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FA-TR-75067

RADIAL PRESSURE CONVERSION OF AN OPTICAL POLISHING MACHINE

August 1975

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: FA-TR-75067	2. GOVT ACCESSION NO. / 3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): RADIAL PRESSURE CONVERSION OF AN OPTICAL POLISHING MACHINE	5. TYPE OF REPORT & PERIOD COVERED: Technical Research Report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): MARTIN H. HORCHLER	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Frankford Arsenal, Attn: SARFA-MTT-O, Philadelphia, PA 19137	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: AMCMS Code: 3297.06.7062; DA Project: 673 7062
11. CONTROLLING OFFICE NAME AND ADDRESS: U. S. Army Armament Command, SARRI-LE Rock Island, IL 61021	12. REPORT DATE: August 1975
	13. NUMBER OF PAGES: 19
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This project has been accomplished as part of the USA MM&T program which has as its objective the timely establishment of manufacturing process techniques or equipment to insure the efficient production of current or future defense materiels.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Conventional Polisher	Normal Force	Pantograph
Radial Polisher	Tangential Force	Pivot Point
Rub	Hemispherical	
Friction	Universal	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The modification of a conventional polishing machine to a radial pressure polishing machine is described. The polishing results obtained with the modified equipment were basically unsatisfactory. Suggestions for improved performance are given.

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INTRODUCTION

In this project, an attempt was made to increase the effectiveness of a conventional optical polishing machine by converting it to a radial pressure machine. A conventional polishing machine uses the intersection of the lap and work surface to convert the vertical force of the weights and the horizontal force of oscillation into a force tangential to and one normal to the work surface. A radial polishing machine uses mechanical means to change the external forces to forces normal to and tangential to the work surface.

BACKGROUND

Polishing Machine

A conventional optical polishing machine consists of a vertical spindle and a horizontally oscillating arm (Figure 1). The vertical spindle is called the bottom spindle. The oscillating arm is referred to as the upper spindle. This upper spindle is hinged in the vertical direction allowing it to move up and down freely.

The tools used with this machine are the lap or polishing tool, and the lens block; both are spherical sections with opposite radii. The convex tool is usually run on the bottom spindle (in this discussion this will always be assumed to be the case), and the concave tool is placed on top of it. The concave tool is then coupled to the upper spindle by a ball joint, which allows it to both oscillate and follow the rotation of the bottom tool.

The sequence of operation of the machine is as follows: Lenses are mounted on the block and ground to a desired geometry. Then a polishing tool is made to conform to this surface. These tools are then mounted on their respective positions, weights are added to the upper spindle and the machine is ready to run. The polishing medium is a powder suspended in water and can be applied either continuously or brushed on at the operator's discretion.

This simple machine, when operated by experienced personnel, can produce extremely high quality spherical optical elements.

Another type of machine used for polishing spherical optics is called a radial machine (Figure 2). This machine differs from a conventional polisher in that the upper spindle oscillates through an arc which is concentric with the tool on the bottom spindle. These machines are quite similar in operation and tooling to conventional polishers, however, they do differ in application. This will become more apparent later on in the report.

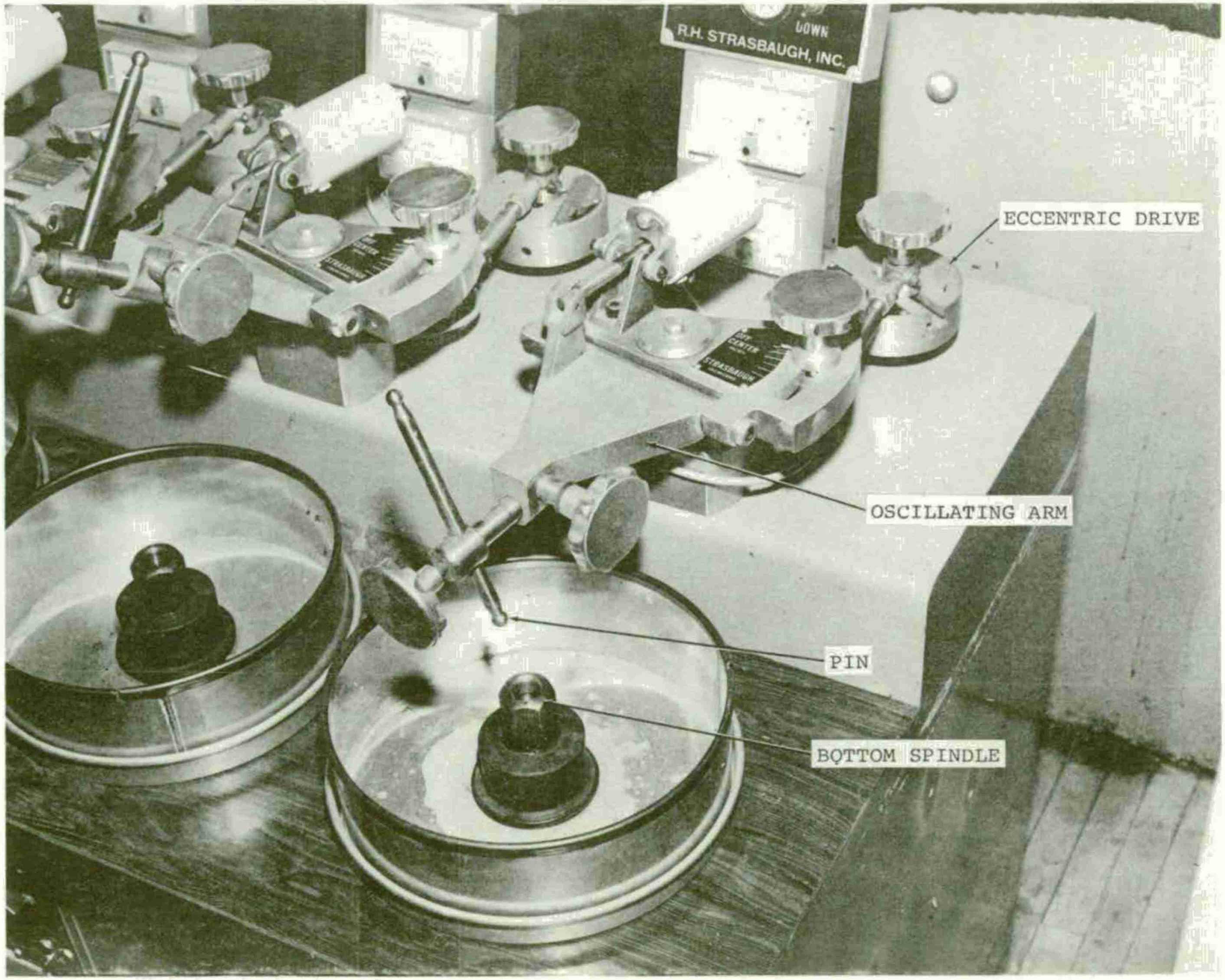

Figure 1. Conventional Polishing Machine

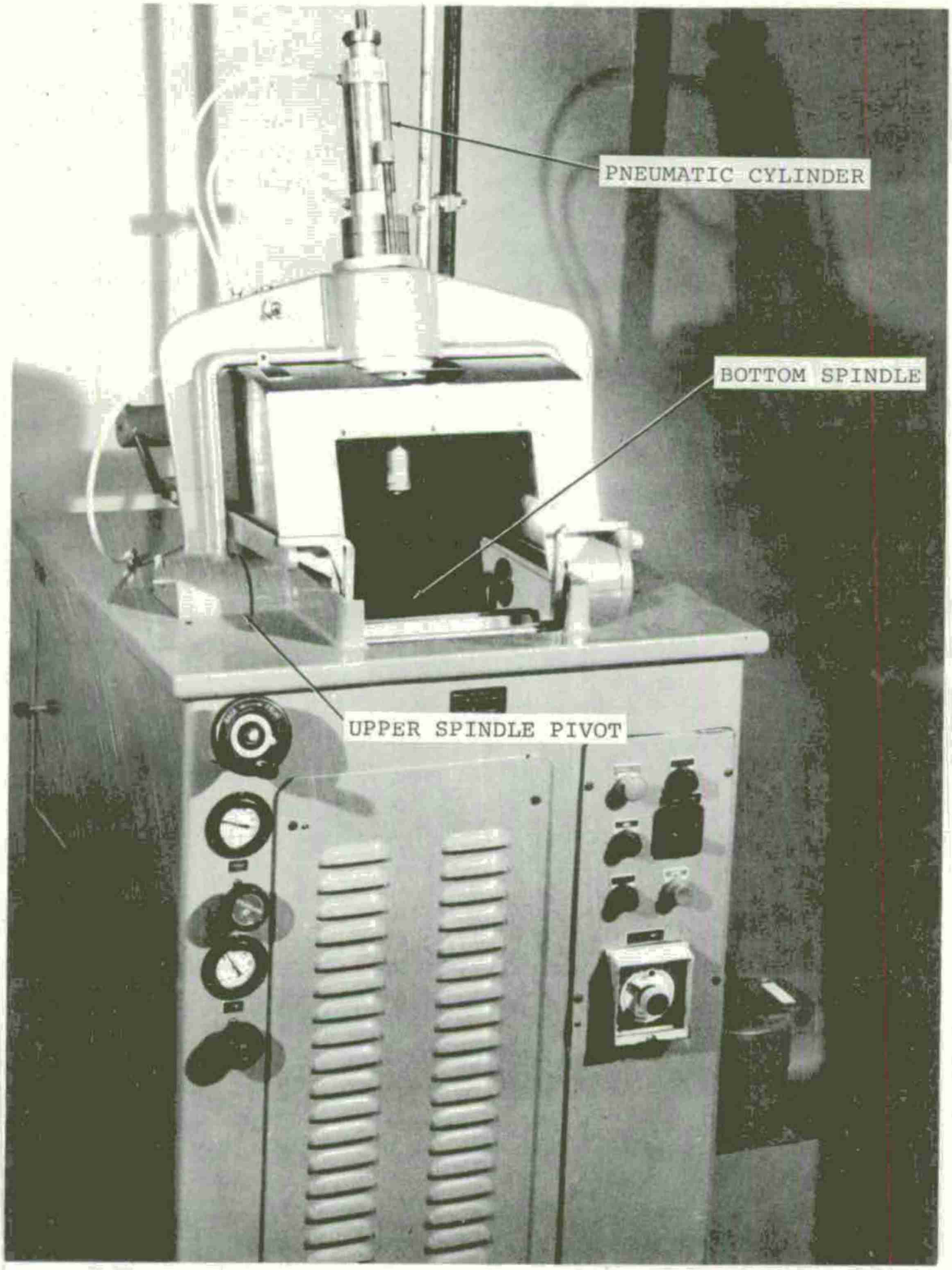

Figure 2. Radial Polishing Machine

Mechanics of Polishing

The amount of polish that an increment of lens surface area receives in a given amount of time is a function of its relative displacement, and its force of friction. This increment of surface area is defined as a section of lens surface over which the pressure between it and the polisher can be considered a constant.

The relative displacement, or rub, between lap and lens is an extremely complicated function composed of two independent and one dependent movement. The independent movements are the bottom spindle rotation and the upper spindle oscillation. The dependent movement is the upper tool following the rotation of the bottom tool.

The force of friction experienced by the increment of lens surface is a product of the coefficient of friction and the local normal forces. The coefficient of friction is influenced by parameters which can vary greatly during a polishing sequence, therefore, a mathematical expression for this coefficient would be a guess at best. However, the magnitude and direction of the local normal force (F_n in Figure 3) can be expressed mathematically.

A mathematical determination of the amount of polish that a particular zone of the lens block receives would be a difficult undertaking and would involve some questionable assumptions. Fortunately in this discussion an analysis of the effects of rub and friction force on polishing is sufficient to show the purpose for this modification.

Effect of Rub - The three movements which determine the amount of rub are the motor driven oscillation of the top spindle, the motor driven rotation of the bottom spindle, and the freewheeling of the top tool.

The oscillation of the upper spindle causes a cyclical linear displacement of the two tools, which is perpendicular to their rotation. The effect of this motion is a uniform rub, since all overlapped surfaces receive the same rub regardless of positions.

The rotary motion of the bottom spindle, when covered by a non-rotating upper tool, will cause a rub between the overlapped surface increment which is proportional to its horizontal distance from the axis of rotation. The effect of this rub is a tendency to make the bottom tool parabolic.

The freewheeling of the upper tool has no effect on the cyclical rub caused by the oscillating arm; it only effects the rotational rub produced by the bottom spindle. The effect is to make the rotational rub more uniform, which in turn keeps the tools spherical. However, some of the rotational rub is used to drive the upper spindle and is no longer available for polishing. The amount of rotational rub available for polishing depends on the relative location of the centers

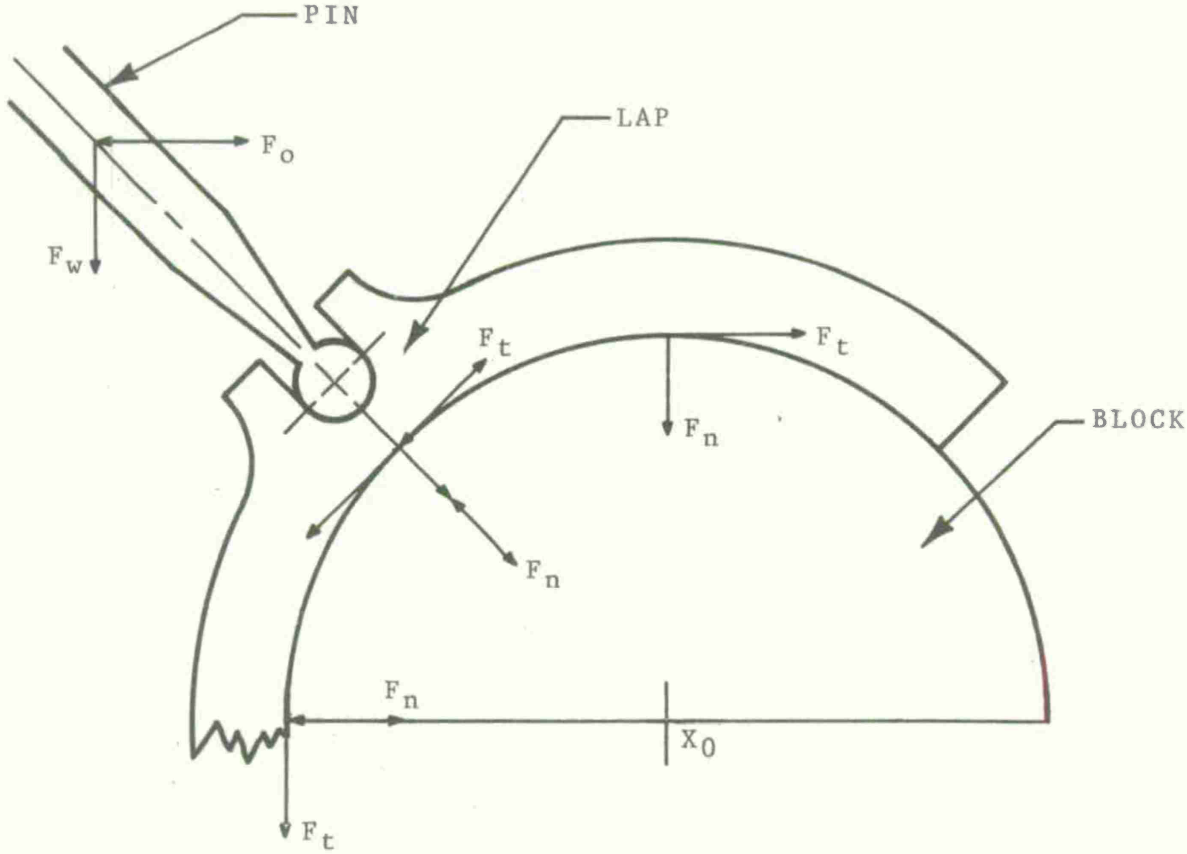

Figure 3. Distribution of the Normal & Tangential Components of the Applied Forces on a Hemespherical Block

of rotation of the two tools. For example, when the centers of both tools coincide, they both rotate together and no rotational rub is available for polishing; when the center of the top tool is at the edge of the bottom tool the top tool stops rotating and maximum polishing occurs. To optimize rotational rub, the experienced operator will usually set the oscillation close to the outer edge of the block, and will rarely oscillate across the center.

Effect of Friction - The force of friction between the two tools is directly proportional to the normal (radial) component of the applied forces. Figure 3 illustrates this force (F_n) for a conventional polishing machine. F_n varies in magnitude depending on its location. This variation becomes most apparent when the tools are hemispherical. In this situation, F_n at the edge of the bottom tool is only the cyclical force (F_o) of the upper spindle oscillation. However, the normal force at the center is a constant equal to the force of gravity (F_w) of the weights placed on the oscillation arm. This normal force at the center is a constant whether the tools are hemispherical or not.

Since F_o is cyclical and is never greater in magnitude then F_w, more work is done by the normal force in the center than at the edge of the block.

Purpose of Modification

Obviously, with a conventional polishing machine there is a conflict between the two basic factors that influence polishing. The rub is greatest at the edge and the friction force is greatest at the center of the block. This modification was an attempt to eliminate this conflict by making a machine which would externally convert the forces F_w and F_o into F_t and F_n (Figure 3), and thereby exert a constant normal force onto the working surface regardless of location. This is also the purpose of radial polishing machines. However, since radial machines are quite expensive, and are not universal machines, modifying a conventional polisher to achieve this goal seemed to be a good approach.

MODIFICATIONS

Objective

The object of this effort was to convert a conventional optical polishing machine into a machine having the following characteristics:

a. The ability to exert a pressure on the top tool which always points at the center of curvature of the bottom tool.

b. Be universal enough to work both sharp (hemispherical) and relatively flat surfaces.

c. The ability to use existing tooling.

The machine selected for this modification was a six spindle 8-inch work diameter machine, which had variable speed drivers for both spindles as well as pneumatic cylinders for upper spindle pressure. The modification was done on only one spindle and did not interfere with the operation of the others.

Development

The modification consisted of a mechanical device which enabled the upper spindle to point at the center of curvature of the bottom tool throughout the oscillating cycle.

Lines (S_0, 0) and (S_1, 0) in Figure 4 represents the upper spindle at two locations in a cycle.

D_1 and D_2 represent the displacement of the upper spindle along the horizontal lines X_1 and X_2 respectively.

X_0 is a horizontal line passing through the center of curvature of the bottom tool.

The relationship between D_1 and D_2 can be expressed by the following equation from Figure 4:

$$\text{Tan } \theta = \frac{D_1}{A} = \frac{D_2}{B}$$

$$\frac{D_2}{D_1} = \frac{B}{A} \qquad (1)$$

The basic mechanism was to drive the upper spindle along the lines X_1 and X_2 and use a pneumatic cylinder to dynamically vary the length of the upper spindle shaft as well as provide the pressure.

Since the ratio of D_1 and D_2 (Equation 1) is a contant, a pantograph was used to link these two displacements. The action of this pantograph is illustrated in Figures 5 and 6.

The pantograph settings and D_1 and D_2 are related by the following equation from Figure 6.

$$\text{Tan } \Phi = \frac{D_2}{Y} = \frac{D_1}{Z}$$

$$\frac{D_2}{D_1} = \frac{Y}{Z} \qquad (2)$$

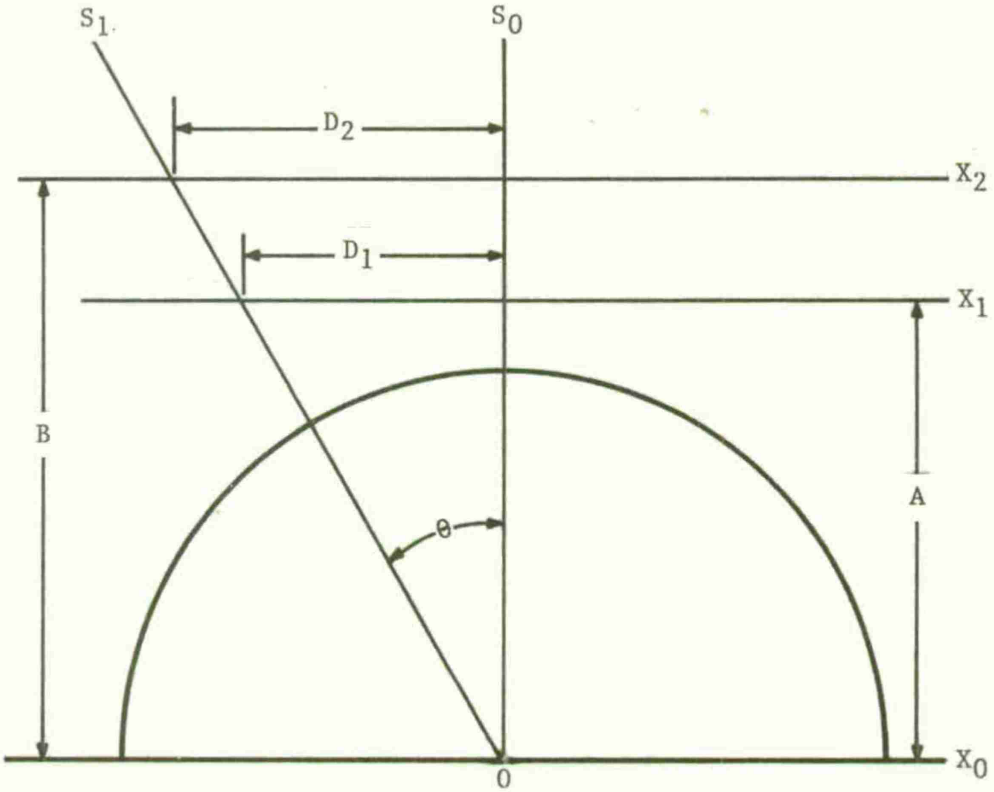

Figure 4. Principle of Operation of the Modification

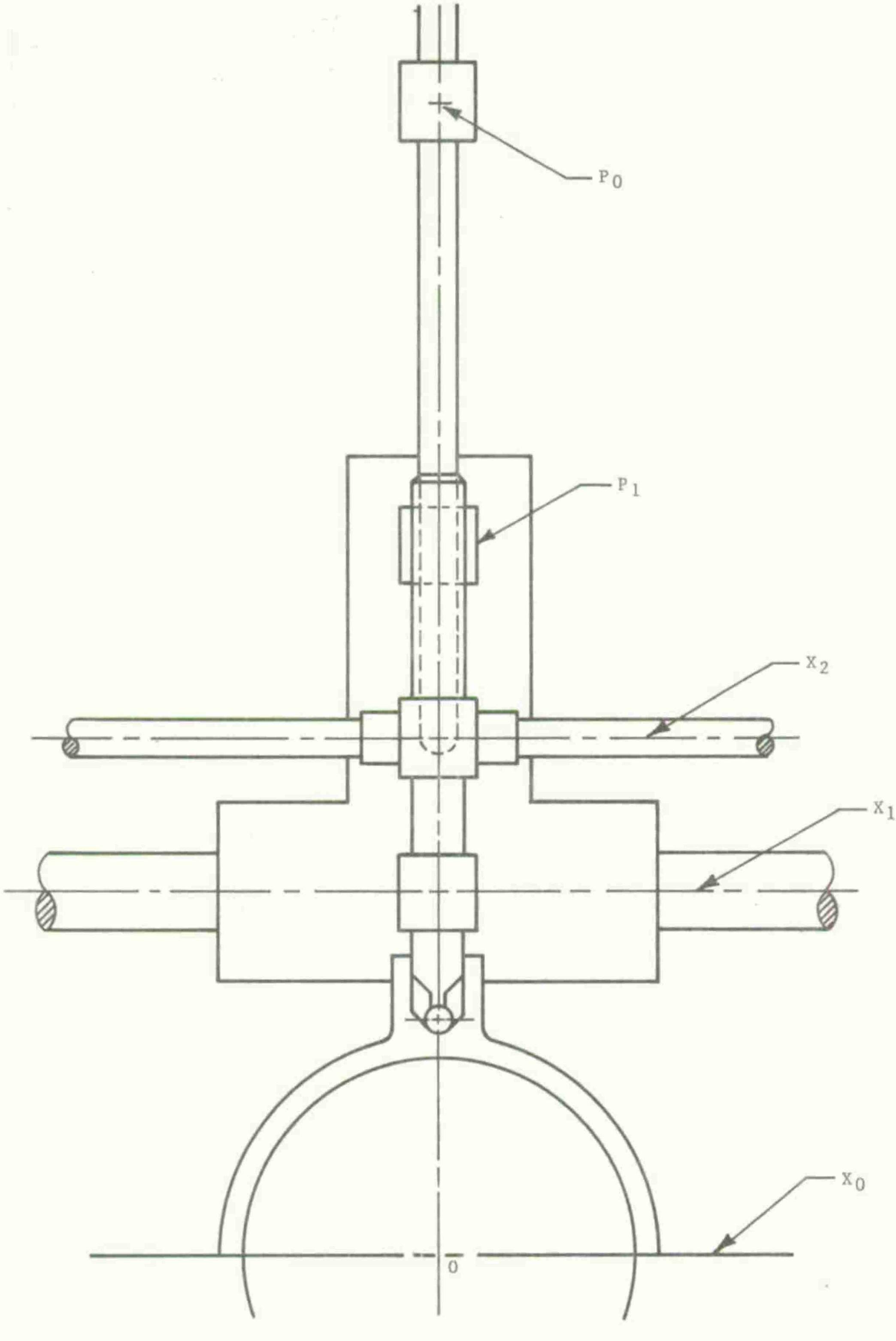

Figure 5. Schematic of the Modification with the Upper Spindle in the Vertical Position

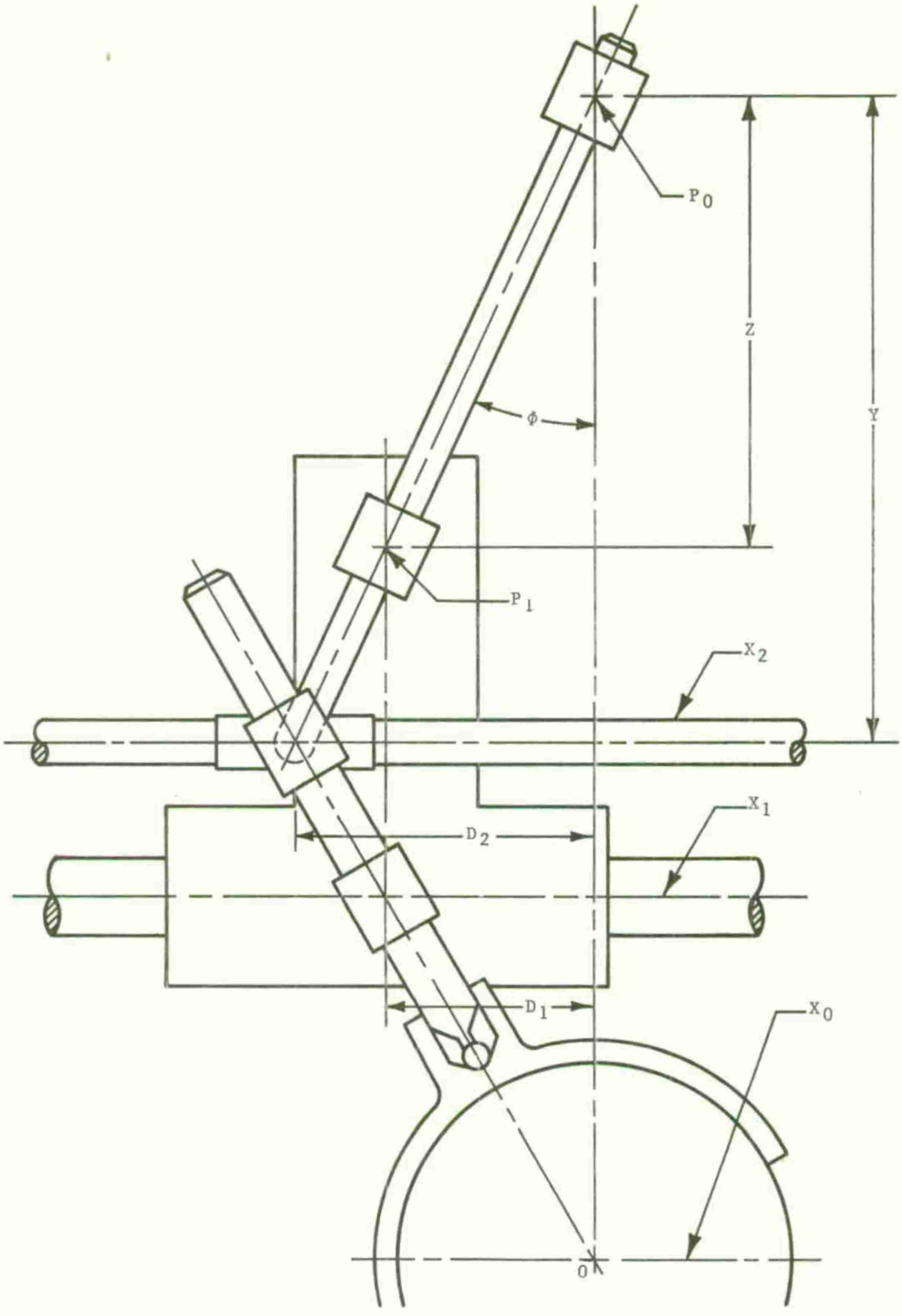

Figure 6. Schematic of the Modification with the Upper Spindle 30° from the Vertical

Implementation

Figures 7 and 8 are photographs of the modification as it was implemented on the six spindle polisher. Figure 7 shows the machine with the upper spindle in the vertical position. Figure 8 shows the spindle offset by an angle of 30^{o} from the verticle. These two figures duplicate the action depicted in Figures 5 and 6.

The reason for the difference between the photographs and the sketches is that, in the modification, the pantograph was placed in a horizontal position. This enables the use of a long pantograph while retaining a rather compact configuration. With this configuration the oscillation of the upper spindle was restricted to one side of the block. This is not a critical restriction since, as previously mentioned, in normal operation the upper spindle will rarely oscillate over the center of the block.

Counterweights were added to the moving platform to offset the weight of the pneumatic cylinder, thereby minimizing the load on the pantograph.

Adjusting the pantograph for various lens blocks was accomplished by loosening the retainer nut on pivot point P_1 (Figures 5 and 6) and operating the machine with reduced pressure in the pneumatic cylinder. In this manner, the pantograph set itself and the need for taking measurements and solving Equation 2 was eliminated.

In early trial runs an unexpected problem caused by bottom spindle wobble arose. In conventional polishers spindle wobble is unimportant because the upper tool is able to follow it. However, in this modification, the upper tool was restrained, and wobble was transmitted to the pneumatic cylinder causing it to bind. This problem was eliminated by adding a pivot ("Perpendicular Pivot" in Figure 7) to the upper spindle, which allowed it to pivot perpendicularly to the oscillation.

PERFORMANCE

The modified machine was evaluated on a regular lens production lot. The lens surface was a crown with a 1.590 inch radius. This surface was chosen because its block is quite sharp (the edge is 75^{o} from its center axis). There were 7 lenses per block and there were 5 sets of tools. Twelve blocks were polished on the modified machine, 50 were polished on conventional machines.

The modified machine performed poorly. With the conventional machines, all blocks were finished in less than 1 hour and 45 minutes. With the modified machine some of the block required two hours of polishing to remove some of the gray from the edge.

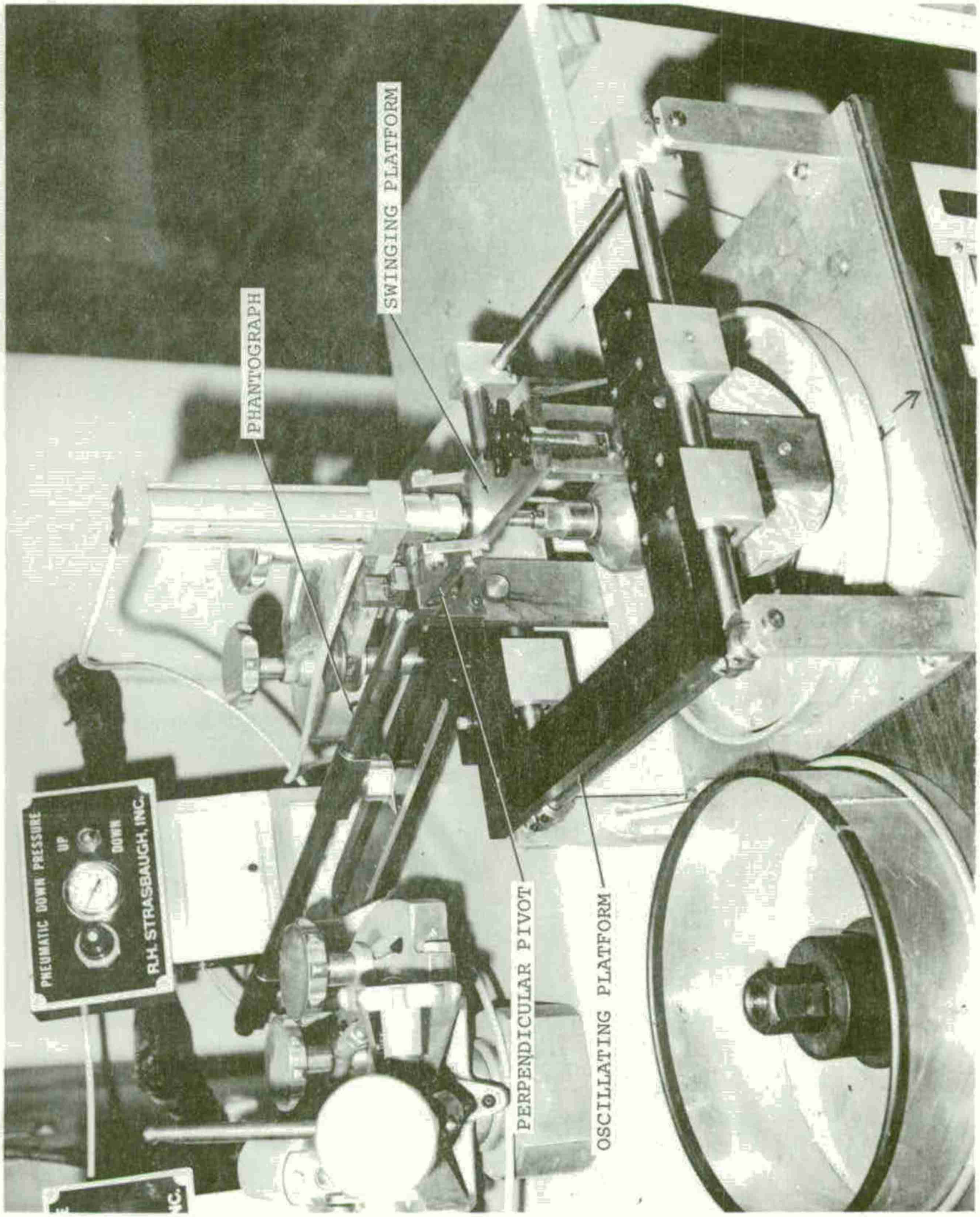

Figure 7. Modified Machine with the Upper Spindle in the Vertical Position

Figure 8. Modified Machine with the Upper Spindle 30° from the Vertical

The major deficiencies were that the modified machine was difficult to set up, and that it could not oscillate close to the edge of the work.

The modified machine is inherently more difficult to set up; there is the pantograph which must be set for each block of lenses, and there is the extra hardware connected to the upper spindle which makes it more difficult to load and unload. The only justification for this additional set up time is a saving in polishing time, which of course was not realized.

The second deficiency is more critical than the first and is the reason for the poor performance demonstrated by this modification. The physical limitation of the mechanism driving the upper spindle and the requirement of remaining within the boundary of one spindle, restricted the swing of the upper spindle. The absolute maximum angle to which the upper spindle could be offset from the verticle was 35^{o}. Therefore, on sharp blocks the upper spindle could not swing close to the edge where optimum rotational rub occurs, resulting in an inefficient polishing machine.

CONCLUSIONS

There are two types of polishing machines for polishing spherical optical surfaces. These are conventional and radial pressure machines. Both have specific advantages and disadvantages.

Conventional machines are universal, since they can polish any radius of curvature. However, these machines are impractical for polishing hemispherical or sharp surfaces.

Radial polishing machines are machines whose upper spindle pressure is directed along the radius of curvature of the work. These machines can readily polish sharp blocks as well as blocks which exceed a hemisphere. However, these machines are restricted in the range of work radii and are, therefore, not universal.

This modification was an attempt to incorporate the advantages of both machines into one unit. The result was a machine which performed poorly.

In retrospect, the poor performance of this modification becomes obvious. Initially, it was assumed that a radial machine is more efficient than a conventional machine at polishing any block configuration. This is not true; radial machines exhibit an improvement in the rate of polishing only when the work is sharp. However, since a sharp block by definition is limited in its radius of curvature, universality for such a machine is unnecessary. Had this been recognized at the beginning of this project a much simpler modification would have resulted.

Another factor which made this modification impractical was the requirement that existing tooling be used. This negated a major advantage of using sharp blocks of lenses which is to greatly increase the capacity of a lens block. Such blocks are impossible to polish with conventional machines, and therefore, conventional tooling is specifically designed to avoid this condition. The only way this advantage could be implemented is through a redesign of the blocking tools.

RECOMMENDATIONS

As a result of this project it is recommended that in order for an optics shop to have the most effective high speed production capability, both radial and conventional polishing machines should be used.

The only advantage to having a radial polisher is its ability to work sharp blocks. This ability, while not necessary, is desirable in large production jobs where the lens capability of a block should be as high as possible. Commercially available radial polishers are, therefore, all high RPM machines that can only be used with high speed fabrication techniques.

Radial polishing machines are available with capacities of up to a 5 inch radius. This range covers about 3/4 of all the lenses normally encountered in an optics shop. Jobs which exceed this range must be done with conventional machines.

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