AN INVESTIGATION OF
FORGING-HAMMER ANVIL FAILURES

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# AN INVESTIGATION OF FORGING-HAMMER ANVIL FAILURES

By

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# CHAPTER I

## INTRODUCTION TO HAMMER ANVIL FAILURES

One of the major problems encountered in the forging industry is the cracking of hammer base anvils in the region of the radii of the sow-block seat. These cracks generally originate at the front or back face and progress across the anvil and down the base to complete failure. The hammer base is twelve feet long, five feet high, and four and one-half feet wide, weighing approximately fifty tons. Figures 1 and 2 show several typical base failures.

The sow-block, which is a separate portion of the hammer that supports the forging dies, is held in the anvil seat by a wedge type sow-block key. This key is driven in place by an air powered key driver. Figure 3 shows a 5,000 pound hammer with sow-block and key in place. This static stress, developed by the wedging action, in addition to the cyclic dynamic stress during forging, produces the combined loads causing failure of the bases.

The purpose of this study is to develop a test procedure and method by which the magnitude of the imposed stresses can be evaluated, to determine if the base material is metallurgically sound, and

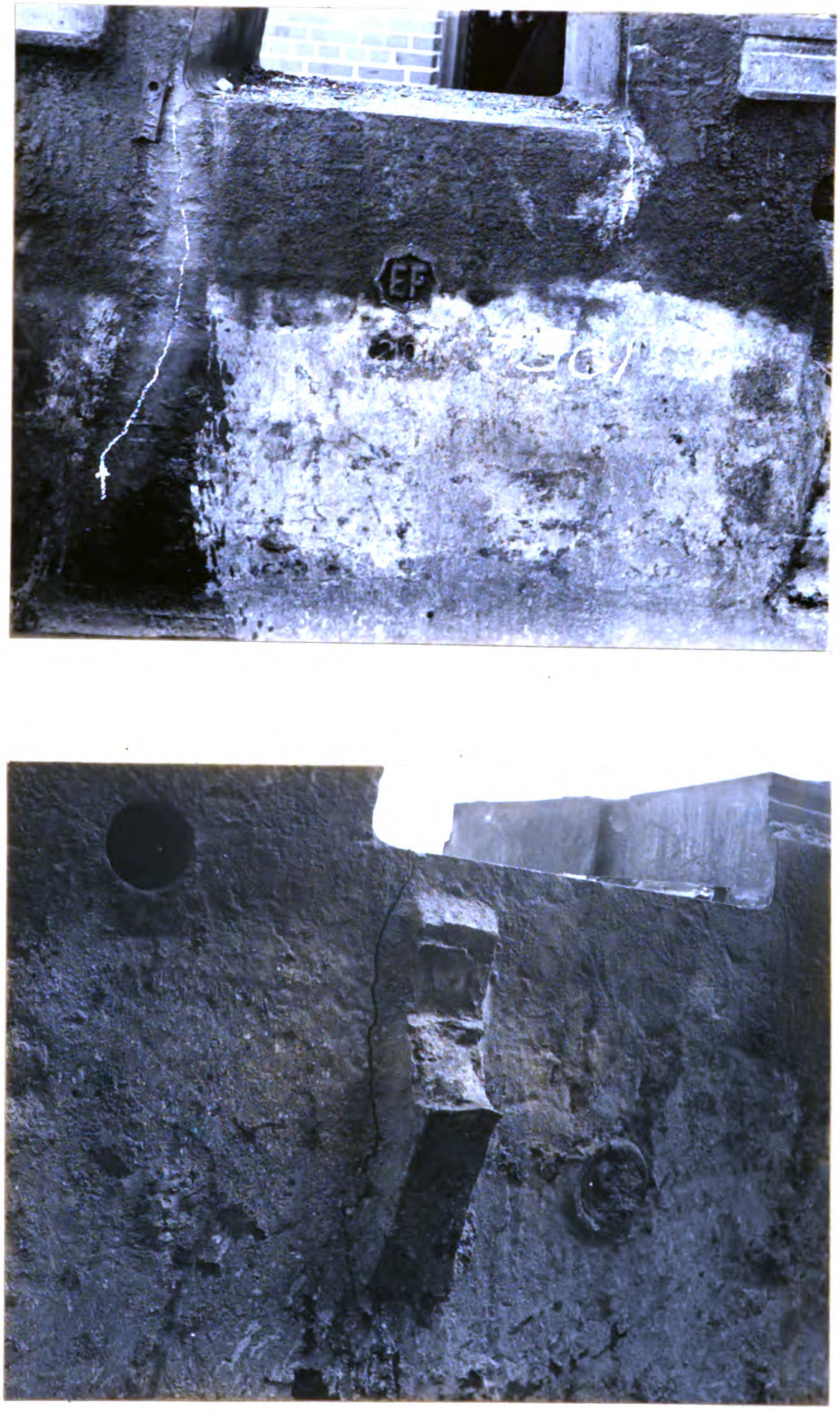

Figure 1. Typical hammer base failures.

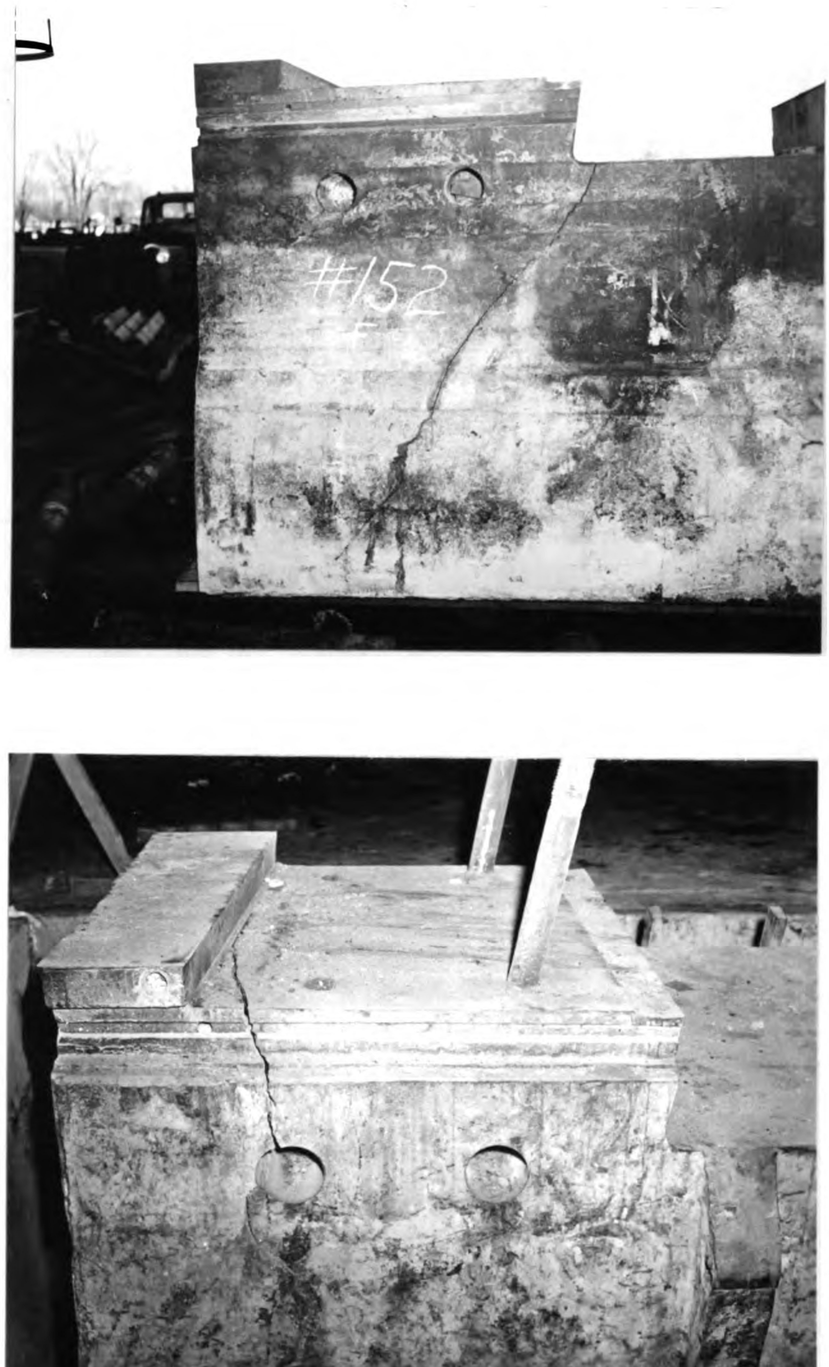


Figure 2. Typical hammer base failures.

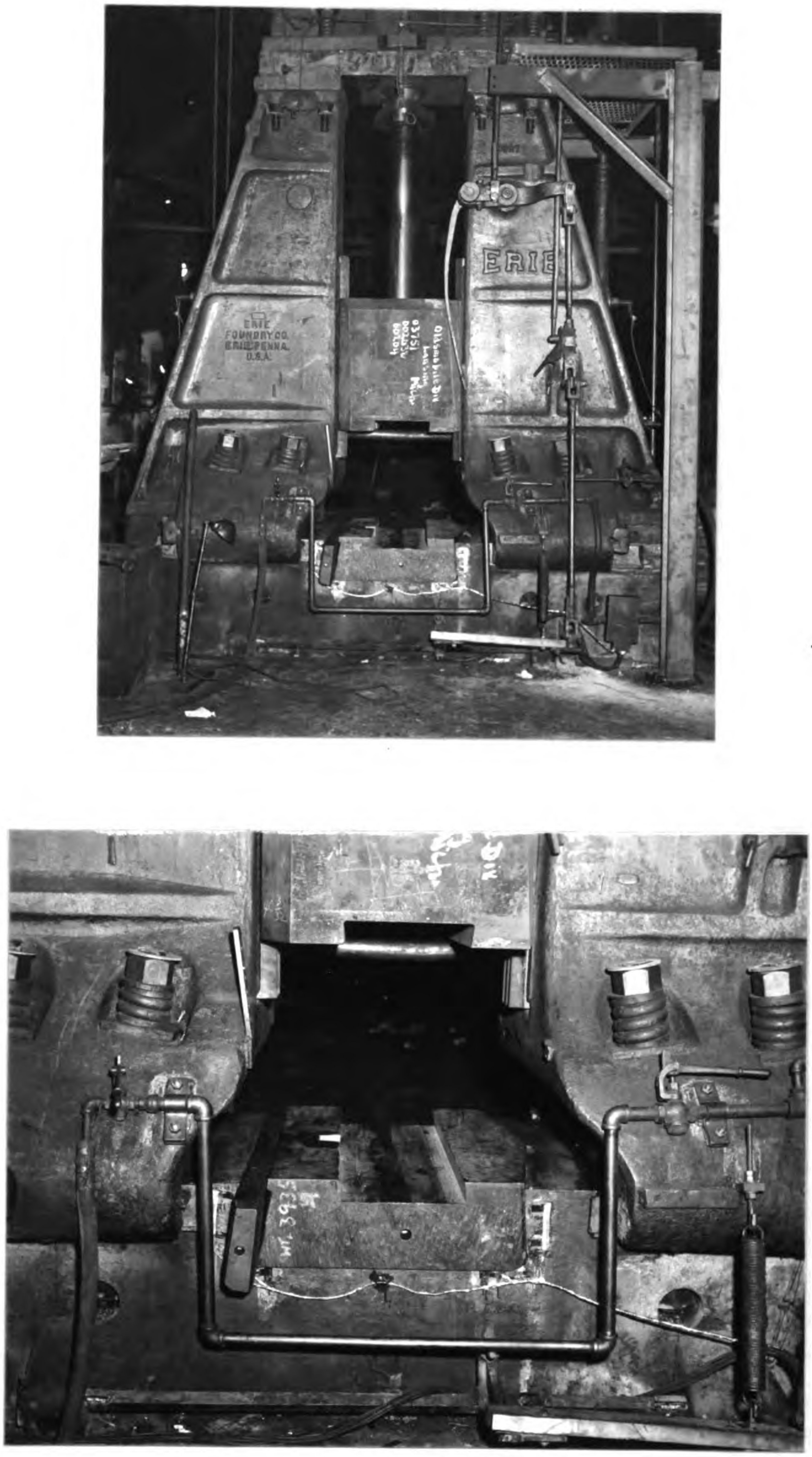


Figure 3. Five-thousand-pound forging hammer with sow-block and key installed.

to establish whether the imposed stresses are within the metallurgical specifications of the hammer base material.

This thesis is subdivided into sections concerned with selection of equipment for evaluation of imposed stresses, general test procedure, electrical strain gage tests, metallurgical tests, and conclusions and recommendations.

The extreme expense involved in replacing a broken hammer base in addition to the productive loss of the equipment makes the solution of this problem of prime importance. A complete analysis of load distribution and intensity together with metallurgical data on present forging hammers will make it possible for both forging hammer manufacturers and users to incorporate metallurgical and design changes necessary to increase the operational life of present and new forging equipment.

The experimental data for this thesis were obtained by the unlimited use of facilities at the Oldsmobile Forge Plant, Lansing, Michigan, through the courtesy of Mr. Thomas E. Darnton, Manufacturing Manager. Appreciation is extended to Dr. Austin J. Smith and Dr. Roland T. Hinkle for their excellent suggestions and guidance throughout this investigation. Grateful acknowledgment is also due the personnel of the Oldsmobile Forge Plant for their cooperation, especially Mr. Jack Gannon for his assistance in photography and reproduction of graphs.

# CHAPTER II

## SELECTION OF TESTING EQUIPMENT

To evaluate the imposed loads under forging conditions it is necessary to develop a nondestructive test method which is reliable and applicable to the severe conditions encountered in a commercial forging plant. The resistance wire electrical strain gage was selected as the most practical tool for study of this problem.

The resistance wire gage is composed of a grid of fine wire cemented between two sheets of treated paper. The basic principle involved in the operation of the gage is that, as the wire is deformed in either tension or compression, the resistance of the wire changes. This change in the resistance of the wire is, then, a measure of the strain to which the wire is subjected.[1]

In selecting instrumentation to use in conjunction with the strain gages, several requirements must be considered. These requirements are portability, static strain indication, dynamic strain

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[1] For a more detailed explanation of the wire resistance strain gage, see A. V. de Forest and H. Leaderman, "The Development of electrical strain gages," Natl. Adv. Comm. Aero. Tech., Note 744.

indication capable of recording strain waves within the base which exceed five hundred cycles per second, and means of accurate recording of strain indications for further calculation.

To meet the static strain requirements the Baldwin-Lima-Hamilton SR-4 Type "L" Portable Strain Indicator was chosen. This instrument reads directly in microinches per inch, with no correction factor when used with a one hundred and twenty ohm resistance strain gage. Compactness and ease of operation were other deciding factors in the choice of this unit.

The dynamic strain instrumentation selected included the Ellis Associates Model BS-6 Switch Balance Unit and the Model BA-2 Bridge Amplifier coupled with a Du Mont Type 304-H Cathode-ray Oscillograph.

This system enables single channel readings of one to four arm bridge circuits to be taken with recording rates of five to twenty-five thousand cycles per second. Accuracy of five percent is maintained. The Model BS-6 Switching Unit allows individually balanced resistance components in six channels and switches one channel at a time into single channel equipment. It can also be used with the SR-4 Type "L" Portable Strain Indicator. The Ellis Model BA-2 Bridge Amplifier incorporates a calibration system and chopper circuit which makes it possible to throw in a zero line while receiving dynamic signals. The Type 304-H Oscillograph is equipped with a triggered sweep and long persistence screen for ease of visual observation. For permanent recording of dynamic readings, the Du Mont Type 297 Oscillograph-Record Camera was selected. This is a Polaroid-Land camera with multiple frame exposure, which makes it possible to determine what signals have been accurately recorded at the test location. In addition to this recording equipment a Simpson Multi-meter Type 260-RT was used to check gage circuits and resistance.

The selection of SR-4 strain gages is dependent upon the specific investigation at hand. A wide variety of types and sizes of strain gages are available from the Baldwin-Lima-Hamilton Corporation, and each has its advantage for certain applications. The necessity that gages be placed in the restricted fillet areas of the anvil seat, resulted in the choice of the A-7 and C-7 type gages. The A-7 gage is a wrap-around type with a 0.250 gage length and 120 ohm resistance. The C-7 is of similar type and dimension with 500 ohms resistance. The C type gages are unstable for static indication but have a higher resistance change for given elongation than the A gage.

With this choice of gage it is possible to place gages directly in the fillet of the anvil beneath the sow-block. The first two tests on the hammers were run using both types of gages. It was found that the amplitude of the dynamic indication was sufficient to permit the use of A type gages for both static and dynamic indications on subsequent tests. This procedure saved considerable time in application of gages and preparation prior to testing.

This collection of equipment provides a complete testing unit capable of recording both static and dynamic strain loadings over a wide range of application. It can easily be moved to the test location and, combined with proper gage application technique, will provide accurate results. Figure 4 shows the combined strain gage instrumentation.

Figure 4. Strain gage instrumentation.

# CHAPTER III

## GENERAL TEST PROCEDURE

The successful use of electrical strain gages is dependent upon correct application of the gage to the structure being tested and correct wiring procedures from gage to strain-recording instruments. The use of strain gages to test steam forging hammers during operation presents many special problems. Surrounding conditions in a forging shop require careful waterproofing techniques to protect strain gages and wiring from the steam, die lubricants, and dirt around the hammers. Extreme care in preparing surfaces for strain gage placement and complete shielding of lead wires from electrical interference are also a necessity. It is the purpose of this chapter to describe the procedures and techniques which were found to be most successful in combating these problems.

I. Surface Preparation.

a. All pits, scale, rust, et cetera, are removed from the gage area with a hand grinder.

b. The surface is degreased and cleaned with gauze saturated with carbon tetrachloride.

c. Metal conditioner is brushed on the surface and wet-lapped with silicon carbide paper.

d. Residue is removed from the surface with tissue.

e. Metal conditioner is again applied to the surface and wiped dry with tissue.

f. Entire gage area is cleaned with gauze saturated with Acetone.

g. The gage area is dried with a small hair dryer for two minutes to remove all moisture from the surface.

II. Cementing.

a. Trim gage paper to desired size and place a small quantity of Duco Cement on forefinger.

b. Place gage between thumb and forefinger and soften for forty-five seconds.

c. Place a small quantity of Duco Cement on prepared surface.

d. Press gage into place with forefinger, squeezing excess cement from around gage edge.

e. Gently apply pressure with pencil eraser to grid area and force grid into intimate contact with the surface.

f. Gently work out the excess cement from under the entire length of the gage.

g. After the gage has dried for approximately two minutes, apply a smooth even coat of cement over the entire gage area.

h. Gage should be allowed to dry for two hours before attaching lead wires and twenty-four hours at room temperature before using.

III. Lead Wire Preparation.

a. Clip the lead wires of the strain gage to three-quarters inch length.

b. Use Beldon 8014 wire or equivalent for connection from gage to terminal board and cut to length.

c. Strip ends of the lead wire and tin both gage and lead wires.

d. Clip ends of tinned lead wires to one-eighth inch and solder to gage wires with a lap joint.

IV. Lead Wire Insulation.

a. Bring both lead wires back over the gage and hold in place with Cellophane tape.

b. Place one inch of Mystik tape at lead wire end of gage so it overlaps the insulating paper flap of the gage.

c. Bring one lead wire back over the gage, forming a small loop running the lead wire out from the gage area perpendicular to the gage axis. This is necessary to provide sufficient clearance for installation of the sow-block.

d. Cover with one inch length of Mystik tape and repeat the procedure with the remaining lead wire.

e. Cover with Mystik tape and coat the entire area with Duco Cement except where tape joins the gage.

Electrical shielding of the strain gage and lead wire is accomplished by placing Aluminum Foil tape over the gage and wires running along the anvil fillet. Wires outside of the anvil are wrapped with this tape from the anvil to the terminal board and grounded to the common ground terminal at that location. Care must be taken to prevent breaks or splices in the shielding, and it must be grounded to a common ground terminal. This terminal is in turn grounded to a fixed ground source in the vicinity to prevent pick-up of electrical disturbance in the amplifying units.

Gage installation is completed by waterproofing the gage area and lead wires on the anvil with three coats of Synthetic Coating Type A-178-B which is produced by the B. F. Goodrich Company. After the second coat of Synthetic Coating, a one inch piece of Koroseal tape is applied over the gage area and serves as additional mechanical attachment and waterproofing. Petrosene wax was used on the first test but did not offer sufficient protection against the steam and oil from the hammer.

A special terminal board with provisions for twelve strain gage connections and two compensating gages was constructed. This board was located at the hammer and connected to a switch box at the instrument location by Beldon 8424 shielded microphone cable. The switch box at the instrument location was constructed of micro-switches to contain two series of six channels each, making it possible to obtain readings from twelve strain gages with the BS-6 Switching Unit. Shielded microphone cable and micro- or radio switches must again be used to prevent interference pick-up in the amplifying units, and the shielding on the cable and the individual switches must be grounded to the common ground terminal.

Instrument operating techniques and procedure varied little during individual tests and a general description follows. A two gage circuit was used on all tests, composed of active and compensating arms. The compensating gage was mounted on a section of material identical to the base material and placed in the vicinity of the sow-block to compensate for temperature changes at the active gage locations.

During static strain readings, an initial reference reading was taken and subsequent readings after each key blow. No calibration is necessary during these readings because the Type "L" Strain Indicator reads directly in microinches and the increase in strain is computed by the difference in successive gage readings.

During dynamic strain readings, the amplitude of the impact signal was adjusted within the range of the oscillograph screen and the calibration switch set to approximate this amplitude as nearly as possible. Record of the calibration was made by sensitizing the film to bring out the screen graph and then photographing the calibration trace on the screen. The procedure for recording the actual impact signal was the same with the exception that a zero reference line was thrown across the screen with the chopper switch on the BA-2 Unit, and the sweep control on the oscillograph was set on triggered sweep. This procedure produced a photographic record of the calibration and impact signals with a graph and zero reference line in the background for simple evaluation of true strain values. Figure 5 pictures a typical gage installation on a five thousand pound hammer.

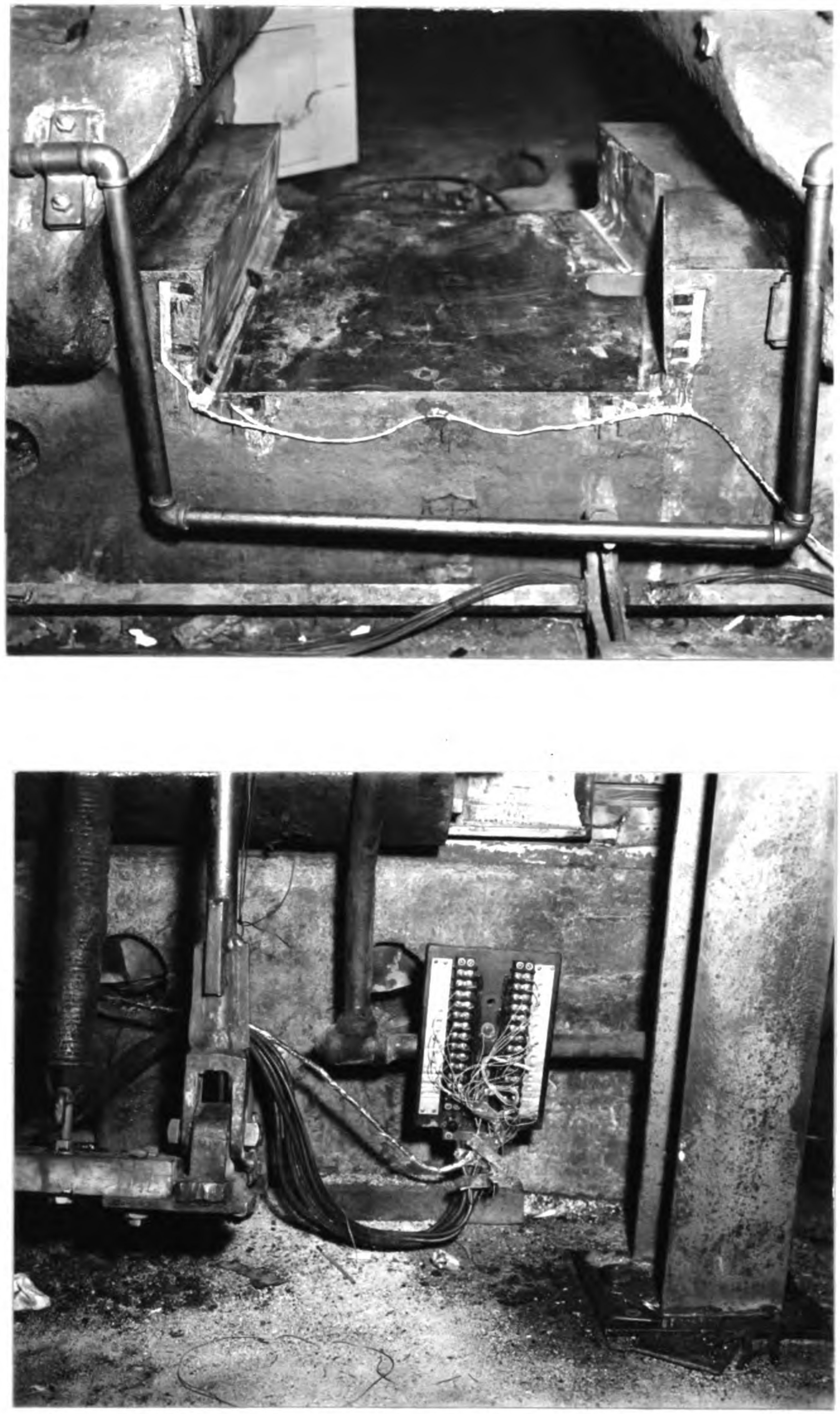


Figure 5. Typical gage installation and hammer terminal board.

# CHAPTER IV

## ELECTRICAL STRAIN GAGE TESTS

A series of four individual tests was conducted on two different forging hammers. The hammers used for these tests were five thousand and fifteen thousand poind steam hammers, Numbers 503 and 153, respectively. As each test was completed, certain points and questions for further evaluation presented themselves and were consequently investigated on following tests. Each test will be described and analyzed individually, and a collected discussion of the combined test results will follow.

The first test was conducted on hammer 503 to determine the magnitude of the static and dynamic stresses imparted to the hammer base anvil in the region of the fillet radii. Strain readings were taken after each blow as the key was driven, during die heat and for the forging blows producing maximum stress signals. Figure 6 shows the gage locations during this test.

The static stresses imposed by driving the key show an interesting relationship between key travel and key fit. As the key was progressively driven and readings taken, it can be noted that the

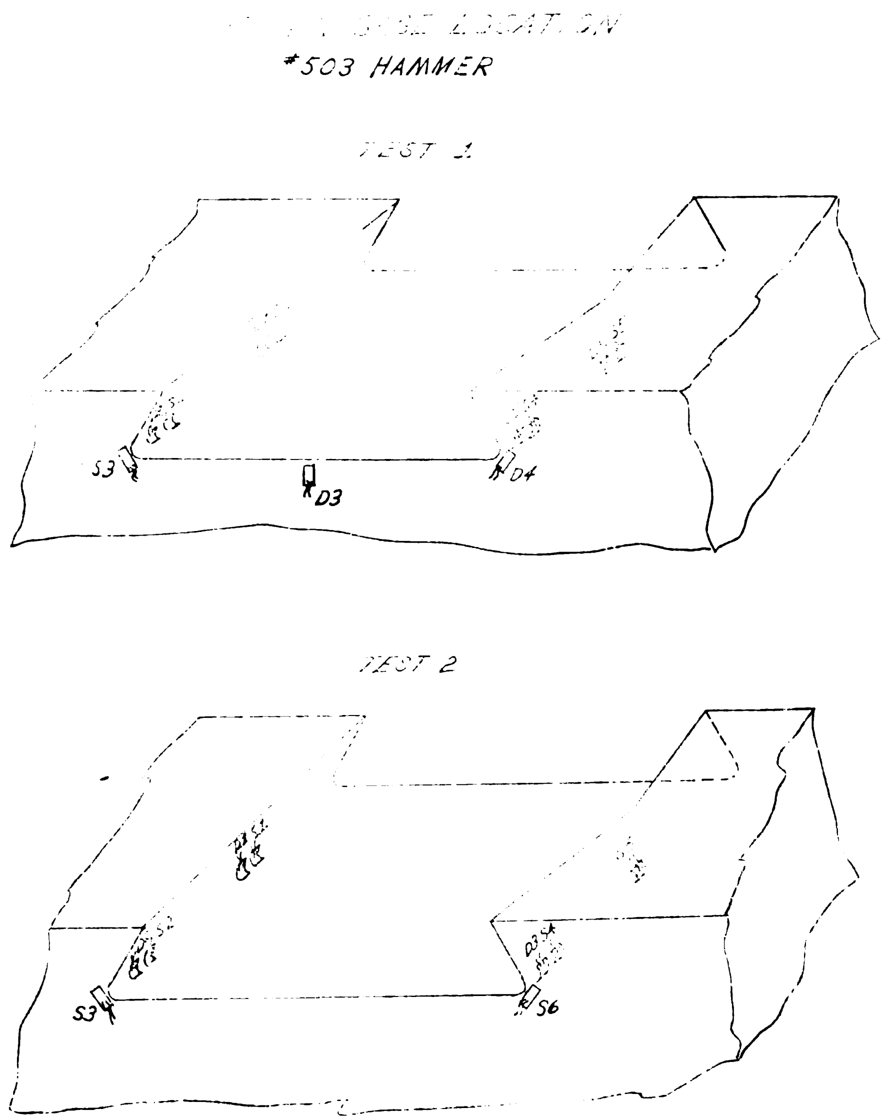



**Figure 6**

bearing area between the key and anvil definitely moves. By reference to Figure 7, it can be seen that as the key is driven, the stress at certain of the gage areas increased much faster than in others and in the early stages of driving actually decreased in some locations. This nonuniform loading would indicate poor key and sow-block fit. With a very accurate fit, the bearing area would remain constant, and the stress rise would also be constant.

The actual numerical value of the static loads was much higher than had been anticipated, and the very high stress of 30,000 p.s.i. indicated by gage S-2, which approaches the yield point of the base material, make the accuracy of this individual gage questionable. However, certain important factors must be considered before eliminating completely the indications of this gage. The gages S-1, S-2, S-4, and S-5 are all located in the fillet radii, where it must be assumed the stress will be considerably higher than on the face of the anvil. The close similarity of loads for gages S-4 and S-5 and the over-all continuity of the readings further strengthens their validity. Noticing that the readings for gage S-2 were excessively high, an attempt was made to verify the readings at the location of S-2 by removing the key and replacing a new gage in the same location. However, this could not be carried out because the key had

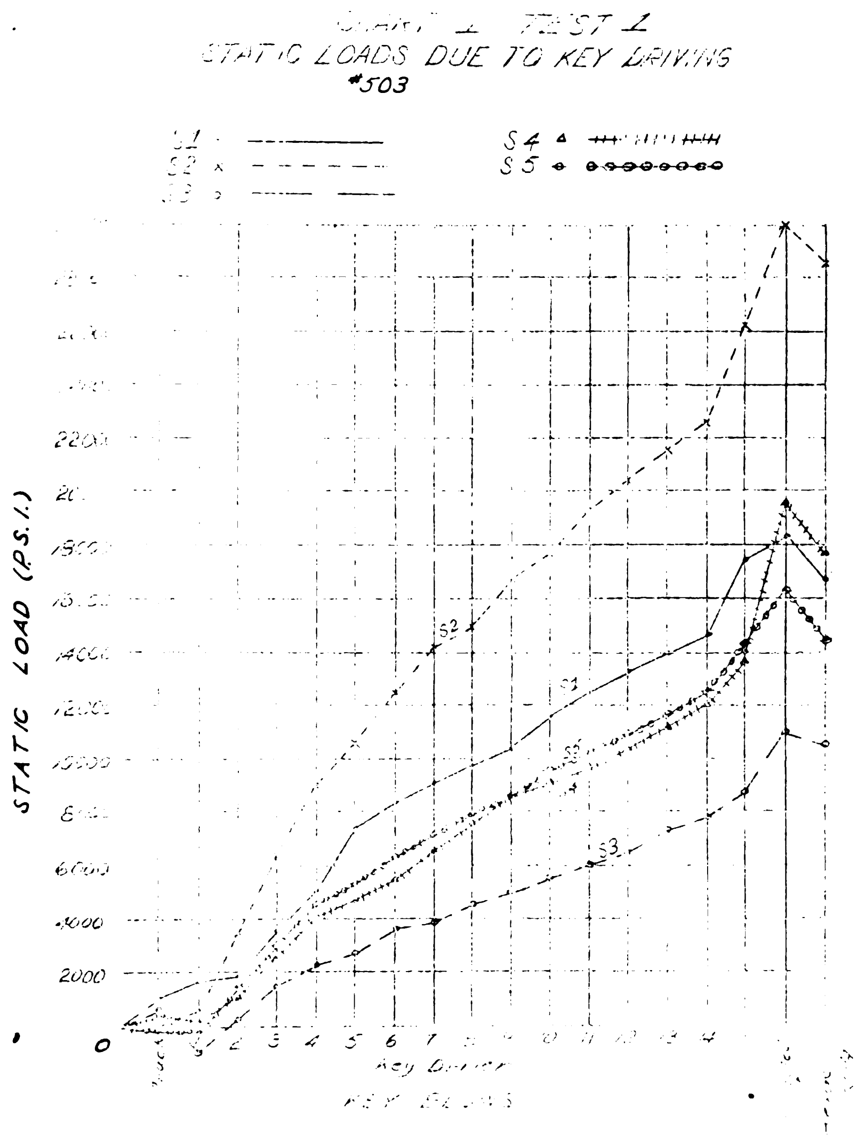

STATIC LOADS DUE TO KEY DRIVING
#503
S4
S5
STATIC LOAD (P.S.I.)
2200
14000
10000
6000
4000
2000
0
S2
S1
S3
2
3
4
5
6
7

Figure 7

become wedged so tightly that it was impossible to remove it. This in itself confirms the high stress imposed on the base. On closer examination of the key, it was found that it had raised seven-eighths of an inch on the front side.

The only way possible for this key to raise without backing out was by imposing an additional stress on the anvil while moving upward. If the original stress on the key was near the yield point, plastic deformation, or permanent set would certainly take place which would then allow further repetition of this cycle. Checking both key and sow-block fit, feeler gages of from 0.004 to 0.019 could be placed between both key and anvil, and the side and bottom of the sow-block and anvil. This nonuniform seating of the sow-block on the anvil would account for some of the sow-block failures which have occurred. Considering these factors, the accuracy of the gage S-2 is perhaps not as questionable as may at first be imagined. Nevertheless, elimination of gage S-2 still gives a residual stress of 19,000 p.s.i. which is far too high in view of the dynamic stresses involved. Uniform bearing of both sow-block and key on the anvil should lower the residual stress necessary to hold these units correctly in place.

Dynamic stresses recorded were very uniform as can be seen by reference to Figure 8, and the maximum stress produced was

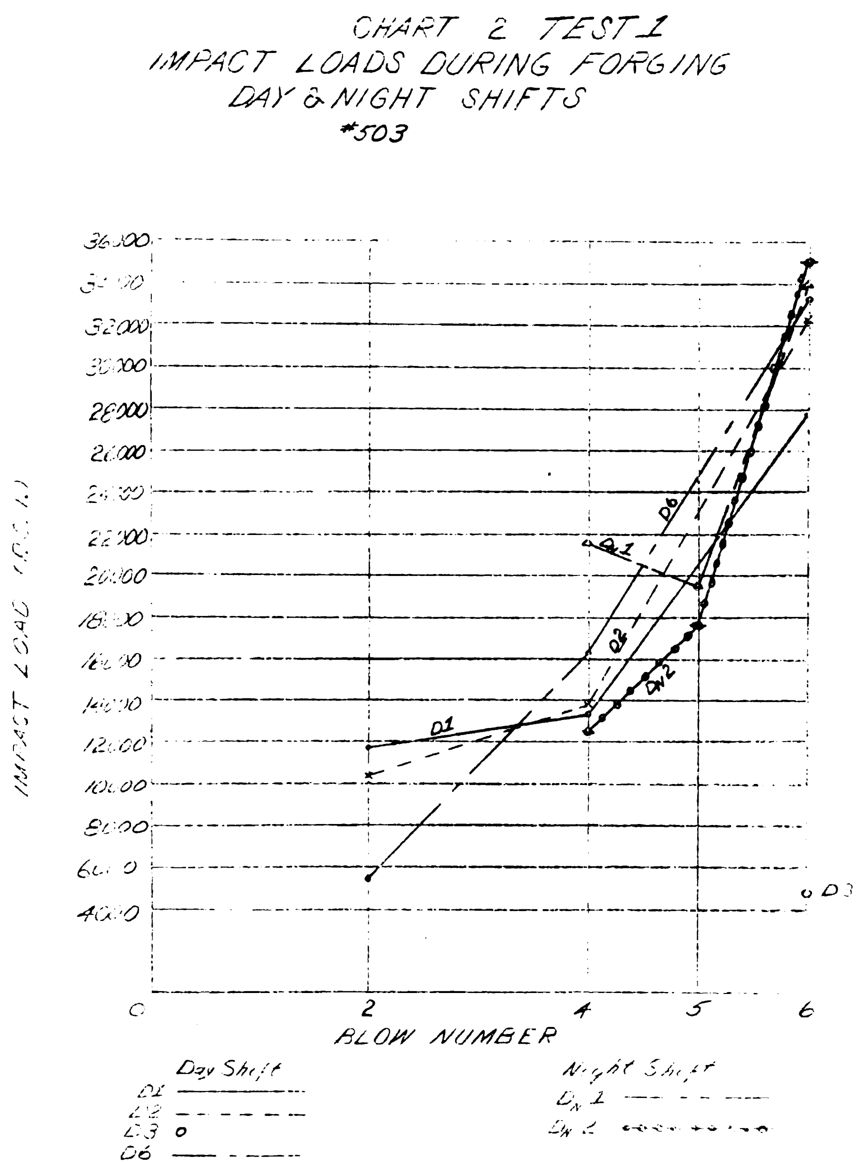


CHART 2 TEST 1
IMPACT LOADS DURING FORGING
DAY & NIGHT SHIFTS
#503
IMPACT LOAD
BLOW NUMBER
Day Shift
Night Shift
D1
D2
D3
D6

**Figure 8**

35,000 p.s.i. These values of maximum stress occurred on the final blow of the finisher where there was a very small amount of flash area, and the energy of impact is almost completely absorbed by the dies and base.

These dynamic stresses are again higher than necessary because of the localized bearing areas through which the dynamic load must be transferred to the base. Uniform load distribution should lower these stresses a considerable amount. The poor bearing surface was observed when the sow-block and key were removed from the anvil before installation of the gages. Definite galling at localized areas could be seen on the anvil face, caused by heavy loading at these spots and movement of the key.

No great difference in dynamic loads between day and night shifts was observed. The main difference was that on the night shift the hammerman used an extra blow on the second impression which subjected the base to one extra cycle of 20,000 p.s.i. for each forging.

It was not possible to obtain readings from gages D-4 and D-5 because steam was accidentally discharged in this area and removed the wax protective coating, shorting the gages and making them unstable. Readings on the night shift were taken only on D-1 and D-2, as the other gages had shorted out during the day shift.

No individual forging blow of excessively high impact stress was observed. Maximum stress values, both observed and recorded, varied little from average values.

The results of this test indicate that the effect of key and sow-block fit on the imposed stresses should be investigated more thoroughly and that Petresene wax does not offer sufficient water-proofing protection for steam hammer testing.

Test number two was conducted on hammer 503 to determine the effect of improved key and sow-block fit on the static and dynamic stresses imparted to the base. Gages were placed in the locations shown in Figure 6. Strain readings were recorded during the key drive, as the dies were brought up to heat, and during the forging operation.

A very marked decrease in the static loads was found in this test. Referring to Figure 9, the maximum load encountered was 6,150 p.s.i., which was only 20 percent of the maximum load in the first test. The number of blows required to drive the key was thirteen, as compared to twenty on the previous test; the progression of key travel was very regular.

The fact that this key fit was still far from perfect, even though greatly improved, was shown by the decrease in load by all

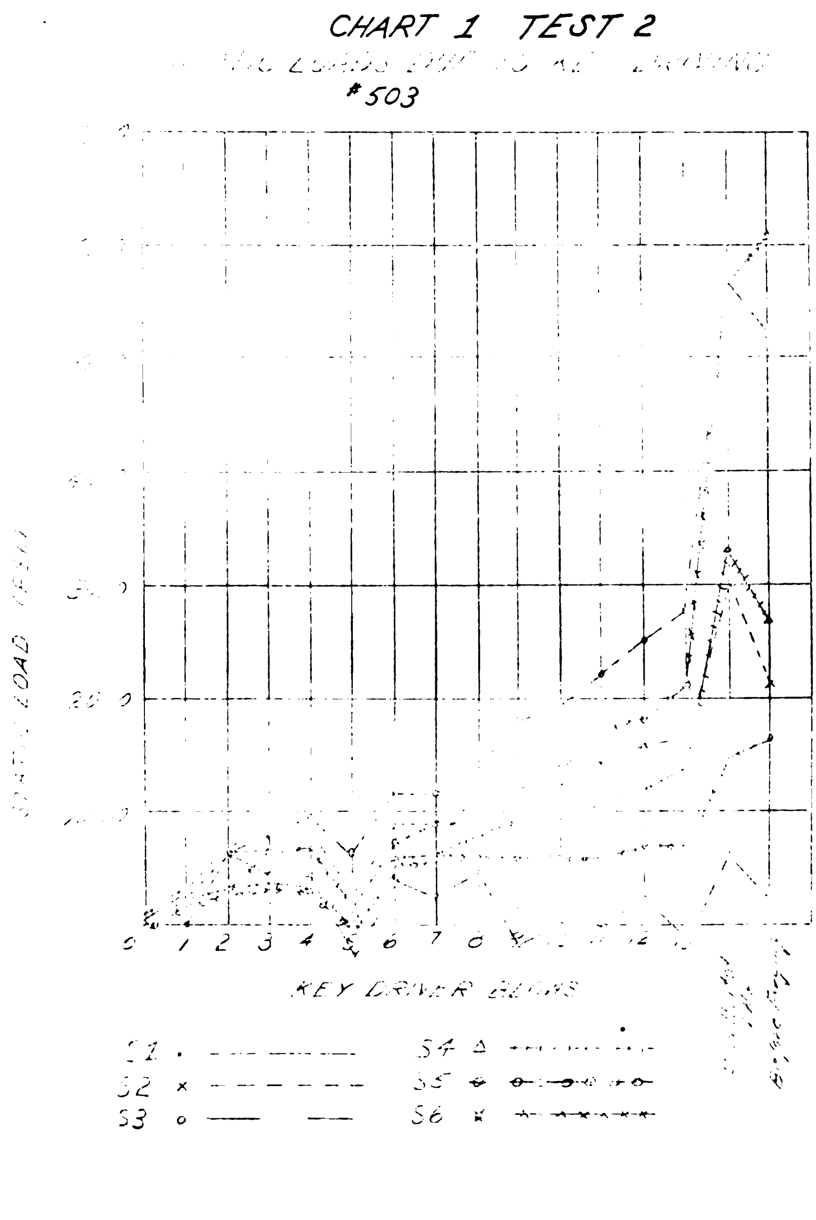



Figure 9

gages on blow five, with gage S-1 actually varying between tension and compression throughout the drive. The over all range of variation, however, is much smaller than that encountered in the first test. Gages S-3 and S-6 indicated the highest stress. These gages located on the face of the anvil would point out that with the fit of this key, the wedging force was initiated at the front edge of the anvil, and this was further supported by the readings of gages S-2 and S-4, which were located in the front edges of the fillet radii.

A one thirty-second inch shim was placed between the key and sow-block in order to determine the effect of this shim on load distribution. Before readings were taken the hammer was operated for one complete shift and at the end of this time it was noticed that there was displacement of the key. To correct this the key was driven out and replaced. The readings of Figure 10 were taken through this procedure. The key was examined when it was removed, and it could be seen that there was a much larger area bearing than before, although there was still evidence of localized bearing areas. In two areas both the key and anvil were gouged quite deeply, presumably from holes left when a key had been burned out. This was the second time that the key had been driven since the original fit, and the combination of localized bearing areas and gouging

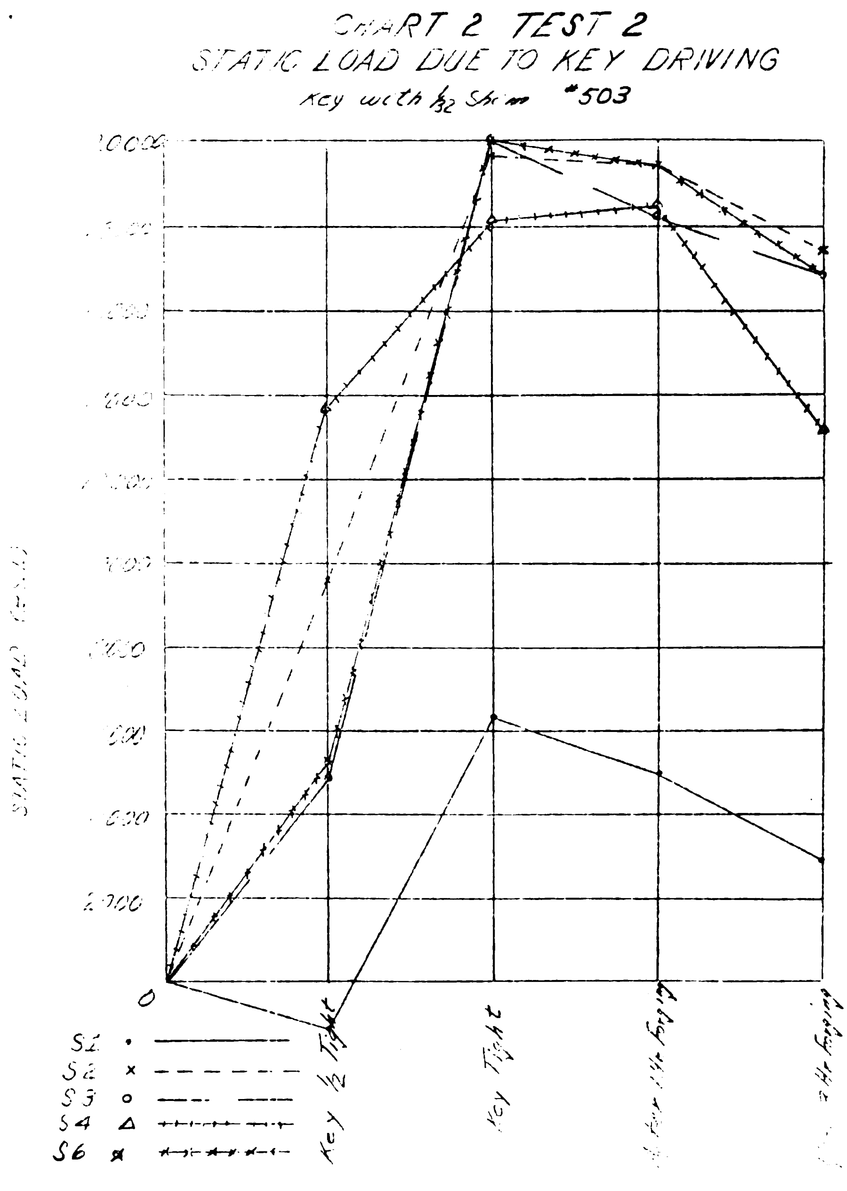


CHART 2 TEST 2
STATIC LOAD DUE TO KEY DRIVING
Key with 1/32 Shim #503
0
S1
S2
S3
S4
S6
Key 1/2 Tight
Key Tight

**Figure 10**

could possibly have been great enough to destroy the degree of fit that had been obtained. This would account for the much greater loads obtained during this operation. However, the locations of high stress and the general trends were the same as previously, which help to verify the accuracy of the data.

Another interesting observation was that immediately after driving the key, gages S-3 and S-6, with the highest loads, indicated very slow relief through localized distribution through the shim. After one hour and three hours of forging, all of the gages indicated a relief of about 3,000 p.s.i. The key did not begin to raise after two days of operation, and it became evident that it is not necessary to drive the key this tightly to hold it.

The dynamic loads were also lower than in the previous test as can be seen in Figure 11. The maximum load was 30,000 p.s.i. as compared to 35,000 p.s.i. previously. The individual gages indicated a stress approximately 5,000 p.s.i. lower, a definite improvement. It was not possible to compare the night operation because of failure of the amplifier unit.

Considering the combined static and dynamic loads, an operating range of 29,000 to 37,000 p.s.i. average can be determined. This range, although vastly improved over the previous test, is still at, or above, the endurance limit of the material. The results of any

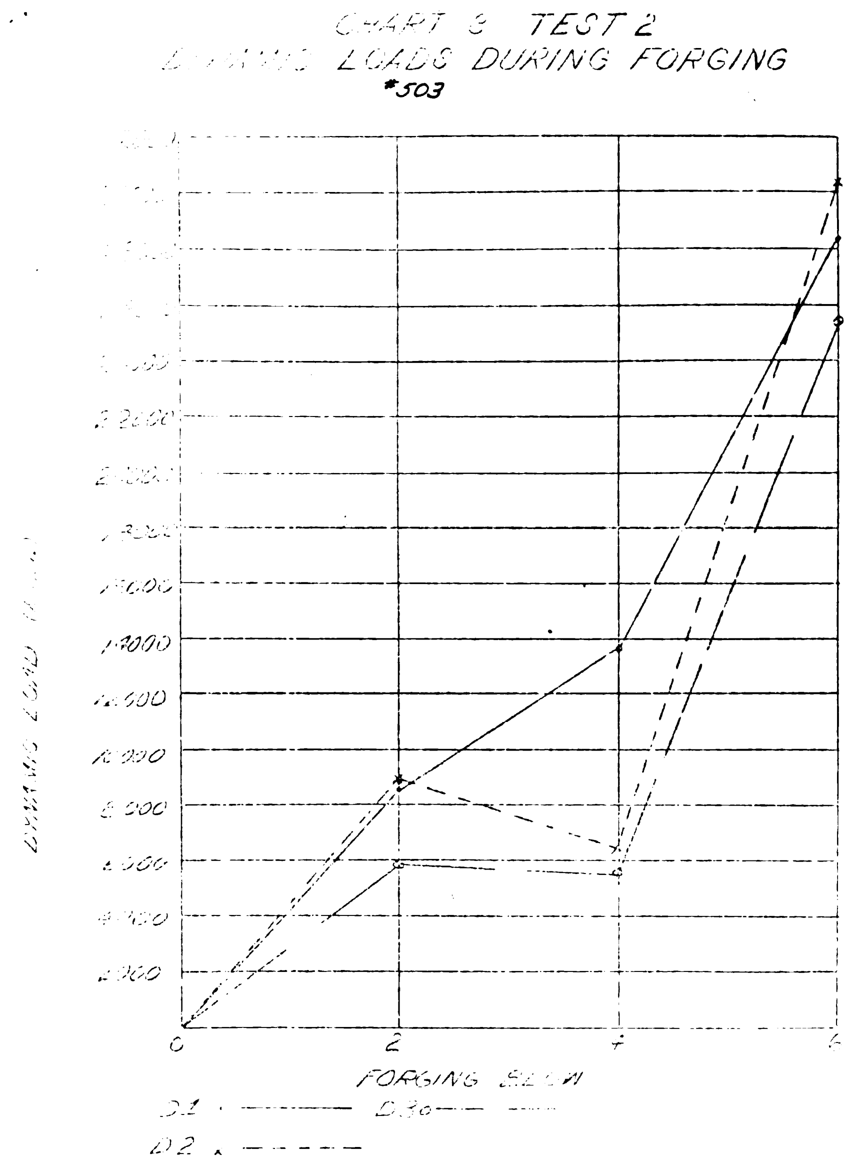



Figure 11

one test cannot be considered conclusive. However, if this degree of improvement can be obtained with the small amount of care that was taken to fit the key and sow-block, a corresponding improvement should be possible with a perfectly machined fit. It becomes apparent that it is necessary to remove the human error involved in hand grinding the anvil base, and substituting mechanical control to do this job.

Test number three on hammer 503 was the last of the tests that was conducted for this problem, but the discussion is placed at this point for continuity in comparison with the earlier five thousand pound hammer tests.

Before conducting the test, a detailed study was made of all previous tests and the configuration of the hammer itself, in order to determine the specific distribution and origin of the dynamic loads on impact of the hammer ram. From this study it became apparent that the principal stresses at the fillet radii were being initiated by the effect of Poisson's ratio which causes the sow-block to expand against the anvil sides during the forging operation. Further, if this is the origin of the load on the fillet radii, the principal stress at this location will be unidirectional and at right angles to the anvil seat. Another factor noted was that the temperature variation in the anvil area produces a major effect on the static stress levels. To get a further picture of stress distribution around the anvil seat, a scale model of a hammer base was made. By use of brittle lacquer techniques, areas of stress concentration under static and dynamic loads were located. Under dynamic loads this model indicated a maximum stress area approximately three inches from the fillet, toward the center of the anvil. With verification of these points in mind, the final test on the five thousand pound hammer was carried out.

Strain gages were located in the positions shown in Figure 12, and readings were again taken as the key was driven, during die heating, and under impact conditions.

Prior to this test, the anvil seat of hammer 503 was completely remachined and a new sow-block and key prepared for installation. The effect of improvement in fit is indicated in Figure 13. The increase of stress with each key blow is very uniform up to the point where the dies were heated. After the die warmers were applied, localized expansion and contraction reduced the compressive load on all of the gages which were under compression. Evidence that this key fit is still not perfect is shown by G-2, G-5, and G-6, which indicated a still further decrease of compressive loading during

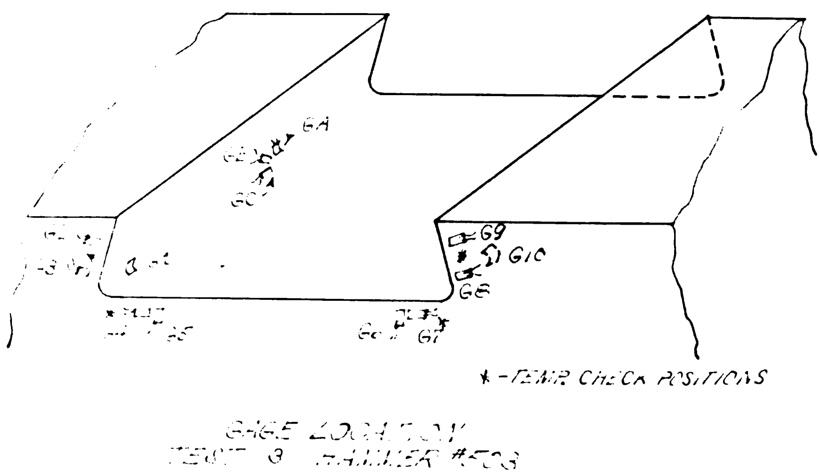



**Figure 12**

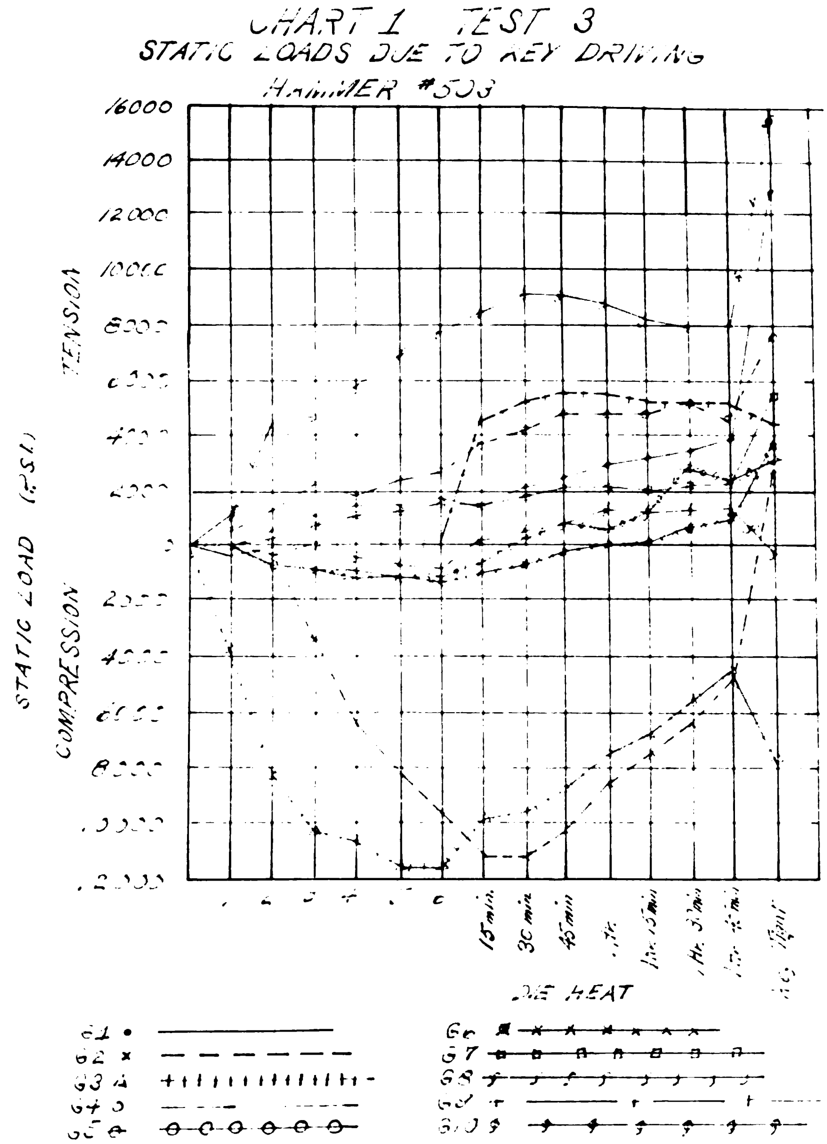


CHART 1 TEST 3
STATIC LOADS DUE TO KEY DRIVING
16000
14000
TENSION
COMPRESSION
STATIC LOAD
15 min
30 min
45 min
DIE HEAT

**Figure 13**

the final tightening of the key. Final static loads with this sow-block and key were lower than those of the original test, which also helps to verify the importance of good sow-block and key fit.

Temperature variation over the face of the anvil during the die warming procedure is shown by Table I. Through the original heating stage, temperature variation was very erratic due to the positioning of die warming blocks. After a period of twenty-four hours, the temperatures around the anvil area were fairly well equalized. This indicates the importance of not driving the key fully tight until the temperature at the anvil area has equalized, thus preventing high localized stresses.

Dynamic readings, which are shown in Figure 14, indicate a maximum of 28,000 p.s.i. which was slightly lower than readings in earlier tests. The distribution of these readings confirmed the hypothesis that the imposed loads originated from Poisson dimensional change of the sow-block. Absence of any noticeable indication on G-5 and G-6 indicates that the dissipation of the stress wave at the anvil seat was widely distributed, and that a stress wave was propagated along the upper surface of the sow-block traveling across the block to the sides of the anvil. This wave was then multiplied by a cantilever action at the fillet radii, causing the high strain indications at those locations.

TABLE I

ANVIL SEAT TEMPERATURE DISTRIBUTION,
HAMMER BASE 503

| Time Die Warmers On | Temperature (° F.) | | | | |
|---|---|---|---|---|---|
| | Sow-Block | Point 1 | Point 2 | Point 3 | Point 4 |
| 30 minutes . . . . . . . . . | 95 | 75 | 70 | 70 | 100 |
| 1 hour . . . . . . . . . . . . | 105 | 75 | 70 | 70 | 100 |
| 1.5 hours . . . . . . . . . . | 100 | 80 | 70 | 70 | 100 |
| 2 hours . . . . . . . . . . . . | 100 | 80 | 75 | 75 | 95 |
| 24 hours . . . . . . . . . . . | 105 | 95 | 80 | 80 | 95 |

Note: Temperature check positions shown in Figure 12 are numbered counterclockwise from the left side.

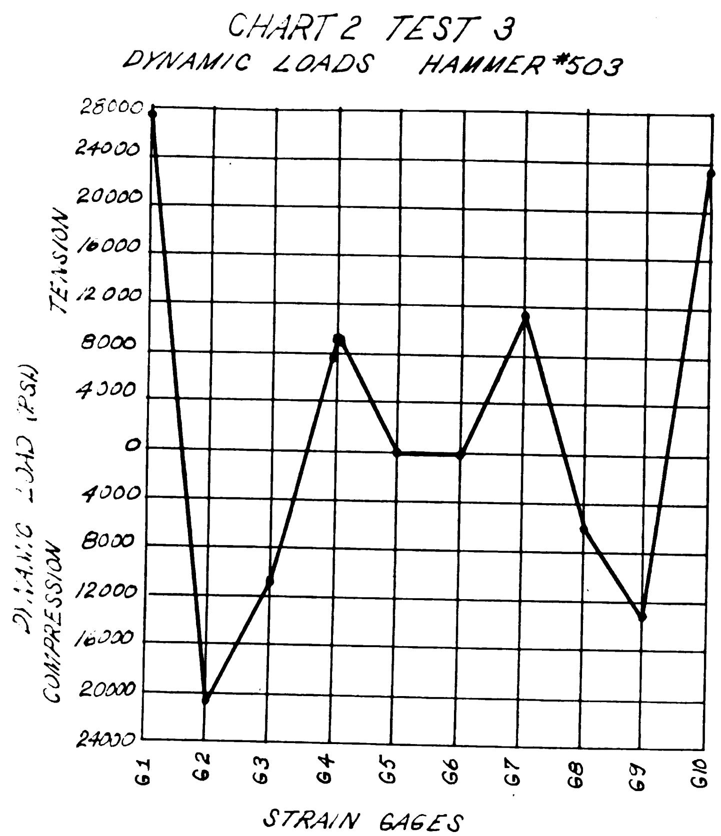


CHART 2 TEST 3
DYNAMIC LOADS HAMMER #503
28000
24000
20000
16000
12000
8000
4000
0
4000
8000
12000
16000
20000
24000
TENSION
COMPRESSION
G1
G2
G3
G4
G5
G6
G7
G8
G9
G10
STRAIN GAGES


Figure 14

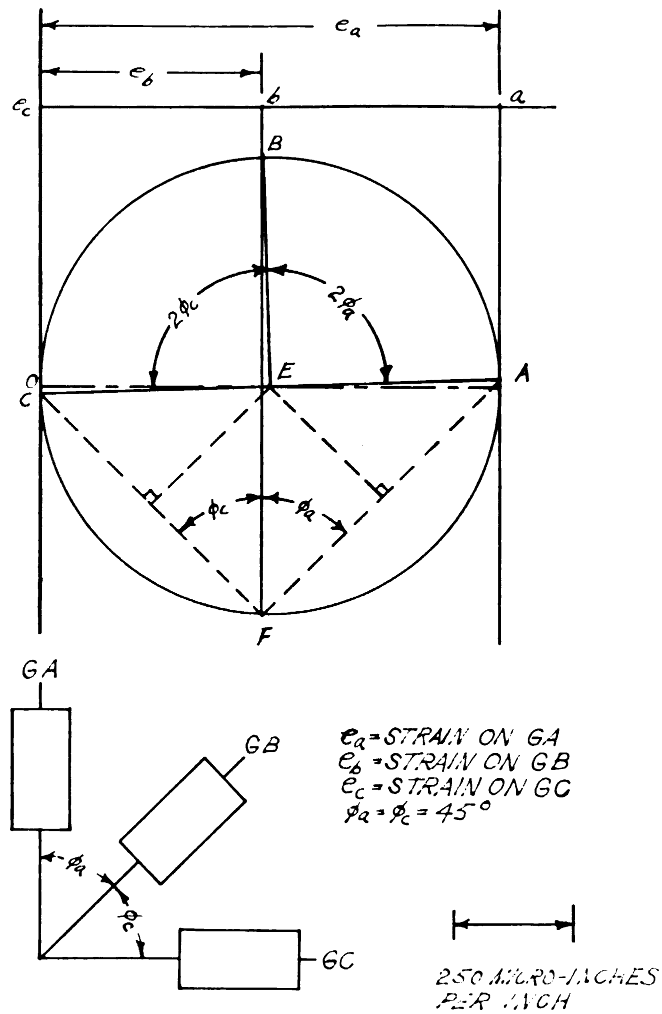
The principal stress directions were determined by means of G-A, G-B, and G-C placed in the anvil fillet. The graphical determination by Murphy's method is shown in Figure 15. The direction of this stress was as anticipated, completing the verification of the effect of Poisson's ratio on imposed loads.

The results of this test gave a fairly complete picture of the distribution of imposed stresses in the area of the anvil seat.

One test was conducted on a fifteen thousand pound steam hammer to obtain a comparison in working loads and general stress distribution with the five thousand pound hammer.

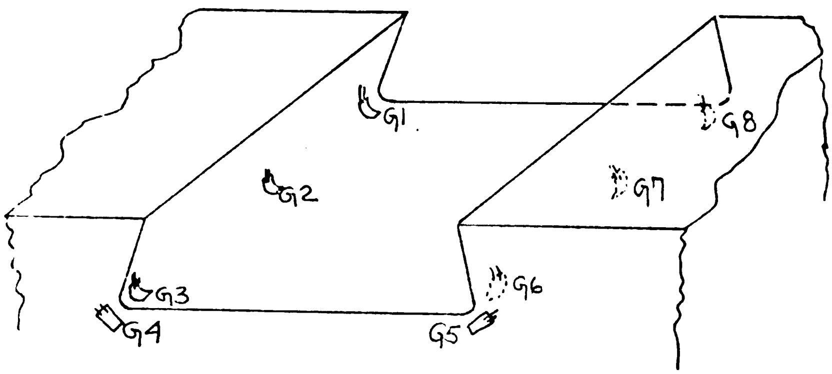
Strain gages were placed in the locations shown in Figure 16, and readings were taken following the same procedure as in earlier tests.

Figure 17 shows the build-up of stress in the base as the key was driven, dies heated and at four different time intervals during forging. The procedure in this case was to drive the key only partially, bring the dies to heat, and finish driving the key. However, due to a misunderstanding the key was driven during the second shift and readings were not taken for the final tightening of the key. Therefore, the section on the chart between die heat and the first forging reading represents the total build-up during this final key drive.




PRINCIPAL STRESS DETERMINATION
(Murphy's Method)

**Figure 15**




GAGE LOCATION #153 HAMMER

Figure 16

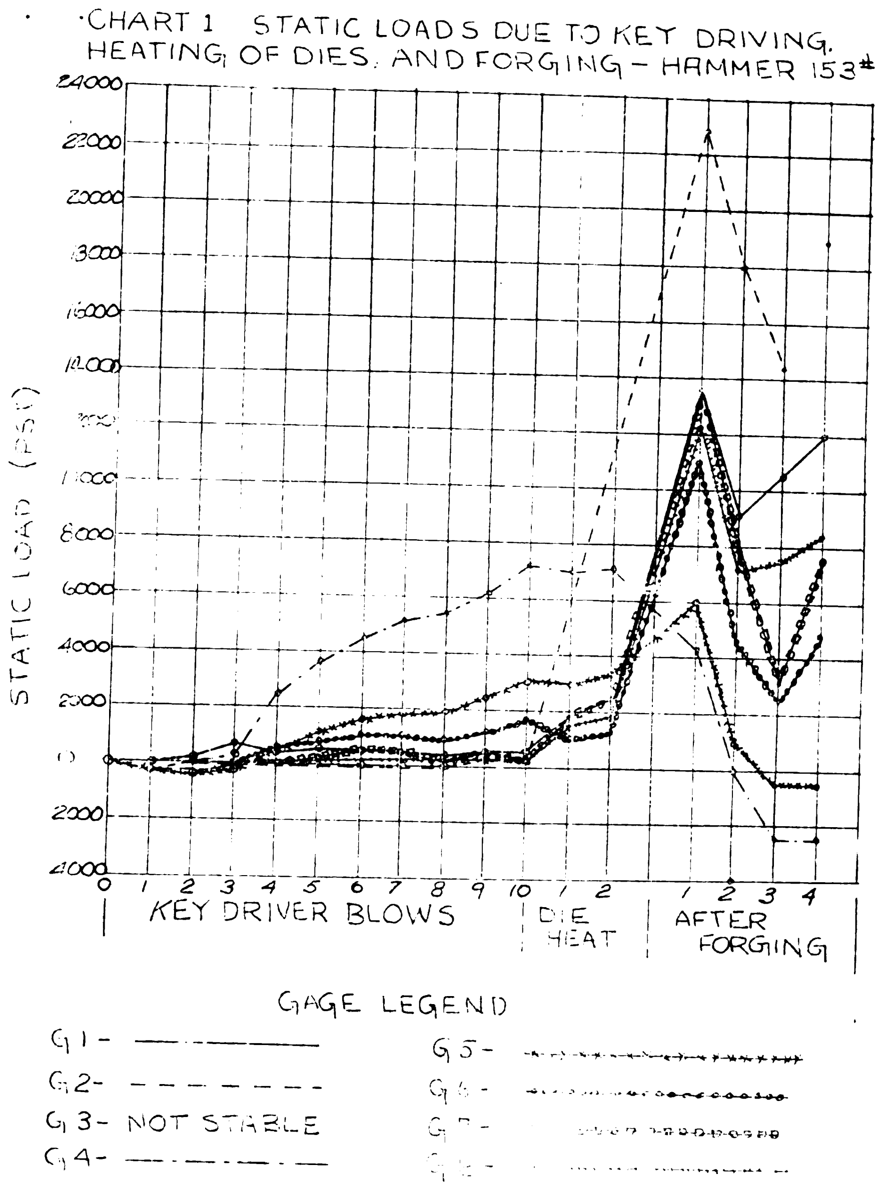


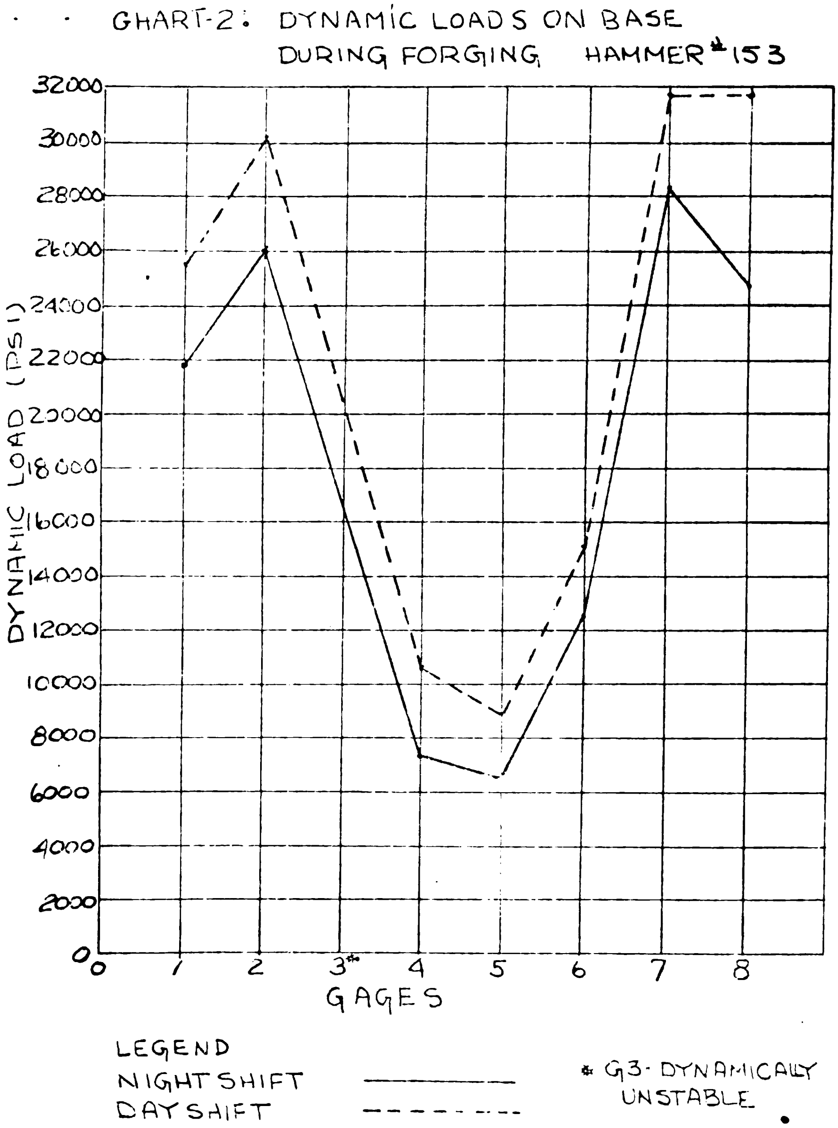
CHART 1 STATIC LOADS DUE TO KEY DRIVING. HEATING OF DIES. AND FORGING - HAMMER 153#
STATIC LOAD (PSI)
24000
22000
20000
4000
2000
0
2000
4000
0 1 2 3 4 5 6 7 8 9 10 1 2 1 2 3 4
KEY DRIVER BLOWS
DIE HEAT
AFTER FORGING
GAGE LEGEND
G1 -
G2 -
G3 - NOT STABLE
G4 -
G5 -

**Figure 17**

The initial build-up was quite uniform with the exception of G-4 which was on the outside face of the anvil. This would indicate that with this key fit the wedging force of the key was taking effect on the front ege of the anvil. Gage 5, also on the face, confirms this. When the dies were heated and the key fully tightened, the load was transferred to the center of the anvil opening. This was due to the shape of the die which was located in the center of the anvil. The maximum load was recorded on Gage 2 at the center of the anvil on the key side. The value was 23,000 p.s.i., with the other gages averaging about 12,000 p.s.i.

The first dynamic readings recorded while forging a large turbine disc are shown in Figure 18. The maximum loads were noted on the same gages with maximum static loads. Both day and night shifts were recorded with a maximum on the day shift of about 32,000 p.s.i. One peculiarity noticed in this forging operation was that after the first two blows, each blow imparted about the same amount of stress to the base. As to the number of blows, the night hammer-men hit four more blows than the day men--the day men using twenty blows to complete the forging.

After completing these forgings, dies were changed for a smaller turbine disc. The key had loosened during forging in the



GHART-2: DYNAMIC LOADS ON BASE DURING FORGING HAMMER #153
DYNAMIC LOAD (PSI)
32000
30000
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
1
2
3*
4
5
6
7
8
GAGES
LEGEND
NIGHT SHIFT
DAY SHIFT
* G3- DYNAMICALLY UNSTABLE


Figure 18

other die and it was retightened with the results shown in Figure 19. The relationship of the gage readings remained unchanged but the final load reached was much higher, with G-2 reaching 31,000 p.s.i. after forging. The readings, ten to fifteen on the chart, represent five different time intervals covering a total period of three days. During this period the hammer had been run intermittently and this is reflected in the variations on the graph. This variation was due to temperature change in the dies. Gages 4 and 5 which were on the face of the anvil still showed very little increase in load through this final drive.

The dynamic loads (Figure 20) on this disc were somewhat higher, reaching a maximum of 33,000 p.s.i. on Gage 2. The general pattern was the same as before. In forging this disc, there was no reheat between the blocker and the finisher which might account for the higher stress which would result from working the colder metal.

Considering both the static and dynamic loads, forging of the first disc resulted in a working load of 55,000 p.s.i., and the working load on the second disc exceeded 60,000 p.s.i. Though it is difficult to compute accurately a true combined stress level, the values indicated in this test exceeded the yield strength of the base material and undoubtedly approach the ultimate strength.

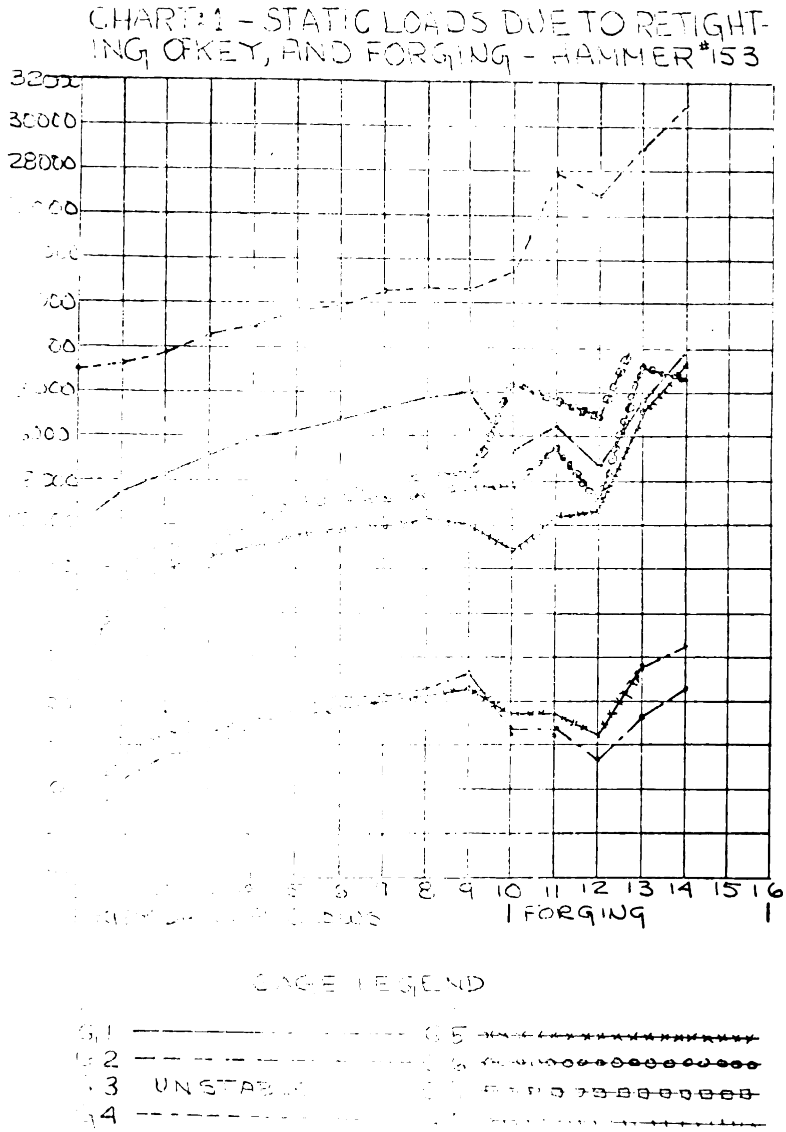


CHART 1 - STATIC LOADS DUE TO RETIGHTING OF KEY, AND FORGING - HAMMER #153
32000
30000
28000
7 8 9 10 11 12 13 14 15 16
1 FORGING 1
UNSTAB
G 2
3
4
G 5

Figure 19

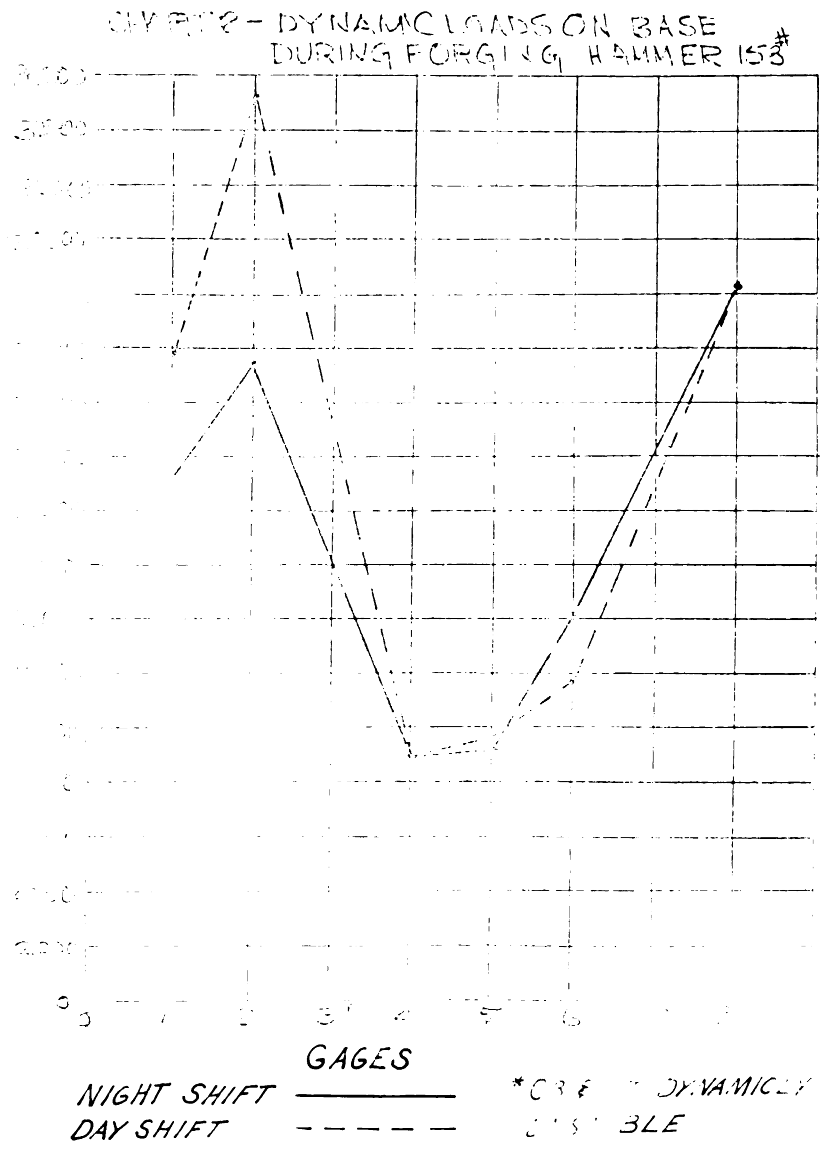

DYNAMIC LOADS ON BASE
DURING FORGING HAMMER 153#
GAGES
NIGHT SHIFT
DAY SHIFT

**Figure 20**

Before this key was installed, certain high bearing areas were evident, and these showed up in several gage areas during the key drive.

The general trends in static and dynamic loading in both five thousand and fifteen thousand pound steam hammers are similar. The intensity of the static loading in both hammers appears to be dependent upon the same factors while the over-all working load is slightly higher for the larger hammer.

# CHAPTER V

## METALLURGICAL INVESTIGATION OF BASE MATERIAL

The determination of imposed stresses on the hammer base anvil during forging established the degree of loading which the base material must be capable of withstanding. The purpose of these present studies was to determine if the base material was metallurgically sound, meeting the specifications under which it was purchased, and if these specifications were capable of withstanding the service stresses during the forging operation.

Test specimens were cut from hammer bases which had failed within the past year. From these samples a tensile bar was machined, chemical analysis determined, and microsamples produced. Table II lists the chemical analysis and physical properties of the various samples. All samples were taken from cast steel bases, both five thousand and fifteen thousand pound. Samples 5431-A, B, C, D were core-drilled from a new base at the foundry. The locations were as follows:

TABLE II

METALLURGICAL ANALYSIS OF HAMMER ANVILS

| Laboratory Sample | Chemical Analysis | | | | |
|---|---|---|---|---|---|
| | C | Mn | P | S | Si |
| 7449 | 0.20 | 0.39 | 0.020 | 0.033 | 0.34 |
| 7331 | 0.22 | 0.44 | 0.023 | 0.034 | 0.40 |
| 7331-A | 0.19 | 0.43 | 0.018 | 0.025 | 0.36 |
| 7949 | 0.26 | 0.66 | | | |
| 5431-A | 0.19 | 0.48 | 0.030 | 0.022 | 0.33 |
| 5431-B | 0.33 | 0.52 | 0.046 | 0.048 | 0.37 |
| 5431-C | 0.16 | 0.48 | 0.035 | 0.035 | 0.34 |
| 5431-D | 0.17 | 0.49 | 0.030 | 0.030 | 0.33 |

TABLE II (Continued)

| | | Physical Properties | | | |
|---|---|---|---|---|---|
| Ni | Cr | Yield Strength | Ultimate Strength | % El. | % R.A. |
| 0.48 | 0.10 | 25,000 | 55,500 | 24.5 | 34.1 |
| 0.44 | 0.05 | 25,000 | 55,500 | 31.0 | 49.2 |
| 0.35 | 0.05 | | | | |
| 0.14 | 0.03 | 26,000 | 60,700 | 25.0 | 34.1 |
| 0.40 | 0.34 | 21,250 | 54,000 | 25.0 | 46.3 |
| 0.38 | 0.34 | 37,500 | 71,900 | 5.5 | 6.2 |
| 0.35 | 0.31 | 20,375 | 47,900 | 27.0 | 56.9 |
| 0.32 | 0.31 | 23,000 | 54,550 | 18.0 | 21.0 |

| Sample | Location |
| --- | --- |
| A | Right side. |
| B | Left side at the sprue. |
| C | Front face. |
| D | Back face. |

All samples were taken twenty-four inches below the anvil seat on the vertical center line of the base.

All other samples were removed in the vicinity of the failure with the exception of sample 7331 which was removed from a solid section of the same base as sample 7331-A.

Hammer bases are purchased on carbon specification only, with no specification as to physical properties. They are pit cast, poured from one end at a pouring temperature of 2850 to 2900° F. The anvil opening is partially cored and machined to size later. Castings are left in the pit one day for each five thousand pounds, approximately twenty days for a fifty ton anvil, and when removed are at a temperature of 200 to 300° F. They are subjected to no further heat treatment.

Figure 21 illustrates the sulfide inclusions and the stringers which were evident in all of the microsamples in an excess amount. These stringers and inclusions are very detrimental to the impact properties of the material, serving as stress concentrators throughout the section. Figures 22, 23, 25, 27, 28, 30, and 31 are typical

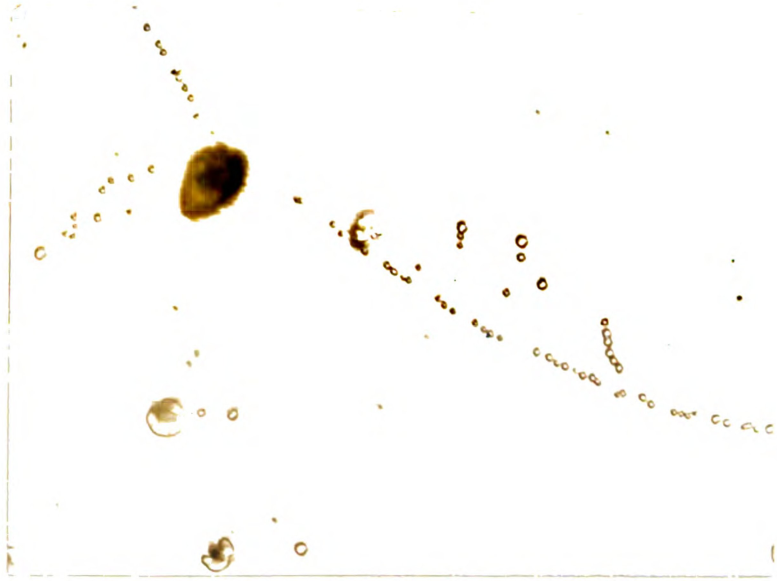


Figure 21. Sample 7449; picric acid etch; X 200; C - 0.20%.

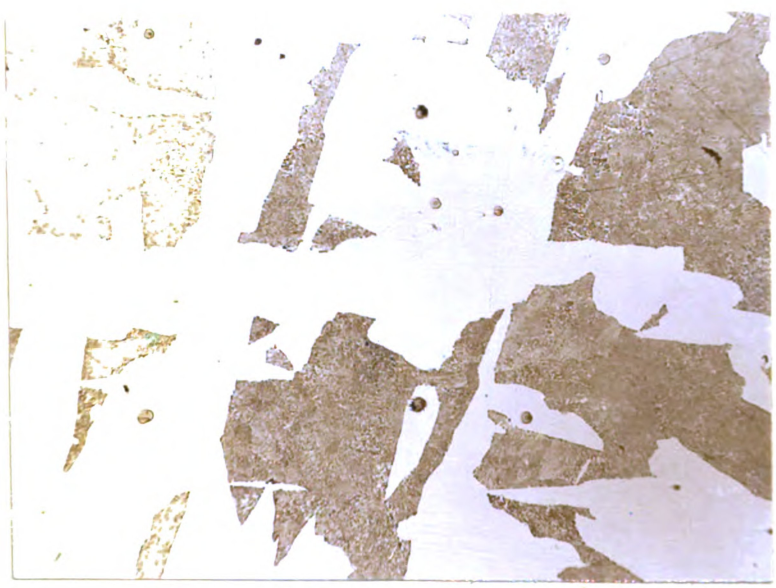


Figure 22. Sample 7449; picric acid etch; X 75; C - 0.20%.

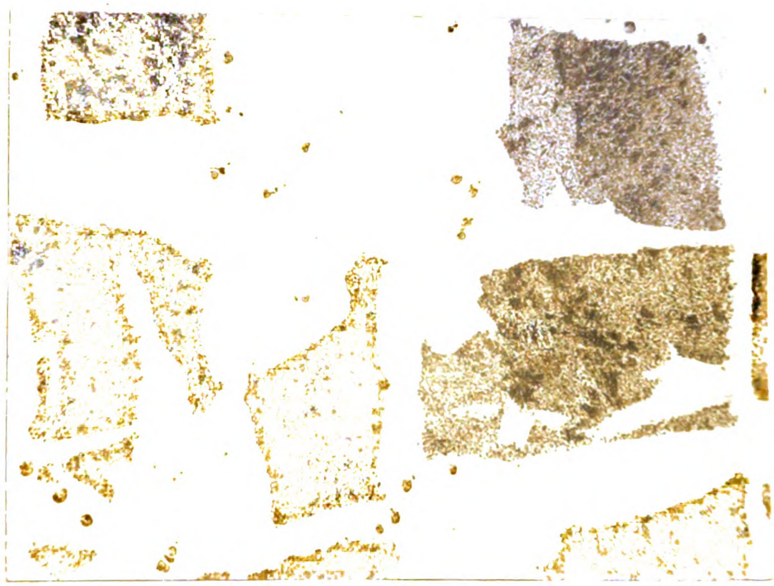


Figure 23. Sample 7331; picric acid etch; X 75; C - 0.22%.

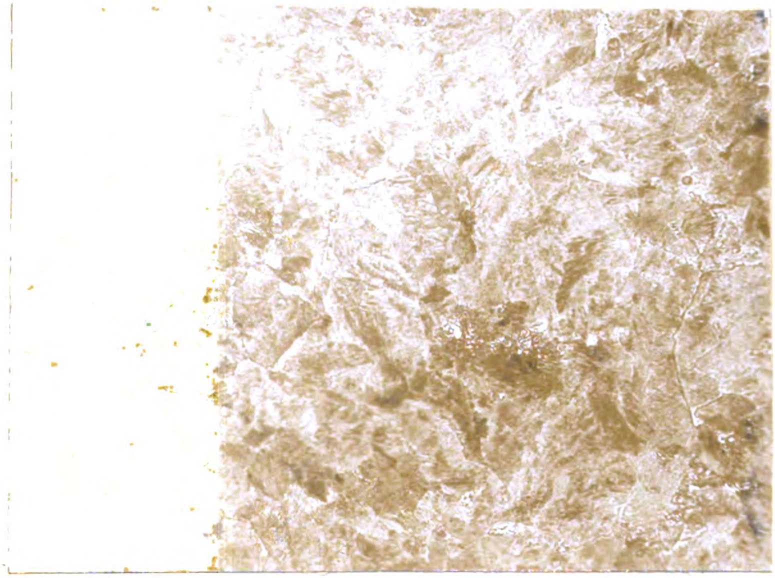


Figure 24. Sample 7331; picric acid etch; X 75; C - 0.47%.

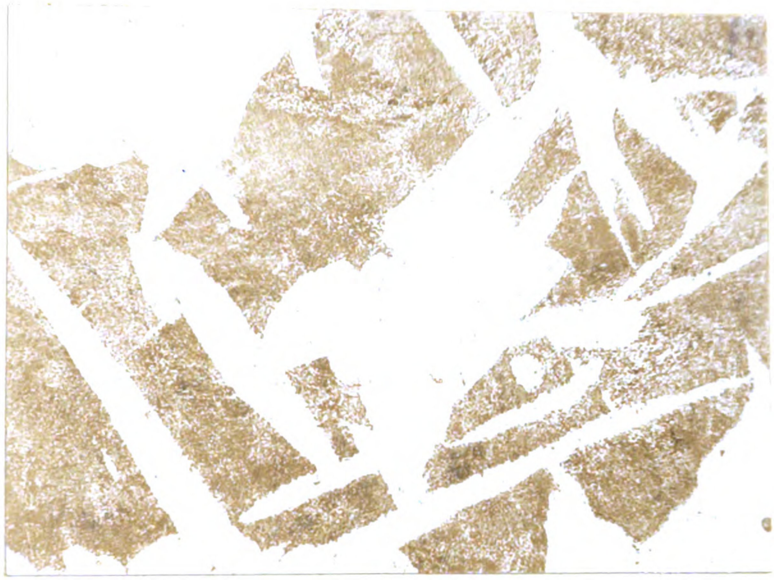


Figure 25. Sample 7331-A; picric acid etch; X 75; C - 0.19%.

Figure 26. Sample 7331-A; picric acid etch; X 75; C - 0.49%.

Figure 27. Sample 7949; picric acid etch; X 75; C - 0.26%.

Figure 28. Sample 5431-A; picric acid etch; X 75; C - 0.19%.

Figure 29. Sample 5431-B; picric acid etch; X 75; C - 0.33%.

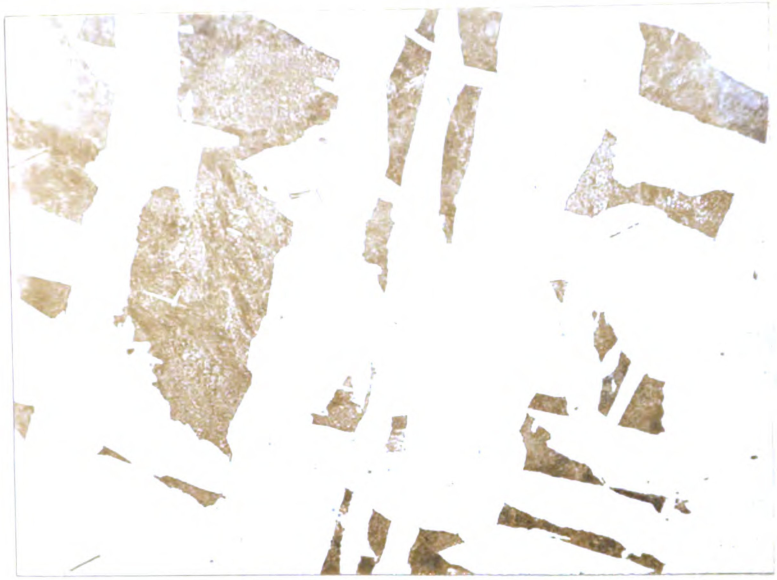


Figure 30. Sample 5431-C; picric acid etch; X 75; C - 0.16%.

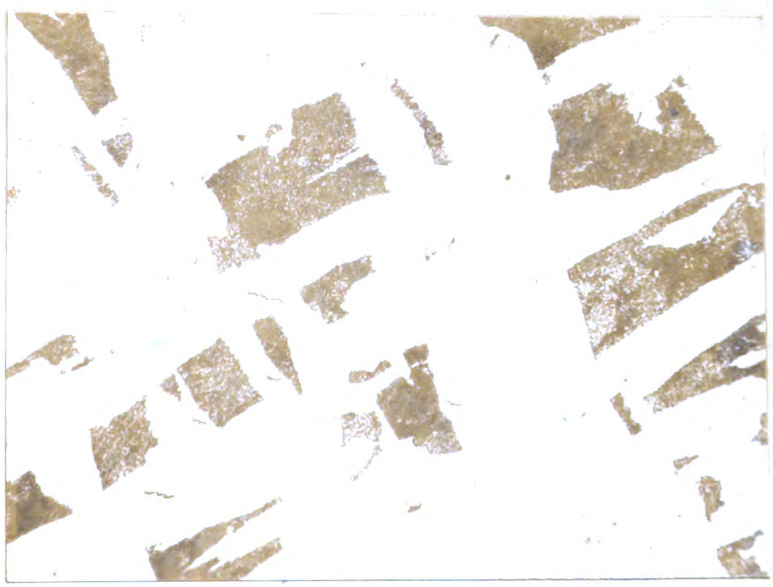


Figure 31. Sample 5431-D; picric acid etch; X 75; C - 0.17%.

examples of the structure of a low carbon cast steel which has been subjected to a very slow cooling rate in a large section size. This structure is pearlite in a matrix of free ferrite. Severe carbon segregation is evident in samples 7331 and 7331-A (see Figures 24 and 26). Two microspecimens were cut from each test sample removed from this base. The microsamples showing the high percentage of pearlite were rechecked for carbon content and indicated 0.47 and 0.49 percent carbon in samples 7331 and 7331-A, respectively. The carbon segregation in this area could possibly explain the failure of this base in the side-frame fillet instead of the usual anvil seat area. The high carbon content of sample 5431-B is due to the segregation of carbon at the sprue during cooling of the casting (see Figure 29).

The physical properties of the samples were quite scattered and generally low for this range of chemical analysis. This further points to segregation and inhomogeneity throughout the casting. Disregarding those deviations from a perfect casting which were present, it can be seen that a perfect casting with the maximum physical properties possible with this analysis and section size would be taxed to its maximum to withstand the imposed stresses recorded during the forging operation.

CHAPTER VI

# CONCLUSIONS AND RECOMMENDATIONS

The investigation carried out to determine the imposed stress levels on hammer base anvils during forging operation has established definite levels which may be expected in the region of the anvil seat. Static loads that may be expected with the presently designed key and sow-block units are in the range of 15,000 p.s.i. to 20,000 p.s.i. with the degree of fitting now used in sow-blocks and keys. This range varies with the accuracy of fitting these units, and smaller tolerances in placing both key and sow-block in the hammer should result in a substantial decrease in static loads. Static stress levels are also aggravated by die warming and the key should not be fully tightened until temperature variations in the anvil seat area have equalized. Dynamic stress levels are also influenced by the degree of sow-block and key fit, and stresses up to 30,000 p.s.i. may be expected in the fillet radii of the anvil.

Perhaps as important as the determination of degree of stress is the determination of distribution and origin of the strain loading. The transfer of load to the sides of the anvil seat is definitely caused by the effect of Poisson's ratio on the sow-block under impact. A theoretical analysis of this effect applied to the hammer base reveals that a unit increase in sow-block width will produce a proportional decrease in transmitted load to the anvil sides. A further investigation of wave propagation across the top of the sow-block is necessary to determine the exact benefit this type of design change would produce. The principal stress in the fillet radii is unidirectional and at right angles to the anvil seat. Modification of key design to produce a key which would act as a stiff spring would also reduce the strain transmitted to the anvil sides. A key of this design would be comparable to two springs in series resulting in smaller deflection per unit load applied.

Metallurgically there is evidence of carbon segregation and excessive inclusions in the present base material. However, with the present type of casting the maximum physical properties are not sufficient to withstand the imposed loads for satisfactory periods of time. An alloy steel casting combined with a normalizing heat treatment to reduce the relative blocky ferrite and elimination of segregation would produce a marked improvement in the physical properties of the base. Because of the orientation of the principal stress in the fillet radii, a correlation of improvement in impact properties would be possible by means of impact testing with a specially designed specimen to evaluate the effects of changes in heat treatment and chemical analysis.

Recommendations for additional work are:

1. Determination of wave propagation in the sow-block by additional strain gage tests.

2. Photoelastic tests with variations in anvil fillet, sow-block and key design.

3. A more extensive examination of one broken base by core-drilling samples from several selected locations.

4. Consultation with hammer base manufacturers to develop a heat-treated alloy steel casting.

5. Impact testing with a specially designed specimen to evaluate proposed changes in chemical analysis and heat treatment.

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# APPENDIX

TABLE III

STATIC STRAIN DATA, HAMMER 503, TEST 1
(gage type A-7, resistance 119.5 ohms, gage factor 1.93)

| Load Readings | Instrument Readings | | | | | |
|---|---|---|---|---|---|---|
| | S-1 | S-2 | S-3 | S-4 | S-5 | S-1 |
| Zero . . . . . . . . | 12-1875 | 12-0720 | 10-0770 | 10-1375 | 12-0155 | |
| Truck drive . . . | 12-1910 | 12-0720 | 10-0800 | 10-1400 | 12-0155 | + 35 |
| Key driver 1 . . | 12-1960 | 12-1740 | 10-0755 | 10-1380 | 12-0150 | + 50 |
| Key driver 2 . . | 12-1970 | 12-0845 | 10-0775 | 10-1420 | 12-0210 | + 10 |
| Key driver 3 . . | 14-0030 | 12-0930 | 10-0820 | 10-1470 | 12-0255 | + 60 |
| Key driver 4 . . | 14-0120 | 12-1070 | 10-0850 | 10-1540 | 12-0330 | + 90 |
| Key driver 5 . . | 14-0147 | 12-1130 | 10-0890 | 10-1555 | 12-0360 | + 25 |
| Key driver 6 . . | 14-0230 | 12-1270 | 10-0935 | 10-1660 | 12-0440 | + 85 |
| Key driver 7 . . | 14-0290 | 12-1360 | 10-0970 | 10-1700 | 12-0490 | + 60 |
| Key driver 8 . . | 14-0310 | 12-1400 | 10-0990 | 10-1720 | 12-0515 | + 20 |
| Key driver 9 . . | 14-0450 | 12-1590 | 10-1060 | 10-1840 | 12-0630 | +140 |
| Dies Heated 1 Hour . . . | 14-0480 | 12-1720 | 10-1140 | 12-0030 | 12-0700 | + 30 |
| Before forging . | 14-0440 | 12-1675 | 10-1130 | 10-1970 | 12-0640 | - 40 |
| Total . . . . . . . | | | | | | +565 |

After key is substantially tight, average key movement is 3/32 inch with stress build-up of 900 p.s.i. per blow.

TABLE III (Continued)

| Strain (microinches/inch) | | | | Stress (p.s.i.) | | | | |
|---|---|---|---|---|---|---|---|---|
| S-2 | S-3 | S-4 | S-5 | S-1 | S-2 | S-3 | S-4 | S-5 |
| 0 | + 30 | + 25 | 0 | +1050 | 0 | +0900 | +0750 | 0 |
| + 20 | - 45 | - 20 | - 5 | +1500 | +0600 | -1350 | -0600 | -0150 |
| +105 | + 20 | + 40 | + 60 | +0300 | +3150 | +0600 | +1200 | +1800 |
| + 85 | + 45 | + 50 | + 45 | +1800 | +2550 | +1350 | +1500 | +1350 |
| +140 | + 30 | + 70 | + 75 | +2700 | +4200 | +0900 | +2100 | +2250 |
| + 60 | + 40 | + 15 | + 30 | +0750 | +1800 | +1200 | +0450 | +0900 |
| +140 | + 45 | +105 | + 80 | +2550 | +4200 | +1350 | +3150 | +2400 |
| + 90 | + 35 | + 40 | + 50 | +1800 | +2700 | +1050 | +1200 | +1500 |
| + 40 | + 20 | + 20 | + 25 | +0600 | +1200 | +0600 | +0600 | +0750 |
| +190 | + 70 | +120 | +115 | +4200 | +5700 | +2100 | +3600 | +3450 |
| +130 | + 80 | + 90 | + 70 | +0900 | +3900 | +2400 | +2700 | +2100 |
| - 45 | - 10 | - 60 | - 60 | -1200 | -1350 | -0300 | -1800 | -1800 |
| +955 | +360 | +595 | +485 | +16950 | +28650 | +10800 | +17850 | +14550 |

TABLE IV

DYNAMIC STRAIN DATA, HAMMER 503, TEST 1
(gage type C-7, 500 ohm resistance, gage factor 3.29)

| Gage No. | Blow No. | Cali-bration Setting | Cali-bration Units | Signal Units | Strain (microin. per in.) | Stress (p.s.i. avg.) |
|---|---|---|---|---|---|---|
| | | | Day Shift | | | |
| D-1 | 2 | 10 | 20 | 5.3 | 399 | 11,950 |
| | 4 | 5 | 15.3 | 10.2 | 50.6 | 15,200 |
| | 6 | 10 | 20 | 12.3 | 930 | 27,900 |
| D-2 | 2 | 5 | 15.3 | 7.1 | 35.4 | 10,600 |
| | 4 | 5 | 15.3 | 10.5 | 52.4 | 15,700 |
| | 6 | 10 | 20 | 14.2 | 1070 | 32,100 |
| D-3 | 2 | Negligible | | | | |
| | 4 | Negligible | | | | |
| | 6 | 1 | 13 | 14 | 164 | 4,900 |
| D-6 | 2 | 5 | 15.3 | 3.5 | 176 | 5,300 |
| | 4 | 5 | 15.3 | 10.8 | 541 | 16,250 |
| | 6 | 10 | 20 | 14.6 | 1108 | 33,250 |
| | | | Night Shift | | | |
| D-1 | 4 | 10 | 20 | 9.5 | 716 | 21,500 |
| | 5 | 10 | 20 | 8.8 | 663 | 19,900 |
| | 6 | 10 | 20 | 15.0 | 1133 | 34,000 |
| D-2 | 4 | 10 | 20 | 5.5 | 412 | 12,350 |
| | 5 | 5 | 15.3 | 11.5 | 575 | 17,250 |
| | 6 | 10 | 20 | 15.2 | 1150 | 34,500 |
| D-3 | Gage unstable | | | | | |
| D-6 | Gage unstable | | | | | |

Note: All stress values to the nearest 50 p.s.i.

TABLE V

STATIC STRAIN DATA, HAMMER 503, TEST 2
(gage type A-7, 119.5 ohm resistance, gage factor 1.93)

| Load Readings | Instrument Readings | | | | | | |
|---|---|---|---|---|---|---|---|
| | G-1 | G-2 | G-3 | G-4 | G-5 | G-6 | G-1 |
| 0 . . . . . . | 12-1950 | 12-1520 | 12-1200 | 12-0030 | 12-0430 | 12-0230 | |
| 1 . . . . . . | 12-1950 | 12-1525 | 12-1205 | 12-0035 | 12-0435 | 12-0235 | 0 |
| 2 . . . . . . | 12-1970 | 12-1540 | 12-1220 | 12-0040 | 12-0440 | 12-0240 | + 20 |
| 3 . . . . . . | 12-1965 | 12-1540 | 12-1225 | 12-0045 | 12-0445 | 12-0250 | - 5 |
| 4 . . . . . . | 12-1965 | 12-1545 | 12-1230 | 12-0045 | 12-0445 | 12-0250 | 0 |
| 5 . . . . . . | 12-1950 | 12-1530 | 12-1220 | 12-0030 | 12-0430 | 12-0235 | - 15 |
| 6 . . . . . . | 12-1960 | 12-1550 | 12-1240 | 12-0050 | 12-0450 | 12-0255 | + 20 |
| 7 . . . . . . | 12-1955 | 12-1550 | 12-1240 | 12-0050 | 12-0450 | 12-0260 | - 5 |
| 8 . . . . . . | 12-1960 | 12-1555 | 12-1250 | 12-0055 | 12-0450 | 12-0260 | + 5 |
| 9 . . . . . . | 12-1945 | 12-1560 | 12-1260 | 12-0060 | 12-0450 | 12-0260 | - 15 |
| 10 . . . . . | 12-1950 | 12-1560 | 12-1265 | 12-0060 | 12-0450 | 12-0275 | + 5 |
| 11 . . . . . | 12-1950 | 12-1565 | 12-1275 | 12-0065 | 12-0450 | 12-0285 | 0 |
| 12 . . . . . | 12-1955 | 12-1570 | 12-1285 | 12-0070 | 12-0455 | 12-0290 | + 5 |
| 13 . . . . . | 12-1945 | 12-1570 | 12-1290 | 12-0075 | 12-0455 | 12-0300 | - 5 |
| Dies heated 1 hour . . | 12-1970 | 12-1620 | 12-1390 | 12-0140 | 12-0480 | 12-0440 | + 25 |

TABLE V (Continued)

| Strain (microinches/inch) | | | | | Stress (p.s.i.) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| G-2 | G-3 | G-4 | G-5 | G-6 | G-1 | G-2 | G-3 | G-4 | G-5 | G-6 |
| + 5 | + 5 | + 5 | + 5 | + 5 | 0 | + 150 | + 150 | + 150 | + 150 | + 150 |
| + 15 | + 15 | + 5 | + 5 | + 5 | + 600 | + 450 | + 450 | + 150 | + 150 | + 150 |
| 0 | + 5 | + 5 | + 5 | + 10 | - 150 | 0 | + 150 | + 150 | + 150 | + 300 |
| + 5 | + 5 | 0 | 0 | 0 | 0 | + 150 | + 150 | 0 | 0 | 0 |
| - 15 | - 10 | - 15 | - 15 | - 15 | - 450 | - 450 | - 300 | - 450 | - 450 | - 450 |
| + 20 | + 20 | + 20 | + 20 | + 20 | + 600 | + 600 | + 600 | + 600 | + 600 | + 600 |
| 0 | 0 | 0 | 0 | + 5 | - 150 | 0 | 0 | 0 | 0 | + 150 |
| + 5 | + 10 | + 5 | 0 | 0 | + 150 | + 150 | + 300 | + 150 | 0 | 0 |
| + 5 | + 10 | + 5 | 0 | 0 | - 450 | + 150 | + 300 | + 150 | 0 | 0 |
| 0 | + 5 | 0 | 0 | + 15 | + 150 | 0 | + 150 | 0 | 0 | + 450 |
| + 5 | + 10 | + 5 | 0 | + 10 | 0 | + 150 | + 300 | + 150 | 0 | + 300 |
| + 5 | + 10 | + 5 | + 5 | + 5 | + 150 | + 150 | + 300 | + 150 | + 150 | + 150 |
| 0 | + 5 | + 5 | 0 | + 10 | - 150 | 0 | + 150 | + 150 | 0 | + 300 |
| + 50 | +100 | + 65 | + 25 | +140 | + 750 | +1500 | +3000 | +1950 | + 750 | +4200 |

TABLE V (Continued)

| Load Readings | Instrument Readings | | | | | | |
|---|---|---|---|---|---|---|---|
| | G-1 | G-2 | G-3 | G-4 | G-5 | G-6 | G-1 |
| Before forging . . | 12-1955 | 12-1590 | 12-1375 | 12-0120 | 12-0485 | 12-0435 | - 15 |
| Key out . . | 12-1445 | 12-0600 | 12-0465 | 10-0665 | Un-stable | 10-1440 | |
| Shim in ½ tight . . | 12-1405 | 12-0915 | 12-0630 | 10-1130 | | 10-1610 | - 40 |
| Key tight . | 12-1655 | 12-1270 | 12-1140 | 12-0270 | | 12-0110 | +250 |
| 1 hour forge . . . | 12-1610 | 12-1260 | 12-1080 | 12-0285 | | 12-0090 | - 45 |
| 3 hour forge . . . | 12-1540 | 12-1180 | 12-1025 | 12-0110 | | 12-0000 | - 70 |

TABLE V (Continued)

| Strain (microinches/inch) | | | | | Stress (p.s.i.) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| G-2 | G-3 | G-4 | G-5 | G-6 | G-1 | G-2 | G-3 | G-4 | G-5 | G-6 |
| - 30 | - 15 | - 20 | + 5 | - 5 | - 450 | - 900 | - 450 | - 600 | + 150 | - 150 |
| +315 | +165 | +465 | | +170 | -1200 | +9450 | +3950 | +13950 | | +5100 |
| +355 | +630 | +140 | | +500 | +7500 | +10650 | +18900 | +4200 | | +15000 |
| - 10 | - 60 | + 15 | | - 20 | -1350 | - 300 | -1800 | + 450 | | - 600 |
| - 80 | - 55 | -175 | | - 90 | -2100 | -2400 | -1650 | -5250 | | -2700 |

TABLE VI

DYNAMIC STRAIN DATA, HAMMER 503, TEST 2
(gage type C-7, resistance 500 ohms, gage factor 3.29)

| Gage | Blows | Cali-bration Setting | Cali-bration Units | Signal Units | Strain (microin. per in.) | Stress (p.s.i.) |
|---|---|---|---|---|---|---|
| D-1 | 2 | 10 | 20 | 7.5 | 283 | 8,500 |
| | 4 | 5 | 20 | 6.1 | 460 | 13,800 |
| | 6 | 5 | 20 | 12.5 | 943 | 28,300 |
| D-2 | 2 | 10 | 20 | 7.8 | 291.7 | 8,750 |
| | 4 | 10 | 20 | 5.8 | 216.7 | 6,500 |
| | 6 | 5 | 20 | 13.5 | 1020 | 30,600 |
| D-3 | 2 | 10 | 20 | 5.2 | 196.7 | 5,900 |
| | 4 | 10 | 20 | 4.9 | 186.7 | 5,600 |
| | 6 | 5 | 20 | 11.1 | 840 | 25,200 |

Note: All stress readings rounded to the nearest 50 p.s.i.

TABLE VII

STATIC STRAIN DATA, HAMMER 503, TEST 3
(gage type A-7, resistance 119.5 ohms, gage factor 1.93)

| Load Readings | Instrument Readings | | | | | |
|---|---|---|---|---|---|---|
| | G-1 | G-2 | G-3 | G-4 | G-5 | G-1 |
| 0 ....... | 14-0010 | 14-0555 | 12-1590 | 14-0520 | 12-1550 | |
| 1 ....... | 14-0010 | 14-0555 | 12-1475 | 14-0540 | 12-1550 | 0 |
| 2 ....... | 14-0030 | 14-0550 | 12-1320 | 14-0565 | 12-1540 | + 20 |
| 3 ....... | 14-0045 | 14-0500 | 12-1255 | 14-0590 | 12-1535 | + 15 |
| 4 ....... | 14-0060 | 14-0400 | 12-1235 | 14-0585 | 12-1530 | + 15 |
| 5 ....... | 14-0060 | 14-0310 | 12-1210 | 14-0595 | 12-1530 | 0 |
| 6 ....... | 14-0070 | 14-0250 | 12-1210 | 14-0600 | 12-1530 | + 10 |
| Dies heated 15 min. . . . | 14-0060 | 14-0200 | 12-1275 | 14-0640 | 12-1540 | - 10 |
| 30 min. . . . | 14-0075 | 14-0200 | 12-1280 | 14-0655 | 12-1560 | + 15 |
| 45 min. . . . | 14-0090 | 14-0235 | 12-1310 | 14-0670 | 12-1575 | + 15 |
| 1 hour . . . | 14-0100 | 14-0285 | 12-1355 | 14-0670 | 12-1570 | + 10 |
| 1 hour, 15 min. . . . | 14-0105 | 14-0310 | 12-1385 | 14-0670 | 12-1580 | + 5 |
| 1 hour, 30 min. . . . | 14-0110 | 14-0340 | 12-1420 | 14-0675 | 12-1620 | + 5 |
| 1 hour, 45 min. . . . | 14-0120 | 14-0375 | 12-1460 | 14-0660 | 12-1605 | + 10 |

TABLE VII (Continued)

| Strain (microinches/inch) | | | | Stress (p.s.i.) | | | | |
|---|---|---|---|---|---|---|---|---|
| G-2 | G-3 | G-4 | G-5 | G-1 | G-2 | G-3 | G-4 | G-5 |
| 0 | -125 | + 20 | 0 | 0 | 0 | -3750 | + 600 | 0 |
| - 5 | -155 | + 25 | - 10 | + 600 | - 150 | -4650 | + 750 | - 300 |
| - 50 | - 65 | + 25 | - 5 | + 450 | -1500 | -1950 | + 750 | - 150 |
| -100 | - 20 | - 5 | - 5 | + 450 | -3000 | - 600 | - 150 | - 150 |
| - 90 | - 25 | + 10 | 0 | 0 | -2700 | - 750 | + 300 | 0 |
| - 60 | 0 | + 5 | 0 | + 300 | -1800 | 0 | + 150 | 0 |
| - 50 | + 65 | + 40 | + 10 | - 300 | -1500 | +1950 | +1200 | + 300 |
| 0 | + 5 | + 15 | + 20 | + 450 | 0 | + 150 | + 450 | + 600 |
| + 35 | + 30 | + 15 | + 15 | + 450 | +1050 | + 900 | + 450 | + 450 |
| + 50 | + 45 | 0 | - 5 | + 300 | +1500 | +1350 | 0 | - 150 |
| + 25 | + 30 | 0 | + 10 | + 150 | + 750 | + 900 | 0 | + 300 |
| + 30 | + 35 | + 5 | + 40 | + 150 | + 900 | +1050 | + 150 | +1200 |
| + 35 | + 40 | - 15 | - 15 | + 300 | +1050 | +1200 | - 450 | - 450 |

TABLE VII (Continued)

| Load Readings | Instrument Readings | | | | | |
|---|---|---|---|---|---|---|
| | G-1 | G-2 | G-3 | G-4 | G-5 | G-1 |
| Key tight . . | 14-0420 | 14-0640 | 12-1340 | 14-0770 | 12-1650 | +300 |
| Total . . . . | | | | | | +410 |
| | G-6 | G-7 | G-8 | G-9 | G-10 | G-6 |
| 0 . . . . . . . | 12-0790 | 14-0185 | 12-1885 | 14-0645 | 12-1110 | |
| 1 . . . . . . . | 12-0790 | 14-0185 | 12-1880 | 14-0645 | 12-1150 | 0 |
| 2 . . . . . . . | 12-0780 | 14-0195 | 12-1885 | 14-0640 | 12-1255 | - 10 |
| 3 . . . . . . . | 12-0775 | 14-0210 | 12-1885 | 14-0645 | 12-1260 | - 5 |
| 4 . . . . . . . | 12-0775 | 14-0220 | 12-1875 | 14-0645 | 12-1300 | 0 |
| 5 . . . . . . . | 12-0770 | 14-0225 | 12-1865 | 14-0645 | 12-1335 | - 5 |
| 6 . . . . . . . | 12-0765 | 14-0235 | 12-1860 | 14-0645 | 12-1365 | - 5 |
| Dies heated 15 min. . . . | 12-0780 | 14-0235 | 12-1890 | 14-0790 | 12-1285 | + 15 |
| 30 min. . . . | 12-0790 | 14-0245 | 12-1910 | 14-0815 | 12-1315 | + 10 |
| 45 min. . . . | 12-0800 | 14-0260 | 12-1920 | 14-0820 | 12-1310 | + 10 |
| 1 hour . . . | 12-0805 | 14-0260 | 12-1940 | 14-0820 | 12-1300 | + 5 |
| 1 hour, 15 min. . . . | 12-0805 | 14-0255 | 12-1940 | 14-0805 | 12-1280 | 0 |

TABLE VII (Continued)

| Strain (microinches/inch) | | | | Stress (p.s.i.) | | | | |
|---|---|---|---|---|---|---|---|---|
| G-2 | G-3 | G-4 | G-5 | G-1 | G-2 | G-3 | G-4 | G-5 |
| +265 | -120 | +110 | + 45 | +9000 | +7950 | -3600 | +3300 | +1350 |
| + 85 | -250 | +250 | +100 | +12300 | +2550 | -7500 | +7500 | +3000 |
| G-7 | G-8 | G-9 | G-10 | G-6 | G-7 | G-8 | G-9 | G-10 |
| 0 | - 5 | 0 | + 40 | 0 | 0 | - 150 | 0 | +1200 |
| + 10 | + 5 | - 5 | +105 | - 300 | + 300 | + 150 | - 150 | +3150 |
| + 15 | 0 | + 5 | + 5 | - 150 | + 450 | 0 | + 150 | + 150 |
| + 10 | - 10 | 0 | + 40 | 0 | + 300 | - 300 | 0 | +1200 |
| + 5 | - 10 | 0 | + 35 | - 150 | + 150 | - 300 | 0 | +1050 |
| + 10 | - 5 | 0 | + 30 | - 150 | + 300 | - 150 | 0 | + 900 |
| 0 | + 30 | +145 | + 20 | + 450 | 0 | + 900 | +4350 | + 600 |
| + 10 | + 10 | + 25 | + 30 | + 300 | + 300 | + 300 | + 750 | + 900 |
| + 15 | + 10 | + 5 | - 5 | + 300 | + 450 | + 300 | + 150 | - 150 |
| 0 | + 20 | 0 | - 10 | + 150 | 0 | + 600 | 0 | - 300 |
| - 5 | 0 | - 15 | - 20 | 0 | - 150 | 0 | - 450 | - 600 |

TABLE VII (Continued)

| Load Readings | Instrument Readings | | | | | |
|---|---|---|---|---|---|---|
| | G-6 | G-7 | G-8 | G-9 | G-10 | G-6 |
| 1 hour, 30 min. . . . | 12-0820 | 14-0260 | 12-1940 | 14-0800 | 12-1265 | + 15 |
| 1 hour, 45 min. . . . | 12-0830 | 14-0260 | 12-1940 | 14-0800 | 12-1265 | + 10 |
| Key tight . . | 12-0910 | 14-0370 | 12-1880 | 14-0790 | 12-1620 | + 80 |
| Total . . . . | | | | | | +120 |

TABLE VII (Continued)

| Strain (microinches/inch) | | | | Stress (p.s.i.) | | | | |
|---|---|---|---|---|---|---|---|---|
| G-7 | G-8 | G-9 | G-10 | G-6 | G-7 | G-8 | G-9 | G-10 |
| + 5 | 0 | - 5 | - 15 | + 450 | + 150 | 0 | - 150 | - 450 |
| 0 | 0 | 0 | 0 | + 300 | 0 | 0 | 0 | 0 |
| +110 | - 60 | - 10 | +355 | +2400 | +3300 | -1800 | - 300 | +10650 |
| +185 | - 5 | +145 | +510 | +3600 | +5550 | - 150 | +4350 | +15300 |

TABLE VIII

DYNAMIC STRAIN DATA, HAMMER 503, TEST 3
(gage A-7, resistance 119.5 ohms, gage factor 1.93)

| Gage No. | Cali-bration Setting | Cali-bration Units | Signal Units | Strain (microin. per in.) | Stress (p.s.i.) |
|---|---|---|---|---|---|
| 1 | 10 | 8 | 11.8 | +915 | +27,450 |
| 2 | 10 | 12 | 13.2 | -682 | -20,460 |
| 3 | 10 | 12 | 7.1 | -366 | -10,980 |
| 4 | 10 | 20 | 10 | +310 | + 9,300 |
| 5 | Negligible | | | | |
| 6 | Negligible | | | | |
| 7 | 10 | 12 | 7.5 | +387 | +11,610 |
| 8 | 10 | 20 | 6.5 | -202 | - 6,060 |
| 9 | 10 | 12 | 8.5 | -440 | -13,200 |
| 10 | 10 | 8 | 10 | +775 | +23,250 |
| A | 10 | 13.5 | 10.5 | 960 | 28,800 |
| B | 10 | 20 | 9.5 | 465 | 13,950 |
| C | 10 | 20 | 0 | 0 | 0 |

Note: All stress values rounded to nearest 50 p.s.i.

TABLE IX

STATIC STRAIN DATA, HAMMER 153
(gage type A-7, resistance 119.5 ohms, gage factor 1.93)

| Load Readings | Instrument Readings | | | |
|---|---|---|---|---|
| | G-1 | G-2 | G-3 | G-4 |
| 0 . . . . . . . . . . . . . . . | 12-0900 | 14-0630 | Unstable | 10-1490 |
| 1 . . . . . . . . . . . . . . . | 12-0900 | 14-0625 | | 10-1490 |
| 2 . . . . . . . . . . . . . . . | 12-0905 | 14-0630 | | 10-1490 |
| 3 . . . . . . . . . . . . . . . | 12-0920 | 14-0630 | | 10-1500 |
| 4 . . . . . . . . . . . . . . . | 12-0910 | 14-0630 | | 10-1570 |
| 5 . . . . . . . . . . . . . . . | 12-0920 | 14-0630 | | 10-1610 |
| 6 . . . . . . . . . . . . . . . | 12-0920 | 14-0630 | | 10-1640 |
| 7 . . . . . . . . . . . . . . . | 12-0920 | 14-0630 | | 10-1660 |
| 8 . . . . . . . . . . . . . . . | 12-0915 | 14-0630 | | 10-1665 |
| 9 . . . . . . . . . . . . . . . | 12-0920 | 14-0635 | | 10-1695 |
| 10 . . . . . . . . . . . . . . | 12-0920 | 14-0635 | | 10-1730 |
| Die heat 1 . . . . . . . . . | 12-0960 | 14-0690 | | 10-1725 |
| Die heat 2 . . . . . . . . . | 12-0980 | 14-0710 | | 10-1730 |
| Forging 1 . . . . . . . . . | 12-1350 | 14-1390 | | 10-1630 |
| Forging 2 . . . . . . . . . | 12-1200 | 14-1230 | | 10-1490 |
| Forging 3 . . . . . . . . . | 12-1250 | 14-1110 | | 10-1410 |
| Forging 4 . . . . . . . . . | 12-1300 | 14-1270 | | 10-1410 |
| Key retight 1 . . . . . . . | 12-1350 | 14-1280 | | 10-1500 |
| Key retight 2 . . . . . . . | 12-1375 | 14-1300 | | 10-1540 |
| Key retight 3 . . . . . . . | 12-1405 | 14-1320 | | 10-1565 |
| Key retight 4 . . . . . . . | 12-1430 | 14-1340 | | 10-1600 |
| Key retight 5 . . . . . . . | 12-1440 | 14-1355 | | 10-1620 |

TABLE IX (Continued)

| Strain (microinches/inch) | | | | Stress (p.s.i.) | | | |
|---|---|---|---|---|---|---|---|
| G-1 | G-2 | G-3 | G-4 | G-1 | G-2 | G-3 | G-4 |
| | | Unstable | | | | Unstable | |
| 0 | - 5 | | 0 | 0 | - 150 | | 0 |
| + 5 | + 5 | | 0 | + 150 | + 150 | | 0 |
| + 15 | 0 | | + 10 | + 450 | 0 | | + 300 |
| - 10 | 0 | | + 70 | - 300 | 0 | | +2100 |
| + 10 | 0 | | + 40 | + 300 | 0 | | +1200 |
| 0 | 0 | | + 30 | 0 | 0 | | + 900 |
| 0 | 0 | | + 20 | 0 | 0 | | + 600 |
| - 5 | 0 | | + 5 | - 150 | 0 | | + 150 |
| + 5 | + 5 | | + 30 | + 150 | + 150 | | + 900 |
| 0 | 0 | | + 35 | 0 | 0 | | +1050 |
| + 40 | + 55 | | - 5 | +1200 | +1650 | | - 150 |
| + 20 | + 20 | | + 5 | + 600 | + 600 | | + 150 |
| +370 | +680 | | -100 | +11100 | +20400 | | - 300 |
| -150 | -160 | | -140 | -4500 | -4800 | | -4200 |
| + 50 | -120 | | - 80 | +1500 | -3600 | | -2400 |
| + 50 | +150 | | 0 | +1500 | +4500 | | 0 |
| + 50 | + 10 | | + 90 | +1500 | + 300 | | +2700 |
| + 25 | + 20 | | + 40 | + 750 | + 600 | | +1200 |
| + 30 | + 20 | | + 15 | + 900 | + 600 | | + 450 |
| + 25 | + 20 | | + 35 | + 750 | + 600 | | +1050 |
| + 10 | + 15 | | + 20 | + 300 | + 450 | | + 600 |

TABLE IX (Continued)

| Load Readings | Instrument Readings | | | |
|---|---|---|---|---|
| | G-1 | G-2 | G-3 | G-4 |
| Key retight 6 . . . . . . . | 12-1460 | 14-1370 | | 10-1640 |
| Key retight 7 . . . . . . . | 12-1475 | 14-1385 | | 10-1660 |
| Key retight 8 . . . . . . . | 12-1490 | 14-1390 | | 10-1675 |
| Key retight 9 . . . . . . . | 12-1500 | 14-1390 | | 10-1695 |
| Forging 1 . . . . . . . . . | 12-1415 | 14-1420 | | 10-1610 |
| Forging 2 . . . . . . . . . | 12-1450 | 14-1570 | | 10-1610 |
| Forging 3 . . . . . . . . . | 12-1390 | 14-1540 | | 10-1565 |
| Forging 4 . . . . . . . . . | 12-1490 | 14-1610 | | 10-1630 |
| Forging 5 . . . . . . . . . | 12-1565 | 14-1670 | | 10-1670 |
| | G-5 | G-6 | G-7 | G-8 |
| 0 . . . . . . . . . . . . . . . | 10-1960 | 12-0720 | 12-0660 | 12-1985 |
| 1 . . . . . . . . . . . . . . . | 10-1955 | 12-0720 | 12-0655 | 12-1980 |
| 2 . . . . . . . . . . . . . . . | 10-1950 | 12-0720 | 12-0660 | 12-1980 |
| 3 . . . . . . . . . . . . . . . | 10-1955 | 12-0720 | 12-0660 | 12-1985 |
| 4 . . . . . . . . . . . . . . . | 10-1975 | 12-0745 | 12-0660 | 12-1990 |
| 5 . . . . . . . . . . . . . . . | 10-1995 | 12-0760 | 12-0665 | 12-1990 |
| 6 . . . . . . . . . . . . . . . | 12-0015 | 12-0765 | 12-0670 | 12-1990 |
| 7 . . . . . . . . . . . . . . . | 12-0020 | 12-0765 | 12-0670 | 12-1990 |
| 8 . . . . . . . . . . . . . . . | 12-0025 | 12-0760 | 12-0665 | 12-1990 |
| 9 . . . . . . . . . . . . . . . | 12-0040 | 12-0770 | 12-0670 | 12-1990 |
| 10 . . . . . . . . . . . . . . | 12-0060 | 12-0785 | 12-0675 | 12-2000 |
| Die heat 1 . . . . . . . . . | 12-0055 | 12-0765 | 12-0725 | 14-0040 |
| Die heat 2 . . . . . . . . . | 12-0070 | 12-0770 | 12-0740 | 14-0050 |

TABLE IX (Continued)

| Strain (microinches/inch) | | | | Stress (p.s.i.) | | | |
|---|---|---|---|---|---|---|---|
| G-1 | G-2 | G-3 | G-4 | G-1 | G-2 | G-3 | G-4 |
| + 20 | + 15 | | + 20 | + 600 | + 450 | | + 600 |
| + 15 | + 15 | | + 20 | + 450 | + 450 | | + 600 |
| + 15 | + 5 | | + 15 | + 450 | + 150 | | + 450 |
| + 10 | 0 | | + 20 | + 300 | 0 | | + 600 |
| - 85 | + 30 | | - 85 | -2550 | + 900 | | -2550 |
| + 35 | +150 | | 0 | +1050 | +4500 | | 0 |
| - 60 | - 30 | | - 45 | -1800 | - 900 | | -1350 |
| +100 | + 70 | | + 65 | +3000 | +2100 | | +1950 |
| + 75 | + 60 | | + 40 | +2250 | +1800 | | +1200 |
| G-5 | G-6 | G-7 | G-8 | G-5 | G-6 | G-7 | G-8 |
| - 5 | 0 | - 5 | - 5 | - 150 | 0 | - 150 | - 150 |
| - 5 | 0 | + 5 | 0 | - 150 | 0 | + 150 | 0 |
| + 5 | 0 | 0 | + 5 | + 150 | 0 | 0 | + 150 |
| + 20 | + 15 | 0 | + 5 | + 600 | + 450 | 0 | + 150 |
| + 20 | + 15 | + 5 | 0 | + 600 | + 450 | + 150 | 0 |
| + 20 | + 5 | + 5 | 0 | + 600 | + 150 | + 150 | 0 |
| + 5 | 0 | 0 | 0 | + 150 | 0 | 0 | 0 |
| + 5 | - 5 | - 5 | 0 | + 150 | - 150 | - 150 | 0 |
| + 15 | + 10 | + 5 | 0 | + 450 | + 300 | + 150 | 0 |
| + 20 | + 15 | + 5 | + 5 | + 600 | + 450 | + 150 | + 150 |
| - 5 | - 20 | + 50 | + 40 | - 150 | - 600 | +1500 | +1200 |
| + 15 | + 5 | + 15 | + 10 | + 450 | + 150 | + 450 | + 300 |

TABLE IX (Continued)

| Load Readings | Instrument Readings | | | |
|---|---|---|---|---|
| | G-5 | G-6 | G-7 | G-8 |
| Forging 1 . . . . . . . . . | 12-0160 | 12-1100 | 12-1110 | 14-0400 |
| Forging 2 . . . . . . . . . | 10-1990 | 12-0880 | 12-0920 | 14-0230 |
| Forging 3 . . . . . . . . . | 10-1935 | 12-0815 | -210755 | 14-0240 |
| Forging 4 . . . . . . . . . | 10-1935 | 12-0890 | 12-0910 | 14-0270 |
| Key retight 1 . . . . . . . | 12-0010 | 12-1045 | 12-0990 | 14-0310 |
| Key retight 2 . . . . . . . | 12-0040 | 12-1070 | 12-1015 | 14-0320 |
| Key retight 3 . . . . . . . | 12-0040 | 12-1105 | 12-1040 | 14-0340 |
| Key retight 4 . . . . . . . | 12-0060 | 12-1130 | 12-1060 | 14-0355 |
| Key retight 5 . . . . . . . | 12-0070 | 12-1145 | 12-1080 | 14-0370 |
| Key retight 6 . . . . . . . | 12-0080 | 12-1165 | 12-1100 | 14-0380 |
| Key retight 7 . . . . . . . | 12-0090 | 12-1180 | 12-1115 | -410385 |
| Key retight 8 . . . . . . . | 12-0100 | 12-1195 | 12-1130 | 14-0395 |
| Key retight 9 . . . . . . . | 12-0105 | 12-1200 | 12-1130 | 14-0390 |
| Forging 1 . . . . . . . . . | 12-0070 | 12-1200 | 12-1270 | 14-0350 |
| Forging 2 . . . . . . . . . | 12-0070 | 12-1260 | 12-1250 | 14-0400 |
| Forging 3 . . . . . . . . . | 12-0040 | 12-1180 | 12-1225 | 14-0340 |
| Forging 4 . . . . . . . . . | 12-0125 | 12-1380 | Unstable | 14-0480 |
| Forging 5 . . . . . . . . . | 12-0165 | 12-1360 | | 14-0540 |

TABLE IX (Continued)

| Strain (microinches/inch) | | | | Stress (p.s.i.) | | | |
|---|---|---|---|---|---|---|---|
| G-5 | G-6 | G-7 | G-8 | G-5 | G-6 | G-7 | G-8 |
| + 90 | +330 | +370 | +350 | +2700 | +9900 | +11100 | +10500 |
| -170 | -220 | -190 | -170 | -5100 | -6600 | -5700 | -5100 |
| - 55 | - 65 | -165 | + 10 | -1650 | -1950 | -4950 | + 300 |
| 0 | + 75 | +155 | + 30 | 0 | +2250 | +4650 | + 900 |
| + 70 | +155 | + 80 | + 40 | +2100 | +4650 | +2400 | +1200 |
| + 30 | + 25 | + 25 | + 10 | + 900 | + 750 | + 750 | + 300 |
| 0 | + 35 | + 25 | + 20 | 0 | +1050 | + 750 | + 600 |
| + 20 | + 25 | + 20 | + 15 | + 600 | + 750 | 600 | + 450 |
| + 10 | + 15 | + 20 | + 15 | + 300 | + 450 | + 600 | + 450 |
| + 10 | + 20 | + 20 | + 10 | + 300 | + 600 | + 600 | + 300 |
| + 10 | + 15 | + 15 | + 5 | + 300 | + 450 | + 450 | + 150 |
| + 10 | + 5 | + 15 | + 10 | + 300 | + 150 | + 450 | + 300 |
| + 5 | + 5 | 0 | - 5 | + 150 | + 150 | 0 | - 150 |
| - 35 | 0 | +140 | - 40 | -1050 | 0 | +4200 | -1200 |
| 0 | + 60 | - 20 | + 50 | 0 | +1800 | - 600 | +1500 |
| - 30 | - 80 | - 25 | - 60 | - 900 | -2400 | - 750 | -1800 |
| +105 | +200 | Unstable | +140 | +3150 | +6000 | Unstable | +4200 |
| + 20 | - 20 | | + 60 | + 600 | - 600 | | +1800 |

TABLE X

DYNAMIC STRAIN DATA, HAMMER 153
(gage type A-7, resistance 119.5 ohms, gage factor 1.93)

| Gage | Calibration Setting | Calibration Units | Signal Units | Strain (microin. per in.) | Stress (p.s.i.) |
|---|---|---|---|---|---|
| | | | Day Shift, First Key Drive | | |
| 1 | 20 | 20 | 13.75 | 830 | 25,500 |
| 2 | 20 | 20 | 16.25 | 1006.7 | 30,200 |
| 3 | Unstable | | | | |
| 4 | 20 | 19 | 5.25 | 350 | 10,500 |
| 5 | 20 | 19 | 4.5 | 293.3 | 8,800 |
| 6 | 20 | 19 | 7.75 | 505 | 15,150 |
| 7 | 20 | 19 | 16.25 | 1060 | 31,800 |
| 8 | 20 | 19 | 16.25 | 1060 | 31,800 |
| | | | Night Shift, First Key Drive | | |
| 1 | 20 | 20 | 11.75 | 726.7 | 21,800 |
| 2 | 20 | 20 | 14 | 866.7 | 26,000 |
| 3 | Unstable | | | | |
| 4 | 20 | 20 | 3.9 | 241.6 | 7,250 |
| 5 | 20 | 20 | 3.5 | 216.7 | 6,500 |
| 6 | 20 | 20 | 6.75 | 417.3 | 12,520 |
| 7 | 20 | 20 | 15.25 | 943.3 | 28,300 |
| 8 | 20 | 20 | 13.25 | 820.0 | 24,600 |
| | | | Day Shift, Key Retightened | | |
| 1 | 20 | 19.5 | 10 | 635 | 19,050 |
| 2 | 20 | 19.0 | 12 | 783.3 | 23,500 |
| 3 | Unstable | | | | |
| 4 | 20 | 19.0 | 4.5 | 293.3 | 8,800 |
| 5 | 20 | 18.5 | 4.5 | 301.3 | 9,040 |
| 6 | 20 | 18.5 | 7.0 | 470.0 | 14,100 |
| 7 | Unstable | | | | |
| 8 | 20 | 18.5 | 13.0 | 873.3 | 26,200 |

TABLE X (Continued)

| Gage | Calibration Setting | Calibration Units | Signal Units | Strain (microin. per in.) | Stress (p.s.i.) |
|---|---|---|---|---|---|
| | | Night Shift, Key Retightened | | | |
| 1 | 20 | 19.5 | 12.5 | 793.3 | 23,800 |
| 2 | 20 | 19.0 | 17.0 | 1106.7 | 33,200 |
| 3 | Unstable | | | | |
| 4 | 20 | 19.0 | 4.5 | 290 | 8,700 |
| 5 | 20 | 18.5 | 4.5 | 316.7 | 9,500 |
| 6 | 20 | 19.0 | 6.0 | 390 | 11,700 |
| 7 | Unstable | | | | |
| 8 | 20 | 18.5 | 13.0 | 873.3 | 26,200 |

# SAMPLE CALCULATIONS

G.R. = Gage resistance in ohms.

G.F. = Gage factor.

C.R. = Calibration resistance in ohms.

e = Strain in microinches per inch.

Calibration setting = Calibration setting on Ellis BA-2 amplifier.

Calibration units = Number of oscillograph screen graph units covered by the calibration signal.

Signal units = Amplitude of impact signal on oscillograph screen graph.

E = Modulus of elasticity for steel ($30 \times 10^6$ p.s.i.).

Computation of strain per unit of oscillograph screen graph:

| | |
|---|---|
| G.R. = 500 ohms | G.F. = 3.29 |
| Calibration setting = 10 | C.R. = 100,000 ohms. |
| Calibration units = 20 | Signal units = 12.3 |

e = [G.R.] ÷ [G.F.(C.R. + G.R.)]

= [500] ÷ [3.29(100,000 + 500)]

= 1512 microinches/inch.

Strain per graph unit = [Strain] ÷ [Calibration units].

Strain per graph unit = 1512 ÷ 20 = 75.6 microinch/inch/unit.

Stress per graph unit = Strain/Unit x E.

Stress per graph unit = $75.6 \times 10^{-6} \times 30 \times 10^{6}$ = 2268 p.s.i./Unit.

Impact stress = Signal units x stress per graph unit.

Impact stress = 12.3 x 2268 = 27,906 p.s.i.