PB-235 272

# HELIX PRESSURE GAUGE TO INDICATE ROOF BOLT LOADS

Virginia Polytechnic Institute and State University

Prepared for:

Bureau of Mines

24 September 1973

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National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

| BIBLIOGRAPHIC DATA SHEET | 1. Report No. BuMines OFR 40-74 | 2. | PB 235 272 |
|---|---|---|---|

| | |
|---|---|
| 4. Title and Subtitle<br>Helix Pressure Gauge to Indicate Roof Bolt Loads | 5. Report Date<br>September 24, 1973 |
| | 6. Performing Organization Code |
| 7. Author(s)<br>Virginia Polytechnic Institute and State University | 8. Performing Organization Rept. No. |
| 9. Performing Organization Name and Address<br>Virginia Polytechnic Institute and State University<br>Division of Minerals Engineering<br>Blacksburg, VA 24061 | 10. Project/Task/Work Unit No. |
| | 11. Contract/[redacted] No.<br>H0111556 |
| 12. Sponsoring Agency Name and Address<br>Office of Assistant Director--Mining<br>Bureau of Mines<br>U.S. Department of the Interior<br>Washington, DC 20240 | 13. Type of Report & Period Covered University research, May 1972-Sep 1973 |
| | 14. Sponsoring Agency Code |

15. Supplementary Notes

Approved for release by Director, Bureau of Mines, August 22, 1974.

16. Abstracts

This report presents the results of a study to design, construct, and test a low-cost pressure gage to be used to monitor the change in load on individual roof bolts. The purpose of the gage is to offer a convenient means of estimating the stability of potential roof fall areas on the premise that the load on individual roof bolts changes prior to failure. The report describes the theory of operation of the gage, the construction methods used to fabricate the gage, and the results of field tests of the gage, which indicate that the gage is reliable and can be used to determine the changing load conditions on roof bolts. The report will be of interest to mine operators who wish to use a low-cost method of monitoring the load on roof bolts in suspect areas of their workings.

17. Key Words and Document Analysis. 17a. Descriptors

Mining
- Roof bolt tensions
- Helix pressure gage

Roof bolting
- Use of pressure gage

17b. Identifiers/Open-Ended Terms



17c. COSATI Field/Group 08I

| 18. Distribution Statement | 19. Security Class (This Report) | 21. No. of Pages |
|---|---|---|
| Release unlimited by NTIS. | UNCLASSIFIED | 64 |
| | 20. Security Class (This Page) UNCLASSIFIED | 22. Price $6.25 |

FORM NTIS-35 (10-70) USCOMM-DC 40329-P71

# HELIX PRESSURE GAUGE TO INDICATE ROOF BOLT LOADS

Bureau of Mines Open File Report 40-74

This report was prepared by the Virginia Polytechnic Institute and State University, Blacksburg, Virginia, under U. S. Bureau of Mines' Contract No. H0111556. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of the Denver Mining Research Center with Mr. Harry R. Nicholls acting as technical project officer. Mr. George Honold was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period of May 1971 to September 1973. This report was submitted by the author on September 24, 1973.

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ABSTRACT

A Helix Pressure Gauge to indicate roof bolt loads was designed, fabricated and field tested. The gauge indicated loads between 3,000 and 15,000 pounds with a ± ten per cent error. The cost of fabrication of the gauge was estimated to be $3.39 including an assumed overhead and profit per indicator for a series production of 5,000 units. The unit can be read on a bolt to within ± 1,000 pounds load from a distance of twenty feet.

# FINAL REPORT

## HELIX PRESSURE GAUGE TO INDICATE ROOF BOLT LOADS

### INTRODUCTION.

The objective of this research project was to develop and fabricate a low-cost gauge to indicate loads for mine roof bolts. Laboratory and field testing were required to validate the design of the gauge. It is the purpose of this final report to summarize the work done, to give a detailed report on the final design and to submit an economic study of the cost to produce the gauge.

### REVIEW OF WORK.

The Helix Pressure Gauge was developed to achieve visual indication of roof bolt tensions in mines. The gauge provides an easy, safe reading of bolt tensions in mines where a potentially dangerous situation might exist. The usefulness of the Helix Pressure Gauge comes to importance in mines in bringing attention to severe roof problem areas.

The gauge consists principally of a Bourdon tube attached to a pressure pad. The pressure pad and tube are mounted between a standard plate and bolt head and torqued to the correct required tension. When the tension on a roof bolt has the correct torque the Bourdon tube shows this tension on the roof bolt indicator. As the tension on the bolt is reduced, due to the reduced efficiency of the anchor over a period of time, the tube provides a visual indication of the residual bolt tension.

The original design concept for the gauge was to use tubing as a pressure cell and form a Bourdon tube from the same tubing. A patent search was done to determine if other investigators had any suggestions on the use of hydraulic pressure to indicate roof bolt loads. No applicable patents were found.

The search showed, without exception, that the previous work was directed at deforming either steel or rubber. These materials gave either a gross indication of loads or a measurable quantification within the elastic limit of the material. The limitation of this approach is the variability of the material itself under deformation. This gave rise to variable results.

A literature survey did not disclose any recent publications on Bourdon tube design but a very recent internal publication of the Handy and Harman Tube Company, Inc., Norristown, Pennsylvania discussed design parameters for Bourdon tube selections. Tip travel is the movement in inches at the tip of the Bourdon tube. The publication recommends the following empirically developed relationship:

$$\text{Tip Travel} = K \frac{p R^2 L \Theta}{S t^3 E}$$

Where K is a constant
p is the applied pressure or vacuum
$\Theta$ is the free angular length of the spring
R is the radius of curvature of the free spring
L is the outside diameter (OD) of the long axis
S is the outside diameter (OD) of the short axis
t is the wall thickness of the tube
E is the modulus of the elasticity of the tube material.

The recommended ratio of the OD major axis to the minor axis is 3.7 to 4.3. The study unfortunately did not give enough design parameters for a prototype roof bolt indicator gauge. The report did suggest keeping the long and short axes outside dimensions constant while varying the wall thickness for prototype development.

Stainless steel tubing was initially chosen for development of the prototype roof bolt gauge because of its corrosion resistance and strength. A series of 316 stainless steel tubing sizes from 1/16 to 1/4 inch were used for early experimental work. The tubing was connected to a Simplex hydraulic pump with a pressure capability of 10,000 psig. Experiments with 1/8 inch tubing showed that at pressures up to 10,000 psig, no movement of the tube tip was observed for a four-inch radius. It was clear that the tubing would have to be flattened to the Bourdon tube configuration. A small hand operated rolling mill with four-inch rolls was designed to roll the tubing material to a tolerance of ± 0.001 inch in size. The tube tip travel of 0.25 inches was recorded at 500 psig with the flattened tubing. But when the pressure was increased to 1,000 psig work hardening of the edges of the tubing caused failure at the edges. This indicated that the Bourdon tube, or hereafter referred to as the Helix indicator coil, would have to be made longer and a configuration was developed to increase the coil length without increasing the overall length of the gauge.

Stainless steel, mild steel and aluminum tubing were investigated for use as a tubing material for the Helix coil. All of the materials could be made to work. The choice was made for aluminum because of the cost factor. During the early part of the investigation the cost for stainless steel tubing was 34 cents per foot, the steel tubing was 17 cents per foot and the aluminum tubing was 9 cents per foot. Combined with this price differential was a significant difference in the modulus of elasticity between steel at $29 \times 10^6$ psi and aluminum at $10 \times 10^6$ psi. It was also determined that the aluminum had advantages over mild steel in normal atmospheres in that it resisted corrosion better than the mild steel. This was determined by leaving coils of steel and aluminum outside for three months during the winter. The steel corroded heavily, while the aluminum surface did not visually show any corrosion. It should be noted that corrosion studies under ground were not conducted.

The aluminum finally chosen for the gauge was a 6061-T6 alloy with a tensile strength of 35,000 psi. The decreased modulus of elasticity of aluminum as against steel results in almost three times as much tip travel. This is shown in the equation for tip travel. This combined with a substantially lower cost for aluminum, clearly indicated that it was the preferred choice for the indicator coil.

Certain equipment was designed here at the Virginia Polytechnic Institute and State University to fabricate the gauge. Other equipment used was standard machine shop equipment. The following equipment was fabricated:

1) a small hand operated rolling mill to flatten the tubing
2) a pad die to crimp the pads from stainless steel
3) a jig to position holes for drilling
4) clips to hold the pad in seat for silver solder sealing
5) a die to bend the top plate to a proper angle

The original design concept for the gauge was to use the tubing as a pressure cell and form the Bourdon tube from the same tubing. It was found that to achieve an adequate tip travel a substantial quantity of fluid was required to expand the Bourdon tube. The tubing used for the pressure cell did not have the requisite spring-back characteristics and became permanently deformed. Therefore, methods were sought to fabricate a cell from plastic. This did not work due to the low tensile strength of the tubing. Under a long term load the walls failed. This, coupled with difficulties in sealing the ends of the tubing, caused the abandonment of this approach.

Subsequently, a cell was designed using stainless steel and a low temperature silver solder for sealing. Static tests of this design indicated with no Helix coil attached that it was possible to obtain 4,000 psi. A load of 2,000 psi was then used for design. This was subsequentially reduced to approximately 1,000 psi in the final design.

It was recognized that the bolt load was too large to be transmitted directly to the pad. The pad size with a full load of 20,000 pounds and a 1,000 psi design limit would require a design upper limit of 20 square inches, or a pad of approximately eight inches in diameter. Clearly, this would be too large and would increase the cost of the gauge significantly. Therefore, a lever was used to reduce the pressure on the pad to approximately 3,000 pounds.

The first method investigated was to use a bar in the lever assembly. This method was abandoned because of the difficulty of holding the bar stock in place. A modified design was tried using the bar concept but gave trouble in that the bolt heads on the roof bolts tended to bend at the bolt head and therefore this design was abandoned. See Figure 1. The material itself was then bent to form a part of the lever and a knife edge was used for one of the other edges of the lever. This gave good results and was incorporated into the final design.

Alignment of the gauge is non-critical due to the clearances on the bolt holes. The lever is placed on the rear edge of the top plate so as to clear the holes. This is done by visual alignment. The lever is then clamped and welded.

The final design was the result of over 300 manufactured prototype gauges. It was found during the investigation that series runs on a particular design were required to obtain information on manufacturing difficulties as well as to obtain enough data on variations between gauges.

Sealing the tip of the tubing. When stainless steel tubing was first investigated it was found that sealing the tip with silver solder by the use of a reducing flame with an acetylene torch gave acceptable results. Brazing the tip of standard steel tubing also worked. In both cases it was an extremely time-consuming operation requiring skill to assure that the tip would not leak. This led to the investigation of the possibility of soldering the ends of the tips with a low-temperature stainless steel solder which melts at 435° Fahrenheit. It was found that after many attempts the internal pressure in the tubing caused the tubing to comeapart, even though the material inside the tubing had been sufficiently wetted. A cold welder was also tried. This device seals the ends of tubing by pinching it shut. It did not work at all. The same phenomenon occurred with this method. The internal pressure blew the tube open.

It was then found that the tip of the tubing could be sealed by putting a moderately soft gasket material in the tip before the rolling operation. The material was then rolled down and a crimping operation in a vice was used to seal the end of the tubing. Very little leaking was experienced if the gasket material filled the tubing to at least 3/4 to one inch from the end of the tubing. The internal pressure in the tubing blows the rubber into the end of the tubing. The pressure thus works to seal the tip.

Final design. The final design of the unit is shown in the attached plates and in Figures 1, 2, 3 and 4.

The pad could have been constructed so as to duplicate presently available pads, but this would have meant a relatively large diameter pad in keeping with the 1,000 psi design limitation. Therefore, a lever was used to reduce the

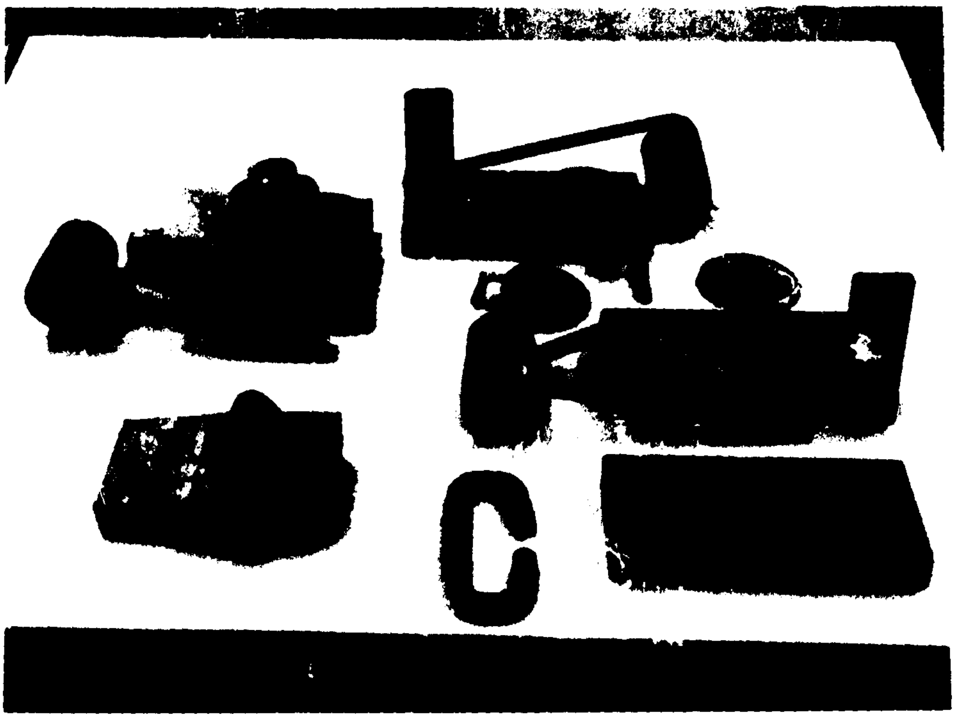



Figure 1. Helix Gauge showing bar and lever concept.

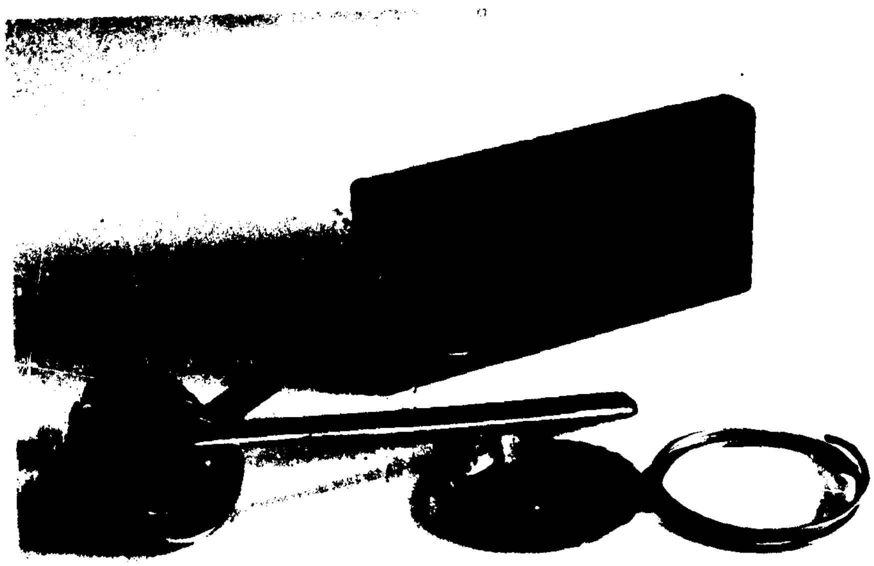


Figure 2. Helix Gauge indicator coil, bottom plate, pad and rings of solder before assembly.

Figure 3. Helix Gauge showing placement of indicator coil, platen and indicator scale before assembly with top plate.

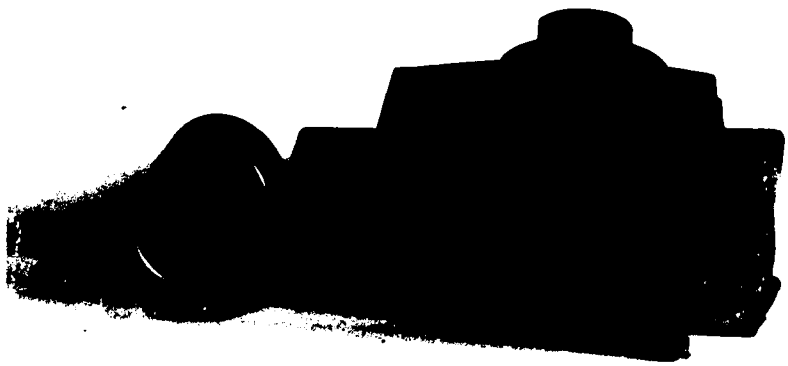


Figure 4. Front view of assembled Helix Gauge.

Figure 5. Rear view of assembled Helix Gauge showing back clip.

pressure on the pad to an acceptable value. Inherent within the design is the need for amplification of coil movement. This amplification is given by the lever on the coil itself. Examination of the coil will show that a small movement of the coil will result in a significantly larger movement of the tip of the coil.

It should be noted that in the final design that the coil tip has no load to carry. Therefore, it should not show any loading problems with the light gauge material that was used. The total gauge could be made smaller if the pressure on the pad could be increased.

No difficulty was experienced with the rupture of the stainless steel pad material itself, but difficulty was experienced with the sealing material which was a low-temperature silver solder. The design for the gauge is seen in plates 1, 2, 3, 4, 5, 6, 7, 8 and 9 in Appendix A.

A manual for the fabrication and assembly of the gauge is also presented in Appendix A.

## RESULTS

Laboratory. On June 20, 1973, random tests were conducted on the Helix Gauge to determine deflection versus load. The following tests show the range of tip deflection versus load in inches. The tests were done on a Baldwin-Tate Emery Testing Machine manufactured by the Baldwin Hamilton Corporation of Philadelphia, Pennsylvania. It was found that off-center loading gave improper readings and it was noted that it was important that the bolt head be flat for accurate readings. For this reason, a hardened steel washer and a soft steel washer were included within the final design so as to distribute the load over the lever arm accurately.

In testing it was found that the bolt head under the 15,000 to 20,000 pound loading tended to bend at the edges of the bolt head. Therefore, a soft steel washer was placed over the hardened steel washer which then worked against the lever arm.

Deflection versus load on the first bolt indicates good results in terms of cycling. This first test shows that replication of the test gave acceptable and accurate results. In rechecking the gauge the bolt cycled well in a pressure test down and in terms of loading the bolt up from 0.00 to 15,000 pounds. Difficulty was experienced in duplicating results during the process of developing the design. This was corrected in the final design, as can be seen by the results shown in Table 1, Table 2 and in Figures 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15. Examination of the data from Table 2 shows that the largest deviation from the testing machine was 1,000 pounds. Given a range of 12,000 pounds this was seen by inspection to fall within the limits of ± 10 per cent for the design. The data shown in Table 1 and Figures 6, 7, 8, 9, and 10 indicate that the hysteresis of the gauge is

Table 1

Deflection Versus Load

(Random Selection)

| Bolt Gauge | Inches * | | Pounds/Pressure ** |
|---|---|---|---|
| 1 | 2.10 | | 15,400 |
| | 1.60 | | 13,000 |
| | 1.40 | | 11,000 |
| | 1.15 | (Down) | 9,000 |
| | 0.80 | | 7,000 |
| | 0.45 | | 5,000 |
| | 0.00 | | 2,600 |
| | The gauge was removed and replaced to check for accuracy | | |
| | 2.10 | | 15,000 |
| | 1.70 | | 13,000 |
| | 1.45 | | 11,000 |
| | 1.15 | (Down) | 9,000 |
| | 0.85 | | 7,000 |
| | 0.45 | | 5,000 |
| | 0.00 | | 2,800 |
| | 0.00 | | 2,500 |
| | 0.45 | | 5,000 |
| | 0.80 | | 7,000 |
| | 1.10 | (Up) | 9,000 |
| | 1.45 | | 11,000 |
| | 1.80 | | 13,000 |
| | 2.10 | | 15,000 |

* As measured with a caliper.

** Tests were performed on a Baldwin-Tate Emery Testing Machine.

Table 1

Deflection Versus Load

(Random Selection)

| Bolt Gauge | Inches * | | Pounds/Pressure ** |
|---|---|---|---|
| | 2.00 | | 14,400 |
| 2 | 1.85 | | 13,000 |
| | 1.60 | | 11,000 |
| | 1.25 | (Down) | 9,000 |
| | 0.95 | | 7,000 |
| | 0.60 | | 5,000 |
| | 0.00 | | 2,400 |
| | 0.00 | | 2,200 |
| | 0.60 | | 5,000 |
| | 0.90 | | 7,000 |
| | 1.20 | (Up) | 9,000 |
| | 1.55 | | 11,000 |
| | 1.80 | | 13,000 |
| | 2.00 | | 14,400 |

* As measured with a caliper.

** Tests were performed on a Baldwin-Tate Emery Testing Machine.

Table 1

Deflection Versus Load

(Random Selection)

| Bolt Gauge | Inches* | | Pounds/Pressure** |
|---|---|---|---|
| 3 | 2.10 | (Down) | 14,500 |
| | 1.90 | | 13,000 |
| | 1.55 | | 11,000 |
| | 1.25 | | 9,000 |
| | 0.85 | | 7,000 |
| | 0.50 | | 5,000 |
| | 0.00 | | 2,600 |
| | 0.00 | (Up) | 2,600 |
| | 0.45 | | 5,000 |
| | 0.80 | | 7,000 |
| | 1.15 | | 9,000 |
| | 1.50 | | 11,000 |
| | 1.80 | | 13,000 |
| | 2.10 | | 14,900 |

* As measured with a caliper.

** Tests were performed on a Baldwin-Tate Emery Testing Machine

Table 1

Deflection Versus Load

(Random Selection)

| Bolt Gauge | Inches* | | Pounds/Pressure** |
|---|---|---|---|
| | 2.00 | | 15,700 |
| 4 | 1.60 | | 13,000 |
| | 1.25 | | 11,000 |
| | 1.00 | (Down) | 9,000 |
| | 0.65 | | 7,000 |
| | 0.40 | | 5,000 |
| | 0.00 | | 3,200 |
| | 0.00 | | 3,200 |
| | 0.40 | | 5,000 |
| | 0.70 | | 7,000 |
| | 1.00 | | 9,000 |
| | 1.30 | (Up) | 11,000 |
| | 1.60 | | 13,000 |
| | 2.00 | | 15,600 |

* As measured with a caliper.

** Tests were performed on a Baldwin-Tate Emery Testing Machine.

Table 1

Deflection Versus Load

(Random Selection)

| Bolt Gauge | Indicator* | | Pounds/Pressure** |
|---|---|---|---|
| | 2.00 | | 15,500 |
| 5 | 1.55 | | 13,000 |
| | 1.20 | (Down) | 11,000 |
| | 0.85 | | 9,000 |
| | 0.45 | | 7,000 |
| | 0.00 | | 4,500 |
| | 0.00 | | 4,700 |
| | 0.50 | | 7,000 |
| | 0.90 | (Up) | 9,000 |
| | 1.25 | | 11,000 |
| | 1.55 | | 13,000 |
| | 2.00 | | 15,500 |

* As measured with a caliper.

** Tests were performed on a Baldwin-Tate Emery Testing Machine.

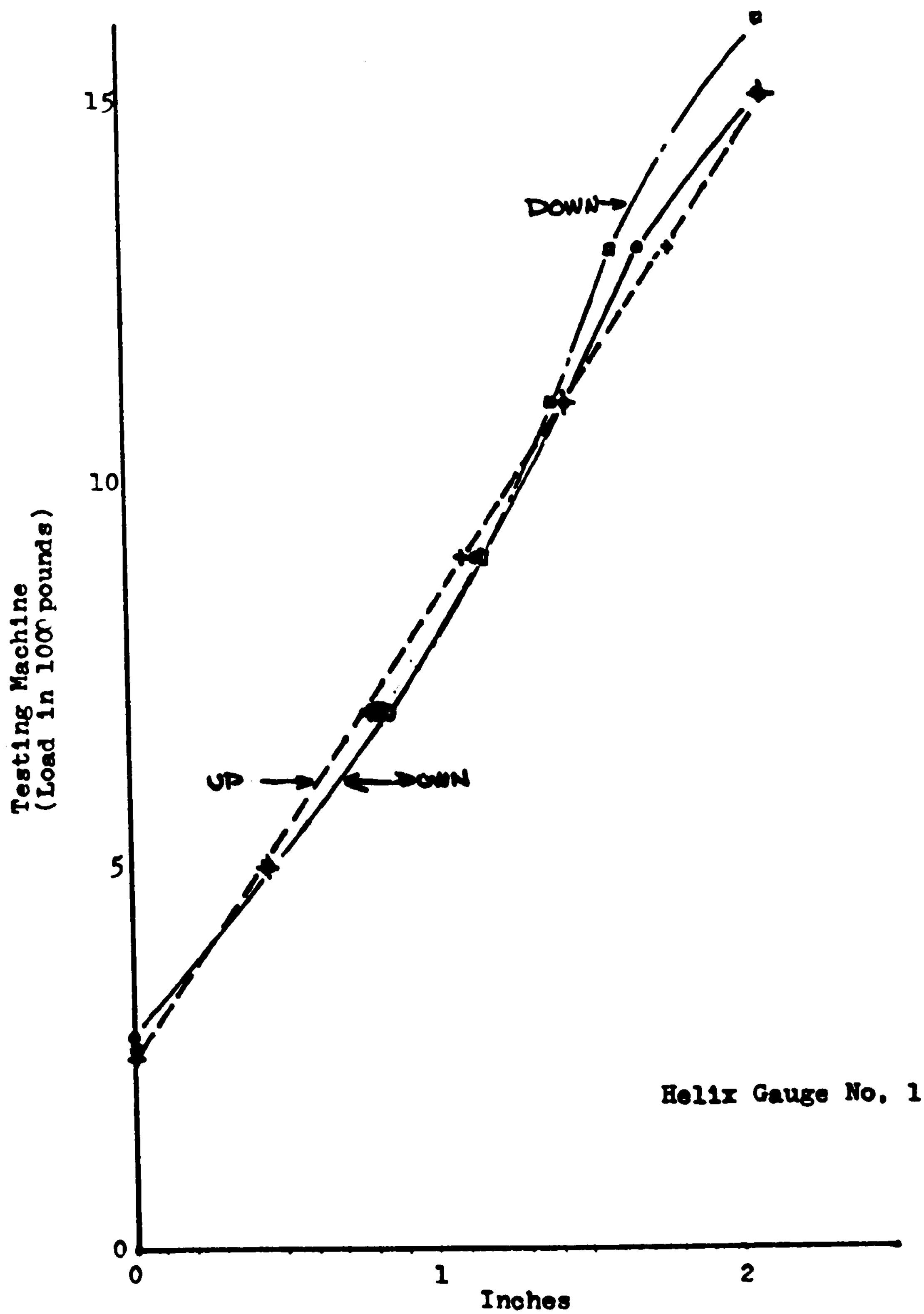



Figure 6. Tip indicator deflection.

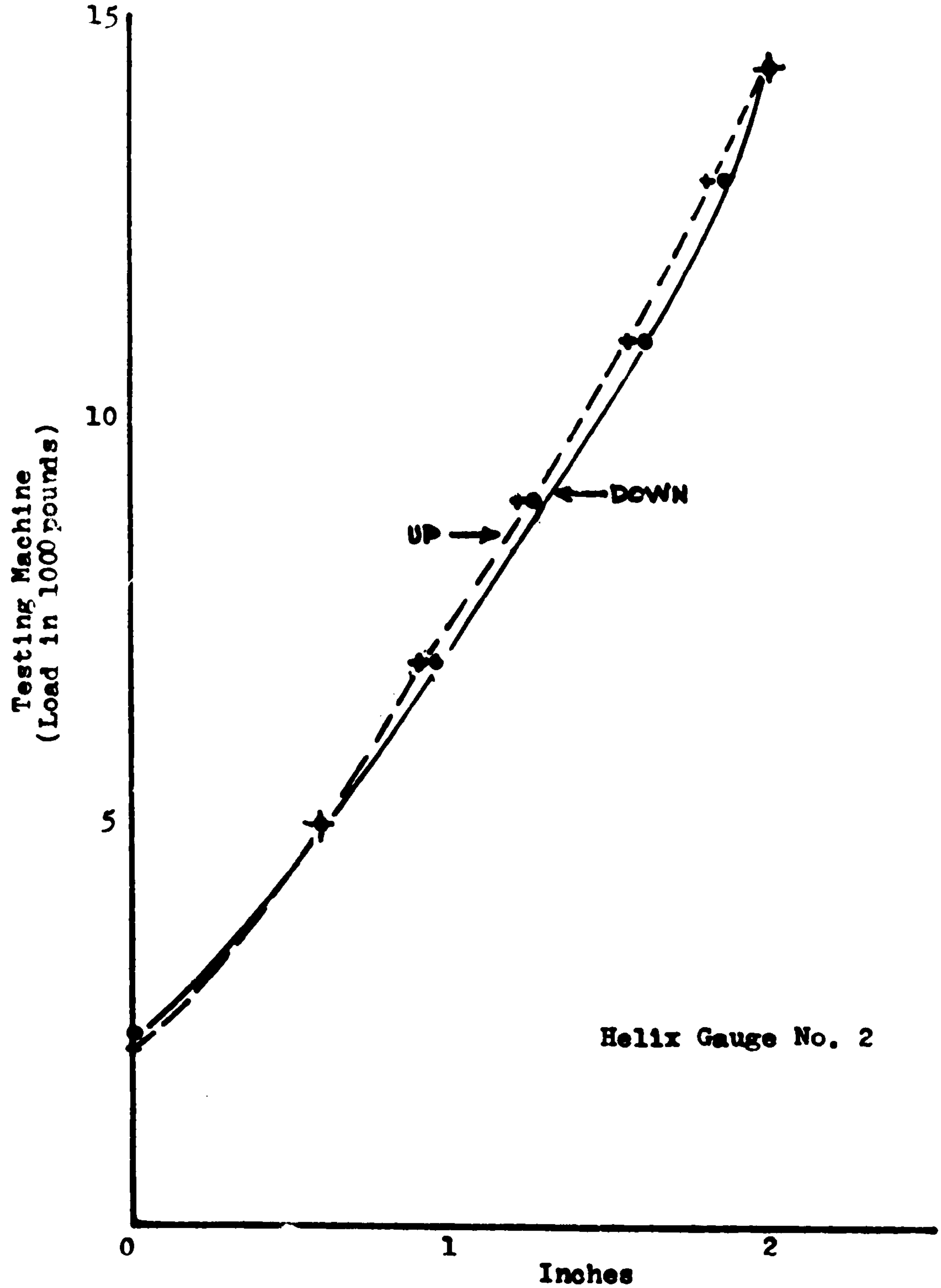



Figure 7. Tip indicator deflection.

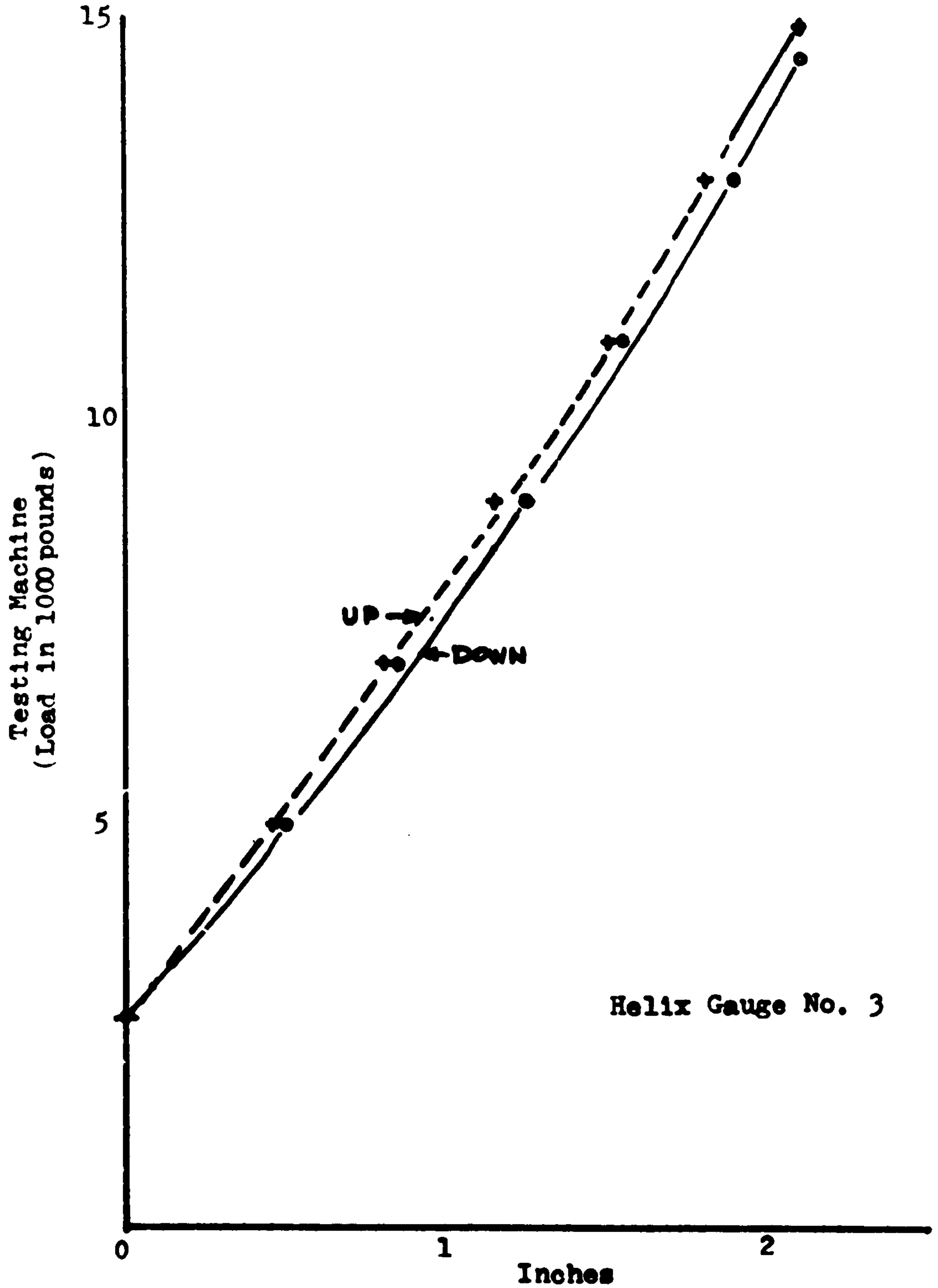



Figure 8. Tip indicator deflection.

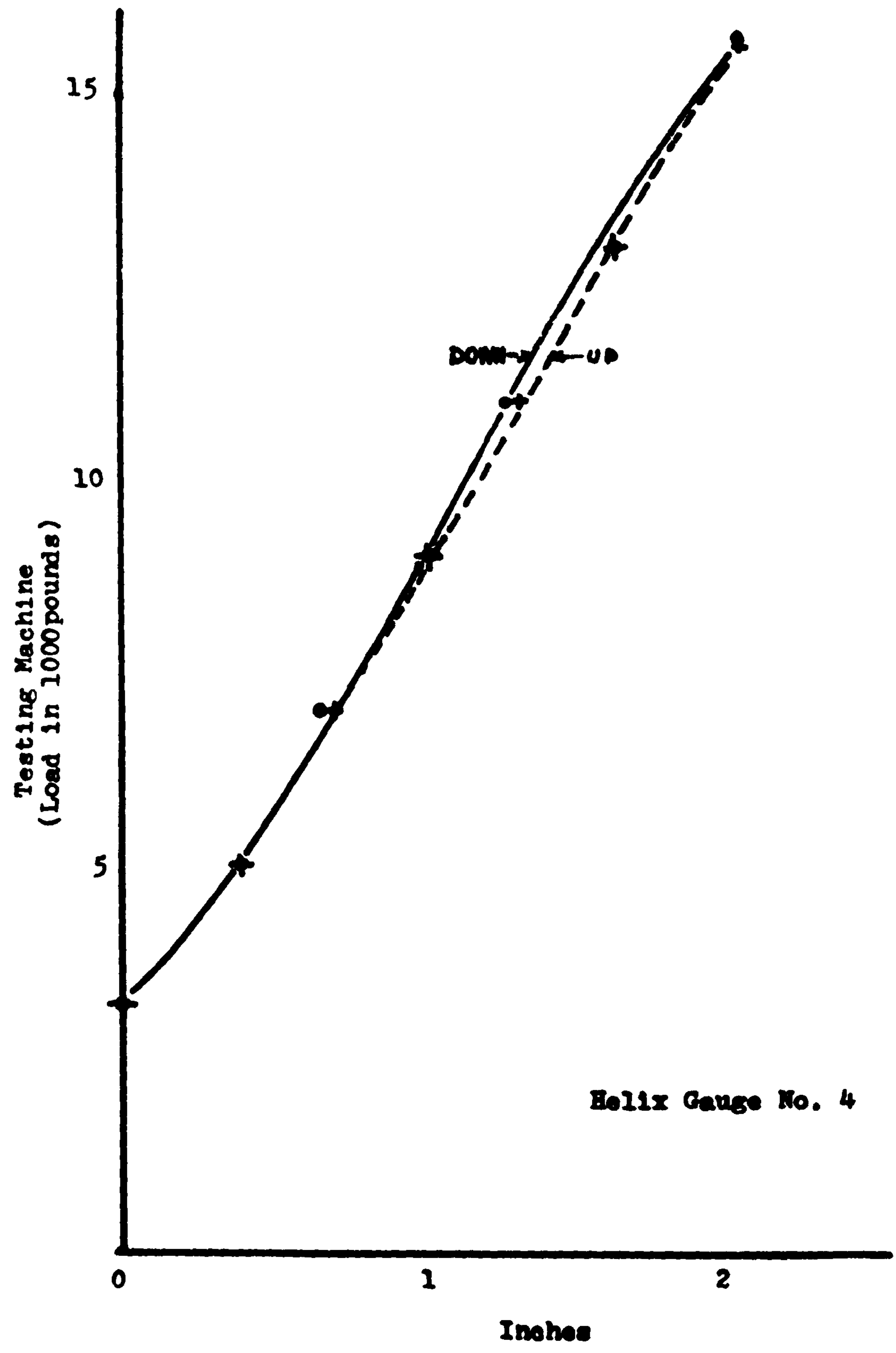



Figure 9. Tip indicator deflection.

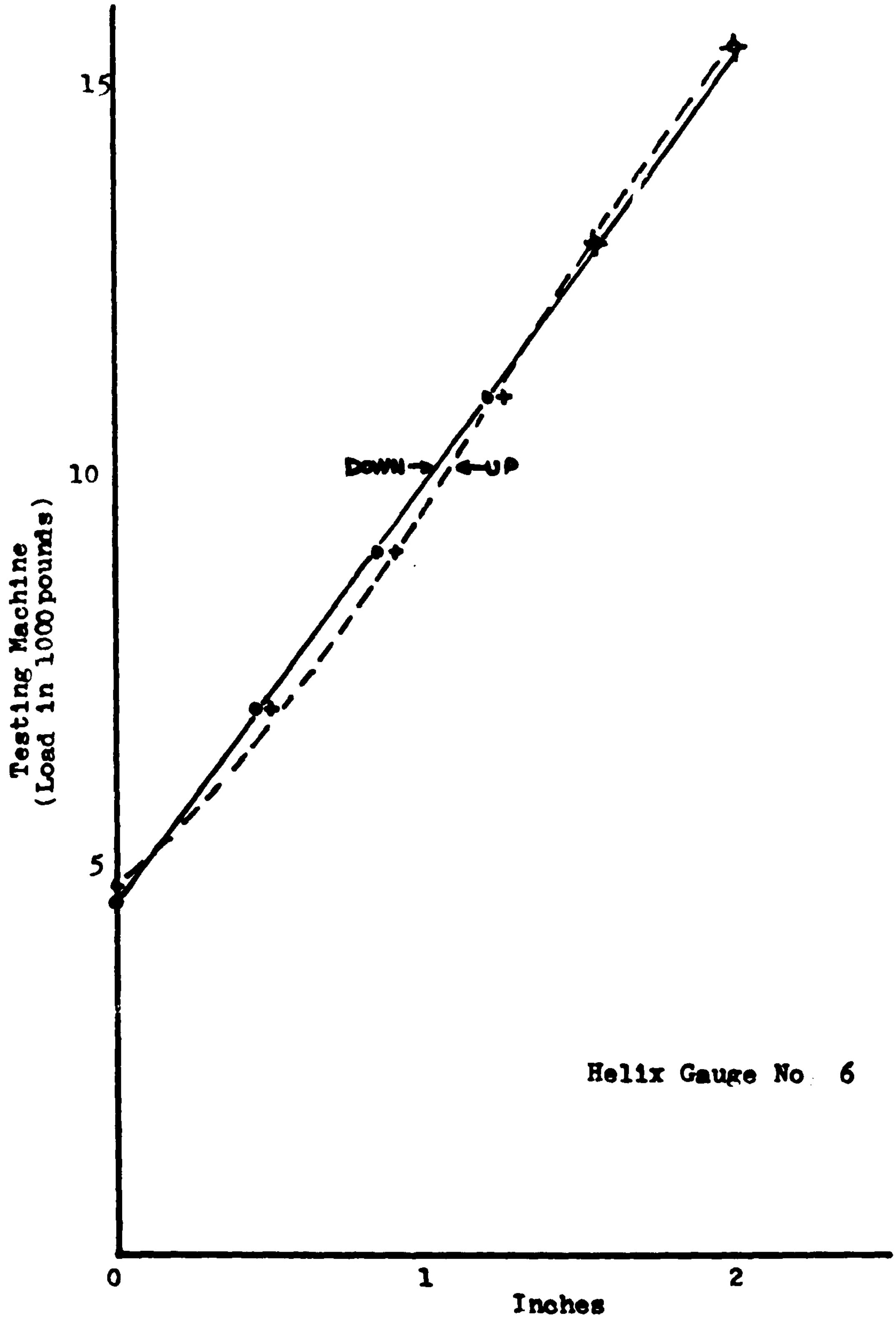



Figure 10. Tip indicator deflection.

Table 2

Helix Gauge Calibrations
Against
Testing Machine

| Bolt Gauge | Tip Indicator * | | Testing Machine ** |
|---|---|---|---|
| 1 | 15,000 | | 15,000 |
| | 14,000 | | 14,000 |
| | 13,000 | | 12,800 |
| | 12,000 | | 11,700 |
| | 11,000 | | 10,500 |
| | 10,000 | | 9,800 |
| | 9,000 | (Down) | 8,700 |
| | 8,000 | | 7,800 |
| | 7,000 | | 6,700 |
| | 6,000 | | 5,900 |
| | 5,000 | | 5,000 |
| | 4,000 | | 4,000 |
| | 3,000 | | 3,400 |
| | 3,000 | | 3,200 |
| | 4,000 | | 3,900 |
| | 5,000 | | 4,800 |
| | 6,000 | | 5,700 |
| | 7,000 | | 6,500 |
| | 8,000 | | 7,600 |
| | 9,000 | (Up) | 8,700 |
| | 10,000 | | 9,700 |
| | 11,000 | | 10,900 |
| | 12,000 | | 11,800 |
| | 13,000 | | 13,000 |
| | 14,000 | | 14,000 |
| | 15,000 | | 15,500 |

* Indicated gauge reading.

** Tests were performed on a Baldwin-Tate Emery Testing Machine.

Table 2

Helix Gauge Calibrations
Against
Testing Machine

| Bolt Gauge | Tip Indicator* | | Testing Machine** |
|---|---|---|---|
| | 15,000 | | 14,400 |
| 2 | 14,000 | | 13,100 |
| | 13,000 | | 12,000 |
| | 12,000 | | 11,000 |
| | 11,000 | | 10,200 |
| | 10,000 | | 9,200 |
| | 9,000 | (Down) | 8,400 |
| | 8,000 | | 7,600 |
| | 7,000 | | 6,700 |
| | 6,000 | | 6,000 |
| | 5,000 | | 5,100 |
| | 4,000 | | 4,400 |
| | 3,000 | | 3,700 |
| | 3,000 | | 3,500 |
| | 4,000 | | 4,400 |
| | 5,000 | | 5,000 |
| | 6,000 | | 5,800 |
| | 7,000 | | 6,600 |
| | 8,000 | | 7,400 |
| | 9,000 | (Up) | 8,400 |
| | 10,000 | | 9,400 |
| | 11,000 | | 10,200 |
| | 12,000 | | 11,000 |
| | 13,000 | | 12,100 |
| | 14,000 | | 13,300 |
| | 15,000 | | 14,300 |

* Indicated gauge reading.

** Tests were performed on a Baldwin-Tate Emery Testing Machine.

Table 2

Helix Gauge Calibrations
Against
Testing Machine

| Bolt Gauge | Tip Indicator * | | Testing Machine ** |
|---|---|---|---|
| 3 | 15,000 | | 16,000 |
| | 14,000 | | 14,500 |
| | 13,000 | | 13,400 |
| | 12,000 | | 12,000 |
| | 11,000 | | 11,000 |
| | 10,000 | | 10,000 |
| | 9,000 | (Down) | 9,000 |
| | 8,000 | | 8,000 |
| | 7,000 | | 7,000 |
| | 6,000 | | 6,000 |
| | 5,000 | | 5,000 |
| | 4,000 | | 4,100 |
| | 3,000 | | 3,100 |
| | 3,000 | | 3,000 |
| | 4,000 | | 4,000 |
| | 5,000 | | 5,000 |
| | 6,000 | | 6,000 |
| | 7,000 | | 6,900 |
| | 8,000 | | 8,000 |
| | 9,000 | (Up) | 9,200 |
| | 10,000 | | 10,300 |
| | 11,000 | | 11,300 |
| | 12,000 | | 12,500 |
| | 13,000 | | 13,500 |
| | 14,000 | | 14,800 |
| | 15,000 | | 16,000 |

* Indicated gauge reading.

** Tests were performed on a Baldwin-Tate Emery Testing Machine.

Table 2

Helix Gauge Calibrations
Against
Testing Machine

| Bolt Gauge | Tip Indicator* | | Testing Machine** |
|---|---|---|---|
| 4 | 15,000 | | 15,700 |
| | 14,000 | | 14,400 |
| | 13,000 | | 13,000 |
| | 12,000 | | 11,800 |
| | 11,000 | | 10,700 |
| | 10,000 | | 9,800 |
| | 9,000 | (Down) | 8,700 |
| | 8,000 | | 7,800 |
| | 7,000 | | 6,800 |
| | 6,000 | | 5,800 |
| | 5,000 | | 5,000 |
| | 4,000 | | 4,100 |
| | 3,000 | | 3,200 |
| | 3,000 | | 3,400 |
| | 4,000 | | 4,300 |
| | 5,000 | | 5,200 |
| | 6,000 | | 6,000 |
| | 7,000 | | 7,000 |
| | 8,000 | | 8,000 |
| | 9,000 | (Up) | 9,400 |
| | 10,000 | | 10,200 |
| | 11,000 | | 10,900 |
| | 12,000 | | 12,300 |
| | 13,000 | | 13,300 |
| | 14,000 | | 14,700 |
| | 15,000 | | 15,900 |

* Indicated gauge reading.

** Tests were performed on a Baldwin-Tate Emery Testing Machine.

Table 2

Helix Gauge Calibrations
Against
Testing Machine

| Bolt Gauge | Tip Indicator * | | Testing Machine ** |
|---|---|---|---|
| 6 | 15,000 | | 15,400 |
| | 14,000 | | 14,000 |
| | 13,000 | | 13,100 |
| | 12,000 | | 12,000 |
| | 11,000 | | 10,900 |
| | 10,000 | | 9,900 |
| | 9,000 | (Down) | 8,800 |
| | 8,000 | | 7,800 |
| | 7,000 | | 6,900 |
| | 6,000 | | 5,800 |
| | 5,000 | | 5,000 |
| | 4,000 | | 4,000 |
| | 3,000 | | --- |
| | 3,000 | | --- |
| | 4,000 | | 4,600 |
| | 5,000 | | 5,800 |
| | 6,000 | | 6,800 |
| | 7,000 | | 7,800 |
| | 8,000 | | 8,700 |
| | 9,000 | (Up) | 10,000 |
| | 10,000 | | 11,000 |
| | 11,000 | | 12,000 |
| | 12,000 | | 13,200 |
| | 13,000 | | 14,200 |
| | 14,000 | | 15,000 |
| | 15,000 | | 15,800 |

* Indicated gauge reading.

** Tests were performed on a Baldwin-Tate Emery Testing Machine.

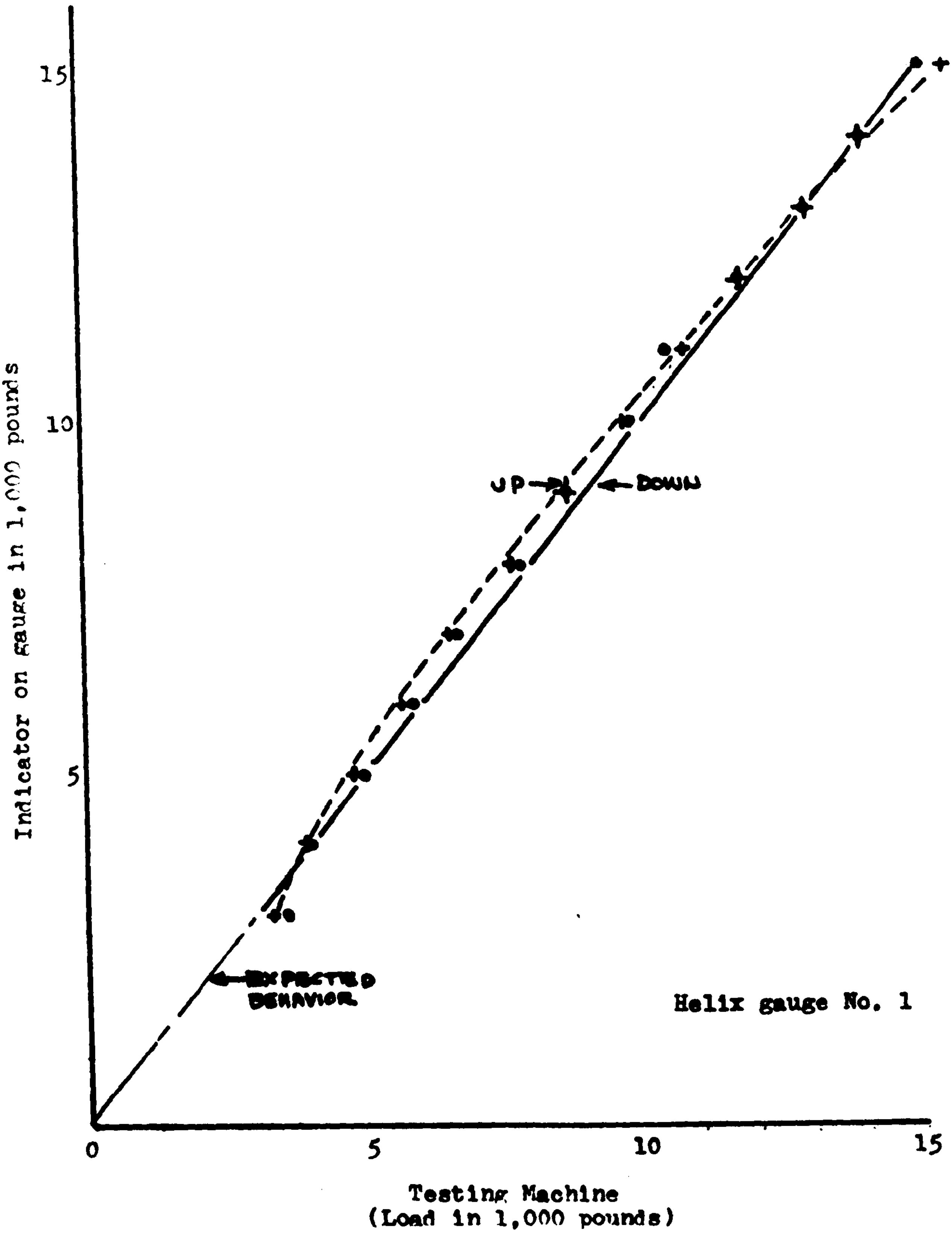



Figure 11. Load versus tip indicator.

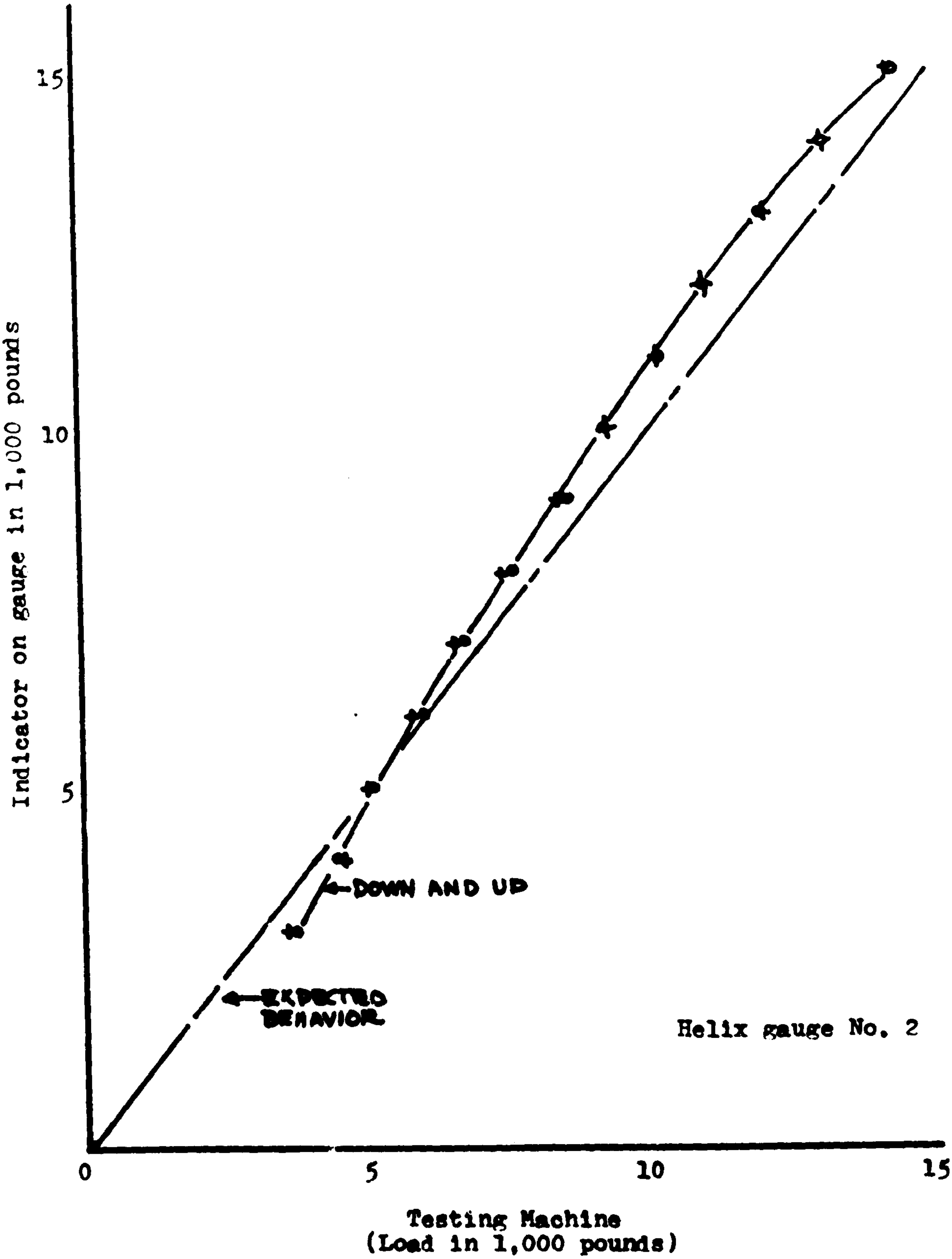



Figure 12. Load versus tip indicator.

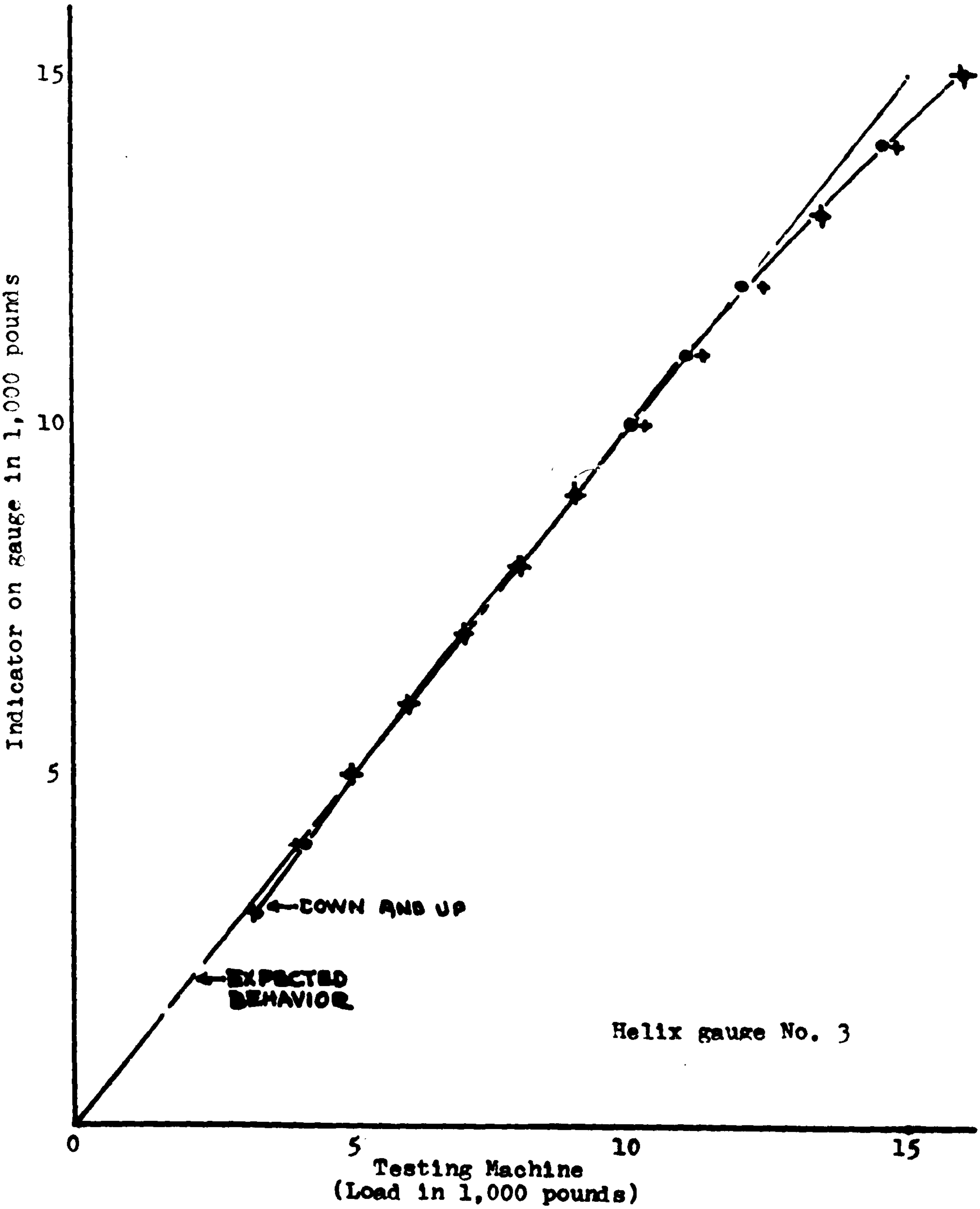



Figure 13. Load versus tip indicator.

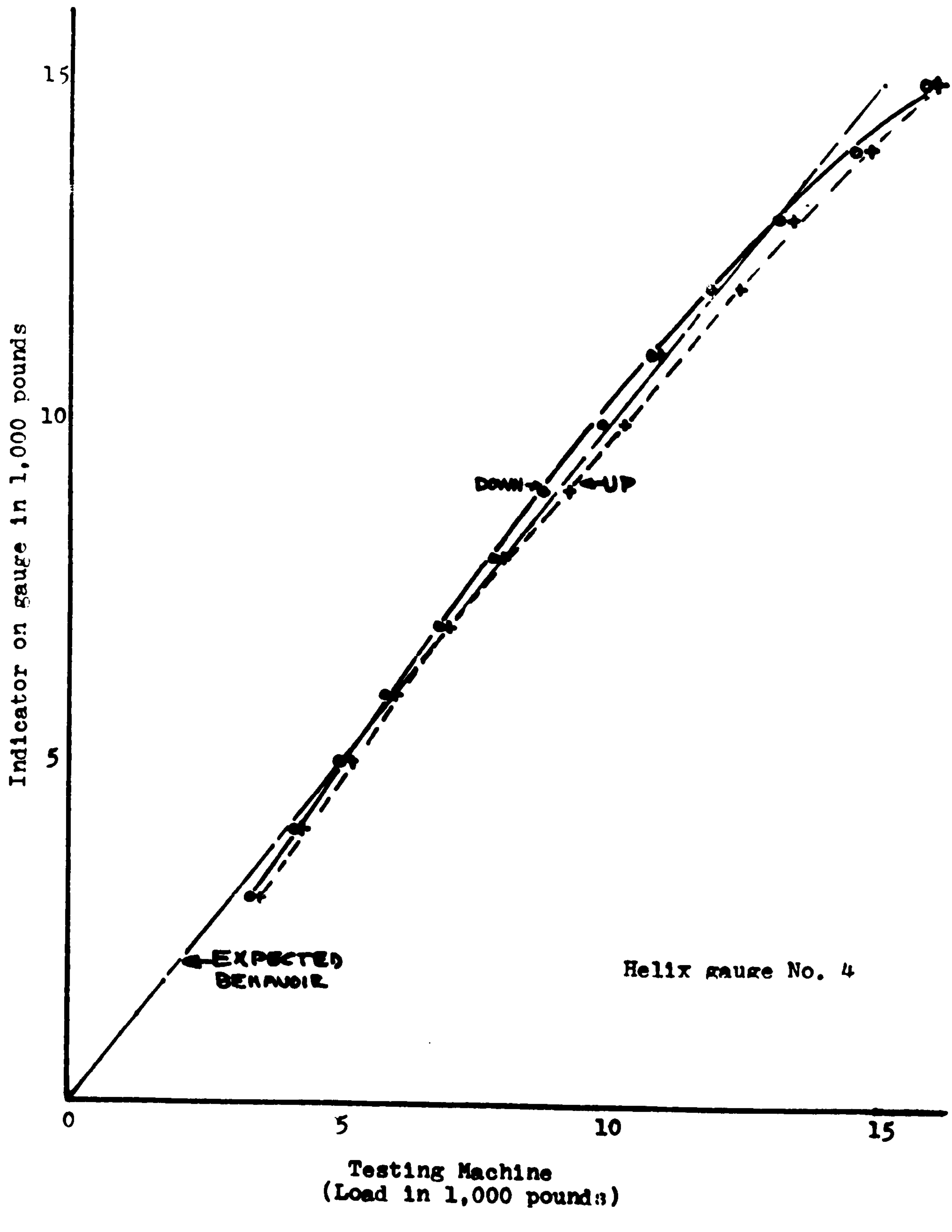



Figure 14. Load versus tip indicator.

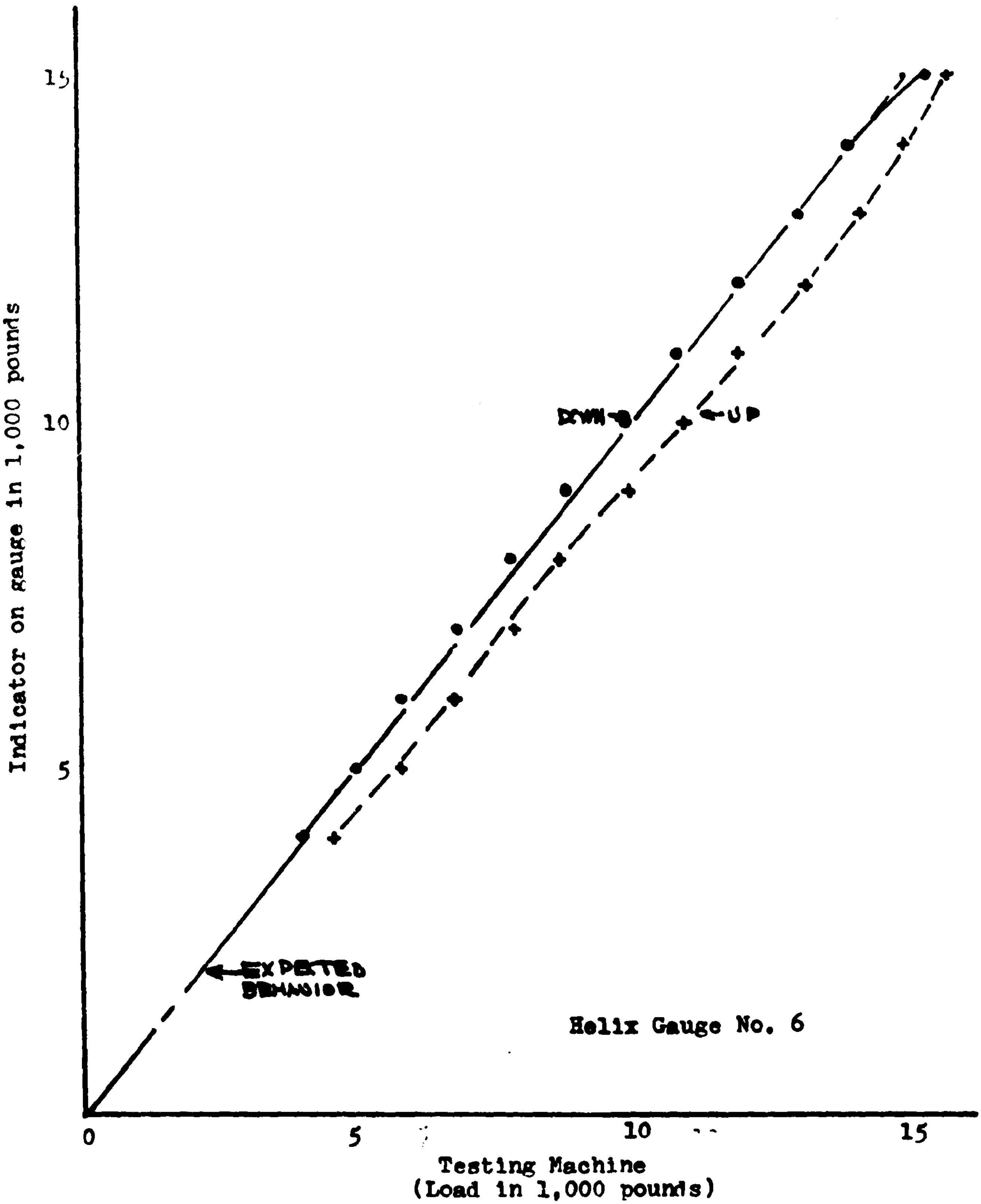



Figure 15.Load versus tip indicator.

relatively low for most of the gauges except for gauge 1. This data was included to show the possible accuracy of the gauges if more precision is required.

A series of gauge scales were made up and were used to calibrate the indicator. The spacing on the scales can be changed so as to show the proper range for the pressure. The gauge can also be adjusted by changing the top plate. It was found to be convenient to simply measure the low point and the high point on the indicator. Given this range, the correct scale which applied within the range of the gauge was glued on to the plate. Figure 16 shows a series of these scales used to calibrate the indicator.

The gauge had to be zeroed by bending the Helix coil. It was found that the coil had to be bent when errors of approximately one to one and a half inches occurred in the coil. Normally, this was done by taking the testing machine to 15,000 pounds by bending the Helix coil with a jig fixture. The load was then taken off and the bottom pressure of the indicator read. The proper scale was then applied to the plate.

It is quite clear that calibration could be done for several gauges at one time. The operation would require loading several gauges on a long rod, to say 15,000 pounds, and hand bending each coil to 15,000 pounds. The rod could then be unloaded to the low point reading of the indicator and then applying the proper range scale for each indicator. It is estimated that ten to fifteen of these units could be calibrated at one time using this technique. This should not be difficult in terms of calibration to achieve a high degree of accuracy. If a lesser degree of accuracy could be accepted, such as a $\pm$ 20 per cent variation, this step could be omitted.

Field testing. The gauge was field tested in various design configurations. The lever using the knife edge and the gauge using the chain-link were both tested.

The chain-link design was essentially the same as the knife edge design. They differed only in that the knife edge was replaced by a 3/8 inch bar which was formed into a chain link with a 3/4 inch opening on one side for the bolt. This link was then tack welded to the top plate to form the lever. The design was not successful because it showed significant hysteresis. The sharp bearing between the chain link and the head of the roof bolts caused failure at the heads of the roof bolts. The assembly was in two parts which caused negative comments from the people in the field. This caused abandonment of the approach in favor of the knife edge.

A significant number of the chain-link designs were made and tested. As with most of the design configurations, it was necessary to manufacture a series run to find production problems. For example, the series production run for the chain-link design was fifteen units.

Approximately thirty-five gauges were tested in the field using various design configurations. Both a Beth-Elkhorn Mine in Jenkins, Kentucky and two United States Steel Mines

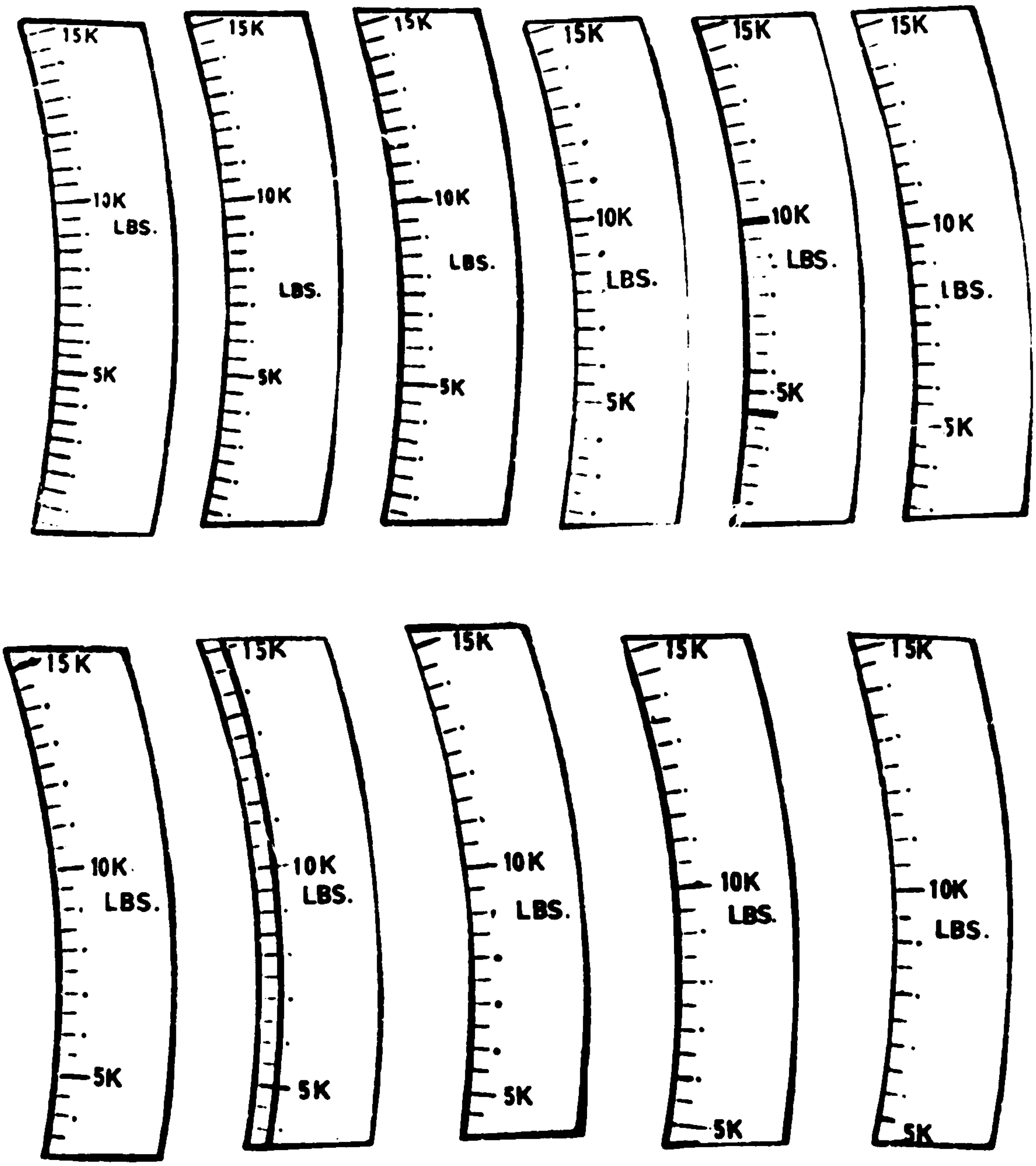



Figure 16. Series of Helix Gauge scales used to calibrate the indicator.

in Gary, West Virginia were used to test the gauges. Comments from the operators and results of field testing led to modification of the final design to the present design as shown in Appendix A.

The gauges were installed with both roof bolters and by hand. Both methods were found acceptable in terms of ease of installation. One gauge was bored out for use in a resin bolt installation. This was not successful. The lever plate ripped away from the other plate. This was due to the fact that the resin bolt did not exert any upward force so as to hold the two plates together. In the final design of the gauge this problem should be lessened, for there is a heavy bar welded to the plate and also a spot welded hinge on the rear of the lever. It is clear that for installation on resin bolts that the gauge should be significantly strengthened in regard to holding it together because of the lack of upward force on installation for the normal 5/8 inch bolt for which the gauge design was made.

It should be noted that the gauges, as sent to the Bureau of Mines, were for the use of a 5/8 inch bolt with a pal nut. For a bail type anchor slots would have to be cut into the top and bottom plates so as to allow it to slide over the bolt. Another design which should not be difficult to incorporate into the design would be for the gauge to be slotted to the rear so as to allow the gauge to be slipped on to the bolt. This would allow removal of the gauge for reuse.

The coil did not pose any great difficulty in handling. Gauges were dropped on the coil several times without damage during the course of this investigation. For the field installation the gauges were wrapped in expanded plastic. At the field site they were placed in a dynamite bag and thrown by a miner into a shuttle car for transportation to the face area. In installation of the gauges only one gauge coil was bent. We were able to bend it back to the original position without failure of the gauge. The coil can be damaged if hit a sharp blow. In normal handling to the point of use no difficulty is foreseen. The aluminum is a tempered high strength material which has a yield strength of 40,000 psi. This value approaches that of a mild steel tubing.

The gauge proved to be easily read from five feet away and the pressure could easily be estimated to the nearest 1,000 pounds load from distances of twenty feet away. Color coding of the indicator on the gauges could show miners who are unable to read indicated safe bolt loads.

Economic study. An economic study was done on fabrication of the roof bolt indicator gauge. It was broken into fabrication time for each of the operations and material costs. The material and source, plus the costs, are shown in the Appendix. The unit cost for materials is $1.60. The fabrication time is 14.67 minutes, as shown in the Appendix. Based on a $3.00 an hour labor cost, the unit cost for labor would be 74¢.

This would make a unit cost price of \$2.34 for the gauge. Assuming 100 per cent labor overhead cost, this would indicate a total cost of \$3.08. Adding on a 10 per cent unit profit of 31¢ the total cost of the gauge is brought to \$3.39.

This price would be highly dependent on the unit cost of the labor. It is believed that no high degree of skill is required to fabricate the gauge. The only critical operation is cutting the kerf so as to put the pad and cell together.

Cost reductions can be made by automation of some of the operations. Constructing the coil on automatic machines would save 60 seconds and drilling the holes in an automated machine would decrease the time for this operation, which amounts to more than one minute now. Bending the plate and cutting it at the same time in a large jig fixture or die would also save a considerable amount of time. It might be estimated that approximately 20 to 30 per cent could be saved on the labor by more efficient techniques.

The costs for materials is somewhat of a variant price in that lower costs can only be achieved by reducing the size and weight of the gauge. As this is highly dependent on the pressure of the cell pad, the design limitation of 1,000 psi is highly significant. If pressures, on the order of approximately 3,000 to 4,000 psi were achieved a smaller gauge could be constructed. This would necessitate the use of a heavier wall Helix Gauge. But, as the price for the tubing is not weight dependent, but rather length dependent, this would not pose a significant problem in regards to cost. It is therefore concluded that the selling price for the gauge to be on the order of approximately \$3.39 per gauge.

This is significantly higher than the goal of approximately \$1 per gauge and is due to both the relative complexity of the design and the weight of the materials. The design of the gauge could be significantly improved if higher pressures could be obtained.

It is the author's view that the potential application of the gauge is in problem areas in mines where control is difficult. Application of the gauge at intersections and other areas would indicate loss of bolt anchorage to the miner. Corrective measures could therefore follow. The gauge has been developed so that even a contract miner can read the gauge to learn of abnormal roof conditions that might affect his safety. Use of the gauge on 16 foot centers in a mine entry or at intersections, even at \$3.39 per gauge, would not significantly affect the cost of the coal produced. The author would estimate that it would add less than 5¢/ton to the cost of producing coal. This cost should be offset against a possible increase in production tonnage resulting from better roof control.

A suggestion for further development to reduce the cost of the gauge is a direct loading cell which would work at a design pressure of 5,000 psi. A prototype was constructed which met these criteria. It was tested and failed at 5,000 psi. This gauge was developed beyond the contract expiration date and has not been pursued further.

## CONCLUSIONS AND RECOMMENDATIONS

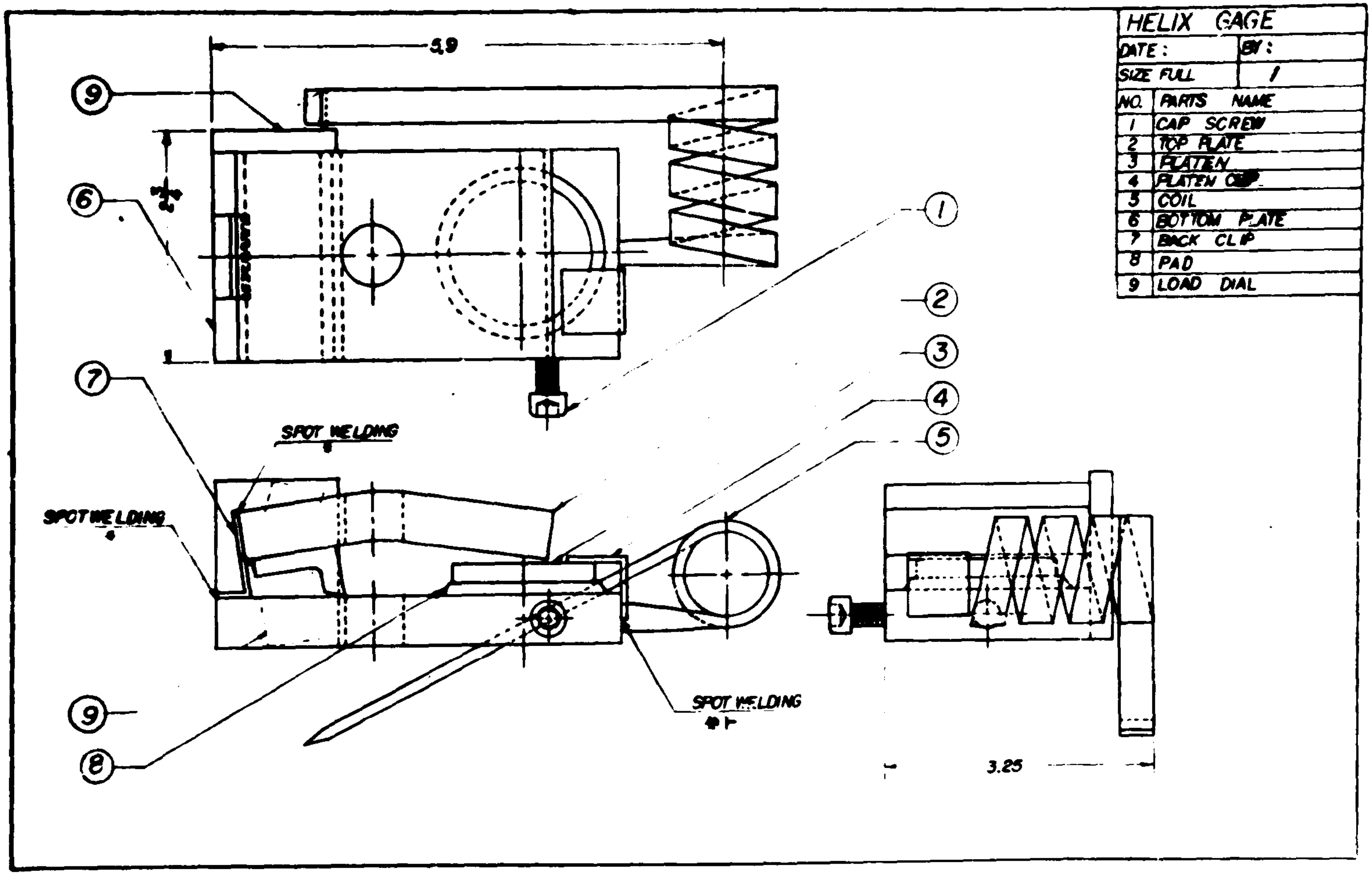
The results of this study showed that a relatively low cost gauge could be fabricated for a price of $3.39 per unit. The gauge could be made to work and show bolt loads to ± ten per cent.

To achieve the goal of an indicator which would sell for approximately $1 would require a significantly high pressure on the pad which would then allow a smaller gauge to be used in terms of material weight. It is therefore recommended that future work on this gauge be directed towards the pad to achieve significantly higher pressures. The pad area, for example, could be reduced in size to approximately 1½ to 1 inch and the width of the gauge could therefore then follow this pad reduction.

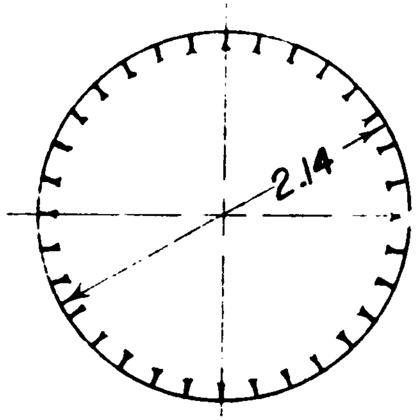
The gauge could be made shorter, thus saving in weight of materials. Also, different design configurations could be achieved by using a lever which would have a one to one ratio for pad pressures of 8,000 to 10,000 pounds. This should significantly increase the efficiency of production of the gauge in that it could allow the discarding of the knife edge and the intregal use of the roof bolt plate as part of the gauge.

Another development which could be done with significantly higher pressures is for a direct reading pressure pad of approximately 2½ inches diameter with the gauge in a clock spring configuration wrapped around the pad. Expansion of the coil would indicate the pressure. This would require pressures on the order of 5,000 to 7,000 psi in the gauge cell itself and are significantly higher than was achieved by the present Helix Gauge. Static pressure tests on cells will achieve quite high loadings. The difficulty comes in when the cell pad itself moves. It then moves the sealing material and can cause rupturing and leakage of the sealing material. A tighter and deeper kerf could allow better sealing and may certainly achieve these values of 5,000 to 7,000 psi.

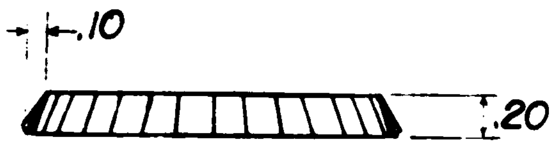
# APPENDIX A

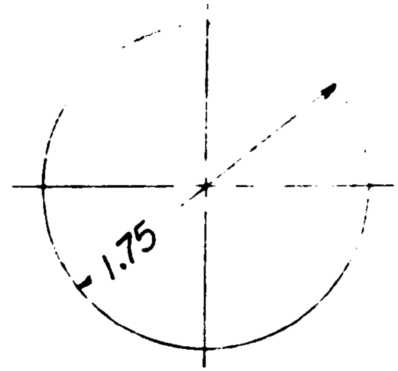


HELIX GAGE
DATE :
BY :
SIZE FULL
1
NO. PARTS NAME
1 CAP SCREW
2 TOP PLATE
3 PLATEN
4 PLATEN CLIP
5 COIL
6 BOTTOM PLATE
7 BACK CLIP
8 PAD
9 LOAD DIAL
5.9
3.25
SPOT WELDING
SPOT WELDING
SPOT WELDING

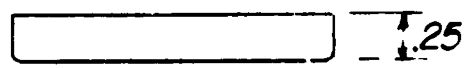



PAD CRIMPED FROM
2.125" DIA. 302S.S.
DISC. .010" THICK

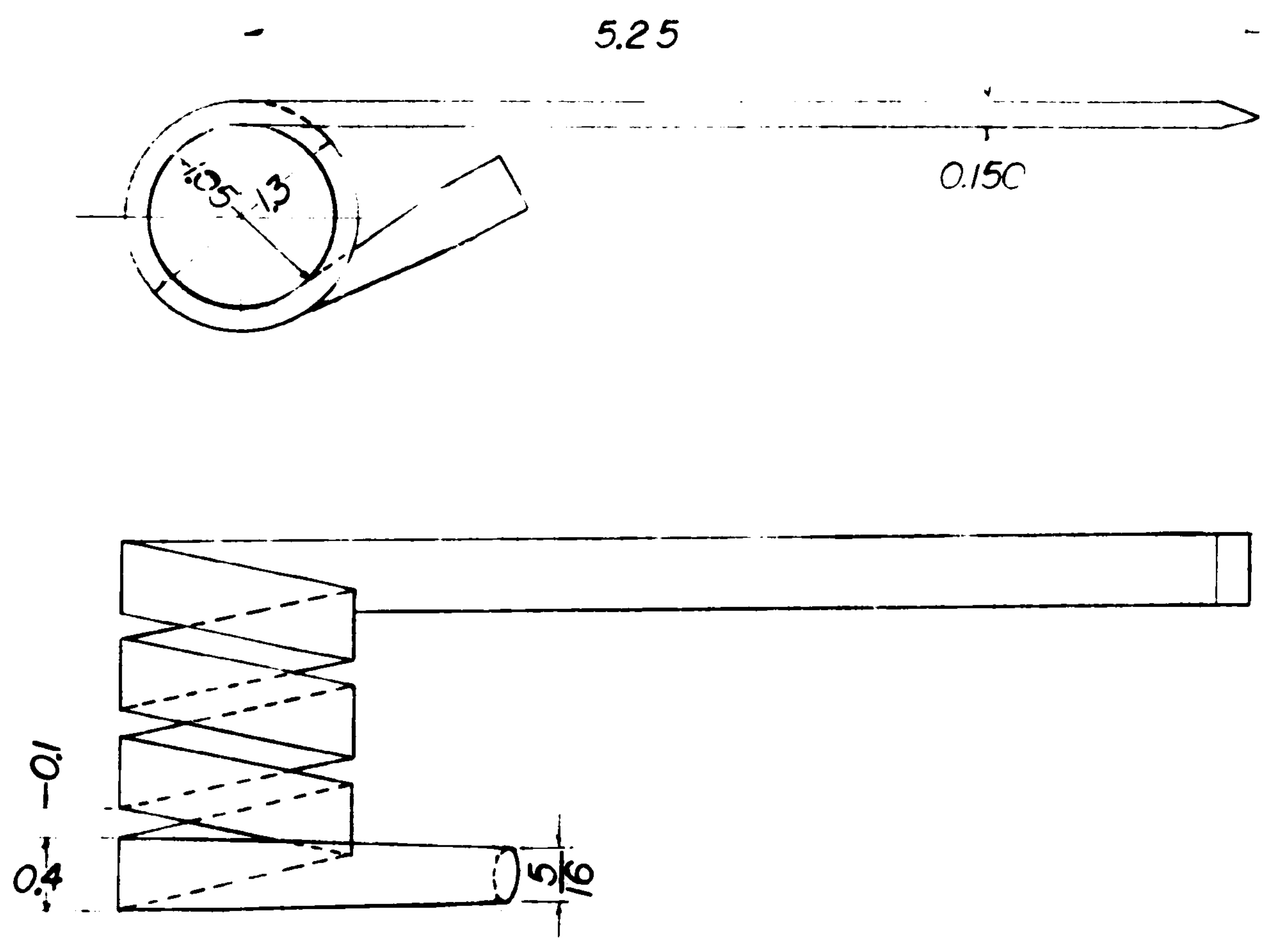


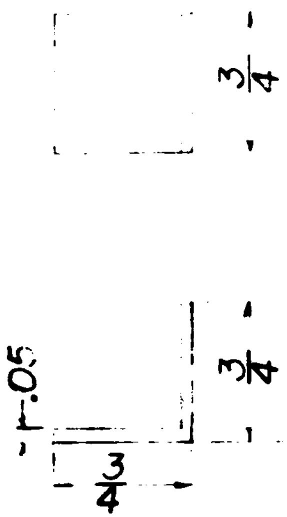

PLATEN CUT
FROM 1.75 COLD ROLLED 1020
STEEL BAR 0.25 THICK



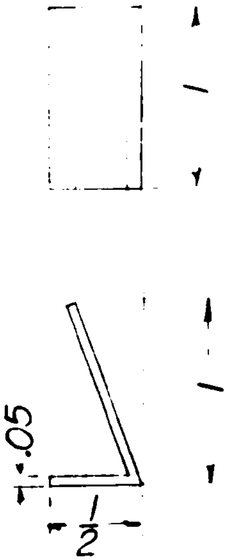

| PLATEN AND PAD | |
|---|---|
| SCALE FULL | DATE 9-23-73 |
| 2 | BY VPI & SU |




| | |
|---|---|
| COIL | |
| MATL: ALUMINUM — 6061-T6 | |
| SCALE FULL | DATE 9-25-73 |
| 3 | BY VPI & SU |

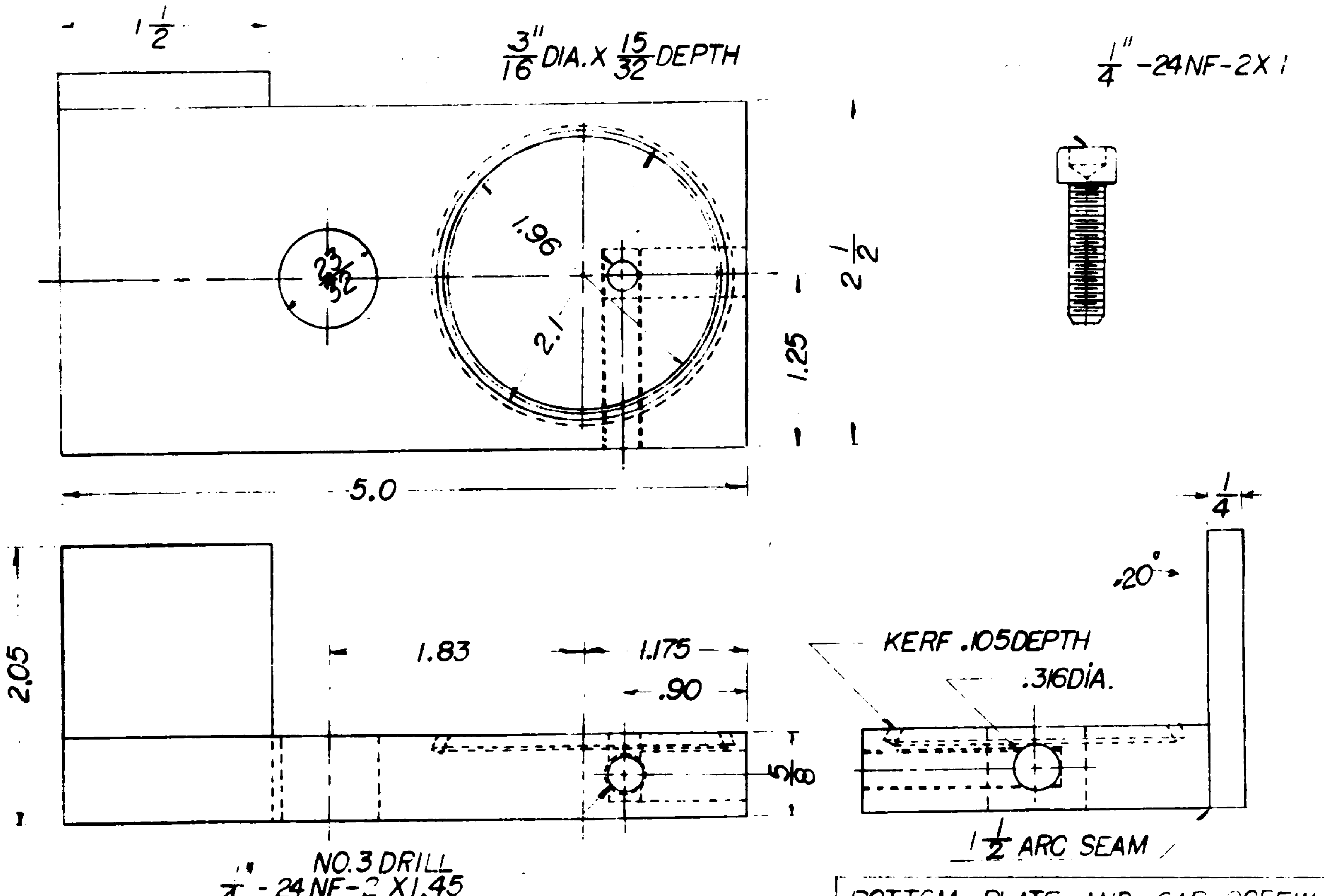



PLATEN CLIP

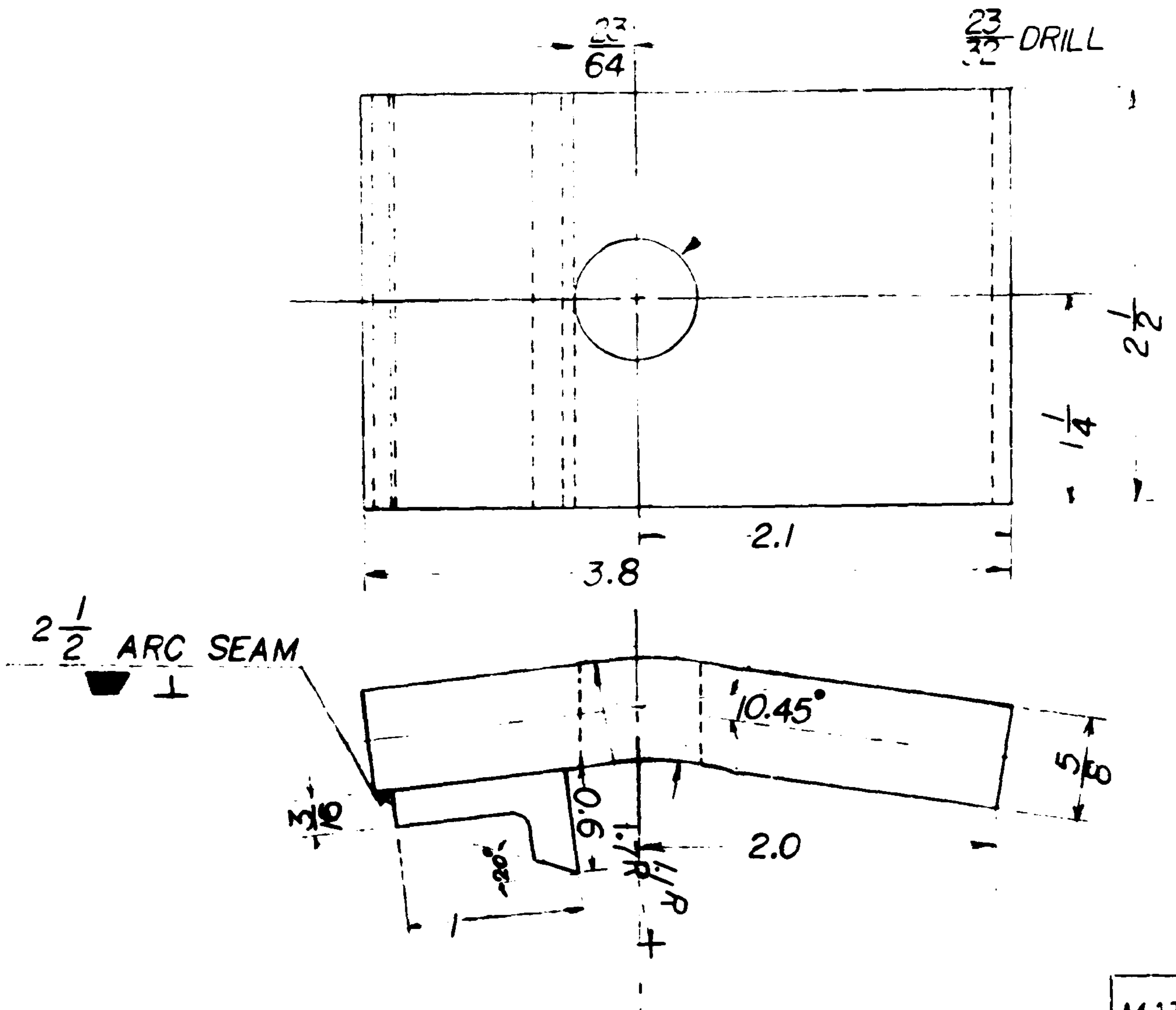



BACK CLIP

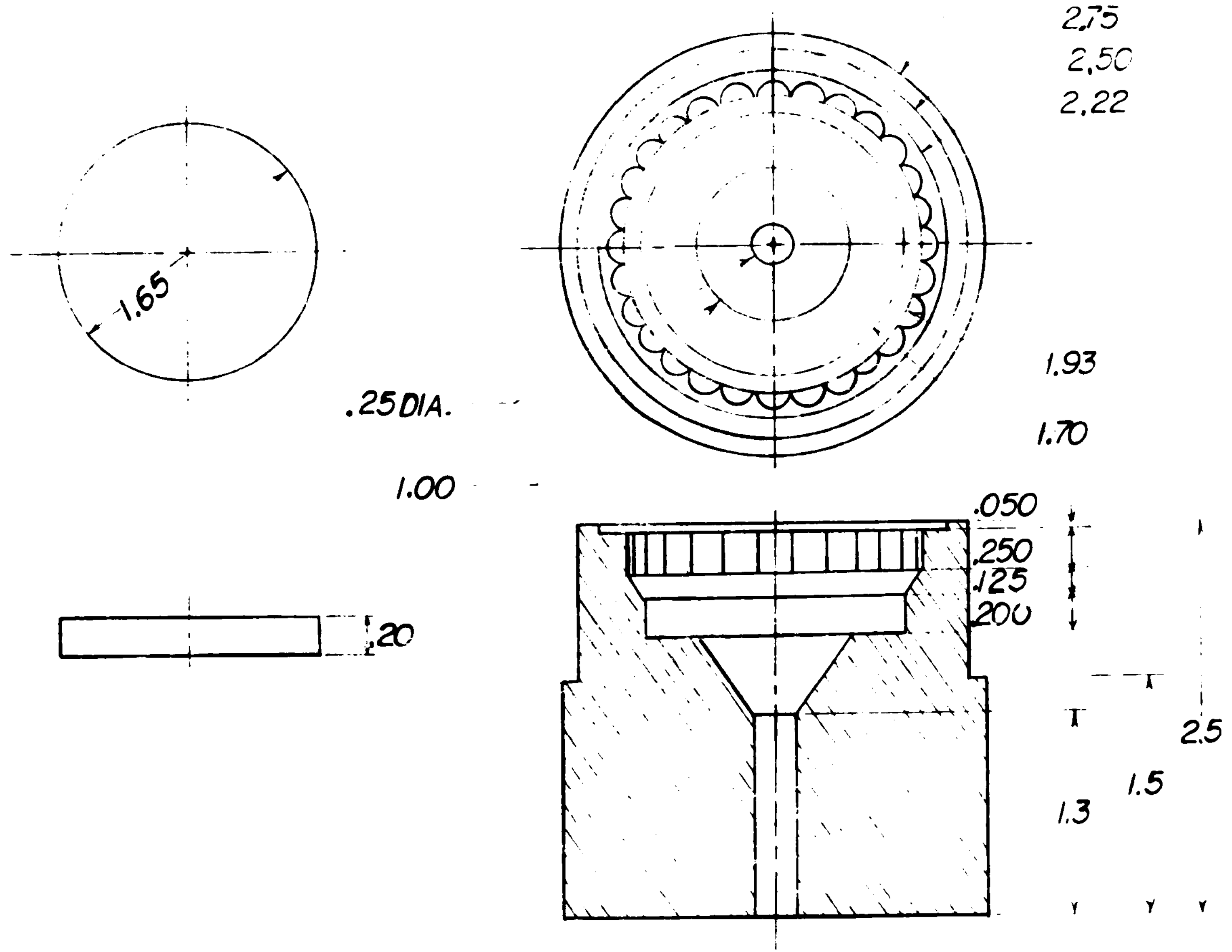
| CLIP | |
|---|---|
| SIZE FULL | 4 |
| DATE 9-25-73 | BY VPI & SU |



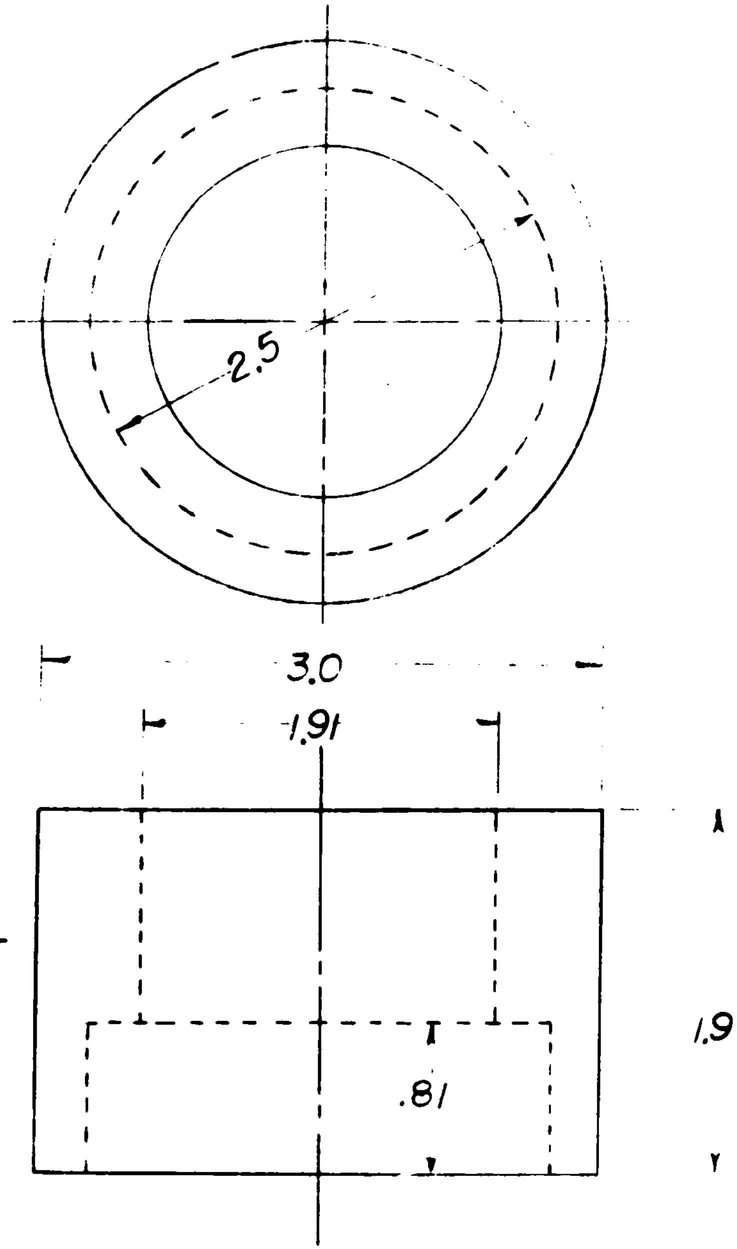

| | | |
|---|---|---|
| BOTTOM PLATE AND CAP SCREW | | |
| MATL: HOT ROLLED STEEL - 1020 | | |
| DATE 9-25-73 | BY VPI & SU | 5 |




| | |
|---|---|
| MATL: HOT ROLLED STEEL | |
| TOP PLATE | |
| SCALE FULL | DATE 9-25-73 |
| 6 | BY VPI & SU |

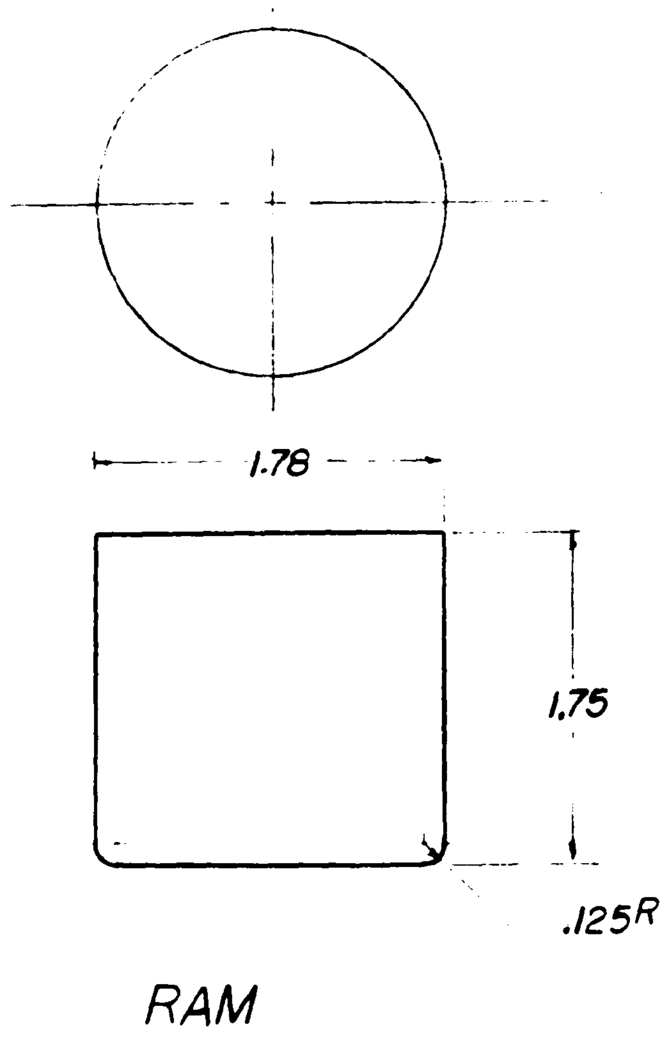



| PAD FORMER | | |
|---|---|---|
| SCALE FULL | | DATE 9-25-73 |
| 7 | | BY VPI & SU |

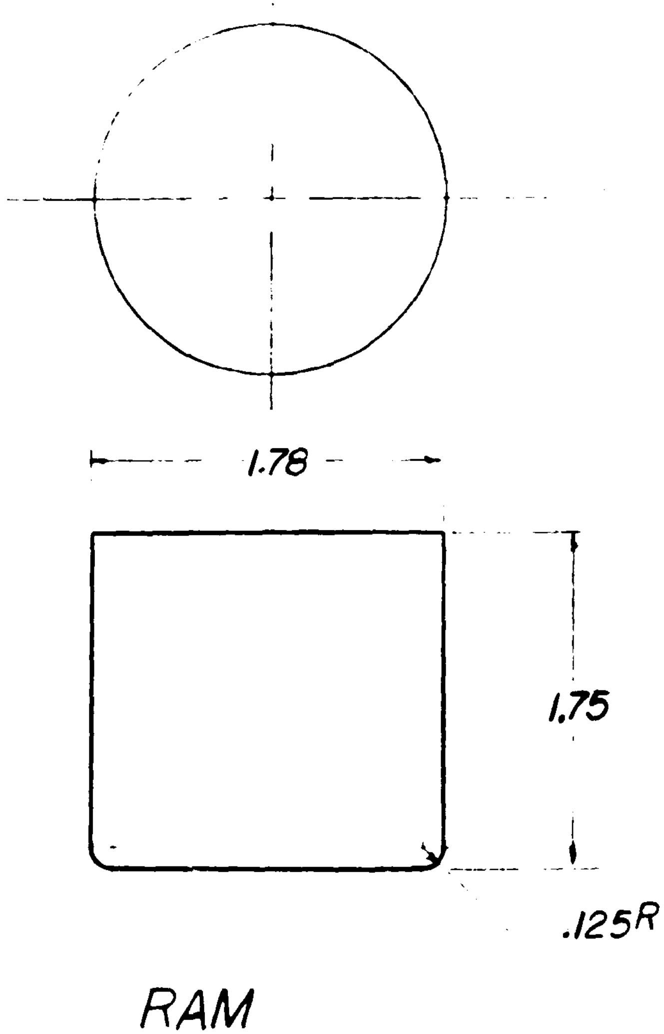



ALIGNMENT FIXTURE
FOR BASE

| | |
|---|---|
| FAC FORMER | |
| SCALE FULL | DATE 9-25-73 |
| 8 | BY [illegible] |




| | |
|---|---|
| PAD FORMER | |
| SCALE FULL | DATE 9-25-73 |
| 9 | BY VPI&SU |




| | |
|---|---|
| PAD FORMER | |
| SCALE FULL | DATE 9-25-73 |
| 9 | BY VPI & SU |

Fabrication Time

| Part | Operation | Estimated Time |
|---|---|---|
| Top plate | -cut (shears) | 3 seconds |
| Bottom plate | -cut (shears) | 3 seconds |
| Bottom plate | -cut kerf (lathe) | 60 seconds |
| | -punch location | |
| " | holes for drill press (fixture) | 20 seconds |
| " | -(No. 3 drill) screw hole (drill press) | 10 seconds |
| " | -(0 drill) coil hole (drill press) | 10 seconds |
| " | -(No. 3 drill) pad hole (drill press) | 10 seconds |
| " | -(No. 3 drill) bolt hole (drill press) | 10 seconds |
| " | - screw hole (tap) | 30 seconds |
| " | -(23/64 drill) bolt hole (drill press) | 60 seconds |
| Top plate | -bend plate in fixture (100,000 pound hydraulic press) | 30 seconds |
| " | -No. 3 drill) bolt hole (drill press) | 10 seconds |
| " | -(23/64 drill bolt hole (drill press) | 60 seconds |
| Coil | -cut to length (tubing cutter) | 10 seconds |
| " | -place rubber in end of tubing | 10 seconds |
| " | -roll in rolling mill | 30 seconds |
| " | -wrap on wrapper | 60 seconds |
| " | -press end of coil in vice | 10 seconds |
| Hinge | -cut and bend | 10 seconds |

## Fabrication Time

| Part | Operation | Estimated Time |
| --- | --- | --- |
| Pad | -form in die from circles | |
| | cut in lathe | 20 seconds |
| " | -solder | 30 seconds |
| Platen | -cut in saw | 20 seconds |
| Indicator Bar | -cut and | 10 seconds |
| | -weld | |
| Knife edge | -cut to length | 10 seconds |
| | -cut edge | 10 seconds |
| Assembly: | -fit coil in plate (glue) | 10 seconds |
| | -fill with oil and screw tight | 60 seconds |
| | -check seal | 30 seconds |
| | -spot weld clips | 30 seconds |
| Assembled Unit | -calibrate (Universal Testing Machine) | 60 seconds |
| | -transfer time | 90 seconds |
| | **Total** | 886 seconds or 14.76 minutes |

Labor unit cost at: $2.00/hr--0.49
2.50/hr--0.62
3.00/hr--0.74
3.50/hr--0.86
4.00/hr--0.98

## Materials Source and Price

| Part No. (shown on plate) | Size | Grade | Source | Amount | Cost | Total |
|---|---|---|---|---|---|---|
| 1 | ½" x 1" 28 NF | Cap screw | Noland Company<br>12th & Center Ave.<br>Roanoke, Virginia | 5,000 | 5.50/100 | 275.00 |
| 2 | 2½" x 5" x 5/8" | 1020 hot rolled steel | Bethlehem Steel Corporation<br>Bethlehem, Pa. | | 69¢/ft<br>185.50/ton | |
| 6 | 2½" x 2.7" x 5/8" | 1020 hot rolled steel | " | 4,000' | | 4,730.01 |
| 3 | 2"x1⅛" | 1020 hot rolled steel | Steel Service Inc.<br>Roanoke Div.<br>Starkey Road<br>Roanoke, Virginia | 1,000' | 43¢/ft | 430.00 |
| 4 | 3/4" x 1½"<br>22 gauge | cold rolled steel | Star Steel Inc.<br>809 Wasena Ave., S.W.<br>Roanoke, Virginia | 129 sq.ft. | | 20.22 |
| 5 | 5/16" x 0.035" wall | 6061-T6<br>324# @ 2.29/# | Reynolds Alum. Supply Co.<br>2605 Cofer Rd.<br>Richmond, Virginia | 9,000' | | 741.96 |

Materials Source and Price

| Part No. (shown on plate) | Size | Grade | Source | Amount | Cost | Total |
|---|---|---|---|---|---|---|
| 7 | 1" x 1½" 22 gauge | Cold rolled | Star Steel Inc. 809 Wasena Ave., S.W. Roanoke, Virgina | see part no. 4 | | |
| 8 | 3" wide strip 0.010 | 302 Stainless steel | Precision Steel Warehouse Inc. 3504 N. Wolf Rd. Franklin Park, Ill. | 1,300' | 160.26/ 100# | 213.13 |
| | Solder-(9 grams) | Stay-Brite SS low temp. | J. W. Harris Co. Inc. 10934 Dearfield Rd. Cincinnati, Ohio | | 100# | 665.00 |
| | Solder flux | Stay-Clean | " | 2 gallons | | 18.00 |
| | Epoxy glue | 6 kts to 1 pt. 2216 B/A | 3-M Company 3-M Center St. Paul, Minnesota 55101 | 5 pts. | 13.19 | 69.95 |
| 2 | 1" x 1" x 3/16 | Angles-1020 hot rolled | Steel Service Roanoke, Virginia | 1,200' | | 201.84 |

Materials Source and Price

| Part No. (shown on plate) | Size | Grade | Source | Amount | Cost | Total |
|---|---|---|---|---|---|---|
| | Rubber 0'.22" Solid Tubing | Medium viscosity rubbing gasket material | Atlantic India Robber Company 573 West Park Street Chicago, Ill. 60607 | Minimum order | | 100.00 |
| Steel Washer | 5/8" Bolt x 2" OD x 1/8" | Hardened steel | Pethlehem Steel Corporation Bethlehem, Pa. | 10,000 | 432.00 | 432.00 |
| Misc. Supplies | Teflon tape, cleaning fluid, oil | | | | 100.00 | 100.00 |

Total cost for a series run of 5,000 units ---------------------------------- $7,997.11

Unit cost for materials ---------------------------------- $ 1.60

Manual.

TOP PLATE

Materials: 1020 hot rolled steel 5/8" x 2½"

Procedure: -The steel is cut into 2.7" lengths.
-Each length is bent on a 5/8" plate, 1" from the end in a hydraulic press at 20 tons.
-A 23/32" hole is drilled 1.5" from the end of the plate. Predrill with No. 3 drill.

PAD

Materials: 304 stainless steel
0.10" thick shim stock

Procedure: -The shim stock is cut to 2.5" x 3.0" pieces.
-It is cut in a lathe to 2.190" diameter circles.
-The circles are then crimped in a die to form the pad.

HINGE FOR TOP AND BOTTOM PLATE

Materials: 1¼ x 2" - 21 gauge sheet steel

Procedure: -The strip is bent in a vice lengthwise at a 60° angle, 5/8" at one side.
-The strip is attached to the top plate with 3 spot welds along the side.

Manual.

HINGE (continued)

Procedure: -The bottom and top plates are clamped together and the holes for the roof bolt are aligned.

-The strip of sheet steel is hammered over the end of the bottom plate.

-The strip is spot welded in three places on the end of the bottom plate.

PLATEN

Materials: 1020 cold rolled steel rod
1.75" in diameter

Procedure: -Platens are cut from the rod to 0.20" thickness.

-The edges are rounded with an electric grinder.

BOTTOM PLATE

Materials: 1020 hot rolled steel
5/8" x 5" x 2¼"

Procedure: -The material is cut to 5" lengths.

-It is placed in a jig fixture on an 11" swing lathe.

-A kerf is cut into the plate-- the O. D. of the cut is 2.070". The kerf is 0.065" wide and 0.110" deep and cut at a 20° angle into the bottom plate.

Manual.

BOTTOM PLATE
(continued)

Procedure: -Holes are drilled for the Helix coil: tap hole, hole for the pad and the 3/4" hole for the roof bolt.

-The tap hole is tapped with ¼" x 28 thread 1" deep.

INDICATOR BAR

Materials: 1" x ¼" 1020 hot rolled steel

Procedure: -The steel is cut into 3" lengths.

-The bar is tack welded to the bottom plate just before soldering.

CLAMP FOR PAD

Materials: hot rolled flat iron 1/8" thick

small pieces of asbestos

Procedure: -Cut iron to 4" x 3/4" pieces

-Iron is placed in a vice and hammered 1.7" and 1" and 1.2" to form an U shape. The opening has a 3/4" clearance (.850)

-The clamp is placed over the pad and plate to hold the pad during soldering.

-A small piece of asbestos is placed between the pad and the clamp.

Manual.

## KNIFE EDGE

Materials: 1" x 1" x 3/16" 1020 hot rolled steel

Procedure: -Cut to 2½" lengths

-Cut edge

## HELIX COIL

Materials: 6061 T6 aluminum (Reynolds)

(coil) .035" wall

5/16" O. D.

3/16" thick rubber obtained from surplus

(plugs) Warco - A-80 2 mil-S-6855-1-80

187 x 36 - 3-Q-68

Procedure: -Tubing is cut to lengths of 20.5"

-Plugs are cut from sheet rubber by a hand punch the same diameter as the tubing, I.D.

-2 plugs are inserted into one end of the tubing.

-The tubing is rolled by successive passes through a rolling mill.

10-15 passes are required to obtain a 0.150" ± .005" thickness.

-The 5/16" tubing ends with the plugs are put into a vice and crimped.

-Each tube is then wrapped 4.5 times around a mandrel-cylinder measuring 1 inch in diameter.

-The indicator is set at a 6" length from the coil.

Manual. ASSEMBLY PROCEDURE

Cleaning: -The seats are washed in acetone.

-They are then cleaned in an ultrasonic bath for 30 minutes.

-They are rinsed in water.

-They are then washed in alcohol.

Soldering: -The pad is fitted into the bottom plate.

-A clamp is fitted to hold the platen and pad into the bottom plate.

-Approximately one milliliter of flux is then put into the seat.

-Two rings of 1/16" low-temperature silver solder are placed around the pad.

-A gas flame from a Bunsen burner is then used to melt the silver solder. Care must be used so as not to over heat the silver solder because oxidation can occur.

Helix coil: -The Helix coil is glued on to the bottom plate with 3M epoxy structural glue 2216 B/A. An over-night cure is recommended. Heat should not be used to cure glue.

Manual.

## ASSEMBLY PROCEDURE
(continued)

Filling pad: -A number of gauges are placed in a glass desiccator.

-The desiccator is evacuated to 500 $\mu$ of mercury and oil is valved into the desiccater.

-The oil filled pads are removed.

-A $\frac{1}{4}$" x 28 cap screw wrapped with Teflon tape is used to seal the unit.

Automobile automatic transmission fluid is used because of the rubber seal in the end of the Helix coil.

Cleaning: -The Helix Gauge is washed with solvent

Spot Welding: -The platen and hinge are welded to the plate: each with three spot welds

Calibration: -The gauges are calibrated against a standard, such as an Universal Testing Machine.

# APPENDIX B

This is to certify that no equivalent or duplicate patents were found for the Helix Gauge to indicate roof bolt loads for a period of 1949 to September 1973.

March 1 1974
Date

William E. Foreman
Signature