its starting point. The $A \leq B$ output of the comparater is routed through G-34 and PD-4 to the sign line. Other inputs to PD-4 are held in the one state so have no effect. If the camera is to the left of X_1, the $A \leq B$ will be in the one state. This produces a one on the sign line which gates the clock line such that the camera will move to the right. The clock enable line is held in the one state by S-U signal (at gate G-31, drawing 1-6-A(3)).

From the truth table it is seen that G-36 is in the zero state initially. This is routed to the X_e line via PD-1 providing an X enable. When X reaches X_1, the $A = B$ output from the comparater rises to the one state, advancing the counter to one step. Gate G-37 now provides a Y_e and again the sign is determined by the comparater. The position encoders are commutated by the enable lines so for each enable state the appropriate position encoder is connected to the comparater.

When $Y = Y_1$, the counter advances again establishing a Z_e. When $Z = Z_1$, the Z_e line drops and an output occurs from G-35. This sets F-10, establishing a scan enable and automatic transfer to programmed scan. This pulse also clears F-9 and latches it in the cleared state since F-12 and F-13 will receive no further inputs (G-33 in inhibited).

Flip-Flops F-14 through F-20 have been latched in the clear state throughout the entire set-up sequence, through I-35.

After transfer to automatic scan, F-14 through F-20 may be set providing Vernier scan has been actuated. This is accomplished by means of the SPDT switches at their inputs. The output of G-39 will be in the zero state. Pressing any switch will set a Flip-Flop. For example, if the X switch is moved to the + position, an X_e signal will appear at the output of G-40. This is routed through G-44 and PD-1 to the

X_e line. Similarly a + sign signal will appear at the output of G-43 which is routed through G-48 and PD-4 to the sign line. The camera will move to its right 0.1 in. and stop. The set input through the switch is brief pulse in the Vernier scan mode. When the clock enable ends, any Flip-Flop (F-14 through F-20) will be cleared via I-36. This again is a single pulse because of the ac coupled input. In automatic scan gates G-44 through G-48 are inhibited and G-50 through G-53 are enabled. The enable and sign signals from the scan control programmer are then routed to the PD output lines.

In full manual operation, Flip-Flop F-11 is set which provides a zero state to the position control switches. In this case, continuous motion on any selected axis occurs when a selector switch is activated. Upon release of the switch, motion will stop upon the next digit change from the position encoder.

The dwell enable (D-0) output is a single pulse in the Vernier mode, or a steady one level in the manual mode, existing as long as a selector switch is held.

f. Scan Control Programmer

The scan control programmer logic is shown in drawing 1-6-A(5). Inputs to the programmer from the start-stop and comparator control logic are the (1) set X-Y-Z sequence, (2) set Z-X-Y sequence, (3) set X-Y-Z(+), and (4) the comparator pulse C_x, and the dwell pulse. Outputs from the programmer to the motor and start-stop control logic are the X, Y, and Z enable pulses, a sign (direct in) signal, and a stop signal.

The scan control programmer provides positioning of the TV camera and X-ray source according to the following sequence of operations:

X-Y-Z Mode

1. Always set X enable (X_e) at end of dwell (EOD), except when $C \cdot X_e = 1$.
2. When $C \cdot X_e = 1$
   a. Toggle X_s at EOD
   b. Set Y_e at EOD
3. If $C \cdot Y_e \neq 1$, set X_e at EOD and return to 1.
4. If $C \cdot Y_e = 1$
   a. Toggle Y_s at EOD
   b. Set A at EOD
   c. Set X_e at EOD
5. When $C \cdot A = 1$, set Z_e at EOD.
6. When ZSC = 1 (end of Z scan)
   a. Set X_e at EOD
   b. Reset A
7. Return to 1.
8. When $Z = Z_2$ ($C \cdot Z_e = 1$), set B at EOD.
9. Return to 1.
10. When $A \cdot B \cdot C \cdot X_e = 1$, STOP at EOD.

Z-X-Y Mode

1. Always set Z_e at EOD, except when $C \cdot Z_e = 1$.
2. When $C \cdot Z_e = 1$
   a. Toggle Z_s at EOD
   b. Set X_e at EOD
3. If $C \cdot X_e \neq 1$, set Z_e at EOD, return to 1.
4. If $C \cdot X_e = 1$
   a. Toggle X_s at EOD
   b. Set A at EOD
   c. Set Z_e at EOD
5. When $C \cdot Z_e A = 1$, set Y_e at EOD.
6. At next EOD
   a. Set Z_e
   b. Reset A

7. Return to 1.
8. When $Y = Y_2$ $(Y_e \cdot C)$, set B at EOD.
9. Return to 1.
10. When $A \cdot B \cdot C \cdot Z_e = 1$, STOP at EOD.

The four motor control signals developed in the scan control programmer and their logic expressions are:

$$X_e = X_1 + X_2$$

$$Y_e = Y_1 + Y_2$$

$$Z_e = Z_1 + Z_2$$

$$s = X_e X_s + Y_e Y_s + Z_e Z_s$$

These logic equations demonstrate that the scan sequence is entirely controlled by a triplet of Flip-Flops in each channel, i.e., the X_{1FF} (F-23), X_{2FF} (F-25), and Y_{sFF} (F-24) for the X channel, Y_{1FF} (F-26), Y_{2FF} (F-28), and Y_{sFF} (F-27) for the Y channel, and Z_{1FF} (F-29), Z_{2FF} (F-31), and Z_{sFF} (F-30) for the Z channel. These Flip-Flops are, in turn, controlled by the gated networks shown in drawing 1-6-A(5), which implements the input logic functions listed in Table VIII-D-4.

To aid in understanding the scan control program, a flow diagram for the scan sequence in the Z-X-Y mode is given on drawing 1-6-A(11). This diagram shows the operations involved in scanning first along the Z-axis in a positive direction and then back in the negative direction after transversing one segment along the X-axis. Table VIII-D-4 should be eferred to in tracing through the flow diagrams to assist in understanding the detail logic control of the gating networks and the A(F-21) and B(F-22) control Flip-Flops.

Table VIII-D-4 CONTROL INPUTS TO PROGRAMMER FLIP-FLOPS

Flip-Flop	Direct Reset Input	Set Gate Input	Reset Gate Input	Clock Input
X_{1FF}(F23)	$\overline{D_{xd}}(X_2 + Y_1 + Y_2 + Z_1 + Z_2)$	$\overline{X_s}(\overline{C \cdot X_e})$	$X_s(\overline{C \cdot X_e})$	$D(P_1S_e + P_2\overline{A}CZ_e)\ (C \cdot X_e)$
X_{2FT}(F25)	$\overline{D_{Xd}}(X_1 + Y_1 + Y_2 + Z_1 + Z_2)$	$X_s(\overline{C \cdot X_e})$	$\overline{X_s}(\overline{C \cdot X_e})$	$D(P_1S_e + P_2ACZ_e)\ (\overline{C \cdot X_e})$
X_{SFF}(F24)	Set XYZ (+)	$\overline{X_s}$ (toggle)	X_s (toggle)	$C \cdot X_e$
Y_{1FF}(F26)	$\overline{\overline{D_{yd}}(X_1 + X_2 + Y_2 + Z_1 + Z_2)}$	$\overline{Y_s}(\overline{C \cdot Y_e})$	$Y_s(\overline{C \cdot Y_e})$	$D(P_1\overline{A}CX_e + P_2ACZ_e)\ (\overline{C \cdot Y_e})$
Y_{2FF}(F28)	$\overline{\overline{D_{yd}}(X_1 + X_2 + Y_1 + Z_1 + Z_2)}$	$Y_s(\overline{C \cdot Y_e})$	$\overline{Y_s}(\overline{C \cdot Y_e})$	$D(P_1\overline{A}CX_e + P_2ACZ_e)\ (\overline{C \cdot Y_e})$
Y_{SFF}(F27)	Set XYZ (+)	$\overline{Y_s}$ (toggle)	Y_s (toggle)	$C \cdot Y_e$
Z_{1FF}(F29)	$\overline{D_{zd}}(X_1 + X_2 + Y_1 + Y_2 + Z_2)$	$\overline{Z_s}(\overline{C \cdot Z_e})$	$Z_s(\overline{C \cdot Z_e})$	$D(P_2S_e + P_1ACX_e)\ (\overline{C \cdot Z_e})$
Z_{2FF}(F31)	$\overline{D_{zd}}(X_1 + X_2 + Y_1 + Y_2 + Z_1)$	$Z_s(\overline{C \cdot Z_e})$	$\overline{Z_s}(\overline{C \cdot Z_e})$	$D(P_2S_e + P_1ACX_e)\ (\overline{C \cdot Z_e})$
Z_{SFF}(F30)	Set XYZ (+)	$\overline{Z_s}$ (toggle)	Z_s (toggle)	$C \cdot Z_e$

g. Vernier Scan Memory Logic

This portion of the scan control logic is used only in the Vernier scan mode. Its purpose is to prevent reentry to the automatic mode unless the X, Y, and Z positions have been returned to the point at which Vernier scan was initiated. The X and Y channels are identical and the Z channel differs only in the addition of two gates, G-103 and G-107. See drawing 1-6-A(6). The operation of the X channel is described in detail followed by a description of the differences in the Z channel.

All Flip-Flops in this portion of the logic are initially cleared by the time delay relay. Following transfer to Vernier scan, pulses will occur at X_1 - 1 or X_2 - 1 whenever the X position level is actuated. For example, if the lever is moved to the X- position, a pulse will appear at X_1 - 1. This will enter F-32 and will toggle this Flip-Flop on its trailing edge. The X_1 - 1 pulse is also used as a reverse count command to gate G-115. The Flip-Flop pair operate as a backward counter for pulses on the X_1 - 1 line and as a forward counter for X_2 - 1 inputs.

In addition to the counter operation of F-32 and F-35, two other Flip-Flops are used in the X channel. These are F-38 and F-41. If the first pulse to enter the system is on line X_1 - 1, the output of G-124 sets F-38 via G-130. If the first pulse had been on line X_2 - 1, F-41 would be set. The state of F-38 and F-41 thus indicate whether the original displacement had been to the right or to the left. When any displacement is indicated, G-142 provides a scan-inhibit to prevent reentry to the auto scan mode.

Motion may continue in the same direction or may be reversed. However, when the two stage counter reaches a count of four in either direction, motion may not continue in that direction. Neither F-38 or F-41 may be reset until the counter returns to zero and a scan stop A pulse occurs. Scan stop A occurs only when the system is pulsed back to the origin. The Z channel operates exactly as the X (or Y) channel if the Z increment is in the five position. With the switch in the 2 position, the Z motion is limited to one increment (0.001 in.).

After operating in the Vernier mode, the operator must pulse any axis for which a reset indicator is on, in the direction indicated by the lamp, until the lamp goes out. When all lamps are out, the auto push-button may be pressed and the system will return to programmed scans.

h. BCD Selector Switch Input Logic

In this section the signals for activating the BCD selector relays are produced. It consists of simple gates and inverters. The X_e-2, Y_e-2, and Z_e-2 are the enable signals produced in the scan program selector logic. The S-U line is in the one state only during set-up time (origin search). During set-up the output of I-74 will be in the zero state, regardless of the value of the sign-2 signal. The output of I-76 will provide an enable signal for gates G-148, G-149, and G-150. The first phase of the set-up mode is to seek X_1. X_e-2 will be in the one state which will result in a one state at the output of I-80. This line controls the relay for the X_1 selector switch. When the Y_e line switches to the one state, an output will appear on line Y_1-2, and on Z_1-2 when the Z_e switches to a one.

During normal scan operations, the S-U line remains in the zero state cutting off I-74. The inputs to the gates are now controlled by the sign-2 line. For a one on the sign line, gates G-145, G-146, and G-147 will be enabled. This will produce outputs on the X_2, Y_2, or Z_2 lines depending upon which enable is on. This in turn selects the positive boundary switch.

i. Clock and Dwell Logic

This portion combines standard logic cards with one special card. The special card contains two unijunction transistors together with NPN transistors to gate them off, see drawing 1-6-A(8). Both unijunctions would operate as multivibrators if the transistor shunting its timing capacitor were turned off. In the lower circuit this is permitted to occur to develop the drive pulses for the stepper motors. When the clock enable, which originates in the scan start-stop logic (drawing 1-6-A(3)), switches to the one state, the output of I-83 drops to zero. This turns off the 2N3904 transistor and the unijunction is permitted to oscillate. Pulses from the unijunction are coupled to the clock line through I-85, I-86, and PD-5. The 50 pf capacitor serves to widen the pulse. Clock pulses are also coupled to the toggle input of F-43. The purpose of this will be discussed as part of the dwell logic.

When the clock enable line returns to zero, the output of I-83 switches to the one state. The clock timing capacitor is shorted by the 2N3904 and the clock stops. Gate G-151 has all three inputs enabled providing the auto-scan and stop lines are in the one state. This is the normal state. The 2N3904 in the dwell circuit now turns off and the 200 MF timing capacitor begins to charge. When the unijunction fires F-43 is set. The EOD line rises to the one state which sets F-2 in the start-stop logic. This initiates a new clock enable pulse and the clock MV restarts. The first clock pulse toggles F-43 to the clear state, ending the EOD pulse. The clock control Flip-Flop, F-2, in the start-stop logic is now permitted to respond to pulses at its toggle input. At the end of a complete automatic scan sequence, the stop input to G-151 drops to zero, preventing any further dwell pulses and consequently any further clock enable pulses.

When the system in initially turned on, the stop line and the output of I-83 will be in the one state.

Auto-scan, however, will not switch to the one state until the set-up cycle ends. This results in a dwell pulse to start the automatic clock recycle operation.

j. Camera Shutter and TV Blanking Logic

This circuitry synchronizes the TV unblanking signal with the reed switch on the derotation drive. Once per revolution the TV system is unblanked for exactly two fields and then blank again. This is accomplished in the circuitry shown in drawing 1-6-A(10).

The input signal at J1-1-6 (a BNC connector) is the vertical drive pulse from the camera control unit. See Section B. This pulse is coupled to the toggle input of F-45. The three stages F-45, F-46, and F-47 are connected as binary counters but are inhibited by the output of F-44 connected to their clear lines. F-44 is normally in the cleared state.

When the reed switch contacts close (connected through F7-1-6), F-44 is toggled, releasing the clear lines of the three stage counter. The counter may now begin counting vertical drive pulses. The gate G-153 is connected such that its output will drop to zero during the fifth and sixth fields after counting begins. At the beginning of the seventh field, G 152 provides a clear pulse to F-44.

A positive unblanking pulse is available at J2-1-6 (0 to +5 volts), and negative (+5 to 0 volts), at J3-1-6.

During the time that F-44 is set, the camera shutter may be actuated. This is done by holding the camera button, starting just after an unblanking of the 17 inch monitor, and releasing it after the shutter operation is heard.

The blanking operation may be turned off by closing the switch which grounds the output of G-153. This permits observation of an unflickering presentation on the 8 inch monitor to aid in focusing the camera optically.

k. Position Control Logic (Chassis 3-5)

The position control logic is located in the special equipment rack in the laminograph room. Two basic functions are accomplished by this circuitry. The first being the interfacing between "Eccologic" of the motor driver amplifiers. "Eccologic" levels are 0 and +5 volts, while the motor driver operates with negative going pulses, 0 to -6 volts. The interface circuitry is shown in drawing 3-5-A(4). The output transistors have their emitters returned to -6 volts. This supply is obtained by Zener regulation of the -28 volt supply from the motor driver amplifier. The 1N431 Zener diodes perform the necessary level shift at the base of the output transistors. The transistors will be off when the gate output is zero and on for +5. The 6 NAND gates perform the routing of the clock pulses to the appropriate driver channels. For example, if the sign is plus, and X_e is in the "one" state, clock pulses will be routed to the X-forward channel. The X_e, Y_e, and Z_e are shown connected to the J7-3-5 on drawing 3-5-A(1). This is a 50 conductor cable and carries the three enable signals from the scan control logic, the polarity (sign) and returns the commutated encoder outputs and the optics positioning lines to the scan control logic.

The second control function performed by this circuitry is commutation of the encoder BCD lines. The overall wiring diagram for this function is shown in drawing 3-5-A(1). Again, the interface buffer is required. The basic logic levels for the position encoder is 0 and +12 volts. PNP transistors are used in the encoders which do not provide proper drive for "Eccologic." The buffers are simply emitter followers with protective diodes. A typical circuit is shown in drawing 3-5-A(2). The actual commutation is done with standard ECCo gates. The positive encoder commutator is shown in drawing 3-5-A(3). The total position control logic uses 8 plug-in cards, five being ECCo gates and three of special fabrication.

To fabricate this chassis refer to drawings: 3-5-C(1) the U-bracket support; 3-5-C(2), the motor drive logic chassis assembly; and 3-5-C(3), connector designation and location on the rear of the chassis.

7. Position Encoders (Chassis 4-2)

The position encoders selected for this system were manufactured by Theta Instruments.* These are of the brush type with integral electronic circuitry for non-ambiguous readout. Complete electrical schematics appear in drawings 4-2-A(1), 4-2-A(2), and 4-2-A(3). Both decimal and binary coded decimal outputs are available. The decimal outputs are used for the position display. The BCD signals are used in the control logic. The encoders for the X and Y axis are identical. These are Theta Model 321-CW-12B. The Z axis is a Model 323C-CW-12B. The decimal output signals are routed through three identical cables to the control console. The cables are designated as K_1, K_2, and K_3. The fact that the

*Theta Instrument Corporation, 22 Spielman Road, Fairfield, New Jersey, 07006.

cables are identical and therefore interchangeable, does not impose a hazard to the system. Interchanging cables would simply cause the scan program sequence to malfunction. The BCD signals are routed through the position control logic by three identical cables designated as T, U, and V. These signals are commutated and a selected set is routed to the control console via Cable F.

The position encoders require a 16 volt power supply. This supply is housed in the equipment rack of the laminograph room. Details relating to the dc supply is presented in Section H.

The connector drawings for the position encoders are 4-2-A(4) through 4-2-A(7). See the mechanical system description for details for encoder installation.

8. Stepper Motor Drive (Chassis 3-2)

The ICON Corporation stepper motor drive amplifier and power supply chassis (chassis 3-2) is an assembly of three ICON Corporation AD-3 motor driver cards and a 28 v dc power supply. This chassis supplies all the necessary power and internal phase sequence logic for driving each of the three Wright* power stepper motors in either selected direction of shaft rotation. These stepper motors are of the four phase (bifilar) winding type, but have only one phase (a phase is one half of each of the two bifilar windings) energized at a time, in contrast to other types of bifilar four phase stepper motors which have two out of the four phases energized at a time. The ICON Corporation AD-3 stepper motor drive cards provide this "one phase at a time" drive in the proper sequence for the respective motor shaft rotation directions. Since

*The manufacturing and sale of the former Wright Model 25L stepper motor is now carried out by the firm of Sigma Instruments Inc., 170 Pearl St., Braintree, Mass., 02185.

each of the Wright Model 25L stepper motors requires an input current of 1.85 amps steady state when it is not stepping, and when it is stepping, this current is effectively switched from phase to phase in accordance with a unique logic sequence internally generated by each of the ICON Corporation AD-3 motor driver cards (one sequence for one direction of shaft rotation, and the reverse sequence for the other direction of shaft rotation), each motor in effect is a constant load of 1.85 amp on the power supply, whether it is stepping or not. Thus the total (relatively constant) load on the ICON Corporation power supply, which is a part of chassis 3-2, is approximately 5.6 amp. The power supply is capable of supplying more than this load.

An input logic pulse which starts from a dc level of -6 v with respect to ground rises to 0 v with respect to ground, dwells at the 0 v level for at least 2.5 μsec, then falls again to a level of -6 v with respect to ground, will cause the stepper motor to advance one step in the forward direction (which in the laminograph machine is X, Y, or Z increasing), when this input logic pulse is applied to a forward input of an AD-3 driver card. A similar input logic pulse applied to the reverse input of an AD-3 driver card will cause the associated stepper motor to retreat one step in the reverse direction (which in the laminograph machine is X, Y, or Z decreasing). A sequence of such pulses with sufficient dwell between them to allow the stepper motor and its attached mechanical load (with its dominant inertial characteristic) to complete each step before another is begun, will result in an equal number of stepper motor 15° steps, in a shaft rotation direction corresponding to whether the pulses were applied to the forward or reverse input of the AD-3 driver card. The schematic of the AD-3 driver card is drawing 3-2-A(1). (Also see drawing 3-2-A(2) for helpful tabular information.)

The input cable to chassis 3-2 is cable H, which carries the forward and reverse input wires for each of the three stepper motor driver cards, signal ground, shield ground (it is a shielded cable), the positive side of the 28 v dc supply which is a part of this chassis (taken as an output to power some external loads), and a filtered negative voltage derived from the negative side of the 28 v dc supply which is a part of this chassis (also taken as an output to power some external loads). The output cable from chassis 3-2 is cable E, which carries six wires from the output of each AD-3 card to each corresponding motor load.

The major purchased item which constitutes most of the equipment designated chassis 3-2 is a "400 series" Model 410-6-1-0 with AD-3 drivers, available from the ICON Corporation, 156 Sixth Street, Cambridge, Massachusetts, 02142, 617/868-5400. The quoted price as of February 1968 is $775.00 FOB Cambridge. Delivery is possible in 2-3 weeks ARO. Additional items to be added to the terminal blocks of this stepper motor driver assembly are shown in Table VIII-D-5.

Connect these components to TB-1 in accordance with drawing 3-2-A(2). Check to see if a common bus connects pins No. 12 and 13 together with each AD-3 card socket (or the terminal blocks) and this bus also connects pins No. 12 and 13 of the three AD-3 cards together and to the minus side of the 28 v dc power supply. If this bus does not exist, it must be added (No. 18 AWG wire). Connect a wire from the minus side of the 28 v supply (at TB2-5 is one place to get it), to TB1-7 (No. 18 AWG wire).

Table VIII-D-5 PARTS LIST FOR STEPPER MOTOR DRIVE

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost[1]
R1-3-2	RC20GF	Resistor, fixed, composition, 100 ohm ± 10%, 1/2 w, Ohmite Mfg. Co.	1	$ 0.13
C1-3-2	600D-506G040DD4	Capacitor, electrolytic, aluminum, type 600D 50 mfd, 40 wvdc at 85°C, Sprague Electric Co.	1	$ 3.06

[1] Prices approximately as of 3/68

For the installation of this unit, the following drawings are necessary:

3-2-A(1) Schematic of ICON Corp. Motor Driver AD-3

3-2-A(2) Chassis Terminal Block Wiring Schematic Diagram, ICON Corp., 410-6-1-0 (with AD-3 drivers) Stepper Motor Drive

3-2-B(1) ICON Corp., 410-6-1-0 Stepper Motor Driver Chassis

9. Scan Stepper Motors (Chassis 4-1)

The three permanent magnet stepper motors used for the X and Y coordinate drive of the TV camera, and the Z coordinate drive of X-ray source, are of the four phase (bifilar) winding type, with six wires brought out. Only one phase (which is one half of a bifilar winding) is energized at a time, and rotation is achieved by switching the excitation from phase to phase, with the permanent magnet rotor following the switched magnetic flux vector in response to the geometry of the winding phase distribution. The direction of rotation is determined by the sequence of energization of the phases, and not a polarity reversal of the excitation applied to a given phase.

The stepper motor selected is the same model for all three applications (X, Y, and Z coordinate drives), and is similar to the Model 25L formerly manufactured by the Wright Division of Sperry Rand Corporation, Durham, North Carolina. In the interim between the design of this portion of the laminograph system and the publication of this report, the design and manufacturing rights for this particular model (along with some other models) were sold to another manufacturer. The "Wright" Model 25L is now manufactured and sold by Sigma Instruments, Inc., 170 Pearl Street, South Braintree, Mass., 02185. A summary of its pertinent specifications with a comment is given below:

Size 25 L

DC volts per phase	28 v
Current per phase	1.85 A
Input watts per phase	52 W
Stall torque, oz.-in.	120 oz.-in.
DC resistance per phase at 25 Deg. C., ohms	12.0 ohms
Step Angle	15 Deg.

Size 25L (Continued)

Max. controlled stepping rate, steps/sec (this is with no load attached to the motor)	250 steps/sec.
Rotation	Reversible
Rotor moment of inertia, oz.-in.^{2}	1.50 oz.-in.^{2}
Weight, lbs.	2.2 lbs.

The actual stepper motors required have the same electrical performance (or very close to it) as the Model 25L, but have some mechanical modifications, such as shaft protrusion at both ends instead of just at one end as in the standard Model 25L.

Connectors and hardware required for the three stepper motors are shown in Table VIII-D-6.

For the completion of the installation (electrical) of these stepper motors, the following drawing is necessary:

4-1-A(1) - Stepper Motor Plug Schematic

For proper support of these short stepper motor wire bundles to the respective connectors J1, J2, and J3 (and for proper support of these connectors), as well as for support of the branches of cable E which connect to them, a self-adhesive cable clamp called the Deklasp™ is recommended. The use of these obviates drilling holes into the laminograph structure itself, and their location can be readily changed if the initial choice is unsatisfactory. They are available from:

DEK Inc., Engineered Plastic Products
117 West St. Charles Road
Lombard, Illinois 60148

They are made of ABS plastic and come in a variety of sizes.

Table VIII-D-6 PARTS LIST FOR STEPPER MOTOR HARDWARE

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost[1]
J1-4-1	MS 3101A 18-12P-X	Connector, 6 pin, cable receptacle, male, Amphenol Corp.	1	$ 1.89
J2-4-1	MS 3101A 18-12P-Y	Connector, 6 pin, cable receptacle, male, Amphenol Corp.	1	$ 1.89
J3-4-1	MS 3101A 18-12P-Z	Connector, 6 pin, cable receptacle, male, Amphenol Corp.	1	$ 1.89
---	MS 3057A-10	Cable clamp, for shell size 18, cable receptacle, Amphenol Corp.	3	$ 2.27
---	AN 3420-6	Bushing, rubber, for cable protection	3	$ 0.30

[1]Prices as of 3/68

Cable E is to be made in accordance with its cable drawing by calculating its length and making the cable at the appropriate time after all of the chassis for the laminograph room station (Unit 3) have been installed, and the laminograph machine itself is assembled and in its final location.

10. The Jarrell-Ash Microfocus X-Ray Unit

a. The X-Ray Source and Power Supply

No additional safety interlocking for equipment or personnel protection shall be provided beyond that provided by the Jarrell-Ash main console before modification and as normally supplied by the manufacturer. All existing safety interlocking features shall be retained.

An audible alarm shall sound in the laminograph room when the X-ray source is turned on with filament current and anode voltage applied.

These design criteria are mainly for operator and equipment safety during all conceivable conditions of normal modes of laminograph operation and maintenance, with a few provisions for operator or equipment protection during abnormal or careless operation. It is recommended that the operator's manual for the Jarrell-Ash Multifocus X-Ray Unit be studied carefully to become aware of the correct operating procedures and precautions required. In addition to all the personnel safety aspects associated with the operation of the X-ray source, and the equipment safety aspects associated with the operation of the Jarrell-Ash main console (described in the operator's manual), the equipment safety of the image orthicon tube in the TV camera is of paramount importance.

CAUTION

BE SURE TV CAMERA IS BLANKED OR TURNED OFF BEFORE ALTERING OR DEFEATING ANY INTERLOCK FUNCTIONS

The X-ray control subsystem derives all of its power from the 230 volt ac single phase input to the Jarrell-Ash main console (Unit 2); this includes the X-ray Control Interface Chassis (chassis 3-1) and the X-ray Control Chassis (chassis 1-2). For this reason the X-ray subsystem may be operated independently from all other subsystems of the laminograph.

For the following detailed discussion of the X-ray subsystem control, refer to drawing 0-0-A(2). The operation of the control shall be discussed in the sequence of normal operation, from a "cold" start of the X-ray subsystem, with the latter stages of operation controlled from the operator's station outside the laminograph room.

Before attempting to operate the X-ray source, especially before attempting to establish a vacuum in the system, be sure to study the Jarrell-Ash 80-000 microfocus X-ray unit manual carefully, with particular attention to pages 31 and 32 of that manual. If the vacuum roughing pump is started, and the diffusion pump is started soon afterwards, the equipment is ruined, because no safety interlocking is provided; there is total dependence on operator skill and judgment.

In order to operate the X-ray equipment, beginning from a completely "cold" start (with atmospheric pressure inside the X-ray tube), the operator must enter the laminograph room to start the vacuum roughing pump. The vacuum pumping switches are not duplicated at the operator's station outside the laminograph room, because the operator must listen to and check the X-ray equipment itself as the tube is being pumped down. (See the Jarrell-Ash Operator's Manual.) After the roughing pump is started, a suitable time period must elapse before the diffusion pump is started. After the cooling water valve has been opened, the diffusion pump is started, and a longer period of time must elapse before the vacuum gage at Unit 2 (in the laminograph room) is turned on to its high pressure range for a brief vacuum check. The vacuum gage knob at Unit 2 must always be returned to the "off" position immediately after this brief check to prevent damage to the vacuum gage sensing device. This checking is done intermittently until a pressure has been reached below the appropriate maximum pressure at which the X-ray tube may be safely operated. This pressure gage is duplicated at the operator's station outside the laminograph room, so that in the latter pumpdown stages, the operator may retire from the laminograph room to the operator's station, and monitor the pressure in the same way at that station.

In order to establish control at the operator's station outside the laminograph room, the operator must turn off the laminograph room lights, and completely close the laminograph room door. Both must be done, and it is possible to do them only in this sequence. When this is accomplished, transfer of control to the operator's station outside the laminograph room is indicated by illumination of indicator legend light 12, "Control at this Station." Under these conditions, all relays except CR4 and CR5 are dropped out. If the anode voltage controls at both operating stations are set at zero, pressing the start button at the operator's station outside the laminograph room activates relays CR6 and CR3. Upon release of the start pushbutton, relay CR6 drops out, because of diode D12, but relay CR3 remains activated because of its own lock-in contact. Momentary activation of CR6 causes power contactor 1RY4 (in Unit 2) to be activated, and it remains activated due to CR3. Activation of 1RY4 energizes the filament variable autotransformer VAT 1 (in Unit 1), and energizes the anode high voltage variable autotransformer VAT 2 (in Unit 1). The "X-RAY ON" indicator lights at both operator's stations are illuminated, and the audio alarm in the laminograph room goes on. Now the filament current, anode voltage, and bias resistance may be adjusted in accordance with the technique described in the Jarrell-Ash operator's manual, until desired X-ray operating conditions are attained. As soon as the anode voltage control is turned up slightly from zero, the relay CR5 drops out, but this affects nothing else.

In a normal orderly shut-down of the X-ray source from full operation, the anode voltage is reduced to zero, then the filament current is reduced to zero. The "stop" pushbutton is pressed, which drops out relay CR3 and momentarily activates relay CR7. This drops out the power contactor 1RY4, so that only the vacuum pumping system remains in operation. If anode voltage and filament current are not reduced to zero, pressing the "stop" pushbutton still causes the power contactor 1RY4 to drop out. If the operator departs from the operator's station outside the laminograph room, with the X-ray source in full operation, and anyone attempts to enter the laminograph room, relay CR1A (along with relays CR1B, CR2A, CR2B, and CR8) is activated, which causes 1RY4 to drop out, and it stays dropped out even after reclosing the laminograph room door, so that the X-ray hazard is removed.

In order to establish control at the operator's station inside the laminograph room, the operator must open the door to the laminograph room. This activates relays CR1A, CR1B, CR2A, CR2B, and CR8. If the room lights are then turned on, these relays lock in through a contact of the room light control relay, CR1. If the laminograph room door is subsequently closed, these relays all remain activated. If the anode voltage controls at both operating stations are set at zero, pressing the "start" button at the operator's station (Unit 2) initiates the usual manner of X-ray source operation, similar to that described for operation from the other operator's station.

The relay CR8 has external components associated with it to make it a time delay on drop out relay (time delay approximately one second), but it has normal pickup with no delay. This is to give a little safety margin in case incandescent lights are used in the room, and they are switched off with the door closed. In this case the filaments will have cooled completely and the room is truly dark before the TV camera is unblanked. Of course similar time delay action occurs upon closing the laminograph room door, but in this case it is not essential. The normally open contact of relay CR1B, that is in series with the relay coil of CRL, is also a guarantee of no overlap occurring, so that relay CR1B (and consequently CR8) must be activated before relay CRL (which switches on the room lights) can be activated.

The relay CR9 operates in conjunction with the defeat pushbutton to establish a special set of operation conditions for the X-ray subsystem. The defeat pushbutton is located on the front panel of the X-ray control interface chassis (chassis 3-1) located in Unit 3, inside the laminograph room. After the laminograph room door is closed, the defeat pushbutton may be pressed. This activates relay CR9 and holds in as long as the laminograph room door remains closed. The laminograph room lights may now be turned on and off at will, from inside the laminograph room, and control of the X-ray source remains at the operator's station in the laminograph room. In this situation the TV camera is blanked all the time, regardless of whether the room lights are on or off. This special mode is necessary to perform certain X-ray tests which require visual observation of the equipment at low light levels.

Examination of the basic circuit of the X-ray source will reveal that in the simple series circuit of the high voltage anode supply (which is said to be variable from 0 to 60 kV), X-ray tube, and "bias" resistor (which actually consists of a "coarse" adjustment of resistors in steps, in series with a "fine" adjustment rheostat), the point chosen for ground is between the minus side of the high voltage supply and one side of the "bias" resistor. The other side of the "bias" resistor is connected to the X-ray tube filament (center-tap). It would appear that with reasonable values of X-ray tube anode current, and with reasonable values of the "bias" resistance, very high potentials above ground could be developed as a consequence of the voltage drop across the "bias" resistor. It would appear that potentials of as high as several thousand volts might occur, and thereby constitute a hazard to the operating personnel. In fact, this cannot occur, due to an inherent "self-bias" current-limiting action of the X-ray tube itself. There is a negative feedback of the steady-state X-ray tube current which raises the X-ray tube cathode (or filament) potential with respect to ground. Since the metal walls of the X-ray tube, and in particular, a metal shield near the filament, are maintained at ground potential all of the time, a "virtual grid" effect takes place, which tends to bias the tube current to lower values. In effect, the X-ray tube filament (and hence the highest potential point of the "bias" resistor) can never become more positive than approximately 300 v above ground, regardless of the value of "bias" resistance, with tube current regulated to give this value or less for any setting of the "bias" resistance.

The meter which is calibrated as the "kilovoltmeter" to read the acutal anode potential is in fact a microammeter which is in series with a calibrated resistance (1R4). The addition of a similar microammeter in series with the original meter (1M1) provides simultaneous dual monitoring of anode voltage and does not affect this calibration, even though it may appear unusual to connect two "kilovoltmeters" in series.

b. <u>Jarrell-Ash Main Console Modifications</u>

Modifications to the Jarrell-Ash main console, as supplied by the manufacturer, are required to convert it into the section of the X-ray subsystem described as Unit 2. Principally these modification consist of the alteration of internal wiring, and addition of wiring to a panel box receptacle which is mounted on a sidewall of this console. A certain number of small components are added to the internal circuit, and certain components are deleted from the internal circuit by having their wiring disconnected, but they may be left physically in place. As supplied by the manufacturer, this console contains all of the components shown on drawing 2-0-A(1) with schematic wiring interconnections as shown on this drawing. The vacuum gage is not shown on this drawing, but an applicable schematic diagram of the Fredericks Company Model 7A2-1-CHS vacuum gage normally supplied with the Jarrell-Ash console, is given in drawing 2-0-A(7). The entire vacuum gage system normally supplied should be replaced with a special vacuum gage system supplied by the Fredericks Company, Huntingdon Valley, Pennsylvania, 19006, in accordance with the specification drawing 2-0-A(6) supplied to them.

In order to perform the modifications to the Jarrell-Ash main console, the following drawings are required:

- 2-0-A(1) Jarrell-Ash 80-000 Multifocus X-Ray Unit Schematic (Original Unmodified Unit)
- 2-0-A(2) Jarrell-Ash 80-000 Multifocus X-Ray Unit Schematic (Modified Internal Wiring)
- 2-0-A(3) Jarrell-Ash 80-000 Mutlifocus X-Ray Unit Schematic Overlay (Modified Internal Wiring)
- 2-0-A(4) Jarrell-Ash 80-000 Multifocus X-Ray Unit Panel Box Receptacle Schematic

2-0-A(5)	Jarrell-Ash 80-000 Multifocus X-Ray Unit P1-2-0 (Test Plug) Schematic
2-0-A(6)	The Fredericks Company Model 7A2-1-CHS Vacuum Gage Modified (Specification Drawing)
2-0-C(1)	Detail of Box Receptacle Location on X-Ray Cabinet (Unit 2-0)

Provide mounting holes for the panel box receptacle J1-2-0 in the approximate location shown on drawing 2-0-C(1). Note that is location and wiring should not impair access to existing equipment in the console, such as the vacuum roughing pump. Make all internal wiring changes in accordance with the cited schematic drawings, keeping in mind that these are schematic drawings, and not wiring diageams. Actual wire routing of the console may exist in any of a variety of ways, each way being in agreement with the schematic drawing 2-0-A(1). Change the actual wiring so that it conforms to the schematic drawing 2-0-A(2) in the schematic sense. Mount lug type terminal strips in appropriate locations to accommodate mounting of the Zener diodes. Diodes Z1, Z2, and Z3 will mount on a 6 lug No. 858 strip, Z4 will mount on a 3 lug No. 857 strip, and Z5 will mount on a 3 lug No. 857 strip. Allow enough cable slack to permit removal of the panel to which the box receptacle is mounted, for servicing. Caution: do not drill into or mount anything on the high voltage power supply "tank." In general, all modifications should be made in such a way as to not impair access to the components which will require maintenance and inspection.

Wire the test plug P1-2-0 in accordance with the schematic drawing 2-0-A(5). The purpose of the test plug is to serve as a maintenance aid for troubleshooting the Jarrell-Ash 80-000 multifocus X-ray unit. When this test plug is inserted into the box receptacle J1-2-0, the internal wiring of Unit 2 is restored to the original unmodified schematic condition, and most normal troubleshooting procedures apply, with the Jarrell-Ash machine acting as a unit entirely independent of the laminograph system. Unit 2 should never be operated without either the test plug P1-2-0, or the cable B plugged into J1-2-0. (The purpose of the zener diodes added is to provide an extra margin of safety in case this warning is ignored.) If the test plug P1-2-0 is used in place of cable B, the TV camera must be continuously blanked or preferably turned off, because the automatic interlocking to turn it off has been interrupted. (A through circuit is provided in pins r and s of J1-2-0, which automatically blanks the TV camera if cable B is not plugged in - as an extra margin of safety in case this warning is ignored.)

A list of the parts required to convert the Jarrell-Ash 80-000 multifocus X-ray unit as supplied (the unit as supplied should include the special modified vacuum gage system installed, with additional loose parts accompanying the unit) into Unit 2, is presented in Table VIII-D-7.

The special vacuum gage system should be supplied by the Fredericks Company, Huntingdon Valley, Pennsylvania, 19006, since it is a minor modification of their Model 7A2-1-CHS. The specification drawing 2-0-A(6) has most of the requisite information, but additional clarification is helpful. The added potentiometer designated P3 can be a duplicate of P1. Wiring on the terminal block 3000-10 must be rearranged to make terminals 8, 9, and 10 available for external wiring, as shown in the drawing. If this is not feasible, an additional terminal block should be provided, with appropriate terminal identification in agreement with the accompanying drawing. A General Electric Type 152 2-1/2 in. rectangular DC microammeter, Catalog No. 157 111 CFCF, 0 to 20 microamp range, but with a blank meter face, should be supplied to the Fredericks Company, or else ordered by them. This meter should be calibrated and marked by

Table VIII-D-7 PARTS LIST FOR JARRELL-ASH MAIN CONSOLE MODIFICATION

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total[1] Cost
J1-2-0	MS 3102A 28-21S	Connector, type MS, 37 pin, box receptacle, Amphenol Corp.	1	$ 3.16
P1-2-0 (test plug)	MS 3106A 28-21P	Connector, type MS, 37 pin, straight plug, Amphenol Corp.	1	$ 4.20
Z1-2-0, Z2-2-0	1N3051	Semiconductor device, zener diode, 1 W, 200 v ± 20% Motorola Semiconductor Prod.	2	$ 5.90
Z3-2-0	1N3036	Semiconductor device, zener diode, 1 W, 47 v ± 20% Motorola Semiconductor Prod.	1	$ 2.85
Z4-2-0, Z5-2-0	1N4742	Semiconductor device, zener diode, 1 W, 12 v ± 10% Motorola Semiconductor Prod.	2	$ 2.52
---	858	Terminal strip, lug type, 6 lugs, H. H. Smith Co.	1[2]	$ 0.70
---	857	Terminal strip, lug type, 3 lugs, H. H. Smith Co.	2[3]	$ 0.40

[1] Prices approximately as of 3/68

[2] Sold 10 to a package; price for 1 package

[3] Sold 10 to a package; price for 1 package. These are used in chassis 3-1 also.

the Fredericks Company, to operate from P3 just as the meter normally supplied operates from P1. The calibration will be for correct operation with only one meter switched in at a time, never both, but with both P1 and P3 in the circuit all of the time. This marked and calibrated 2-1/2 inch "extra" meter will be part of the "special" vacuum gage to be installed by Jarrell-Ash, but will be a separate item shipped along with it, since it must mount in a panel elsewhere in the laminograph system.

Unit 2 is installed in the laminograph room, close enough to the laminograph machine to facilitate connections of the high voltage, filament leads, and oil tubes to the X-ray tube on the laminograph machine. Unit 2 can be placed near the wall, but should be capable of being easily moved away for inspection and maintenance. The front panel should be readily accessible for X-ray source control at this operator's station.

c. X-Ray Control Interface Chassis and Safety Interlocks (Chassis 3-1)

The X-ray control interface chassis principally contains an unregulated unfiltered full-wave rectified DC relay power supply, and a number of relays required for the implementation of the switchovdr interlocking and control functions of the dual station X-ray control. It also contains the "X-ray on" audio alarm, and the "defeat" pushbutton; these are mounted on the front panel.

Cable C, which connects from this chassis to the various room light switches, the room lights and lighting supply circuit, and the door interlock are all considered a part of this chassis, although they are physically separate. Cable C and the other components are shown on the system block diagram, 0-0-A(1).

In order to construct this chassis, the following drawings are required:

3-1-A(1)	X-Ray Control Interface Chassis Schematic
3-1-B(1)	X-Ray Control Interface Chassis Front Panel Layout
3-1-C(1)	X-Ray Control Interface Chassis Components Layout
3-1-C(2)	X-Ray Control Interface Chassis Connector Layout

A parts list for the parts required to construct the X-ray control interface chassis (chassis 3-1) is shown in Table VIII-D-8.

Layout of the components on the chassis is shown in drawing 3-1-C(1). This layout is approximate, and may be varied. Allow clearance toward the front of the chassis for the panel-mounted components, and wiring space toward the rear of the chassis for the box receptacle connectors mounted there. Some required grommeted holes for wiring passage through the chassis are not shown on the layout. Provide a hole near T1 and a hole near T2, for transformer lead passage, and a hole near each of relays CR2A, CR2B, and CRL, for lead passage to all utilized contacts and coils. Provide a hole near relay CR8, for lead passage through the chassis to the top-mounted time delay components. In laying out these holes, allow room between rows of relays for wiring bundles. Additional holes may be required for cable clamps to secure wiring bundles. Affix all the indicated labels and add the following warning at the rear, next to the line of connectors:

WARNING - 230 V AC VOLTAGES

Table VIII-D-8 PARTS LIST FOR X-RAY CONTROL INTERFACE AND SAFETY INTERLOCKS

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost[1]
Sonalert-3-1	SC110	Audio alarm device, "Sonalert," 110 v AC/DC, P.R. Mallory & Co.	1	$ 8.75
S1-3-1	2201	Snap-action momentary pushbutton, (N.O.) series 2000, red button, Grayhill, Inc.	1	$ 2.05
---	10C1015	Button guard, for series 2000 pushbutton, Grayhill, Inc.	1	$ 0.25
CR1A,CR1B,-3-1	62R6-24DC	Control relay, series 62, 6PDT, 24 v DC coil, Sigma Inst. Inc.	2	$ 9.70
---	AD26	Socket for control relay 62R6, Sigma Instruments Inc.	2	$ 1.90
CR2A,CR2B,-3-1	PM17DY(24 v DC)	Power relay, PM 17, 4PDT, 24 v DC coil, Potter and Brumfield	2	$24.80
CR3,CR8,-3-1	62R4-24DC	Control relay, series 62, 4PDT, 24 v DC coil, Sigma Inst. Inc.	2	$ 7.60
---	AD24	Socket for control relay 62R4, Sigma Instruments Inc.	2	$ 1.30

[1] Prices as of 3/68

Table VIII-D-8 (Continued)

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost[1]
CR4-3-1	KRP11A(240 v AC)	Control relay, DPDT, 240 v AC coil, Potter and Brumfield	1	$ 6.75
---	146-103	Octal socket for control relay KRP11A, Potter and Brumfield	1	$ 1.50
CR5, CR6, CR7, CR9,-3-1	62R2-24DC	Control relay, series 62, 2PDT, 24 v DC coil, Sigma Inst. Inc.	4	$13.60
---	AD22	Socket for control relay 62R2, Sigma Instruments Inc.	4	$ 2.20
CRL	PR11DY(24 v DC)	Power relay, DPDT, 24 v DC coil, Potter and Brumfield	1	$ 6.75
T1	C1-13363	Power transformer, 100 VA, 60 Hz, Primary 240/480 v, secondary 120 v, Milwaukee Transformer Co.	1	$11.05
T2-3-1	23V104	Rectifier transformer, 50/60 Hz., primary 115 v, secondary 24/27/30/33/36 at 3A.,Thordarson-Meissner	1	$12.00
C1-3-1	36D132G050 AA2A	Electrolytic capacitor, type 36D 1300 mfd, 50 wvdc, Sprague Electric	1	$ 1.86
---	(Allied Electronics 43E7973)	Mounting ring for 1-7/16 in. diam. electrolytic capacitor (C2)	1	$ 0.18

[1]Prices as of 3/68

Table VIII-D-8 (Continued)

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost [1]
SS-3	6RS21SA1D1	Thyrector surge suppressor, 25 v RMS working voltage, General Electric	1	$ 1.87
BR-3	MDA952-2	Bridge rectifier assembly, 6 A. av., 100 V_{RM}, Motorola Semiconductor	1	$ 3.50
D1 through D16,-3-1	1N4001	Silicon diode, "Surmetic" 1A.av 50 V_{RM}, Motorola Semiconductor	17	$ 7.65
R1-3-1	RC32GF	Resistor, fixed, composition 330 ohms, 10% tol., 1 W., Ohmite Corp.	1	$ 0.18
R2-3-1	RC32GF	Resistor, fixed, composition 10 ohms, 10% tol., 1 W., Ohmite Corp.	1	$ 0.18
S1, TS2-3-1	871	Terminal strip, lug type, 5 lugs, H. H. Smith Co.	2 [2]	$ 0.55
---	CB-662	Chassis base, steel, 18 gauge, zinc plated, 3 in. x 17 in. x 12 in., Bud Radio Inc.	1	$ 4.45
---	PS-1253	Relay rack panel, steel, 7 in. height, smooth gray finish, Bud Radio Inc.	1	$ 2.55
---	MB-449	Chassis mounting brackets, steel pair, Bud Radio Inc.	1	$ 1.95

[1] Prices as of 3/68

[2] Package of 10, but only 2 needed

Table VIII-D-8 (Continued)

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost[1]
J2-3-1	MS 3102A 28-21P	Connector, type MS, 37 pin box receptacle, Amphenol Corp.	1	\$ 3.16
J3-3-1	MS 3102A 36-15S	Connector, type MS, 35 pin box receptacle, Amphenol Corp.	1	\$ 3.97
J4-3-1	MS 3102A 28-2S	Connector, type MS, 14 pin box receptacle, Amphenol Corp.	1	\$ 2.29
---	HKP	Fuseholder, type HKP for 3AG fuse 1/4 in. x 1-1/4 in., Littlefuse, Inc.	1	\$ 0.37
F1-3-1	3AG	Fuse, type 3AG, standard, 1/8 A.	5[2]	\$ 0.78
R4-3-1	RC20GF	Resistor, fixed, composition 100 ohm ± 10%, 1/2 W., Ohmite Corp.	1	\$ 0.12
C2, C3,-3-1	96P-10496	Capacitor, fixed, paper 0.1 mfd ± 10%, 600 v.	2	\$ 4.22
J5-3-1	MS 3102A 20-7P	Connector, type MS, 8 pin box receptacle, Amphenol Corp.	1	\$ 1.19

[1] Prices as of 3/68

[2] Package of 5 is smallest unit which can be ordered

All silicon diodes which are connected direcly across relay coils are to be connected right at the coil terminals of the relay socket, if it has a socket, otherwise they are to be connected directly across the coil terminals at the coil terminal lugs. Note proper diode polarity with respect to the power supply polarity. R3, C2, and C3 are mounted on terminal strip TS2; D6, D7, R1, and R2 are mounted on terminal strip TS1.

Layout of the rear connectors and fuseholder is shown in drawing 3-1-C(2). Layout of the front panel is shown in drawing 3-1-B(1). Cables B, C, and D are to be made in accordance with the respective cable drawings. The lengths of the cables must be measured after all of the chassis for this cabinet rack unit have been constructed. Cable C will enter a steel thinwall conduit at some point in the laminograph room (it needs no sheathing inside the conduit) and this conduit shall be routed along the wall to a junction box. From the junction box one conduit shall go to the laminograph room light junction box (where wires to all the room overhead lights and the 115 v ac light supply circuit should be available). Another conduit shall go from the wall junction box to the wall light switchbox inside the laminograph room, then another conduit should go through the wall from this switchbox to the wall light switchbox outside the laminograph room door. Another conduit should go from the wall junction box inside the laminograph room to the switchbox or point at which the laminograph room door interlock limit switch is mounted. Variations on this thinwall conduit routing scheme are possible, so long as correct schematic connections according to the cable C drawing are made.

The wall light switches inside and outside the laminograph room which control the laminograph room lights are not conventional light switches, but are momentary pushbuttons. The DPDT limit switch, which is the laminograph room door interlock switch, should have a long actuator attached, and a suitable actuating boss should be attached to the door. The mounting of this limit switch should be mechanically adjustable so that the limit switch can be set to be just held actuated when the laminograph room door is fully closed. The slightest opening of the door should allow the switch to return to its unactuated state.

A parts list for parts required for the wall light switches and the laminograph room door interlock switch itself is shown in Table VIII-D-9.

d. X-Ray Control Chassis at Control Station (Chassis 1-2)

The X-ray control chassis at the operator's station contains all of the manual controls and meters required for the operator's station control and monitoring functions. These controls and meters by their functional nature are front panel mounted, so that only a small simple U-shaped bracket behind this panel is required to support the connector, which is the only item in this chassis not mounted on the front panel.

In order to construct this chassis, the following drawings are required:

1-2-A(1)	X-Ray Control Chassis at Control Station Schematic
1-2-B(1)	X-Ray Control Chassis at Control Station Panel Layout (with dimensions)
1-2-B(2)	X-Ray Control Chassis at Control Station Connector and Bracket Detail
1-2-B(3)	X-Ray Control Chassis at Control Station (panel legends)

A parts list for the parts required to co... uct the X-ray control chassis at the operator's control station (chassis 1-2) is presented in Table VIII-D-10.

Table VIII-D-9 PARTS LIST FOR WALL LIGHT SWITCHES

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total[1] Cost
Wall light push-button "ON"	2201	Snap-action momentary pushbutton, (N.O.) series 2000, red button, Grayhill, Inc.	2	$ 4.60
---	7Z1047 (Red)	Button cap, red, 1 in. diameter, accessory for "ON" pushbutton, Grayhill, Inc.	2	$ 0.80
Wall light push-button "OFF"	2202	Snap-action momentary pushbutton, (N.C.) series 2000, black button, Grayhill, Inc.	1	$ 2.30
---	7Z1047 (Black)	Button cap, black, 1 in. diameter, accessory for "OFF" pushbutton, Grayhill, Inc.	1	$ 0.40
Door interlock limit switch	Type DT	Snap-action momentary limit switch, DPDT contacts, long leaf actuator, Microswitch Division of Minneapolis-Honeywell	1	

[1] Prices as of 3/68

Table VIII-D-10 PARTS LIST FOR CONTROL CHASSIS AT CONTROL STATION

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total[1] Cost
VAT1-1-2	10B	Variable autotransformer, 120 v input, 50/60 Hz., 0-120 v output, 3 A, Superior Electric Co.	1	$10.00
I1-1-2	10EA2C1J4L(R) N1R1V13 X-RAY ON	Indicator light, series 10E, 115 v AC neon bulbs, legend panel - X-RAY ON, Masters Specialties Company	1	$20.00 (approx)
M1-1-2	157 141 LSLS	Ammeter, AC. 0-5 A, RMS, 2-1/2 in. rectangular case size, General Electric Co., Instrument Dept.	1	$15.64
M2-1-2	(Special item)	Milliammeter, DC, dual range, 0-1 ma, and 0-10 ma, 2-1/2 in. rectangular size (scaling resistors may be internal or external, but if external, they must be specified or supplied and are designated R12, R13-1-2), General Electric Company, Instrument Department	1	
M3-1-2	(Special item)	Microammeter, DC, 0-600 ma, 2-1/2 in. rectangular case size, scale to read 0-60 kilovolts, General Electric Company, Instrument Dept.	1	

[1]Current prices as of 3/68

Table VIII-D-10 (Continued)

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost [1]
M4-1-2	(Special item)	Microammeter, DC, 0-20 ma, 2-1/2 inch rectangular case size, scale to be blank with no markings (special markings for vacuum gage use to be added by The Fredericks Co., Huntingdon Valley, Pa.), meter supplier - General Electric Company, Instrument Dept.	1	
---	1012K11702	Hardware, mounting, for behind panel mounting (with bezel) of 2-1/2 in. rectangular case size meters, General Electric Co. Instrument Dept.	4	$ 4.60
I2-1-2	10EA2C1J3L(W) N1R1V14 CONTROL AT THIS STATION	Indicator light, series 10E, 28 v DC incandescent bulbs, legend panel - CONTROL AT THIS STATION, Masters Specialties Company	1	$20.00 (approx)
S1-1-2	PA 2522	Rotary selector switch, shorting type, 11 position, 3 pole, Centralab Div. of Globe-Union	1	$ 5.16
R1 through R10-1-2	Type 200, style 200-20, Stock no. 1860	Resistor, fixed, wirewound 100K ohms, 5% tolerance, "Brown Devil," 20 watts, Ohmite Mfg. Co.	10	$14.00

[1] Current prices as of 3/68

Table VIII-D-10 (Continued)

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost[1]
R11-1-2	MG100K	Resistor, vairable, wirewound potentiometer, rotary 100K ohms, 12.5 watts, Ohmite Mfg. Co.	1	$ 2.72
---	DS125-3-2	Knob, for S1-1-2 and R11-1-2 Raytheon Co., Industrial Components Division	2	$ 2.50
S2-1-2	81021AV	Toggle switch, SPDT, bat handle, wiping action, silver contacts, Arrow-Hart and Hegeman Electric Co.	1	$ 0.99
R12-1-2	(Special item)	Precision wirewound scaling resistor for M2-1-2 (if required only)	1	
R12-1-2	(Special item)	Precision wirewound scaling resistor for M2-1-2 (if required only)	1	
VAT2-1-2	216BU	Variable autotransformer, 240 V input, 50/60 Hz., 0-240 v output, 5 A., Superior Electric Co.	1	$24.00
S4-1-2	Type 10-722	Limit switch, snap-action, SPDT, pivoted roller lever actuator, Licon Div. of Illinois Tool Works (to be mounted on VAT2-1-2)	1	$ 2.65

[1] Current prices as of 3/68

Table VIII-D-10 (Continued)

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost[1]
S3-1-2	2201	Snap-action momentary pushbutton normally open, series 2000, Red button, solder terminals, Grayhill, Inc.	1	$ 2.05
---	7Z1047 (Red)	Button cap, red, accessory for pushbutton S3-1-2, Grayhill, Inc.	1	$ 0.40
S5-1-2	7-26B	Snap-action momentary pushbutton SPDT, series 2000, black button, Grayhill, Inc.	1	$ 3.50
---	7Z1047 (Black)	Button cap, black, accessory for S5-1-2 pushbutton, Grayhill, Inc.	1	$ 0.40
S6, S7-1-2	35-1 (N.O.)	Wiping contact momentary push-button, DPST, red button, series 35, solder terminal, Grayhill, Inc.	2	$ 2.80
---	7C1040	Decorative mounting nut for S6, S7-1-2, Grayhill, Inc.	2	$ 0.40
---	PS-1255	Relay rack panel, steel, 10-1/2 inch height, smooth gray finish, Bud Radio, Inc.	1	$ 2.55
J6-1-2	MS 3102A 36-15P	Connector, 35 pin, box receptacle, male, Amphenol Corp.	1	$ 3.97

[1] Current prices as of 3/68

Three of the meters to be mounted on this panel are special items, and require additional clarification. M2-1-2 is to be a dual-range DC milliammeter (0 to 1 and 0 to 10 ma) which duplicates the one used in Unit 2, but in the 2-1/2 inch rectangular case size. This is not a stock meter. The supplier must be contacted for the price and delivery, and to determine if the meter has "built-in" scaling resistors (and has what amounts to 3 terminals instead of just 2) or if external resistor(s) have to be provided. In the latter case, the values and tolerance must be determined. M3-2-1 is to be a dc microammeter (0 to 600 microamps) in the 2-1/2 inch rectangular case size, but the front scale must read 0 to 60 kilovolts (preferably with numbers for every 10 KV increment) with scale graduations each 1000 volts. Similarly, the supplier will have to be contacted for price and delivery of such a meter, and to determine if they can readily supply it with the required scale markings. The vacuum gage meter M4-1-2 must be a dc microammeter (0 to 20 microamps) in the 2-1/2 inch rectangular case size, and must have initially no markings at all on its face. It is to be supplied to the Fredericks Company, the vacuum gage equipment manufacturer, for special calibration and marking of its face.

Layout of the components on the panel is shown in drawing 1-2-B(1). The resistors R1 through R10 mount right on the decks of rotary selector switch S1-1-2. It is advisable to arrange them carefully and to span the middle deck, to achieve the correct switching sequence according to the schematic drawing 1-2-A(1). The variable autotransformer VAT2-1-2 and the snap-action limit switch S4-1-2 together comprise a mechanical assembly. A mounting bracket with provision for mechanical adjustment must be made to attach the switch to the variable autotransformer such that the switch is just actuated when the shaft of the autotransofrmer is rotated to the initial extreme where the output voltage is zero. It is possible to purchase this variable autotransformer and switch as a complete assembly (duplicating the one which is a part of the equipment of Unit 2) from the Jarrell-Ash Company.

After the panel is painted and the markings applied in accordance with drawing 1-2-B(3), make the connector mounting bracket as shown on drawing 1-2-B(2). Wire the chassis, and lace the wiring to the connector. Affix the following warning to a convenient location on the rear of the panel:

WARNING
230 V AC VOLTAGES

Cable A is to be made in accordance with its cable drawing after measuring its length after all of the chassis for this cabinet rack unit have been installed.

11. Lens Selector Subsystem

a. General

Because of the necessity of having a range of magnifications for the laminograph and the impossibility of design a "zoom" type system to meet the desired range of magnification and the required image quality, three separate lens arrangements were designed to provide 0.2X, 1.0X, and 4X magnifications. These separate magnifications required various separate lens subsystems, and of necessity included some means for achieving optimum focusing. The following functional table lists the position of various components at the three magnifications.

OPERATING MODE - LENS SELECTION

Element / Operating Mode	0.2X	1X	4X
0.2 X Lens	in	out	out
4 X Lens	out	out	in
Camera Tube	back*	forward*	back

*back is away from derotation lens and forward is toward lens.

The mechanical drive associated with the 4X lens is called the "turret," and the mechanical drive associated with the 0.2X lens is called the "slide," when discussed elsewhere in this report.

b. Subsystem Component Location

The lens selection control subsystem is divided into three physical sections. One section is the optics position control chassis (chass 3-3) located in the laminograph room rack (Unit 3). Another section is the group of three adjacent illuminated legend pushbuttons, located on the front panel of the scan control chassis (chassis 1-6), which is part of the operator's station (Unit 1) outside the laminograph room. The third section consists of the drive motors, ancillary solenoid clutch and limit switches which are respectively part of the "turret" mechanism, the "slide" mechanism, and the specially modified TV camera which has a means of moving the image orthicon tube fore and aft by a 2-speed motor drive. The limit switches on each of the three drives are for control purposes, and are not safety stops.

c. System Description

For the following detailed description of the optics position control, refer to drawing 3-3-A(1), the complete optics position control schematic. The system will first be described in terms of some of its design goals, general features, and operating characteristics, followed by a description of a specific sequence of operations in changing from one magnification to another.

Since each optical element of the system has only two defined positions, and since relays are required for switching and reversing motors, all the logic functions in this subsystem are performed with relays. There are eight relay functions required in the control system. Since it is desired to use plug-in relays of a readily available type, with a maximum number of contacts per relay of 3C (3PDT), some of the relays have to be "duplicated" to get the requisite number of contacts. Due to the complexity of the manner in which the 0.2X slide motor is reversed, and due to the requirement of many relay contacts for some of the relay functions, 12 relays are required. The diversity of the mechanical drives for the three optical elements imposes a condition of diversity of transit times for each of the two "changes" involved in going from one magnification to another (refer to the previous table), and each of these transit times is a random variable, so that the optics control system must be designed to accommodate any transit time for each "change," and also to accommodate any sequence of termination of motion of the two elements that have changed. Limit switches are used to provide the binary state feedback to indicate when an optical element is at one of its two defined positions, and they are also used to control the legend lamp readout of the state of the optical system. When the optics position control system is quiescent, only one out of the three illuminated legend pushbuttons is illuminated, as expected. When either of the non-illuminated pushbuttons is pressed momentarily, the optics position control system causes the motors to drive the optical elements to the required positions for the selected magnification. As a consequence of the design, all pushbuttons are dark while the optics system elements are in motion. If any of the pushbuttons are pressed while all are dark, there is no effect to alter the course of events leading to the previously selected magnification.

To describe a specific sequence of operations, assume that the optics position control system is quiescent with the optical elements in the required positions for the 0.2X magnification. The schematic representation of the optics position control system given by drawing 3-3-A(1) shows the system in this 0.2X initial state, and the ensuing description is in reference to this drawing. Assume that a transition to the 4X magnification is desired, so that the operator momentarily presses the "4X" pushbutton. Since all relays are initially dropped out, this momentary contact of S9 (the "4X" pushbutton) causes relay CR8 to pick up and hold through its own normally open (N.O.) contact. The pickup of relay CR8 in turn causes the pickup of relay CR1, CR4A, and CR4B. The pickup of relay CR1 causes the time delay-on-drop-out relay CR9 to pickup immediately, and this in turn causes the 4X lens drive motor to drive the 4X lens <u>into</u> the optical path of the optics system. The pickup of relay CR4B causes engagement of the 0.2X lens drive solenoid clutch, and it causes the 0.2X lens drive motor to drive the 0.2X lens <u>out of</u> the optical path of the optics system. Each drive continues, until the following events may take place. The 4X lens arrives at its destination (into alignment with the optical axis). This causes the actuation of limit switch S1, which in turn causes the drop-out of relays CR8 and CR1. The drop-out of CR1 de-energizes the time delay-on-drop-out relay CR9, but this relay stays closed throughout its one second delay interval, then it too drops out, which turns off the 4X lens drive motor. This one second of "additional" drive is to ensure that the 4X lens holder is driven solidly against its mechanical stop, which determines the accuracy of alignment of its axis with the optical axis of the system. It would appear that the drop-out of relay CR8 would stop the drive of the 0.2X lens out of the optical path of the system, short of the required distance, but this does not happen because relay CR4A is held closed with its own N.O. contact. When the 0.2X lens is fully off the optical path, the limit switch S4 is actuated, which causes relay CR4A to drop out. This in turn causes relay CR4B to drop out, which de-energizes the solenoid clutch and turns off the 0.2X lens drive motor. Now if the opposite "arrival" sequence had occurred, limit switch S4 would have been actuated first, which would stop the 0.2X lens drive at the proper time. The drive of the 4X lens towards the optical path would continue until limit switch S1 is actuated, which would stop the 4X lens drive at the proper time. Note that in either sequence of arrival, the "4X" illuminated legend is not lighted until limit switch S1 and relay CR4A have dropped out, so that the indicator does not come on until the optics position control is quiescent and optical elements are truly in the positions corresponding to the 4X magnification.

The sequence of operations corresponding to the other five possible optics position control "transitions" are detailed for each case on the optics system electrical control and readout - timing chart. Some similarities are noted, but special requirements arise when the image orthicon tube of the TV camera is one of the optical elements to be moved. When the image orthicon tube is in its "forward" position, it must be moved all the way to its "back" position before motion of the 4X lens into the optical path may begin, when the 1X to 4X transition is made. This "sequential" rather than "simultaneous" motion is required to eliminate the possibility of mechanical interference of these two elements. The opposite sequence is required in the 4X to 1X transition, with the 4X lens moved out of the optical path before forward motion of the image orthicon tube may begin.

d. Optics Position Control Chassis (Chassis 3-3)

The optics position control chassis (3-3) contains all of the relays required in the optics position control system. It has its own self-contained relay DC power supply (nonregulated and nonfiltered full wave rectified 24 v ac.) which is also used to power the illuminated legends of the pushbuttons and indicators on the front panel of the scan control chassis (chassis 1-6). The front panel of the optics position control chassis (chassis 3-3) has no components installed on it. The rear of the chassis has three connectors, plus the line cord entry grommeted hole.

In order to construct this chassis, the following drawings are required:

3-3-A(2)	Optics Position Control Chassis Schematic
3-3-C(1)	Optics Position Control Chassis (Chassis Layout)
3-3-C(2)	Optics Position Control Chassis (Rear Connector Layout)
3-3-C(3)	Optics Position Control Chassis (Box Chassis and Panel Assembly)

A parts list for the parts required to construct the optics position control chassis (chassis 3-3) is shown in Table VIII-D-11.

The layout of components on the chassis is shown in drawing 3-3-C(1). Allow adequate clearance between the rows of relay sockets for wiring and clamping to the chassis. A grommeted hole is required near T1 for wire passage through the chassis for T1 and the bridge rectifier BR. Avoid placing components in the region of the chassis adjacent to the portion of the rear where the box receptable connectors are to be mounted, to allow clearance for the large number of wires to those receptacles. Layout of the connectors is shown in drawing 3-3-C(2). Labels must be affixed to the chassis to identify connectors, fuses, their rating, etc.

In regard to wiring relay CR9 it is necessary to first identify its connector designations. When these are determined, for completeness, add the appropriate notations to drawing 3-3-A(2). Bench test this relay, and adjust the drop-out

Table VIII-D-11 PARTS LIST FOR OPTICS POSITION CONTROL CHASSIS

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total[1] Cost
CR1-3-3	62R2-24DC	Control relay, series 62, DPDT, 24 v DC coil, Sigma Inst. Inc.	1	$ 3.40
---	AD22	Socket for control relay 62R2, solder terminal, Sigma Inst. Inc.	1	$ 0.55
CR2, CR3B, CR4B, CR5B, CR6B, -3-3	KRP14D(24 v DC)	Power relay, type KRP 3PDT, 24 v DC coil, 5 A. contacts, Potter and Brumfield	5	$39.00
---	77M1P11	Relay socket, for KRP14D relay, 11 pin, Amphenol Corp.	5	$ 1.45
CR3A, CR4A, CR6A, CR7, CR8, -3-3	63R6-24DC	Control relay, series 62, 6PDT, 24 v DC coil, Sigma Inst. Inc.	5	$24.25
---	AD26	Socket for control relay 62R6, solder terminal, Sigma Inst. Inc.	5	$ 4.00
CR9-3-3	CHB38-70011	Time delay relay, with DPDT power contacts (15 A.) time delay on drop-out, adjustable 0-10 sec. 115 v AC coil, Potter & Brumfield	1	$22.50

1 Current prices as of 3/68

Table VIII-D-11 (Continued)

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost [1]
---	77M1P11	Relay socket, for CR9-3-3 relay, 11 pin, Amphenol Corp.	1	$ 0.29
T1-3-3	23V104	Rectifier transformer, 50/60 Hz., primary 115 v, secondary 24/27/30/33/36 at 3 A., Thordarson-Meissner	1	$12.00
SS-3-3	6RS21SA1D1	Thyrector surge suppressor, 25 v RMS working voltage, General Electric	1	$ 1.00
BR-3-3	MDA952-2	Bridge rectifier assembly, 6 A. av., 100 V_{RM}, Motorola Semiconductors	1	$ 3.50
D1 through D11-3-3	1N4001	Silicon diode, "Surmetic," 1 A. av., 50 V_{RM}, Motorola Semiconductors	11	$ 4.95
F1-3-3	3AG (Standard)	Type 3AG standard-blow fuse, 1 A., 1/4 in. x 1-1/4 in., Littlefuse, Inc.	1[2]	$ 0.30
F2-3-3	3AG (Slo-Blo)	Type 3AG slow-blow fuse, 1/4 A., 1/4 in. x 1-1/4 in., Littlefuse, Inc.	1[2]	$ 1.05
---	HKP	Fuseholder for type 3AG fuse, 1/4 in. x 1-1/4 in., Bussman Division of McGraw Edison	5	$ 1.85
---	AC-411	Chassis base, aluminum, 16 gage material, 7 in. x 15 in. x 3 in., Bud Radio, Inc.	1	$ 3.30

[1] Current prices as of 3/68

[2] Price of a box of 5 fuses, only 1 needed.

Table VIII-D-11 (Continued)

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost [1]
---	PA-1104	Relay rack panel, aluminum, 7 in. height, smooth gray finish, Bud Radio, Inc.	1	$ 2.80
J6-3-3	MS 3102A 28-12S	Connector, type MS, 26 pin, box receptacle, Amphenol Corp.	1	$ 3.20
J7-3-3	MS 3102A 18-1S	Connector, type MS, 10 pin, box receptacle, Amphenol Corp.	1	$ 1.43
J8-3-3	MS 3102A 20-27S	Connector, type MS, 14 pin, box receptacle, Amphenol Corp.	1	$ 1.86

[1] Current prices as of 3/68

delay for 1 second. The silicon diodes which are connected directly across relay coils are to be connected right at the coil terminals of the relay socket. Caution: observe diode polarity with respect to the power supply polarity as shown.

When fabrication of the laminograph system is near completion, and at least after the various mechanical drives (and their respective motors and clutches) for the three optical elements are installed, the fuses F3, F4, and F5 must be determined.

Cables G, S, W, and line cord Y are to be made in accordance with the applicable cable drawings, calculating the lengths and making them at the appropriate time after all of the chassis for this laminograph room cabinet rack (Unit 3) have been constructed.

e. Optics Positioning Motors (4-4)

The motor for the 4X lens turret drive is a reversible split phase capacitor Bodine Gearmotor No. B8192E-900M. It drives the turret through a mechanical slip clutch, so that the one second time delay drop-out of CR9-3-3 will allow it to drive against a mechanical stop. The motor for the 0.2X lens "slide" drive is a resistance split phase start, single phase run Boston Ratiomoter Model M109-5-AAS. It has 6 leads brought out, and is reversible by reversing the phase of the starting winding with respect to the phase of the run winding. This motor also drives through a solenoid clutch, which is energized when the motor is energized. The solenoid clutch decouples the motor inertia at the end of the 0.2X lens "slide" drive into the optical path of the system.

In order to wire the connectors for these motors, the following drawings are required:

4-4-A(1) 0.2X Lens Slid Drive Motor, Clutch, and Limit Switches Schematic

4-4-A(2) 4X Lens Positioner Drive Motor, and Limit Switches Schematic

The limit switches S1, S2, S3, and S4 shown on these drawings are the same limit switches identified in this way on drawing 3-3-A(1).

A parts list for the connectors required for these motors is shown in Table VIII-D-12.

A very important fact to take into consideration before wiring the connectors to the respective motors is that at the time of this report writing, the correct wiring for a given direction of rotation of each motor is unknown. This information is supposed to be included on a tag or instructions with the motor, but this may not be the case. This information will most likely have to be determined by trial wiring of each motor in a bench test, with observation of the direction of rotation for the allowable connections to the motor. The drawing 4-4-A(1) should be correct insofar as the colors of the motor leads and the terminal markings on the accelerating current relay are concerned, but it may be discovered that to get the 0.2X lens slide motor to turn in the correct direction sense as required by the mechanics, the blue and yellow wires to pins C and D (respectively) of J1-4-4, may have to be interchanged. If this is found to be the case, modify the drawing 4-4-A(1) accordingly. Before mounting the 0.2X lens slide motor on its drive mechanism (or by study of the mechanical drawings) determine in which sense (CCW or DW) the motor shaft must turn to drive the 0.2 lens into (or toward) the optical path of the system. (Refer to drawing 3-3-A(1).) This direction of rotation corresponds to the motor being wired in the following way for a bench test - the blue lead connected to terminal 3 of the accelerating current relay, the yellow and black leads connected to each

Table VIII-D-12 PARTS LIST FOR CONNECTORS FOR OPTICS POSITION MOTORS

Reference Designations	Part Number	Description and Manufacturer	Quantity	Total Cost[1]
J1-4-4	MS 3101A 20-27P	Connector, 14 pin, cable receptacle, male, Amphenol Corp.	1	$ 2.27
J2-4-4	MS 3101A 18-1P	Connector, 10 pin, cable receptacle, male, Amphenol Corp.	1	$ 2.09
---	MS 3057A-12	Cable clamp, for shell size 20 cable receptacle, Amphenol Corp.	1	$ 0.87
---	MS 3057A-10	Cable clamp, for shell size 18 cable receptacle, Amphenol Corp.	1	$ 0.79
---	AN 3420-8	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.12
---	AN 3420-6	Bushing, rubber, for cable protection, Amphenol Corp.	1	$ 0.10

[1]Current prices as of 3/68

other and to one side of the 115 v ac line, the red lead connected to terminal 2 of the accelerating current relay, and terminal 4 of the accelerating current relay connected to the other side of the 115 v ac line.

This technique can be repeated in simpler fashion for the 4X lens positioner drive motor. Here the reversal (if required) of the connection sense is achieved by interchanging the leads to pins A and B of J2-4-4 (see drawing 4-4-A(2)). Be sure to modify drawing 4-4-A(2) if interchange is required.

For proper support of these short motor and limit switch wire bundles to the connectors J1 and J2-4-4, as well as for support of the cables which connect to these cable receptacles, a self-adhesive cable clamp called the Deklasp™ is recommended. The use of these obviates drilling holes into the laminograph structure itself, and their location can be readily changed if the initial choice is unsatisfactory. They are available from:

DEK Inc., Engineered Plastic Products
117 West St. Charles Road
Lombard, Illinois 60148

They are mode of ABS plastic and come in a variety of sizes.

f. <u>TV Camera Orthicon Positioning Motor (A Part of the TV Camera, Chassis 4-3)</u>

One of the three movable optical "elements" of the optical subsystem of the laminograph is the image orthicon tube in the TV camera. Since changing magnification by inserting or removing the 4X and 0.2X lenses causes the position of the final focal plane to move along the optical axis, the photosensitive surface of the image orthicon tube, upon which the image is focused, must be moved so that the final focal plane coincides with it. A mechanism which allows movement of the orthicon tube is standard in the Maryland Telecommunications, Inc. (MTI) TV cameras, but the movement is accomplished by turning the mechanism by hand, via a "focus" knob. This is, of course, an <u>optical</u> focus, and not an electronic focus. MTI has built special TV cameras in which a small motor is provided to turn the shaft to which the "focus" knob is attached. Thus, with appropriate feedback, the optical focus of the TV camera can be performed from a remote location.

Movement of the image orthicon along the optical axis in the laminograph system is accomplished in two steps. First there is coarse positioning which occurs automatically as controlled by the optics position control when magnification is changed. The final focus adjustment is then performed manually by operation of the manual slew pushbuttons on the scan control (chassis 1-6) front panel. The two step operation dictates that the TV camera have a two speed drive motor, that there be adjustable limit switches to sense the position of the image orthicon tube when it is at (or near) each of the two required positions along the optical axis, and that positive mechanical stops be provided (if not standard) to prevent mechanical overtravel of the image orthicon beyond either end of the defined range of travel along the optical axis. The two speed drive is essential because the coarse positioning of the orthicon involves a travel of some 0.88 inches, which must occur in a reasonable interval of time, such as 10 seconds to 1 minute, while the fine manual slewing of the orthicon must be done to an accuracy of 0.001 inch, so that it should have a speed of perhaps only 1/10 of that used during fast coarse positioning. The two speed drive can be accomplished with what amounts to be a two-speed motor, or it can be done with a single speed motor and a solenoid clutch operated planetary gear change, or both. The positive mechanical stops (and the mechanism in general) must resist the full stall torque when the stops are encountered. The limit switch actuation point along the axis of orthicon travel must be adjustable within reasonable limits, so that the coarse positioning point can be adjusted to come as close as possible to the actual focus. Of course, manual slew fine focus will always be required in any case because of the impossibility of getting a limit switch actuation point adjusted to the precision of 0.001 inch.

It is known that the motor used probably will be of the permanent magnet dc type, and it is shown as such on the drawing 3-3-A(1). The voltage required is unknown, but it is assumed to be 24 v dc or less (if less, insert an appropriate series dropping resistor, which has the further advantage of giving the motor a "soft" stall characteristic to limit stall torque). If this is not the case, this part of the optics position control will have to be modified appropriately.

The specification drawings 4-4-D(1) and 4-4-D(2) cover most of the mechanical requirements for this special image orthicon tube drive. These should be submitted to MTI along with sufficient explanation and drawings to clarify the other requirements for this special TV camera. It is required that the motor leads, and any solenoid clutch leads (if used), and two SPDT limit switches inside be brought out through a separate connector, to be mounted on the back of the TV camera. Schematic drawing 3-3-A(1) shows that all three wires of each of the SPDT limit switches S5 and S6 are required, thus it is imperative that all three terminals of each SPDT limit switch be brought out to pins on the added rear connector. This requirement is not stated on the specification drawings 4-4-D(1) and 4-4-D(2).

Since it is anticipated that all the special TV camera modification will be done by MTI, and that the required connection data will be supplied by MTI, no additional modification shall be required, and cable S can be made to fit the connector added to the TV camera by MTI.

E. The Mechanical System Design Details and Specifications

The mechanical system has been completely described in the set of engineering drawings V6034-R-100 through V6034-R-1200. Additional detail has been included as part of Section III-E. All parts lists are included.

REFERENCES

1. H. G. Hamre, R. B. Moler and Raymond A. Zalewski, "Nondestructive Testing Techniques for Multilayer Printed Wiring Boards," IITRI-E6024-15, Contract No. NAS8-11288.

2. S. Takahashi, Rotation Radiography, Japan Society for the Promotion of Science, March 1957.