ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

PRECISION PHOTOENGRAVING OF MACHINE PARTS

Technical Memorandum No. 31
Electronic Defense Group
Department of Electrical Engineering

By: A. L. Rock

Approved by: J. A. Boyd

Project 2262

TASK ORDER NO. EDG-7
CONTRACT NO. DA-36-039 sc-63203
SIGNAL CORPS, DEPARTMENT OF THE ARMY
DEPARTMENT OF ARMY PROJECT NO. 3-99-04-042
SIGNAL CORPS PROJECT 194B

August, 1956

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I. INTRODUCTION

The problem of developing processes for the precision photoengraving of machine parts arose in this laboratory during the course of constructing a radar target simulator in which a projectile trajectory is generated by a series of rectilinear[1] cams scaled to determine azimuth, elevation, and range of the target at any instant of flight. Due to the necessity of reducing a large range variation and wide angular change to a small scale, high cam accuracy had to be maintained for a true representation of trajectory. Calculations of trajectory points and reduction to scale size were accomplished satisfactorily, but common methods of layout on metal would not have held within the desired limits.

Many techniques are available for placing an unusual pattern on a metal plate, the simplest being a direct drawing of the desired shape on the metal. However, the choice of technique is narrowed when high accuracy is desired. In small precision parts, such as the trajectory cams described above, even the thickness of the guide lines is a critical factor, and drawing an indelible marking of high accuracy on carbon steel is an extremely difficult task for even the most expert draftsman. A method which has been used in recent years is that of photoengraving. Photoengraving has been practiced by printers and lithographers for over 125 years using soft metals, such as zinc or copper. However, the employment of harder metals has been fairly recent.

1. Rectilinear cams are operated in translation motion rather than in rotation.

The basic principles of photoengraving apply, however, regardless of the metal used. The pattern desired is obtained on film and, by means of the film, is transferred to a metal surface which has been light-sensitized in such a manner that the exposed portion is resistant to etching baths. The plate is then etched by means of acid or electrolysis.

II. THE PHOTOENGRAVING PROCESS

The photoengraving method described in this report was used in manufacturing a set of trajectory cams, which had maximum dimensions of approximately five inches by one half inch. The cams were machined from 1/16 inch carbon steel gage stock to an accuracy of approximately two mils. The photography, photoengraving and machining were done in our own laboratories to obtain the highest possible accuracy, and in the interests of time saving and economy (see Appendix A). The procedures followed are described in detail below.

2.1 Drawings

The first step in the production of the finished cam is to make an accurate India ink drawing, as shown in Fig. 1. The drawing can be scaled up by any convenient factor, and in this case the cam was drawn five times the actual size. To minimize heat- and humidity-induced distortions in the drawings, a heavy grade of paper or Bristol board should be used. Since the desired width of line on the final cam outline was not to exceed 5 mils, inked lines on the original drawing had to be held within 25 mils. Needless to say, the drawings themselves had to be smoothly and accurately drawn. In essence, the finished cam will be an exact replica of the drawing; thus, all lettering and guide lines needed for the cam must be properly placed on the paper. Unnecessary markings should be omitted completely, at least within the cam area.

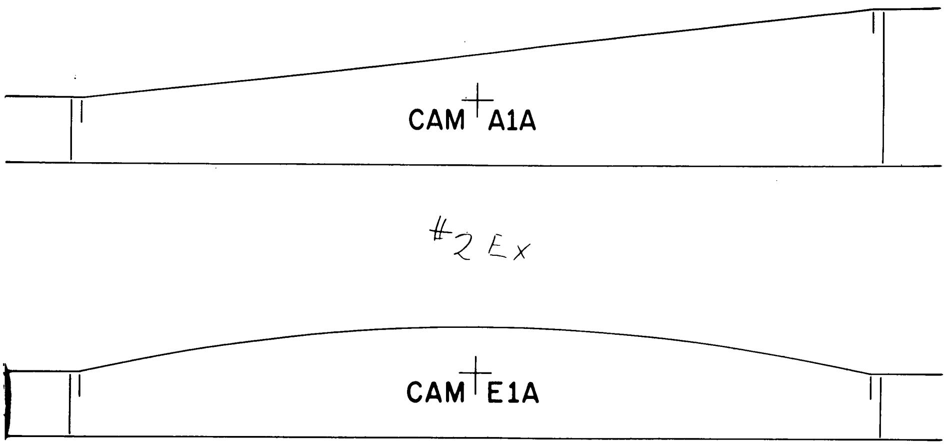


FIG. I PHOTO OF CAM DRAWING

2.2 Camera Adjustments

A Crown Graphic Camera was used to obtain the original negative. The proper distance for the camera was ascertained by viewing the image on a ground glass plate prior to the exposure. In the case of 5:1 reduction, the camera was mounted on a tripod and set 28-5/16 inches from the copy board to the front edge of the camera bed. It is important that the optic axis be perpendicular to the copy board to avoid distortion. The copy board and camera back were both rendered vertical using a bubble square as shown in Fig. 2. To render the optic axis perpendicular to the board in the horizontal plane, a 10" by 20" inked grid of one inch squares was placed on the copy board. The ground glass image of this grid was compared with common 5-squares-per-inch graph paper as a check for distortion and proper sizing. Focussing is performed at wide aperture, and later stopped down for the exposure. After focussing, the reduction ratio must be rechecked, since focussing changes this ratio slightly. After adjustments are made, and the camera is properly positioned to photograph the cam, the cam drawing is taped in position on the copy board.

2.3 Lighting

For photocopy work, two No. 2 photoflood lamps were placed as shown in Fig. 3. The beams were directed to produce approximately uniform illumination of the copy or drawing, as indicated by an exposure meter.

2.4 Exposure

The exposure meter was set for an ASA rating of 4 and used to measure the illumination on the white surface of the drawing. The indicated exposure was then multiplied by 5 to obtain the proper exposure. This procedure is recommended by the Kodak Company and gives a clear, white-line negative with a dense black background. (If the meter reading is taken on an 18% gray card, the recommended exposure is that indicated by the meter).

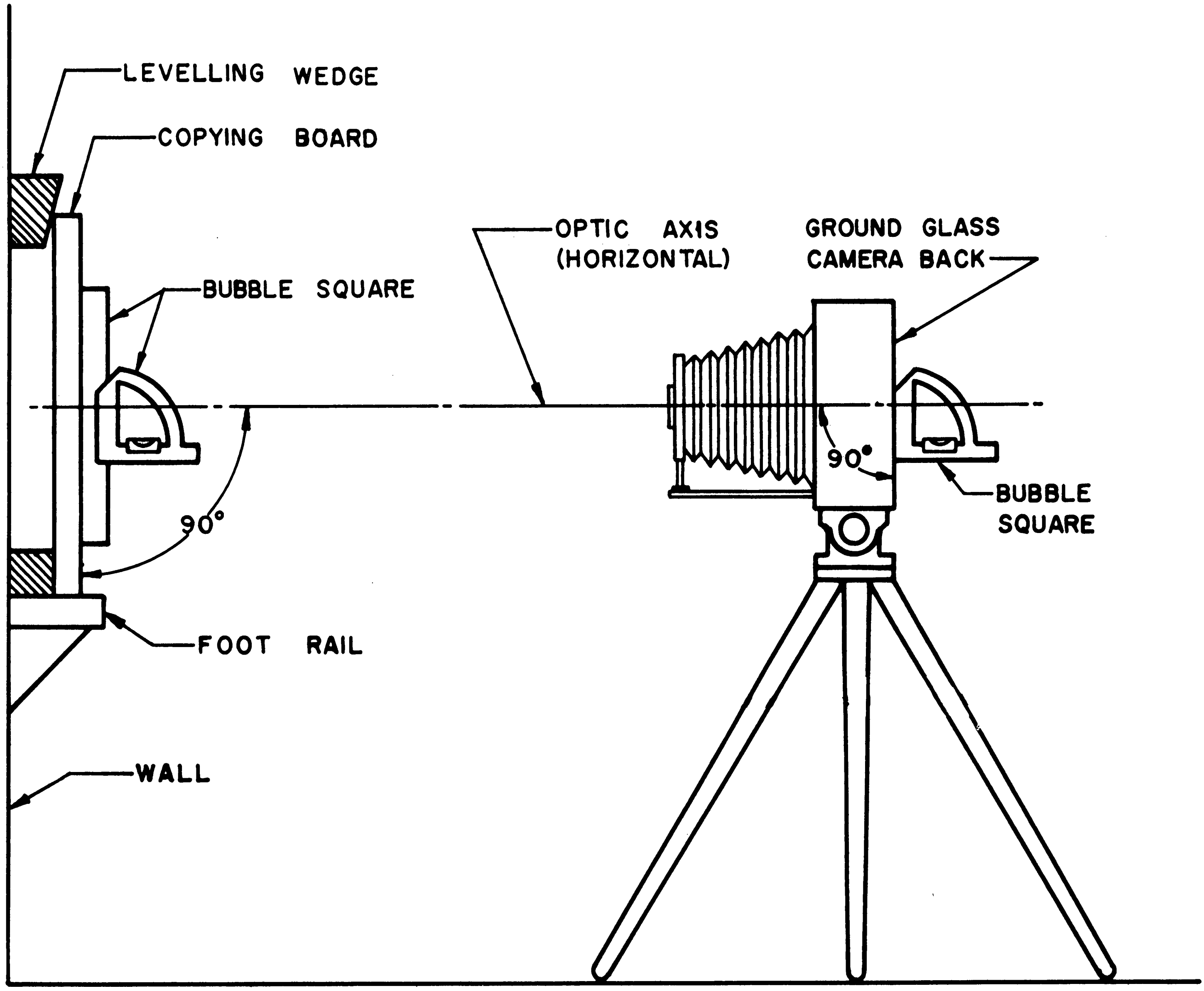


FIG. 2 ELEVATION VIEW

THE COPY BOARD AND CAMERA BACK ARE MADE VERTICAL WITH A BUBBLE SQUARE

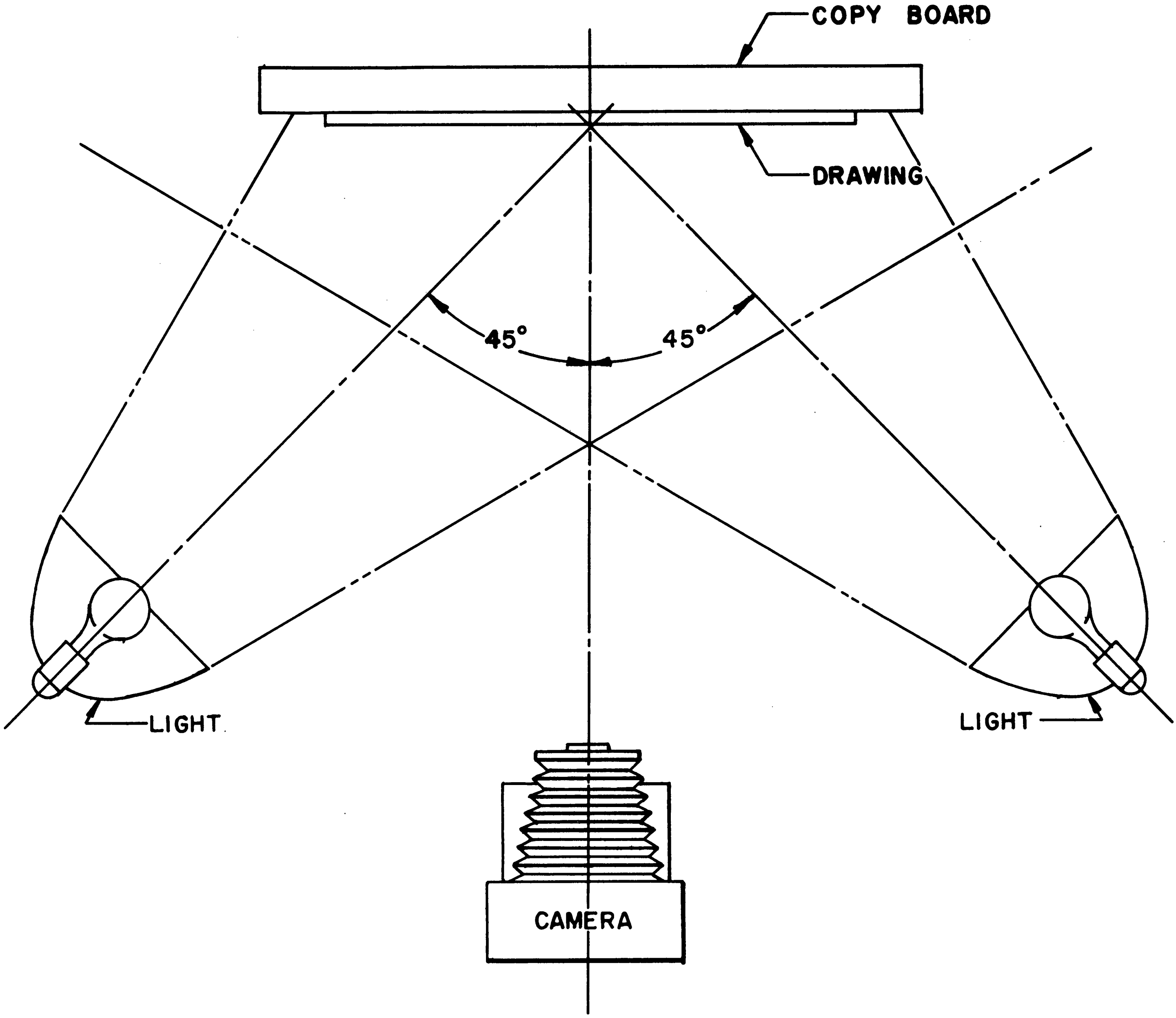


FIG. 3 PLAN VIEW SHOWING PLACEMENT OF LIGHTS

An additional exposure time correction factor is made to account for the increase in bellows extension when making close-up shots. If m is the magnification (i.e., the ratio of image size to object size), a correction of $(1+m)^2$ must be applied. In the case of 5:1 reduction used for the target cams where m = 0.2, the exposure is increased by a factor of $(1+0.2)^2$, or 1.44. Where image and object sizes are equal, m = 1, and the exposure correction factor is $(1+1)^2 = 4$.

2.5 Negatives and Processing

Kodalith Super Ortho Film was used for making the negatives. This material has high contrast, an ASA film speed of 4, and is easily handled without fogging under bright ruby lamps, or Safelites with Wratten Series 1 or 1A filters.

The negatives were tank developed in Kodalith developer and fixed in F6 Fixer Solution using standard processing techniques.

2.6 Blackline Positive

After the cam drawing has been accurately photographed, the film negative bears an exact-sized image of the finished cam. It is possible to use this negative directly on the sensitized metal but, for reasons which will be discussed in the next section, this would result in the cam outline in relief on the metal, whereas the opposite is desired. Therefore, a positive print is made from the negative. The negative is placed over a sheet of unexposed Kodalith film in a printing frame, and exposed for 0.5 second to a 60 watt incandescent light source at 5 feet. The blackline positive thus obtained is processed as described in Section 2.5.

2.7 Placing the Image on Steel

The next step in the process is to transfer the photographed image to a light-sensitized steel plate. Light-sensitive materials for photoengraving are known as "resists" since, as the name implies, they resist acids and other etching chemicals. Various types of resists are used by engravers, many of them falling in the category of trade secrets, but, for this project, a commercial compound, Kodak Photo Resist (KPR), was employed. KPR gave good results and involved relatively simple procedures and equipment. When a metal plate treated with resist is exposed to a light source, the exposed portion is rendered insoluble while the unexposed portion can be washed off with the proper solvents.

KPR is essentially a plastic material in solution. Among its advantages are stability, ease of application and relative insensitivity to ordinary incandescent light, thus allowing plates to be pre-coated and stored for future use. Among its disadvantages are its aversion to water, necessitating thorough drying of metal and glassware before use, and the volatility of KPR and its associated compounds, requiring adequate ventilation.

The process described here is a variation based upon the most recent recommendations of the Eastman Kodak Company. Thorough cleaning of the metal is the first step. Trichorethylene was found to be adequate for degreasing, although any ordinary cleaning material such as kitchen scouring powder is satisfactory. The metal should be clean enough to retain a light water film. The plate is then chemically treated by immersion in 20% phosphoric acid for three minutes at $170^{\circ}F$, causing the surface to gas and blacken. The plate is then washed carefully in water until all residue is removed, and is then dried in a warm air flow until all traces of moisture are gone. Blowing warm air is most effective for drying operations as it prevents the formation of drops. A simple and very convenient method of drying in all stages of the process is to use a common hairdryer which may be combined with a drying box as shown in Fig. 4.

The plate is now ready for a coating of resist. It is possible to apply KPR by different methods, such as dipping or spraying, but uniformity of thickness cannot always be obtained by such methods. To obtain a uniform thickness of resist material, the plates were coated and were then whirled in the set-up shown in Fig. 5. All that is needed is a common hand

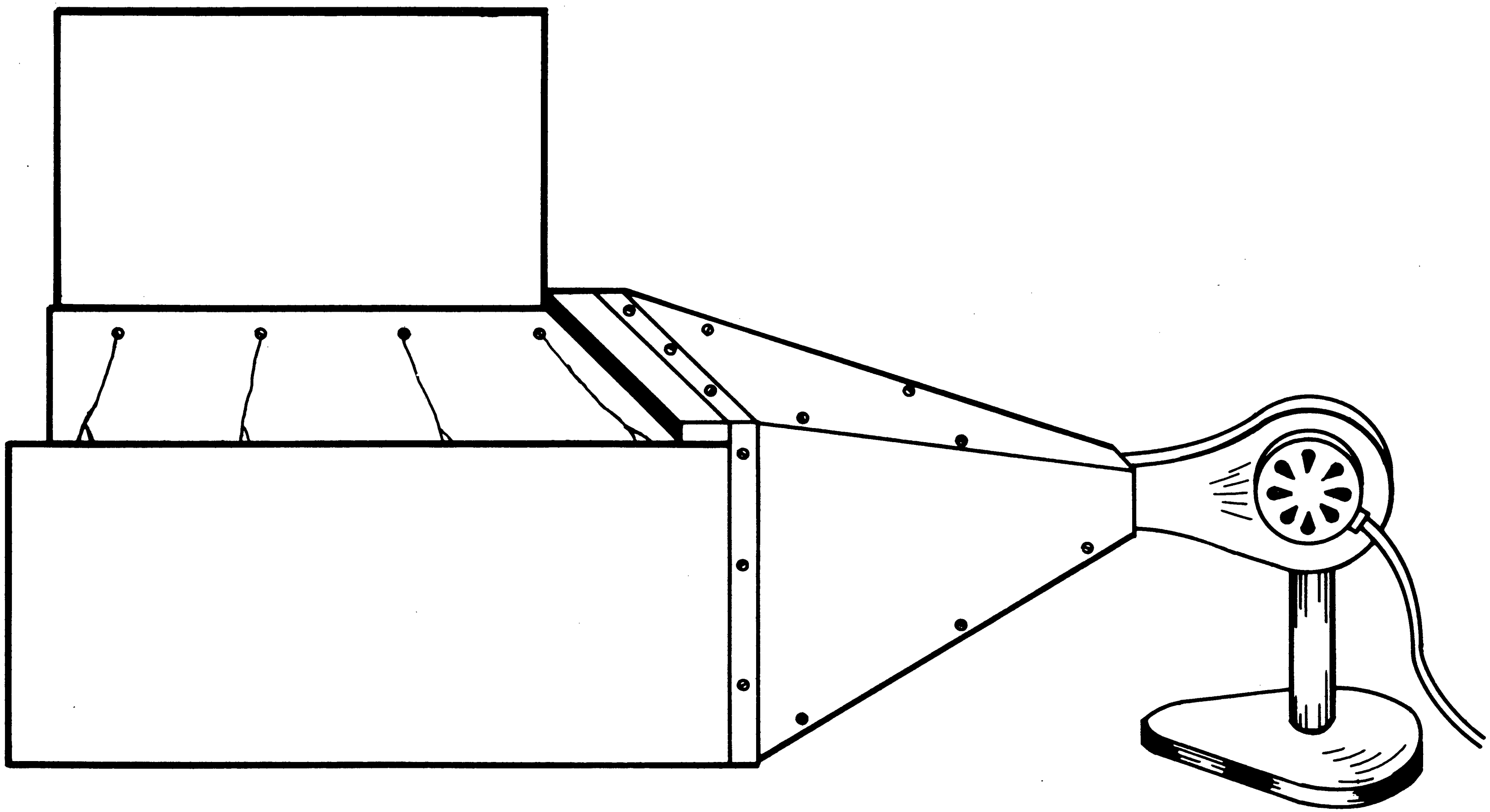


FIG. 4 DRYING BOX

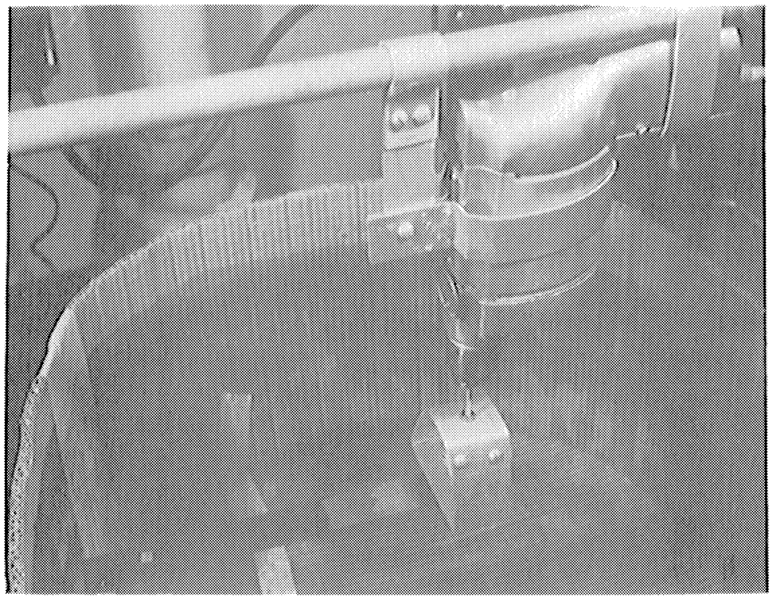


FIG. 5 PLATE WHIRLER

drill, a variac for speed control, a simple device for holding the plate, and a cardboard splash wall.

KPR is flowed onto the metal and the whirler is started. A speed of 60 to 100 rpm for 8 minutes at room temperature is adequate. Before stopping the whirler, it is helpful to increase the speed for a few seconds in order to throw off any loose drops. This method is very satisfactory as a uniform thickness is assured; the only disadvantage is the tendency of KPR to form a slight beading at the end and trailing edge of the plate. However, these areas can usually be avoided without difficulty when the plate is exposed. The coating process can be hastened if heat is applied, warm air being preferable to infra-red. Although full strength KPR was found to be desirable in this case, thinner coatings may be obtained if desired, by dilution with Kodak Photo Sensitive Lacquer Thinner. Filtering KPR through cheesecloth is advisable if the presence of any residue is suspected.

A convenient method of determining the proper exposure time is to use the No. 2 Kodak Photographic Step Tablet, which is a strip of film having a series of steps of increasing opacity to light. Exposing the resist through the tablet for a certain length of time, say five minutes, results in the plate having a varying degree of coating ranging from very heavy to none. The last step with a solid resist coating is the preferred exposure, although earlier steps may be chosen if desired. Excellent results were obtained by placing a No. 2 photoflood 4 inches from the plate and exposing for 2.5 minutes. A simple frame may be used so long as it holds the film firmly against the steel. A glass plate clamped upon the film and steel is adequate.

While No. 2 photofloods were used in this case, there are alternate light sources which should be considered if conditions warrant. The prime requisite for the light is that it be rich in ultra-violet. A high amperage arc light or a 275 watt sun lamp bulb are both excellent in this regard. Arc lighting was not attempted due to lack of sufficient ventilation. Sun lamps were tried and proven adequate, although tests with the step tablet indicated increasing exposure four times that of the photofloods for comparable results. The main disadvantage of photofloods and sun lamps is the large generation of heat. Conceivably this heating could expand the film image, causing erroneous results in the resist image. A table fan was used to cool the printing jig during exposure, thus minimizing errors induced by thermal expansion.

After exposure, the steel was immersed in KPR developer for a minimum time of two minutes (over-developing is impossible) and was then placed in KPR dye for at least 30 seconds. The dying is necessary to view the image. The plate should be agitated in these solutions, but should not be swabbed, since the image is tender at this stage. After drying the plate is washed in running water, $65^{O}F$ or warmer, until all excess dye has been removed and dried by blotting or blowing. Due to the low contrast with steel, imperfections in the KPR coating may not be apparent until the dye has been applied.

The plate should be baked to assure proper adhesion of the coating. Heat in the range of 350^{O} to $530^{O}F$ should be applied 5 to 20 minutes. The plate is ready for etching when the color changes from black to a purplish brown hue.

2.8 Etching

Electrolytic etching is the most convenient method to use. A ferric chloride solution (one pound per 1150 cc solution) is used as the electrolyte with a lead cathode and the steel plate as the anode. The etching rate for steel is about 1 mil per minute using a 2 volt source supplying 4 amperes per square inch. For the cams, an etching depth of about one mil was used. It is advisable to protect the back and edges of the plate with wax so that these areas will not be needlessly etched. The plate is washed and dried at the end of the etching period, and it is then ready to be machined.

2.9 Machining

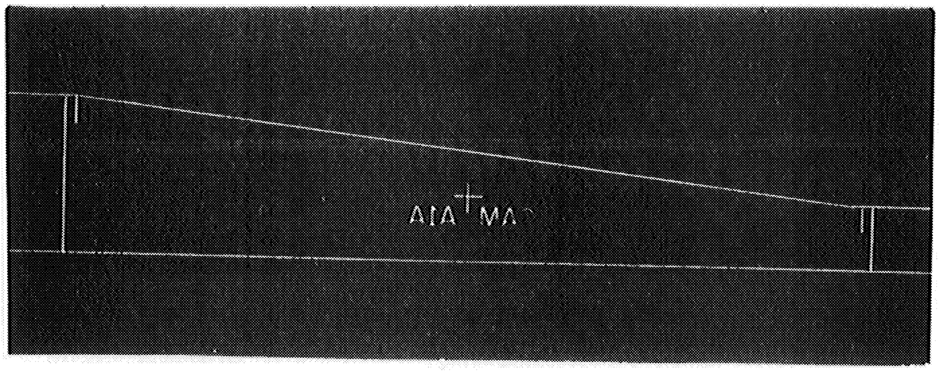
Assuming a 5 mil line, as in this particular case, a machinist can split this line thereby restricting error to less than 2.5 mils. This tolerance is minimized even further when consideration is made that it is the differential of the trajectory that is used and not merely the static points.

When the final cam has been completed by a machinist, there is a relatively simple method of checking its accuracy. Holding the cam tightly over a sheet of unexposed film, and then exposing, results in a negative containing the cam's silhouette. This negative is then placed in the camera, so that a strong light source placed behind it will project the cam onto the copyboard containing the original drawing. If the camera positioning is the same as when taking the original image, the cam shadow should exactly cover the drawn outline. Any variations can be observed and checked for tolerance. Figure 7 shows the finished cam in place in the precision carriage of the target simulator.

3. CONDITIONS AND PRECAUTIONS

Very little special equipment is needed. Any area which can be made light tight can be used for a photoengraving process room. It is helpful, but not essential, to have running water available. Damp areas should be avoided due to the rapid oxidation of carbon steel after cleaning. Some ventilation is necessary for proper working conditions since many of the necessary chemical compounds are highly volatile as well as inflammable.

If good control of the line width is desired, certain precautions should be observed in the processing. In the printing of positives, a minimum exposure is desirable, as experience has shown that light diffusion tends to produce a thicker line with longer exposures. Conversely, when exposing the image onto the resist, slightly longer exposure will result in a thinner



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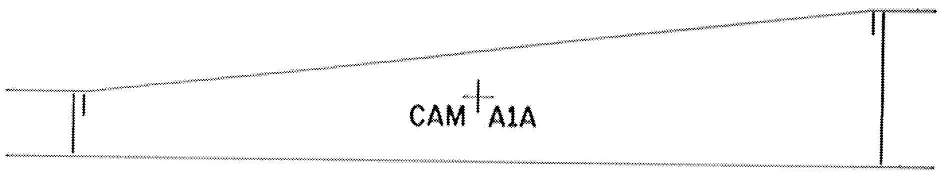

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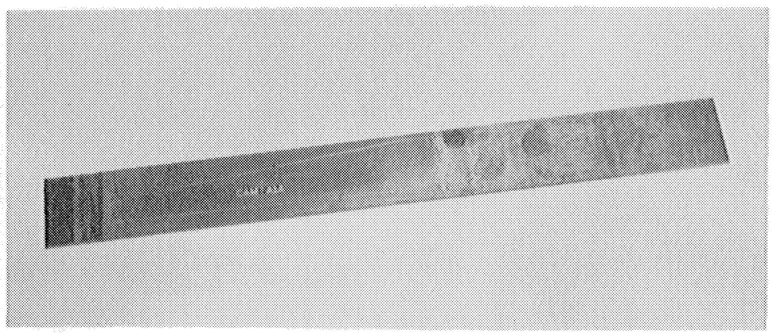

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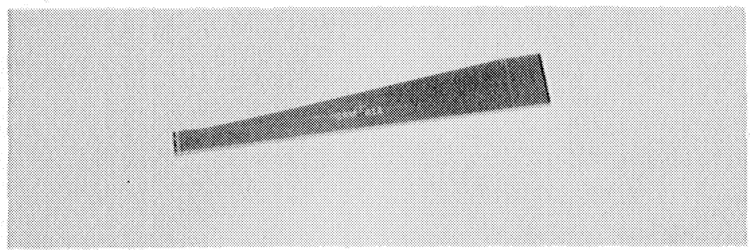

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FIG. 6 STEPS IN PROCESS

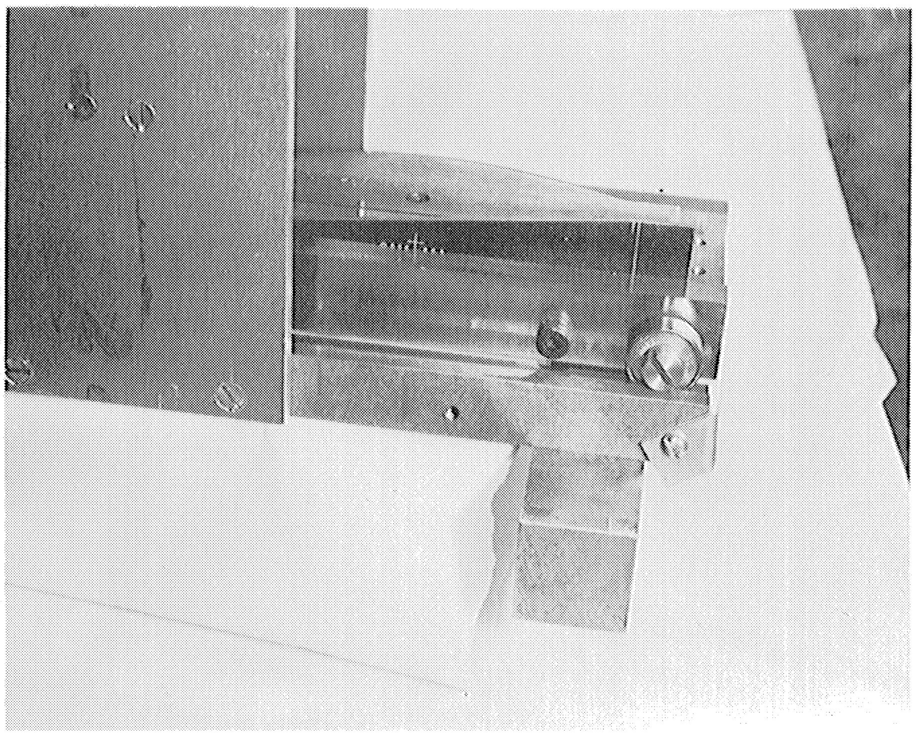

FIG. 7 CAM IN CARRIAGE

line due to rendering the resist more insoluble at the line edges.

Inadequate baking also results in spreading of the etched line. It is therefore essential that the plate be baked for a long enough time to harden the resist coating thoroughly.

Line undercutting was not encountered in the cam processing, as the etch depth was held to approximately one mil. However, if the etched area is to be fairly deep, special precautions must be employed to prevent this. The common method is to brush resin powder against all exposed edges after each successive "bite" in the etching bath and harden it with heat. Thus, a continuous protective surface is maintained.

4. CONCLUSIONS

The photoengraving process is a very versatile one. Patterns for machining can be laid out with precision; accurate markings can be made on small parts; or, if fairly thin metal parts are needed, they can be made by etching completely through the metal. The process is relatively simple and can be mastered satisfactorily by an unexperienced person with a little practice. The cost is extremely low in regard to the results obtained. See Appendix A.

APPENDIX A

Approximate Cost of Photoengraving Materials

Kodak Photo Resist	per quart	$13.00
KPR Thinner	per quart	3.75
KPR Developer	per gallon	6.00
KPR Dye	per quart	3.50
Step Tablet (Kodak No. 2)		3.60
1 Box Kodalith Super Ortho 4 x 5 Film	50 sheets	3.12
Trichlorethylene	per quart	.40
1 Box Kodalith Developer (2 gal. size)		1.38
F-6 Hypo	per gallon	.35
Acetic Acid 28%	per quart	1.00
Phosphoric Acid 85%	per pound	.80
Ferric Chloride	per pound	.83
Kodak Opaque, black	per ounce	.45

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