# AN INVESTIGATION OF THE EFFECTIVENESS OF SHEET METAL DRAWING LUBRICANTS

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# AN INVESTIGATION OF THE EFFECTIVENESS OF SHEET METAL DRAWING LUBRICANTS

by

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Abstract

Many sheet-metal parts are produced by the operation called drawing. A major difficulty encountered is the selection of a suitable drawing lubricant. Previous attempts to solve this problem have not met with success.

This experiment was conducted to determine the most effective drawing lubricant for use in a cupping die. The experiment was restricted to cold rolled mild steel which was .040 inches in thickness. Twelve lubricants were tested. These lubricants represent those presently used by sheet-metal working plants.

Lubricant effectiveness was assumed to be proportional to the reduction in friction between the sheet metal and the die members. The reduction in friction was measured in three ways:

1. Reduced drawing force
2. Increased cup wall thinning
3. Increased die temperature

In addition to the maximum drawing force, the characteristic curve for drawing force was also found.

The data was analyzed using statistical methods of analysis. Tests for homogeneity of standard deviations and significance in difference of means were applied. The lubricants were then rated with the best lubricant having the lowest mean and lowest standard deviation. The lubricant found to be most effective in reducing friction was chlorinated wax. The second most effective lubricants were dry wax and medium pigment.

Recommendations are suggested for future research on other technical and economical factors which must be known before efficient selection of drawing lubricants will be possible.

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## Introduction

Present day styling makes the drawing of more complex sheet-metal parts a significant manufacturing problem. Many of the sheet-metal operations use lubricants as an aid to working the metal. A wide variety of lubricants are presently being used with apparently equal success or failure. Some of the lubricants are more costly than others and some are more difficult to clean off of the sheet-metal parts. The engineer is presented with the problem of selecting the proper lubricant for a particular draw die. He has a vast list of brand names as well as chemical names from which to choose. Actually the present method of obtaining the proper drawing lubricant is too often through a process of trial and error. This process is both costly and time consuming.

This thesis tested lubricants in order to find their effectiveness and also to make comparisons in drawing forces. Since most of the sheet-metal used on operations of this type is low carbon cold rolled steel, this project was designed to test lubricants for this metal exclusively. Other important sheet metals such as aluminum, stainless steel and brass could also be tested in the same manner.

A draw die was built because testing in an actual draw die should give more valid results than special test fixtures which do not duplicate the true drawing situation. The draw die built was for producing cups since cupping is the only true drawing operation.

It was assumed that the lubricant is used to reduce friction between surfaces having a relative motion. Since the force caused by friction in a draw die would add to the stress placed upon the sheet-metal, this friction force may be great enough to cause breakage when an improper lubricant is used. Therefore the lubricant which most effectively lowers friction should be desirable. If all forces in a draw die, except blankholding force are exerted by the punch, by measuring a reduction in force exerted by the punch, the reduction in friction forces by each lubricant may be measured. To do this, strain gages were mounted in the punch.

The above condition holds true only when other variables are held constant or nearly constant. Control of unwanted variables was an important consideration in setting up the experiment plan. Close specifications were placed on surface finish and age hardening of the sheet-metal, blankholding force drawing speed, blank size and the amount of lubricant used.

Other methods used to measure the lubricant effectiveness in reducing friction were:

To measure the wall thickness

To measure the die temperature

The first of these measures is based on the assumption that greater stress causes:

1. Thinning or necking of the sheet-metal.
2. Breaking or fracturing of the sheet-metal.

The second is based upon the fact that heat would be generated by friction. It was assumed that the temperature of the die would be an indicator of the amount of friction present.

Since a large number of lubricants are used in draw dies, a careful selection of a few for the test was necessary. The lubricants selected represented the basic types found to be the most successful in actual plant use. These were standard lubricants as purchased from the supplier and have not been altered.

Secondary objectives could also be gained from this experiment. The strain gage curves provided the maximum force required to draw a specific size and shape of cup from a known metal. Also the characteristic curve for the drawing operation was found. These will be great aids in understanding and teaching the fundamental theory of drawing.

# I. Theory of Drawing

An understanding of the theory of drawing sheet-metal is necessary before the reasoning behind this experiment may be fully appreciated. The theory presented here has been supported by experiment and is in agreement with most authors.[1, 2, 3]

Because the cupping operation most truely represents sheet-metal drawing it will be used to present the theory of drawing.

First an analysis should be made of what happens as the punch and die first start to draw the blank. Refer to Figure 1. The edge of the blank is being pulled or "drawn" in towards the center. The blank edge is forced down to a smaller circumference. This reduction in edge circumference is also evident in Figure 2. Such a reduction means that a compressive force is being applied to the metal. The compressive force produced will cause wrinkles to occur at the edge of the blank. These wrinkles are practically impossible to remove after they have started. The wrinkles are undesirable from an appearance and strength standpoint as shown in Figure 3.

To prevent the wrinkles from occurring, the blankholder is added to the die. This blankholder is a ring which fits around the punch. The outer ram of a press is used to obtain pressure for the blankholder.

[1] Crane, E. V., Plastic Working in Presses, John Wiley & Sons, New York, 1948.

[2] Sachs, G., Principles and Methods of Sheet-Metal Fabricating, Reinhold, New York, 1955.

[3] Hinman, C. W., Pressworking of Metals, McGraw-Hill, New York, 1941.

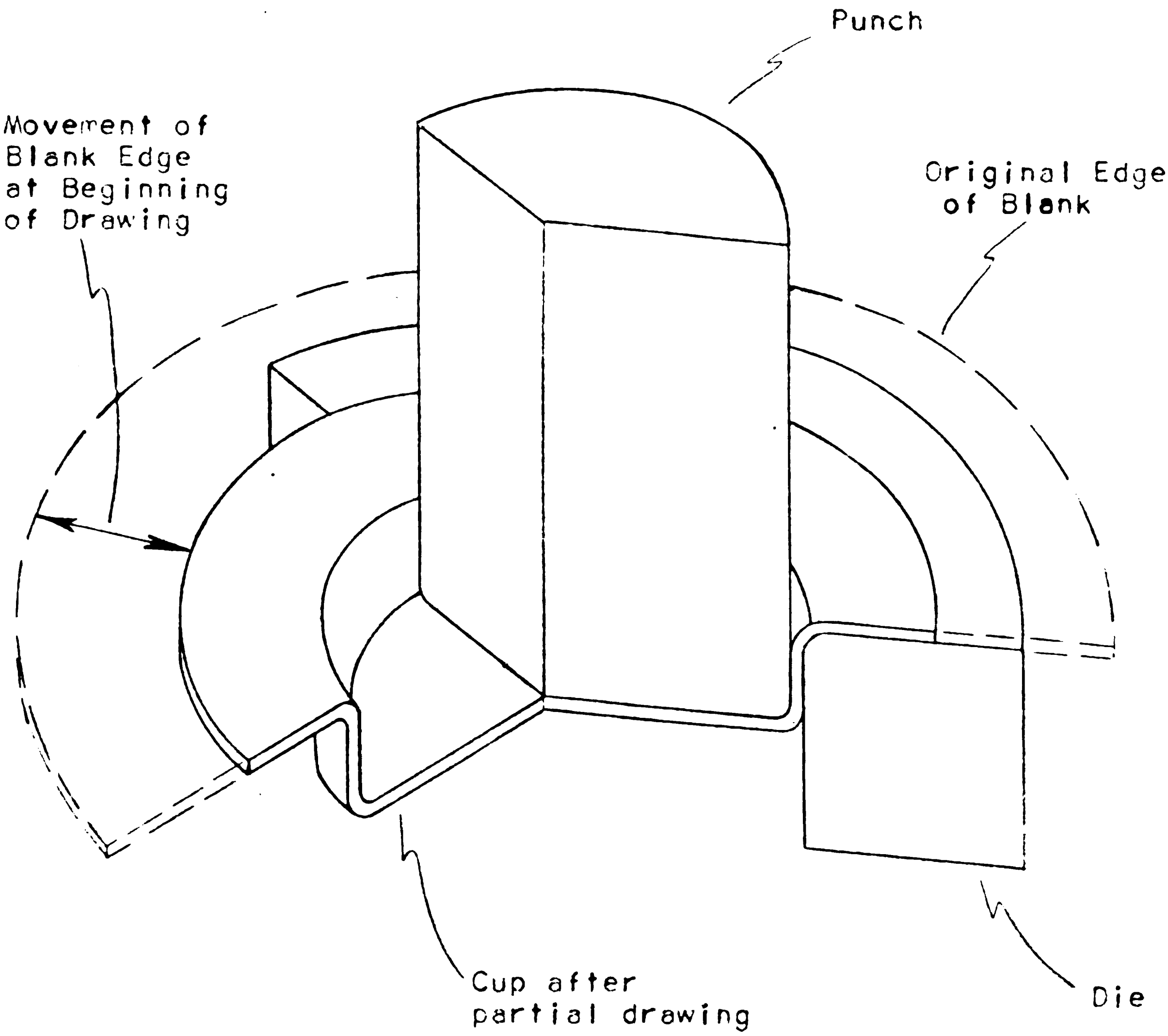



Figure 1. Cut-Away View of Draw Die

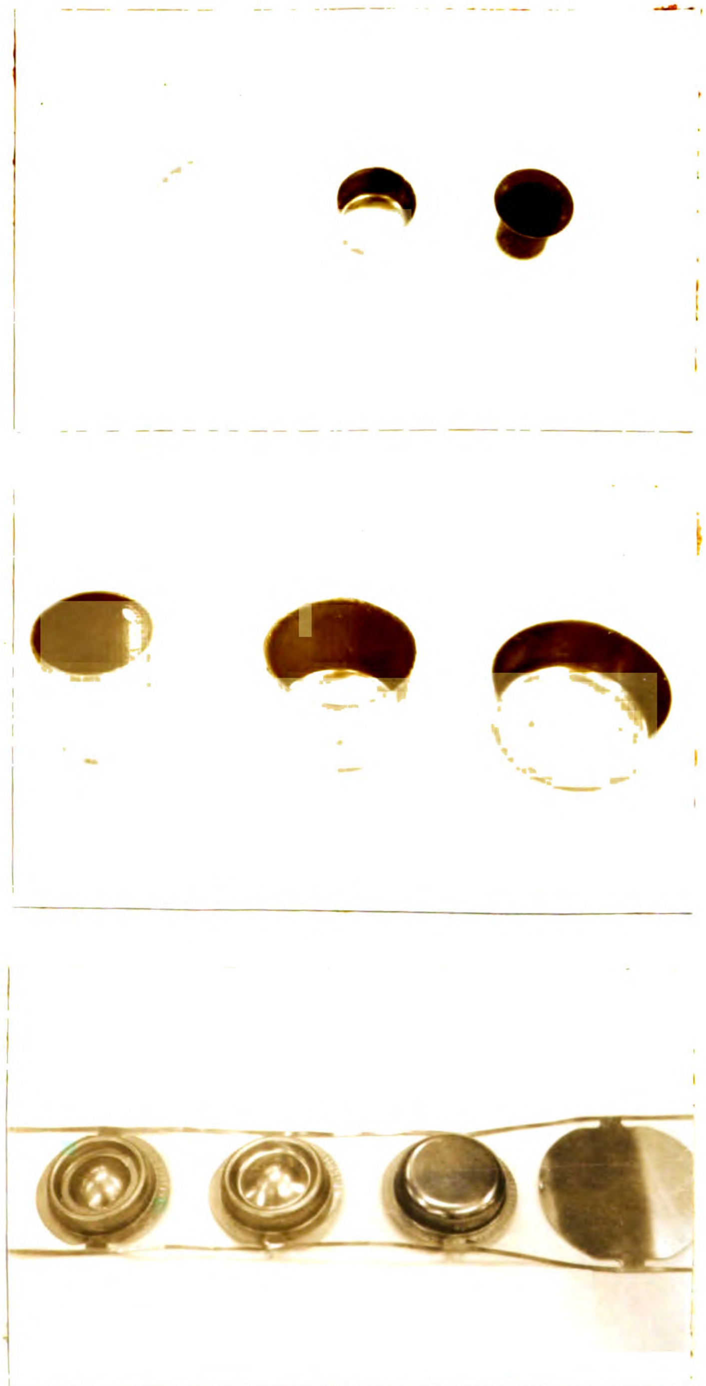


Figure 2. Examples of Cupping

Figure 3. Draw Wrinkles

The pressure exerted by the blankholder prevents wrinkles from starting in the sheet-metal blank. The metal is being compressed but cannot wrinkle. Therefore the metal thickens and extrudes. This condition is shown in Figure 4.

The thickening of the metal may be found by measuring the wall thickness of a cup when the original blank thickness is known. The extruding effect may also be shown. On the blank shown in Figure 2, a line drawn across the blank and through the center measures four and five-eighths inches long. The same line when measured on the cup measures about five and three-quarters inches long. If drawing were a pure stretching operation, this much radial elongation would have caused failure of the metal. Actually, this increased length is then due only partially to stretching of the metal. The remaining increase in length is a result of extrusion caused by the compressive force which is present due to the excess of metal. Therefore these terms --- compression, wrinkling, thickening, extrusion and excess of metal all refer to the condition at the outer extremity of the blank during a cupping operation.

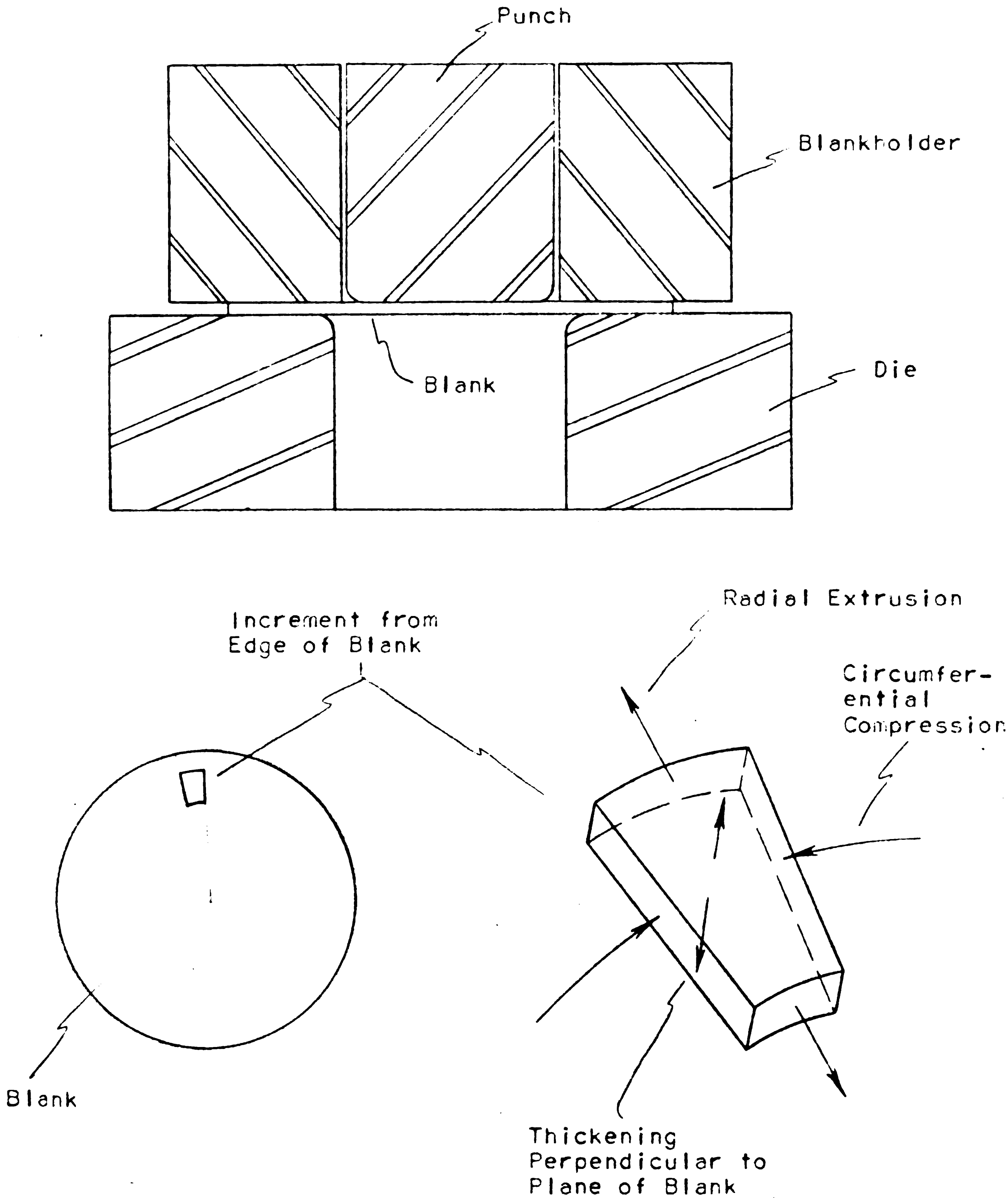



Figure 4. Thickening and Extrusion

When the sheet-metal thickness is large relative to the blank diameter then the metal is rigid enough to thicken without wrinkling. In this case, the blankholder may be eliminated.

Besides the compressive forces described, certain bending forces are also present during cupping. The bending forces occur at the radii where the flange and side wall and where the side wall and bottom meet. These forces consist of tension on the outside of the bend and compression on the inside of the bend.

The third set of forces are those which are caused by friction. Friction occurs between the sheet-metal blank and the blankholder, punch and die. This friction is present due to the fact that the sheet-metal flows past these surfaces as the cupping operation progresses. Figure 5 illustrates the forces occurring during cupping.

The function of the punch is now defined. It must exert a force of a magnitude great enough to overcome friction, bend the metal at the corners and compress and extrude the metal in the flange area or top of the cup.

The force exerted by the punch to accomplish this work is shown in Figure 5. Notice that the punch actually exerts its force by pushing on the bottom of the cup. This action causes a tensile stress at the point where the bottom radius and the side wall of the cup meet. This point is where the maximum tension will occur in the cup. If the cup breaks, it will normally break at this point as illustrated in Figure 6. Breaks that occur at other points in the cup are usually due to defective material. The maximum tension point may be found by locating the smallest cup wall thickness. The wall thickness at this point will be somewhat less than the original blank thickness. Figure 7 shows a typical flanged cup and wall thicknesses at various points. Figure 8 illustrates these conditions for a straight cup. The thickness variations shown occur only when no ironing occurs in the draw die.

The maximum tensile force caused by the punch pressing on the cup bottom must not exceed the ultimate strength of the metal. Otherwise failure will occur. This tensile force is actually composed of three forces. First, a tensile force is necessary to overcome friction. Secondly, a tensile force is necessary to bend. Thirdly, a tensile force is necessary to compress and extrude the metal in the top of the cup. Therefore the sum of these three tensile forces must not exceed the ultimate tensile strength of the metal.

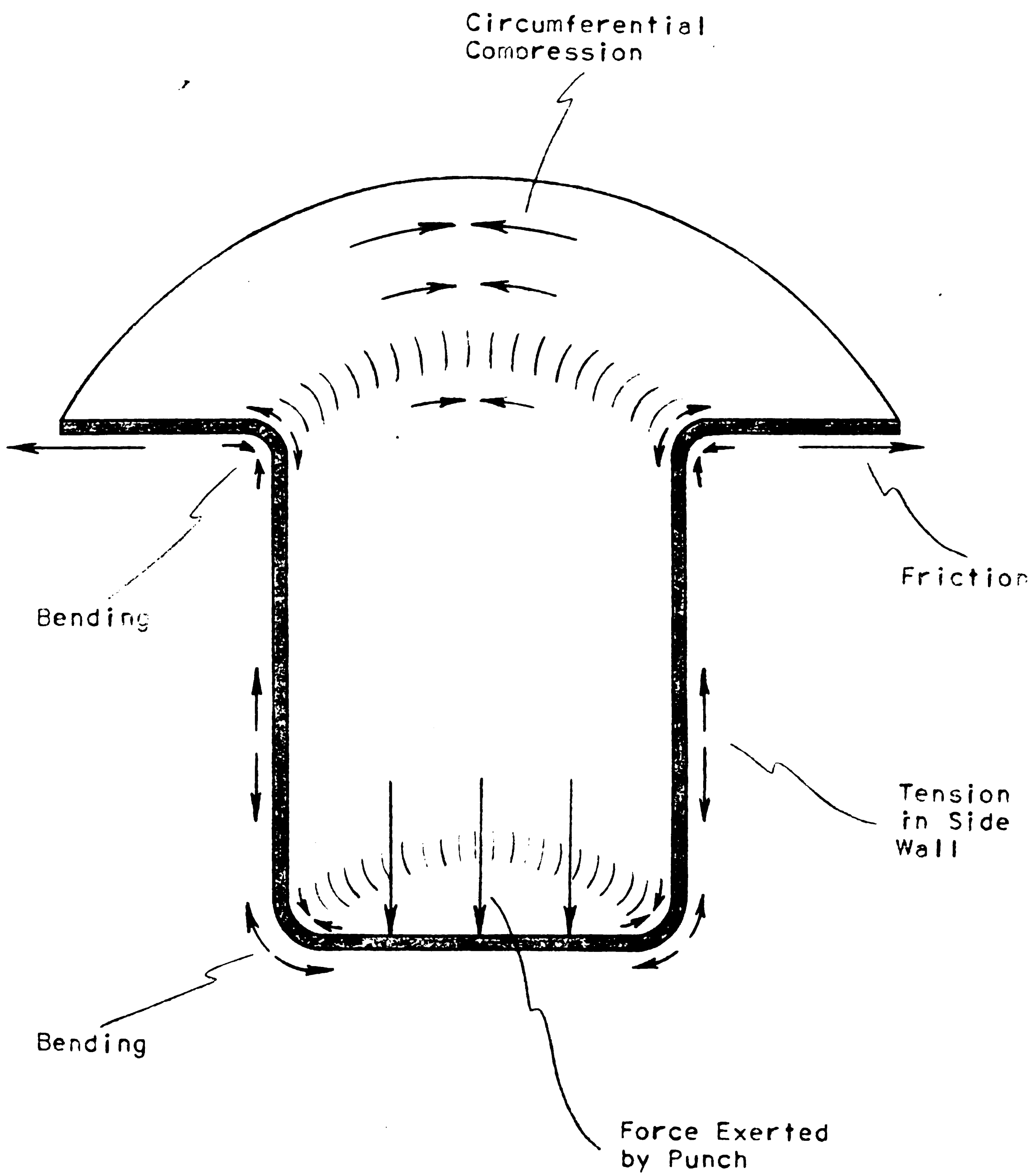



Figure 5. Forces During Cupping

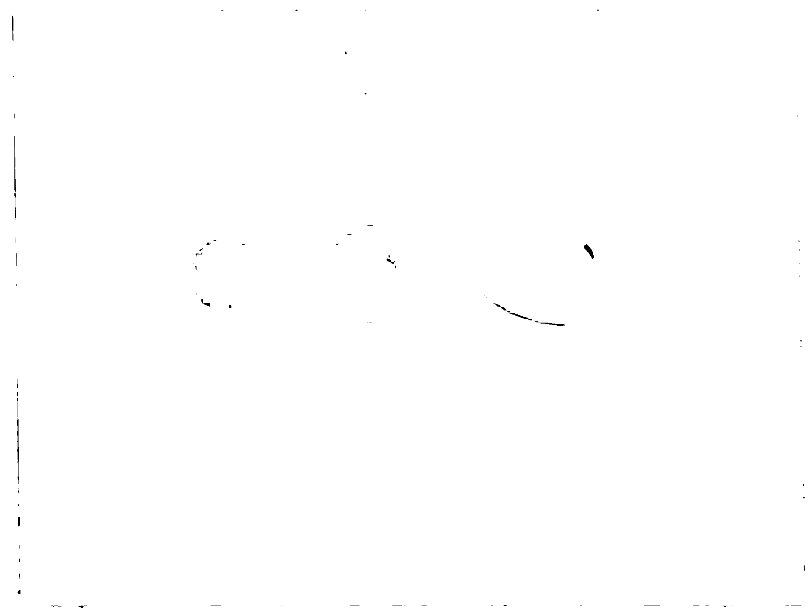


Figure 6. Cup Breaks

ORIGINAL BLANK THICKNESS --- .040"

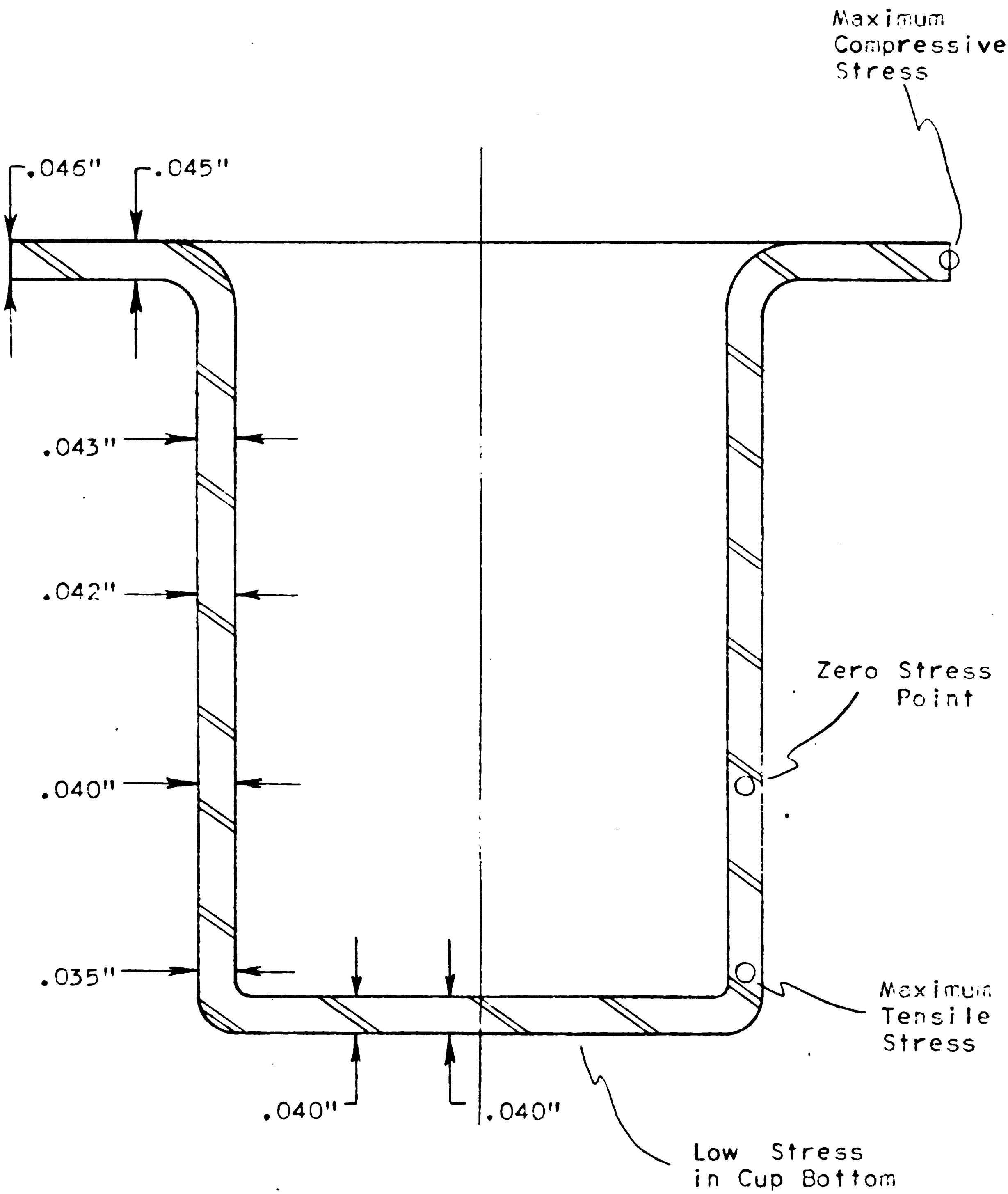



Figure 7. Wall Thicknesses - Flanged Cup

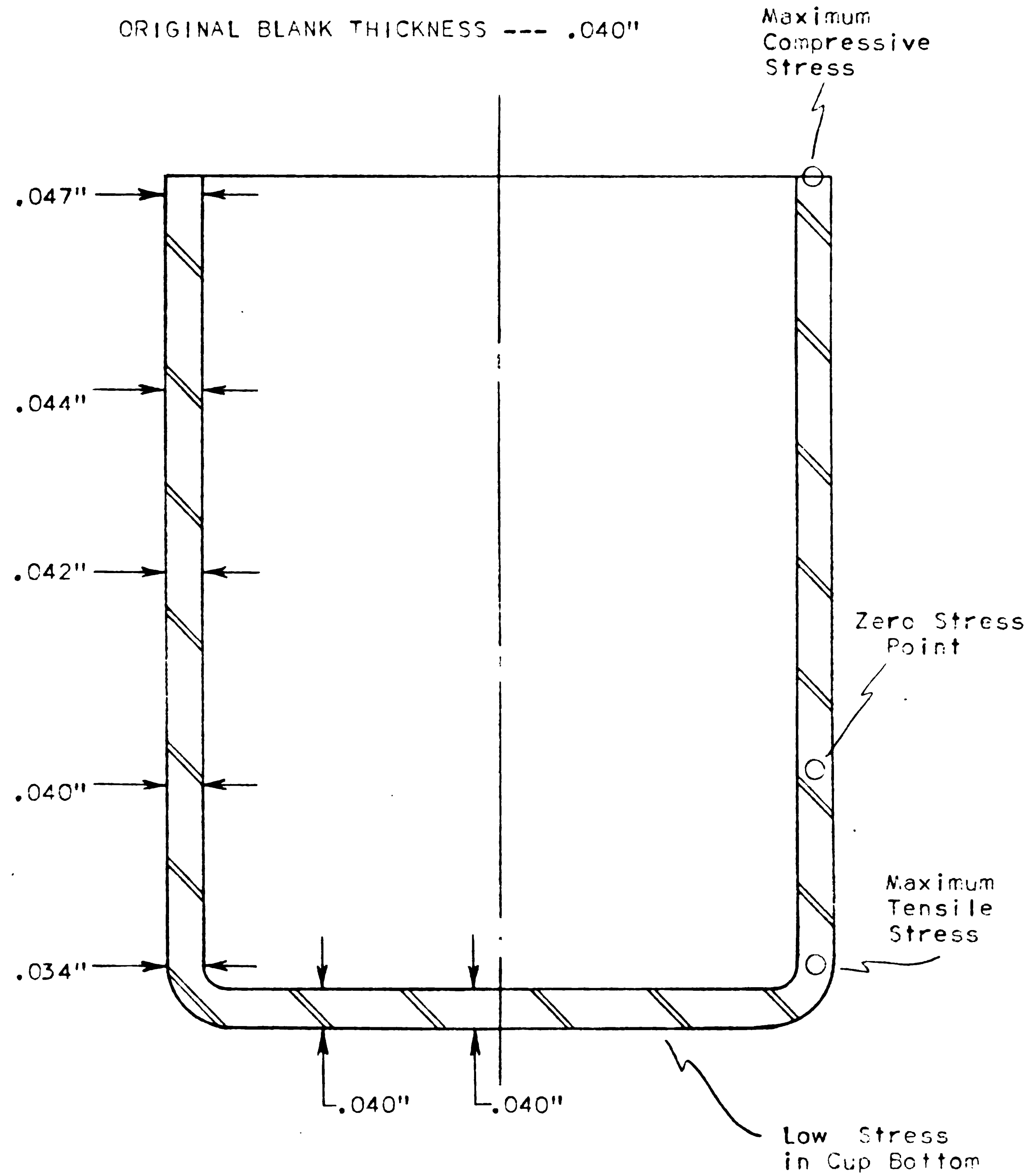



Figure 8. Wall Thicknesses - Straight Cup

## II. The Experiment Plan

The operation of a cupping die involves many variables. To obtain valid results, most of these variables must be held constant or nearly constant so that the desired variables may be measured. When the variables cannot be held constant to the degree desired, then a statistical approach is necessary to determine the relative effect and interaction of these variables.

The variables occurring in a cupping die are listed below. Those variables which were held "constant" are indicated as such. The variables to be measured are indicated as "variables."

Variables in the sheet metal:

| | |
|---|---|
| Hardness | Constant |
| Thickness | Constant |
| Surface Finish | Constant |
| Ultimate Tensile Strength | Constant |
| Direction of Rolling | Constant |

Variables in the die:

| | |
|---|---|
| Hardness | Constant |
| Surface Finish | Constant |
| Punch Radius | Constant |
| Die Radius | Constant |
| Die Clearance | Constant |
| Blankholding Force | Constant |
| Temperature (Die) | Variable |
| Drawing Speed | Constant |
| Drawing Lubricant | Variable |

Variables in the cup produced:

| | |
|---|---|
| Wall Thickness | Variable |
| Surface Markings (Galling, scratching, scoring or orange peel) | Variable |
| Wrinkling or Breaking | Variable |

Variables in forces required:

| | |
|---|---|
| Force exerted by punch | Variable |
| Force due to friction | Variable |
| Force due to bending | Constant |
| Force due to circumferential compression | Constant |

The discussion of the experimental procedure which was developed is divided into the following subjects:

1. Selection of Lubricants
2. Selection of Sheet Metal
3. Design of Cupping Die and Force Measuring Equipment
4. Temperature Measuring Equipment
5. Thickness Measuring Equipment
6. Blank Preparation
7. Setup of Die and Press (Trial Run)
8. Sequence of Testing Lubricants and Sample Size
9. The Experiment Procedure

Selection of Lubricants

The desired characteristics of a drawing lubricant are as follows:

To reduce friction.
To stop galling and scoring.
To cool the die and part.
To reduce die wear.
To not stain the sheet metal.
To not cause subsequent corrosion.
To be applicable.
To be cleanable.
To be economical.
To not affect the operator - - non-toxic.

Eleven lubricants were selected for testing. The twelfth lubricant tested was the protective oil placed on the sheet metal at the steel mill. This is referred to as "mill oil." The lubricants selected are commonly used in sheet-metal working plants today. Some lubricants are used to a greater extent than others. These lubricants are used as a result of testing different compounds by trial and error. The poorer lubricants were eliminated. In other words, the experiences of many men have contributed to the selected list of lubricants.

The lubricants selected for testing are listed below:

| Lubricant | Code Letter |
|---|---|
| Mill Oil | A |
| Wet Soap | B |
| Dry Wax | C |
| Plastic | D |
| Reclaimed Oil | E |
| Molybdenum Disulfide | F |
| Wet Wax | G |
| Lard Oil | H |
| Pigmented - Medium | J |
| Chlorinated Wax | K |
| Heavy Oil | L |
| Graphite | M |

A code letter was assigned to each lubricant. These code letters were used for identification in the remainder of the project. Thus, a tendency for bias towards particular lubricants was lessened.

The lubricants were applied to the blanks with a brush. This was the most suitable means of application for this experiment. The brush could be easily cleaned between lubricants and the brush produced a uniform coating of lubricant. Both sides of the blank were fully covered with lubricant.

No lubricant was placed directly on the die surfaces. Lubricant did, however, accumulate there and the die was cleaned each time the lubricant was changed.

Handling the blanks with tongs prevented removal of the lubricant when placing the blanks in the die.

Selection of Sheet Metal

Since one of the more common sheet metals used in the automotive industry is cold rolled mild carbon steel, it was selected for this experiment.

The hardness of the sheet metal must be held nearly constant because this variable would otherwise interfere with measurement of other variables. Therefore an aluminum killed steel was selected because aluminum killed steels age harden very slowly. If a rim steel had been used, age hardening might have caused too much variation in hardness. To further control the hardness, all of the sheet metal that was used in the experiment was cut from a single coil. This also assured relatively uniform chemical and physical properties.

The specifications of the sheet metal were as follows:

SAE 1010 Cold Rolled Steel
Fully Annealed Deep Drawing
Aluminum Killed
.041 inches thick
10 inches wide x 80 inches long
To be coated with rust preventative oil

The above thickness was selected because it was a common thickness available in this metal. The stock width and length were determined by the blank diameter to be used for the cupping operation.

After 2400 pieces had been blanked, 240 blanks were randomly selected and tested for hardness in order to represent the hardness variation within the total lot. The hardness of the pieces in this sample is shown in Figure 9.

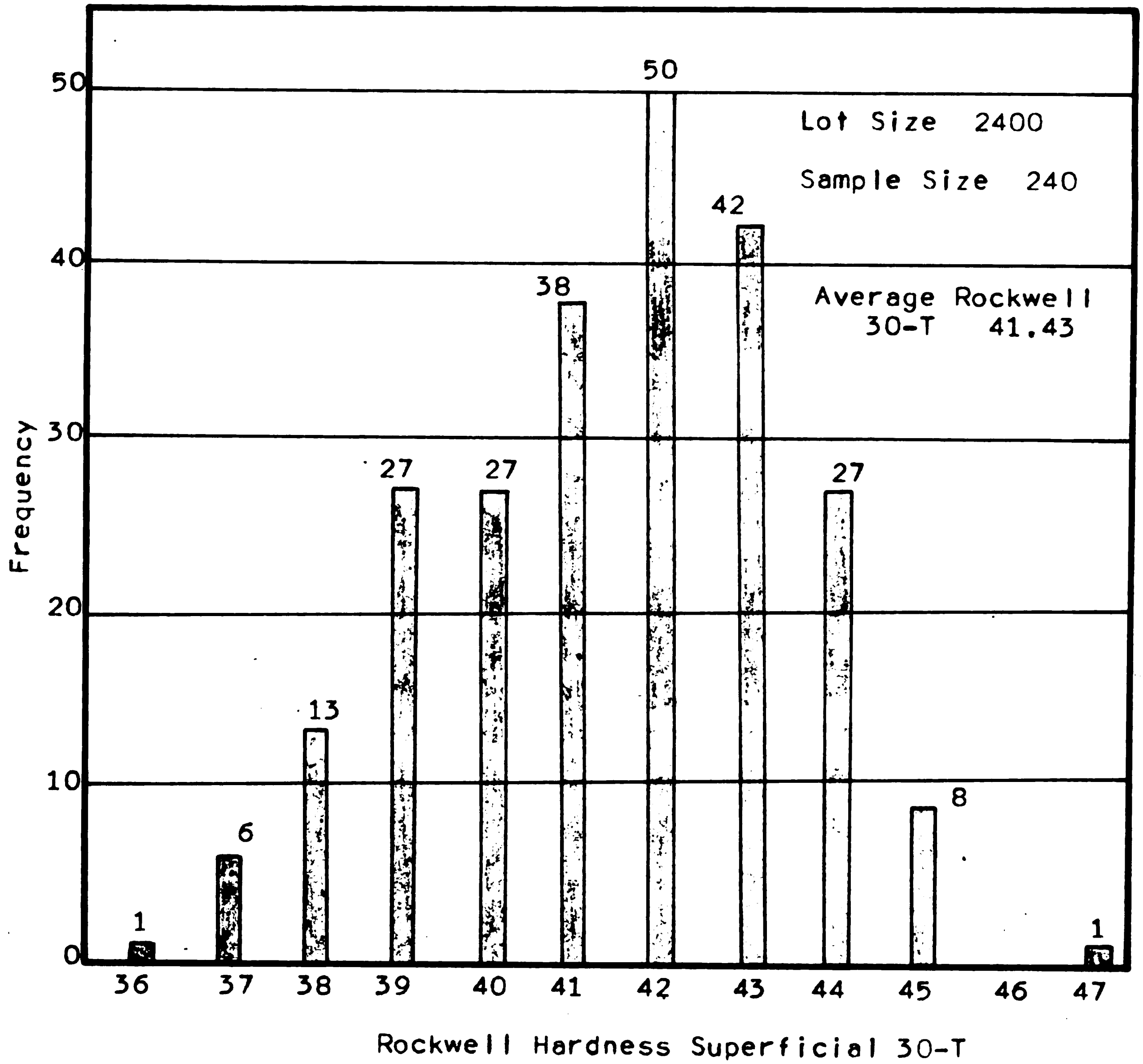



Figure 9. Blank Hardness Histogram

The bell-shaped curve indicated that a random distribution actually existed.

Tensile tests were then run in a Baldwin Test Machine to find the ultimate tensile strength, the per cent elongation and their variation. Speciments were cut out both with the direction of rolling and across the direction of rolling. Since rolling might have caused a severe fibre condition in the sheet metal, it was desired to know if significant differences in tensile strength and elongation were caused by the direction of rolling.

Histograms were plotted for the force and elongation data. These results are shown in Figures 10 and 11. The sample means and the deviations were computed in order to determine whether or not there was a significant difference of means.[4] A five per cent confidence interval was selected for this analysis.

[4] Grant, E. L., Statistical Quality Control, McGraw-Hill, New York, 1952, pp 96-97

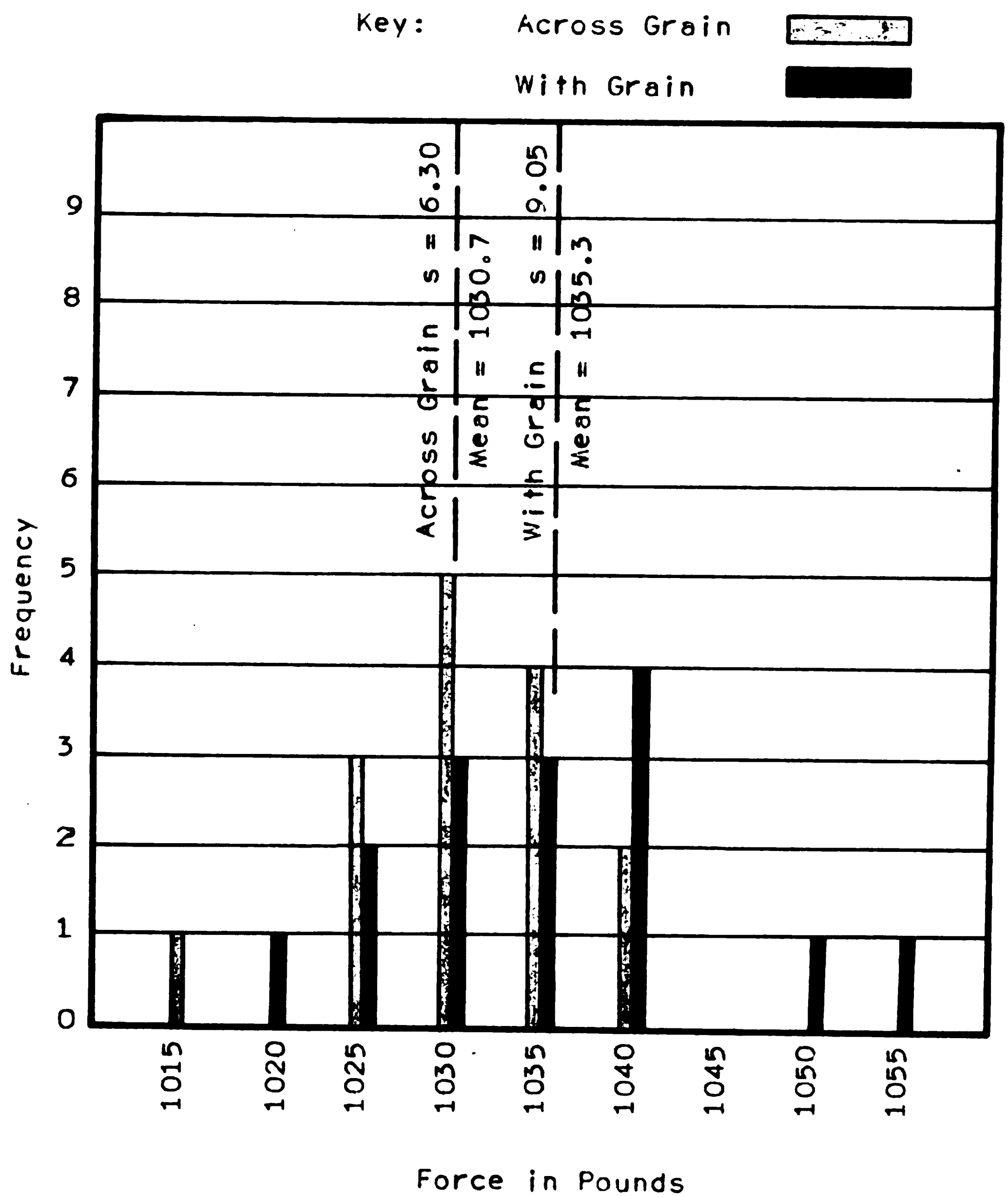



Figure 10. Tensile Force Histograms

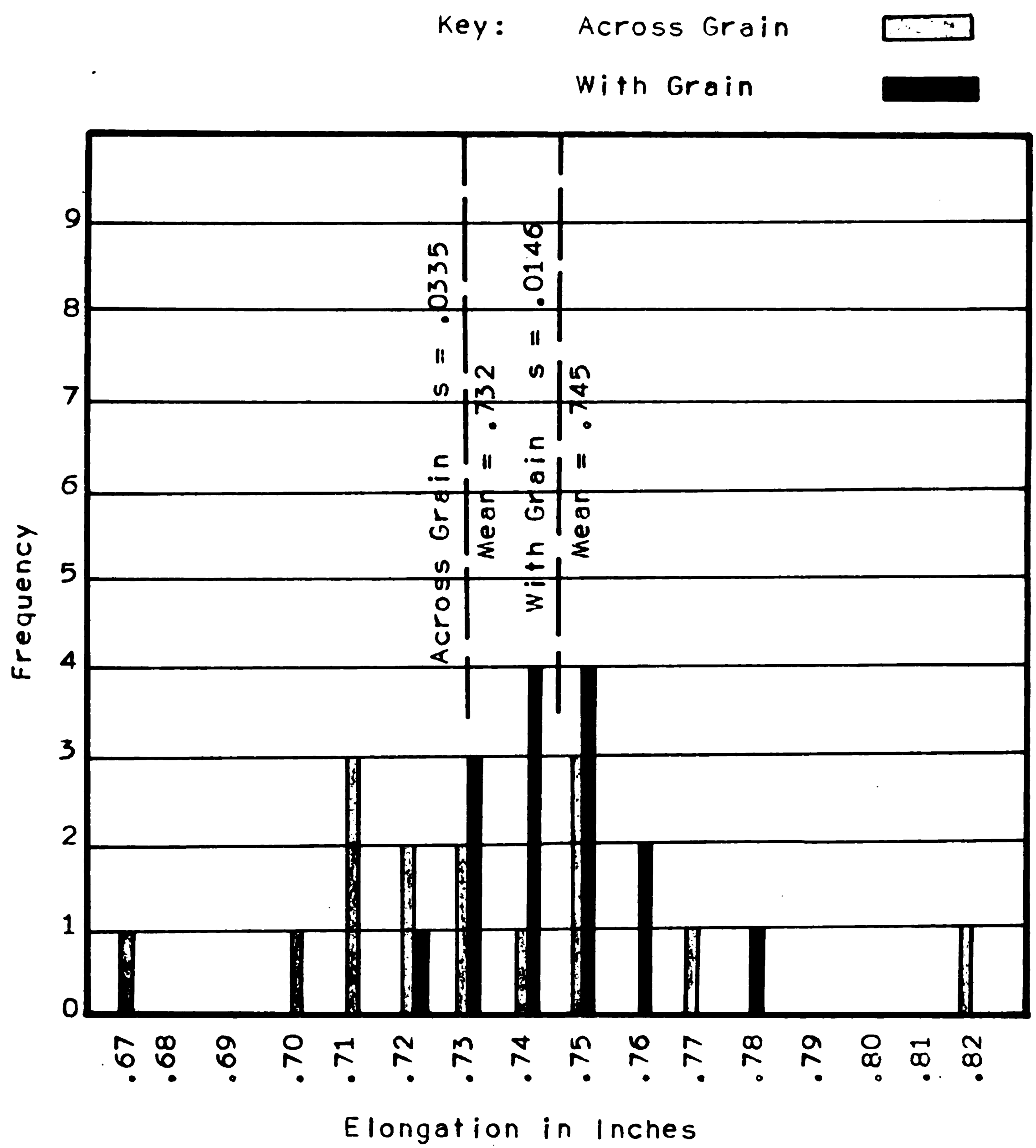



Figure 11. Elongation Histograms

Tests of Significance were now applied as follows:[5]

<u>Test B4</u> Test for difference in variability in two samples. (Test for homogeneity)

Tensile Force: $F = \left(\frac{9.05}{6.30}\right)^2 = 2.06$

Elongation: $F = \left(\frac{.0335}{.0146}\right)^2 = 5.29$

$DF_1$ and $DF_2 = 14$

Tensile Force --- Using Table E, the probability is above 0.05 that this difference may occur by chance. Therefore the samples are homogeneous.

Elongation --- Using Table E, the probability is less than 0.01 that this difference may occur by chance. Therefore the samples are not homogeneous.

<u>Test B2</u> Test for difference between two sample means.

Tensile Force: $t = \dfrac{1035.3 - 1030.7}{\sqrt{\dfrac{(9.05)^2 + (6.30)^2}{15 - 1}}}$

$t = 1.57$ $DF = 28$

Tensile Force --- Probability from Table = .134. Using 0.05 probability for this experiment, a significant difference does not exist. The probability is .134 that the difference occurs by chance.

Since a significant difference in tensile strength due to direction of rolling does not exist, the direction of rolling does not have to be considered when locating the blanks in the cupping die.

5 Juran, J. M., <u>Quality Control Handbook,</u> McGraw-Hill, New York, 1951, pp 380 and 382

The variances of the elongation samples were not homogeneous. Therefore the test for significant difference of means was not made. This lack of homogeneity may account for the earing effect on the top edge of the cups produced in the experiment. Due to the large sample size, this variable was factored out of the experiment results.

The surface finish of the sheet metal was held nearly constant by the specification that it be cut from a single coil. Some variation still existed due to the surface finish of the rollers, the speed of rolling, the temperature of rolling and the reduction made at the various passes.

Surface finish measurements were made with a Model BL-102 Brush Surface Analyzer Pickup. Root Mean Square Meter readings in microinches were found for eighty randomly selected blanks. These values are shown in Figure 12.

A short strip of oscillograph tape was run to illustrate the surface finish graphically. A typical tape is shown full size in Figure 13.

The thickness of the sheet metal should be nearly constant because the sheets were cut from the same coil.

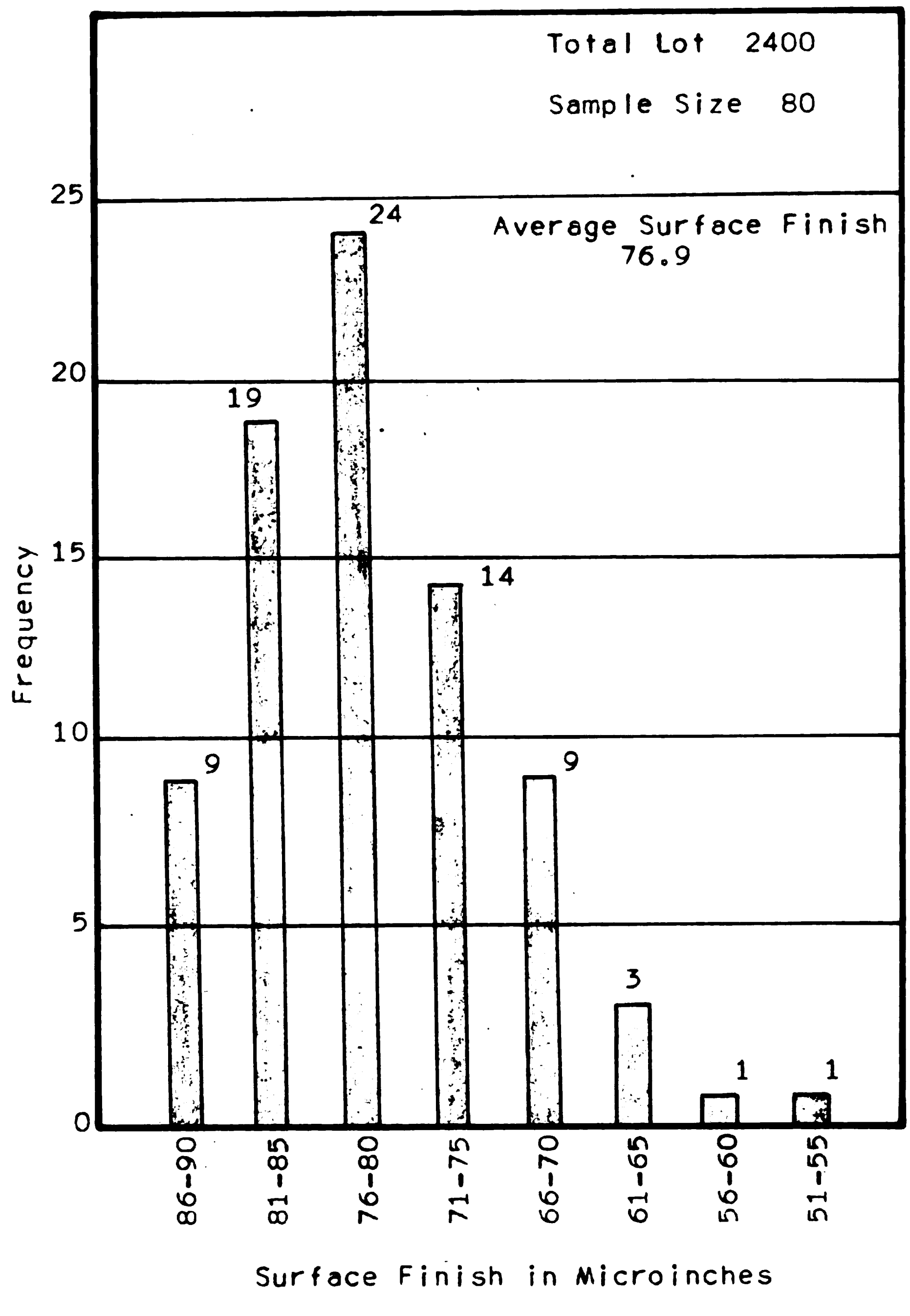
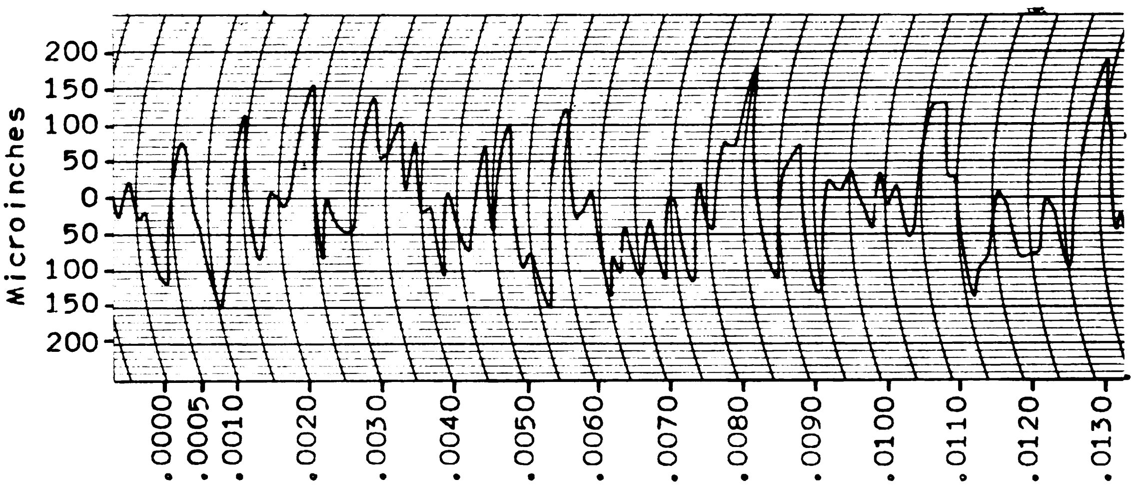



Figure 12. Blank Surface Finish Histogram

One Small Division = 10 Microinches




Surface Covered in Inches ⟶

Figure 13. Blank Surface Finish Graph

The thicknesses of 240 blanks were selected at random and measured with hand micrometers. These thicknesses are shown in Figure 14. Note that in this case a bell-shaped curve did not result.

Due to the wide range of thicknesses, it was suspected that a sizeable drawing force error might result. Therefore the drawing force was calculated for the minimum and maximum thicknesses encountered. These calculations are shown on pages 92 and 93 of the appendix. An error of plus or minus 6.9% from the mean drawing force could exist. Since this error would cause incorrect measurement of the reduction of the force due to friction, a means of factoring the thickness variable out of the experiment was devised.

The blanks were sorted by thickness into the following catagories:

.040 - .0409 inches
.041 - .0419
.042 - .0429
.043 - .0439
.044 - .0449
.045 - .0459
.046 - .0469
.047 - .0479
.048 - .0489
.049 - .0499

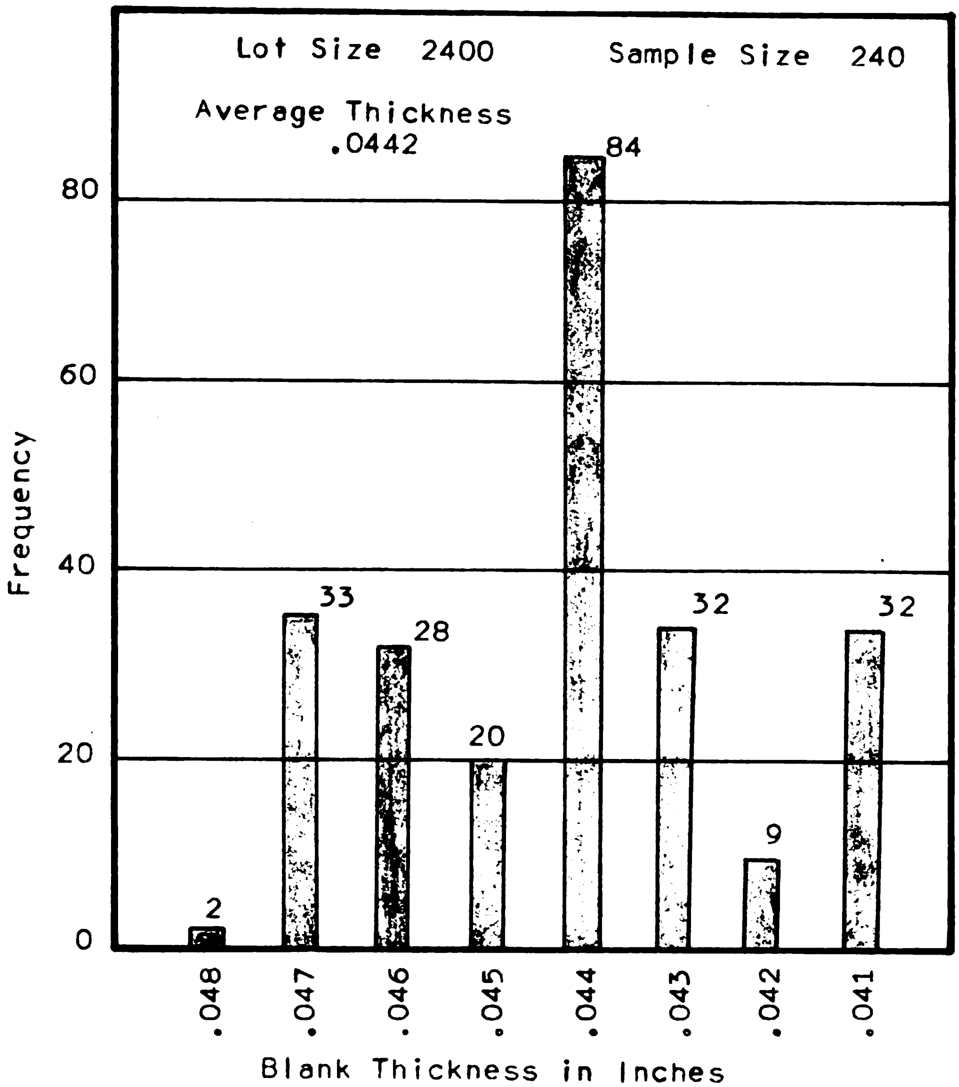



Figure 14. Blank Thickness Histogram

The blanks were then divided equally among the twelve lubricants to be tested. Each sample of 200 blanks for each lubricant had an identical number of blanks of each thickness. Therefore no lubricant had any advantage due to variations in blank thickness.

Design of Cupping Die and Force Measuring Equipment

To enable measurement of the punch force, die temperature and side wall thinning so as to check lubricant effectiveness in reducing friction force, a suitable die was required. A draw die of desired accuracy was already available. This die was constructed so that the punch and die steels could be easily interchanged. One of the available die steels was selected for use in this experiment. It was decided, however, that a new punch steel would have to be designed and built. Only solid punches were available. A hollow punch was desired for this experiment.

There are two main reasons for using a hollow punch. First, the cross-sectional area in compression was reduced. Thus the strain would be greater and more readily measured. Secondly, the hollow punch permitted mounting the strain gages close to the end of the punch. Since the punch force was to be measured, this was the proper position for strain gages. The punch exerts its force where the bottom radius and side blend together at the tangent point. Hollowing out the punch end has no effect on the contour of cup produced. The cup bottom is an area of low stress or strain.

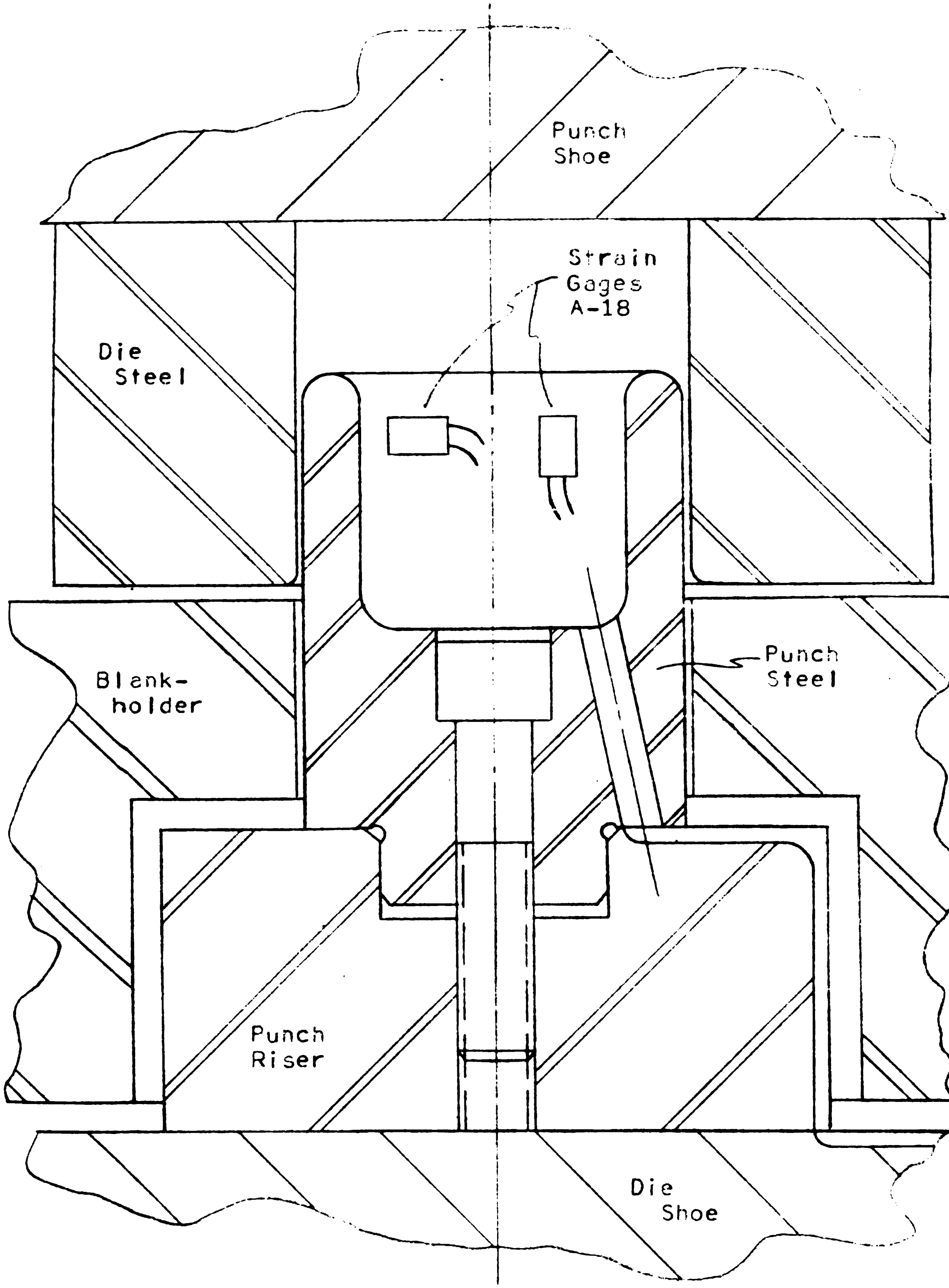



Figure 15. Cupping Die Design (Full Scale)

Due to clearances in the die, placement of the strain gages in other parts of the die would have been difficult.

Refer to Figure 15 for a cross-sectional view of the die. Two strain gages were mounted in the punch steel. One gage was cemented vertically to measure the punch force exerted. This will be the major gage for the experiment. A second gage was cemented horizontally in the punch steel. A gage was placed in this position to measure the circumferential force on the punch steel. Measurements from this gage were not used to support the experiment conclusions. Both strain gages measured compressive strains or forces. It may be difficult to actually calculate or calibrate the circumferential force due to the non-uniform area on which it acts. The characteristic curve may be obtained however.

In Figure 15, notice the groove cut in the punch riser and die shoe to carry the four strain gage leads out of the die. A slanted hole in the punch steel carries the leads through to the groove. This method was necessary to prevent the blankholder from cutting or mashing the leads.

The strain gage specifications were as follows:

Baldwin SR-4 Strain Gages
Type A-18 3/16 inches minimum width
Resistance 120.5 ± .3 ohms
Gage Factor 1.70 ± 2%
Lot 232-11 C-55

Melted beeswax was poured into the hollow punch steel to protect the strain gages and leads from moisture and from the lubricants. Since the punch steel is mounted on the lower or die shoe, the lubricants tended to run down into the punch. Room was left in the center of the beeswax for the punch-steel retaining screw.

The draw-die specifications are included on page 94 of the appendix. Critical die dimensions are given. The clearance has been made so that no burnishing or ironing of the cup side wall would occur because ironing would have caused an increased thinning of the side wall and an increased punch force. Ironing would have made it extremely difficult to measure the true drawing punch force because it would have been impractical to calculate and factor out the increase in punch force due to ironing.

Temperature Measuring Equipment

Die temperature rise should be a good indicator of the heat generated by friction. A greater temperature rise would indicate partial failure of the lubricant. The three main components of a cupping die would normally have the following relationship as far as friction and temperature:

| | |
|---|---|
| Punch Steel | Lowest temperature due to the least amount of motion or sliding in relation to the sheet metal. |
| Blankholder | Medium temperature due to the maximum amount of motion or sliding in relation to the sheet metal. The larger mass prevents the blankholder from attaining the highest temperature. |
| Die Steel | Highest temperature due to the maximum amount of sliding in relation to the sheet metal. |

The die steel temperature was measured with a General Electric Type FH-1 Hand Pyrometer. This pyrometer gave an almost instantaneous reading. The specifications of the pyrometer are given on page 95 of the appendix. Figure 16 illustrates the pyrometer and its attachments. The flexible extension cable facilitated getting the probe into the die. Temperature measurements were taken only after every fifth cup.

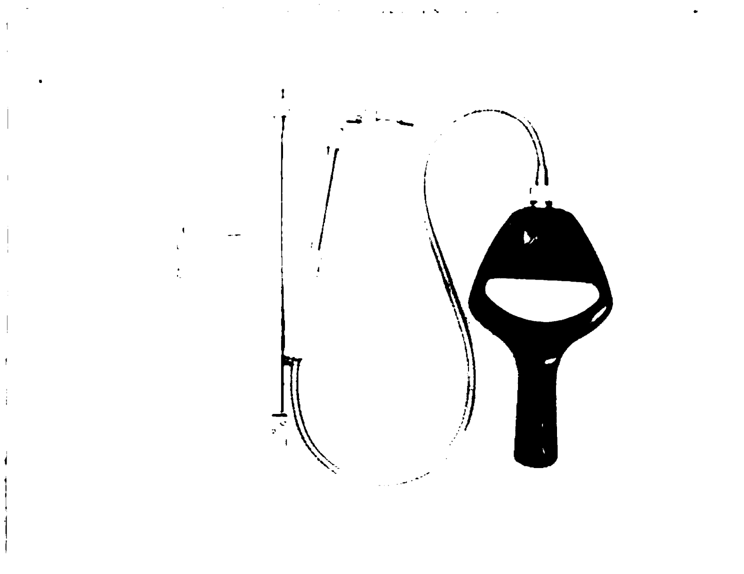


Figure 16. General Electric Hand Pyrometer
(Courtesy General Electric Company)

## Thickness Measuring Equipment

A deep-throat micrometer was selected for measuring the wall thickness of each cup. Fast accurate readings were possible. Another decision was to make three wall thickness measurements on each cup drawn. Thus the maximum thinning as well as the maximum thickening of the side wall was found. Figure 17 shows the positions at which the wall thicknesses were measured. Each position was designated by a letter and they were recorded separately on the test data forms.

## Blank Preparation

The blanks as cut had a small burr on the edge. If left in this condition, the burr might have scratched the die surface. Also the burr might have broken off during drawing. Pieces of metal in the die would certainly have altered the accuracy of the measurements. Defects would have been produced in the cup such as galling, scoring or imbedded metal particles. To eliminate this condition, the burrs were completely removed by using a flexible-belt sanding machine. Thus the contour of the blank was not altered. Then care was taken to wipe off all burr fragments and sand particles which stuck in the mill oil on the blanks. After the thickness measurements had been taken and the sorting was completed, the blanks were wrapped in aluminum foil to prevent any contamination or rusting.

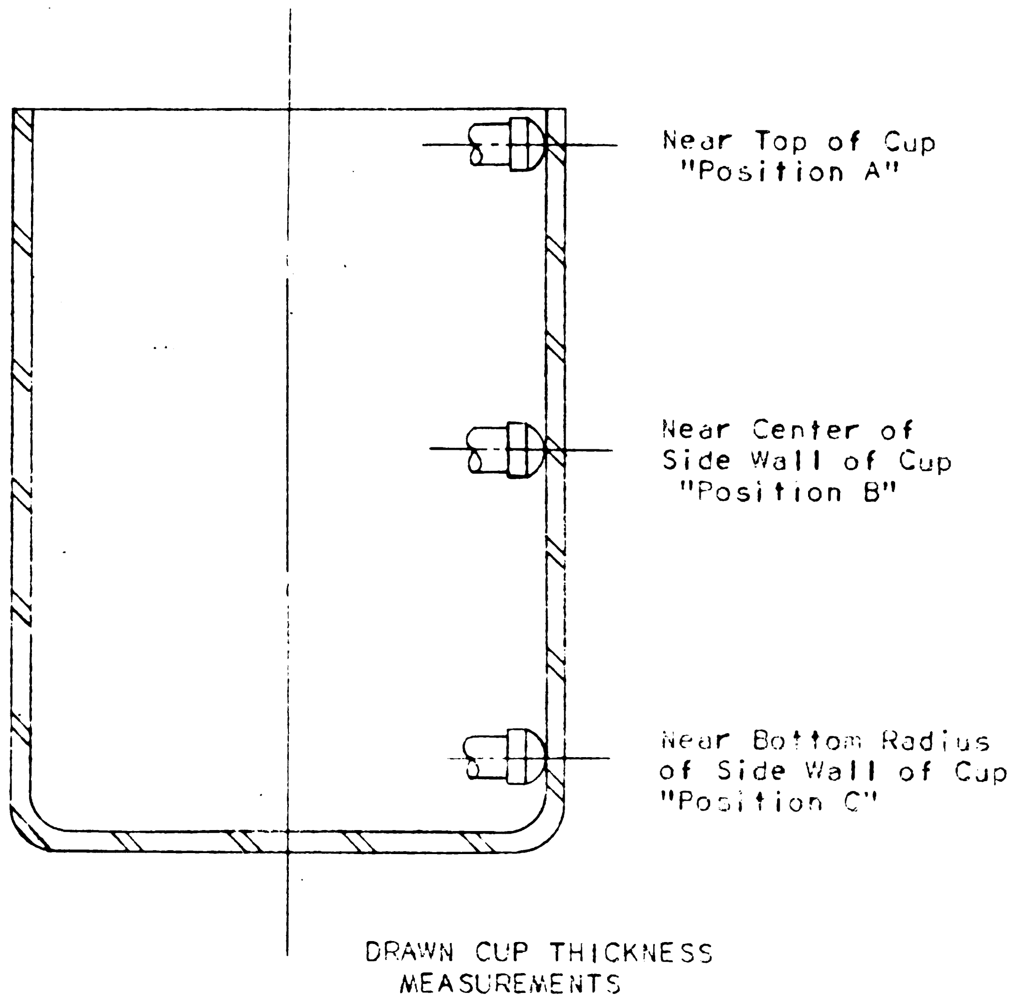



Figure 17. Cup Wall Thickness Measurements

Setup of Die and Press (Trial Run)

Before certain adjustments could be determined and the experiment procedure written, the die had to be setup and a trial run made. After setting up the die and calibrating the Sanborn Recorder, the press was started.

The press clutch air pressure was adjusted to fifty pounds per square inch. This pressure was recommended by the press manufacturer.

The press counterbalance air pressure was adjusted to twenty pounds per square inch. Such a pressure was needed to counterbalance the weights of the ram, the punch shoe and the die steel.

The press strokes per minute was set at forty. This was recommended as the minimum SPM for continual operation of the press.

The cushion air pressure was set at fifteen pounds per square inch. A blank was inserted in the die and a cup drawn. The cup broke indicating too much blankholding force. The pressure was readjusted to ten pounds per square inch. The resulting cup was without breaks or wrinkles. The pressure was again readjusted to five pounds per square inch. The resulting cup had small wrinkles. Therefore, ten pounds per square inch was selected as the cushion setting.

With the cushion set at ten pounds per square inch, the blankholding force would be as follows:

Cushion Rating --- 13 tons at 100 psi

$$\frac{13}{100} = \frac{x}{10}$$

$$x = 1.3 \text{ tons or } 2,600 \text{ pounds}$$

Blankholding Force = 2,600 pounds

For the trial run, an oil similar to mill oil was placed on both sides of each blank. After drawing, the cups were too hot to handle, indicating a generation of heat caused by friction. Part of the heat is generated from working the sheet metal.

Another decision made during the trial run was that the Sanborn Recorder attenuator could be set on (1) thus obtaining greater sensitivity. The deflection readings would not go off of the scale at this setting. Figure 18 shows the deflection readings as taken during the trial run. Both the vertical and circumferential deflections are shown. Fifteen cups were run with an average deflection of 23.7 millimeters.

All of the cups produced during the trial run had the defect of "ears." This would indicate that some directionality or direction of rolling does exist in the sheet metal. The ears were not severe, however, and would be cut off during the trimming operation. This defect will not mar the final product. Ears were present on all cups drawn in the experiment. This defect was not recorded as such because it was common to all lubricants tested.

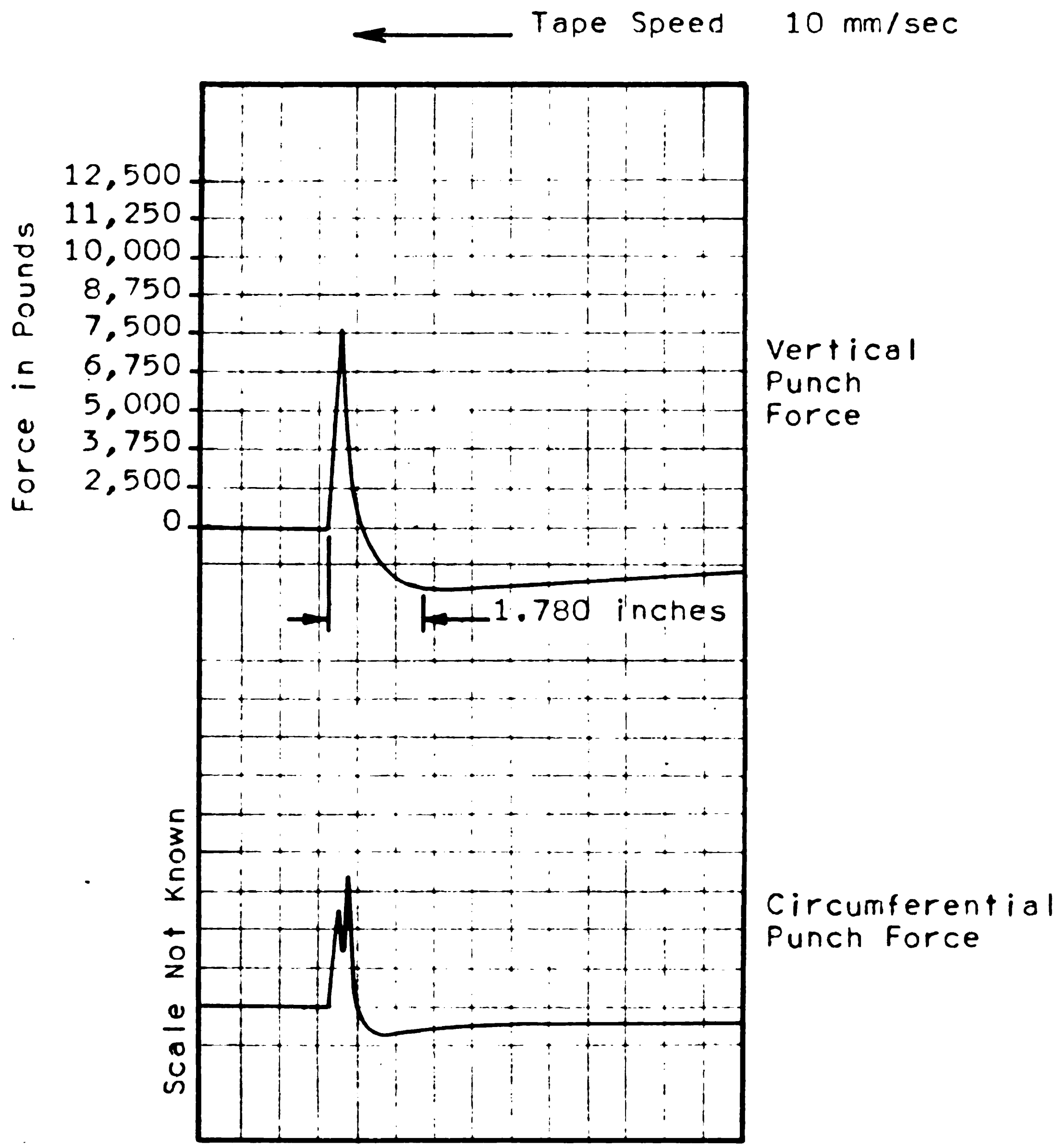



Figure 18. Trial Run Force Curves

An "orange peel" effect was also produced on all of the cups. This was a good indication that the lubricant used was not functioning properly.

No burnishing or ironing was present indicating that the die clearance was sufficient as estimated.

With the press speed set at forty strokes per minute, the contact velocity of the drawing punch would be as follows:[6]

$$\text{Velocity} = 0.5233 \times \text{SPM} \times \sqrt{dy - y^2}$$

$$y = \text{Cup Depth} = 1.781 \text{ inches}$$

$$d = \text{Press Stroke} = 6.000 \text{ inches}$$

$$\text{SPM} = \text{Strokes per Minute} = 40$$

$$V = 55 \text{ feet per minute}$$

This contact velocity is quite high for drawing. Because of this velocity, the cupping operation used for the experiment would be considered a severe working of the sheet metal.

Sequence of Testing Lubricants and Sample Size

Actually, it was impractical to determine an exact sample size since the expected variation in readings was not known. The sample size was set at 200 cups per lubricant as a starting point.

A total of 2,400 blanks were required for the twelve lubricants. When continual breakage or scoring of cups occurred in one sample for a particular lubricant, the experiment was halted for that sample. Thus all 200 blanks were not run for each lubricant. Cup damage would indicate failure of the lubricant without measuring the reduction in punch force or thinning of the side wall. Further use of the lubricant would be unnecessary.

To reduce the effects of sequence of testing lubricants, the sample of 200 was divided into four sub-samples of fifty cups each. By doing this, randomness was introduced into the sequence. Each lubricant could follow any other of the twelve lubricants. To introduce randomness, a table of random numbers was used.[7]

6 Crane, p 195, Op. Cit.

7 Wilson, E. B. Jr., An Introduction to Scientific Research, McGraw-Hill, New York, 1952, p 287

When converted to code letters, the sequence of testing lubricants was as follows:

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| J | K | L | F | K | E | A | L | L | M | E | K | K | B | B | H |
| C | F | J | M | D | L | F | F | A | G | J | D | G | M | B | C |
| C | C | E | G | B | E | H | H | J | M | A | H | G | D | A | D |

The Experiment Procedure

The experiment procedure was divided into the following three catagories:

1. Press Adjustments
2. Sanborn Recorder Calibration
3. Running the Experiment

Since the entire experiment cannot be run at one time, the Sanborn Recorder and the Minster Press were completely adjusted for each separate running of samples. Each day the experiment was run, all three procedures were followed for the initial setup. After that, only procedure three was followed. These detailed procedures are included on pages 90 through 96 of the appendix.

It was assumed that one strain gage mounted in the punch was sufficient to measure the variation in punch force due to changes in the friction force. Four strain gages would have been used if it was desired to find the average punch force. Verification of the above assumption was deemed necessary. Therefore after the major portion of the experiment was completed, three additional strain gages were mounted in the punch and several cups made. The results were recorded on tape by the Sanborn Recorder.

Samples of the test data forms used to record data are shown on the following pages.

TEST DATA

LUBRICANT: ____________________

SAMPLE NUMBER ______

| Cup No. | Vertical Deflection | Circum-ferential Deflection | Wall Thickness | | | Temp. |
|---|---|---|---|---|---|---|
| | | | A | B | C | |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 10 | | | | | | |
| 11 | | | | | | |
| 12 | | | | | | |
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| 14 | | | | | | |
| 15 | | | | | | |
| 16 | | | | | | |
| 17 | | | | | | |
| 18 | | | | | | |
| 19 | | | | | | |
| 20 | | | | | | |
| 21 | | | | | | |
| 22 | | | | | | |
| 23 | | | | | | |
| 24 | | | | | | |
| 25 | | | | | | |

Temperature in Degrees Fahrenheit
Wall Thickness in Inches
Deflection in Millimeters

TEST DATA (CONTINUED)

LUBRICANT: ______________________________

SAMPLE NUMBER ______

| Cup No. | Vertical Deflection | Circum-ferential Deflection | Wall Thickness | | | Temp. |
|---|---|---|---|---|---|---|
| | | | A | B | C | |
| 26 | | | | | | |
| 27 | | | | | | |
| 28 | | | | | | |
| 29 | | | | | | |
| 30 | | | | | | |
| 31 | | | | | | |
| 32 | | | | | | |
| 33 | | | | | | |
| 34 | | | | | | |
| 35 | | | | | | |
| 36 | | | | | | |
| 37 | | | | | | |
| 38 | | | | | | |
| 39 | | | | | | |
| 40 | | | | | | |
| 41 | | | | | | |
| 42 | | | | | | |
| 43 | | | | | | |
| 44 | | | | | | |
| 45 | | | | | | |
| 46 | | | | | | |
| 47 | | | | | | |
| 48 | | | | | | |
| 49 | | | | | | |
| 50 | | | | | | |

**Temperature in Degrees Fahrenheit**
**Wall Thickness in Inches**
**Deflection in Millimeters**

| DRAWING DEFECTS RECORD | | | |
|---|---|---|---|
| Defect Description | Lubricant Code Letter | Sample No. | Cup No. |
| | | | |
| | | | |
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## III. The Experiment

The experiment was completed without serious difficulty or interferences. Minor disturbances which occurred during the experiment are recorded in this section.

The room temperature varied somewhat during the course of the experiment. The range in room temperature was from 70 to 76 degrees Fahrenheit. Therefore any temperature averages had to be adjusted to a common room temperature of 70 degrees.

The same experiment procedure was followed for each sample. It was expected that the duration times for each sample would then be uniform. If such a condition existed the die temperature rise could then be used with validity to show presence of friction. A factor existed however, which prevented uniformity of duration times. This factor was the viscosity of the lubricant. Lubricants with high viscosity were easily applied and the duration time for running these lubricants was low. Other lubricants with low viscosity were very difficult to apply uniformly on the blank surfaces. The duration time for these lubricants was higher. Because of the variation in duration times, die temperature could not be used as a factor in determining which lubricant was most effective in reducing friction in a cupping die.

The following pages list the duration times for each of the forty-eight samples as recorded during the experiment.

EXPERIMENT DURATION TIMES

| Lubricant Code Letter | Cups Made | Duration Time-Hrs. | Sample Number |
|---|---|---|---|
| A | 55 | .08 | 1 |
| | | .41 | 2 |
| | | .20 | 3 |
| | | .11 | 4 |
| B | 154 | 1.00 | 1 |
| | | 1.00 | 2 |
| | | .95 | 3 |
| | | .95 | 4 |
| C | 200 | 1.10 | 1 |
| | | .80 | 2 |
| | | .67 | 3 |
| | | .67 | 4 |
| D | 200 | 1.08 | 1 |
| | | 1.00 | 2 |
| | | .87 | 3 |
| | | .77 | 4 |
| E | 63 | .33 | 1 |
| | | .27 | 2 |
| | | .21 | 3 |
| | | .30 | 4 |
| F | 47 | .13 | 1 |
| | | .33 | 2 |
| | | .17 | 3 |
| | | .25 | 4 |
| G | 93 | .50 | 1 |
| | | .33 | 2 |
| | | .33 | 3 |
| | | .33 | 4 |
| H | 85 | .25 | 1 |
| | | .30 | 2 |
| | | .33 | 3 |
| | | .38 | 4 |

| Lubricant Code Letter | Cups Made | Duration Time-Hrs. | Sample Number |
|---|---|---|---|
| J | 200 | 1.33 | 1 |
| | | 1.33 | 2 |
| | | 1.27 | 3 |
| | | 1.17 | 4 |
| K | 200 | 1.17 | 1 |
| | | .91 | 2 |
| | | .83 | 3 |
| | | .83 | 4 |
| L | 200 | 1.08 | 1 |
| | | 1.00 | 2 |
| | | .91 | 3 |
| | | 1.20 | 4 |
| M | 148 | .30 | 1 |
| | | 1.25 | 2 |
| | | 1.00 | 3 |
| | | .88 | 4 |

The cupping die used incorporated a solid-knockout arrangement for ejecting the cup from inside of the die steel opening. Another difficulty was encountered here. When a lubricant with low viscosity was being tested, the cups stuck to the knockout-pad ejector with such adhesiveness that several hard blows were necessary to release the cup. This slowed the experiment considerably and increased the duration time for those lubricants.

Before each temperature reading was taken with the hand pyrometer, the die surface was wiped clean with a towel. This was necessary to prevent lubricant from filling the ceramic cup which housed the thermocouple. Again, with the lubricants having low viscosity, cleaning of the die steel was hampered. This allowed the die to cool before the reading could be taken. Thus, another factor entered the experiment which invalidated the use of die temperature as an indica-of friction.

Measurement of the cup wall thickness at position "A" was found to be difficult. Due to the rapid thickening of the wall near the top edge, a very slight shift in the micrometer caused considerable change in the reading taken. A more gradual change in wall thickness was found at positions "B" and "C." This condition accounts for the wider range of thickness readings at position "A." A cross-section of a typical cup is shown in Figure 19.

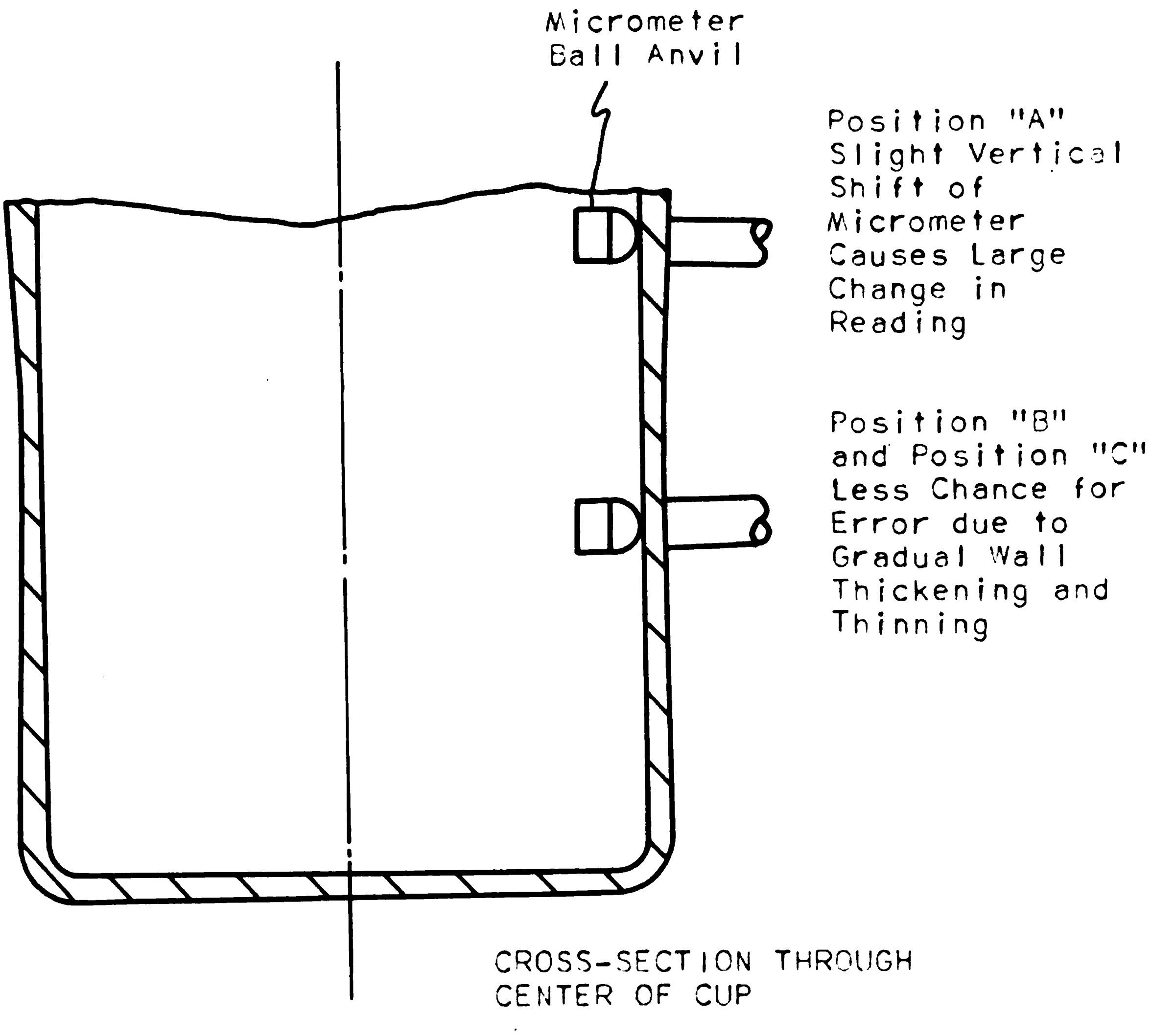



Figure 19. Excessive Wall Thickening at Position "A"

When lubricants with high viscosity were being tested, as the die closed lubricant would spray all over the work area. Shields had to be placed around the press to help control or limit the spraying to a more confined area. The cleaning job after using such a lubricant was a factor which lengthened the time required to run the overall experiment.

The following pages show the filled test data forms for one of the lubricants. Also shown is one of the drawing defects records taken of the experiment. These examples show how the data varied from cup to cup. The remaining test data forms are not included here. Histograms of the data are included and these show the frequency and range of readings for each lubricant. Most of the histograms are in the appendix of this thesis.

Photographs were taken of the experiment setup. Figure 20 is a photograph showing the press controls and the cupping die. Also seen in the photograph are the dial gages for setting clutch air pressure, counterbalance air pressure, cushion air pressure and strokes per minutes of the ram. The palm buttons may also be seen at the front of the press. The cupping die is visible with the punch steel and blank-holder on the lower shoe. The press ram is in the extreme up position at this time.

## TEST DATA

LUBRICANT: J

SAMPLE NUMBER 1

| Cup No. | Vertical Deflection | Circum-ferential Deflection | Wall Thickness A | B | C | Temp. |
|---|---|---|---|---|---|---|
| 1 | 14.0 | 8.0 | .040 | .035 | .032 | 70 |
| 2 | 20.5 | 12.0 | .043 | .034 | .032 | |
| 3 | 20.5 | 13.0 | .042 | .033 | .037 | |
| 4 | 21.0 | 15.5 | .041 | .032 | .035 | |
| 5 | 22.5 | 15.5 | .039 | .032 | .034 | |
| 6 | 19.0 | 7.5 | .042 | .032 | .033 | 71 |
| 7 | 18.0 | 7.0 | .040 | .031 | .035 | |
| 8 | 19.0 | 4.0 | .045 | .032 | .031 | |
| 9 | 20.0 | 14.0 | .041 | .031 | .031 | |
| 10 | 18.0 | 5.5 | .039 | .030 | .032 | |
| 11 | 18.5 | 10.0 | .045 | .031 | .034 | 72 |
| 12 | 19.5 | 10.0 | .043 | .030 | .031 | |
| 13 | 19.0 | 3.5 | .039 | .032 | .030 | |
| 14 | 17.0 | 9.5 | .038 | .030 | .029 | |
| 15 | 18.0 | 9.0 | .040 | .031 | .030 | |
| 16 | 18.5 | 7.0 | .038 | .031 | .030 | 75 |
| 17 | 19.0 | 13.5 | .042 | .031 | .032 | |
| 18 | 20.0 | 9.5 | .044 | .032 | .032 | |
| 19 | 19.0 | 3.0 | .040 | .031 | .031 | |
| 20 | 18.5 | 8.0 | .041 | .031 | .033 | |
| 21 | 21.5 | 7.5 | .042 | .034 | .032 | 73 |
| 22 | 21.0 | 18.5 | .043 | .034 | .034 | |
| 23 | 20.5 | 17.5 | .044 | .033 | .032 | |
| 24 | 20.0 | 11.0 | .038 | .031 | .030 | |
| 25 | 19.5 | 9.5 | .038 | .030 | .030 | |

Temperature in Degrees Fahrenheit
Wall Thickness in Inches
Deflection in Millimeters

TEST DATA (CONTINUED)

LUBRICANT: J

SAMPLE NUMBER 1

| Cup No. | Vertical Deflection | Circum-ferential Deflection | Wall Thickness | | | Temp. |
|---|---|---|---|---|---|---|
| | | | A | B | C | |
| 26 | 20.5 | 17.0 | .042 | .034 | .033 | 75 |
| 27 | 16.0 | 7.0 | .045 | .031 | .032 | |
| 28 | 16.0 | 6.5 | .039 | .030 | .029 | |
| 29 | 21.5 | 17.0 | .042 | .033 | .031 | |
| 30 | 22.0 | 15.5 | .040 | .030 | .029 | |
| 31 | 18.5 | 9.5 | .037 | .029 | .028 | 75 |
| 32 | 24.0 | 8.5 | .043 | .031 | .035 | |
| 33 | 18.0 | 10.5 | .039 | .030 | .028 | |
| 34 | 18.0 | 7.0 | .037 | .028 | .030 | |
| 35 | 18.0 | 6.5 | .037 | .028 | .028 | |
| 36 | 19.0 | 13.0 | .037 | .029 | .029 | 75 |
| 37 | 18.0 | 6.5 | .038 | .030 | .030 | |
| 38 | 20.5 | 10.5 | .038 | .031 | .031 | |
| 39 | 18.0 | 6.5 | .040 | .030 | .031 | |
| 40 | 17.5 | 10.0 | .041 | .030 | .030 | |
| 41 | 17.5 | 7.5 | .045 | .030 | .032 | 75 |
| 42 | 18.0 | 10.0 | .041 | .030 | .029 | |
| 43 | 19.5 | 11.5 | .045 | .030 | .030 | |
| 44 | 18.5 | 7.5 | .043 | .029 | .021 | |
| 45 | 18.0 | 9.0 | .040 | .029 | .030 | |
| 46 | 18.5 | 5.5 | .037 | .029 | .029 | 75 |
| 47 | 20.0 | 5.5 | .044 | .032 | .031 | |
| 48 | 17.0 | 11.0 | .037 | .028 | .028 | |
| 49 | 23.0 | 11.5 | .040 | .029 | .029 | |
| 50 | 23.0 | 13.0 | .041 | .032 | .029 | 75 |

Temperature in Degrees Fahrenheit
Wall Thickness in Inches
Deflection in Millimeters

| DRAWING DEFECTS RECORD | | | |
|---|---|---|---|
| Defect Description | Lubricant Code Letter | Sample No. | Cup No. |
| Cup Broke | B | 2 | 21 |
| " " | " | " | 23 |
| " " | " | " | 35 |
| Small Wrinkles | C | 1 | 8 |
| " " | " | " | 10 |
| " " | " | " | 14 |
| Cup Broke | H | 1 | 1 |
| " " | " | " | All |
| Cup Broke | F | 2 | All |
| Severe Wrinkles | D | 1 | 4 |
| Cup Broke | M | 2 | 2 |
| " " | " | " | 25 |
| " " | " | " | 26 |
| Cup Broke | F | 3 | 2 |
| " " | " | " | All |
| Cup Broke | A | 2 | 3 |
| " " | " | " | 6 |
| " " | " | " | 7 |
| Wrinkles | D | 2 | 1 |
| Cup Broke | G | 2 | 1 |
| " " | " | " | 2 |
| " " | " | " | 3 |

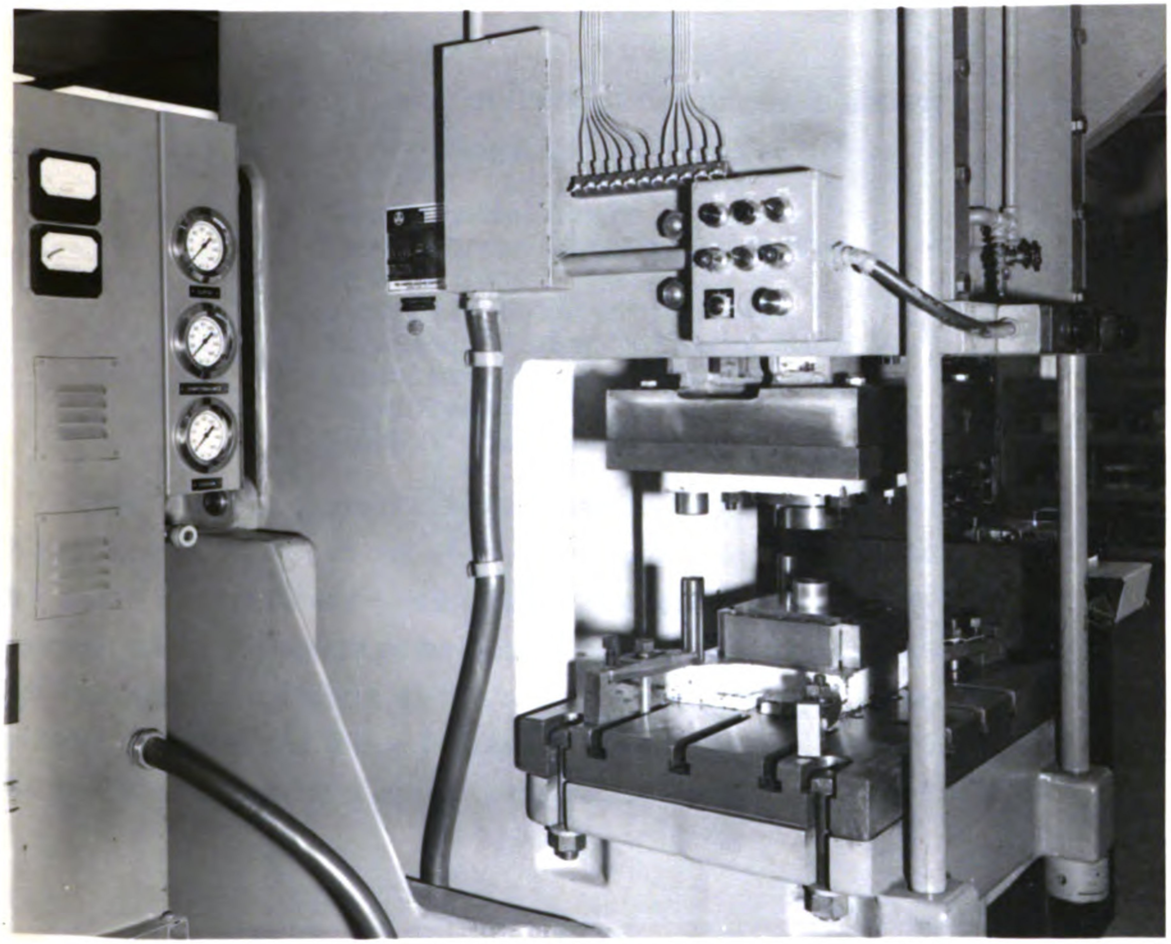


Figure 20. Press Controls and Cupping Die

Left-Front View

The Sanborn Multi-Channel Analyzer may be seen in Figure 21. Also shown here is a right-front view of the press and cupping die. The strain-gage leads from the die to the analyzer are visible. The air cushion which operates the blankholder is visible between the legs of the press.

The general work area in front of the press is shown in Figure 22. From left to right are shown the following articles:

Cup Disposal Truck
Deep-Throat Micrometer in Vise
Broken Cups
Test Data Form in Clipboard
Lubricant Pail with Mixing Stick
Aluminum Tongs and Blank
Hand Pyrometer
Stack of Blanks and Paint Brush

The cupping characteristic curves are shown in Figure 23. These curves were cut out of the tape from the Sanborn Analyzer. The same general curve was present for all lubricants. The only change was in the average height of the curve. The curves show a high instantaneous force when the cupping operation starts. A more gradual reduction of force follows. This indicates, as predicted, that the initial part of a cupping operation is the most severe.

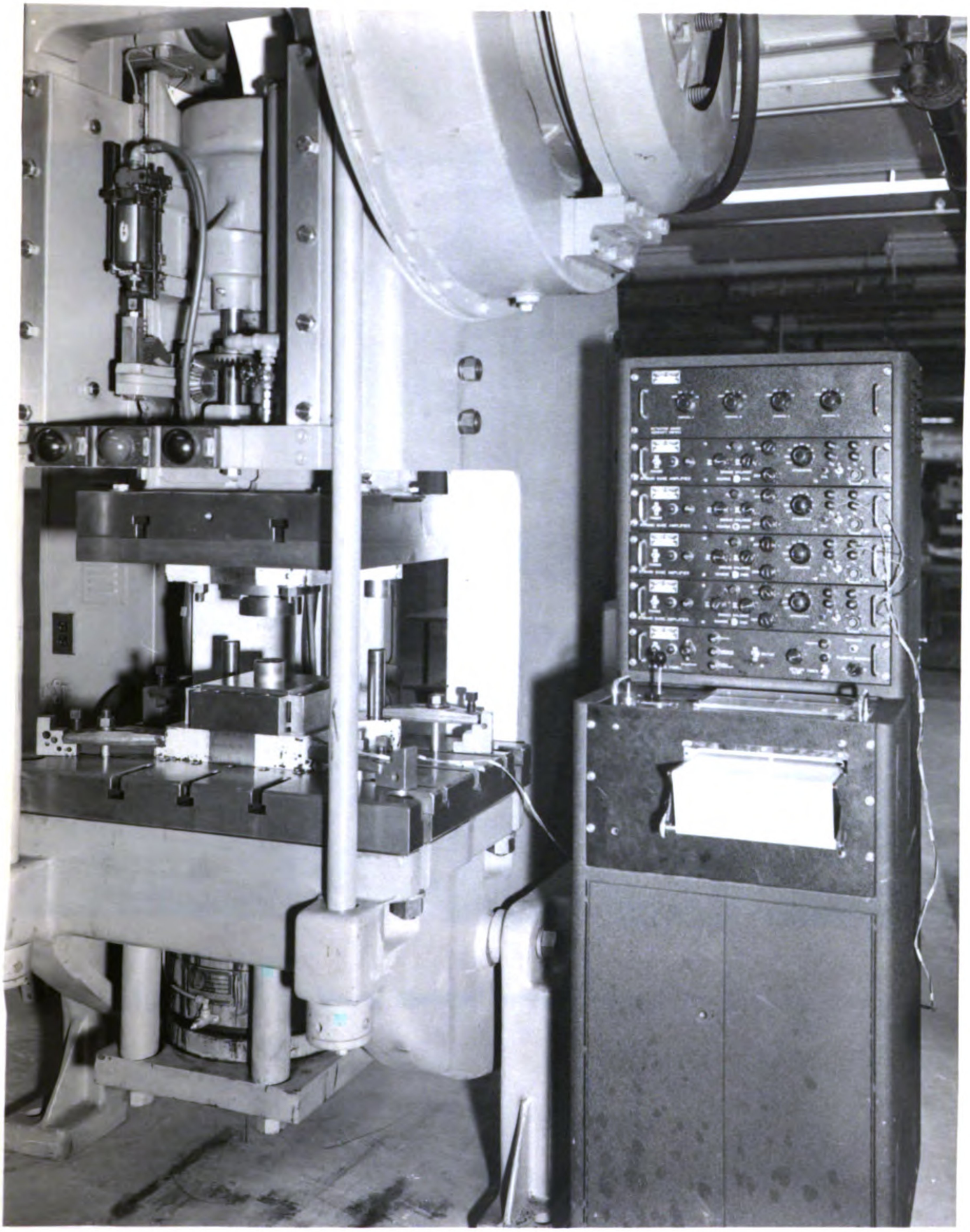
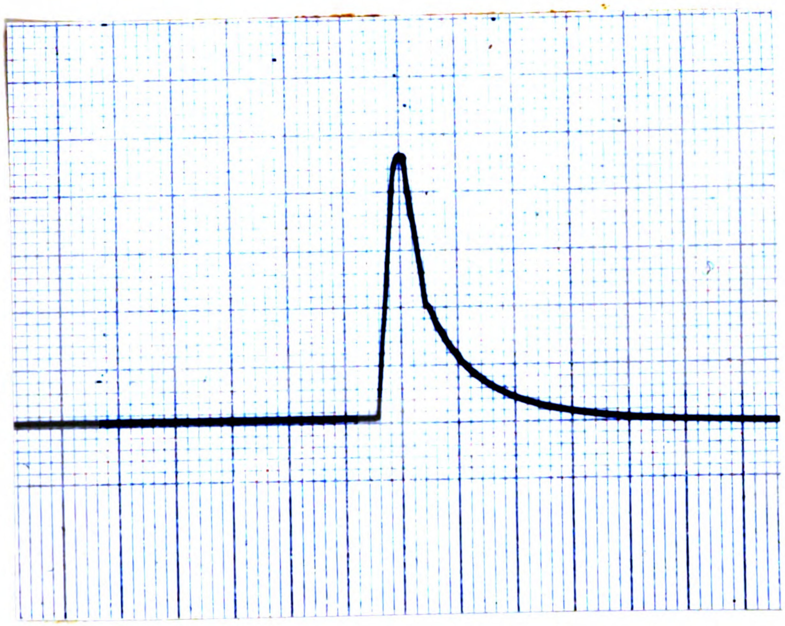


Figure 21. Press, Cupping Die and Sanborn Multi-Channel Analyzer

Right-Front View

Figure 22. Work Bench Arrangement Opposite Press



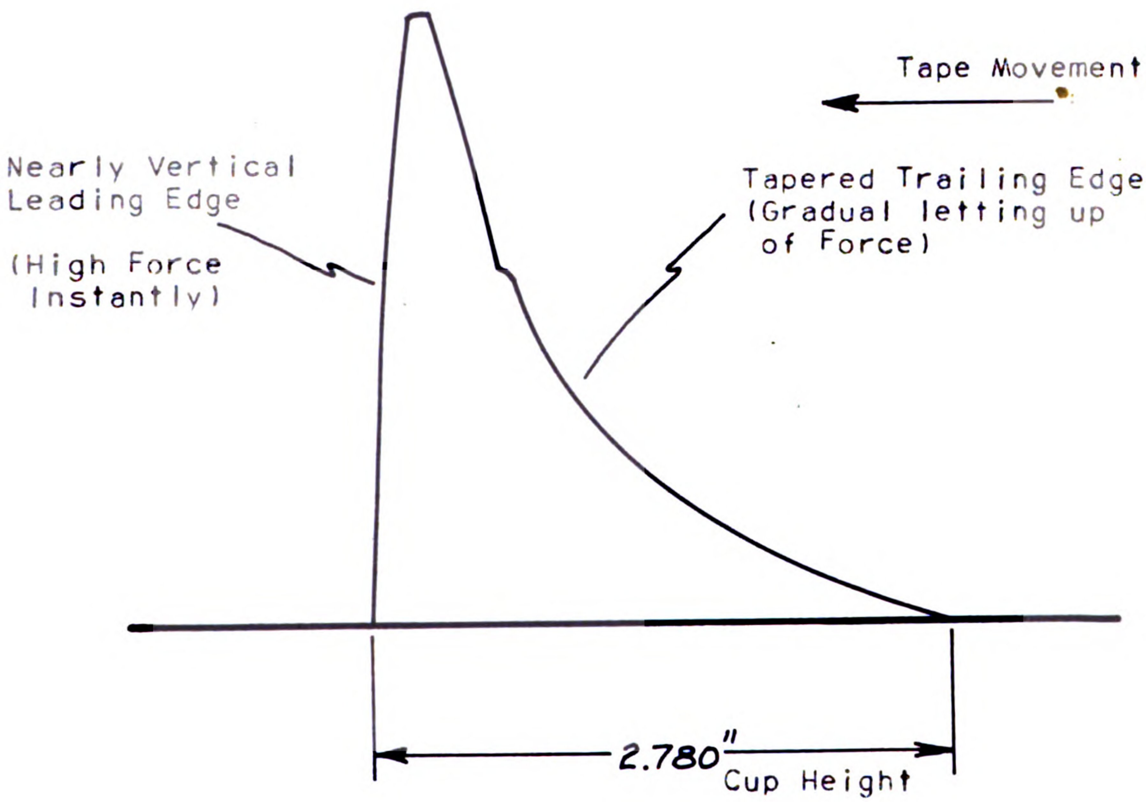



Figure 23. Cupping Characteristic Curves

## IV. Results and Analysis of Data

In order to conveniently compute the means and the standard deviations of the test results, the deflection values were partitioned into cells of one millimeter and the wall thicknesses into cells of .001 inches. Partitioning the raw data also permitted the construction of histograms which graphically portray the experimental results.

For the force histograms, it was found more convenient to work with the deflection readings rather than the force in pounds. The deflection readings are used from here on in place of force. Conversion of deflection to pounds of force was then not necessary.

With the above cell sizes, the histograms have from ten to twenty cells, as recommended by most statisticians.[8,9] A total of twenty-eight histograms were plotted. For each lubricant, a histogram was made for the deflection data. Then histograms were made for each of the wall thickness measurement positions. A typical histogram is shown in Figure 24. All of the other histograms contain the same information and are included in the appendix.

A statistical analysis will not be applied to the lubricants which caused high cup breakage. The per cent of breakage is in itself sufficient to use as a method of rating these lubricants.

### Discrimination of Data

The following groups of data were then ready for analysis:

| | |
|---|---|
| Deflection | |
| Wall Thickness | Position "A" |
| Wall Thickness | Position "B" |
| Wall Thickness | Position "C" |
| Temperature | |

[8] Grant, p. 46, Op. Cit.

[9] Juran, p. 360, Op. Cit.

Due to difficulties encountered when running the experiment, the following groups of data were not considered to be reliable for making an analysis:

Wall Thickness Position "A"

Wall Thickness Position "B"

Temperature

Several reasons for not relying on the temperature data were discussed previously. Difficulty in applying the lubricant to the blank caused a variation in duration times for each sample of fifty blanks. In some instances, the die was allowed a longer time for cooling between operations. Difficulty in cleaning the die steel prior to measuring temperature also permitted cooling of the die steel. It was necessary to remove all lubricant from the die steel for each temperature reading. Otherwise the sensitive thermocouple probe would have become covered with lubricant. This lubricant would have insulated the thermocouple slightly and caused an error in the readings.

With certain lubricants, it was difficult to remove the cup from the die. The lubricants were very tacky and acted as an adhesive. This also permitted cooling of the die steel causing an additional variation in temperature measurements.

Refer to Figure 19. Due to the rapid change in wall thickness at position "A," a slight shift of the micrometer caused a large variation in the reading obtained. This possibility of error thus partially invalidated the data recorded. The same condition existed, to a lesser degree, at position "B" and therefore the data was also somewhat invalidated. Rather than take the risk of uncontrollable variables affecting the analysis, these data were not used for the analysis of the lubricants.

The deflection data and the wall-thickness position "C" data were utilized for analysis. The data for each lubricant was analyzed by comparing averages and variabilities. The following are then the measurements to be used in the analysis of lubricants:

| | |
|---|---|
| Deflection: | Average |
| | Variability |
| Wall Thickness Position "C": | Average |
| | Variability |

Standard Deviations and Means

The standard deviation and mean were calculated for each histogram by the short method.[10] An example of this method and sample calculations are included on pages 102 and 103 of the appendix. A summary of the results is shown on the following page.

The lubricants for which these calculations were not made and their per cents of cup breakage are as follows:

| Lubricant Code Letter | Per cent Breakage |
|---|---|
| H | 70.6 |
| G | 75.3 |
| E | 77.8 |
| A | 92.7 |
| F | 95.7 |

The means and standard deviations are illustrated graphically in Figures 25 and 26 to show the degree of correlation existing between deflection and wall thickness results. If correlation does exist, when analyzed by later tests, then wall thickness measurements of drawn parts may be used to find the drawing force required. Use of strain gages and other intricate equipment would not be necessary.

[10] Grant, p. 58, Op. Cit.

| Lubricant Code Letter | Deflection | | Wall Thickness | | Sample Size |
|---|---|---|---|---|---|
| | $\bar{X}$ | s | $\bar{X}$ | s | |
| A | | HIGH | BREAKAGE | | |
| B | 27.75 | 2.82 | 28.47 | 1.53 | 154 |
| C | 25.95 | 3.52 | 29.81 | 1.60 | 200 |
| D | 27.11 | 3.92 | 29.37 | 1.69 | 200 |
| E | | HIGH | BREAKAGE | | |
| F | | HIGH | BREAKAGE | | |
| G | | HIGH | BREAKAGE | | |
| H | | HIGH | BREAKAGE | | |
| J | 24.74 | 4.52 | 30.27 | 1.61 | 200 |
| K | 26.65 | 2.90 | 31.13 | 1.58 | 200 |
| L | 27.15 | 4.35 | 30.57 | 1.58 | 200 |
| M | 25.66 | 3.68 | 29.95 | 1.35 | 148 |

Note: Deflection is directly proportional to frictional force.

Wall Thickness is indirectly proportional to frictional force.

Wall-Thickness Position "C" data was used.

Deflection in millimeters.

Wall Thickness in thousandths of an inch.

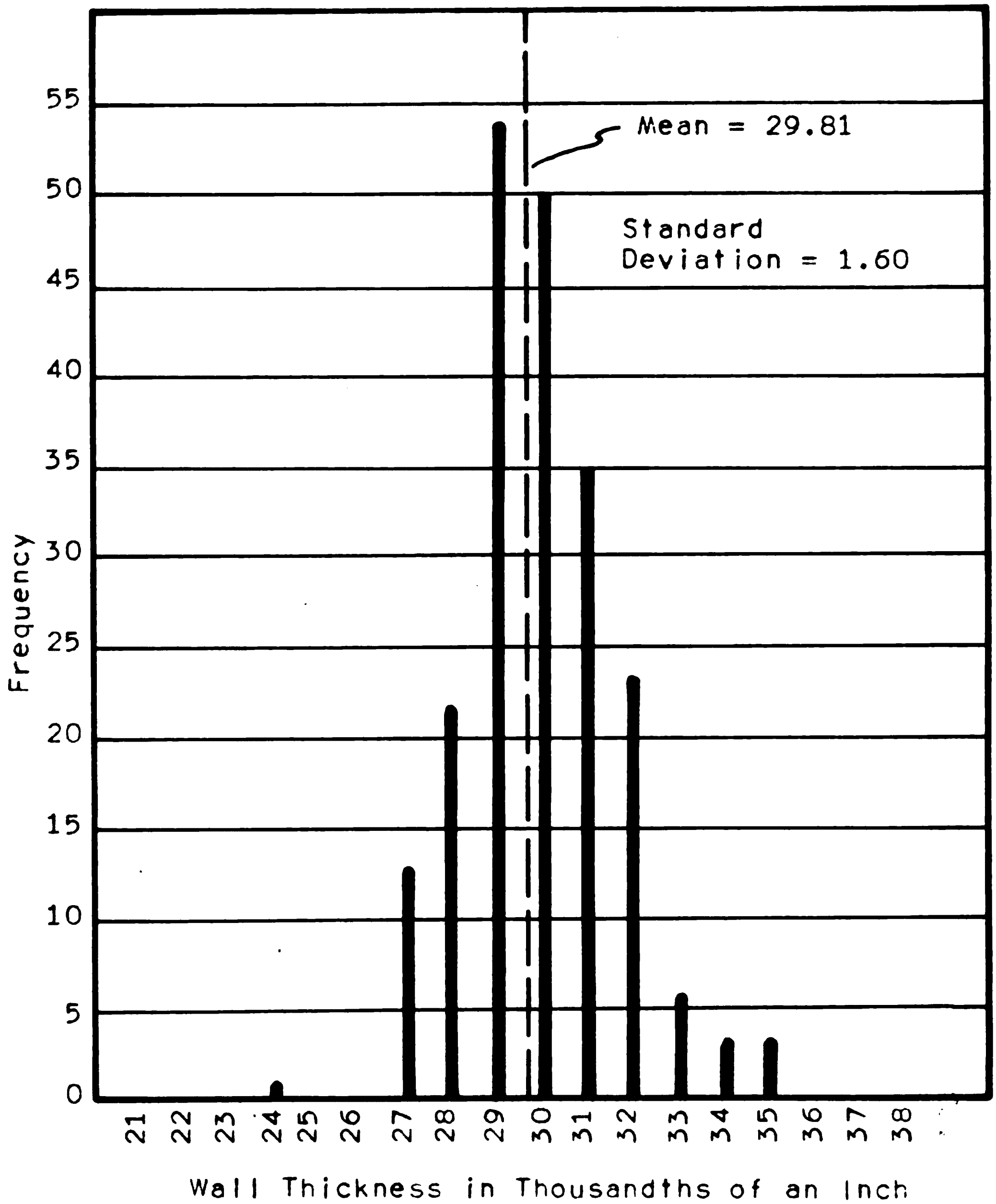



Figure 24. Wall Thickness Position "C" Lubricant "C" Histogram

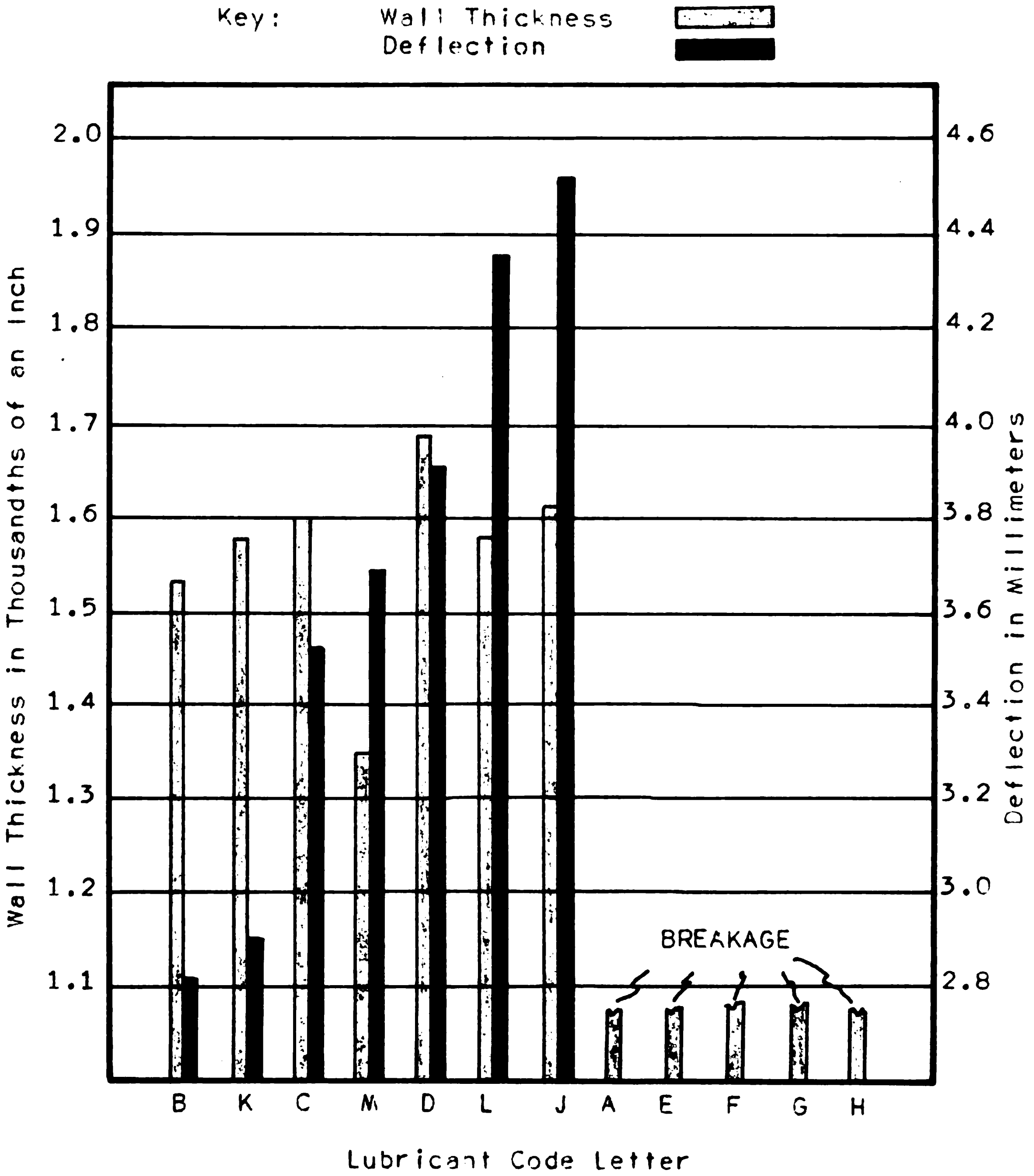



Figure 25. Standard Deviation Values for Lubricants

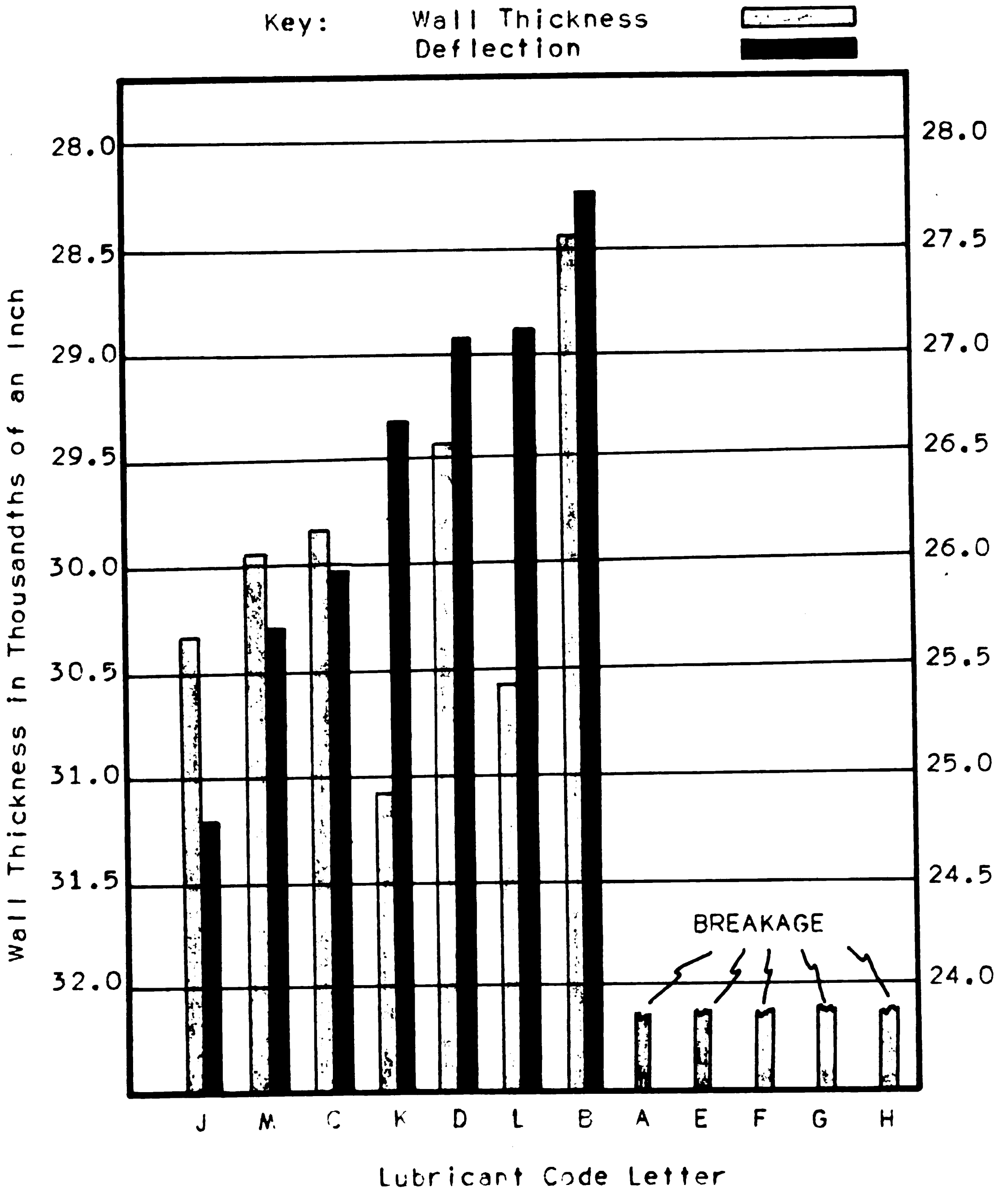



Figure 26. Mean Values for Lubricants

## Rating of Lubricants by Deflection

Differences did occur between the means and the standard deviations of the seven lubricants analyzed. These differences were used to rate the lubricant's effectiveness. First, tests were made to eliminate discrimination between lubricants where a significant difference did not exist.

Ratings of lubricants based on deflection measurements were developed first. A suitable test for significant difference of standard deviations or homogeneity was found.[11] A description of this test is included on pages 104 and 105 of the appendix. Sample calculations are on page 106 of the appendix. The results of the tests are shown on the following page. Where the test results indicate homogeneity, a significant difference of standard deviations does not exist.

The lubricants were then rated by standard deviations. The lubricant having the lowest standard deviation was given a number one rating as this lubricant would cause less variation of force required for cupping and better control of the operation could be maintained. The rating is as follows:

| Lubricant Code Letter | Temporary Rating | Revised Rating |
|---|---|---|
| B | 1 | 1 |
| K | 2 | 1 |
| C | 3 | 2 |
| M | 4 | 2 |
| D | 5 | 2 |
| L | 6 | 3 |
| J | 7 | 3 |

11 Juran, p. 382, Op. Cit.

HOMOGENEITY OF STANDARD DEVIATIONS FOR DEFLECTION

| Test | F | $DF_1$ | $DF_2$ | F' | F - F' Difference | Homogeneous |
|---|---|---|---|---|---|---|
| B-C | 1.56 | 200 | 154 | 1.29 | Greater | NO |
| B-D | 1.93 | 200 | 154 | 1.29 | Greater | NO |
| B-J | 2.56 | 200 | 154 | 1.29 | Greater | NO |
| B-K | 1.06 | 200 | 154 | 1.29 | Less | YES |
| B-L | 2.37 | 200 | 154 | 1.29 | Greater | NO |
| B-M | 1.70 | 148 | 154 | 1.31 | Greater | NO |
| C-D | 1.24 | 200 | 200 | 1.26 | Less | YES |
| C-J | 1.65 | 200 | 200 | 1.26 | Greater | NO |
| C-K | 1.47 | 200 | 200 | 1.26 | Greater | NO |
| C-L | 1.53 | 200 | 200 | 1.26 | Greater | NO |
| C-M | 1.10 | 148 | 200 | 1.29 | Less | YES |
| D-J | 1.33 | 200 | 200 | 1.26 | Greater | NO |
| D-K | 1.82 | 200 | 200 | 1.26 | Greater | NO |
| D-L | 1.23 | 200 | 200 | 1.26 | Less | YES |
| D-M | 1.14 | 200 | 148 | 1.29 | Less | YES |
| J-K | 2.43 | 200 | 200 | 1.26 | Greater | NO |
| J-L | 1.08 | 200 | 200 | 1.26 | Less | YES |
| J-M | 1.51 | 200 | 148 | 1.29 | Greater | NO |
| K-L | 2.25 | 200 | 200 | 1.26 | Greater | NO |
| K-M | 1.61 | 148 | 200 | 1.29 | Greater | NO |
| L-M | 1.40 | 200 | 148 | 1.29 | Greater | NO |

F Calculated value of F.

F' Value of F from Table E.

A confidence interval of 0.05 was chosen for this experiment.

If F is less than the value of F', then the probability is greater than 0.05 that the difference may occur by chance. The difference is not significant. Therefore the samples and their deviations are homogeneous.

If F is greater than the value of F', then the probability is less than 0.05 that the difference may occur by chance. The difference is significant. Therefore the samples and their deviations are not homogeneous.

A test for determining significance in difference of means was found.[12] A description of this test and sample calculations are included on pages 107 and 108 of the appendix. This test may be applied only to those means having standard deviations which are homogeneous. Applying this test to non-homogeneous samples would not yield meaningful results.

A test for determining significance in difference of means when the samples are not homogeneous was found.[13] A description of this test and sample calculations are included on pages 109 and 110 of the appendix.

The lubricants were given a temporary rating according to their deflection means. The lubricant having the lowest mean was given a number one rating. Low deflection indicated a low punch force which in turn indicated a low friction force. A low friction force indicates that the lubricant is funtioning properly. Presence of less friction causes less strain and wall thinning is not as severe. Better cups result.

Where a significant difference of means did not exist, the rating was revised to account for this fact. Where a significant difference did exist, the temporary rating was left intact. The revised rating shown is then the rating of the lubricants based on difference of means for deflection data.

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[12] Juran, p. 380, Op. Cit.

[13] Ireson, W. G. and Grant, E. L., Handbook of Industrial Engineering and Management, Prentice-Hall, New York, p. 852-853.

SIGNIFICANT DIFFERENCE
OF
DEFLECTION MEANS
(Homogeneous Samples)

| Test | $\overline{X} - \overline{X'}$ | t | DF | t' | t - t' Differ-ence | Sign. Difference |
|---|---|---|---|---|---|---|
| C-D | 1.16 | 3.10 | 398 | 1.96 | Greater | YES |
| D-L | .04 | .10 | 398 | 1.96 | Less | NO |
| M-C | .29 | .74 | 346 | 1.96 | Less | NO |
| K-B | 1.10 | 3.54 | 352 | 1.96 | Greater | YES |

$\overline{X}$ and $\overline{X'}$ Deflection Means of the two samples in question.

t Calculated value of t.

t' Value of t from Table C.

The confidence interval for this experiment was set at 0.05.

When t is greater than the value of t', then the probability is less than 0.05 that the difference occurs due to chance. A significant difference between means does exist.

When t is less than the value of t', then the probability is greater than 0.05 that the difference occurs due to chance. A significant difference between means does not exist.

SIGNIFICANT DIFFERENCE
OF
DEFLECTION MEANS
(Non-homogeneous Samples)

| Test | $\overline{X} - \overline{X'}$ | t | v | t' | t - t' Difference | Sign. Difference |
|---|---|---|---|---|---|---|
| J-M | .92 | 2.09 | 343 | 1.96 | Greater | YES |
| C-K | .70 | 2.17 | 398 | 1.96 | Greater | YES |
| K-D | .46 | 1.33 | 398 | 1.96 | Less | NO |
| L-B | .60 | 1.57 | 343 | 1.96 | Less | NO |

The interpretation of the values here is the same as that shown above.

The rating of lubricants by deflection means was as follows:

| Lubricant Code Letter | Temporary Rating | Revised Rating |
|---|---|---|
| J | 1 | 1 |
| M | 2 | 2 |
| C | 3 | 2 |
| K | 4 | 3 |
| D | 5 | 3 |
| L | 6 | 3 |
| B | 7 | 4 |

When the degrees of freedom (v) was computed for the non-homogeneous samples, the result was 343. The degrees of freedom (DF) when computed for the homogeneous samples of the same size was 346. Therefore with the large samples used in the experiment, the degrees of freedom remain relatively the same regardless of whether the samples are homogeneous or not. The test for significance of difference between means of homogeneous samples was applicable to all samples. Therefore only one test was applied from this point on.

## Rating of Lubricants by Wall Thickness

The test for significance of difference between standard deviations was then applied to the wall thickness data measured at position "C." The results are shown on the following page. Notice the large percentage of homogeneity which existed. When the standard deviations are homogeneous, a significant difference does not exist.

The lubricants were then rated with the lubricant having the lowest standard deviation receiving a number one rating. Where a significant difference did not exist, the next lowest lubricant received the same rating as the previous lubricant. Where a significant difference did exist, the rating number was changed to a higher figure.

The rating was as follows:

| Lubricant Code Letter | Temporary Rating | Revised Rating |
|---|---|---|
| M | 1 | 1 |
| B | 2 | 1 |
| K | 3 | 2 |
| L | 4 | 2 |
| C | 5 | 2 |
| J | 6 | 2 |
| D | 7 | 2 |

The test for significance in difference of means was made for the wall thickness data. The lubricants were given a temporary rating by means. The lubricant with the highest mean was given a number one rating. A high wall thickness mean indicated less thinning of the cup side wall. Less wall thinning was assumed to indicate a lower friction force which in turn should indicate a better lubricant.

Where a significant difference existed, the rating was left intact. Where a significant difference did not exist, the rating was revised to agree with this fact. The results of this test are shown on the following page. The revised rating is then the rating based on the wall thickness means as follows:

| Lubricant Code Letter | Temporary Rating | Revised Rating |
|---|---|---|
| K | 1 | 1 |
| L | 2 | 2 |
| J | 3 | 2 |
| M | 4 | 3 |
| C | 5 | 3 |
| D | 6 | 4 |
| B | 7 | 5 |

HOMOGENEITY OF STANDARD DEVIATIONS FOR

WALL THICKNESS POSITION C

| Test | F | $DF_1$ | $DF_2$ | F' | F - F' Difference | Homogeneous |
|---|---|---|---|---|---|---|
| B-C | 1.10 | 200 | 154 | 1.29 | Less | YES |
| B-D | 1.22 | 200 | 154 | 1.29 | Less | YES |
| B-J | 1.11 | 200 | 154 | 1.29 | Less | YES |
| B-K | 1.07 | 200 | 154 | 1.29 | Less | YES |
| B-L | 1.07 | 200 | 154 | 1.29 | Less | YES |
| B-M | 1.28 | 154 | 148 | 1.31 | Less | YES |
| C-D | 1.12 | 200 | 200 | 1.26 | Less | YES |
| C-J | 1.01 | 200 | 200 | 1.26 | Less | YES |
| C-K | 1.03 | 200 | 200 | 1.26 | Less | YES |
| C-L | 1.03 | 200 | 200 | 1.26 | Less | YES |
| C-M | 1.41 | 200 | 148 | 1.29 | Greater | NO |
| D-J | 1.10 | 200 | 200 | 1.26 | Less | YES |
| D-K | 1.14 | 200 | 200 | 1.26 | Less | YES |
| D-L | 1.14 | 200 | 200 | 1.26 | Less | YES |
| D-M | 1.57 | 200 | 148 | 1.29 | Greater | NO |
| J-K | 1.04 | 200 | 200 | 1.26 | Less | YES |
| J-L | 1.04 | 200 | 200 | 1.26 | Less | YES |
| J-M | 1.42 | 200 | 148 | 1.29 | Greater | NO |
| K-L | 1.00 | 200 | 200 | 1.26 | Less | YES |
| K-M | 1.37 | 200 | 148 | 1.29 | Greater | NO |
| L-M | 1.37 | 200 | 148 | 1.29 | Greater | NO |

F — Calculated value of F.

F' — Value of F from Table E.

A confidence interval of 0.05 was chosen for this experiment.

If F is less than the value of F', then the probability is greater than 0.05 that the difference may occur by chance. The difference is not significant. Therefore the samples and their deviations are homogeneous.

If F is greater than the value of F', then the probability is less than 0.05 that the difference may occur by chance. The difference is significant. Therefore the samples and their deviations are not homogeneous.

SIGNIFICANT DIFFERENCE
OF
WALL THICKNESS MEANS

| Test | $\overline{X} - \overline{X'}$ | t | DF | t' | t - t' Difference | Sign. Difference |
|---|---|---|---|---|---|---|
| K-L | .56 | 3.53 | 398 | 1.96 | Greater | YES |
| L-J | .30 | 1.88 | 398 | 1.96 | Less | NO |
| J-C | .46 | 2.86 | 398 | 1.96 | Greater | YES |
| C-D | .44 | 2.67 | 398 | 1.96 | Greater | YES |
| D-B | .90 | 5.15 | 352 | 1.96 | Greater | YES |
| J-M | .32 | 2.01 | 346 | 1.96 | Greater | YES |
| C-M | .14 | .88 | 346 | 1.96 | Less | NO |

$\overline{X}$ and $\overline{X'}$ Wall Thickness Means of the two samples in question.

t Calculated value of t.

t' Value of t from Table C.

The confidence interval for this experiment was set at 0.05.

When t is greater than the value of t', then the probability is less than 0.05 that the difference occurs due to chance. A significant difference between means does exist.

When t is less than the value of t', then the probability is greater than 0.05 that the difference occurs due to chance. A significant difference between means does not exist.

## Correlation Analysis

Correlation tests were made to determine if a relationship does exist between the deflection and wall thickness data. If such a correlation exists, wall thickness measurements of drawn parts could be used to determine the drawing force required and in turn the effectiveness of the lubricant in reducing friction and the expensive and time-consuming application of strain gages would not be necessary. The results could be used to aid in the selection of lubricants as well as predicting overload of presses.

The Original Data Method of correlation analysis was selected for this test.[14] This method was more lengthly but provided greater accuracy in the results. It was found that a computer was necessary to make the correlation tests. Errors in the fifth or sixth significant figure caused large errors in the final results. Sometimes the results would be entirely impractical. A description of the correlation test and sample calculations are included on pages 111 and 112 of the appendix.

This test was used to find the correlation coefficient between the means of the deflection and wall thickness data. The test was also used to find the correlation coefficient between the standard deviations of the deflection and wall thickness data. Scatter diagrams were made to further illustrate the correlation of the data. Figure 27 shows the scatter diagram for standard deviations. Figure 28 shows the scatter diagram for means. All of the test results are noted on each diagram.

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[14] Juran, p. 472, Op. Cit.

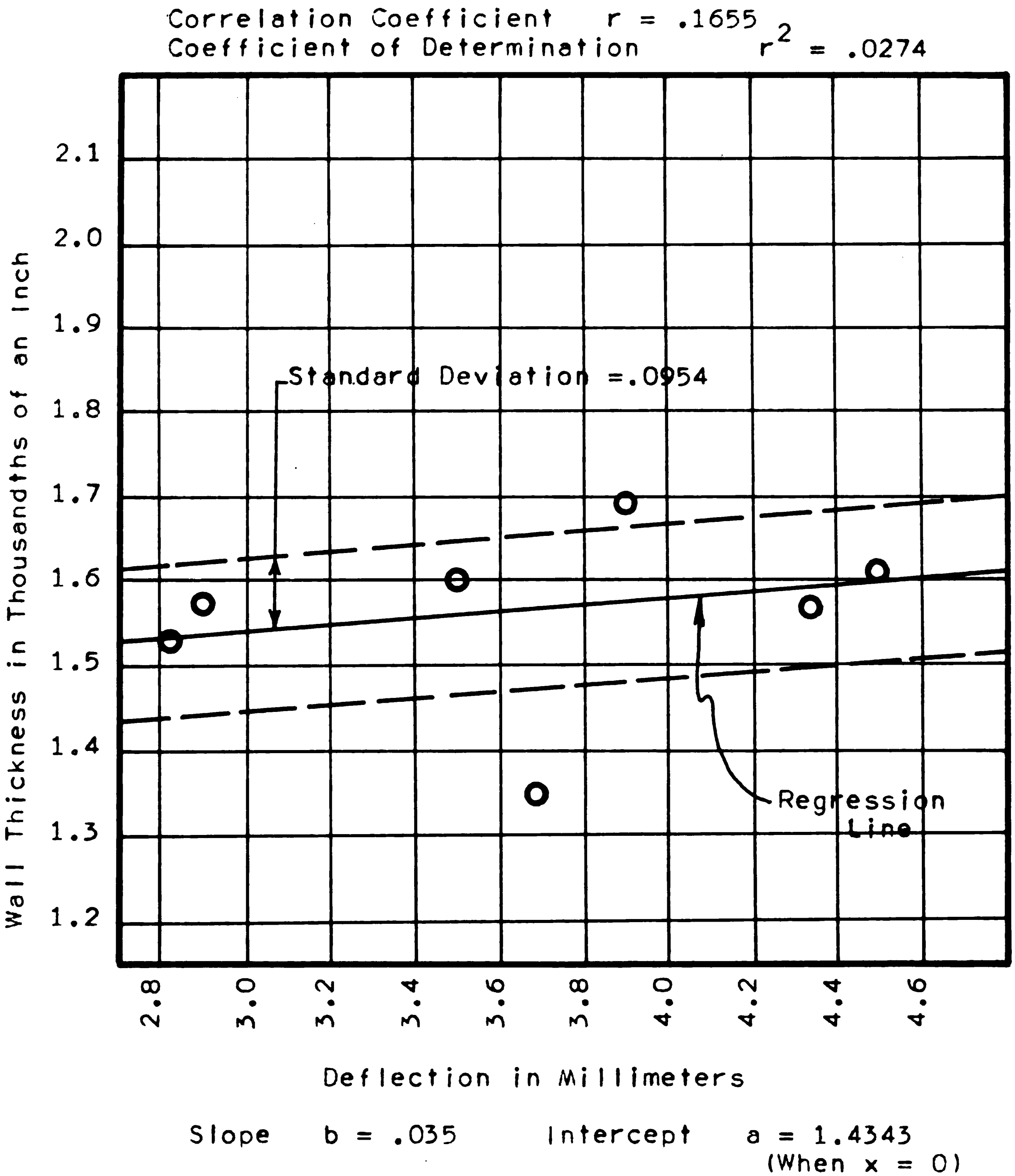
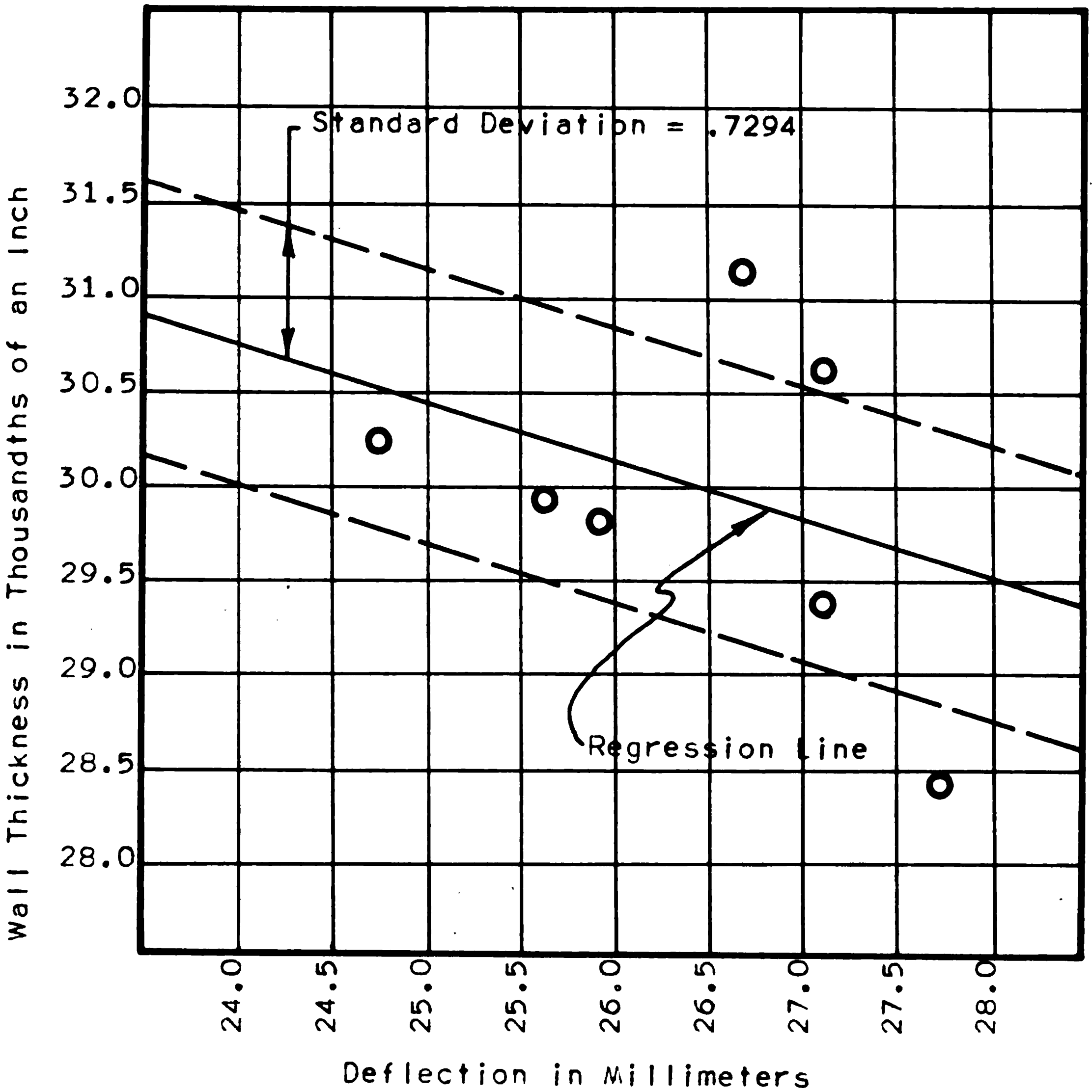



Figure 27. Correlation of Standard Deviations Scatter Diagram

Correlation Coefficient r = .3948
Coefficient of Determination $r^2$ = .1559




Slope b = -.3279 Intercept a = 38.6050
(When x = 0)

Figure 28. Correlation of Means
Scatter Diagram

## V. Conclusions and Recommendations

### Conclusions

The four statistical ratings and the percents of cup breakage were combined to obtain a final rating. No weighing factors were used in this combination of ratings. The final rating is as follows:

| Lubricant and Code | % Break. | Deflec. | | Wall Thick. | | Total | Final Rating |
|---|---|---|---|---|---|---|---|
| | | X | s | X | s | | |
| K Chlorinated Wax | 00.0 | 3 | 1 | 1 | 2 | 7 | 1 |
| J Pigmented - Med. | 00.0 | 1 | 3 | 2 | 2 | 8 | 2 |
| M Graphite | 00.0 | 2 | 2 | 3 | 1 | 8 | 2 |
| C Dry Wax | 00.0 | 2 | 2 | 3 | 2 | 9 | 3 |
| L Heavy Oil | 00.0 | 3 | 3 | 2 | 2 | 10 | 4 |
| D Plastic | 00.0 | 3 | 2 | 4 | 2 | 11 | 5 |
| B Soap | 23.0 | 4 | 1 | 5 | 1 | 11 | 5 |
| H Lard Oil | 70.6 | | | | | | 6 |
| G Wet Wax | 75.3 | | | | | | 7 |
| E Reclaimed Oil | 77.8 | | | | | | 8 |
| A Mill Oil | 92.7 | | | | | | 9 |
| F Molybdenum Disulf. | 95.7 | | | | | | 10 |

Correlation. Correlation does not exist between the means or between the standard deviations of the force and wall thickness data. Therefore wall thickness measurements cannot be used to determine the drawing force or the effectiveness of the lubricant in reducing friction.

Characteristic Force Curve. The characteristic force curve for drawing has an almost vertical leading edge with a gradually reducing trailing edge. Thus the maximum drawing force occurs at the first instances when the punch contacts the sheet-metal blank.

The maximum drawing force is relative to the ratio between the punch diameter and the blank diameter. Leaving a flange on the cup has no effect on the maximum drawing force required.

## Recommendations

From experience gained in this eperiment, the need for future research in several areas became evident. The conclusions reached here pertain only to one technical aspect of lubricant selection. Other factors should be analyzed and evaluated before efficient lubricant selections can be made.

Technical Factors. It is recommended that the following technical factors be determined by experiment to aid in the selection of lubricants:

1. The effectiveness of other drawing lubricants not tested in this experiment.
2. The effectiveness of drawing lubricants for other sheet metals such as stainless steel, brass, magnesium and aluminum.
3. The effects of different drawing speeds on the lubricant used.
4. The effects of varying the die or blank temperature on the lubricant required.
5. The effects of different die or punch radii on the lubricant required.

Economical Factors. It is recommended that the following economical factors be determined by experiment to aid in the selection of lubricants:

1. Cost of lubricants.
2. Ease of application.
3. Ease of cleaning.
4. Method of application.

5. Miscellaneous effects such as skin disease, corrosion and staining.

6. Effects on subsequent manufacturing operations such as welding, brazing, soldering, plating and painting.

Only when all of these factors have been analyzed can efficiency of lubricant selection be determined.

From the results of this experiment, it is recommended that chlorinated wax be used under the stated conditions until future experiments prove otherwise.

Theory of Drawing. It is recommended that the characteristic curve for drawing force as well as the other conclusions be utilized for teaching the theory of drawing. Factual support will increase the significance of the theory.

Drawing Force. It is recommended that future experiments be made to determine actual drawing forces for various shapes of parts and types of sheet metal. Afterwards, a suitable drawing force formula could be developed.

# Appendix

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D. B. Ballantyne
Buick Motor Division
Flint, Michigan

The problem investigated in this report is that of determining before blanking whether or not designated coils of sheet metal are of a drawing quality suitable for fabricating Buick hoods, right front fenders and right rear fender panels. Samples from 100 coils for each part were inspected for drawing performance; specimens prepared from samples were tested to determine relationships of their mechanical chemical and microstructural deep-drawing properties to their drawing performance. Included are scatter diagrams for the correlation of variables.

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Chapter VII. Cold-Working of Plastic Metals

Plasticity. Experiments in strain-hardening. Upper and lower limits of the plastic range. Tentative rates of strain-hardening. The plastic cycle. Structural changes. Ductility differences. Temperature and plasticity. Hot and cold working. Rate and uniformity of plastic working.

Chapter VIII. The Drawing Group of Press Operations

Metal movement and stresses in drawing. Drawing formulae. Blankholding theory. Blank and shell relations, redrawing limits and methods. Wall thickening and thinning. Ironing. Drawing rectangular and irregular shapes. Types of dies.

Chapter IX. Plastic States, Metallic and Non-Metallic

Crystoplastic, thermoplastic, soluplastic, thermosetting, solusetting. Temperature and plasticity. Elasticity. Internal structure. Pressure welding in powders. Creep. Speed of flow. Polymers. States of internal bonding. Mixtures. Plasticizers.

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Martin A. Deane — Chevrolet Motor Division
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Chapter IV. Stamping and Forming Non-Ferrous Metals

Specifications for non-ferrous metals. Typical mechanical properties of wrought aluminum alloys. Lubricants for drawing aluminum. Crain size is the measure of softness in brass.

Chapter V. Specifications for Ordering Sheet Materials

Testing for hardness and ductility. Lubricants for drawing steel. Lubricants for drawing brass and copper. Lubricants for drawing zinc. Lubricants for drawing aluminum. Applying lubricants both sides of strip.

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Chapter III. Defects and Difficulties (General)

Defects and difficulties attributable to the metal used. Unsuitable crystal structure. Directionality. Special defects and unsuitable physical properties. Troubles attributable to too high a speed of drawing. Unsatisfactory lubrication. Insufficient supply of lubricant. Lubricant unsuited to the metal. Inadequate film strength. Troubles due to non-removal of lubricant. Staining, corrosion and adhering lubricant.

Chapter VI. Defects and Difficulties (Steel)

The theory of lubrication. Fluid friction. Solid Friction. Theory applied to lubrication in actual drawing operations. Surfaces bearing an absorbed film. Properties desired of a drawing lubricant. Oiliness. Measurement of slipperiness. Film strength Resistance of temperature. Cost. Ease of removal. Spreading power. Adhesiveness. Corrosiveness. Stability. Typical Lubricants.

Chapter XII. The Testing of Sheet Metal

Chemical analysis. Microscopical examination. Hardness tests. Bend tests. Slotted-strip test. Tear-length test. Cupping tests. Actual drawing tests. Special tensile testing. Wedge-drawing tests.

Chapter XIII. Properties Which Determine the Behavior of Metal During Deep-Drawing

Chemical composition. Crystal size. Average grain size. Ductility and tenacity. Work-hardening. Reaction to speed of deformation. Hardness. Directionality. Reaction to annealing. Surface condition.

Die Design and Diemaking Practice 1930

Franklin D. Jones The Industrial Press

New York

Chapter XII. Classes of Drawing Dies and General Designing Information

Formation of wrinkles in drawing. Depth of the first drawing operation. Diameter obtained in one drawing operation. Troubles encountered in drawing light gage metal. Effects produced by trapped oil, air and water. Press-room lubricants. Lubricants for drawing brass. Lubricants for drawing steel. Lubricants for aluminum and zinc. Lubricants for non-metallic materials. Grain growth and its cause. Annealing temperature at which grain growth occurs. Grain growth in hot-rolled stock. Restriction of grain growth.

The Use of Plastics as an Aid in Die Construction 1955
T. L. Kubani Fisher-Die & Machine Plant
Detroit, Michigan

Press Work Pressures 1935
C. W. Lucas McGraw-Hill Book Co., Inc.
New York

Analysis of Drawing Stresses as an Aid to Automotive Draw Die Design 1953
C. A. Luthe Fisher Body Division
Cleveland, Ohio

A study of sheet steel properties, drawing stresses and strains, and how they are considered in draw die design. Findings and deductions from past research preferences and actual industrial data. Stresses automotive die problems, including the determinating factors of draw beads, irregular binder surfaces, drawing radii die friction and corner relief notches. Includes tables and graphs of data on sheet steel properties and test results. Bibliography includes an extensive reference to past work on deep drawing.

Mechanical Engineers' Handbook 1941
Lionel S. Marks McGraw-Hill Book Co., Inc.
New York

Lubricants 772-780

(a) Cleansing 2179

(b) Coefficients of friction 241

(c) Effect of temperature 2175

(d) Extreme Pressure 777

(e) Film strength 2175

(f) For press work 1768

(g) Oiliness 777

(h) Tests 776

(i) Viscosity 245

Lubrication 2175-2181

(a) Factors 2175

(b) Fluid 1016

(c) Semifluid 1016

(d) Viscous 232

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E. C. Marshall — McGraw-Hill Book Co., Inc.
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Flint, Michigan

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Paul W. Morrow — Chevrolet Motor Div.
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A. Nadai — McGraw-Hill Book Co., Inc.
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William Neubecker — American Technical Society
Chicago, Illinois

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Edmund A. Nowolinski — Author, Detroit, Michigan

An Engineering Approach to Die Tryout — 1954
J. A. Patterson — Fisher Body Division, Pontiac, Michigan

Sheet Metal Industries — Periodicals
Industrial Newspapers, Ltd., London, England

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Andresen, Inc., Pittsburgh, Pennsylvania

Inspection of Metals — 1941
Harry B. Pulsifer — The American Society of Metals, Cleveland, Ohio

Chapter II. Tests for Composition

Sampling. Bend Test. Magnetic tests. Solution rates. Spectroscope lines. Microscopic patterns. Analysis of S. A. E. Steel.

Chapter IV. Hardness Testing

File texting. Brinell. Rockwell. Schleroscope. Monotron. Vickers. Hardness conversion tables.

Chapter V. Tensile Testing Including Shear

Lever machines. Hydraulic machines. Calibration. Diagrams. Test specimens. Precautions. Calculations.

Chapter VI. Soundness Testing

Bend and fracture tests. Resonance test. X-Ray negatives. Magnetic and Magnaflux tests. Crack intensification.

Chapter IX. Grain Size Testing

Structural grain size. Fracture grain size. McQuaid-Ehn grain size. Normality. Austenitic grain size. Measuring grain size. Grain size chart.

Chapter XI. Impact, Fatigue and Creep Testing

Izod. Charpy. Test specimens. Ranges. Fatigue machines. Corrosion fatigue. Creep ranges. Resistant compositions.

Principles and Methods of Sheet-Metal Fabricating 1955

George Sachs Reinhold Publishing Corp.
New York

Information relative to drawing.

Part I: Sheet Metal and Sheet Metal Parts

Chapter II. Formability Tests

General principles of formability tests for flanged, straight, curved and recessed parts.

Chapter III. Sheet Metals

Development of ferrous, non-ferrous and composite sheet materials.

Chapter IV. General Properties of Sheet Metals

Specifications and grain size requirements for sheet metals. Stretcher strains, directionality and stress cracking.

Part II: Principles of Forming Various Part Types

Chapter IV. Forming of Deep Recessed Parts

Classification of deep-recessed parts. Strains and failures in cupping. Buckling and hold-down problems. Forming of very deep parts. Material problems in forming deep-recessed parts.

Part III: Principles of Deep Drawing

Chapter I. Drawing and Thin Walled Cylindrical Cups

Factors governing the draw force and cup strength. Strains and failures encountered in cupping. Forming limits for cupping thin blanks. Hold-down problems.

Chapter II. Redrawing of Tubular Parts

Classification of redrawing processes. Factors governing the draw forces and strength of a drawpiece. Reductions between anneals. Further problems of progressive redrawing. Reducing operations.

Chapter IV. Drawing a Thick Walled Cylindrical Cups

General problems of cupping thick blanks. Stress and strain relationships. Condition of the cup edges. Forming limits.

Chapter V. Drawing of Box Shaped Parts

General problems, strains and failures and blank development for box-shaped parts. Forming limits. Redrawing.

Part IV: Press-die Forming of Sheet-Metal Parts

Chapter I. Equipment, Tools and Lubrication for Press-Die Forming of Sheet Metal Parts

Classification of lubricants.

Chapter III. Press Die Forming of Recessed Parts

Die forming of closed, open, deep-recessed, semi-tubular, disk-shaped double-curvature and smoothly contoured parts.

Economical Utilization of Sheet Metal in Presswork — 1954
H. R. Schaal — Chevrolet Motor Division, Flint, Michigan

Punches and Dies — 1943
Frank A. Stanley — McGraw-Hill Book Co., Ltd., New York

Chapter IX. Drawing Dies and Drawing Methods

Importance of material in drawing. Direction of metal displacement. Movement of metal structure.

An Analysis of Automobile Body Die Design as Related to Die Construction, Maintenance, Tryout and Production — 1954
R. L. Stoothoff — Fisher Body Division, Hamilton, Ohio

Tool and Die Design Standards — 1954
Ternstedt - Columbus Division, General Motors Corporation, Columbus, Ohio

The Application of Cemented Carbide to Piercing and Blanking Dies

John R. Willson — 1948

Delco-Remy Division
Anderson, Indiana

The Collection of Data to Facilitate the Development of Experimental Draw Progressive Die Strips — 1949

Jay D. Wisner

Chevrolet Motor Division
Flint, Michigan

An Analysis and Definition of the Factors Affecting Deep-Drawing Operations — 1952

C. E. Zimmerman

Brown-Lipe-Chaplin
Syracuse, New York

This study investigates the factors affecting die life and on-the-job repairs connected with deep drawing of bumper guards and hub caps and initiates a program of control for testing of new drawing compounds, for the quality control checking of steel, and for the investigation are described and supported by data. Conclusions stated regarding satisfactory tolerances for bumper stock, gage variations, lubricating compounds, and stock failure and die damage due to steel surface defects.

FORCE CALCULATIONS ----- Due to variations in blank thickness.

Punch Diameter 2.563 inches Cup Inside Diameter

Sheet-Metal Thickness Range .041 to .047

Cup Outside Diameter for .041 inches thick:

$$2.563 + .041 + .041 = 2.645$$

Cup Outside Diameter for .047 inches thick:

$$2.563 + .047 + .047 = 2.657$$

Formula: Force = Pressure x Area

Pressure:[15] Ultimate Tensile Strength = 40,000 psi for dead soft No. 6

(This will give the maximum force possible to produce at the cup bottom)

$$\text{Area} = \pi(r^2 - r_1^2) \quad \text{or} \quad \pi(r_2^2 - r_1^2)$$

$$r \text{ and } r_2 = \frac{\text{Cup Outside Diameter}}{2}$$

$$r_1 = \frac{\text{Cup Inside Diameter}}{2}$$

For .041 inches thick:

$$r = \frac{2.645}{2} = 1.3225$$

$$r^2 = 1.749$$

For .047 inches thick:

$$r_2 = \frac{2.657}{2} = 1.3285$$

$$r_2^2 = 1.765$$

$$r_1 = \frac{2.563}{2} = 1.2815$$

$$r_1^2 = 1.642$$



15 Crane, p. 91, Op. Cit.

Force for .041 inches thick:

$$F = (40,000)\ (3.14)\ (1.749 - 1.642)$$

$$F = 13,440 \text{ lbs. or } 6.72 \text{ tons}$$

Force for .047 inches thick:

$$F = (40,000)\ (3.14)\ (1.765 - 1.642)$$

$$F = 15,450 \text{ lbs. or } 7.725 \text{ tons}$$

FORCE VARIATION DUE TO VARIATION IN THE BLANK THICKNESS: (Drawing Force -- Maximum)

$$7.725 - 6.72 = 1.005 \text{ tons}$$

or

$$15,450 - 13,440 = 2,010 \text{ lbs.}$$

Average Tonnage for Average Blank Thickness of .044 inches:

7.22 tons

Expected Error:

$$\frac{.5}{7.22} \times 100 = 6.9\%$$

DRAW DIE SPECIFICATIONS:

1. Punch Steel 2.566 inches diameter.

2. Die Steel 2.680 inches diameter.

3. Clearance .057 inches.

4. Largest sheet-metal or blank thickness is .047 inches. The clearance provided allows for .010 inches of thickening during drawing without causing ironing or burnishing of the cup side wall. The normal thickening of a cup of this size and metal thickness would be approximately .006 inches.

5. Punch steel radius 3/16 inch.

6. Die steel radius 1/16 inch.

7. Punch steel -------- 46M oil hardening tool steel.

8. Blankholder operated by pressure pins from a 13-ton air cushion.

9. Blankholder retained by block-type keepers.

10. Die steel ---------- 34M water hardening tool steel.

11. Blankholder -------- cold rolled steel with tool steel welded on the critical wearing surface.

12. Die mounted in a standard Danly die set.

| Die Component | Rockwell "C" Hardness | Surface Finish in Microinches |
|---|---|---|
| Punch Steel | 53.6 | 13.5 |
| Die Steel | 58.5 | 31.4 |
| Blankholder | 54.0 | 37.8 |

HAND PYROMETER SPECIFICATIONS:

1. General Electric Hand Pyrometer Type FH-1 Cat. No. 8947945G1 with Fahrenheit scale.

2. Surface-type Thermocouple Cat. No. A302G2.

3. Flexible Extension Cable Cat. No. A300G1 34 inches long.

4. Two scales provided with temperature ranges from 0 - 500 F and from 0 - 1500 F. Least count is ten degrees. Scale is 3-1/2 inches long.

5. Weight is 1-1/2 pounds.

6. Accuracy of entire assembly is + or - 4-1/2% of the full scale.

7. Surface Tip ------- chromel-constantan thermocouple with ceramic insulation. Three inches long.

8. Automatic cold-junction compensation on both ranges counteracts the influence of ambient-temperature changes.

9. High speed response. Less than 15 seconds.

10. No preliminary adjustments necessary.

11. Tips are interchangeable without recalibration of instrument.

12. Calibrated accuracy of instrument is + or - 2%.

## Press Adjustment Procedure

1. Turn on all air pressure to the press. This involves throwing five valves.
2. Shut off petcocks at the two surge tanks and cushion.
3. Open the air valves to the three air pressure gages.
4. Adjust the clutch pressure to (50) psi.
5. Adjust the counterbalance pressure to (20) psi.
6. Adjust the cushion pressure to (10) psi.
7. Set the motor direction switch on "forward."
8. Set the stroke switch on "single stroke."
9. Set the Inching-Off-Run switch to "run."
10. Throw the switch on the control panel.
11. Throw the main switch at the building column.
12. Turn the electronic controls "on."
13. Push the motor "start" button.
14. After flywheel gains full speed, adjust the strokes per minute to (40).

## Sanborn Recorder Calibration

1. Connect ground lead to press piping.
2. Plug extension cord into 120 volt outlet.
3. Connect active strain gage leads to the two terminals marked $R_2$ . (From step three and on, follow the same procedure for both vertical and circumferential strain gages.)
4. Connect dummy strain gage leads to the two terminals marked $R_1$ .

5. Set the R-T switch on "R."

6. Turn on the main power switch.

7. Turn on the individual channel power switches.

8. Turn on the motor switch.

9. Set the paper speed at 1.0 mm per second.

10. Pull up the paper drive clutch to start paper in motion.

11. Throw the Coarse-Fine Switch to the Coarse Position, and with the attenuator at the "OFF" position, observe the position of the stylus. (It will normally be Near the center of the recording chart.)

12. Advance the Attenuator to the X100 position. Unless the bridge circuit is accidentally in balance, the stylus will be deflected upscale. Using the Resistance Balance (Res Bal) control, try to bring the stylus back towards the position it occupied when the Attenuator was at the "OFF" position. When the minimum position is found with the Resistance Balance control, try to improve the minimum using the Capacity Balance (Cap Bal) control.

13. Advance the Attenuator to X20 position and readjust the Resistance and Capacity Balance controls slightly, trying to bring the stylus down as close as possible to its initial position. Repeat these adjustments as the Attenuator is advanced to each succeeding position.

14. Return the Attenuator to the "OFF" position and throw the Coarse-Fine Switch to the Fine position.

15. Using the zero control, set the stylus (5) mm from the right hand edge of the graph for that channel.

16. Advance the Attenuator knob to (1) and if necessary reset the Resistance Balance slightly to bring the stylus back to the baseline position which had been selected with the zero control. If this adjustment is properly made, the Attenuator knob may be turned from one position to another without disturbing the stylus position. It is understood of course, that these adjustments are made with no load on the strain-sensitive elements.

17. The electrical sensitivity of the system can now be checked by pushing the Calibrating (Cal) button, and the sensitivity may be adjusted to (25) mm by using the Gain control.

18. Since the position of the Gain control may affect the baseline positions slightly it may be advisable momentarily to return the attenuator to the "OFF" position to establish the baseline position, and then with the Attenuator returned to the operating level, reset the stylus to this position using the Resistance Balance control.

19. The strain gage amplifier is now ready for use.

## Running the Experiment

After the press was adjusted and the recorder calibrated, the experiment was run by the following procedure:

1. Measure the die temperature and record on the Test Data form. The temperature at the start of each sample of (50) must be at room temperature. Measure the temperature hereafter only after drawing every fifth cup.

2. Apply lubricant uniformly over the entire area on both sides of the blank with a paint brush.

3. Using the aluminum hand tongs, place the blank in the locating nest in the die. Never put the blank in the die with your hands!

4. Visually check the cushion pressure and strokes per minute of the press. These may have to be readjusted occasionally.

5. Make sure all objects are clear of the die. Then press the two "black" palm buttons to operate the press.

6. In an emergency, stop the press ram by pushing the single "red" palm button located between the two black palm buttons. The motor may then be stopped by pushing the "red" push button on the press control panel.

7. After the press stops, remove the cup with the tongs. The cup is too hot to handle at this time.

8. Read both the vertical and circumferential strain deflections from the Sanborn Recorder and record on the Test Data form.

9. It may be necessary to reset the stylus on the baseline or zero line again using the Resistance Balance control. Since the maximum sensitivity of the Recorder is being used, the bridge may become slightly unbalanced.

10. Measure the three wall thicknesses with the deep-throat micrometer at positions A, B and C. Record on the Test Data form.

11. Wipe the cup clean and visually check for defects. If any occur, record on the form provided. If the defect is severe, mark the lubricant code letter, sample number and cup number on the cup. Set the cup aside for future reference.

12. If no defects occur, discard the cup in the container provided.

13. Repeat steps (1) through (12) for each cup.

14. After the last of the (50) cups of a sample is drawn, measure the final temperature of the die steel.

15. Shut off the press motor.

16. Shut off the air to the cushion.

17. Open the petcock at the cushion to drain off all air. This allows the blankholder to drop leaving the punch steel exposed for cleaning.

18. Clean the punch steel, die steel and blankholder with towels and oleum. All visual traces of lubricant must be removed.

19. Turn the air back on to the cushion and adjust as before.

20. Repeatly measure the die temperature until room temperature is reached.

21. Turn the press motor on.

22. The setup is now ready for running the next sample of (50) parts.

    Note: When two samples in sequence happen to be for the same lubricant, then steps 15 to 19 and steps 21 and 22 are neglected. Step 20 must be carried out, however.

Temperature Measurements

| Lubricant Code Letter | Average Temperature Degrees F | Number of Cups Made |
|---|---|---|
| A | 74.6 | 55 |
| B | 79.8 | 200 |
| C | 75.9 | 200 |
| D | 80.1 | 200 |
| E | 75.2 | 63 |
| F | 74.5 | 47 |
| G | 75.6 | 93 |
| H | 76.4 | 85 |
| J | 76.4 | 200 |
| K | 79.6 | 200 |
| L | 79.4 | 200 |
| M | 78.8 | 165 |

COMPUTATION OF AVERAGE AND STANDARD DEVIATION
OF
FREQUENCY DISTRIBUTION --- SHORT METHOD

| Cell<br><br>X | Frequency<br><br>f | Deviation in cells from assumed origin<br>d | <br><br>fd | <br><br>$fd^2$ |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| Totals | | | | |

n = Sample Size

Average or Mean $(\overline{X}) = \frac{\Sigma fd}{n}$ In cells from assumed origin

Average or Mean $(\overline{X})$ = Assumed Origin + $\frac{\Sigma fd}{n}$ (Cell Interval)

In original units from true origin

Standard Deviation $(s) = \sqrt{\frac{\Sigma fd^2}{n} - \left(\frac{\Sigma fd}{n}\right)^2}$

In cell units.

Standard Deviation (s) = (s in cell units) (cell interval)

In original units.

## COMPUTATION OF AVERAGE AND STANDARD DEVIATION OF FREQUENCY DISTRIBUTION --- SHORT METHOD

| Cell in Thous. of an Inch | f | d | fd | $fd^2$ |
|---|---|---|---|---|
| 35 | 5 | 4 | 20 | 80 |
| 34 | 12 | 3 | 36 | 108 |
| 33 | 18 | 2 | 36 | 72 |
| 32 | 36 | 1 | 36 | 36 |
| 31 | 48 | 0 | 0 | 0 |
| 30 | 50 | -1 | -50 | 50 |
| 29 | 25 | -2 | -50 | 100 |
| 28 | 6 | -3 | -18 | 54 |
| Totals | 200 | | 10 | 500 |

SAMPLE CALCULATIONS: (Wall Thickness Position "B" Lub. "J")

$\bar{X} = \frac{10}{200} = .05$ Cells from Assumed Origin

True Origin = 31.00 + .05 = 31.05

$$\text{Sigma } (s) = \sqrt{\frac{500}{200} - \left(\frac{10}{200}\right)^2}$$

$s = 1.58$

## TEST B4

Test for difference in variability ( $\sigma_1$ and $\sigma_2$ ) in two samples.

(Test for homogeneity)

$$F = \left( \frac{\sigma_1 \sqrt{\frac{n_1}{n_1 - 1}}}{\sigma_2 \sqrt{\frac{n_2}{n_2 - 1}}} \right)^2$$

$\sigma_1$ = Standard Deviation (Largest)

$\sigma_2$ = Standard Deviation (Smallest)

$n_1$ = Sample Size (For larger $\sigma$ )

$n_2$ = Sample Size (For smaller $\sigma$ )

Where:

$$n_1 = n_2$$

$$F = \left( \frac{\sigma_1}{\sigma_2} \right)^2$$

Degrees of Freedom:

Numerator $DF_1 = n_1 - 1$

Denominator $DF_2 = n_2 - 1$

If "F" is less than the value from Table E, then the probability is greater than 0.05 that the difference may occur by chance. The difference is not significant. Therefore the samples and their deviations are homogeneous.

If "F" is greater than the value from Table E, then the probability is less than 0.05 that the difference may occur by chance. The difference is significant. Therefore the samples and their deviations are not homogeneous.

FOR THIS EXPERIMENT, PROBABILITY = 0.05 HAS BEEN SET FOR CONFIDENCE.

Since seven lubricants will be tested for significance, the following pairs will be checked for homogeneity of standard deviations:

| | | | | | |
|---|---|---|---|---|---|
| B - C | | | | | |
| B - D | C - D | | | | |
| B - J | C - J | D - J | | | |
| B - K | C - K | D - K | J - K | | |
| B - L | C - L | D - L | J - L | K - L | |
| B - M | C - M | D - M | J - M | K - M | L - M |

TOTAL ---- 21 tests

## TESTS FOR HOMOGENEITY OF STANDARD DEVIATIONS

SAMPLE CALCULATIONS: (Deflection Data)

Test C-K:

Lubricant C $s = 3.52$

Lubricant K $s = 2.90$

$n_1 = n_2 = 200 \quad DF_1 = DF_2 = 200$

$$F = \frac{(3.52)^2}{(2.90)^2} = 1.47$$

Value of F in Table E for a confidence interval of 0.05 = 1.26

$F' = 1.26$

F is greater than F', therefore the samples are not homogeneous.

Test J-L:

Lubricant J $s = 4.52$

Lubricant L $s = 4.35$

$n_1 = n_2 = 200 \quad DF_1 = DF_2 = 200$

$$F = \frac{(4.52)^2}{(4.35)^2} = 1.08$$

Value of F in Table E for a confidence interval of 0.05 = 1.26

$F' = 1.26$

F is less than F', therefore the samples are homogeneous.

TESTS FOR SIGNIFICANCE

TEST B2

Test for difference between two sample means ( $X_1$ and $X_2$ ) where $\sigma'$ is unknown but believed to be the same for the two populations.

$$\sigma' = \sqrt{\frac{n_1\sigma_1'^2 + n_2\sigma_2'^2}{n_1 + n_2 - 2}}$$

Different Sample Sizes

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sigma'\sqrt{\frac{n_1 + n_2}{n_1 n_2}}}$$

$$DF = n_1 + n_2 - 2$$

Same Sample Sizes

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{\sigma_1^2 + \sigma_2^2}{n - 1}}}$$

$$DF = 2\ (n - 1))$$

| | | |
|---|---|---|
| Small Probability (less than 0.05) | -------- | Significant Difference does exist |
| Large Probability (more than 0.05) | -------- | Significant Difference does not exist |

$t$ = Calculated value

$t'$ = Value from Table C

When t is greater than the value of t', then the probability is less than 0.05 that the difference occurs due to chance. A significant difference between means does exist.

When t is less than the value of t', then the probability is greater than 0.05 that the difference occurs due to chance. A significant difference between means does not exist.

SAMPLE CALCULATIONS (Wall Thickness Position "C")

| | | | |
|---|---|---|---|
| Test K-L | Lubricant K | $s = 1.58$ | $\bar{X} = 31.13$ |
| | Lubricant L | $s = 1.58$ | $\bar{X} = 30.57$ |

$n_1 = n_2 = 200$ DF = 2 ( 200 - 1 )

DF = 398

$$t = \frac{31.13 - 30.57}{\sqrt{\frac{(1.58)^2 + (1.58)^2}{200 - 1}}} = 3.53$$

$t' = 1.96$

t is greater than t', therefore a significant difference does exist between the means

# TESTS FOR SIGNIFICANCE

Test for difference between two sample means ($X_1$ and $X_2$) where $\sigma'$ is unknown and not necessarily equal for the two samples.

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\dfrac{s_1^2}{n_1} + \dfrac{s_2^2}{n_2}}}$$

Degrees of Freedom = v

$$v = -2 + \frac{\left(\dfrac{s_1^2}{n_1} + \dfrac{s_2^2}{n_2}\right)^2}{\dfrac{\left(\dfrac{s_1^2}{n_1}\right)^2}{n_1 + 1} + \dfrac{\left(\dfrac{s_2^2}{n_2}\right)^2}{n_2 + 1}}$$

t = Calculated value

t' = Value from Table C

When t is greater than the value of t', then the probability is less than 0.05 that the difference occurs due to chance. A significant difference between means does exist.

When t is less than the value of t', then the probability is greater than 0.05 that the difference occurs due to chance. A significant difference between means does not exist.

SAMPLE CALCULATIONS: (Deflection)

Test J-M: Lubricant J $s = 4.52$ $\overline{X} = 24.74$
$n = 200$

Lubricant M $s = 3.68$ $\overline{X} = 25.66$
$n = 148$

$$t = \frac{25.66 - 24.74}{\sqrt{\frac{(3.68)^2}{148} + \frac{(4.52)^2}{200}}} = 2.09$$

$$v = -2 + \frac{\left(\frac{(3.68)^2}{148} + \frac{(4.52)^2}{200}\right)^2}{\frac{\left(\frac{(3.68)^2}{148}\right)^2}{148 + 1} + \frac{\left(\frac{(4.52)^2}{200}\right)^2}{200 + 1}}$$

$v = 343$

$t' = 1.96$

t is greater than t', therefore a significant difference does exist between the means.

## CORRELATION CALCULATIONS

## ORIGINAL DATA METHOD

**Basic Formula** $Y = bx + a$ (Regression Line)

Slope $$b = \frac{n \Sigma XY - \Sigma X \Sigma Y}{n \Sigma X^2 - (\Sigma X)^2}$$

Intercept $$a = \frac{\Sigma Y - b \Sigma X}{n}$$

$n$ = Sample Size

Correlation Coefficient $$r = \sqrt{\frac{a \Sigma Y + b \Sigma XY - n\bar{Y}^2}{\Sigma Y^2 - n\bar{Y}^2}}$$

Correlation Coefficient Definition:

A prediction of how data taken in the future will correlate or fit to the regression line found for the given data.

Standard Error of Estimate (Standard Deviation)

$$SY = \sqrt{\frac{\Sigma Y^2 - a \Sigma Y - b \Sigma XY}{n}}$$

Coefficient of Determination ($r^2$)

The percentage of the variance of Y that can be accounted for by predicting from X. (Per cent effectiveness for forecasting variance in Y using X)

$r^2 \longrightarrow$ Equal to or greater than .50 to be useful

CORRELATION

SAMPLE CALCULATIONS: (means)

Key: X = Deflection Means

Y = Wall Thickness Means

| $\Sigma X^2$ | $\Sigma X$ | $\Sigma XY$ | $\Sigma Y$ | $\Sigma Y^2$ |
|---|---|---|---|---|
| | 27.75 | | 28.47 | |
| | 25.95 | | 29.81 | |
| | 27.11 | | 29.37 | |
| | 24.74 | | 30.27 | |
| | 26.65 | | 31.13 | |
| | 27.15 | | 30.57 | |
| | 25.66 | | 29.95 | |
| 4,896.2653 | 185.01 | 5,536.8195 | 209.57 | 6,278.6511 |

$$\overline{Y} = \frac{209.57}{7} = 29.9386$$

$$\overline{Y}^2 = 896.3198$$

$$\text{Slope } b = \frac{(7)(5,536.8195) - (185.01)(209.57)}{(7)(4,896.2653) - (185.01)(185.01)}$$

$$b = -.3279$$

$$\text{Intercept } a = \frac{209.57 - (-.3279)(185.01)}{7}$$

$$a = 38.6050 \quad \text{When } X = 0$$

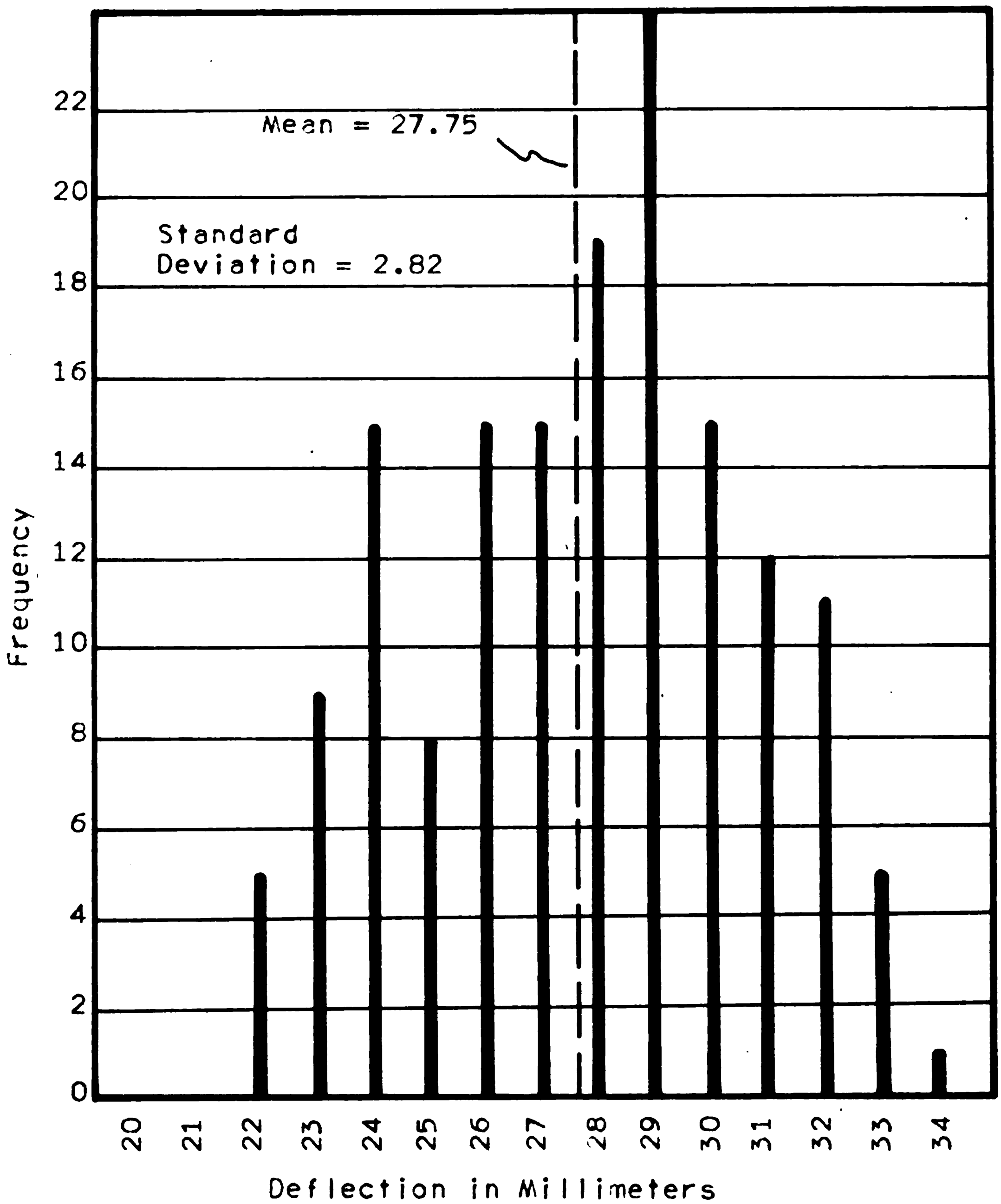
$$r = \sqrt{\frac{(38.6050)(209.57) + (-.3279)(5,536.8195) - (7)(896.3198)}{6,278.6511 - (7)(896.3198)}}$$

$$r = .3948$$

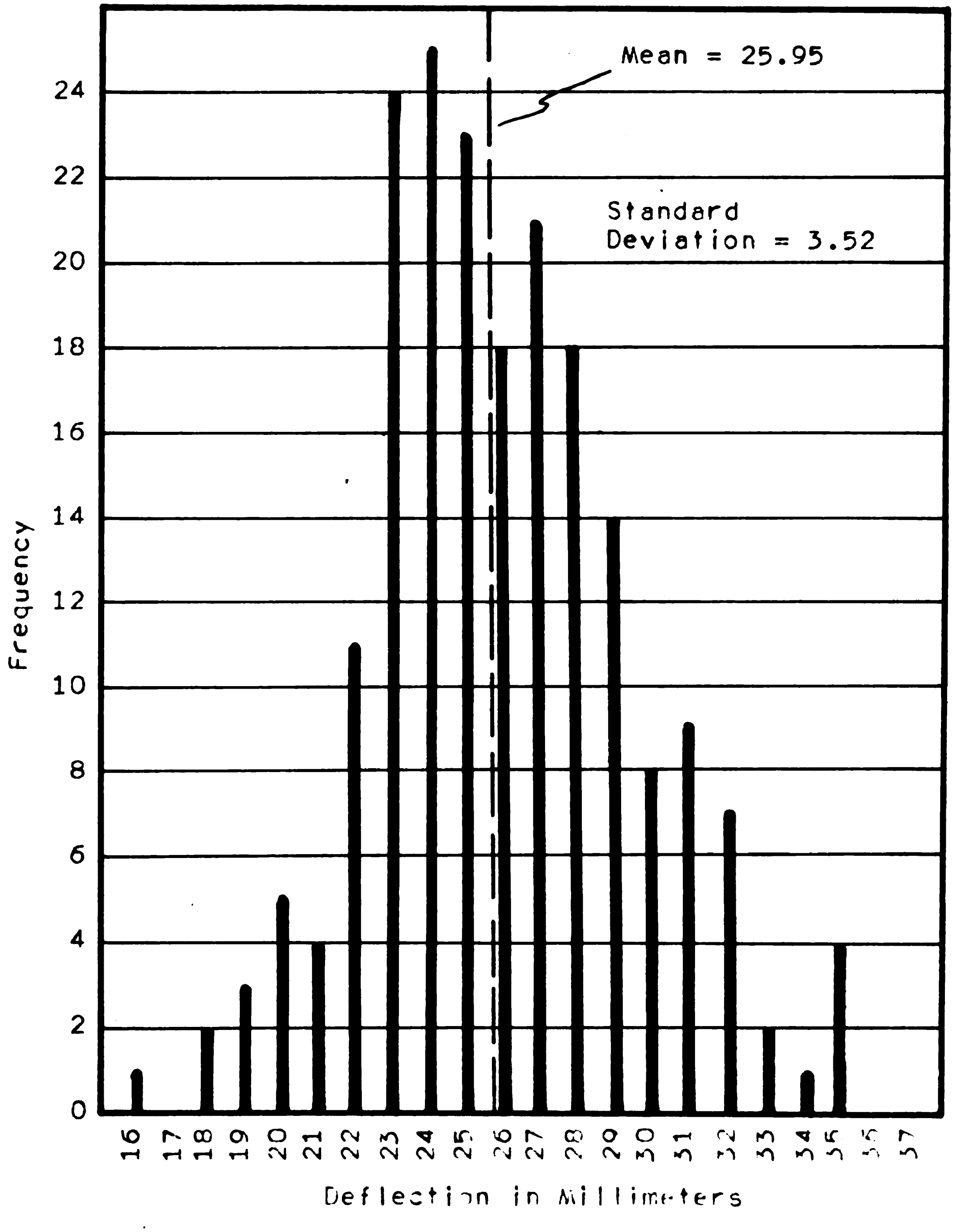
$$r^2 = .1559$$

$$S_y = \sqrt{\frac{6,278.6511 - (38.6050)(209.57) - (-.3279)(5,536.8195)}{7}}$$

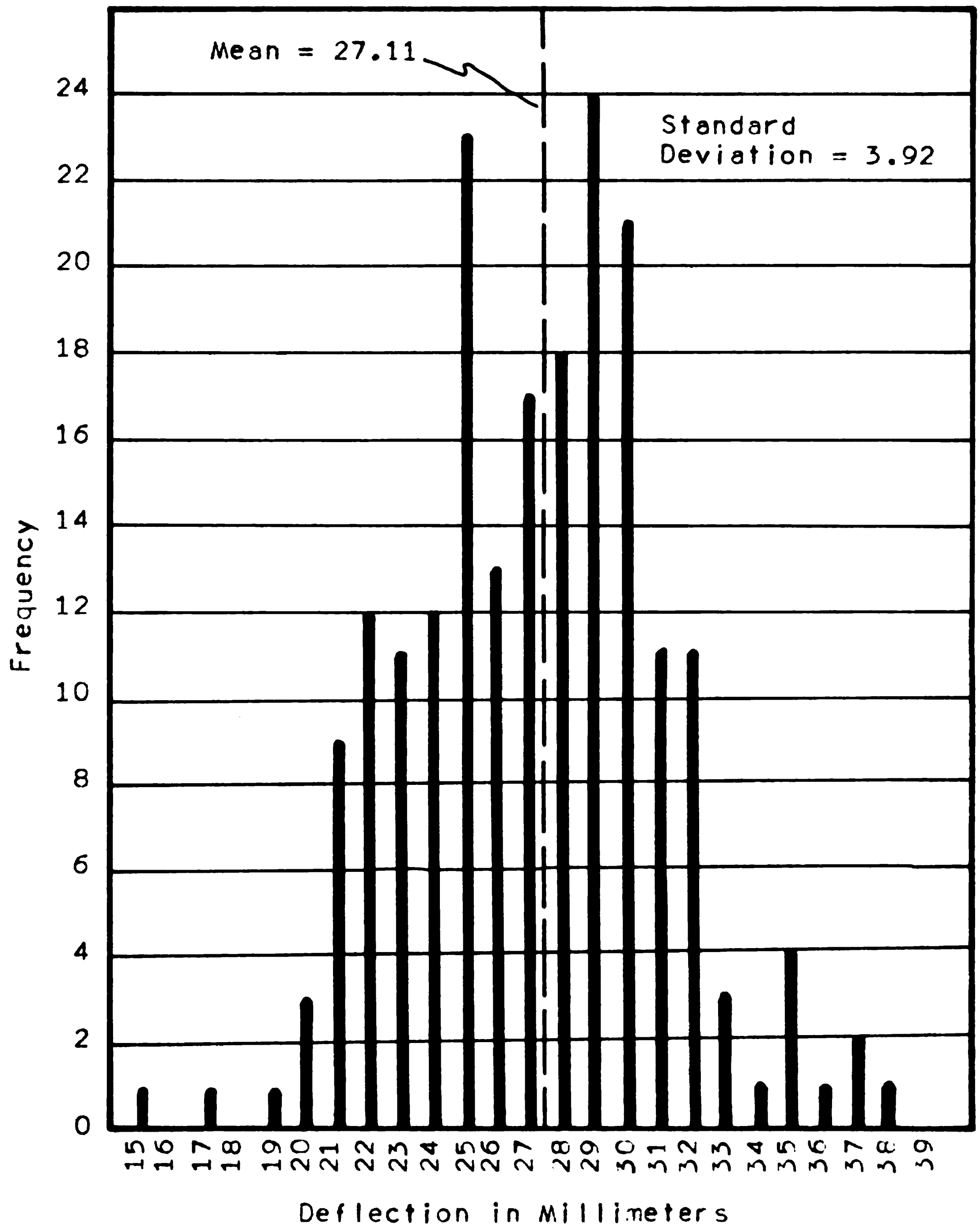
$$S_y = .7294$$



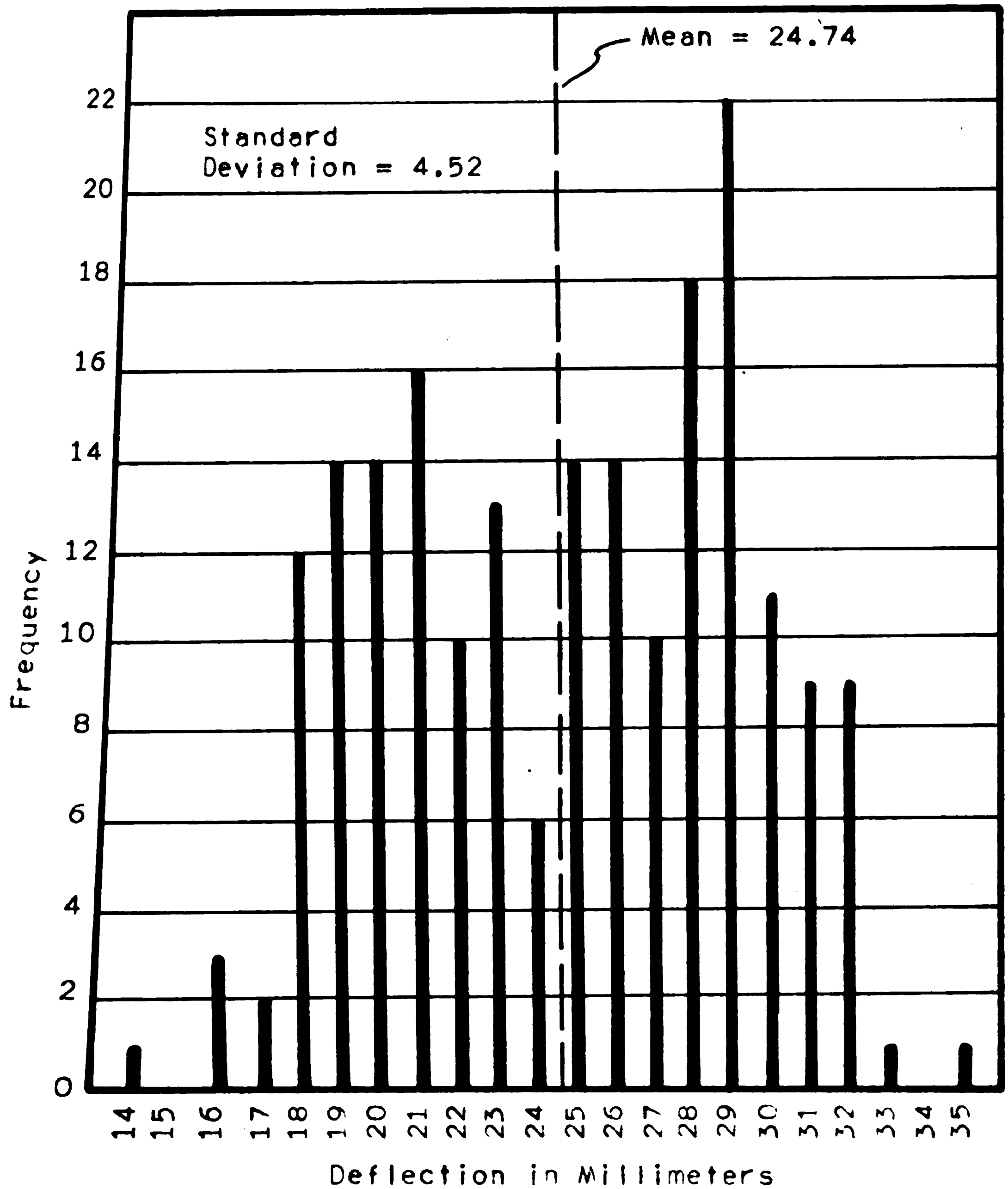

Deflection Histogram for Lubricant "B"



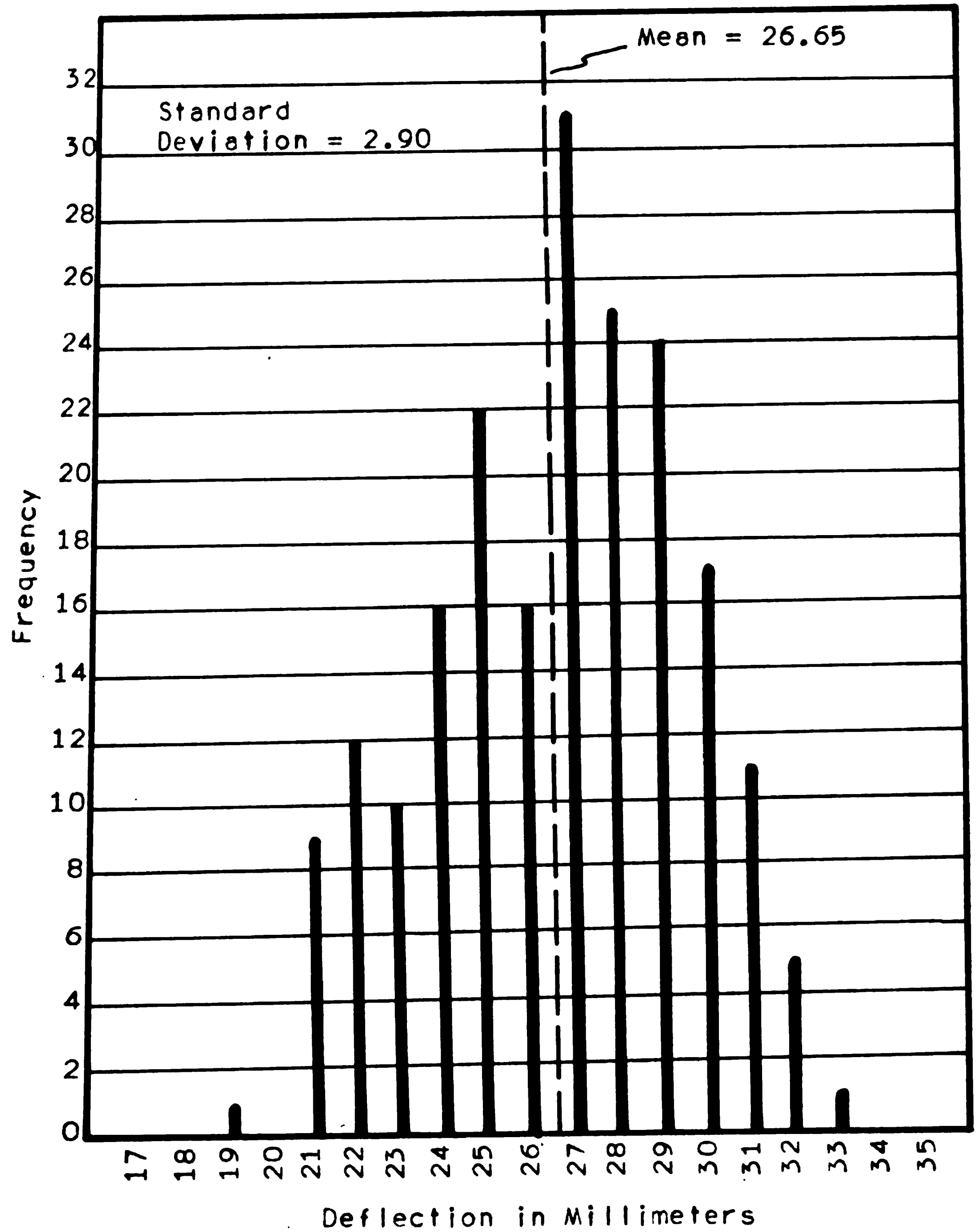

Deflection Histogram for Lubricant "C"



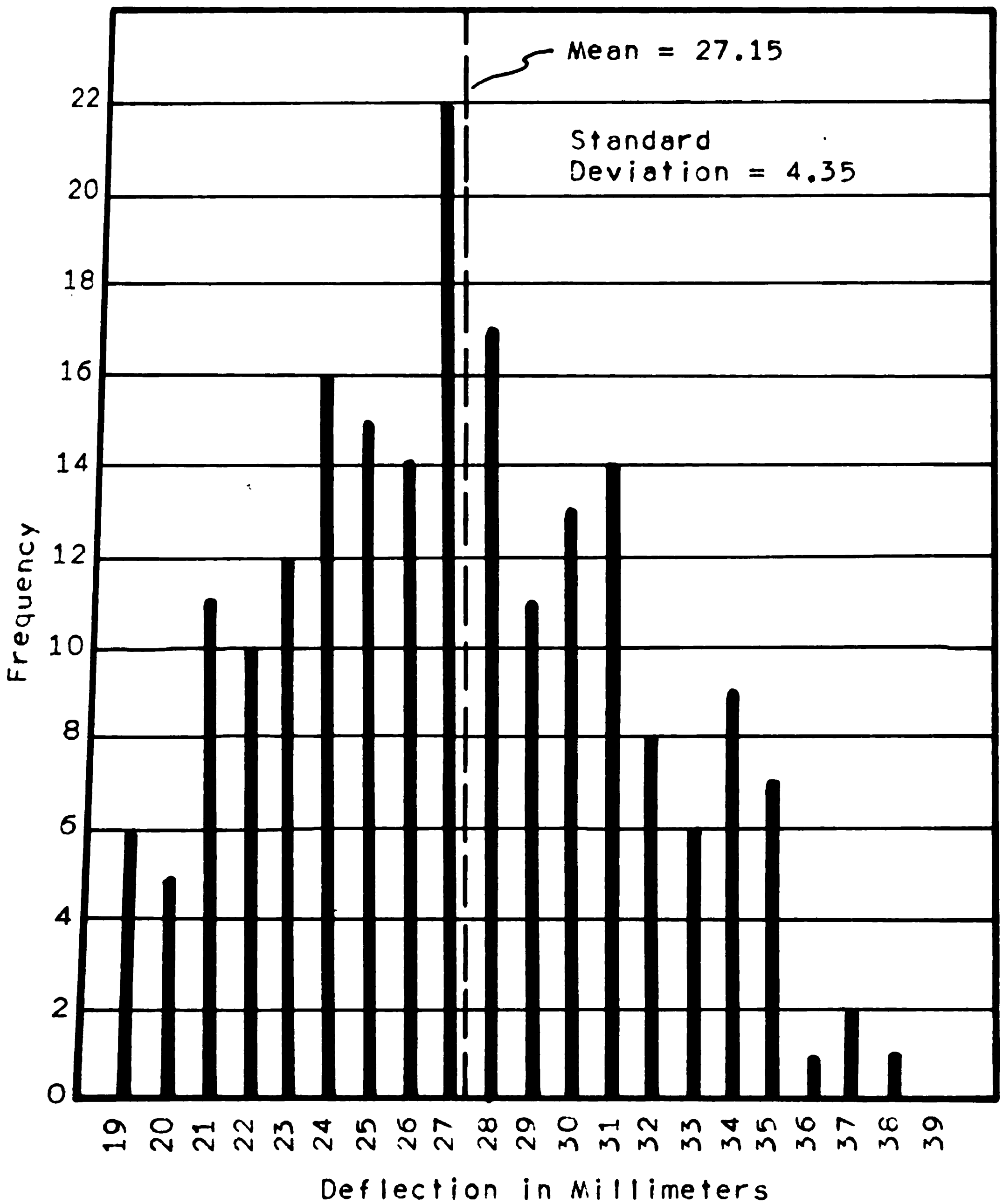

Deflection Histogram for Lubricant "D"



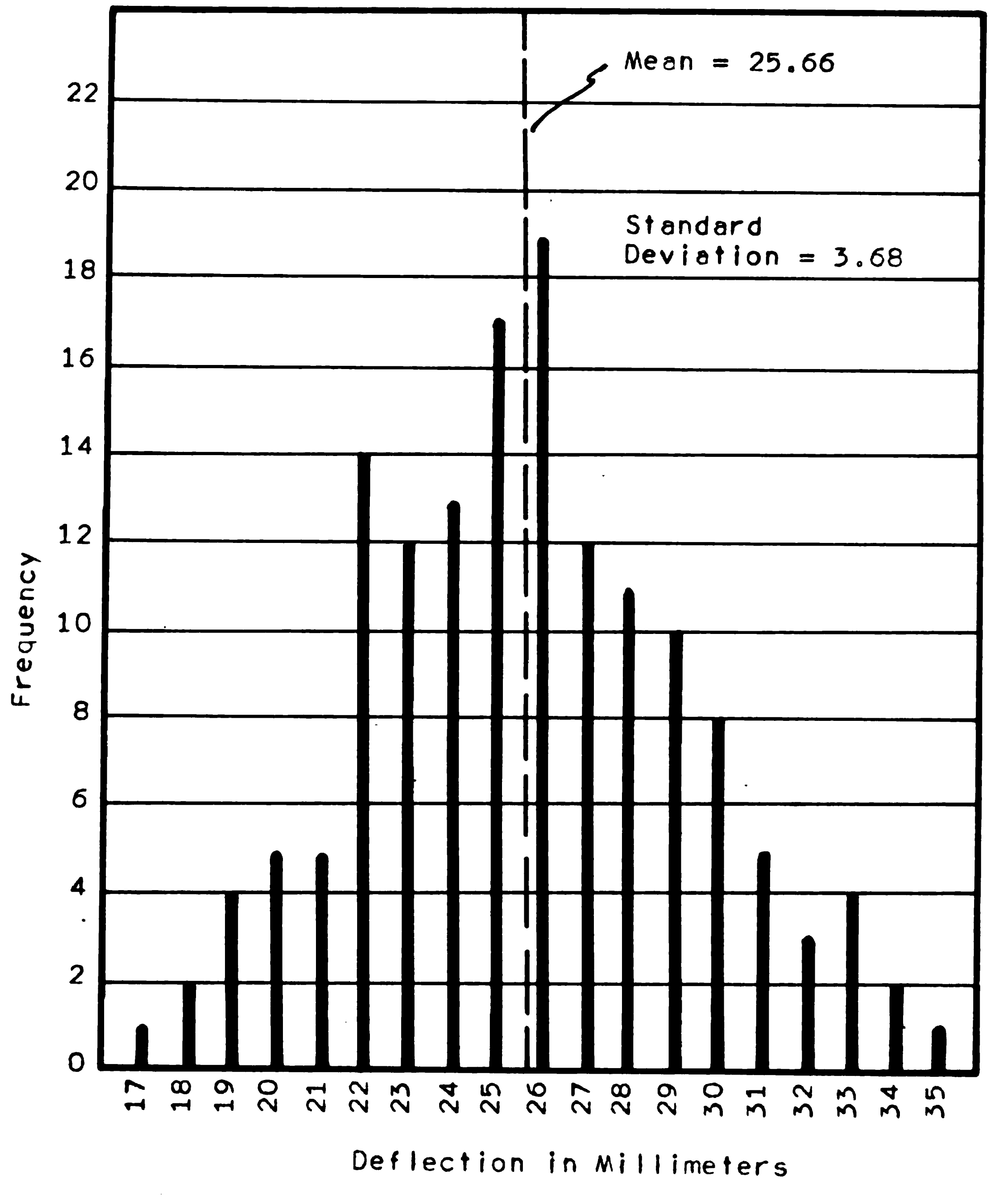

Deflection Histogram for Lubricant "J"



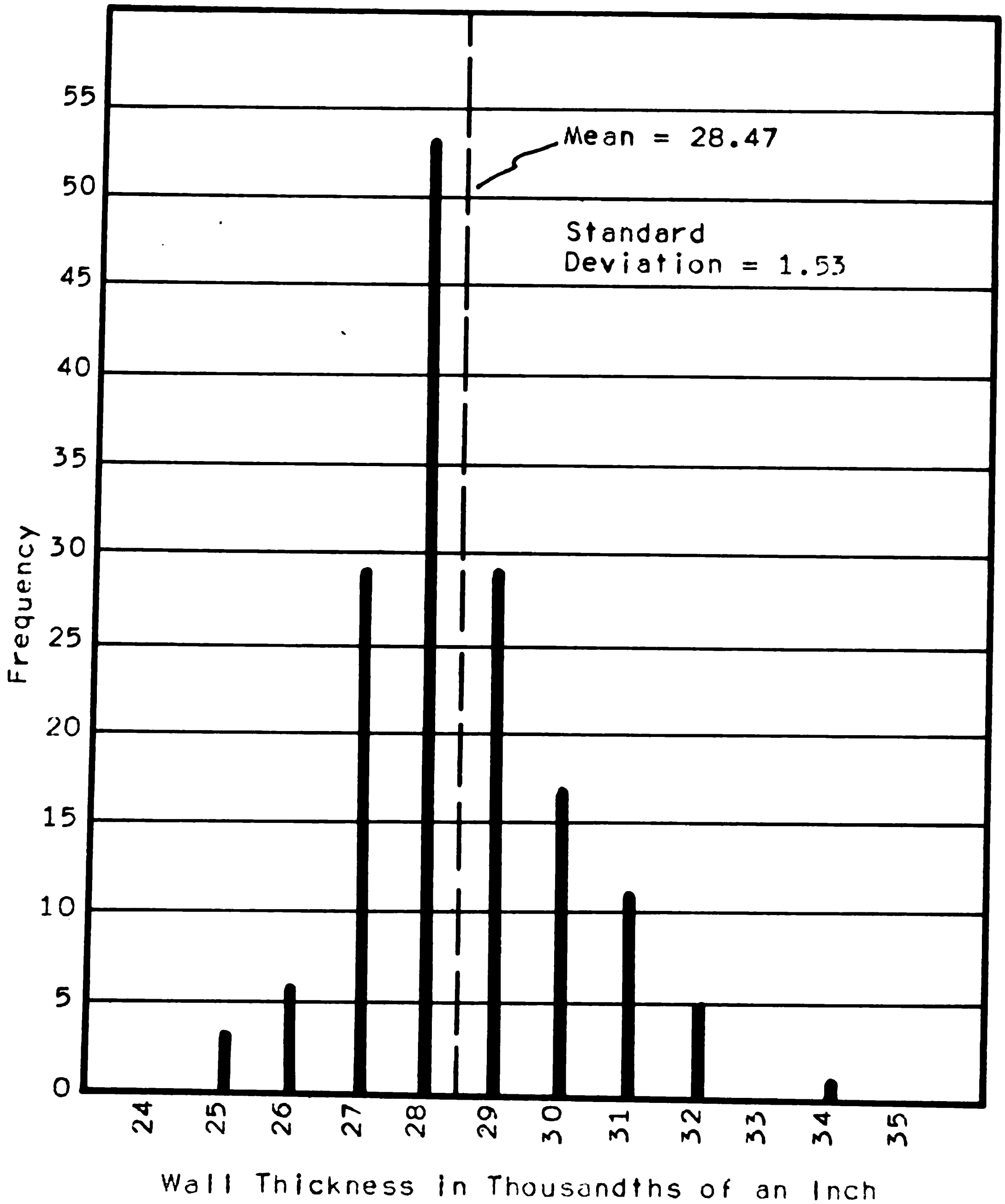

Deflection Histogram for Lubricant "K"



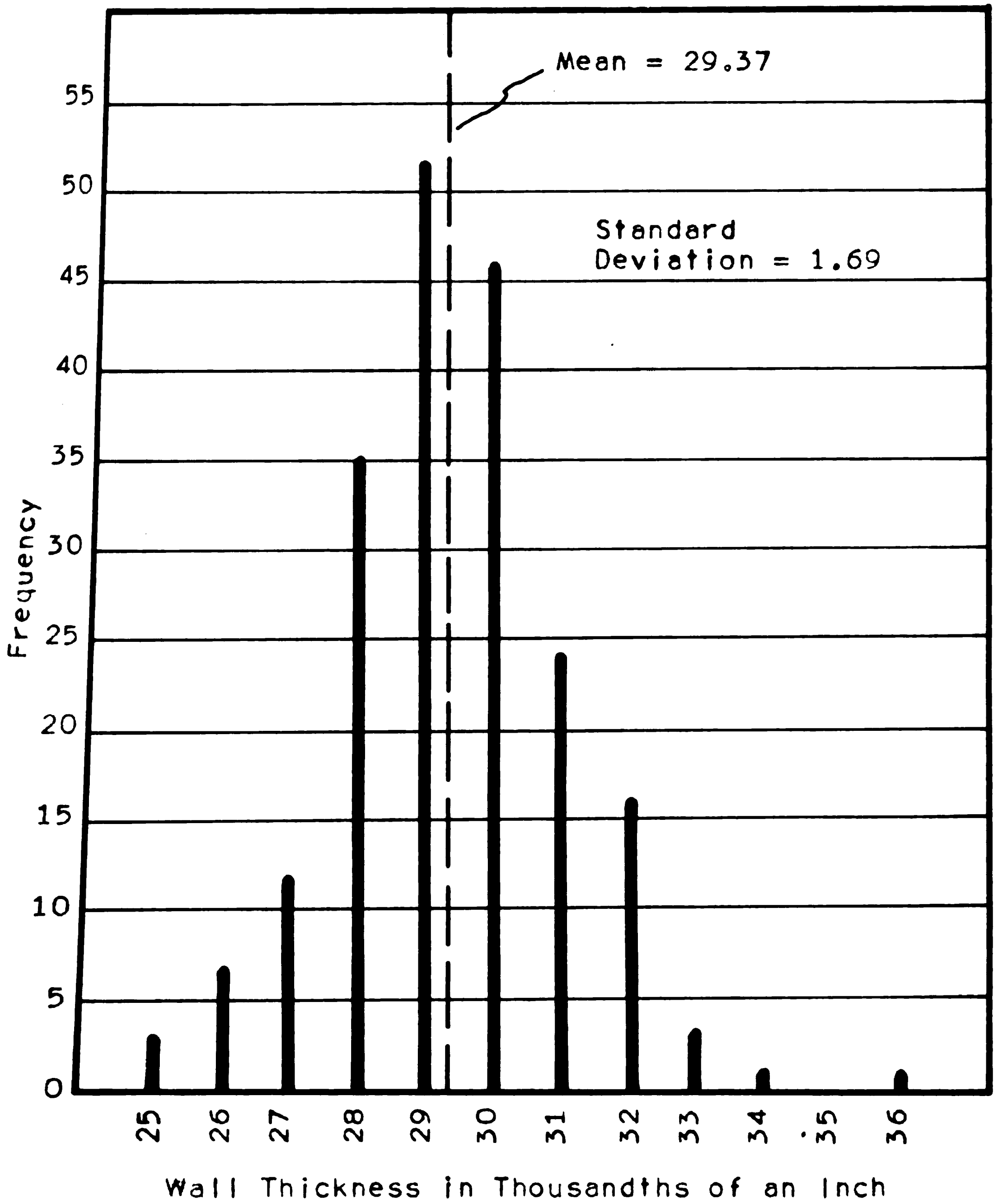

Deflection Histogram for Lubricant "L"



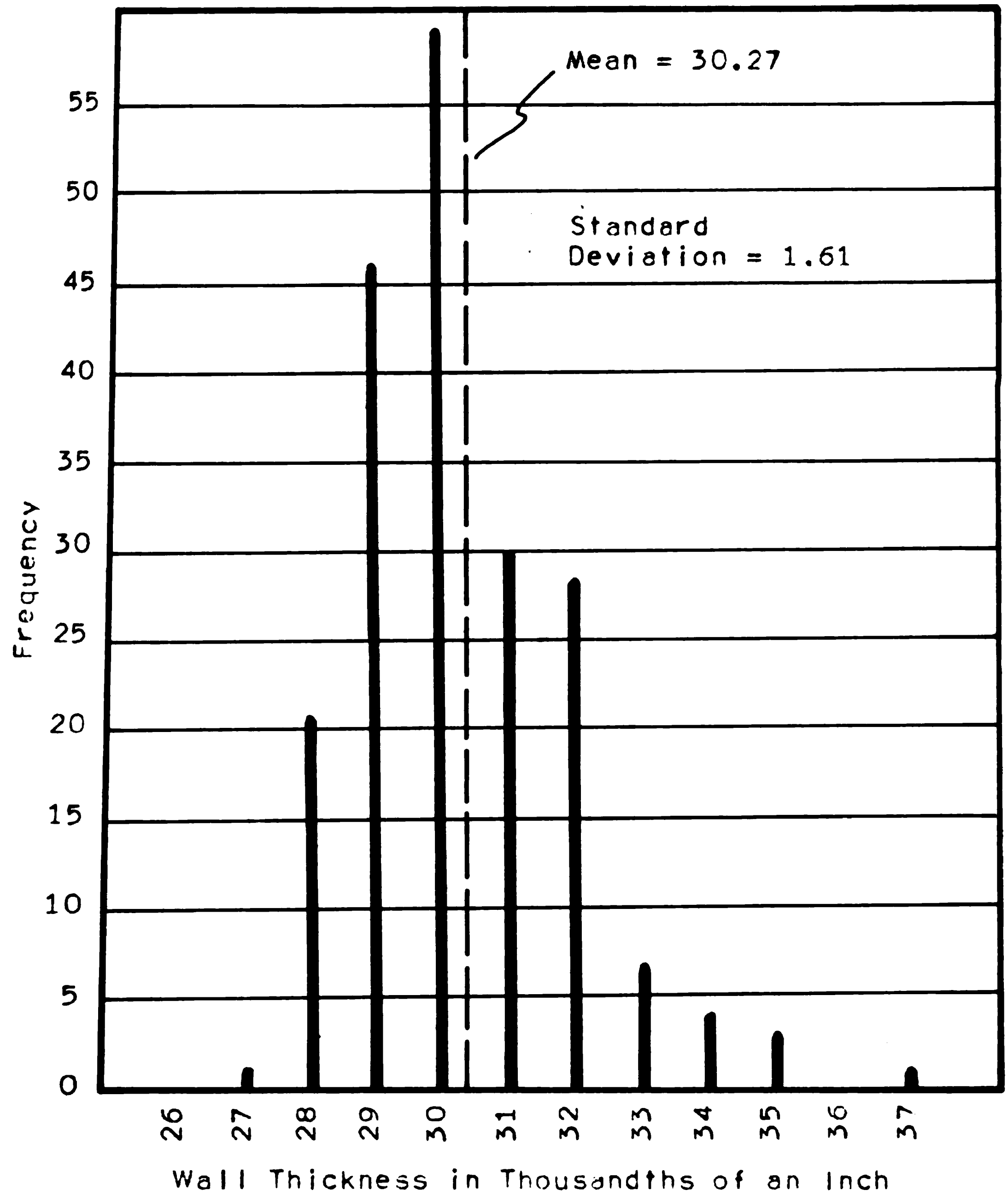

Deflection Histogram for Lubricant "M"



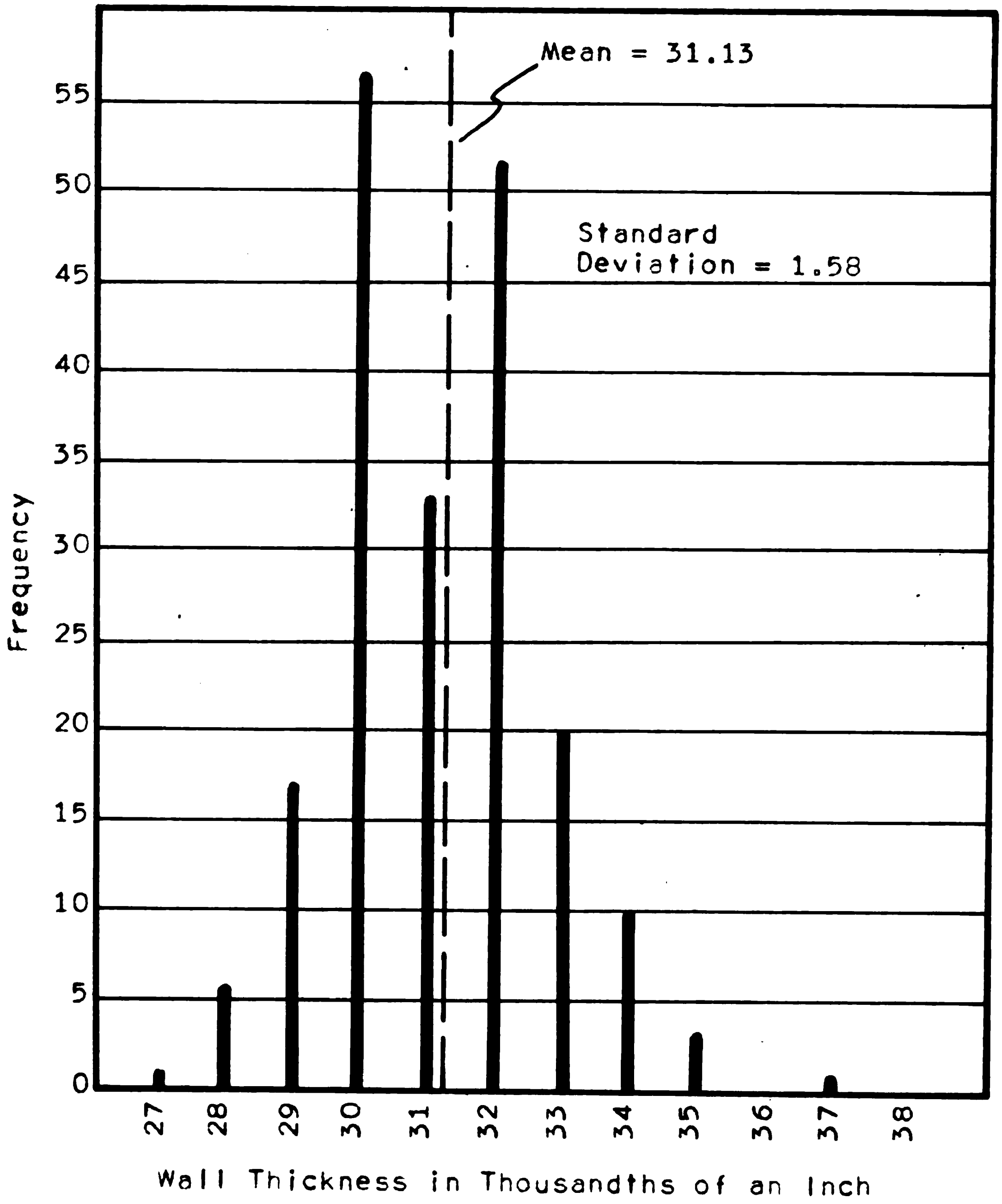

Wall Thickness Position "C" Lubricant "B"
Histogram



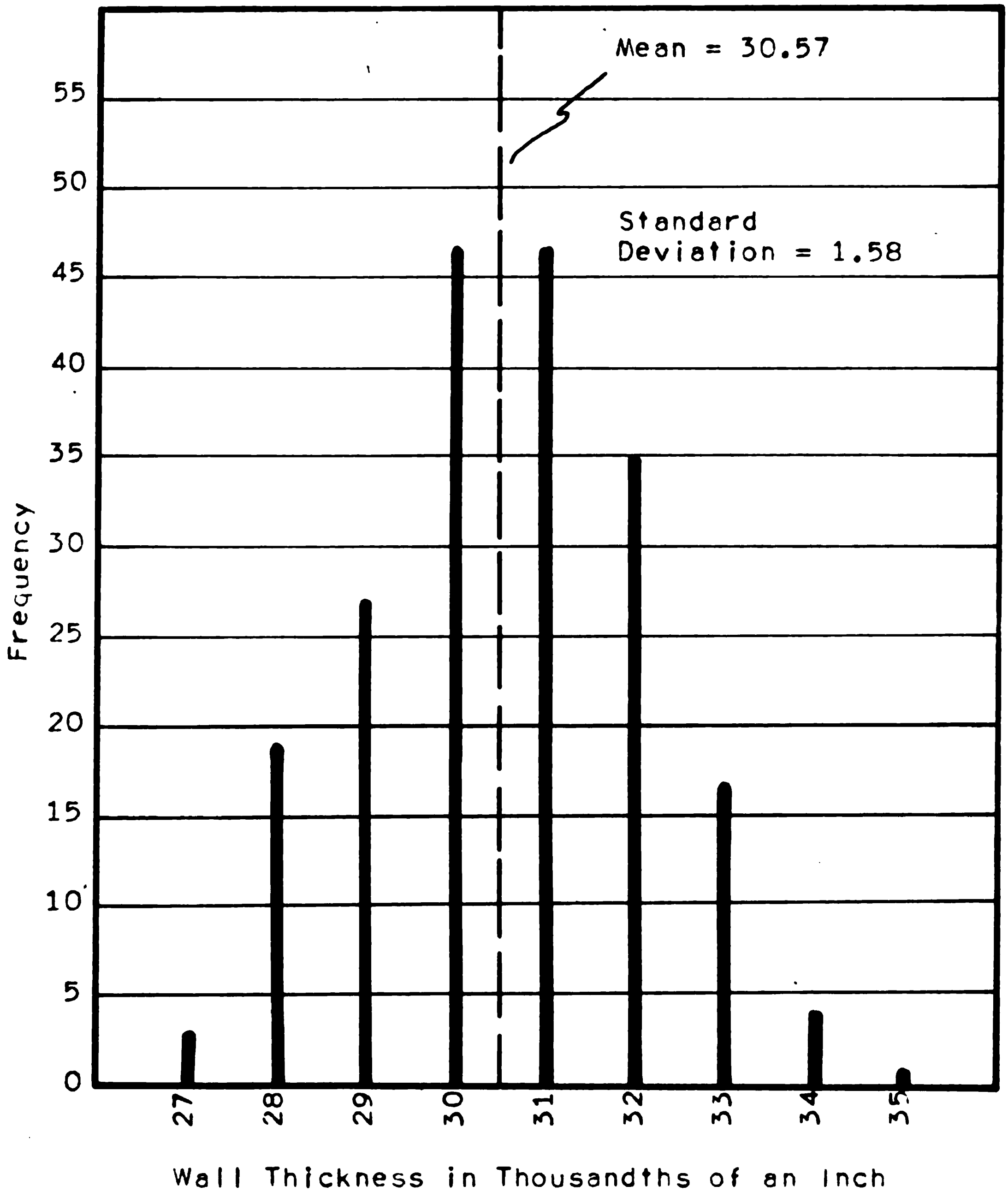

Wall Thickness Position "C" Lubricant "D"
Histogram



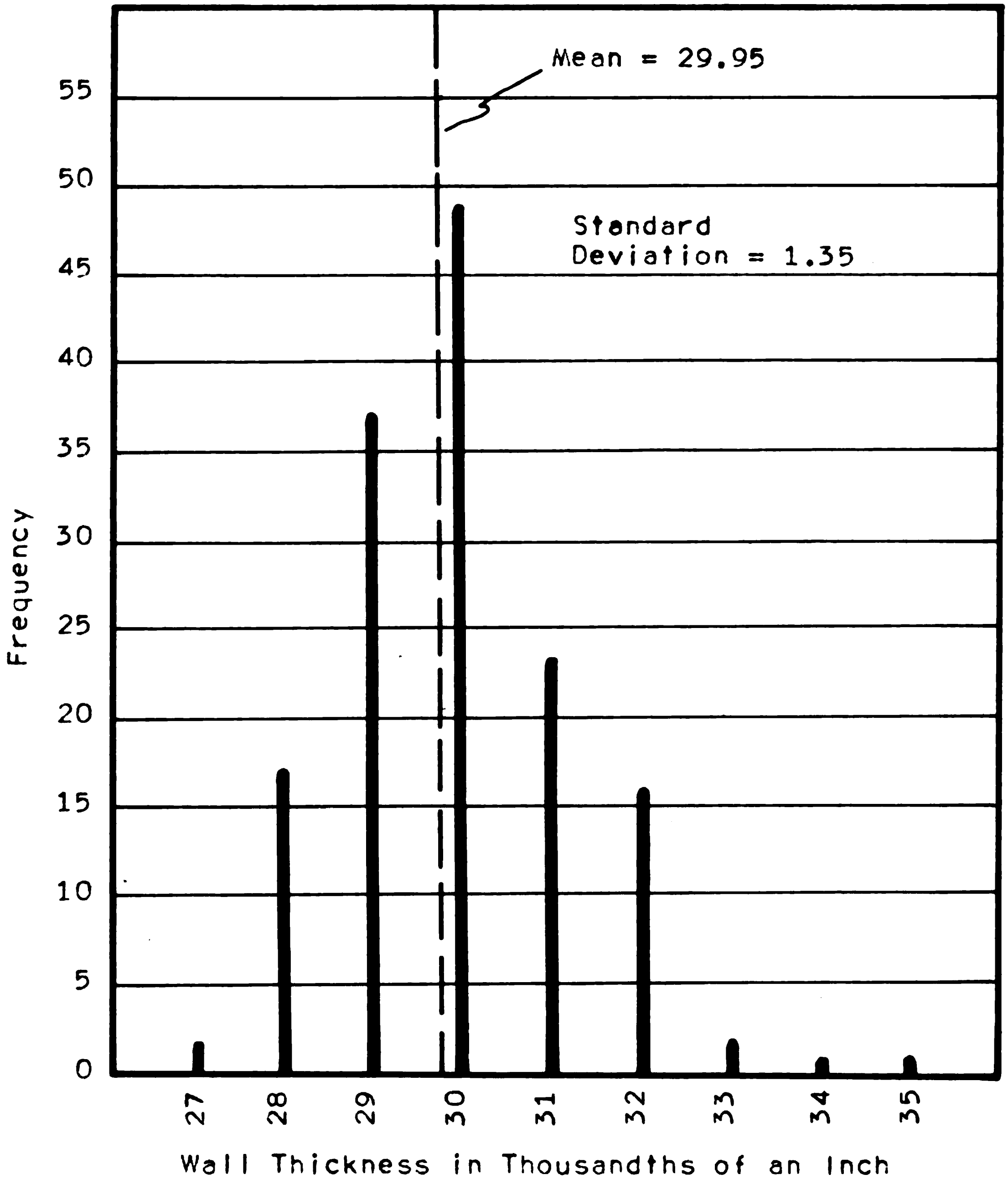

Wall Thickness Position "C" Lubricant "J"
Histogram



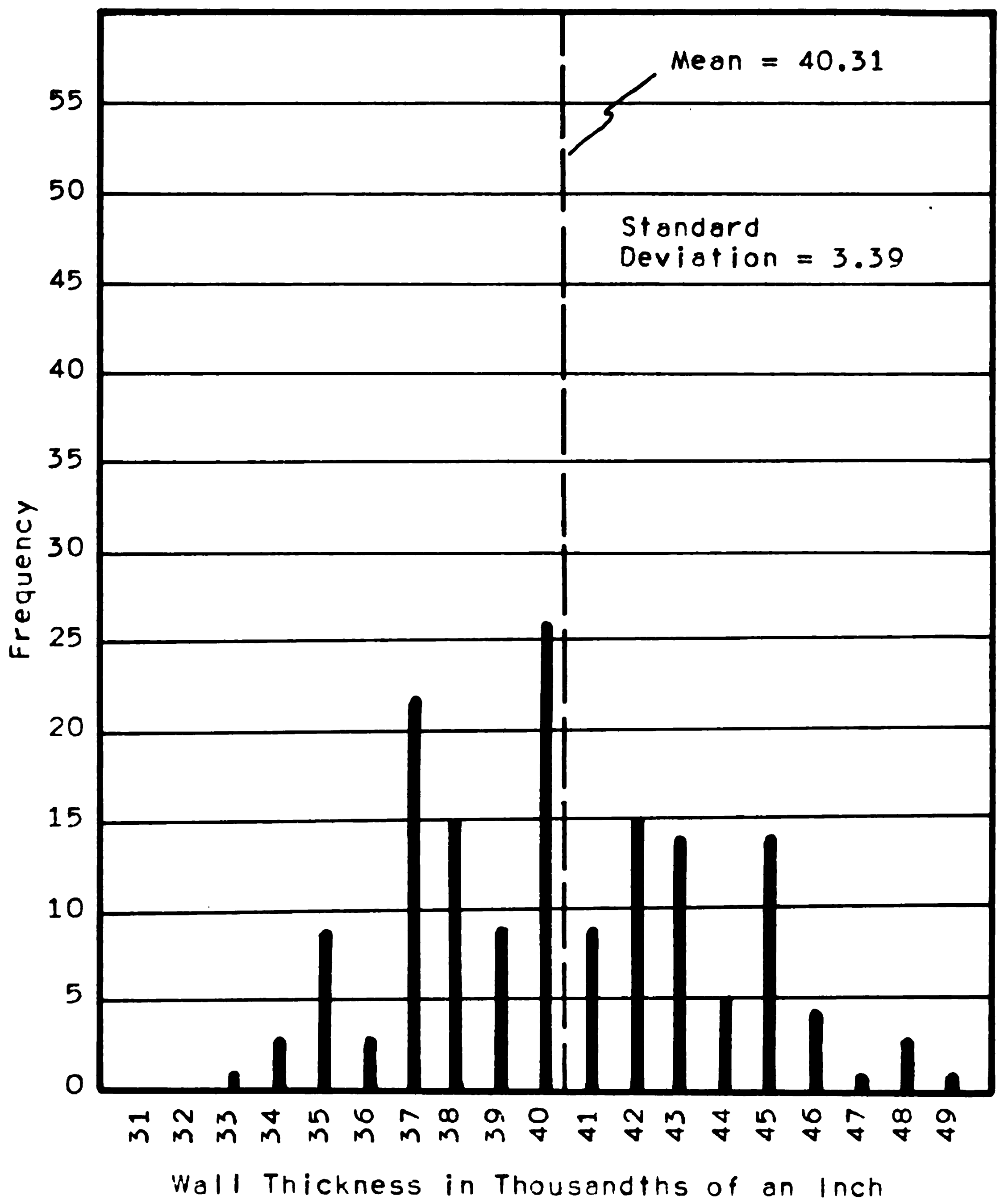

Wall Thickness Position "C" Lubricant "K"
Histogram



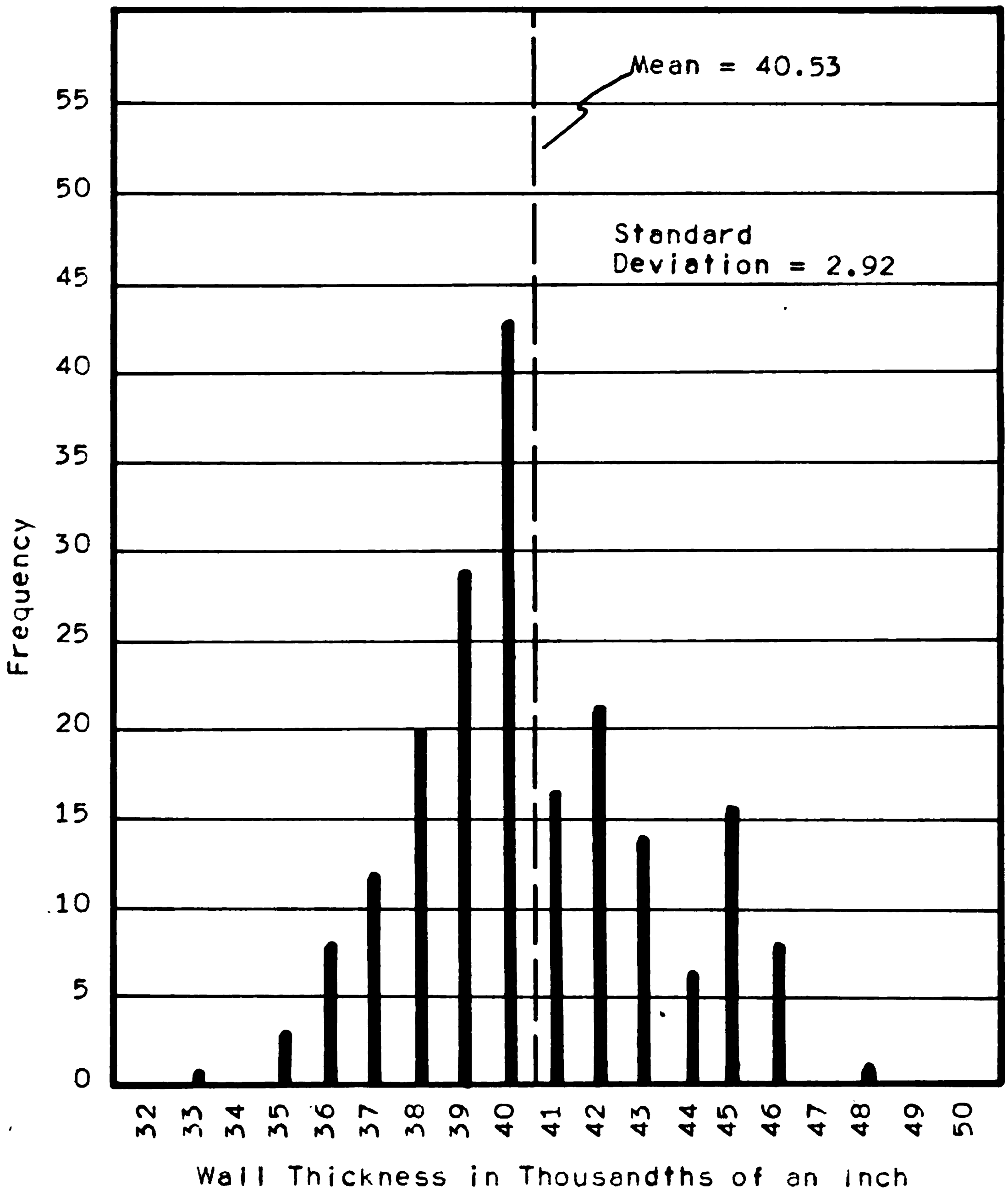

Wall Thickness Position "C" Lubricant "L"
Histogram



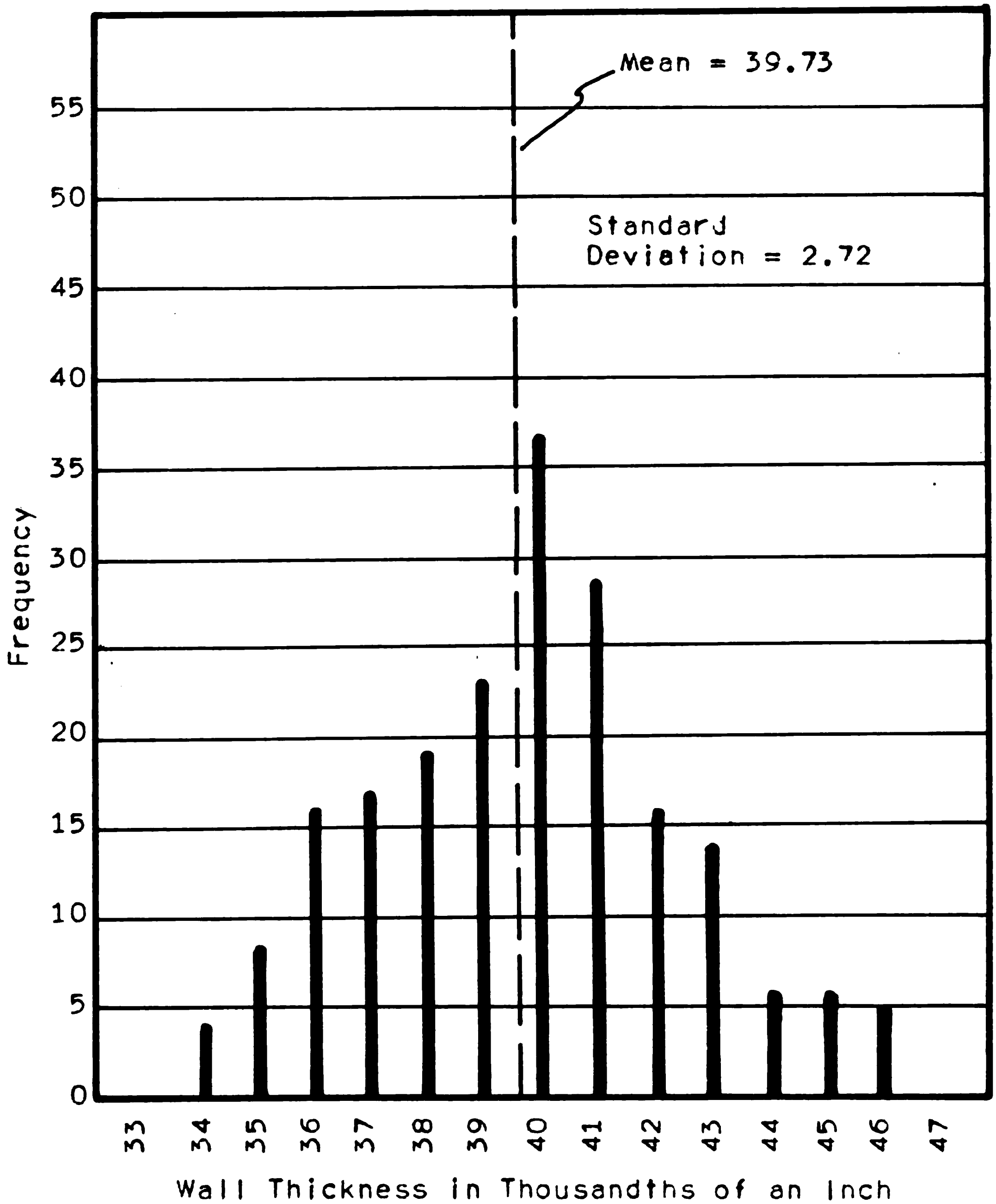

Wall Thickness Position "C" Lubricant "M"
Histogram



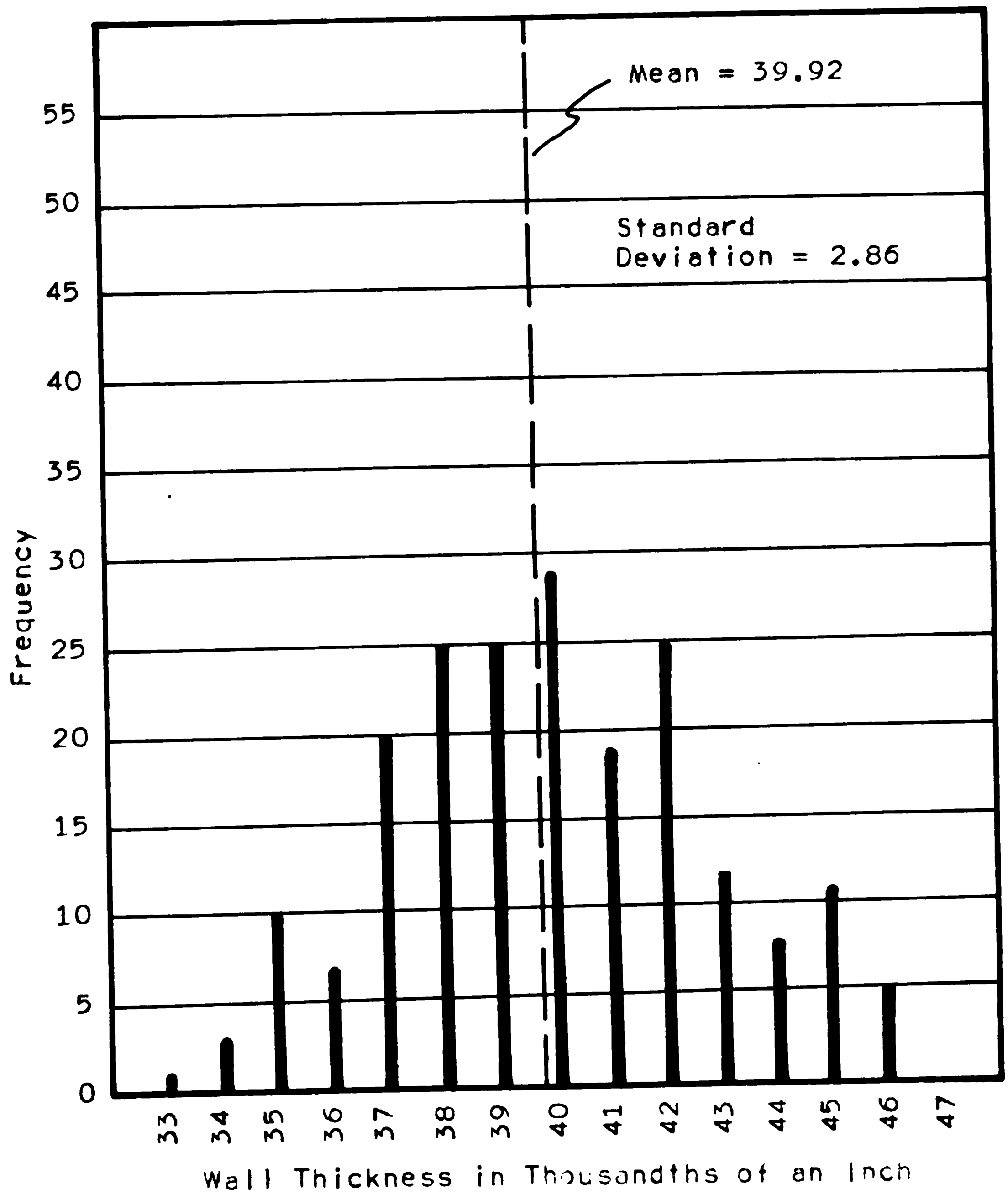

Wall Thickness Position "A" Lubricant "B"
Histogram



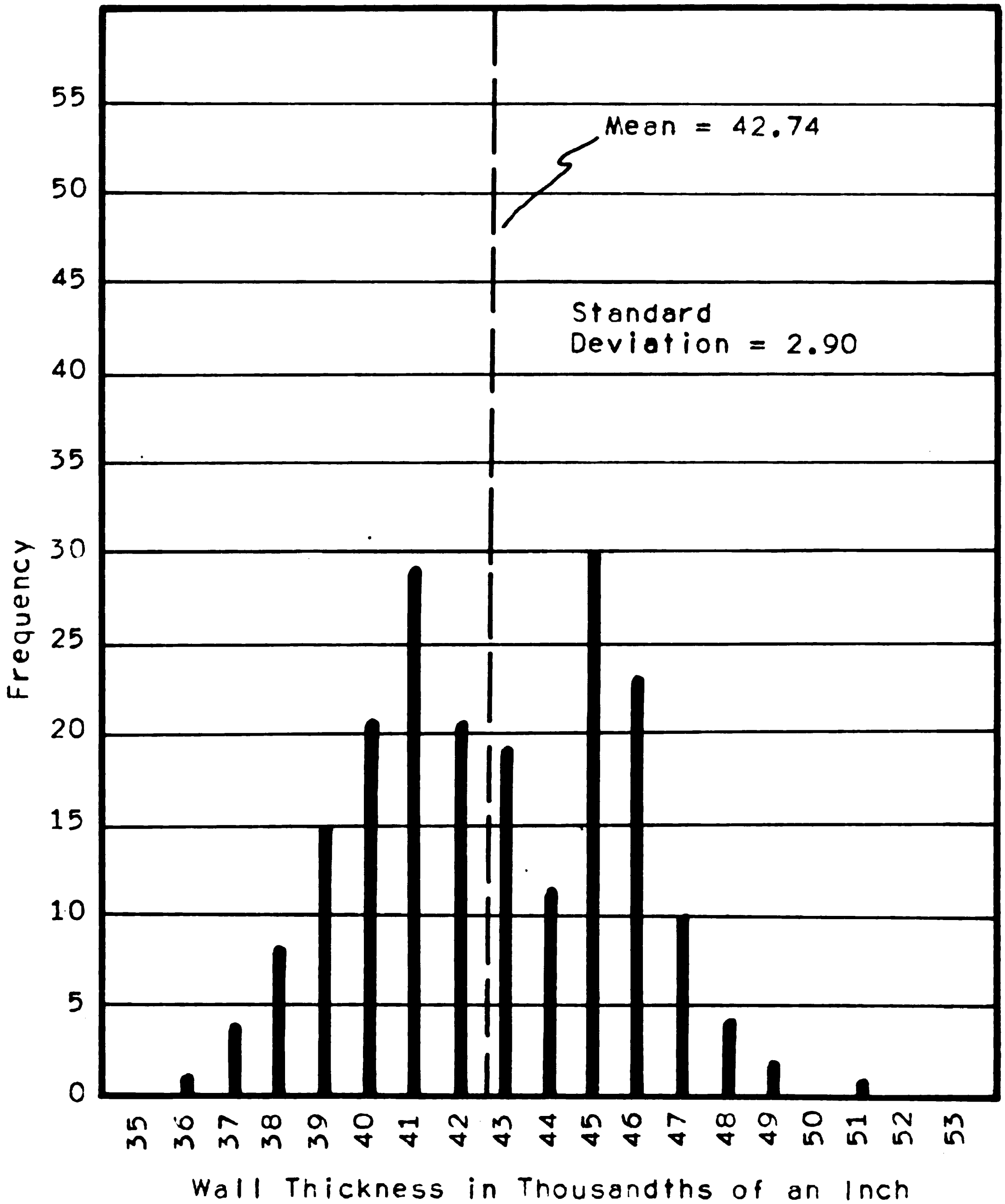

Wall Thickness Position "A" Lubricant "C"
Histogram



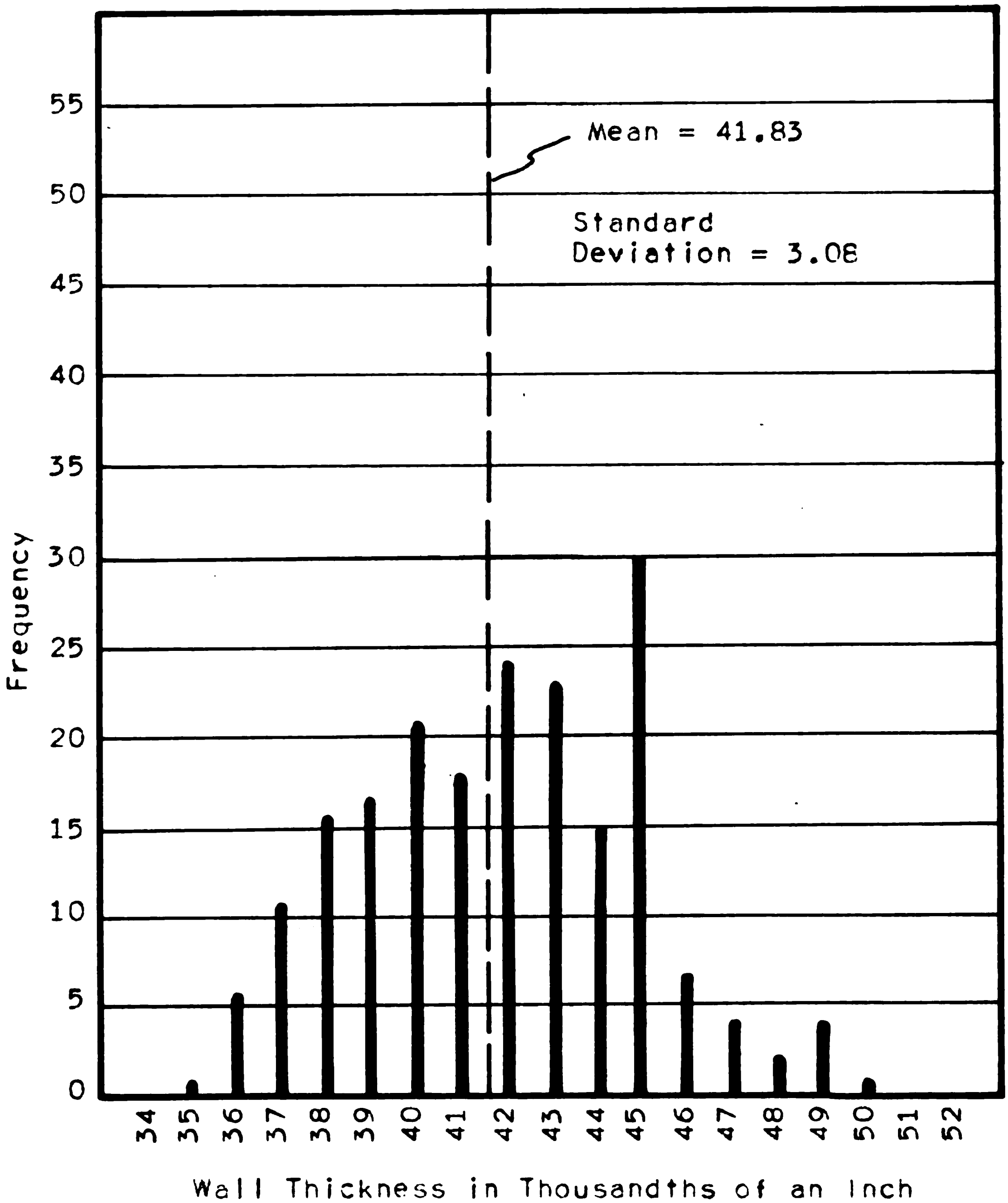

Wall Thickness Position "A" Lubricant "D"
Histogram



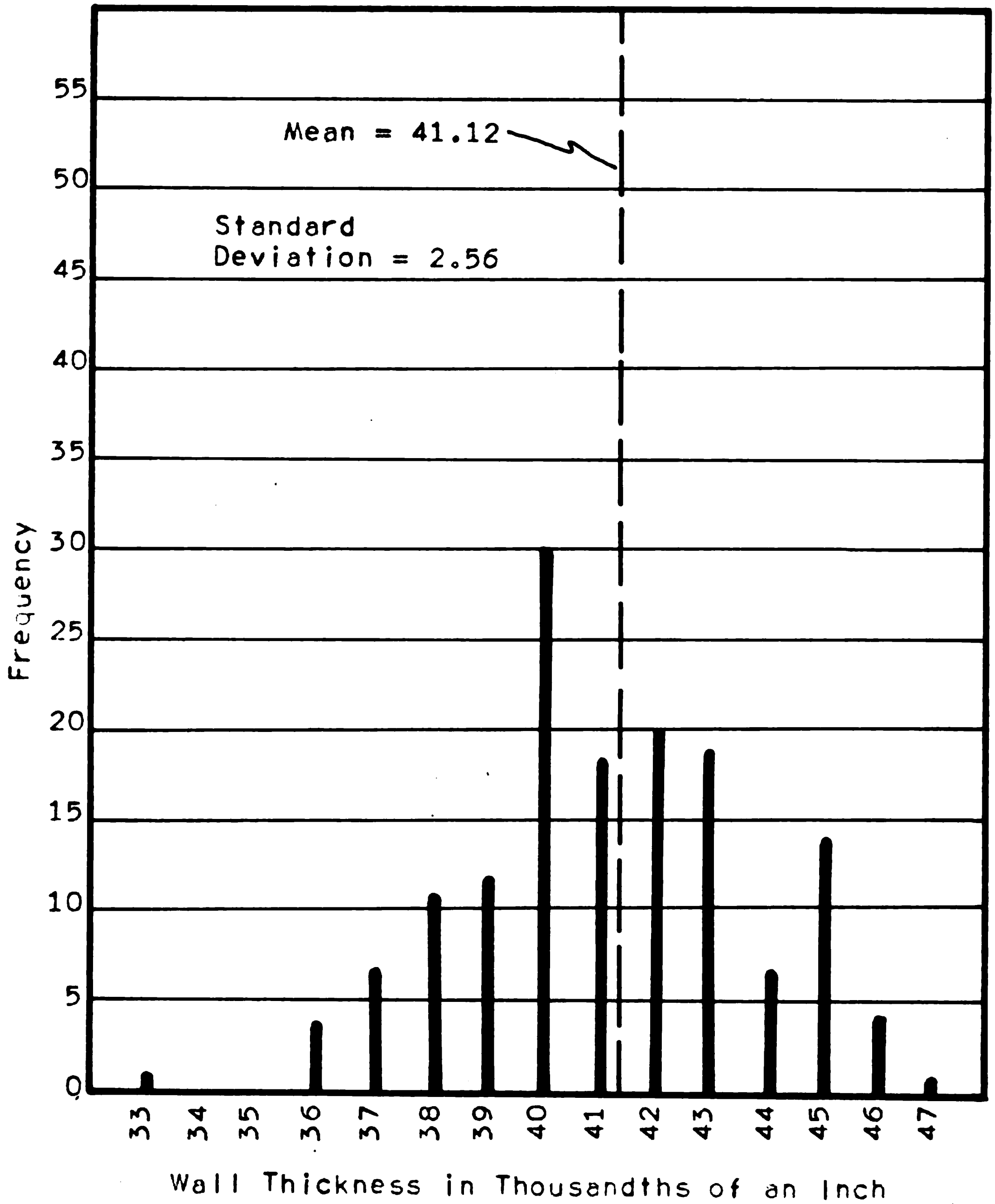

Wall Thickness Position "A" Lubricant "J"
Histogram



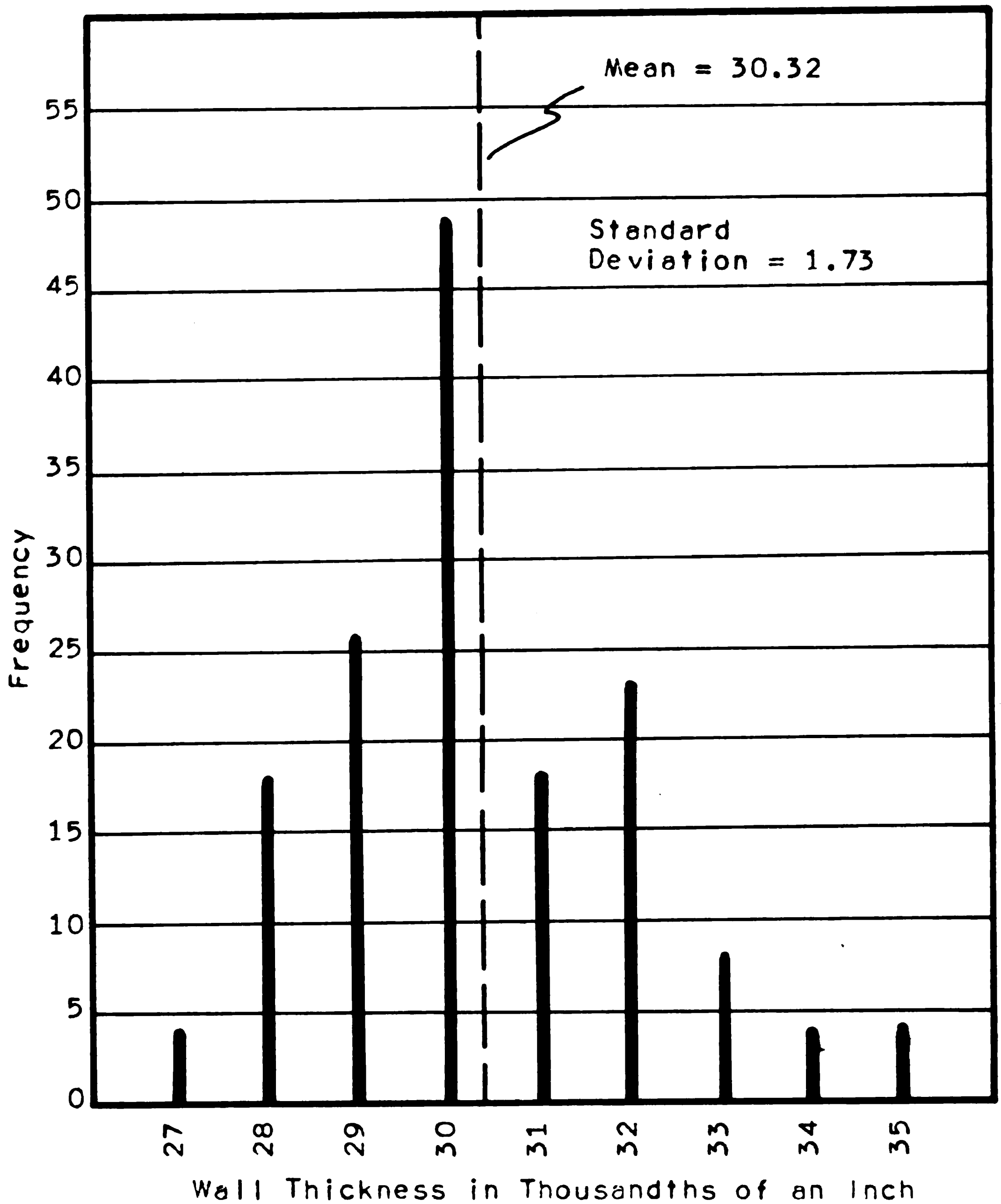

Wall Thickness Position "A" Lubricant "K"
Histogram



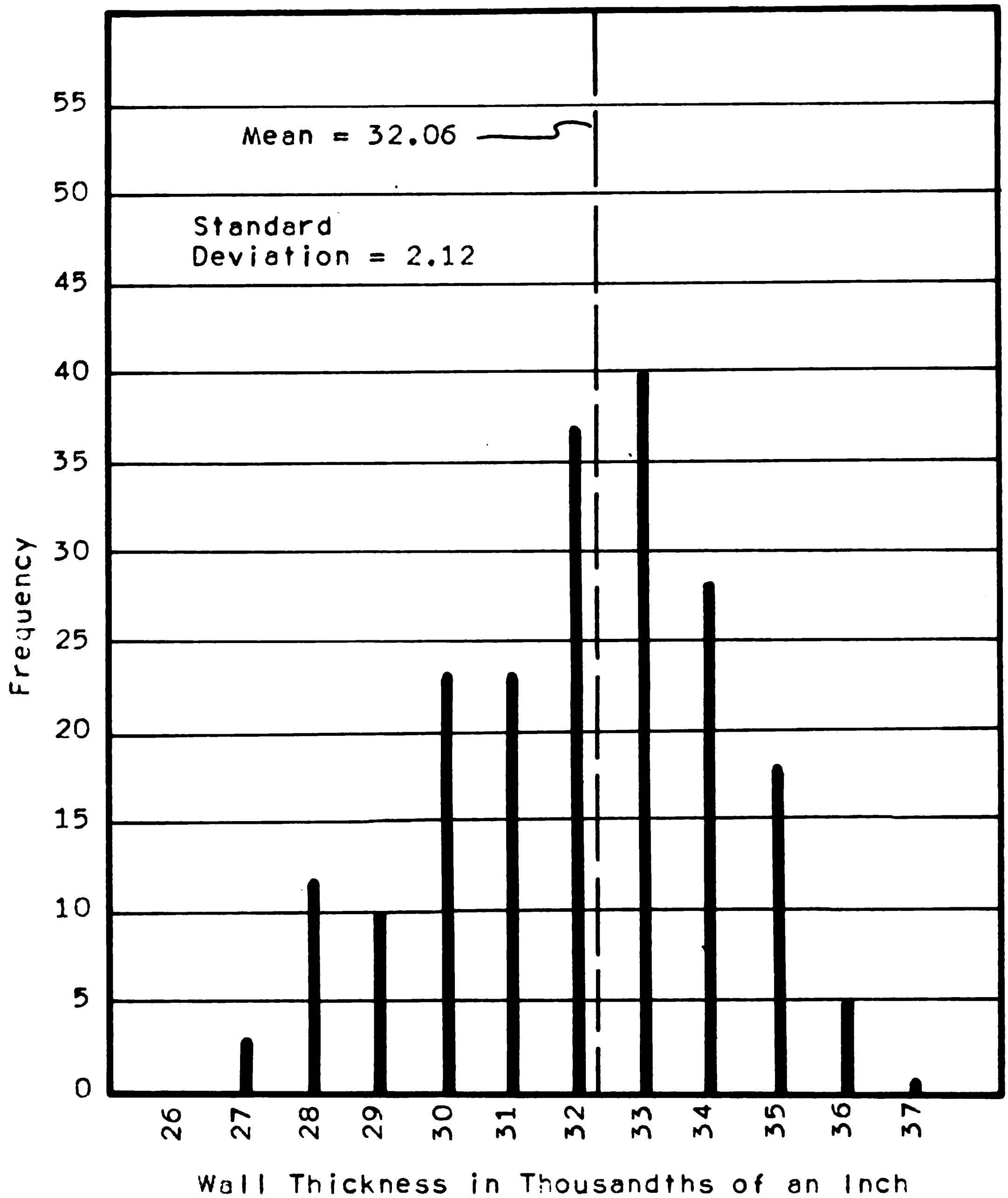

Wall Thickness Position "A" Lubricant "L"
Histogram



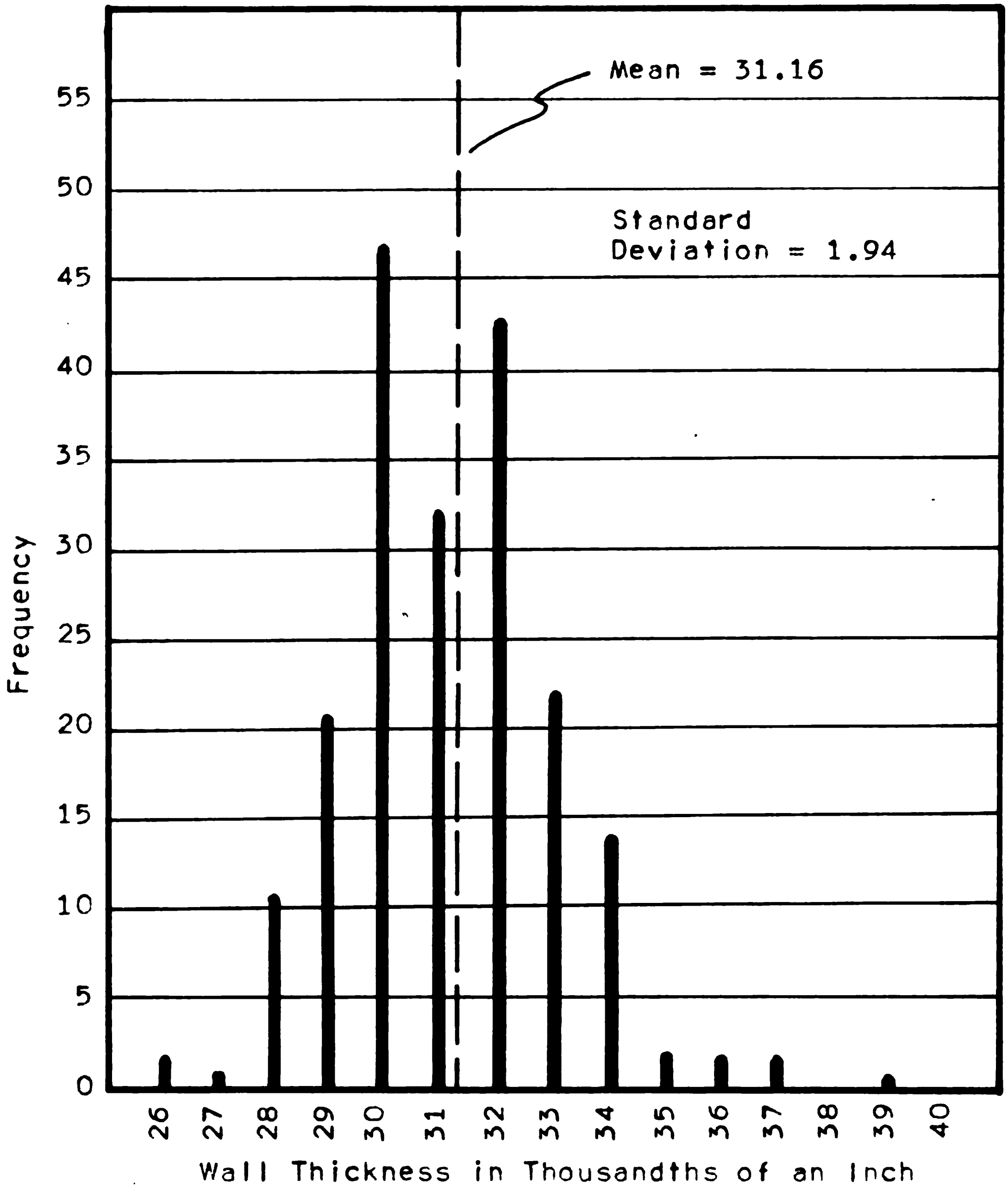

Wall Thickness Position "A" Lubricant "M"
Histogram



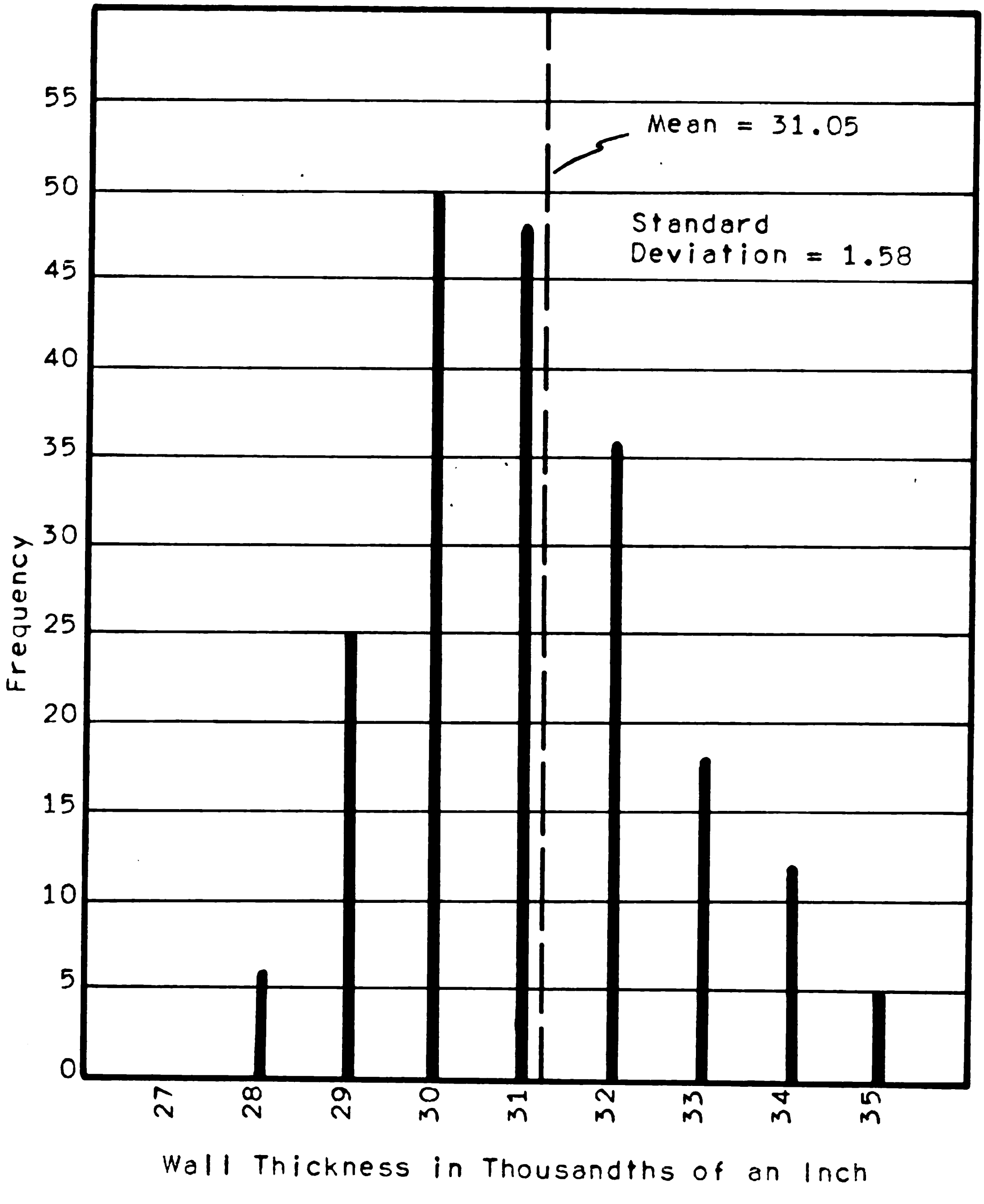

Wall Thickness Position "B" Lubricant "B"
Histogram



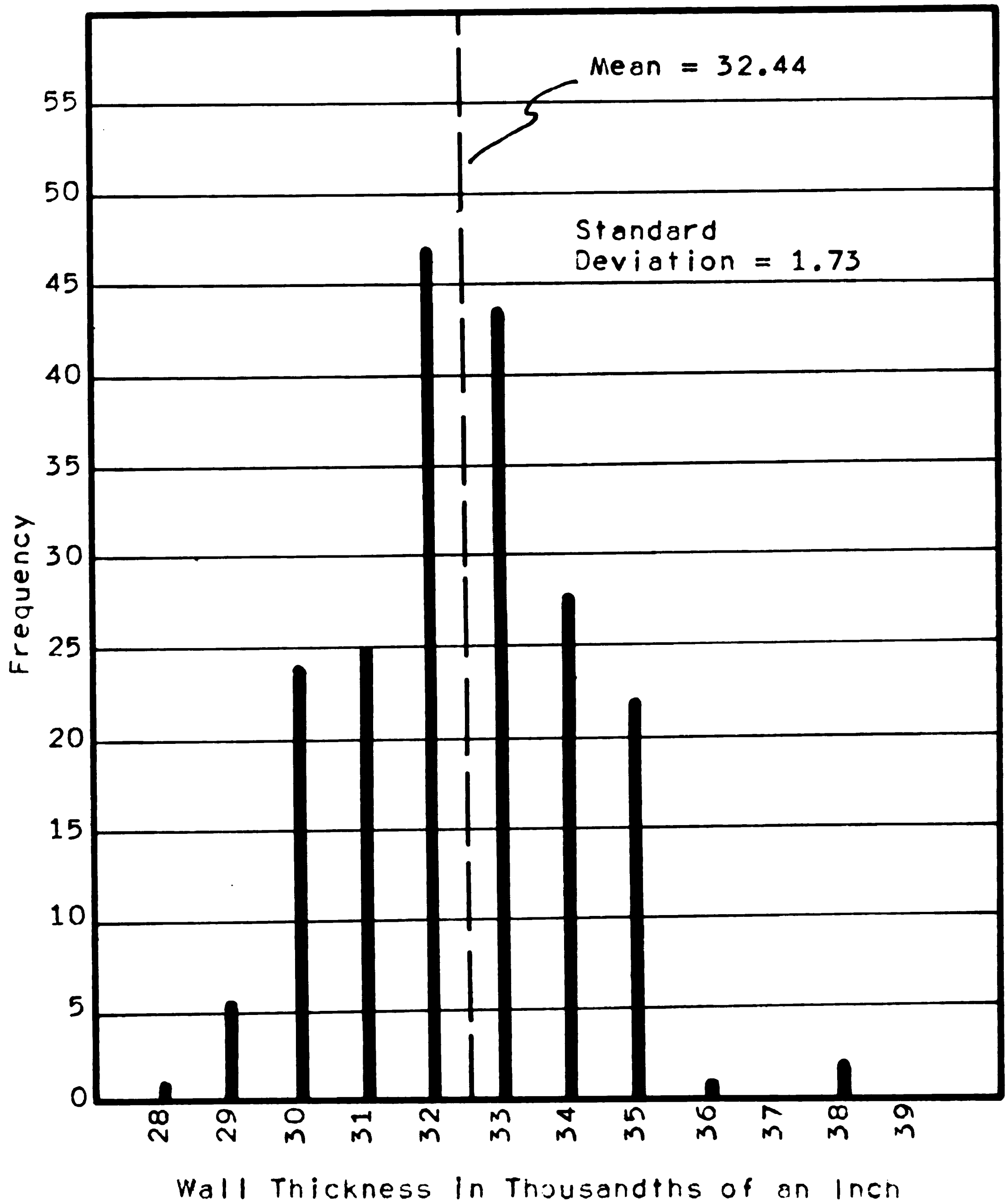

Wall Thickness Position "B" Lubricant "C"
Histogram



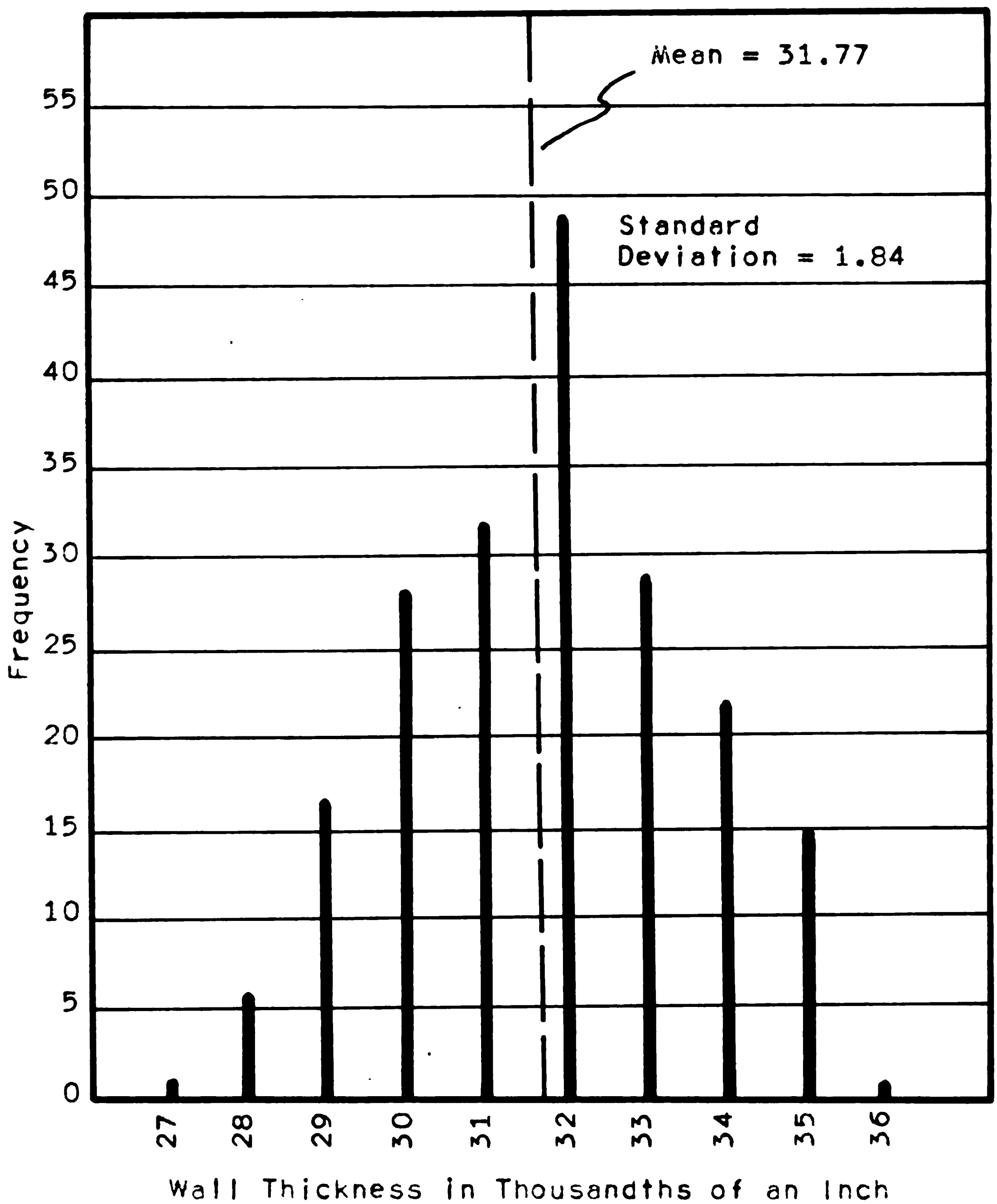

Wall Thickness Position "B" Lubricant "D"
Histogram



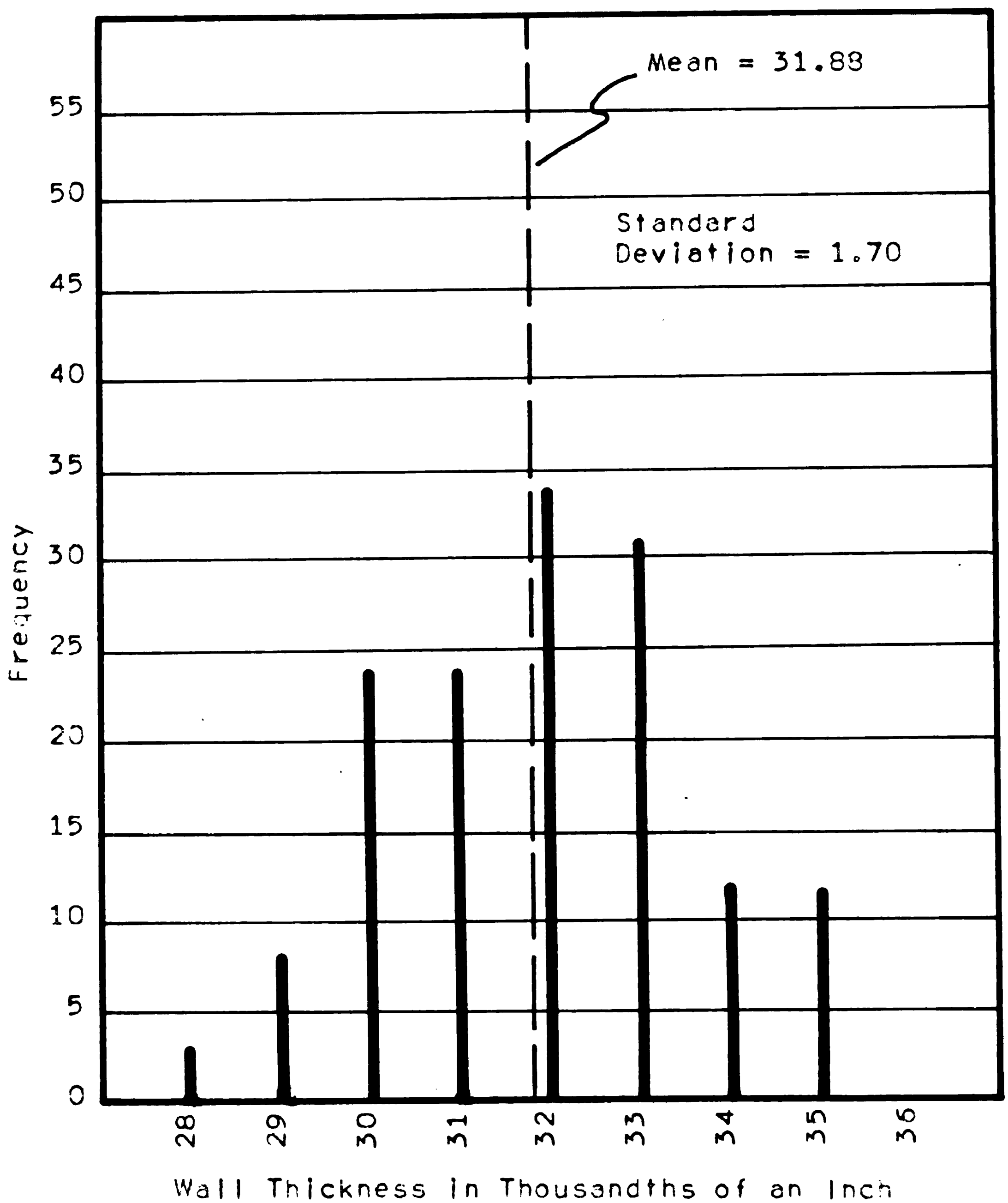

Wall Thickness Position "B" Lubricant "J"
Histogram




Wall Thickness Position "B" Lubricant "K"
Histogram




Wall Thickness Position "B" Lubricant "L"
Histogram




Wall Thickness Position "B" Lubricant "M"
Histogram

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**Date Due**

ROOM USE ONLY

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