RESIDUAL STRESSES IN BIMETALLIC STRIPS

Thesis by

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The writer takes this opportunity to thank Professor F. J. Converse of the California Institute of Technology for his helpful suggestions and criticisms as director of this research. Thanks are also due to Dr. Donald S. Clark, also of the California Institute, for much of his valuable time spent with the writer, to Mr. W. F. Hirsch of the Industrial Research Laboratories, Los Angeles, for the chemical analysis and Diamond Brinell Hardness tests, Mr. Eugene Graham for the preparation of the curves, Mr. J. R. Campbell of the General Electric Company, and to all others who gave of their time to this investigation.

STATEMENT OF THE PROBLEM

It has been found in the use of bimetallic strips in thermostats for high temperature operation that quite frequently the bimetallic blades are permanently set because of overload. The stresses present in bimetallic strips when operating as thermostats at high temperature are due to three factors, first residual stresses at room temperature with no external loading, second increase of temperature, and third mechanical loading of the strips. The objects of this investigation are (1) to determine the residual stress distribution in the bimetallic strip, (2) to determine how the residual stresses change when the bimetallic strip is subjected to electric flatiron operating temperature for a long period, and (3) to determine the allowable mechanical loads which may be applied to the bimetallic strip in bending.

ABSTRACT

It is concluded (1) that under the assumption mentioned on page 56 the residual initial stress at room temperature in the outer fiber of the invar side of the bimetallic strip ranges from 35,000 lb. per sq. in. tension to zero stress depending on the rolling hardness of the strip. The residual stress distribution over the entire cross section was not determined. (2) With subjection of the bimetallic strip to a temperature of 600° F. for 504 hours the residual stress in the invar outer fiber is in general reduced. (3) When the bimetallic strip is considered as a homogeneous material, the proportional elastic limit in bending ranges from 39,000 to 126,000 pounds per square inch in the outer fiber if the strip is bent so as to put the steel side in tension, and ranges from 28,000 to 70,000 pounds per square inch in the outer fiber if the strip is bent so as to put the invar in tension. The proportional elastic limit varies with the rolling hardness of the strip.

INTRODUCTION

Discussion of the Problem:

It may be well at this time to include a very short analysis of the action of bimetallic strips with an increase in temperature. For a complete analysis see "Analysis of Bi-Metal Thermostats" by S. Timoshenko in Journal "Optical Society of America" July-Dec., 1925, Vol. 11 page 233.

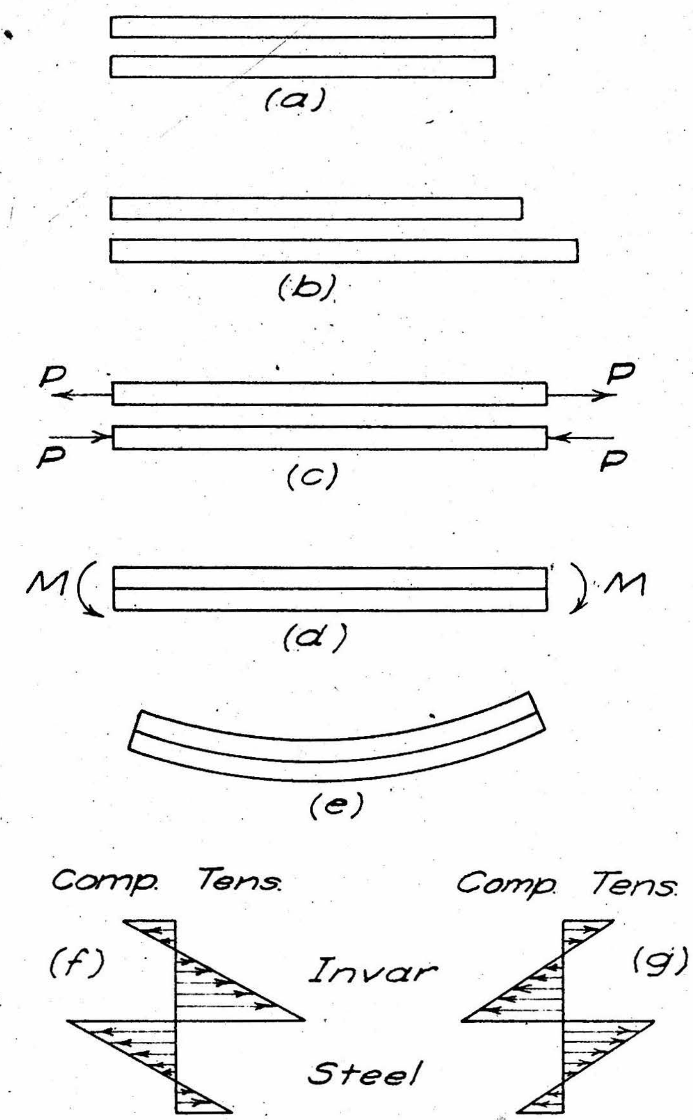


Fig. 1

Fig 1 (a) represents two metal strips of different coefficient of thermal expansion and of the same length at room temperature. With an increase in temperature the strips expand as is shown in (b) to different lengths. Now in order to have both strips of the same length at this new temperature, forces P must be applied as shown in (c). Suppose now the two strips are joined together while under the loads as in (c) to make a bimetallic strip, then considering the two forces P at each end as moments M, the strip will remain straight as in (d). Now removing the moments M, as there is no external moment on a free-to-deflect heated bimetallic strip, the strip will become curved and will be in the same final shape as if the two strips had been joined together at room temperature and then heated, one end deflecting with respect to the other, (e). The final stress distribution resulting from the increase in temperature is shown in (f). This is identical with the distribution which occurs when a bimetallic strip, having no internal stress at room temperature, is heated. Conversely the stress distribution resulting from a decrease in temperature will be the exact opposite and is represented in (g). These stress distributions are for strips of equal thickness and equal moduli of elasticity, and are more complicated in the actual case, where the moduli are different. The stress in the outer fiber in lb. per sq. in. is of the order of 40T, where T is the change of temperature in degrees Fahrenheit. The stresses at the bond are twice as great.

The particular problem involved is the determination of the residual temperature stresses in the bimetal due to a decrease in temperature from the rolling temperature and any other residual stresses due to the fabrication of the bimetal.

Availability of Information on the Subject:

The writer has not been able to find any report of work done on the residual stress distribution of bimetallic strips, most of the literature on bimetallic strips being concerned with stresses and deflections considering an initial stress distribution of zero and stresses below the elastic limit. However, a report by Mr. N. Dawidenkow in Zeitschrift für Metallkunde, February 1932, p 25, on the "Determination of Internal Stresses in Cold-Drawn Brass Tubes" gave a method of determining residual stresses by dissolving the tubes in acid and measuring change in diameter and length. The writer had started something similar, the dissolving of bimetallic strips in acid and measuring the resultant curvature, before seeing this article and worked on this method for a considerable length of time. This will be discussed later.

Opinions on Residual Stress Distribution:

The H. A. Wilson Company, manufacturers of bimetallic strips, in reply to a question on residual stresses gave an opinion that "stresses can be reduced to a minimum at some temperature which is between two extreme temperatures". Mr. F. W. Riddington, of the General Electric Company, was of the opinion that at some temperature, possibly 300° F., the stresses in the bimetal could be considered to be zero without much error.

Original Plan of Attack:

The sum of the internal forces acting on the cross section of a beam is equal to the external force, and for the case of a free-to-deflect bimetal strip, the external force is zero. This condition is then expressed as $\Sigma \underline{F} = 0$. The existence of residual stresses in a bimetallic strip then means that some fibers or sets of fibers are in tension at the expense of others being in compression. From the condition of equilibrium can be written the equation that the external moment on a beam is equal to the internal moment and for this particular case, a free-to-deflect bimetallic strip, the external moment is zero. Therefore $\Sigma \underline{M} = 0$. These two equations may now be written as integrals in terms of the stress at any point distant $\underline{y}$ from the neutral axis of the beam. They are

$$(1) \quad \Sigma F = \int_{-\frac{h}{2}}^{+\frac{h}{2}} S \, dy = 0$$

$$(2) \quad \Sigma M = \int_{-\frac{h}{2}}^{+\frac{h}{2}} S y \, dy = 0$$

where the beam is of unit width and of depth $\underline{h}$. $\underline{S}$ is the stress at any point $\underline{y}$. The first equation shows that the magnitudes of the positive forces must counterbalance the negative forces, and the second equation shows that these forces must be so distributed that the moment of the forces about the neutral axis is zero, i.e. there is as much negative moment as positive moment. It is thus seen that residual stresses may be present in bimetals. Definite proof that there are residual stresses is obtained by dissolving a piece of bimetal and watching the strip take on a curvature.

The rolling of metal strips gives rise to residual stresses being present in the rolled strip. These residual stresses are distributed symmetrically over the cross section of the strip; in general there is residual tension in the outer fibers and residual compression in the center fibers of the strip. Since bimetallic strips dissolved in acid always took on a curvature such that the steel side, the high expanding side, became concave, it was concluded that residual stresses due to temperature change must be present and that this temperature change was the decrease in temperature the bimetal underwent in cooling from the rolling temperature to room temperature. Therefore a stress distribution somewhat like that shown in Fig. 1 (g) is to be expected. That distribution is sketched here again for reference. It is seen that the outer fiber of the invar is in tension while that of the steel is in compression. Also the bond fiber of invar is in compression while the bond fiber of steel is in tension. The effect of external loads on the strip is to add bending stresses to this residual stress distribution. The effect of increasing or decreasing the temperature of the strip is to add temperature stresses to those stresses already present. Thus in case of combined heating and loading of a bimetallic strip, the

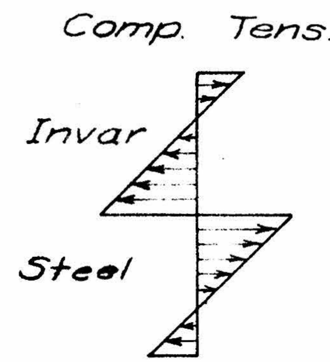


Fig 1 (g)

stress distribution is the sum of the residual stresses, the temperature stresses, and the loading stresses.

The assumption is now made that the individual materials in the bimetallic strip have the same proportional elastic limit in tension as in compression. Refer now to the sketch of a probable qualitative stress distribution shown in Fig. 1 (g). Considering the outer fiber of the invar side it can be seen that in bending the strip so that the loading causes tensile stresses in the invar side, the outer fiber will reach its proportional elastic limit at a lower external moment than if the bending of the strip were in the opposite direction. The same consideration can be made for the steel outer fiber, i.e. if the strip is so loaded that the steel is put in tension, a greater external moment will be required for the stress to be changed from an initial residual compressive stress, through zero actual stress, up to the proportional elastic limit in tension than would be required to reach the proportional elastic limit in compression with bending in the opposite direction. Bending of a beam sets up a linear stress distribution over the section of the beam, compression on the concave side, tension on the convex side, and zero stress at the middle. Therefore relatively high residual stresses near the center of the beam will not be disturbed, i.e. they will not be brought up to their proportional elastic limit by external loading, and the proportional elastic limit obtained in bending of the bimetallic strip may be considered to mean that an outer fiber has reached the proportional elastic limit. It is for this reason that transverse bending tests were made in this investigation. A suitable combination of the results obtained in this way will give a value for both the residual stress and the proportional elastic limit.

Now considering again the sketch of Fig. 1 (g), it is seen that presumably the bond fiber of the steel is in the highest state of residual tension; therefore if a direct tensile force is applied over the cross section of the strip, i.e. one which will add tensile stresses to all parts of the strip, it is likely that the bond fiber of steel will come up to the proportional elastic limit first. However if the proportional elastic limit of the invar is considerably lower than that of the steel, the outer fiber of the invar may reach the proportional elastic limit first and thus cause the strip as a whole to reach a proportional elastic limit. It is for this reason that tension tests were made on the bimetallic strips, for if the stress necessary to bring the material to a proportional elastic limit is known, and if the proportional elastic limit of the individual strip is determined separately, then the residual stress at the particular point in the bimetallic strip will be known.

Conversely the addition of a uniform compressive stress to the bimetallic strip cross section would bring the invar bond fiber to a proportional elastic limit first and in the same way would be a factor in the determination of the initial residual stress at that point. However, compression testing is so complicated due to the difficulty of central loading of the specimen and due to buckling of specimens that such tests could not be satisfactorily carried out for the bimetals.

Again referring to the sketch in Fig. 1 (g) consider what effect a change in temperature will have on the stress distribution. Since this presumable stress distribution is a temperature stress distribution, any change in temperature will simply change the magnitudes of all the residual stresses proportionally, diminishing all stresses toward and through zero to stresses of the other sense with an increase in temperature, or an increase in all stresses in the same sense with a decrease in the temperature. Thus with an increase in temperature the bond fiber of the invar will probably reach a proportional elastic limit first, while with a decrease in temperature the bond fiber of the steel will probably reach a proportional elastic limit first. There are two ways of detecting the passing of the proportional limit due to temperature stresses (1) by plotting the temperature deflection curve and finding the break from proportionality and (2) by repeatedly heating to successively higher temperatures, cooling the specimen to room temperature between each heating, and measuring the permanent set taken by the specimen. Probably only the second method could be used in the case of cooling to temperatures below room temperature. The determination of residual stresses by this method was not done because of the numerous difficulties involved, mainly (1) changes in strengths and elastic limits of the metals with temperature, and (2) changes in the moduli of elasticity with temperature.

The properties of the individual metals were to be determined from tests on samples of various hardnesses furnished by the manufacturers. The properties of the sides of the bimetallic strips were to be determined by a correlation with their hardness and the hardnesses of the test samples of the individual metals.

During the course of the investigation, a method of measuring stress distribution by dissolving in acid was developed and work done along that line, which, as mentioned above, will be discussed later in this report.

EXPERIMENTAL WORK

Terminology:

Bimetallic strips are made up of two strips of metal, one of whose coefficient of thermal expansion is higher than that of the other. The manufacturers distinguish between these strips by calling them "high expanding steel" and "low expanding steel" respectively. The writer has used these terms and also the words "steel" and "invar" to mean high and low expanding strips, respectively. It is to be understood that invar is a patented alloy of about 36% nickel in iron, which according to the chemical analysis following is not the same composition as the low expanding steel.

The phrases "residual stress" and "initial stress" are used interchangeably.

Materials used in the investigation:

The first sets of tests made were transverse bending tests and direct tension tests on four hardnesses of the H. A. Wilson Company's Highheat Thermometal, representing the four tempers of Highheat Thermometal. The specimens used for bending were designated as 1-IT, 1-IC, 2-IT, etc., the number representing the material and the letters designating invar in tension (IT) and invar in compression (IC). The specimens pulled in tension were given the numbers 1GE52, 2GE53, 3GE54, & 4GE55, the first figure representing the material as above and the GE number a number given the specimen by the writer. After the above samples were tested, all further samples were heated for one hour at 650 deg. F. at the suggestion of the H. A. Wilson Company so that the material would be in the same condition in testing as it was intended to be in the thermostat.

The set of tests referred to later as "oven tests" was made on the three hardest of the four hardnesses of highheat thermometal purchased from the H. A. Wilson Co. The specimens were designated by three characters such as 2F4 and 3B2, where the first figure represents the material, as above, the letter represents the time which the specimen was in the oven, and the last figure is the specimen number. The hardness of these specimens and those used in the first set of tests was given by the Wilson Co. as #1-fully annealed, #2-15 points hard, #3-10 points hard, and #4-20 points hard. This is rolling hardness and corresponds to reduction in thickness after the last anneal.

At the request of the writer the H. A. Wilson Co. sent samples of the individual strips which make up the bimetal. Strips of high expanding steel from heat #5147 and strips of low expanding steel from heat #7384 of four rolling hardnesses were sent. Also samples of highheat thermometal made up of the above two heats were sent for test. These were all sent without charge. The designations of these strips follows:

Steel No.	Type of Steel	Heat #	Rolling Hardness			
			.055	.040	.026	Fully Annealed
2	High Expanding Highheat	5147	2-A	2-B	2-C	2-D
3	Low Expanding #47 Highheat	7384	3-A	3-B	3-C	3-D

Thermometal	Heat #	Rolling Hardness			
		.020	.015	.010	Fully Annealed
Highheat	7384 vs. 5147	H-A	H-B	H-C	H-D

To the samples of the individual steels the numbers 1 & 2 were prefixed to denote the number of the specimen. To the samples of the thermometal used in transverse bending the numbers 1 & 2 were prefixed as for the individual steels. To the samples of thermometal used in direct tension the numbers 1 & 2 were suffixed to the number given in the table above. These bimetallic strips (7384 vs. 5147) will be spoken of as "H-thermometal".

A chemical analysis of the steels 2 & 3 and the H-thermometal was made by Mr. W. F. Hirsch of the Industrial Research Laboratories, Los Angeles. The compositions are given in the following table.

Specimen	% Carbon	% Chromium	% Nickel	% Iron
Steel #2	.08	11.16	18.20	balance
Steel #3	.07	none	41.80	balance
H-thermometal	.09?	5.51	30.15	balance

Transverse Bending:

In order to determine the strengths of thermometal in transverse bending a cantilever bending machine was designed by Mr. Riddington of the General Electric Company and the writer. This is shown in Fig. 2, page 17, while the sketch in Fig. 3 shows the forces acting on the tested strip.

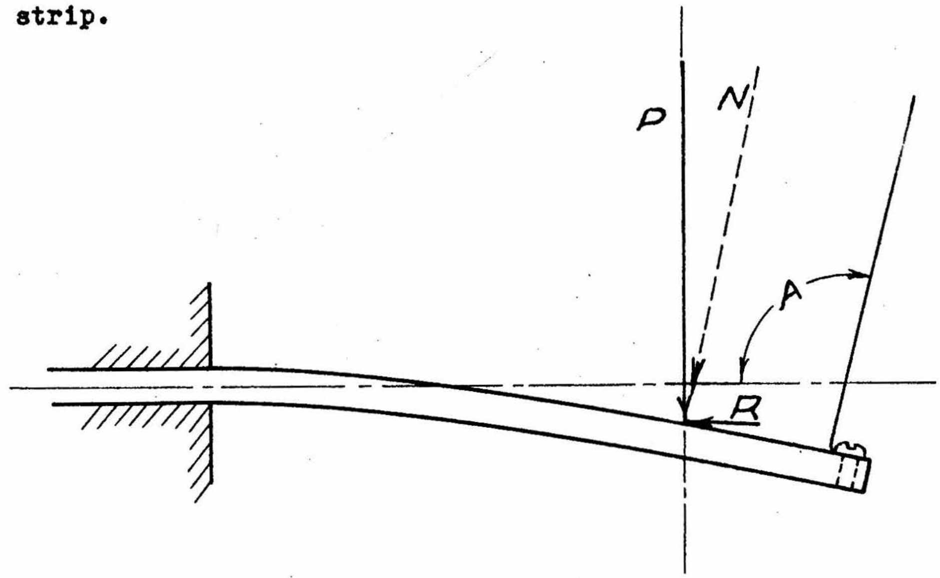


Fig. 3

The machine consists of a fixed support for the strip, and a loading rod and pans for applying the load. The deflection of the loaded point of the strip is measured by an Ames dial gage resting on the end of the loading rod. The edge of the block may be set at any convenient distance from the loading rod by sliding it in a slot in the four inch channel section base of the machine. A straight wire is screwed into the strip outside the loading point

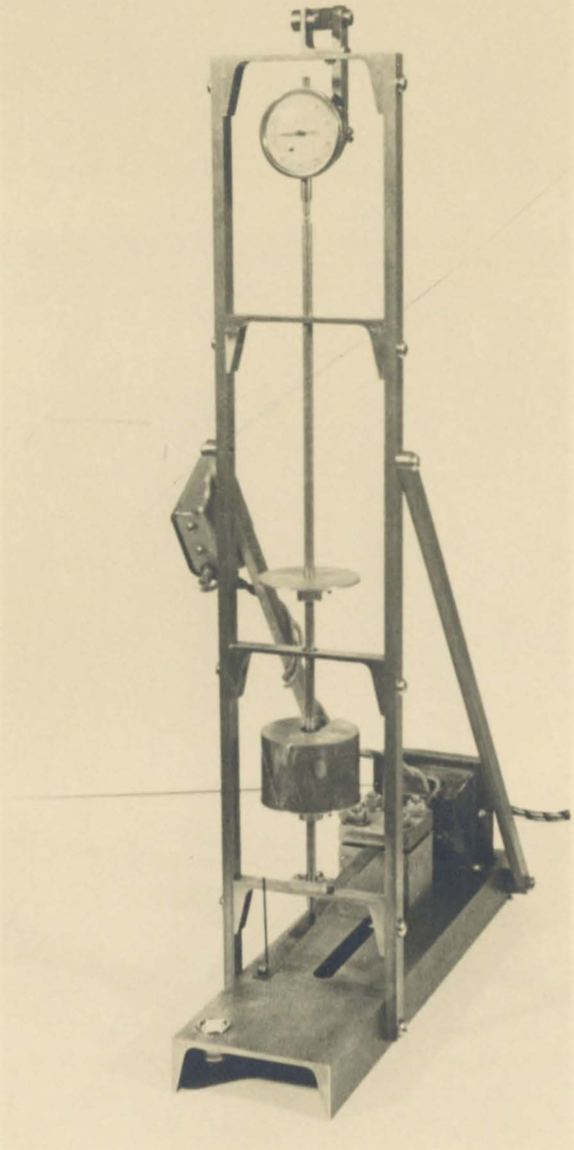


Fig. 2.

and its angle with the horizontal (angle A) is measured with a machinist's protractor during the test. The loading rod is mounted in three bearings in a vertical line. The readings taken during the transverse bending test are (1) load on the rod, (2) deflection of rod, and (3) angle A. As the load P (see Fig. 3) increases the deflection and the angle A increase. Since the end of the loading rod is a ball point, the force on the strip is normal to the surface of the strip (N in Fig. 3) and has as its components P the vertical force due to the load and R a horizontal reaction due to the inclination of the normal force. The bending moment on the strip at its support is due to both P and R. In order to determine the effect of R, its magnitude is found by getting the inclination of N through measuring the angle A; the moment arm of R is a function of the deflection of the strip. The stress is $(M+N)c/I$ and the unit strain is $\frac{6c(M+N)\,y}{l^2(2N+3M)}$, where M is the moment due to P, N is the moment due to R, c is the half-thickness of the strip, I is the moment of inertia of the cross section of the strip, y is the deflection under the load P, and l is the length of the strip between the support and the load P. The units used are pounds and inches.

The bending tests were carried out under the assumptions (1) that the material was of the same modulus of elasticity throughout, (2) that the ordinary beam formulae held for this loading, and (3) that the strip was narrow in comparison with its length. The first assumption is obviously not correct for the bimetals. A correction was later applied to the results so that actual stresses in the invar and the steel would be known. The method of calculation of this correction is discussed later, and does not invalidate the results of the testing.

The effects of original curvature of the specimen, zero load (weight of the pans and rod), zero deflection, and zero load angle reading A were taken into account. The friction at the loading point was minimized with a drop of oil, and the friction on the loading rod at the bearings was eliminated by the vibration of the entire framework of the machine by an electric buzzer seen mounted on the left side of the frame (Fig. 2) and by revolving the loading rod manually.

The size of the test specimens for the oven test samples and the H-thermometal was .030" by 3/8" in cross section with a gage length of $1\frac{3}{4}$". The width of the first set 1-IC, etc. was $\frac{3}{4}$". In all the succeeding bending tests the width of the $1\frac{3}{4}$" gage length specimens was reduced to 3/8" as it was felt that erroneous results would be obtained with such a comparatively wide specimen.

The results of the testing of thermometals in transverse bending are given as stress strain curves of the outer fiber of a homogeneous material and are to be found in Appendix A. The original data for all curves in Appendix A are to be found in the same order in Appendix C. The determination of the physical properties in bending for the transversely tested specimens is given in Tables I to IV, starting on page 34. The corrected values of actual stress in the strips at the proportional elastic limit of the specimen are included in these tables.

The method of loading the specimen in the transverse test is not the simple addition of increments of load to the specimen, but the addition and removal of the entire load (except zero load, the weight of the rod and pan) for each loading. In this way any permanent set may easily be detected by a change in the zero load reading. The zero load reading was read after each removal of load to the nearest third of a division on the Ames dial (1 div.=.001"). A curve representing the increase in zero load reading for each additional load during the test was plotted and designated as the "delta set curve". If the abscissae of the points on the delta set curve opposite the experimental points on the main curve be added together up to any load or stress, the sum will represent the total set of the specimen at that stress. The delta set curve then represents the rate at which the set is increasing. The writer has noted in general that where the delta set curve starts to increase rapidly, the main curve may be seen to deviate from proportionality. The true elastic limit is that maximum stress which may be applied to a material without any permanent deformation. If then this definition were adhered to, the elastic limit of many of the samples would be as low as 20% of the value chosen as the proportional elastic limit, as one third of a division on the dial represents, in some cases, only .000005 inches per inch unit strain. Therefore the proportional elastic limit as picked out for each curve was chosen with two factors in mind, (1) the shape of the delta set curve and (2) the deviation of the main curve from proportionality.

The fine line parallel and to the right of the main curve represents the unloading of the specimen between the points connected. This line terminates at the zero load stress.

Direct Tension:

All of the direct tension testing was done on a 3000 lb. Riehle tension machine. Fig. 4 shows the machine, including the loading wheel, the beam, the specimen holders, and the specimen in position for testing. The load is applied by hand and the beam is balanced for the load reading. An extensometer of 10 centimeter gage length was used for measuring the extension of the specimen. The extensometer dial divisions are in hundredths of millimeters, so that the extension of the 10 cm. length of the specimen by .01 mm. would move the dial pointer one division. Therefore the dial reads directly in 1/10000 unit strain. The details of the extensometer and specimen set up may be seen in Fig. 5. The method of taking the readings on the test was first loading the specimen by the hand wheel until the dial pointer was directly over a scale division on the dial and then balancing the beam and reading the load to the nearest pound. Until after the material being tested definitely passed the yield point, readings of load and deformation were taken for every 1/10000 unit

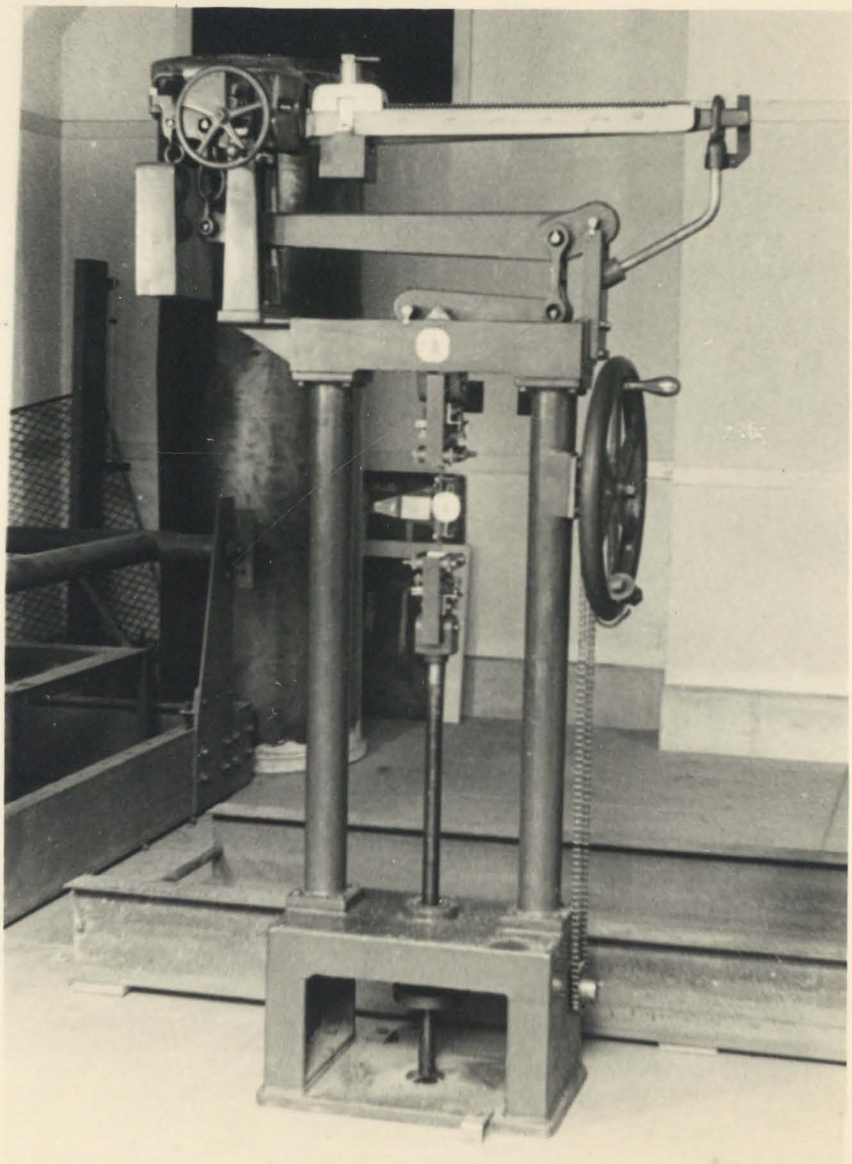


Fig. 4.

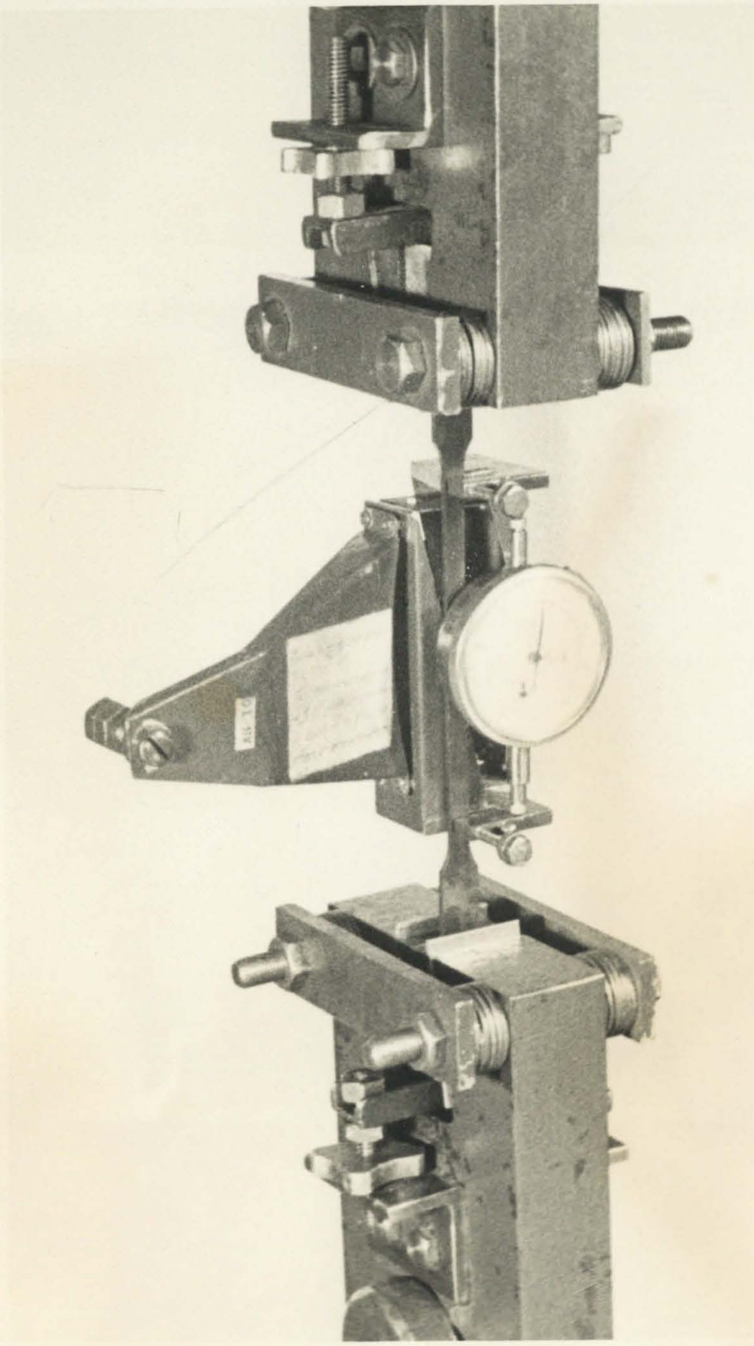


Fig. 5.

strain, i.e. for every scale division. After the yield point the strain increment was gradually increased as the load did not increase as quickly. The rate of loading below the yield point was approximately .0015" per minute; this rate increased above the yield point gradually up to .03" per minute.

Fig. 6 shows some of the tensile test specimens, somewhat reduced in size. The H-thermometal tension specimens were .030" thick, $\frac{3}{4}$" wide at the ends and milled to $\frac{1}{8}$" for a length of $4\frac{1}{4}$" in the center. The invar and steel specimens were .080" thick, $\frac{1}{2}$" wide at the ends and milled down to $\frac{1}{4}$" for the same length in the center.

In Fig. 6 it may be seen that the ends of the top specimen are bent to the shape of an "S" to fit into a certain set of holding clamps. Much difficulty was encountered in the holding of the specimens with the clamps and wedges that were at hand in that the specimens being hard would slip in the holders, and it was not until a hard set of wedges was made up that this difficulty was overcome. The objection to the "S" clamps was that the specimen was not always straight and bending as well as tension deformations would be measured --this is seen very well on the curve #1-3A, page B-17. With the new set of wedges the remaining strips were pulled without bending, without slipping, and without difficulty. See the center specimen in Fig. 6.

It is to be noted that the tension testing was not done in the same manner in which the bending tests were made, i.e. the permanent

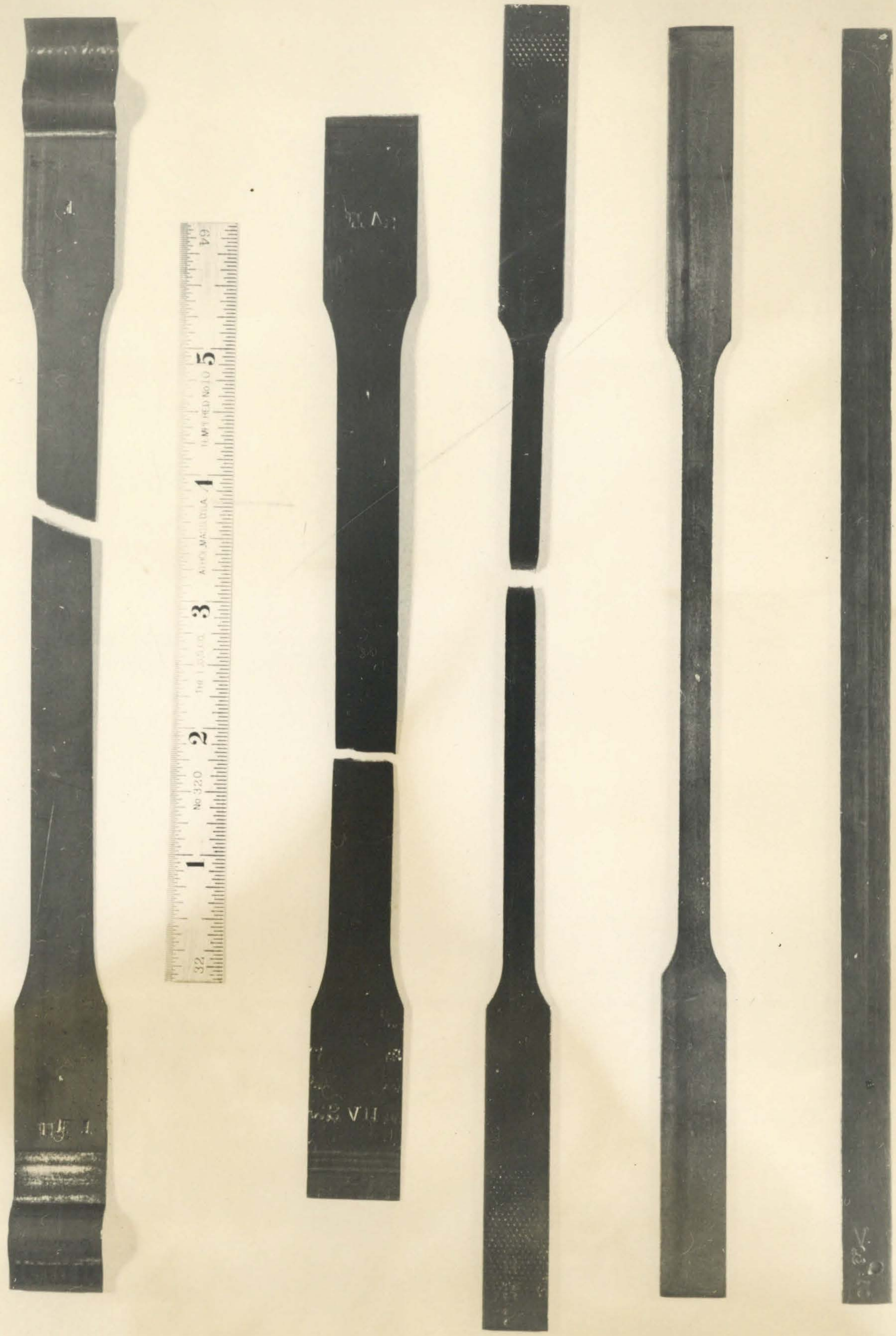


Fig. 6.

set after each increase in load was not measured. Measurement of the final elongation only was made after failure because in the tension test unloading is very delicate and troublesome. Due to the method of applying the load to the specimen in this particular tension machine, there is a noticeable torque put on the specimen because of the loading screw. It is therefore important during the course of each test to load the strip with increases of load only; thus any permanent sets measured after unloading would be of questionable value.

The proportional elastic limit in tension was chosen by inspection of the stress strain diagrams as that stress where the stress was no longer proportional to the strain. The general shape of the tension curves was one of gradual deviation from the Hooke's law relation and in general a considerable amount of elongation just below the ultimate strength.

In order to show the entire range of the curve and the elastic portion clearly on one sheet of paper, a contracted scale was used for the stress strain relations above the first one per cent unit strain. The curve drawn to this contracted scale is shown as a broken line.

In general before the tension specimen failed, it started to neck down somewhere within the gage length. With this necking the balance beam of the tension machine dropped, and with successive elongations of the specimen the load on the specimen dropped. The following of this decrease in load may be seen in the diagrams just previous to the failure of the specimen. Although the actual physical stress increased as the elongation increased, the engineering stress, based on the original cross sectional area, decreased rapidly. An effort was made to keep the beam balanced up until the moment of failure, but just before failure occurred the load fell off so rapidly that the beam could not be balanced.

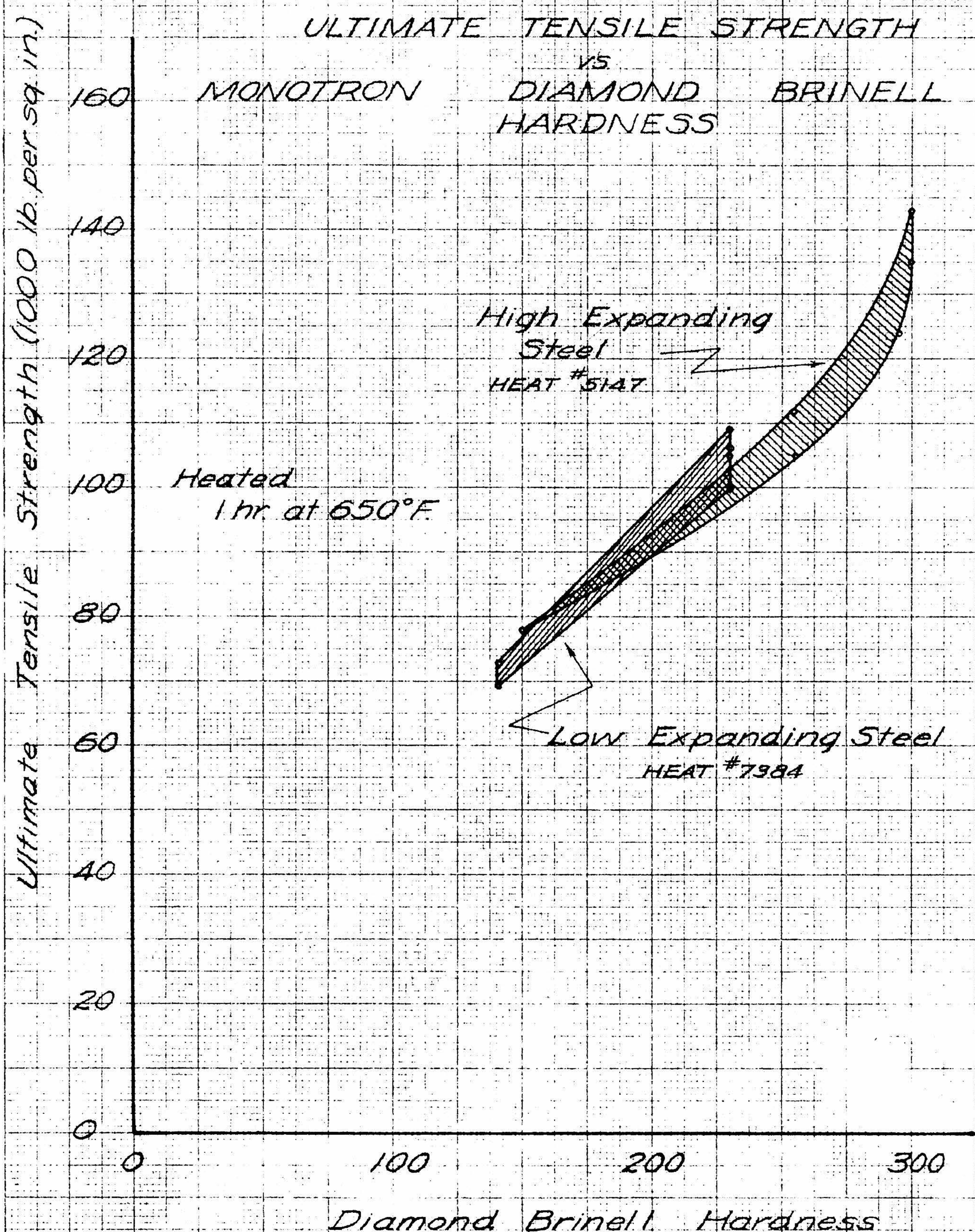
The results of the tension testing of both the thermometals and the individual metals are given as stress strain curves of a homogeneous material and are to be found in Appendix B. The original data for all curves in Appendix B are to be found in Appendix D. A tabulation of the physical properties observed from the tension tests is included with those in transverse bending in Tables I to IV, starting on page 34. The corrected values of the actual stresses in the bimetallic strips are included in these tables. The method of calculation of the correction of the above values is developed later, as use is made of the results of the tension tests of the individual metals in the computation.

Hardness tests:

Measurements of hardness were taken on at least one of each kind of sample. These were (1) Scleroscope, (2) Rockwell "B" with 100 kg. load using a 1/16" steel ball, and (3) the Diamond Brinell, which measures the load in kilograms per unit area necessary to indent a $\frac{3}{4}$ mm. diamond ball 9/5000" into the material being tested. The values read correspond to actual Brinell numbers without conversion. Only the diamond brinell hardness has no "anvil effect" due to the .030" thickness of the bimetallic strips.

The data taken on hardnesses of the specimens used in this investigation are incorporated into the Tables I to IV, page 34ff.

Several efforts were made by the writer to correlate the physical properties of the tested samples with their hardness, but were made without the desired success. The relation between ultimate tensile strength and Monotron Diamond Brinell hardness is shown on page 29 for the two sets of steels, the high expanding and the low expanding. Only a general relation can be identified and as is seen by the differing values of strength for two samples of the same material and hardness this relation is indefinite. The ranges shown for the two metals are charted to include all the tests made on each metal. Four different diamond brinell hardnesses, corresponding to the four rolling hardnesses may be distinguished for the high expanding steel, while for the low expanding steel it is to be noted that the three highest rolling hardness samples all gave a single value for diamond brinell. Therefore because of the spread of values, the hardness strength relations have proved of little value. What was particularly desired from the hardness tests was a relation between the proportional elastic limit and the hardness of the material, but as mentioned above no such relation was found.


ULTIMATE TENSILE STRENGTH
vs.
MONOTRON DIAMOND BRINELL
HARDNESS
Ultimate Tensile Strength (1000 lb. per sq. in.)
160
140
120
100
80
60
40
20
0
High Expanding
Steel
HEAT #5147
Heated
1 hr. at 650°F.
Low Expanding Steel
HEAT #7384
0
100
200
300
Diamond Brinell Hardness

Oven Tests:

Several specimens of the three hardest types of highheat thermometal were kept at a temperature ranging from 600 to 625 deg. F. in a thermostatically controlled oven for various lengths of time. Sets of samples were taken out at 3, 24, 96, 168, & 504 hours, those being taken out at 3 hours named B and those at 504 hours named F. Only the specimens of these two lengths of heating were tested, the others still remaining on hand. The tests made on these specimens were transverse bending in both directions and the three hardness tests mentioned above.

The curves plotted from these bending tests appear in Appendix A, pages 9 to 20 inc.; the data are in Appendix C. The physical properties of the strips used in the oven test are tabulated in Table II, page 35. The results of the oven test cannot be discussed at this point and are taken up later, page 63, after a consideration of initial stress distribution, which can not be made at this time. The results of the oven test are given later in Tables V and VI, page 61f.

Acid immersion method of determining stress distribution:

During the experimental work involved in this investigation a piece of brass invar bimetal (not highheat thermometal) was immersed in nitric acid until the brass side was completely eaten off. There was noted a slight change in curvature in the remaining invar side, which side being highly resistant to corrosion was not eaten by the acid. Some time later the writer tried dissolving the bimetallic strips in aqua regia. As the specimen was eaten by the acid and decreased in thickness, it took on a very noticeable curvature; it also warped. The top specimen shown in Fig. 7 is such a strip. This bending of the strip shows the existence of residual stresses in the strip.

The writer worked out a method of measuring the magnitude and distribution of these residual stresses under a few assumptions (1) that the acid will eat the material at a uniform rate over an appreciable length, (2) that the strip is long as compared with its width, and (3) that the curvature can be measured sufficiently closely. The general equation developed is

$$\frac{1}{r} = a_1 S_K + a_2 S_S$$

where $1/r$ is the change in curvature, $\overline{S}_k$ is the average stress in the steel between the original outside fiber and the new outside fiber, $\overline{S}_s$ is the corresponding stress in the invar, and a_1 and a_2 are constants depending on the dimensions of the strip at the time the curvature is measured.

In the above equation it is to be noted that both and therefore neither of the unknowns $\overline{S}_k$ and $\overline{S}_s$ can be determined simply by measuring the radius of curvature, r. Therefore, in order to use the equation one of the constants must be made zero, which is done by allowing only one side of the strip to be dissolved in the acid. In this way the stress distribution over the entire cross section can be

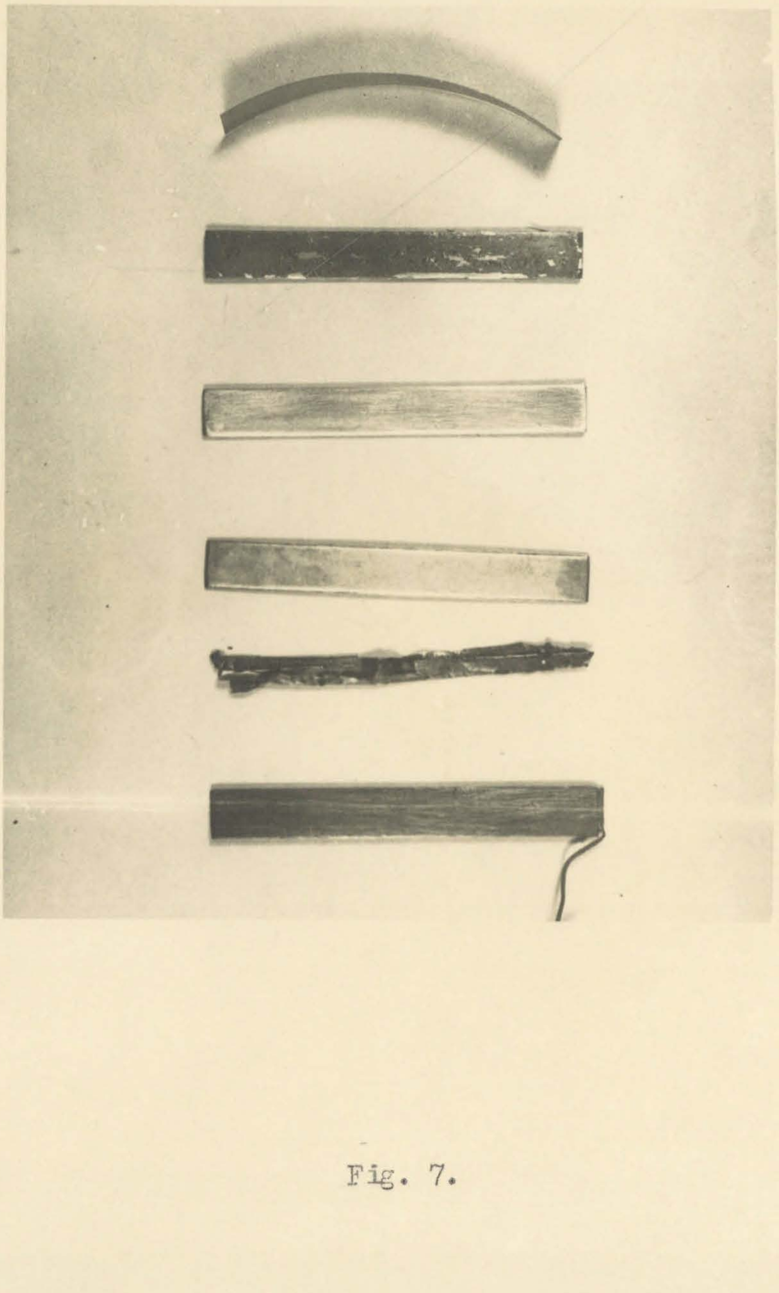


Fig. 7.

determined.

A good deal of work was done experimenting with methods to protect one side of the strip from acid action. The plating of a very thin layer of gold on the side to be protected, suggested by Dr. D. S. Clark of the California Institute of Technology, proved to be the most successful. However no quantitative results were obtained and the method given up due to the limitation of time and the necessity of making numerous physical tests on the other samples. The main difficulties involved were (1) the gold plate did not form a perfect bond with either side of the bimetallic strip although the strip was finely polished and thoroughly cleansed before plating, (2) the nitric acid, not a solvent of gold, penetrated underneath the gold plating and dissolved enough of the strip to cause the gold plate to flake off, (3) the rate of eating is greater right at the edge as is seen in the two center specimens in Fig. 7, and (4) that the specimen warped as well as bent and it was difficult to know where to measure the curvature.

Fig. 7 shows at the top the acid eated specimen mentioned above, a gold plated specimen from which the gold is starting to flake, two specimens showing the differential eating at the edges, a strip of gold flaked from a specimen, and last a gold plated specimen with the plating wire still attached. Fig. 7 is actual size.

TABLE I STOCK HIGHHEAT THERMOMETAL

Specimen Number	Hardnesses				Tens. Stresses at Prop.El.Lim. (1000 p.s.i.)			Transverse Bending Stresses at Prop. Elastic Limit (1000 lb. per sq.in.)						Ult. Strength in Tension (1000 lb. per sq. in.)	Modulus of Elasticity (10^6 p.s.i.)	
								Steel in Tens. Invar in Comp.			Invar in Tens. Steel in Comp.					
	Side of Specimen	Diamond Brinell	Rockwell "B" 100kg-1/16"ball	Scleroscope	Curve Stress	Steel Stress	Invar Stress	Curve Stress	Steel Stress	Invar Stress	Curve Stress	Steel Stress	Invar Stress		Tension	Bending
1-IC	I	140						20	21	19						20.5
1-IT	S	135									20	21	19			21.5
1GE52	I		65	19.5	20	22	18							75	19.4	
1GE52	S		71.5	20												
2-IC	I	230						125	133	119						23.2
2-IT	S	255									35	37	33			22.7
2GE53	I		99.5	41	77	86	68							117	25.8	
2GE53	S		102	42												
3-IC	I	205						55	58	52						21.8
3-IT	S	250									55	58	52			21.4
3GE54	I		93	36	65	72	58							105	24.5	
3GE54	S		96	38												
4-IC	I	240						135	143	128						23.6
4-IT	S	300									65	69	62			23.4
4GE55	I		101	41	73	81	65							130	25.7	
4GE55	S		103.5	45												

TABLE II OVEN TEST SPECIMENS

Specimen Number	Hardnesses: Side of Specimen	Hardnesses: Diamond Brinell	Hardnesses: Rockwell "B" 100kg-1/16"ball	Hardnesses: Scleroscope	Transverse Bending Stresses at Proportional Elastic Limit (1000 lb. per sq. in.) — Steel in Tens. Invar in Comp.: Curve Stress	Steel in Tens. Invar in Comp.: Steel Stress	Steel in Tens. Invar in Comp.: Invar Stress	Invar in Tens. Steel in Comp.: Curve Stress	Invar in Tens. Steel in Comp.: Steel Stress	Invar in Tens. Steel in Comp.: Invar Stress	Bending Mod. of Elasticity (10^6 lb. per sq. in.)
2B2	I	230									
2B2	S	290						63	67	60	21.9
2B4	I		98	40	123	130	117				23.2
2B4	S		98	43							
2F1	I	225									
2F1	S	290						73	77	69	22.6
2F4	I		100	39	124	131	118				23.3
2F4	S		100	43							
3B2	I		96	36.5	93	99	88				22.2
3B2	S		98	38.5	93	99	88				22.2
3B4	I	210						60	64	57	21.3
3B4	S	265									
3F3	I		96	36							
3F3	S		97	38	112	119	106				22.3
3F4	I	225						68	72	65	22.2
3F4	S	245									
4B1	I		99	40							
4B1	S		100	45				60	64	57	21.7
4B3	I	220			126	134	120				22.7
4B3	S	300									
4F2	I		101	39.5							
4F2	S		102	45				63	67	60	21.7
4F3	I	205			123	130	117				22.3
4F3	S	300									

TABLE III INDIVIDUAL METALS

Specimen Number	Hardnesses			Proportional Elastic Limit (1000 p.s.i.)		Ult. Strength—Tension (1000 p.s.i.)	Modulus of Elasticity (10^6 p.s.i.)	
	Diamond Brinell	Rockwell "B" 100kg-1/16"ball	Scleroscope	Tension	Bending		Tension	Bending
2A	300	110.5	54					
1-2A				72		143	28.8	
2-2A				95		135	25.5	
2B	295	108.5	51					
1-2B				--		124	----	
2-2B				74		124	27.0	
2C	255	105.5	43					
1-2C				47		112	30.4	
2-2C				76		105	27.2	
2D	150	72.5	18.5					
1-2D				21		78	21.0	
2-2D				20		78	27.3	
3A	230	106	44					
1-3A				74		109	19.0	
2-3A				73		100	22.8	
3B	230	103	45					
1-3B				67		105	21.7	
2-3B				72		106	22.6	
3C	230	102	42.5					
1-3C				61		100	20.3	
2-3C				68		100	21.8	
3D	140	79	21.5					
1-3D				28	33	73	21.7	18.4
2-3D				19		69	18.5	

TABLE IV H-THERMOMETAL

Specimen Number	Hardnesses: Side of Specimen	Hardnesses: Diamond Brinell	Hardnesses: Rockwell "B" 100kg-1/16"ball	Hardnesses: Scleroscope	Tens. Stresses at Prop.El.Lim. (1000 p.s.i.): Curve Stress	Tens. Stresses: Steel Stress	Tens. Stresses: Invar Stress	Transverse Bending Stresses at Prop. Elastic Limit (1000 lb. per sq.in.) — Steel in Tens. Invar in Comp.: Curve Stress	Steel in Tens. Invar in Comp.: Steel Stress	Steel in Tens. Invar in Comp.: Invar Stress	Invar in Tens. Steel in Comp.: Curve Stress	Invar in Tens. Steel in Comp.: Steel Stress	Invar in Tens. Steel in Comp.: Invar Stress	Ult. Strength in Tension (1000 lb. per sq.in.)	Modulus of Elasticity (10^6 p.s.i.): Tension	Modulus of Elasticity: Bending
1-HA	I	225	100	40				126	134	120						22.3
2-HA	S	285	101	45.5							53	56	50			20.8
HA 1					70	78	62								24.9	
HA 2					64	71	57							119	25.4	
1-HB	I	215	98	39				123	130	117						21.4
2-HB	S	270	100	42.5							66	70	63			20.9
HB 1					74	82	66							113	24.9	
1-HC	I	220	95	37							70	74	66			20.9
2-HC	S	255	97	39				95	101	90						21.4
HC 1					55	61	49							106	24.7	
1-HD	I	125	74	20							28	30	27			21.1
2-HD	S	140	76	20				39	41	37						20.7
HD 1					22	24	20							77	21.7	

INITIAL STRESSES

The calculation of the initial stresses in the bimetallic strip involves a number of steps, including the determination of the moduli of elasticity of the steel and the invar, the relative thicknesses of each metal in the bimetal, and the correction or reduction of the proportional elastic limits obtained in the tests to actual stresses in the invar and steel sides of the bimetal. After these steps are taken-certain assumptions are made and the residual initial stress in the outer fiber of the invar side of the thermometal is calculated. The distribution over the remaining portion of the cross section can only be estimated.

In Tables I to IV are tabulated the results of all the hardness tests, the proportional elastic limits in bending and in tension, the moduli of elasticity of the strip as a whole in bending and in tension, and the ultimate strength of the strip if measured, for all the strips investigated. Each table is for a definite set of samples, Table I giving the results for the stock highheat thermometal, Table II the results of the oven test samples, Table III the tests on the individual metals, and Table IV the tests on the H-thermometal. The properties mentioned were taken from the hardness test data and the stress strain curves in bending and in tension. Also included in these tables are the corrected values of actual stress in the invar and steel sides of the bimetal when the bimetal as a whole reached its proportional elastic limit. The method of calculation of the actual stresses follows.

Determination of the moduli of elasticity of the individual metals:

The values of the modulus for the high expanding steel were taken from Table III. The average of these figures in million lb. per sq. in. is 26.9; leaving the value of 21.0 for #1-2D, one of the softest specimens, out of the average, a figure of 27.7 is obtained. Again if the highest value, 30.4, is left out also, a figure of 27.16 is obtained. The writer feels that a value of E = 27,000,000 lb. per sq. in. should then be taken as the steel modulus of elasticity.

The average of the moduli in million lb. per sq. in. for the low expanding steels is 21.05; leaving out the value of 18.5 for #2-3D, the average becomes 21.4; leaving out the value of 19.0 for #1-3A solely because it was low in comparison with the others, an average of 21.8 results. Again, using all the figures and listing them in the order of their magnitude, the median two figures are 21.7. Therefore a value of 21,500,000 lb. per sq. in. was chosen as the modulus of elasticity for the low expanding steel.

The ratio of the modulus of the invar to that of the steel is then

$$n = \frac{21.5}{27.0} = .796 \quad \text{or} \quad 0.80$$

Reduction of tensile test results on bimetal strip:

As has been mentioned before the tension test curves for the bimetal strips were based on the assumption of a homogeneous specimen; since the bimetallic strip is made up of two strips of metal of different moduli of elasticity, a correction is necessary to obtain the moduli of the individual metals. Consider the sketches in Fig. 8. The upper figure represents the cross section of the strip considered as a homogeneous material; the lower figure represents the equivalent steel section, obtained by reducing the width w of the invar side to nw and considering then this resulting area as the cross section of a steel strip being pulled in tension. (n is the ratio of the moduli.)

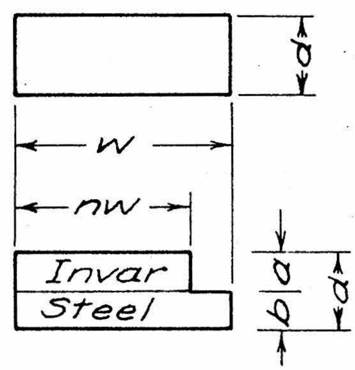


Fig. 8

(1) For a rectangular cross section the elongation is given by

$$y = \frac{Pl}{AE_t}$$

(2) For the reduced section the elongation is

$$y = \frac{Pl}{A_r E_s}$$

where P is the load, l is the length of the specimen, A and A_r are the rectangular and reduced section areas respectively, and E_t and E_s are the moduli of the homogeneous material (the observed modulus) and the steel side respectively.

From these two equations

$$\frac{E_t}{E_s} = \frac{A_r}{A} = nf + g$$

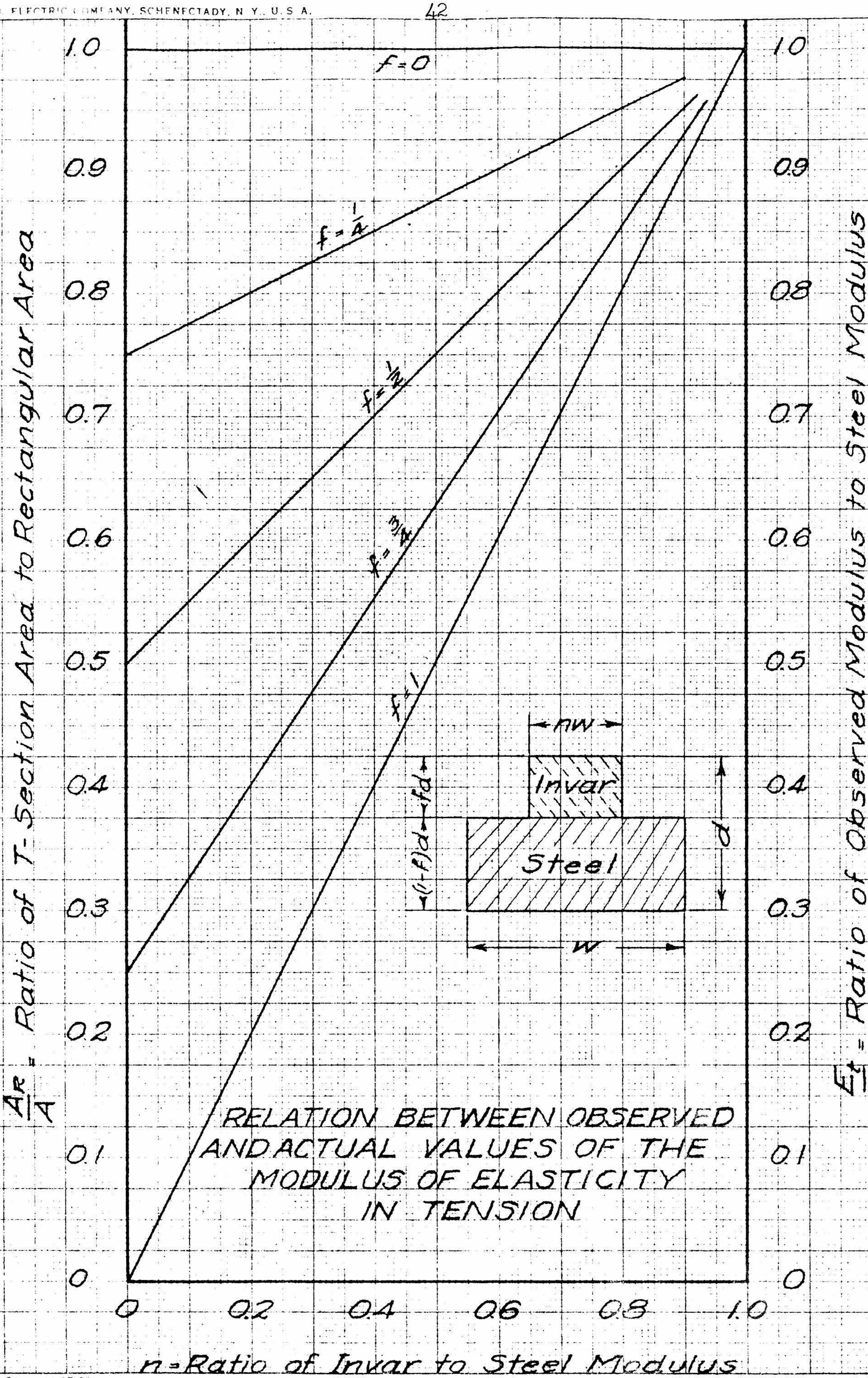
where n is the ratio of the invar to the steel modulus, f is the fraction of invar, and g the fraction of steel in the cross section of the actual strip. This equation is charted as a set of curves on page 42. Thus from the curve the relation between the observed modulus and actual steel modulus may be obtained for any value of n and f. ($f + g = 1$)

The value of 0.80 was found for n as shown above. In order to determine the relative thicknesses of the invar and the steel sides in the thermometal, samples of the four hardnesses of H-thermometal were clamped together between two brass blocks, ground and polished on their edges and so prepared for observation under the microscope. An etch of aqua regia showed the structure in the steel side of the strips and definitely marked the boundary of the two metals in the bimetal strips. This etch did not bring out the structure of the invar side. At a magnification of 62X observations were made of the relative thicknesses of the sides of the strips with a Filar micrometer, with the following results:

	H-A	H-B	H-C	H-D
Fraction steel (g)	.495	.505	.523	.475
Fraction invar (f)	.505	.495	.477	.525

The above figures represent averages at three locations. The average of these averages is $g = .4995$ and $f = .5005$. Thus it is seen that the error in considering the strip half and half is negligible.

Therefore the relation $E_t/E_s = (.8)(.5) + (.5) = 0.9$ for the


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
f=0
f=1/4
f=1/2
f=3/4
f=1
nw
Invar
Steel
(1-f)d
fd
d
w
RELATION BETWEEN OBSERVED
AND ACTUAL VALUES OF THE
MODULUS OF ELASTICITY
IN TENSION
0
0.2
0.4
0.6
0.8
1.0
n=Ratio of Invar to Steel Modulus
A_R/A = Ratio of T-Section Area to Rectangular Area
E_t/E_s = Ratio of Observed Modulus to Steel Modulus

bimetallic strips.

Now in order to find the stresses in the two sides separately from the average stress calculated for the tension test curves, consider Fig. 9, which represents a specimen of two materials being stretched in tension. Using the following notation

S = stress figured on total area

S_i = stress in invar

and S_s = stress in steel,

the unit elongation e is the same for each part of the specimen and the specimen as a whole;

$$e = \frac{S}{E_t} = \frac{S_i}{nE_s} = \frac{S_s}{E_s}$$

then

$$S_s = \frac{E_s}{E_t} S = \frac{10}{9} S$$

and

$$S_i = nS_s = \frac{8}{9} S$$

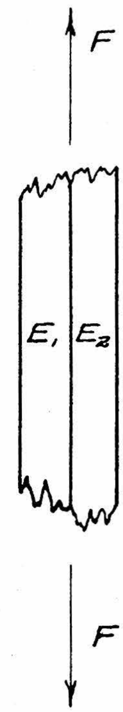


Fig. 9

The values of the stresses S_s and S_i are tabulated with S in Tables I to IV, page 34ff.

Now referring to Fig. 10, which represents the bimetallic strip being pulled in tension, we can consider the force F as being made up of two forces, one pulling the invar and one the steel. Then we can write the following equation:

$$F = F_1 + F_2$$

and if e is the elongation and E the modulus,

$$2 A E_t e = A E_1 e + A E_2 e$$

then

$$E_t = \frac{E_1 + E_2}{2}$$

showing that the observed modulus is the average of the moduli of the two strips. From the determinations of the individual strip moduli

$$E_t = \frac{21.5 + 27.0}{2} \times 10^6 = 24.25 \times 10^6 \ \#/in^2$$

The average modulus value in million lb. per sq. in. of the tension specimens #1GE52 to #4GE55 is 23.8 and if the low value of 19.4 is left out of the average, is 25.3. For the H-thermometals the average value of five specimens is 24.3. The results are sufficiently close.

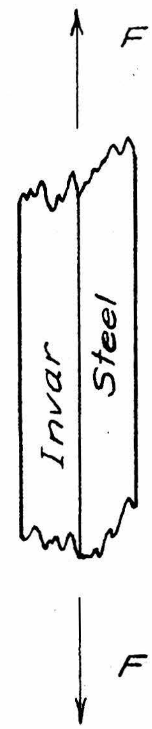


Fig. 10

Reduction of results of transverse bending tests on bimetal strip:

As has been mentioned above the transverse bending curves for the bimetal strips were based on the assumption of a homogeneous specimen and since the bimetallic strip is made up of two strips of metal of different moduli of elasticity, a correction is necessary to obtain the actual stresses in each metal when it is loaded in the bimetal strip. The relation between the observed bending modulus of the entire strip to that of the steel side alone will be developed first. Fig. 11 shows the most general condition of a bimetallic strip of width w and thickness d. The ratio of moduli of invar to steel is n, the thickness of the invar a and that of the steel b. The upper figure represents the cross section of the strip considered as a homogeneous material; the lower figure represents the equivalent steel section, obtained by reducing the width w of the invar side to nw and considering then the resulting area as the cross section of steel strip in transverse bending.

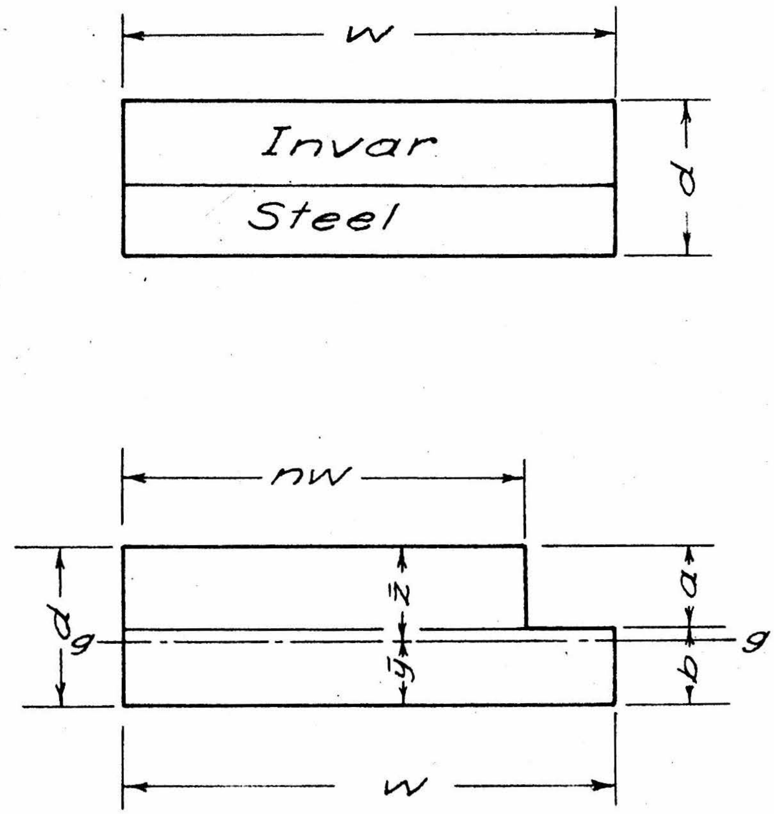


Fig. 11

(1) For a rectangular cross section the deflection is given by

$$y = \frac{Pl^3}{3EI}$$

(2) For the reduced section the deflection is

$$y = \frac{Pl^3}{3E_sI_s}$$

where P is the load, l the length of the specimen, E the modulus of the homogeneous material (the observed modulus), E_s the actual modulus of the steel side, I the moment of inertia of the rectangular cross section, and I_s the moment of inertia of the reduced cross section.

From these two equations

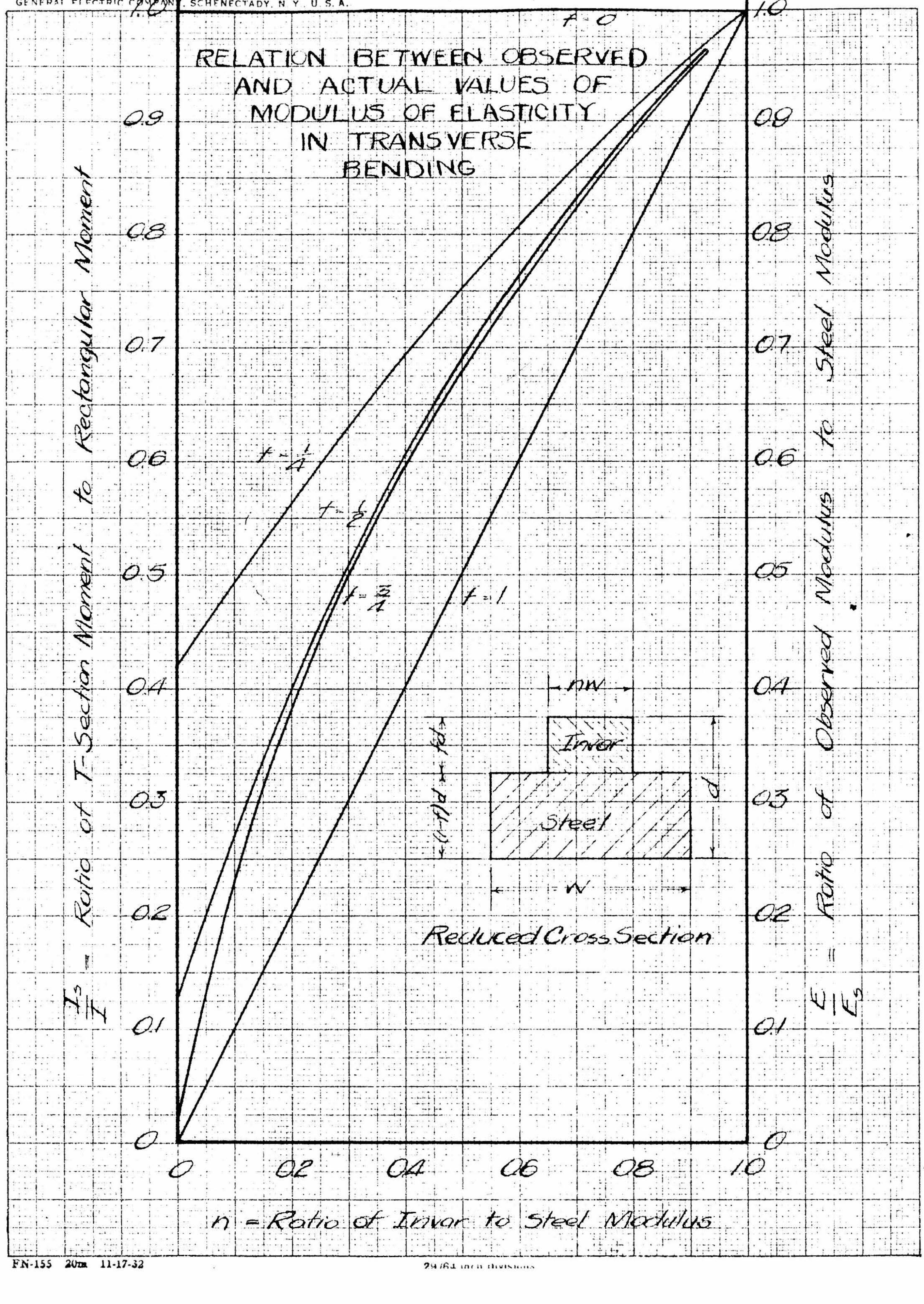
$$EI = E_s I_s$$

and then putting in the I's in terms of the dimensions of the sections, the following equation results:

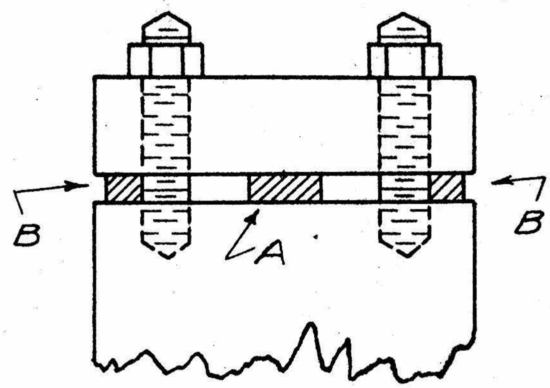
$$\frac{E}{E_s} = \frac{I_s}{I} = \left[4(nf^3+g^3) - \frac{3(nf^2-g^2)^2}{(nf+g)}\right]$$

where n is the ratio of the invar to the steel modulus, f is the fraction of invar, and g the fraction of steel in the bimetal. The complication of the equation is due to the fact that the moment of inertia of the reduced section must be calculated about the gravity axis g--g of the section. This involves first solving for the distance $\bar{y}$ to locate the gravity axis. The above equation is charted as a series of curves on page 47. Each curve represents a bimetal strip whose fraction of invar is constant along the curve. Besides the five curves shown in the figure, curves for $f = .45$ and $f = .55$ were calculated, but were so close to that of the $f = .50$ curve, at least for the higher values of n, that the three curves could not be distinguished if charted. This then shows that the amount by which the studied bimetallic strips are not half invar and half steel is insignificant as far as transverse bending is concerned. Thus from the curve, for $n = 0.8$, and $f = .50$, $E/E_s = .895$ or roundly 0.90.

Now if the steel modulus is 27,000,000 lb. per sq. in., E_s, then the observed modulus in bending should be 0.9 E_s or 24,300,000 lb. per sq. in. But the average value of the bending modulus for the


RELATION BETWEEN OBSERVED
AND ACTUAL VALUES OF
MODULUS OF ELASTICITY
IN TRANSVERSE
BENDING
f = 0
f = 1/4
f = 1/2
f = 3/4
f = 1
nw
Invar
Steel
fd
(1-f)d
d
w
Reduced Cross Section
I_s/I = Ratio of T-Section Moment to Rectangular Moment
E/E_s = Ratio of Observed Modulus to Steel Modulus
n = Ratio of Invar to Steel Modulus
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
0.2
0.4
0.6
0.8
1.0

first set of samples, #1-IC to #4-IT, pp. A-1 to A-8, is 22,300,000 lb. per sq. in. The average bending modulus for the oven test samples, pp. A-9 to A-20, is 22,300,000 lb. per sq. in. The average bending modulus of the H-thermometals, pp. A-21 to A-28, is 21,200,000 lb. per sq. in. The writer believes that this discrepancy between the observed values and the value calculated can be explained as due to the method of supporting the cantilever test specimen at its base. Fig. 12 is a sketch of the method of clamping the cantilever specimen between two steel blocks. The sketch is drawn to scale except for the thickness of the strips, which in the case of the bi-metal used are .030" thick. The clamping blocks may be seen in the picture, Fig. 2. The auxiliary strips (B in Fig. 12) are inserted so that there is a more uniform pressure on the tested strip from the top block. The nuts are tightened soundly to hold the strips.



A - Tested Strip
B - Auxiliary Strips

Fig 12 Base Support

The reasons that the method of holding the specimens at the base was thought responsible for the discrepancy mentioned were: (1) before the auxiliary strips B were used in testing, curves showing an increase in stiffness with increase in load were obtained--the strips B eliminated this but there were still likely to be deviations from true cantilever support, and (2) a bending test performed on specimen #1-3D, page A-29, showed about the same discrepancy between the bending modulus and tension modulus from test #1-3D, page B-23, in tension.

The ratios of observed modulus in bending to the calculated modulus from the tension test results are (1) for the specimens #1-IC etc. 0.92, (2) for the oven test samples 0.92, and (3) for the H-thermometal 0.87, and (4) for the specimen #1-3D 0.85. Complete bending tests were not made on any other strips of the individual metals since it was not originally intended that this test be made on these strips and also because when the discrepancy in question was recognized, there was not time to make the necessary tests; however, a few of these individual metals were put in the cantilever machine and the deflection due to a one pound load was compared with the results of the tested specimen #1-3D. In general the bending modulus was some ten per cent below the corresponding tension modulus. The bending and tension specimens of the individual metals were in each case cut from the same 1" x 10" x .080" strip furnished by the H. A. Wilson Company; therefore even though the modulus changed from strip to strip, it was considered that within the 1" x 10" strip there was a constant modulus.

Therefore in order to explain this discrepancy a coefficient of end fixity is introduced into the deflection equation, making it

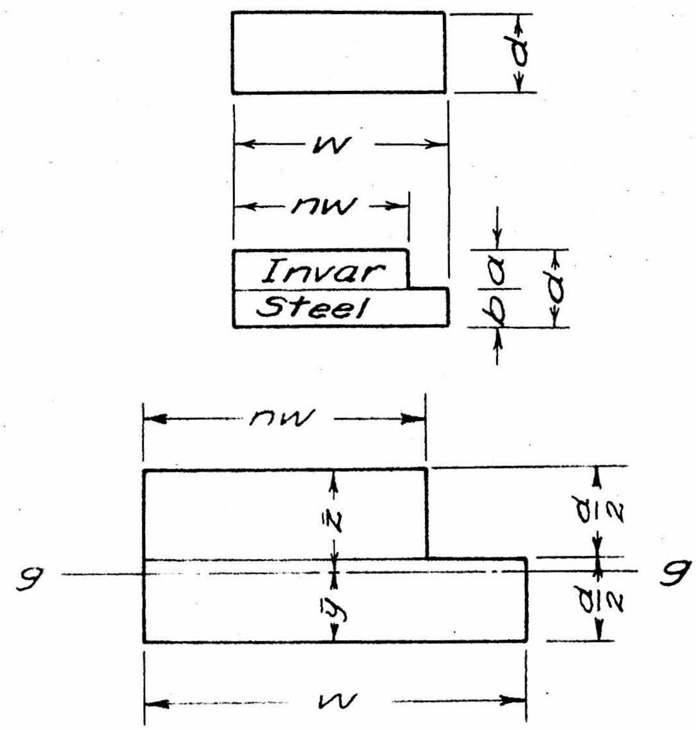
$$y = \frac{Pl^3}{k\,3EI}$$

where k is the coefficient of end fixity. If the support is a true cantilever support, k = 1; in other cases k is less than one and in the extreme case when k = 0, there is no support. The condition that must be satisfied in true cantilever loading is that the slope of the beam at the support is zero, which condition is not the case in this investigation because of the elasticity of the clamping blocks. This coefficient k is a constant during a given test because the deformations and stress concentrations of the clamping block are proportional to the load applied to the specimen. If then for example k is chosen as 0.87 for the H-thermometal, the bending modulus will be correct. There is not much doubt that k varies from one set up to another and probably depends on the thickness, width, and modulus of the specimen and the modulus of the clamping blocks.

The existence of a coefficient of end fixity different from 1 does not change any of the values of the stresses listed in the tables and shown on the curves, since it is the unit deformation which is corrected by the coefficient. If the curves were corrected for this coefficient the slope of the curves only would be changed.

Calculation of actual steel and invar stresses produced by bending:

The transverse bending curves included in this report give the relation between outer fiber stress of a homogeneous material, i.e. one with a constant modulus of elasticity throughout, and the unit deformation of that outer fiber. The proportional elastic limit shown on each curve therefore is that for the whole strip and is not to be taken as the stress at any particular point in the strip. Since the bimetallic strip has as its components two metals of different moduli of elasticity, in order to find the actual stress at any point due to the loading, a correction factor must be applied to the stress given on the stress strain curve. The correction factor for two fibers, the outside steel fiber and the outside invar fiber, will be developed here and applied to the value of the proportional elastic limit of each bending test. The resulting values will then give the actual stresses added to the outside fibers of the bimetal at the time when the strip as a whole is at its proportional elastic limit due to the mechanical loading of the strip. Consider Fig. 13, which represents first the cross section of the strip of homogeneous material of width w and thickness d, and below it the reduced section considered as a steel strip and obtained as before. The bottom sketch is an enlarged



Equivalent Steel Section
Fig 13

view of the equivalent steel section, showing that the thickness of each strip is the same. The gravity axis g--g is on the steel side because of the greater width of that side. The calculations for the stresses for an applied moment M follow.

Location of neutral axis

$$\bar{y} = \frac{(nw\frac{d}{2})(\frac{3}{4}d) + (w\frac{d}{2})(\frac{d}{4})}{\frac{d}{2}(nw + w)}$$

$$\bar{y} = \frac{d^2(\frac{3}{8}n + \frac{1}{8})}{d(\frac{n+1}{2})} = d\,\frac{3n+1}{4n+4} = .472\,d$$

distance from neutral axis to steel outer fiber = .472 d = $\bar{y}$

distance from neutral axis to invar outer fiber = .528 d = $\bar{z}$

then the moment of inertia of the reduced cross section about the g--g axis is

$$I = \frac{nw(\frac{d}{2})^3}{12} + (nw\frac{d}{2})(.278d)^2 + \frac{w(\frac{d}{2})^3}{12} + (w\frac{d}{2})(.222d)^2$$

$$I = wd^3[.00873 + .0309 + .01042 + .0246] = .0743\,wd^3$$

from these follow the stress in the invar and the steel outer fibers;

for the invar

$$S_i = \frac{M\bar{z}}{I} = \frac{M(.528d)\,n}{wd^3(.0743)}$$

for the steel

$$S_s = \frac{M\bar{y}}{I} = \frac{M(.472\,d)}{wd^3(.0743)}$$

but the stress shown on the curves is

$$S = \frac{M6}{wd^2}$$

where $\underline{wd}^2/6$ is the section modulus of a rectangular cross section.

Now for a bending moment $\underline{M}$ we have three stresses, (1) actual stress in invar outer fiber, (2) actual stress in outer steel fiber, and (3) that stress computed in the transverse bending calculations and shown on the curves. The ratio of actual stress to computed stress may now be found.

Ratio of actual invar outer fiber stress to "curve" stress

$$R_1 = \frac{(.528)(.8)}{(.0743)(6)} = 0.95$$

Ratio of actual steel outer fiber stress to "curve" stress

$$R_2 = \frac{(.472)}{(.0743)(6)} = 1.06$$

Therefore the actual outer fiber invar stress is five percent less than the curve stress while the actual outer fiber steel stress is six per cent greater than the curve stress.

These adjusted values are tabulated in tables I to IV, pp. 34ff.

<u>Calculation of the initial residual stress in the invar outer fiber:</u>

The results of the bending and direct tension tests made on the bimetal strips and the individual metals are the data used for the calculation of the residual initial stresses at room temperature in the bimetallic strip. For the direct tension tests on the individual materials the data are proportional elastic limits. The direct tension tests on the bimetallic strips give, after the correction mentioned above, the actual stresses added to each side of the bimetal strip at the point when the strip as a whole reaches its proportional elastic limit. The transverse bending test results used in the determination of initial stresses are the actual stresses in the outer fibers of the steel and the invar due to the bending of the bimetallic strip.

When the investigation of the physical properties of the individual metal strips was undertaken, it was expected that the stress strain diagrams in tension would show a definite proportional elastic limit and yield point. However, such was not the case as can be seen from the curves plotted for the tests (see Appendix B). Because of the gradual deviation of the stress strain diagrams in tension from the proportionality line, as mentioned before in this report, it was in general very difficult to establish any given stress as the proportional elastic limit. In general it was even harder to pick out a proportional elastic limit for the tension curves than for the bending curves, even though from the nature of the bending test the calculated curve would be expected gradually to deviate from proportionality near the elastic limit.

Let Fig. 14 represent the unknown stress distribution in the bimetal strip. Denoting tensile stresses as positive and compressive stresses as negative, let

$\underline{S_1}$ = initial stress in invar outer fiber,

S_2 = initial stress in invar bond,

S_3 = initial stress in steel bond,

S_4 = initial stress in steel outer fiber,

B = proportional elastic limit of steel in tension,

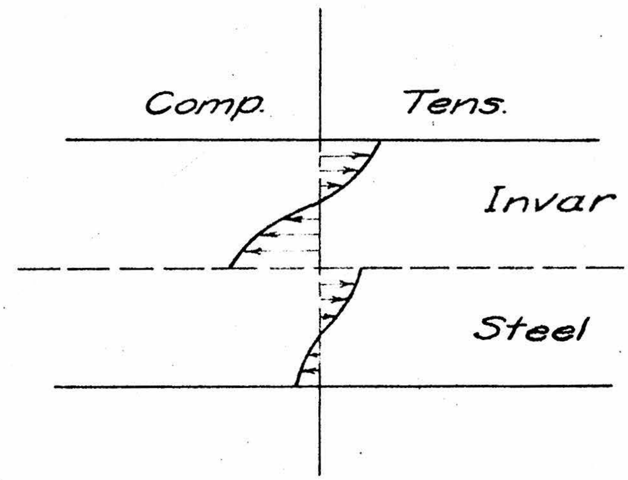


Fig. 14

$-B$ = proportional elastic limit of steel in compression,

C = proportional elastic limit of invar in tension,

and $-C$ = proportional elastic limit of invar in compression.

The assumption made here is that the proportional elastic limit of the two steels (the invar and steel) is the same in compression as in tension.

Now let the stresses in the outer fibers when the proportional elastic limits in bending are reached be designated as

S_c = steel stress with steel in compression,

S_t = steel stress with steel in tension,

I_c = invar stress with invar in compression,

I_t = invar stress with invar in tension.

If the bimetal strip is bent so that the steel side is put in tension, the invar side is put in compression. Then the reason for the strip as a whole reaching its proportional elastic limit is that either the steel reaches its proportional elastic limit in tension or the invar reaches its proportional elastic limit in compression. Using the notation above, this may be expressed as

$$S_4 + S_t = B$$

$$S_1 + I_c = -C$$

If the first of these equations is correct, the interpretation would be that the applied stress S_t added in the steel outer fiber to that already present at that point, S_4, makes the resulting stress B, the proportional elastic limit of the steel in tension. If the second is correct, the interpretation would be that the applied stress I_c added in the invar outer fiber to that already present at that point, S_1, makes the resulting stress $-C$, the proportional elastic limit in compression for the invar.

With the same analysis applied to the bimetal strip when tested with the steel put in compression, the two equations are

$$S_4 + S_c = -B$$

$$S_1 + I_t = C$$

The assumption now made to calculate the magnitude of the stress

$\underline{S_1}$ is that the bimetallic strip reaches it's proportional elastic limit because the invar outer fiber reaches its proportional elastic limit before the outer steel fiber does so. This assumption is made for bending in either direction.

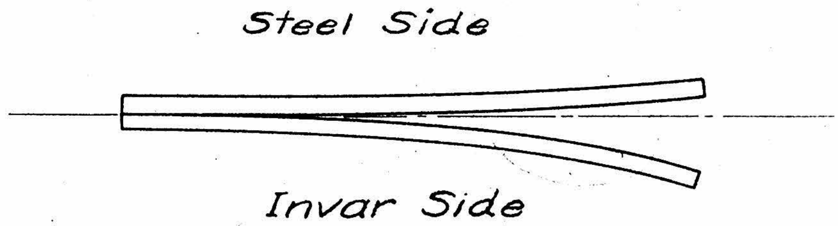


Fig. 16 Split Sample

The justification for this assumption follows. During the shearing of the samples of highheat thermometal into specimens to be used in the oven test included in this investigation, some three or four specimens were found to have split apart at the bond. Fig. 15 shows two pictures of four specimens, three of which were split to various degrees. The specimen with the ragged edges originally had only a small portion of the bimetal split apart. The writer tried to split the entire specimen apart, but was not able to proceed very far as the bond between the two metals was quite satisfactory when the specimen was split as far as is shown in the picture. The specimen with the longest split is sketched in Fig. 16. It is seen that the invar side took on the greater curvature of the two sides on splitting of the strip. Therefore there was a much greater tensile stress originally in the invar outer fiber than in the steel. Therefore there is not much doubt that in bending a bimetallic strip so that the invar side is put in tension, the invar outer fiber will reach its proportional elastic limit first and thus cause the whole strip to show a propor-

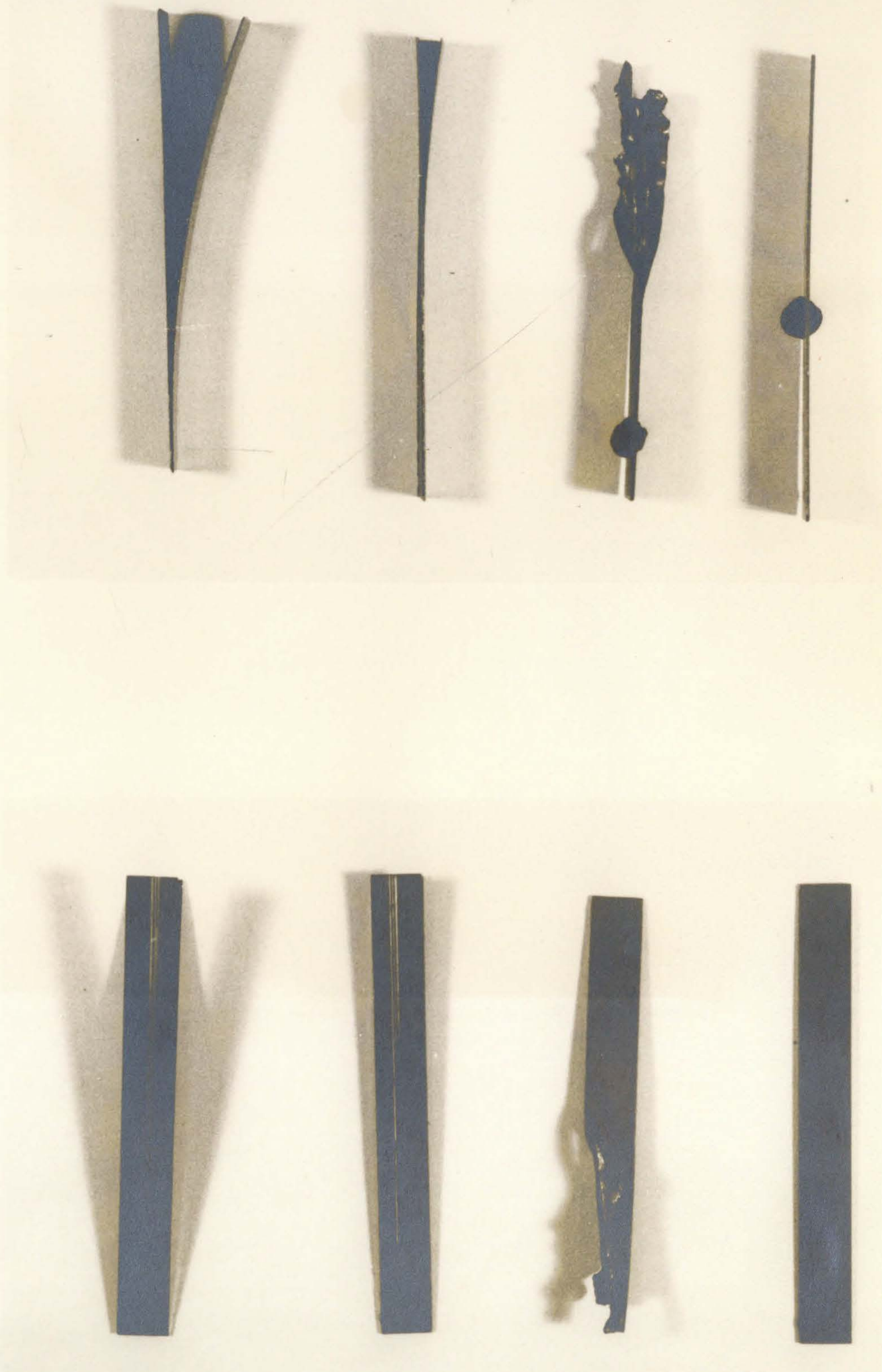


Fig. 15.

tional elastic limit. The justification for the assumption made for bending in the opposite direction follows.

Although the proportional elastic limit is in general only a little lower for the invar metal than for the steel as shown by the tension tests on the individual metals, the ultimate strength of the invar is considerably lower. The general relation between the steel and invar curves in tension is shown in the sketch in Fig. 17, where #2 is the steel curve and #3 the invar curve. A proportional elastic limit in one side of the bimetal strip cannot be said to correspond absolutely to that of the individual metal because the outer fiber stress in question increases with greater loading as does the individual metal in tension instead of staying at the proportional elastic limit, or yield point, as would the material if it had a definite yield. The yield of the invar and the steel individual samples, if there is one, corresponds more nearly to the ultimate strength. It is the yielding in the material that is detected as deviation from the proportionality line in the transverse bending test. Referring to

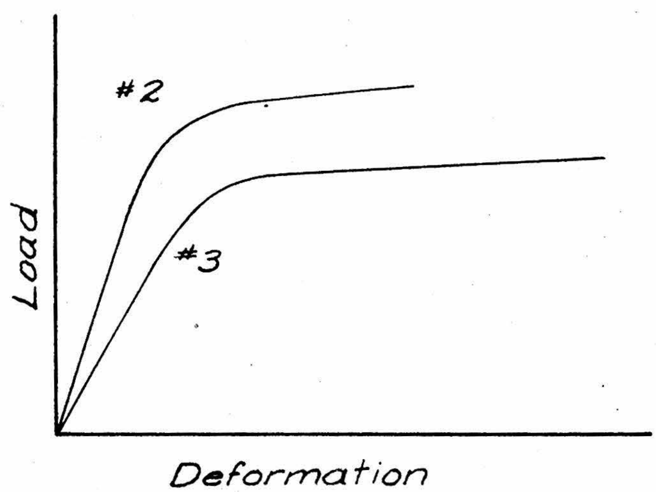


Fig. 17

the sketch of the split sample again it is to be seen that the bending of the steel is small, indicating small differences in initial stresses over the steel side, i.e. stresses of small moment. The outer fiber of the steel may be in a slight tension due to the fact that the steel strip curved outward. It simply may be in less compression than the portion of the steel near the bond. Therefore, in the bending of bimetal so that the invar side is put in compression and the steel put in tension, although the actual initial stresses in the steel outer fiber are unknown, it is believed that the invar side will be responsible for the proportional elastic limit of the strip as a whole becuase (1) the ultimate and therefore the yield of the invar is much lower than that of the steel, and (2) there is no considerable initial tensile stress in the steel outer fiber.

Using the assumption made and justified above that the properties of the invar are responsible for the proportional elastic limit of the bimetal strip in bending, the second equations of the two sets of equations on page 56 are solved simultaneously for each of the sets or pairs of bimetal strips tested in transverse bending. The values obtained are (1) $\underline{S_1}$, the residual stress in the invar outer fiber, and (2) $\underline{C}$, the proportional elastic limit of the invar. As mentioned in the preceding discussion, this proportional elastic limit would correspond more nearly to a yield point and would be expected to be higher than the proportional elastic limit found on individual invar strip curves. This is the case. The initial stresses found in

TABLE V INITIAL STRESSES				
Specimen Numbers Invar side in		Bending Stress in Invar at Pr.El.Lim. (lb. per sq. in.)	Initial Stress in Invar Outer Fiber (lb. per sq. in.)	Calculated Invar P.E.L. (p.s.i.)
Comp.	Tens.			
1-HA		120,000	35,000 T	85,000
	2-HA	50,000		
1-HB		117,000	27,000 T	90,000
	2-HB	63,000		
2-HC		90,000	12,000 T	88,000
	1-HC	66,000		
2-HD		37,000	5,000 T	32,000
	1-HD	27,000		
1-IC		19,000	0	19,000
	1-IT	19,000		
2-IC		119,000	43,000 T	76,000
	2-IT	33,000		
3-IC		52,000	0	52,000
	3-IT	52,000		
4-IC		128,000	33,000 T	95,000
	4-IT	62,000		
2B4		117,000	28,000 T	88,000
	2B2	60,000		
2F4		118,000	24,000 T	84,000
	2F1	69,000		
3B2		88,000	16,000 T	72,000
	3B4	57,000		
3F3		106,000	20,000 T	85,000
	3F4	65,000		
4B3		120,000	32,000 T	88,000
	4B1	57,000		
4F3		117,000	28,000 T	88,000
	4F2	60,000		

TABLE VI OVEN TEST RESULTS

Material Number	Tension in	Time at 600° F.	Specimen No.	Prop. El. Lim. p.s.i.	E (10^6 p.s.i.) Loading	E (10^6 p.s.i.) Unload.
2	Steel	3 hr.	2B4	123,000	23.2	23.9
		504 hr.	2F4	124,000	23.3	23.8
	Invar	3 hr.	2B2	63,000	21.9	22.5
		504 hr.	2F1	73,000	22.6	23.0
3	Steel	3 hr.	3B2	93,000	22.2	22.7
		504 hr.	3F3	112,000	22.3	23.8
	Invar	3 hr.	3B4	60,000	21.3	22.3
		504 hr.	3F4	68,000	22.2	23.0
4	Steel	3 hr.	4B3	126,000	22.7	23.3
		504 hr.	4F3	123,000	22.3	22.6
	Invar	3 hr.	4B1	60,000	21.7	22.2
		504 hr.	4F2	63,000	21.7	22.2

this way are shown in Table V, page 61.

Interpretation of oven test results:

Table VI, page 62, shows the results of the oven test samples tested in transverse bending. In Table V are given the computed residual stresses in these samples. In material #2 the residual stress is seen to decrease from 28,000 to 24,000 lb. per sq. in. tension due to the heating at 600 deg. F. for 504 hours. The corresponding decrease in material #4 is from 32,000 to 28,000 lb. per sq. in. tension. Material #3 shows an apparent increase in the residual stress in the invar outer fiber, but the writer believes this to be wrong because the values of C obtained were so greatly different. Probably in this case the samples tested were not similar at the beginning of the test.

Therefore it can be concluded that subjection of the bimetal to 600 deg. F. for a long period of time does decrease its initial stress distribution to some degree. Yet this amount is small in comparison with proportional elastic limits of the harder thermometals when bent so that the steel is put in tension. It can be seen from Table VI that the properties of the thermometals are not affected greatly.

GENERAL DISCUSSION

The initial residual stresses in bimetallic strips have been found to be very complicated. It is probable that the effect of the rolling of the bimetal does have a considerable effect on the stress distribution. Rolling will give tensile stresses in the outer fibers with compressive stresses in the center. Thus if the residual stresses are composed of the sum of the temperature stresses and the rolling stresses, there will be the sum of two tensions on the invar outer fiber; and on the steel outer fiber there will be the sum of a tension due to rolling and a compression due to temperature change, with the result that the magnitude of the outer fiber steel stress, whether compression or tension, is less than that of the invar outer fiber. This corresponds with the bending of the two sides of the split bimetal strip, Fig. 16.

The writer wishes to state at this point that he feels that the determination of the residual stresses in the bimetal strip using the method of acid immersion would without doubt make a much neater exposition of the distribution and magnitude of these stresses than was possible in this investigation. With a residual stress distribution obtained in this way the effects of rolling and cooling from rolling temperature could be distinguished.

The difficulties involved in this mechanical investigation are numerous. The properties of the tested samples of both the individual metals and the bimetals vary considerably from strip to strip of the same sheet of stock. There was found no definite relation between hardness and physical properties. There was no definite yield point of the materials tested.

It will be remembered that the ordinary beam formulae are used in the calculation of stresses and loads in the transverse bending tests. The deflection of a $1\frac{3}{4}$" specimen during the test was in general about $\frac{1}{2}$", which is a large deflection in comparison to the depth (.030") of the beam specimen. The ordinary beam formulae are for beams whose deflections are not great in comparison to their depth and whose slopes are small: this is then not the case in this investigation. The justification for the simplification in using the ordinary beam formulae in this investigation is that in design of flat strip thermostats in general this assumption is made.

In the discussion of end fixity, page 49 ff., it was concluded that clamping between two steel blocks was not rigid enough to be considered true cantilever support, with the result that the deflections due to external mechanical loading (which is always present in thermostats set for high temperature operation) are greater than calculated with the assumption of a fixed end for the thermostat blade. In many of the thermostats with which the writer is acquainted, the base of the thermostat is fixed only by screwing it to a flat surface with a round head screw. The writer feels that the method of fixing the ends of thermostat blades should be given attention in the design of thermostats.

BIBLIOGRAPHY

National Metals Handbook.

"Wilco Thermometal", The H. A. Wilson Co., Newark, N. J.

"Strength of Materials", Vol. I, II, S. Timoshenko.

"Analysis of Bimetal Thermostats", S. Timoshenko, Journal--"Optical Society of America and Review of Scientific Instruments" July-Dec., 1925.

"Determination of internal stresses in Cold-Drawn Tubes", N. Dawidenkow, Zeitschrift für Metallkunde, Vol. 24, 1932, pp. 25-29.

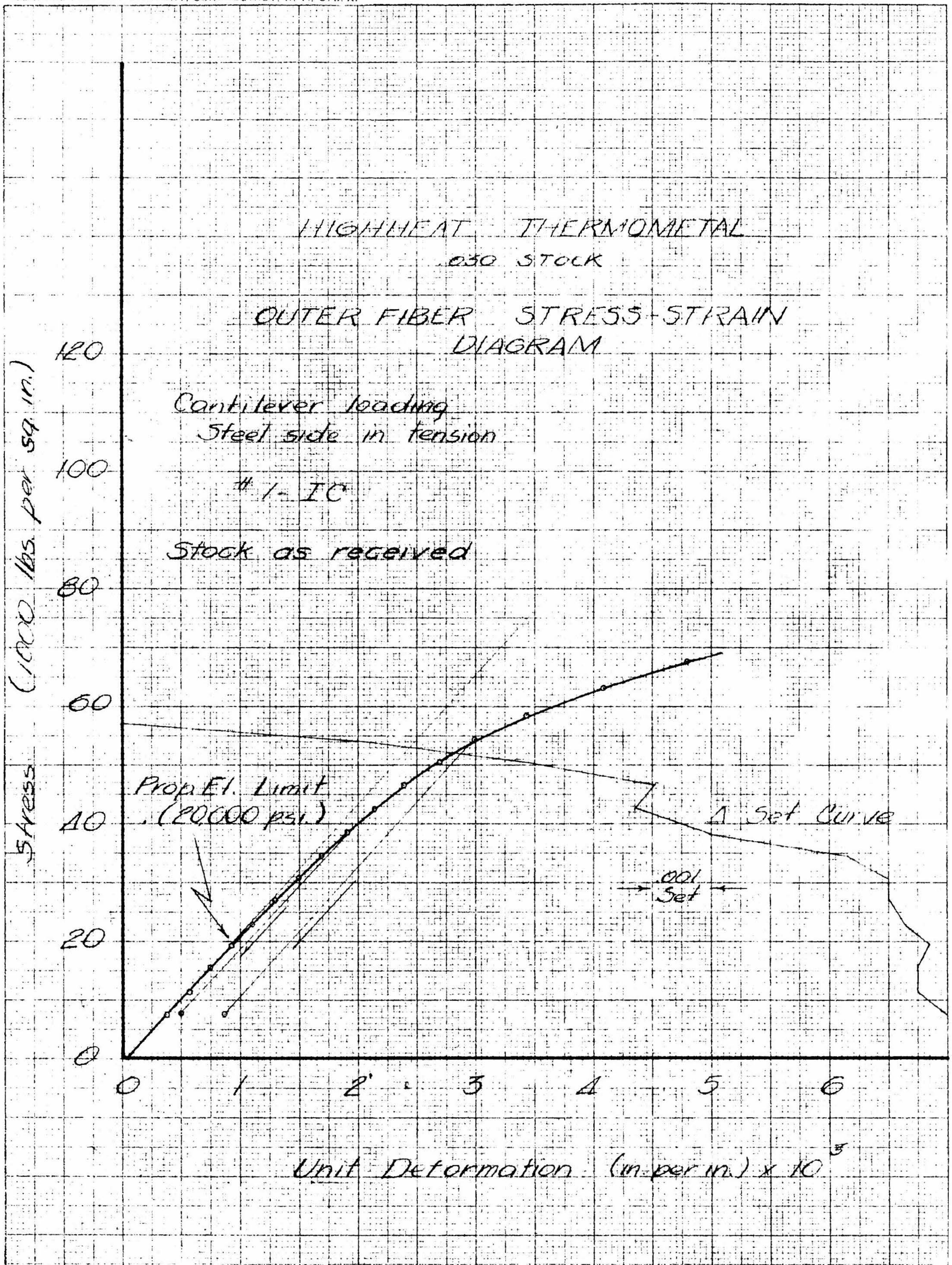
Data folder #55215, General Electric Company.

"Electro Metallurgy", McMillan and W. R. Cooper.

APPENDIX A

TRANSVERSE BENDING CURVES

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A.



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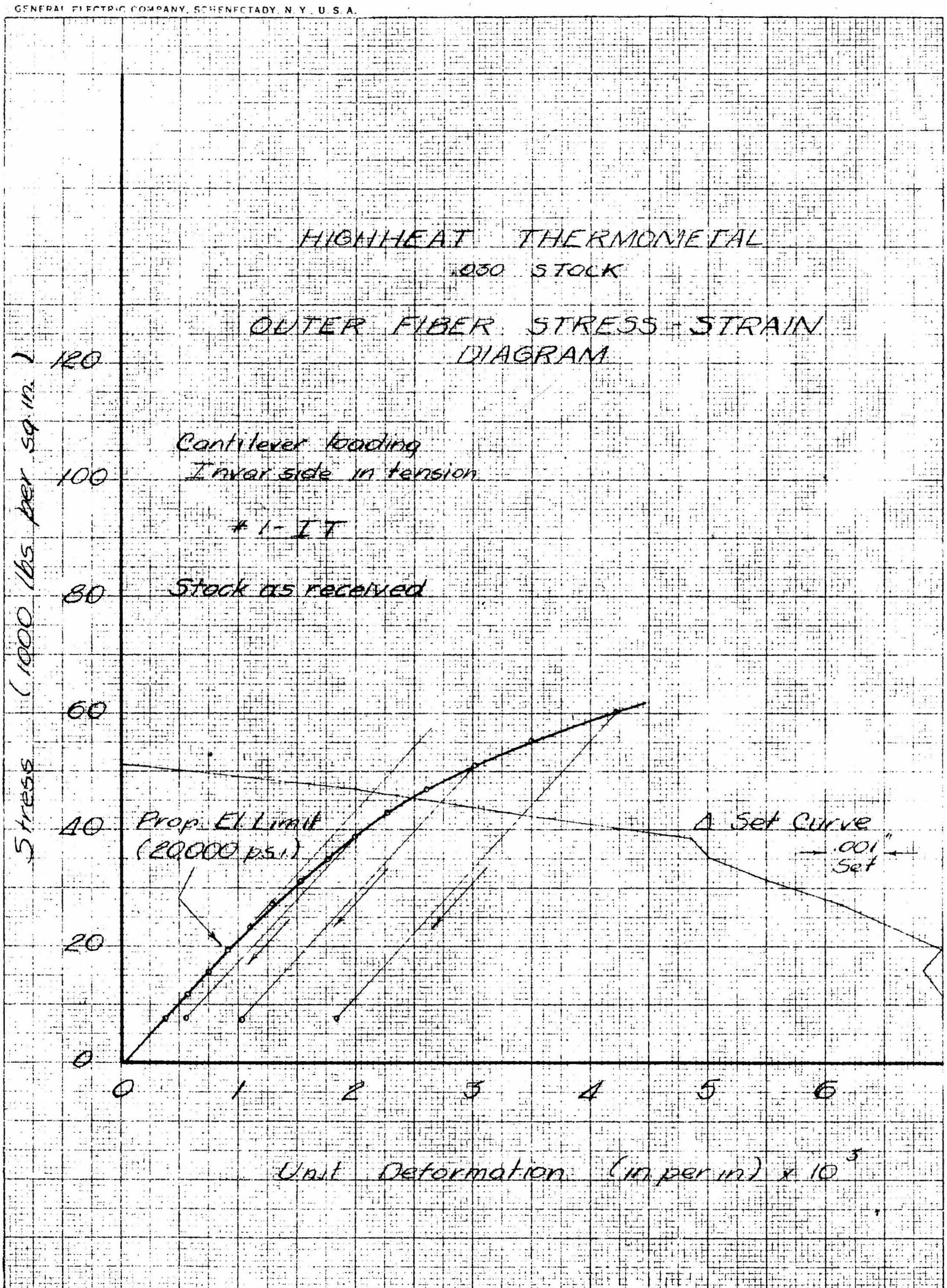
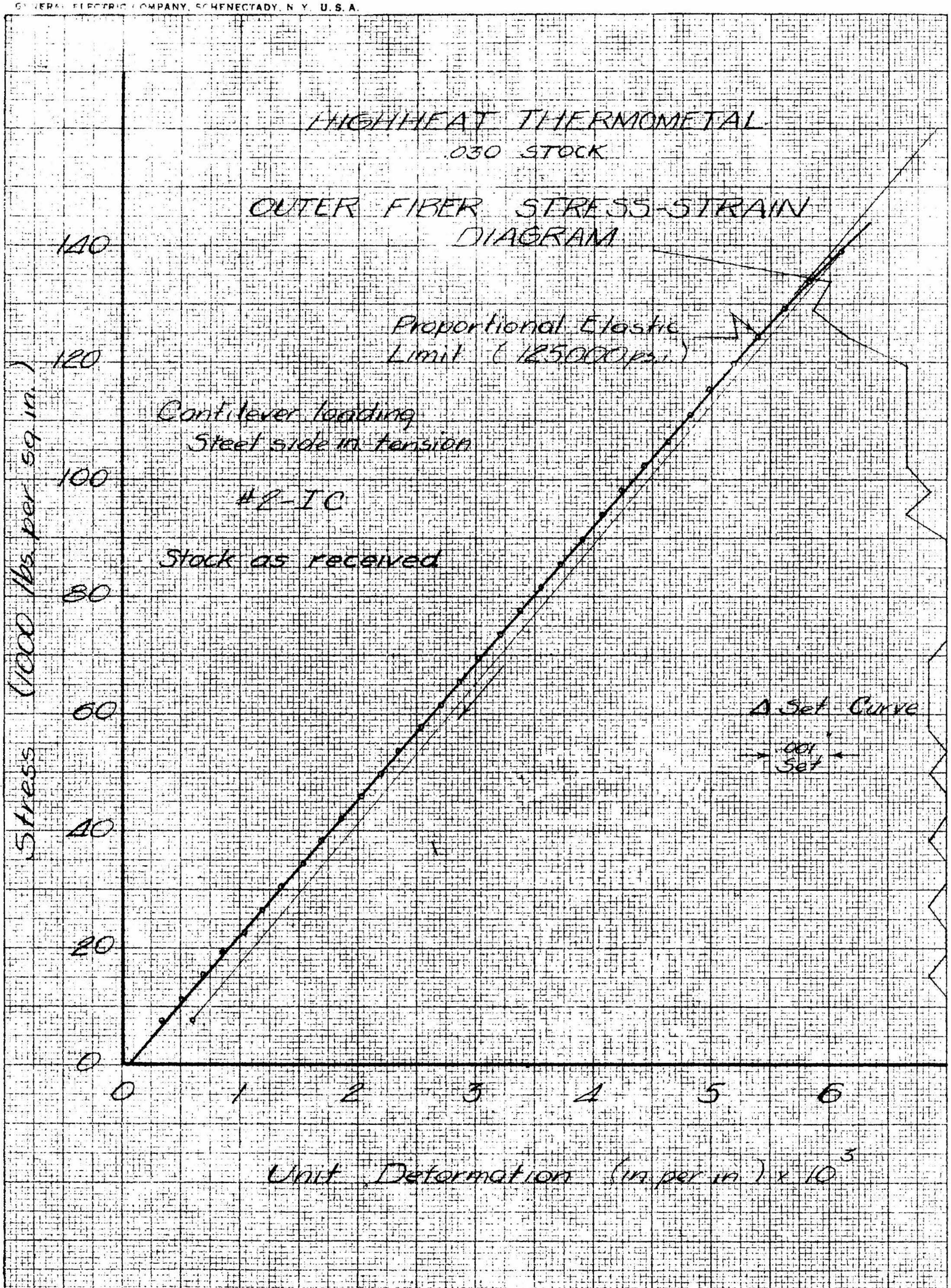
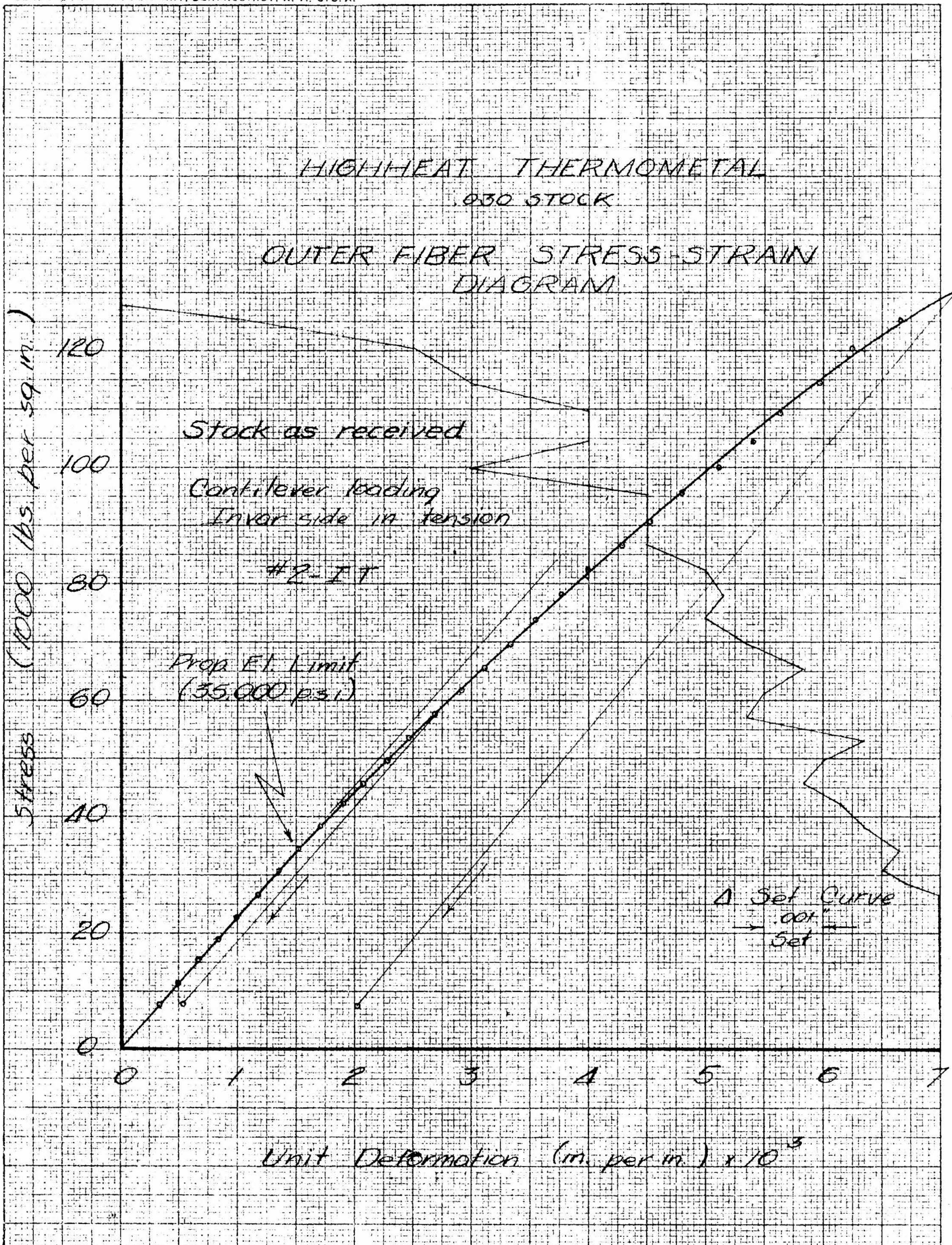



HIGHHEAT THERMOMETAL
.030 STOCK
OUTER FIBER STRESS-STRAIN DIAGRAM
Proportional Elastic Limit (125000 psi.)
Cantilever loading
Steel side in tension
#2-IC
Stock as received
Δ Set Curve
.001 Set
Stress (1000 lbs. per sq in.)
0
20
40
60
80
100
120
140
0
1
2
3
4
5
6
Unit Deformation (in per in) x 10^3


HIGHHEAT THERMOMETAL
.030 STOCK
OUTER FIBER STRESS-STRAIN DIAGRAM
Stock as received
Cantilever loading
Invar side in tension
#2-IT
Prop. El. Limit (35,000 psi)
Δ Set Curve
.001" Set
Stress (1000 lbs per sq. in.)
0
20
40
60
80
100
120
0
1
2
3
4
5
6
7
Unit Deformation (in. per in.) x 10^-3

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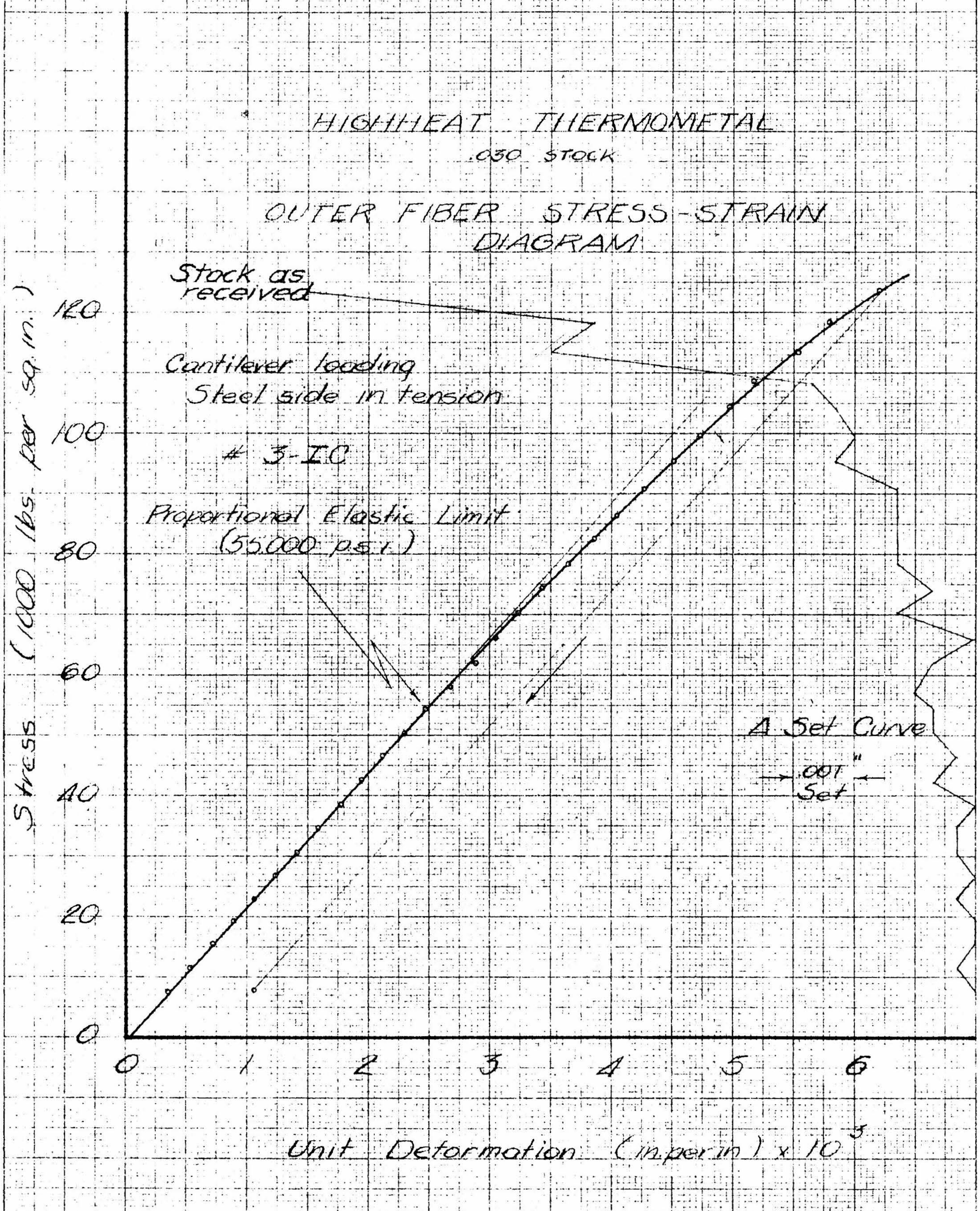

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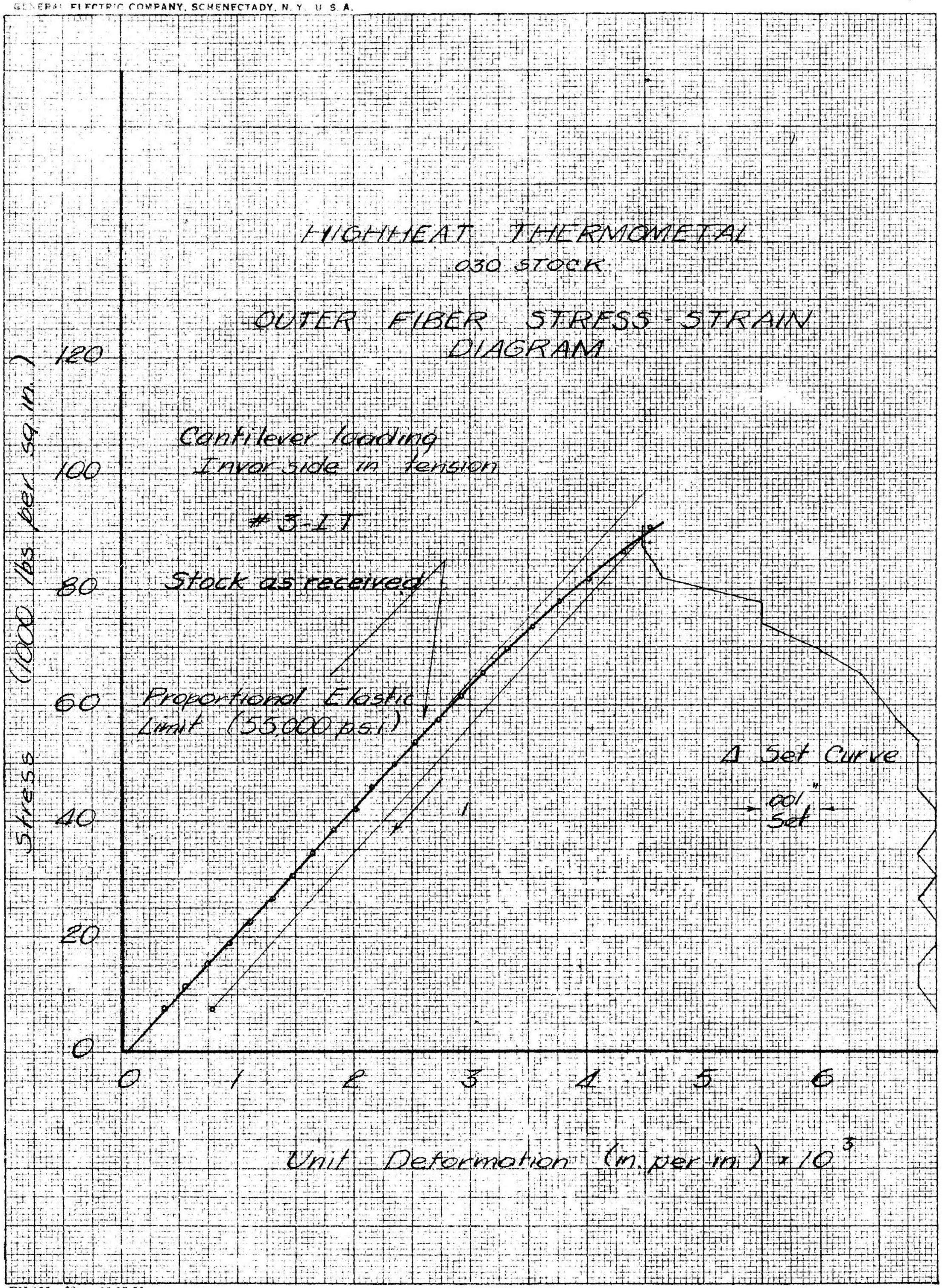

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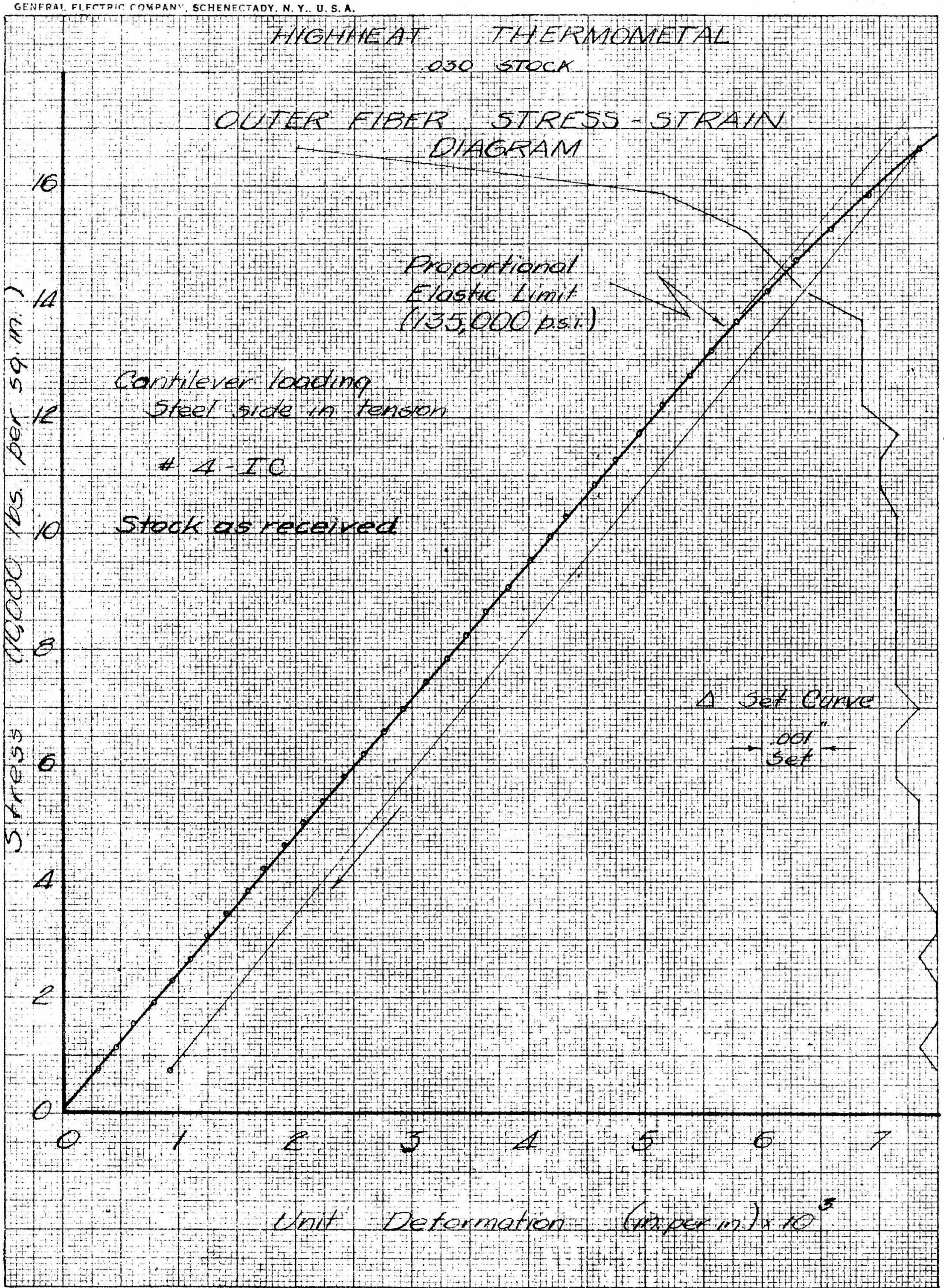
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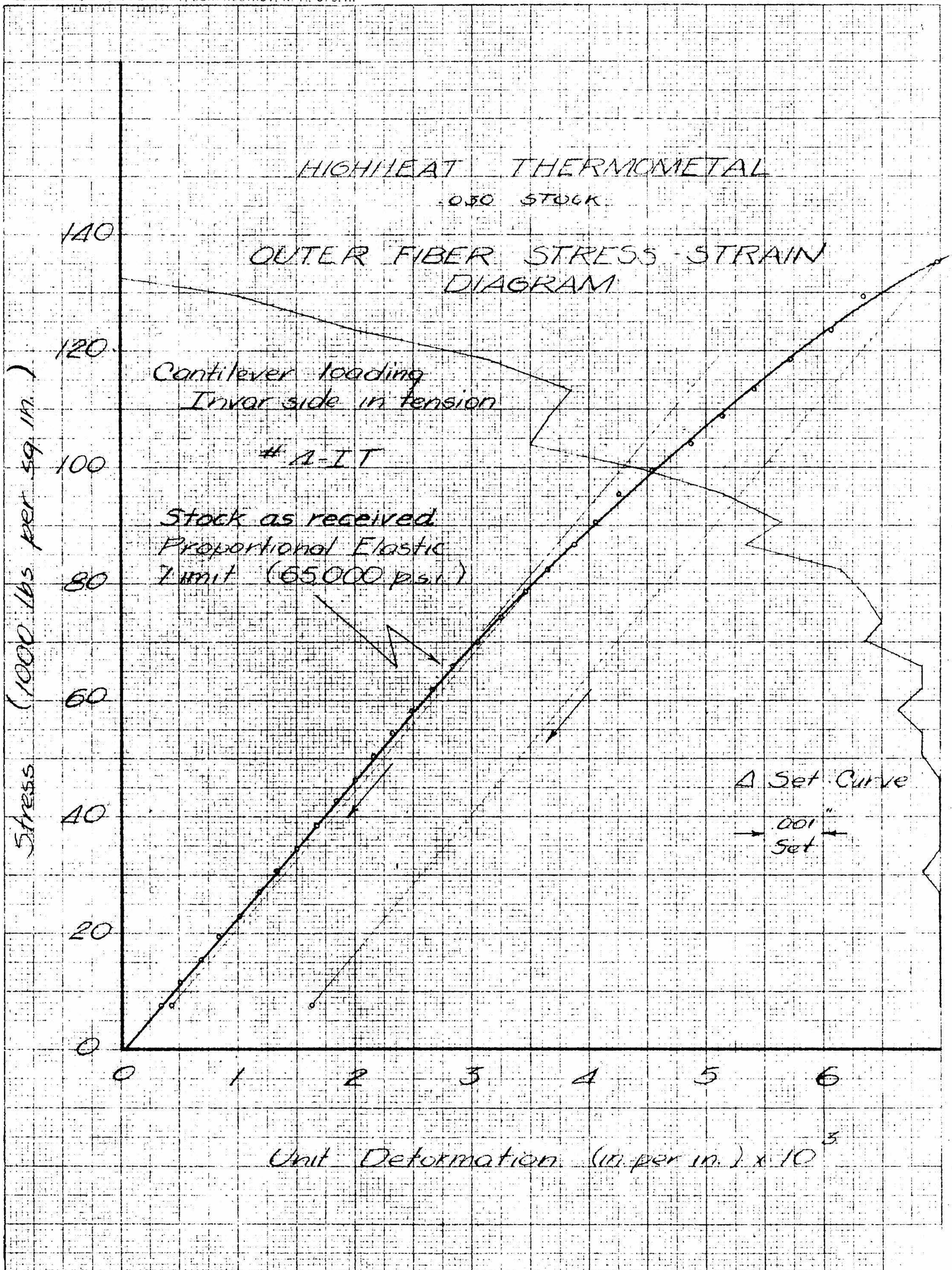
.030 STOCK
OUTER FIBER STRESS-STRAIN DIAGRAM
Proportional Elastic Limit (135,000 p.s.i.)
Cantilever loading
Steel side in tension
4-IC
Stock as received
Δ Set Curve
.001" Set
Stress (10,000 lbs. per sq. in.)
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7
Unit Deformation (in. per in.) x 10^{3}

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A.



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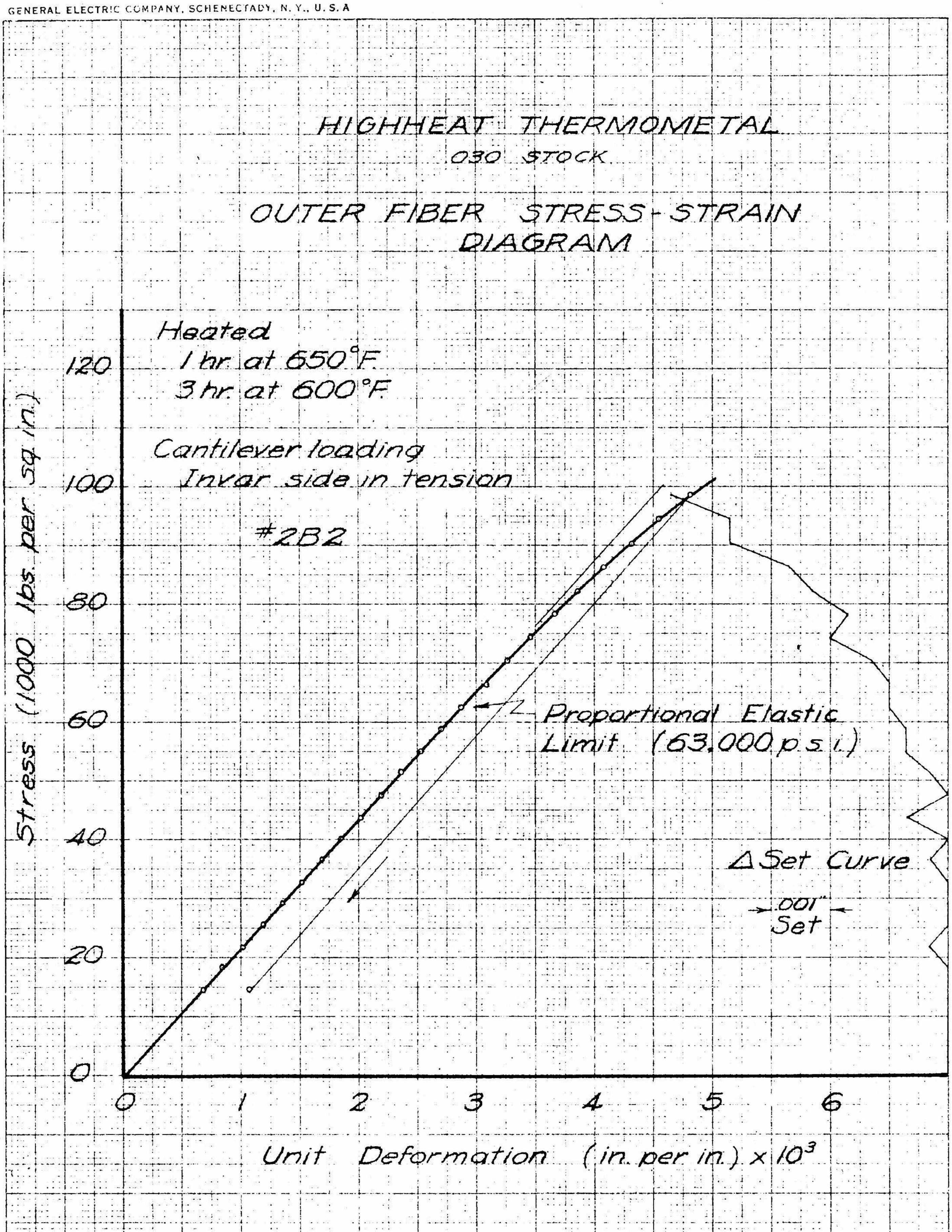

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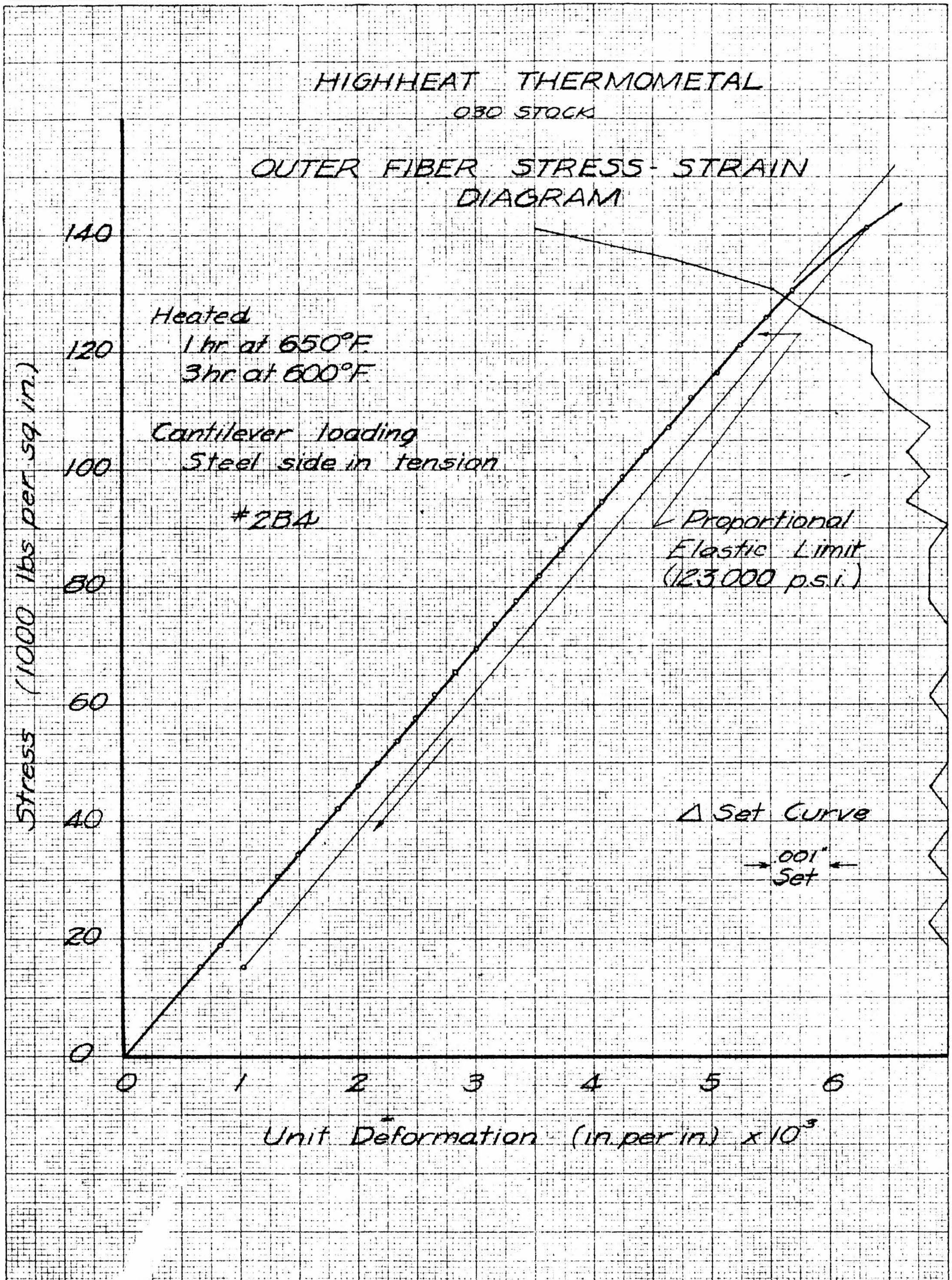
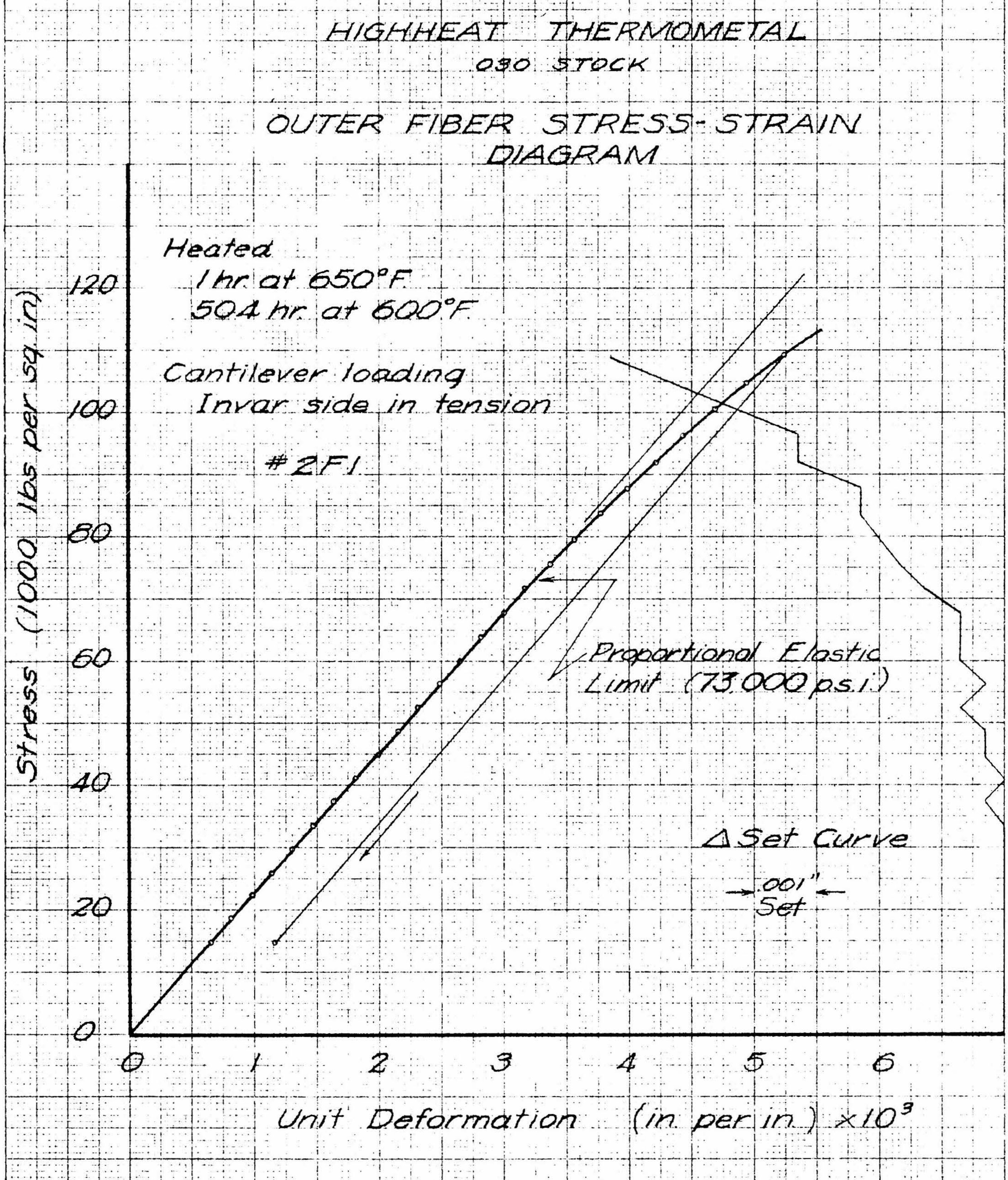
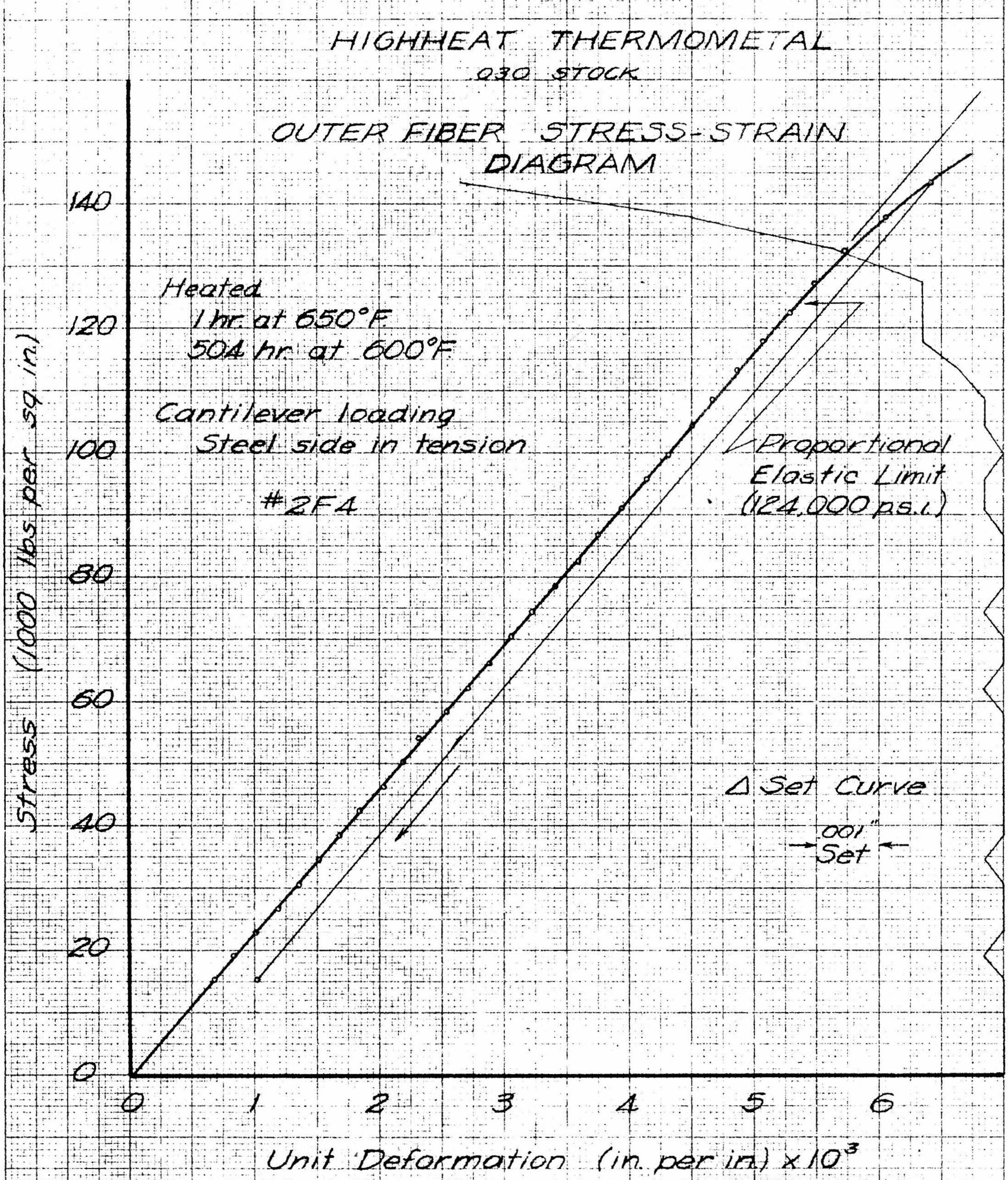

HIGHHEAT THERMOMETAL
.030 STOCK
OUTER FIBER STRESS-STRAIN DIAGRAM
Heated
1 hr at 650°F
3 hr at 600°F
Cantilever loading
Steel side in tension
#2B4
Proportional Elastic Limit
(123000 p.s.i.)
Δ Set Curve
.001" Set
Stress (1000 lbs per sq in.)
0
20
40
60
80
100
120
140
Unit Deformation (in. per in.) x 10^3
0
1
2
3
4
5
6


HIGHHEAT THERMOMETAL
030 STOCK
OUTER FIBER STRESS-STRAIN DIAGRAM
Heated
1 hr. at 650°F
504 hr. at 600°F
Cantilever loading
Invar side in tension
#2F1
Proportional Elastic Limit (73,000 p.s.i.)
Δ Set Curve
.001" Set
Stress (1000 lbs per sq. in)
0
20
40
60
80
100
120
0
1
2
3
4
5
6
Unit Deformation (in per in.) ×10³

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A



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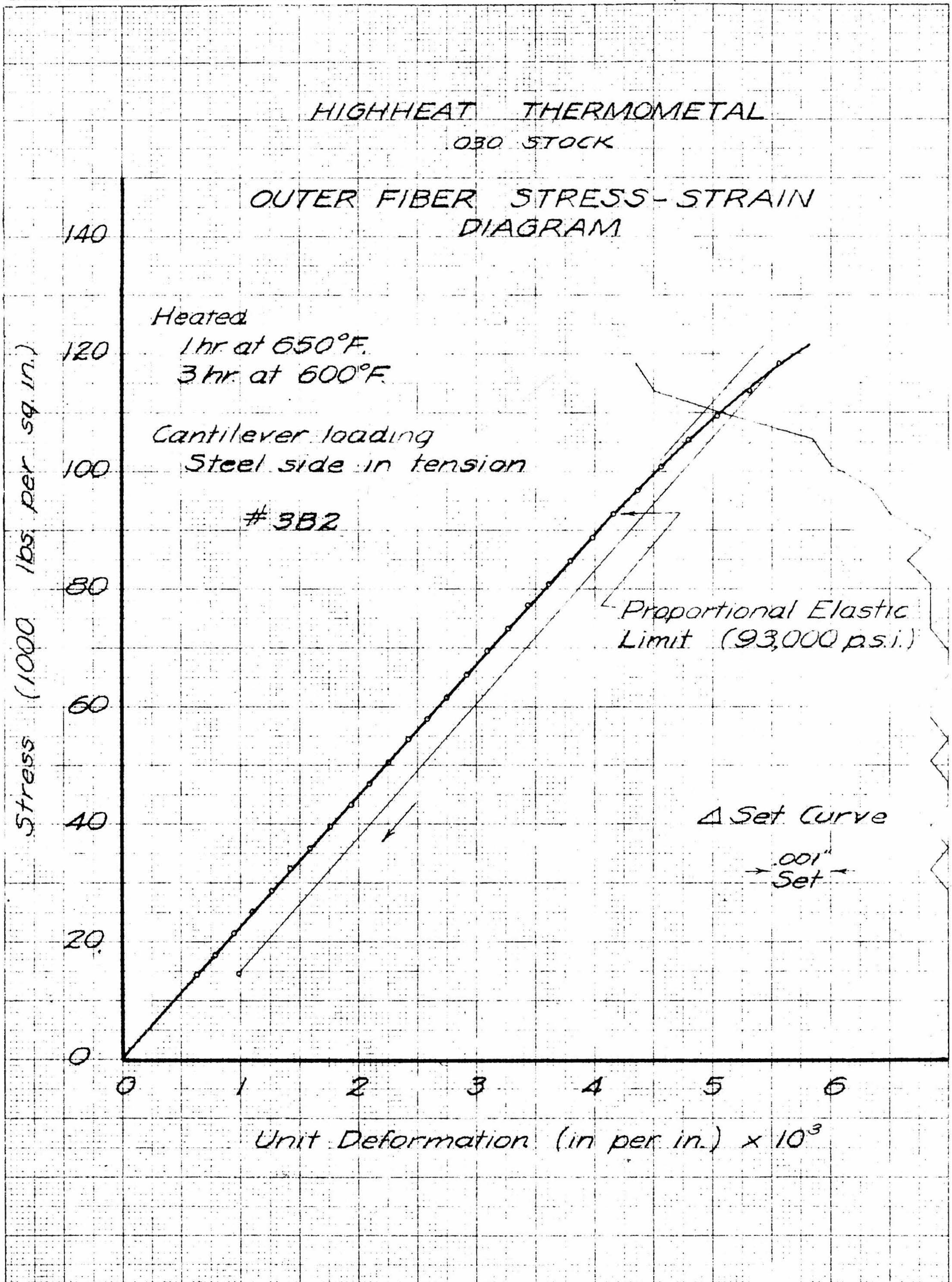
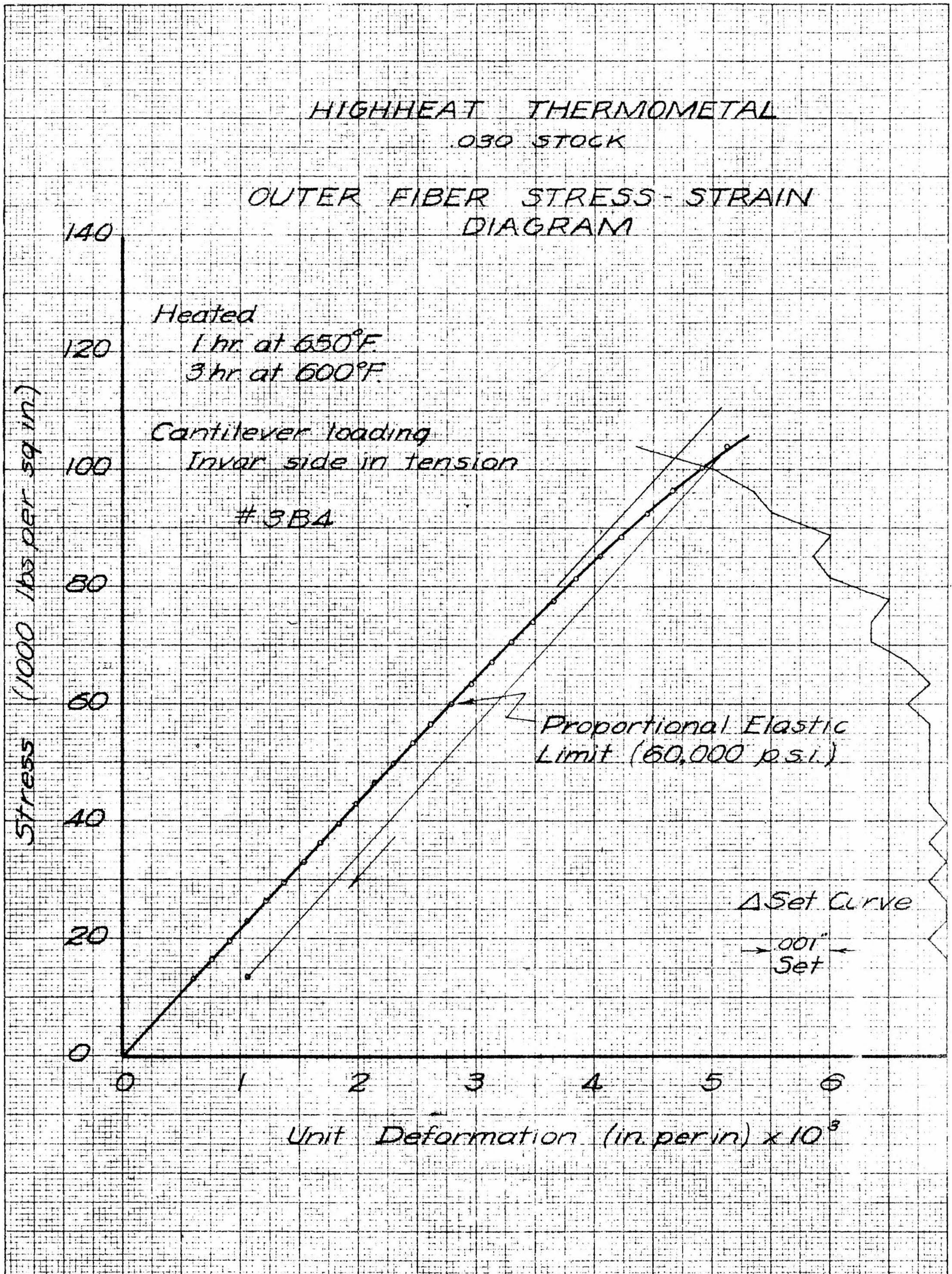
29/64 inch Divisions


HIGHHEAT THERMOMETAL
.030 STOCK
OUTER FIBER STRESS-STRAIN DIAGRAM
Heated
1 hr. at 650°F.
3 hr. at 600°F.
Cantilever loading
Steel side in tension
3B2
Proportional Elastic Limit (93,000 p.s.i.)
Δ Set Curve
.001" Set
Stress (1000 lbs. per sq. in.)
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
Unit Deformation (in per in.) x 10^3

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A.



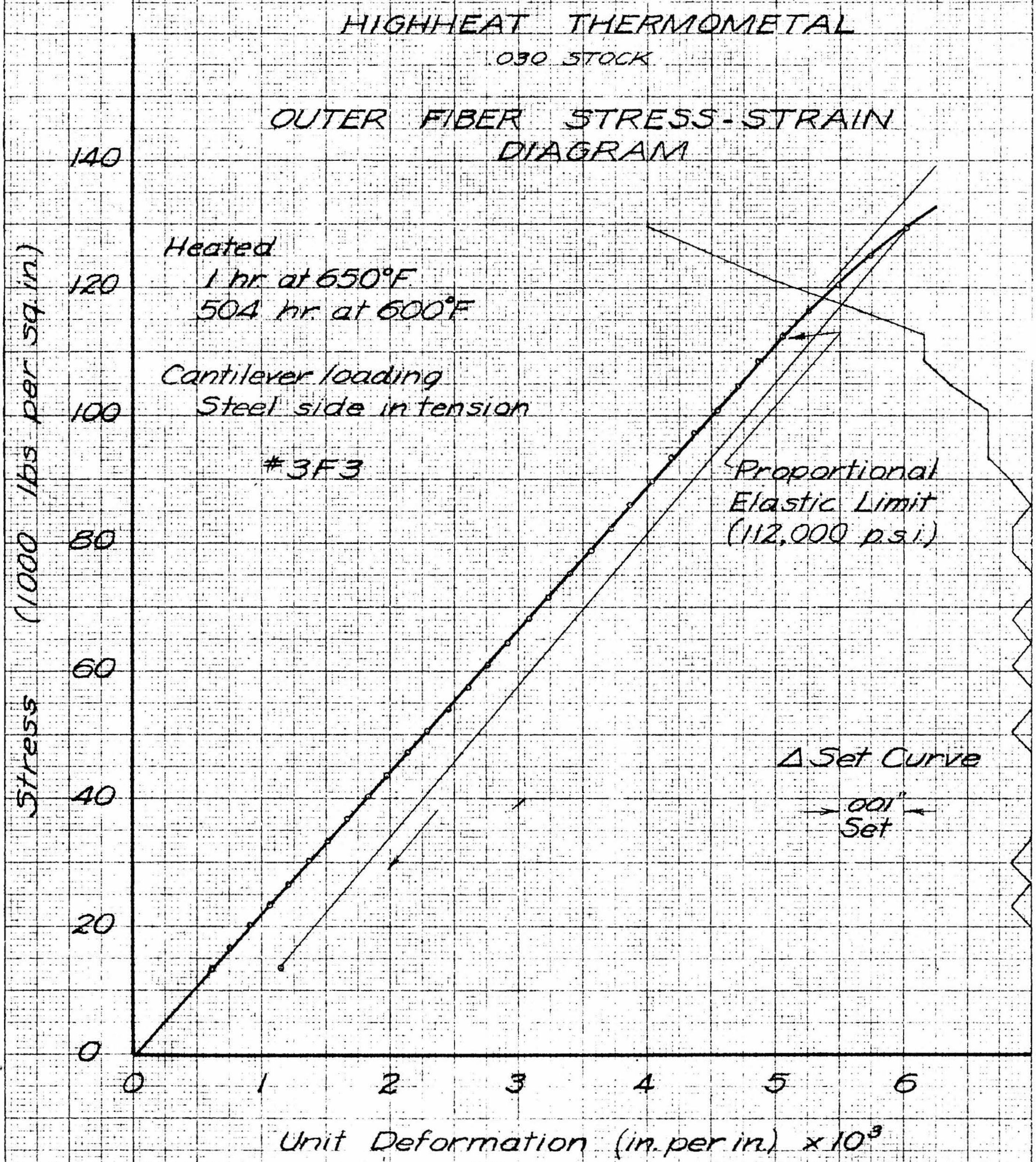
IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE

THIS MARGIN RESERVED FOR BINDING.

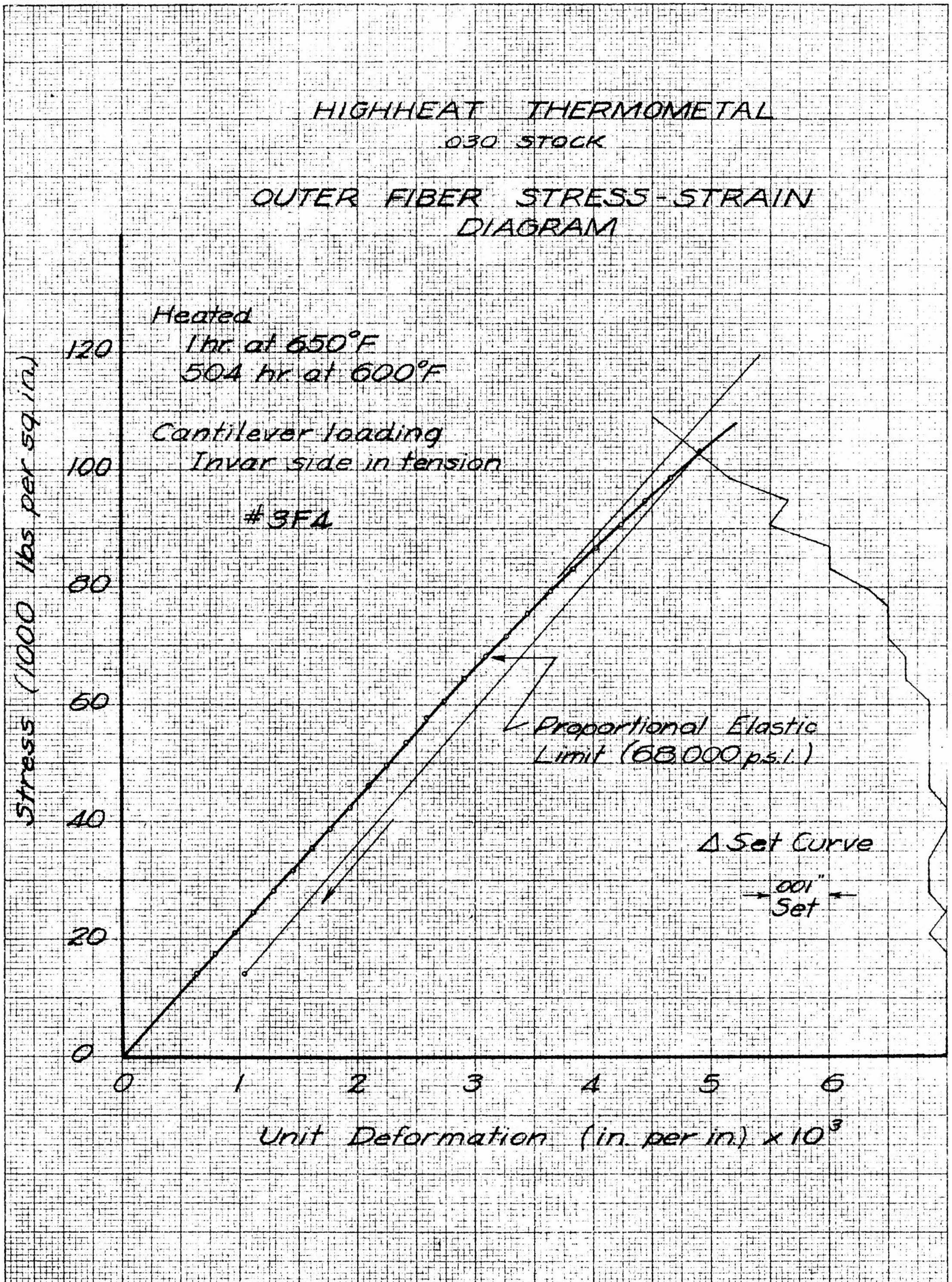
GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A

IF SHEET IS READ THIS WAY (HORIZONTALLY) THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY) THIS MUST BE LEFT-HAND SIDE.

THIS MARGIN RESERVED FOR BINDING.



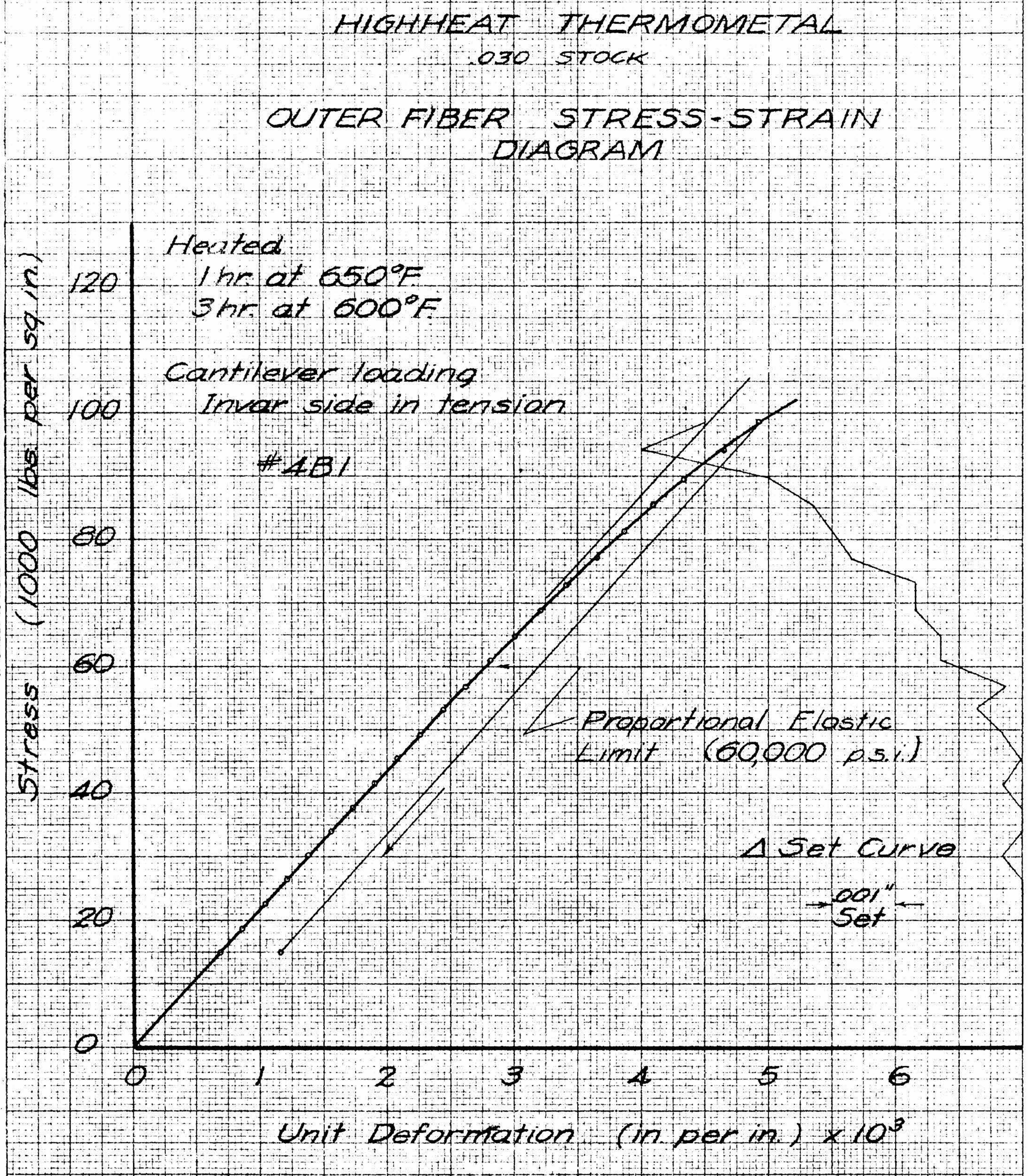
29/64 inch Divisions


HIGHHEAT THERMOMETAL
.030 STOCK
OUTER FIBER STRESS-STRAIN DIAGRAM
Heated
1 hr. at 650°F
504 hr. at 600°F
Cantilever loading
Invar side in tension
#3F4
Proportional Elastic Limit (68,000 p.s.i.)
Δ Set Curve
.001" Set
Stress (1000 lbs per sq in.)
0
20
40
60
80
100
120
0
1
2
3
4
5
6
Unit Deformation (in per in) x 10³

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A

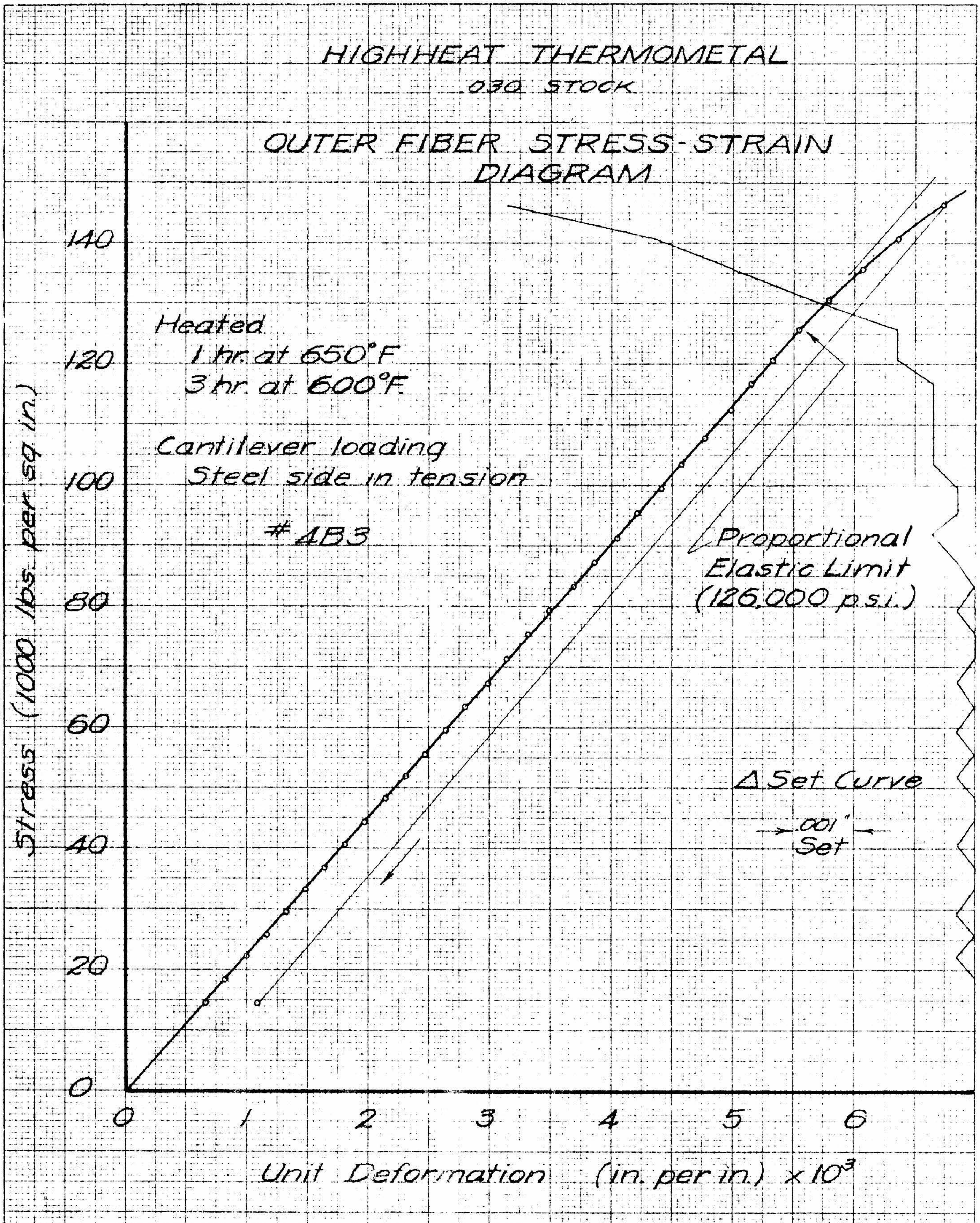
IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE

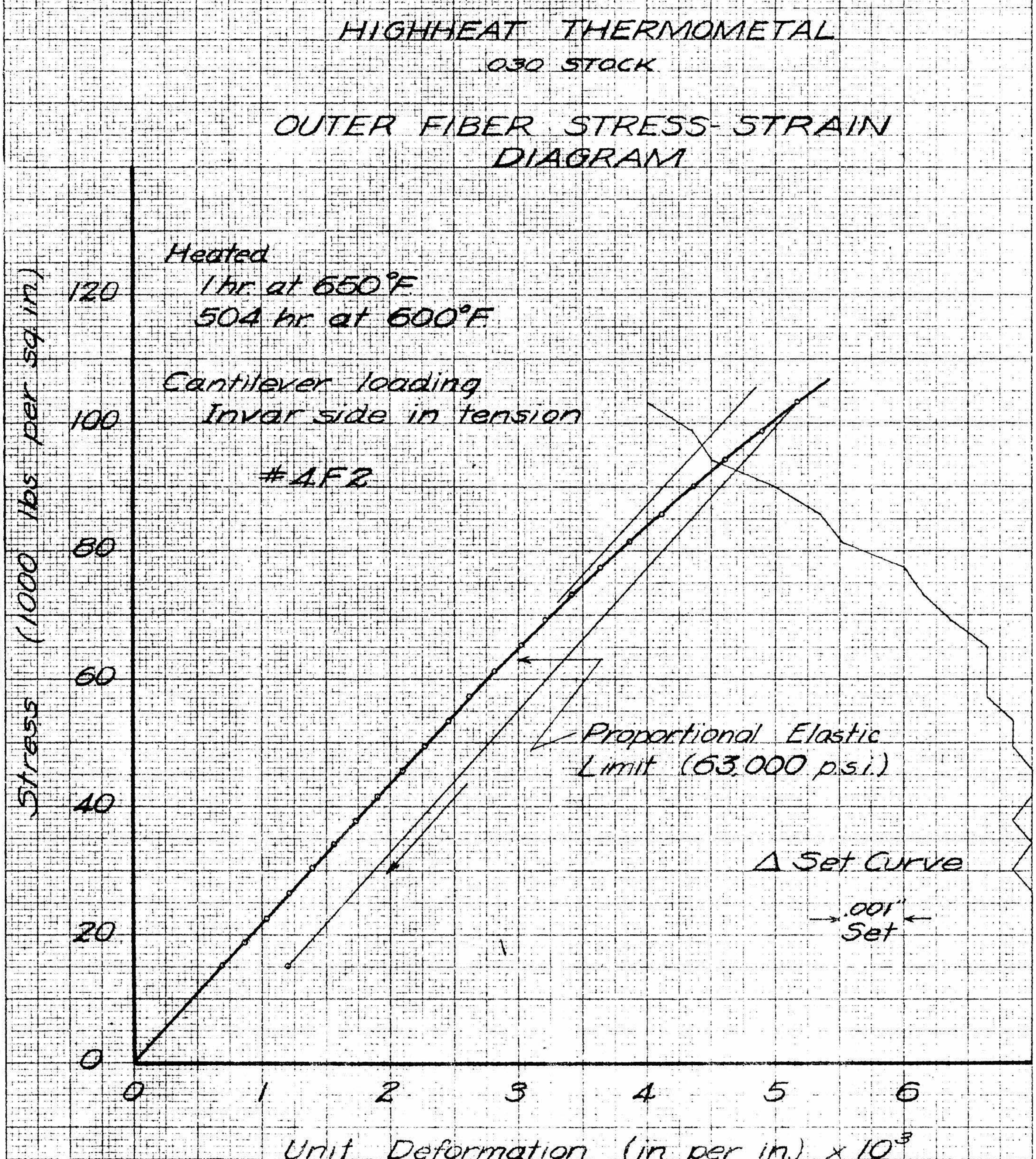
THIS MARGIN RESERVED FOR BINDING.



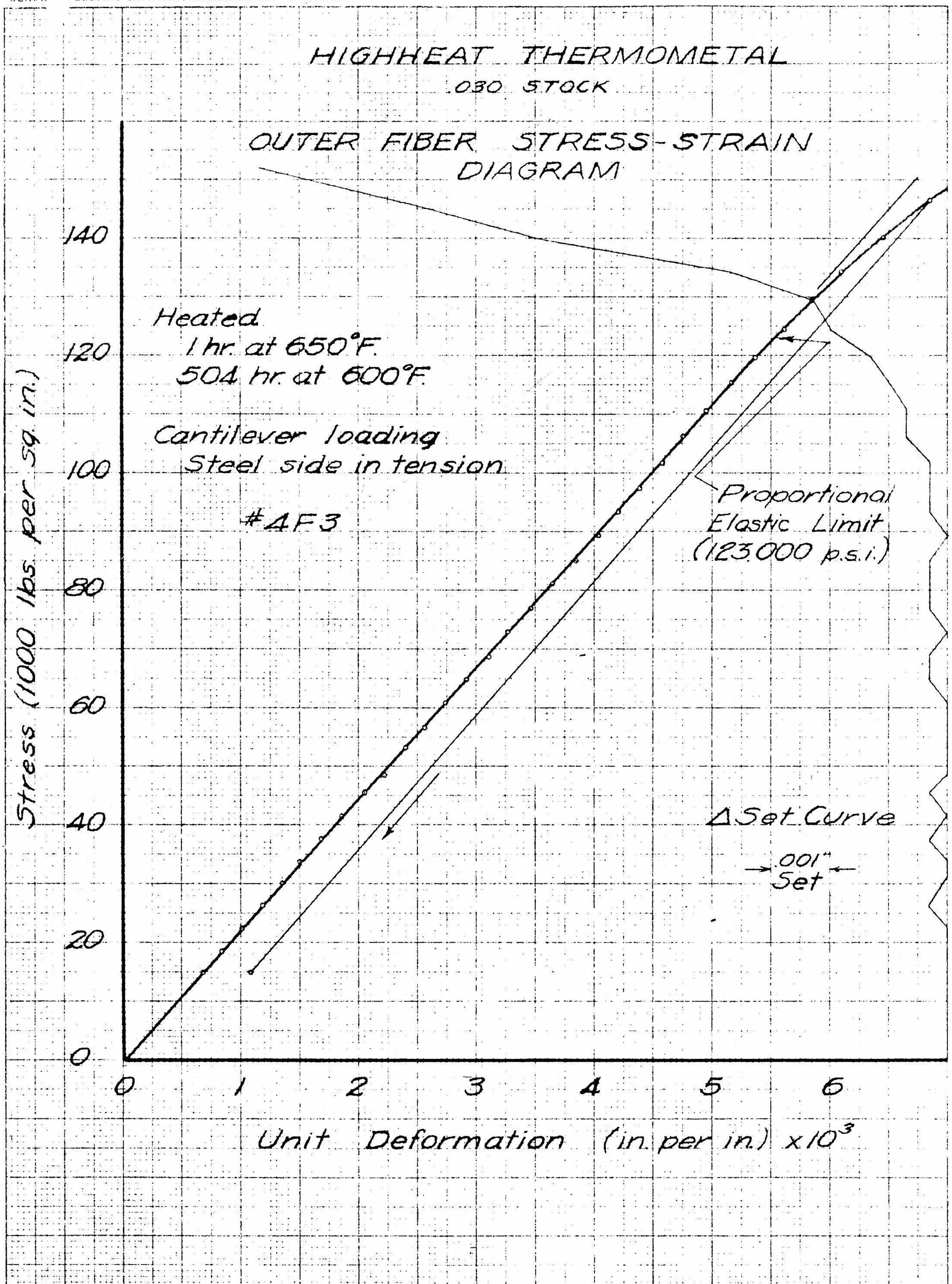
FN-155 20m 11-17-32

29/64 inch Divisions


HIGHHEAT THERMOMETAL
.030 STOCK
OUTER FIBER STRESS-STRAIN DIAGRAM
Heated
1 hr. at 650°F
3 hr. at 600°F
Cantilever loading
Steel side in tension
4B3
Proportional Elastic Limit
(126,000 p.s.i.)
Δ Set Curve
.001" Set
Stress (1000 lbs. per sq. in.)
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
Unit Deformation (in. per in.) x 10^3


HIGHHEAT THERMOMETAL
.030 STOCK
OUTER FIBER STRESS-STRAIN DIAGRAM
Heated
1 hr. at 650°F
504 hr. at 600°F
Cantilever loading
Invar side in tension
#4F2
Stress (1000 lbs per sq. in.)
120
100
80
60
40
20
0
Proportional Elastic Limit (63,000 p.s.i.)
Δ Set Curve
.001" Set
0
1
2
3
4
5
6
Unit Deformation (in. per in.) x 10³

GENER[illegible] ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A



IF SHEET IS READ THIS WAY (HORIZONTALLY) THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY) THIS MUST BE LEFT-HAND SIDE

THIS MARGIN RESERVED FOR BINDING.

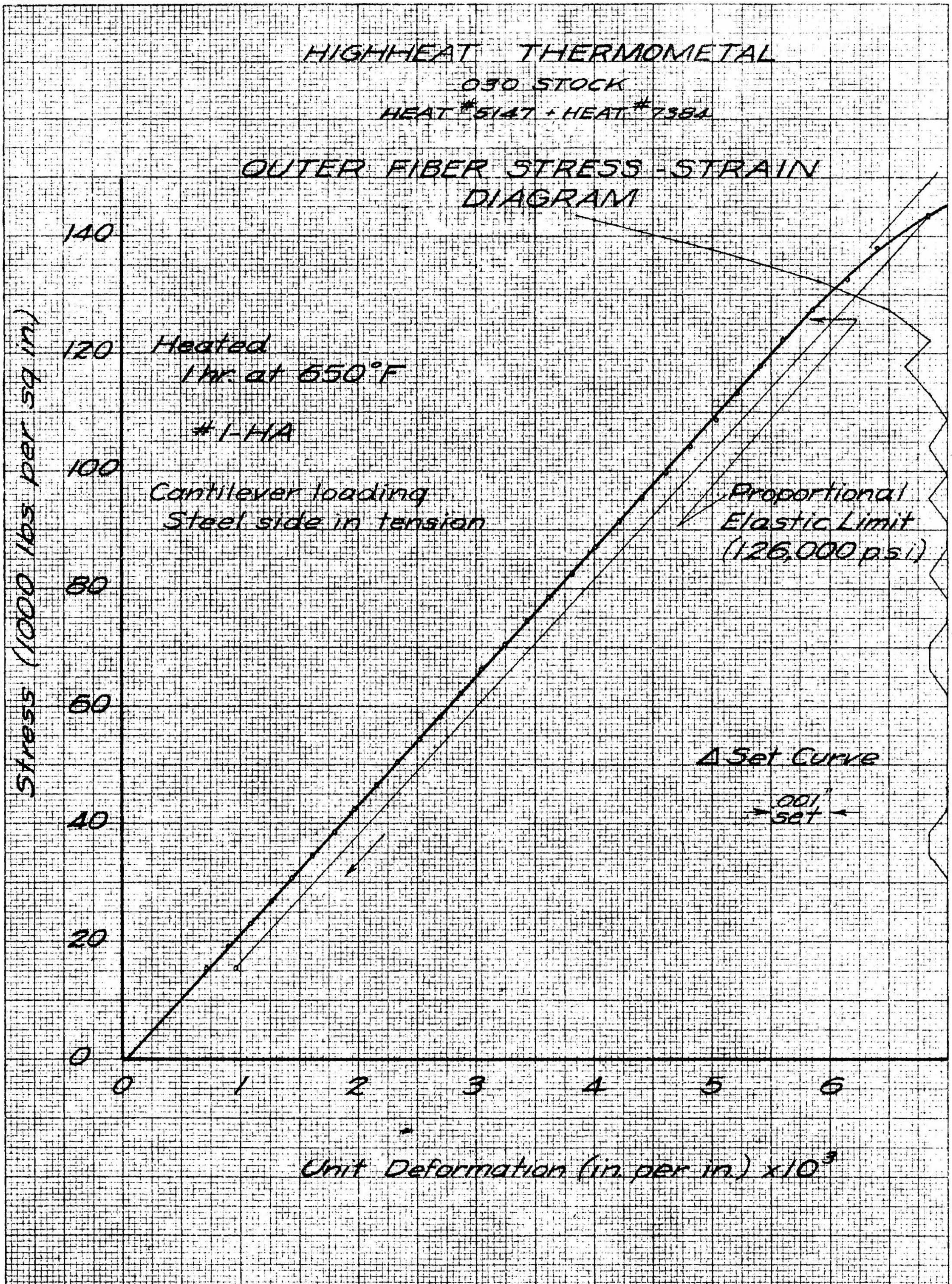
FN-155 20m 11-17-32

29/64 inch Divisions

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A

IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.

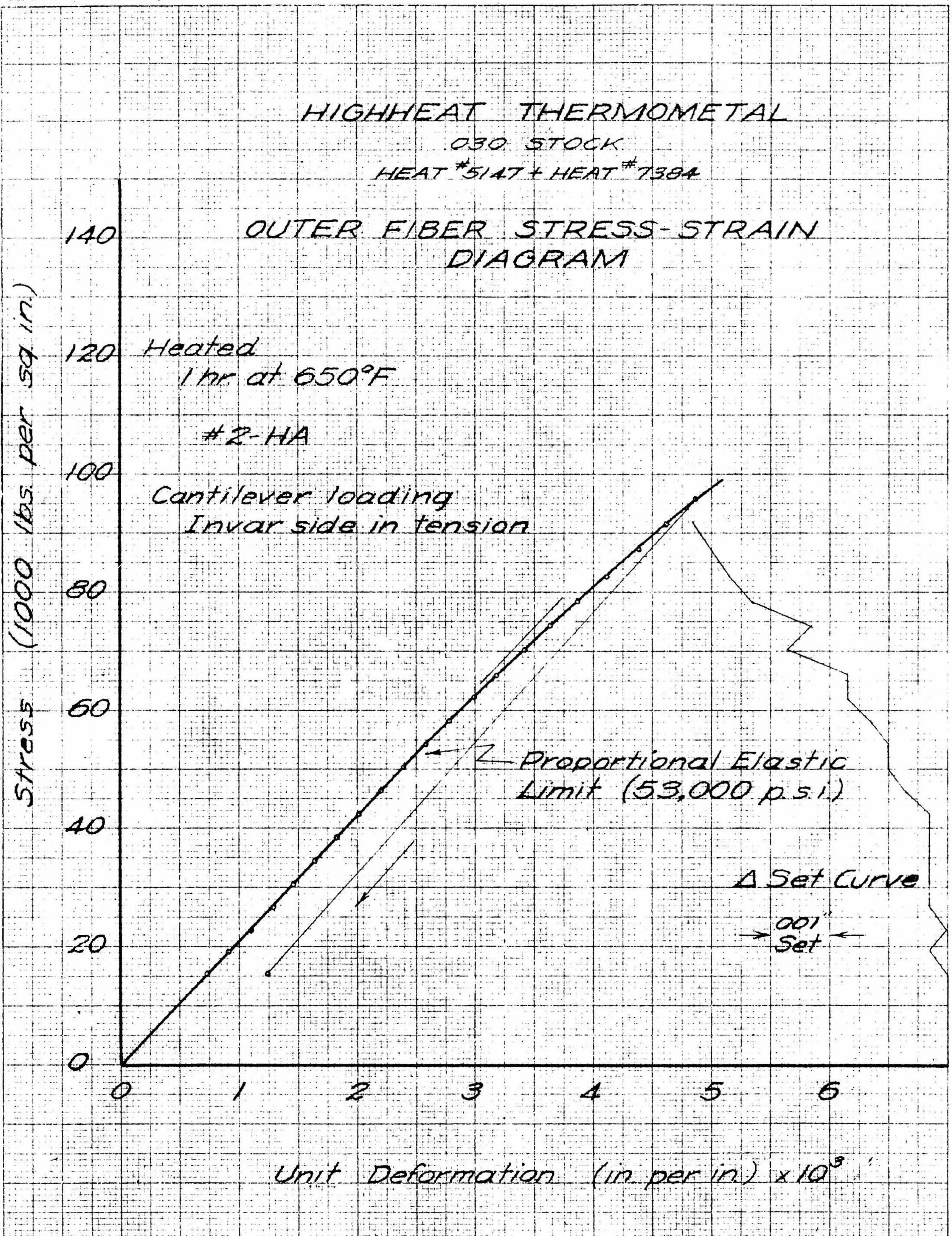
THIS MARGIN RESERVED FOR BINDING.



FN-155 20m 11-17-32

29/64 inch Divisions

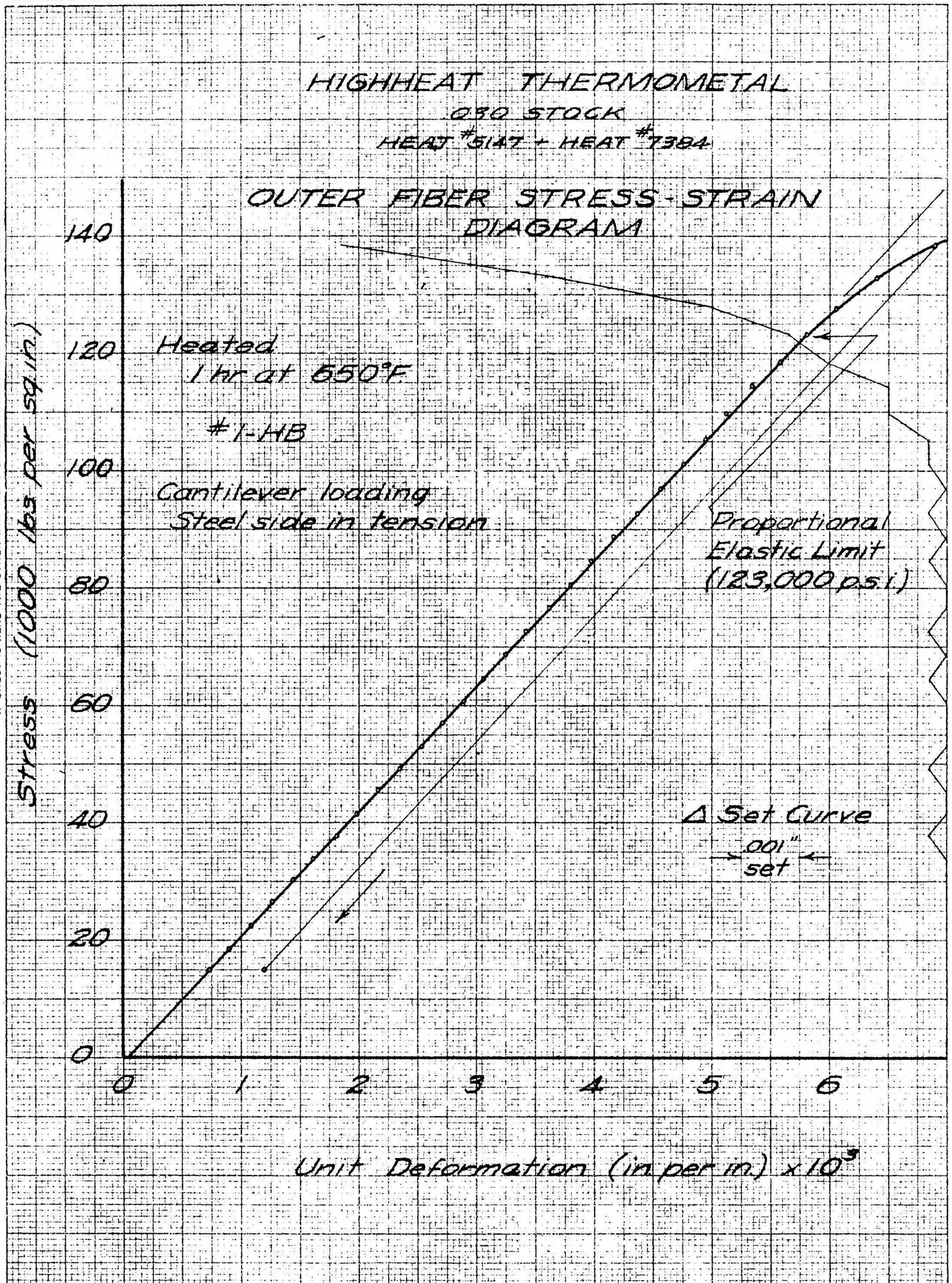
GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A



IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE

THIS MARGIN RESERVED FOR BINDING.

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A

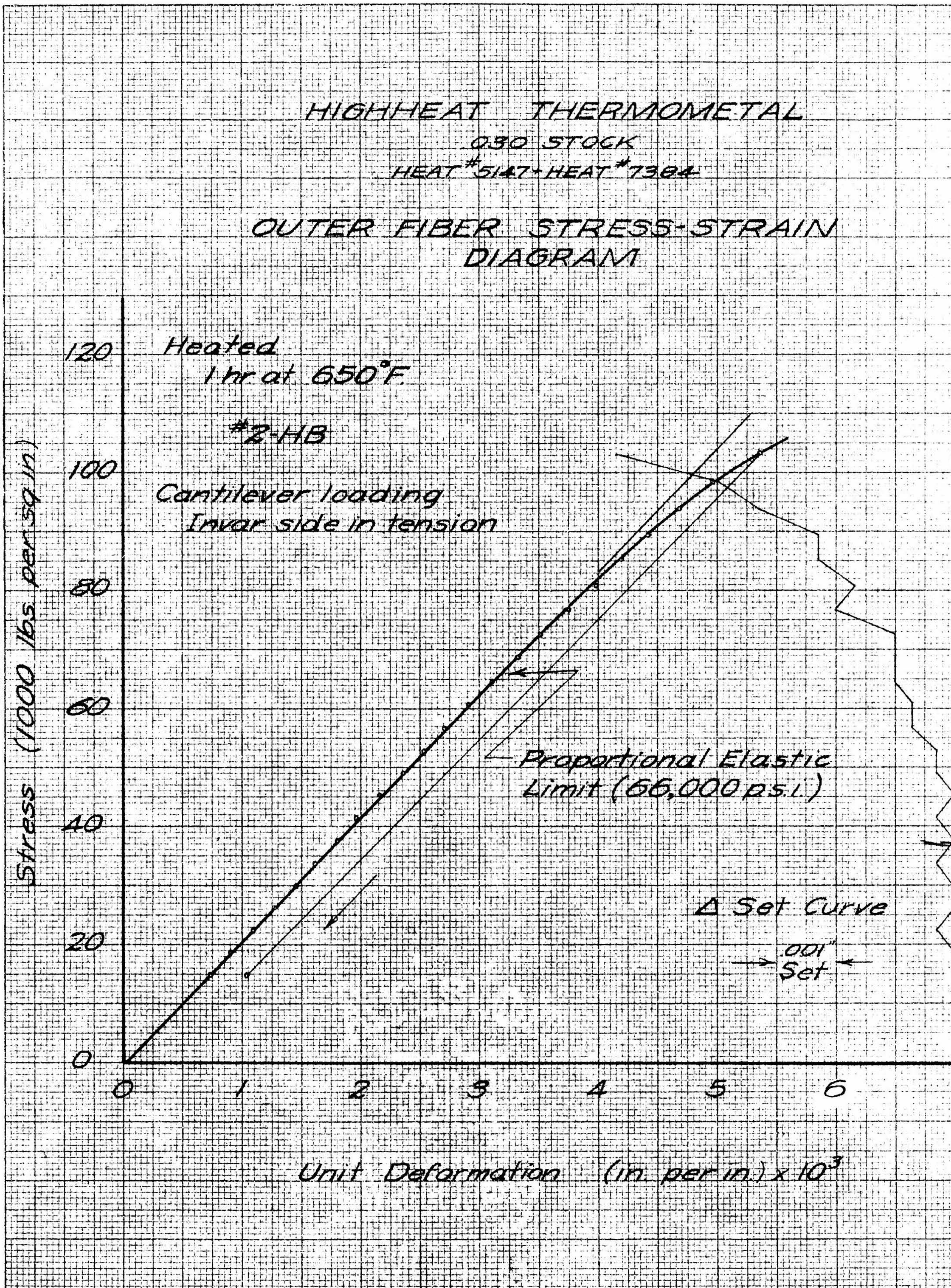


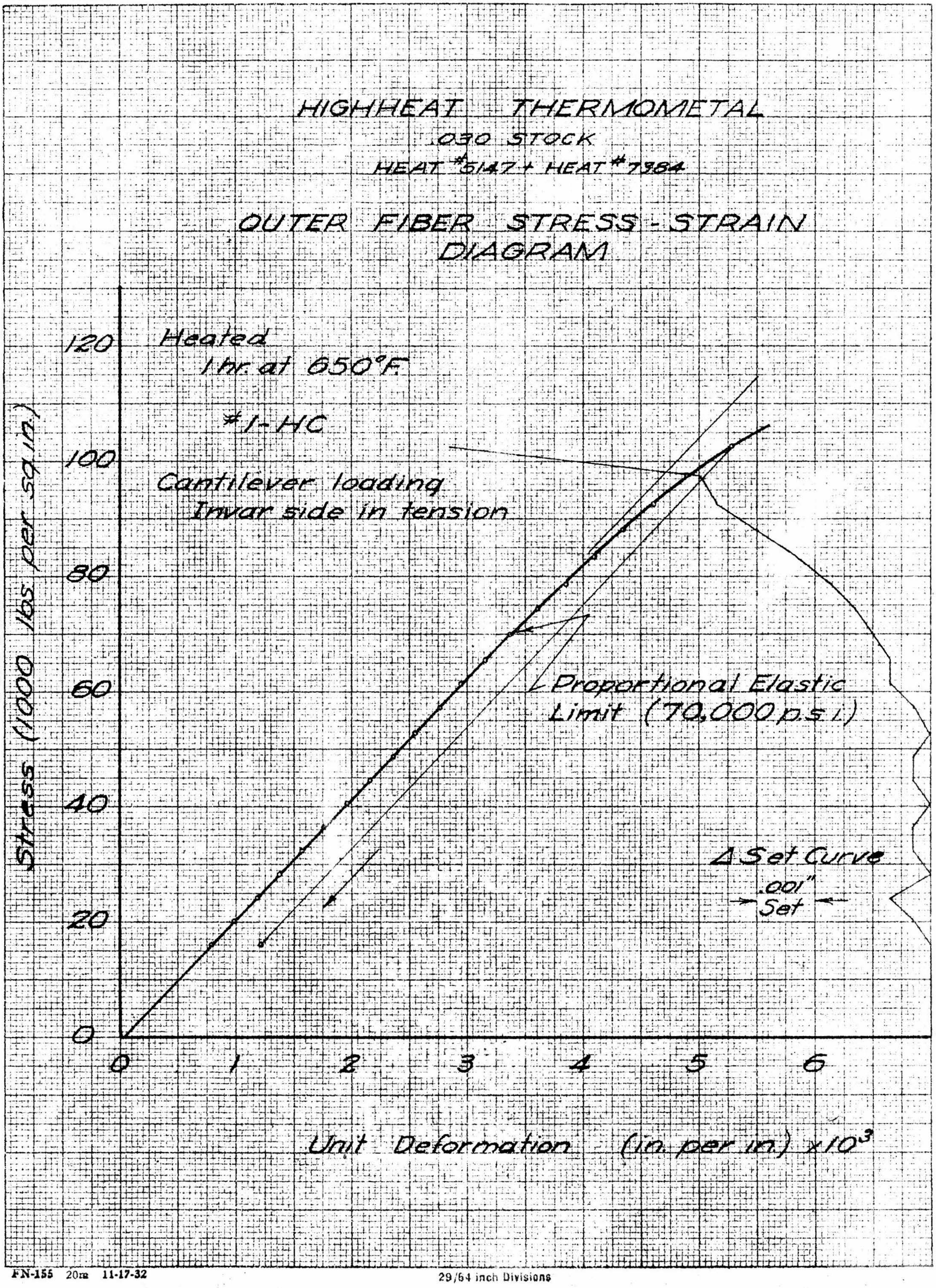
IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.

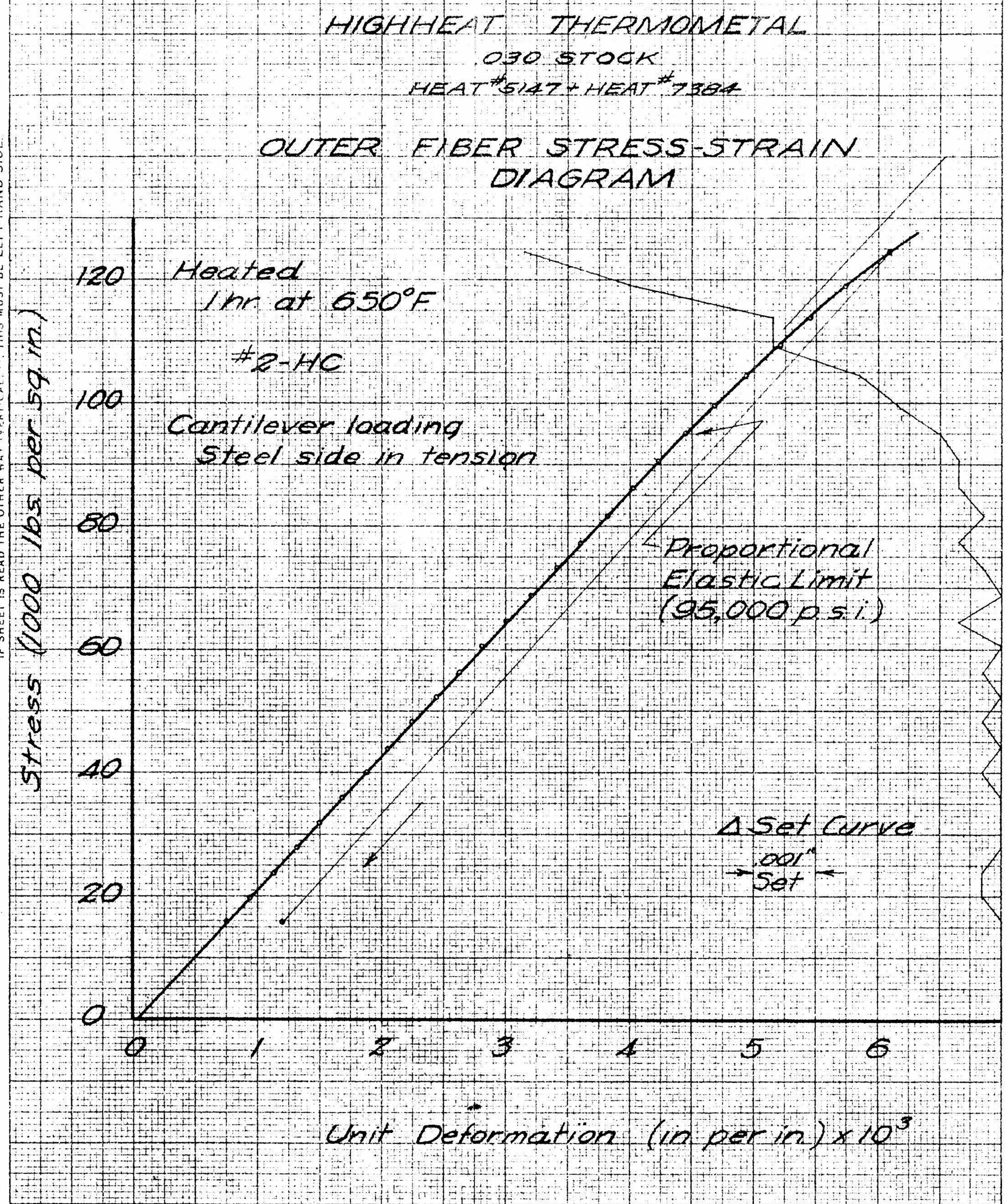
THIS MARGIN RESERVED FOR BINDING.

FN-155 20m 11-17-32

29/64 inch Divisions

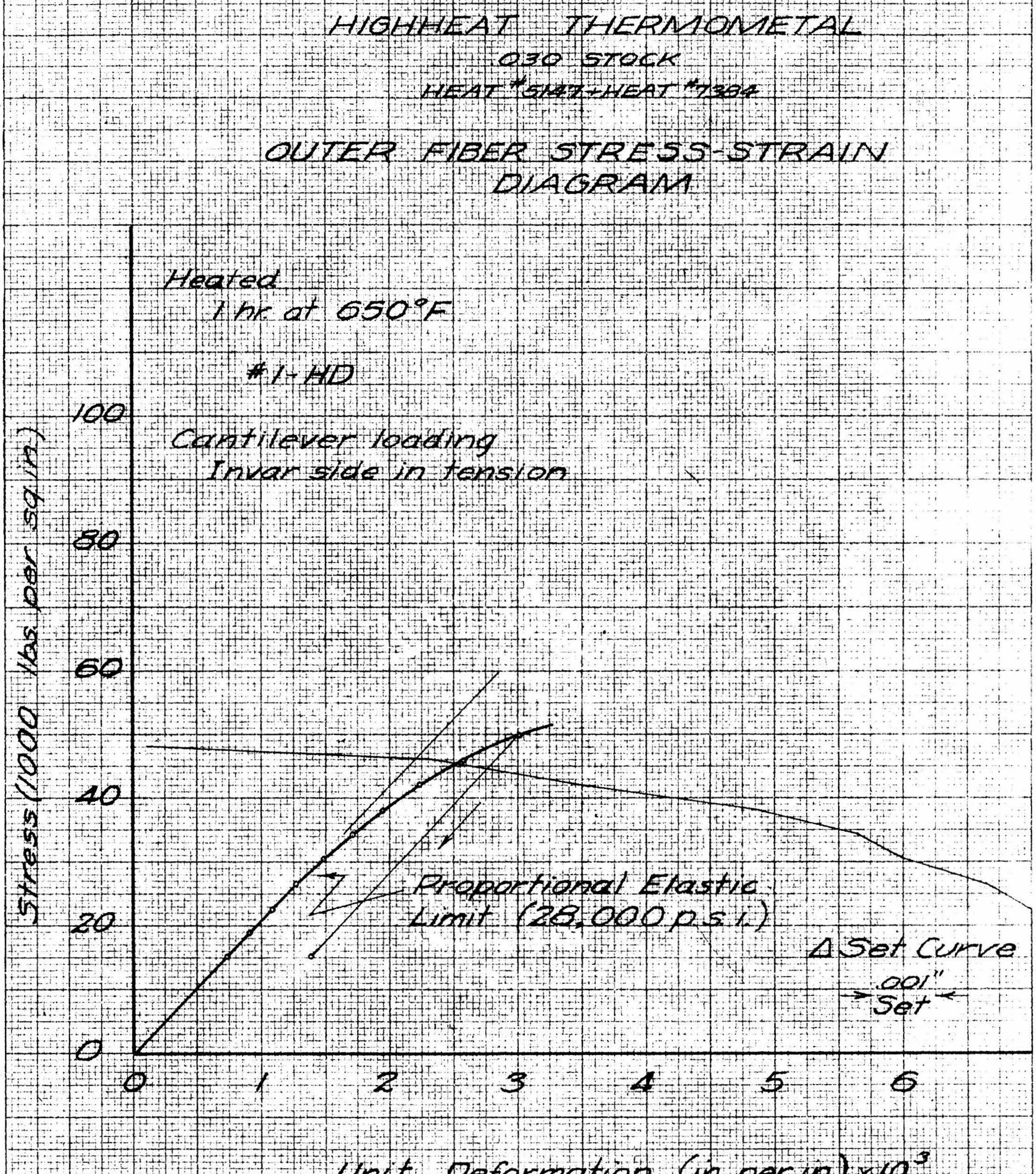

HIGHHEAT THERMOMETAL
.030 STOCK
HEAT #5147 + HEAT #7384
OUTER FIBER STRESS-STRAIN DIAGRAM
Heated 1 hr at 650°F
#2-HB
Cantilever loading
Invar side in tension
Stress (1000 lbs per sq in)
0
20
40
60
80
100
120
Proportional Elastic Limit (66,000 p.s.i.)
Δ Set Curve
.001" Set
0
1
2
3
4
5
6
Unit Deformation (in. per in.) x 10^3

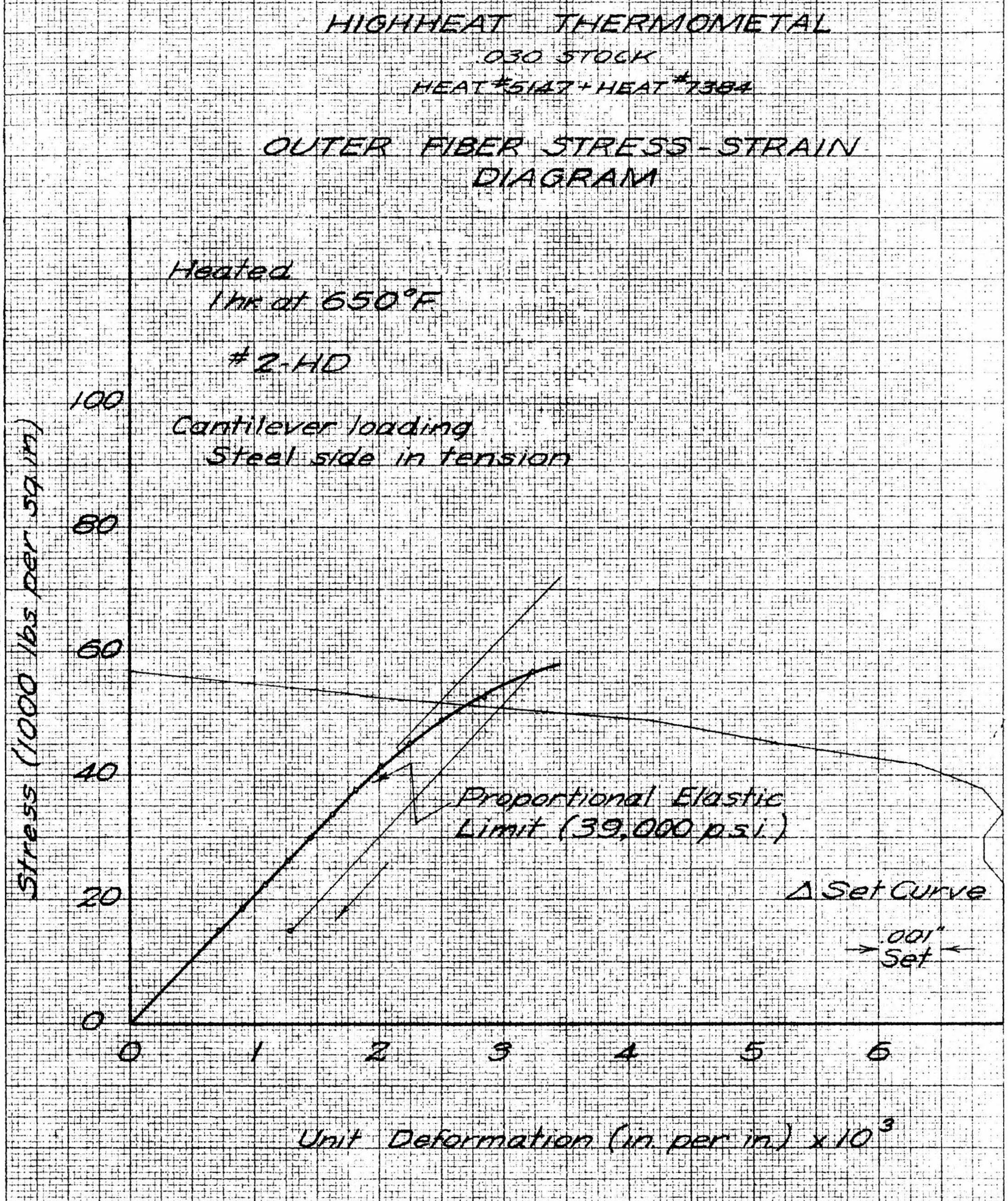

HIGHHEAT THERMOMETAL
.030 STOCK
HEAT #5147 + HEAT #7984
OUTER FIBER STRESS - STRAIN DIAGRAM
Heated 1 hr. at 650°F.
#1-HC
Cantilever loading
Invar side in tension
Proportional Elastic Limit (70,000 p.s.i.)
Δ Set Curve
.001" Set
Stress (1000 lbs per sq. in.)
120
100
80
60
40
20
0
0
1
2
3
4
5
6
Unit Deformation (in. per in.) x10³

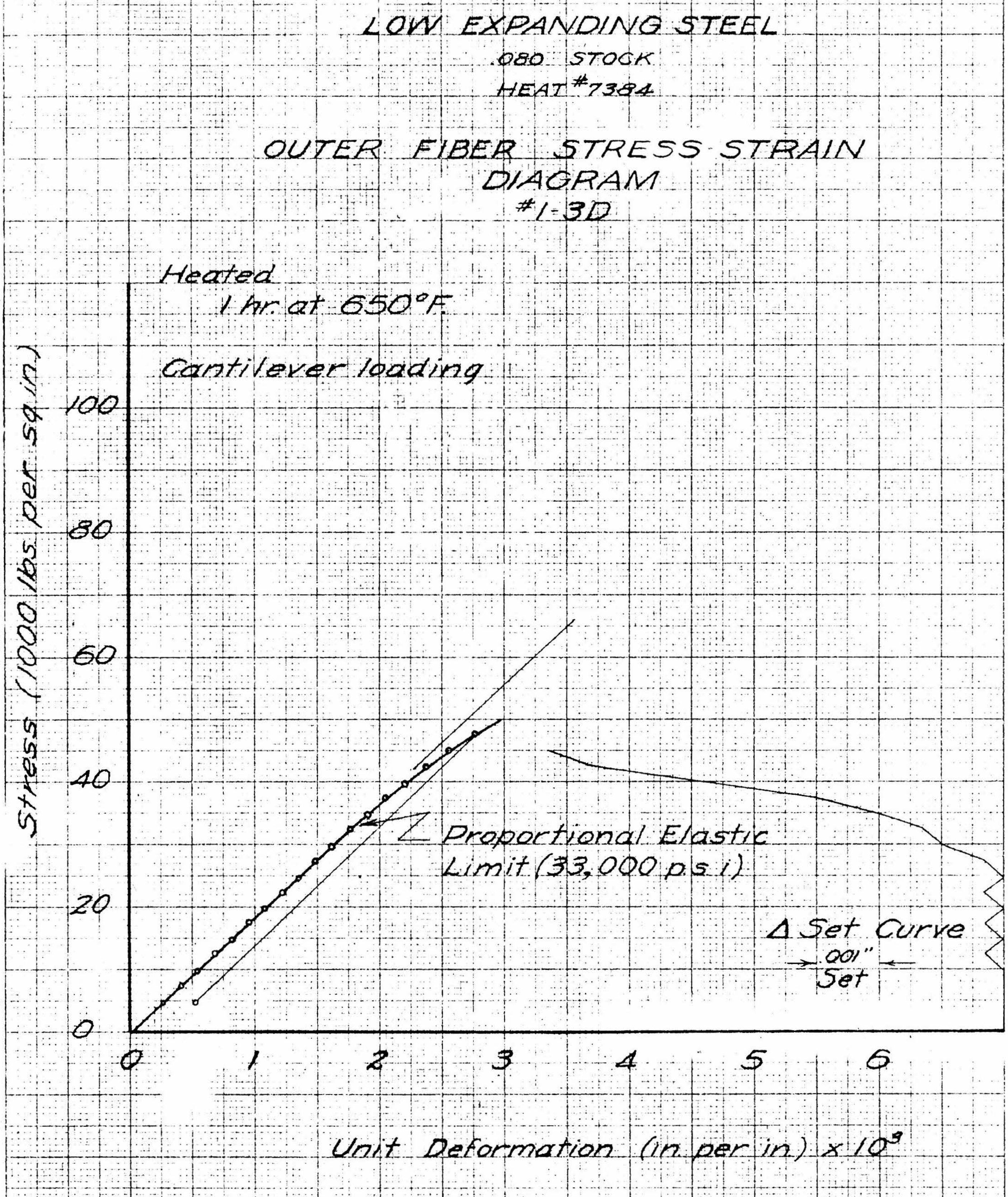

HIGHHEAT THERMOMETAL
.030 STOCK
HEAT #5147 + HEAT #7384
OUTER FIBER STRESS-STRAIN DIAGRAM
Heated 1hr. at 650°F
#2-HC
Cantilever loading
Steel side in tension
Proportional Elastic Limit (95,000 p.s.i.)
Δ Set Curve
.001" Set
Stress (1000 lbs per sq in.)
Unit Deformation (in per in.) x 10^3
0
20
40
60
80
100
120
1
2
3
4
5
6

IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.

THIS MARGIN RESERVED FOR BINDING.

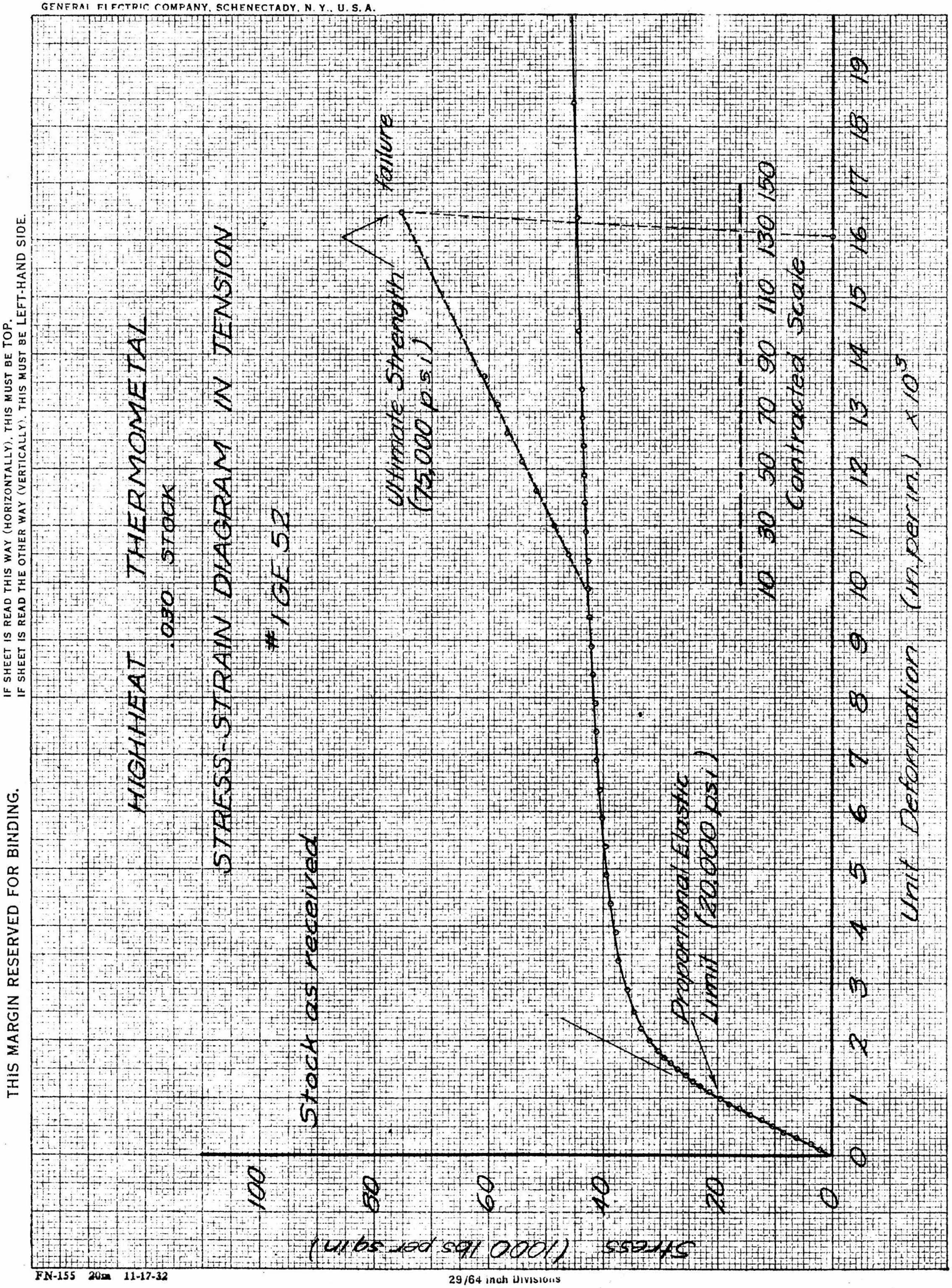


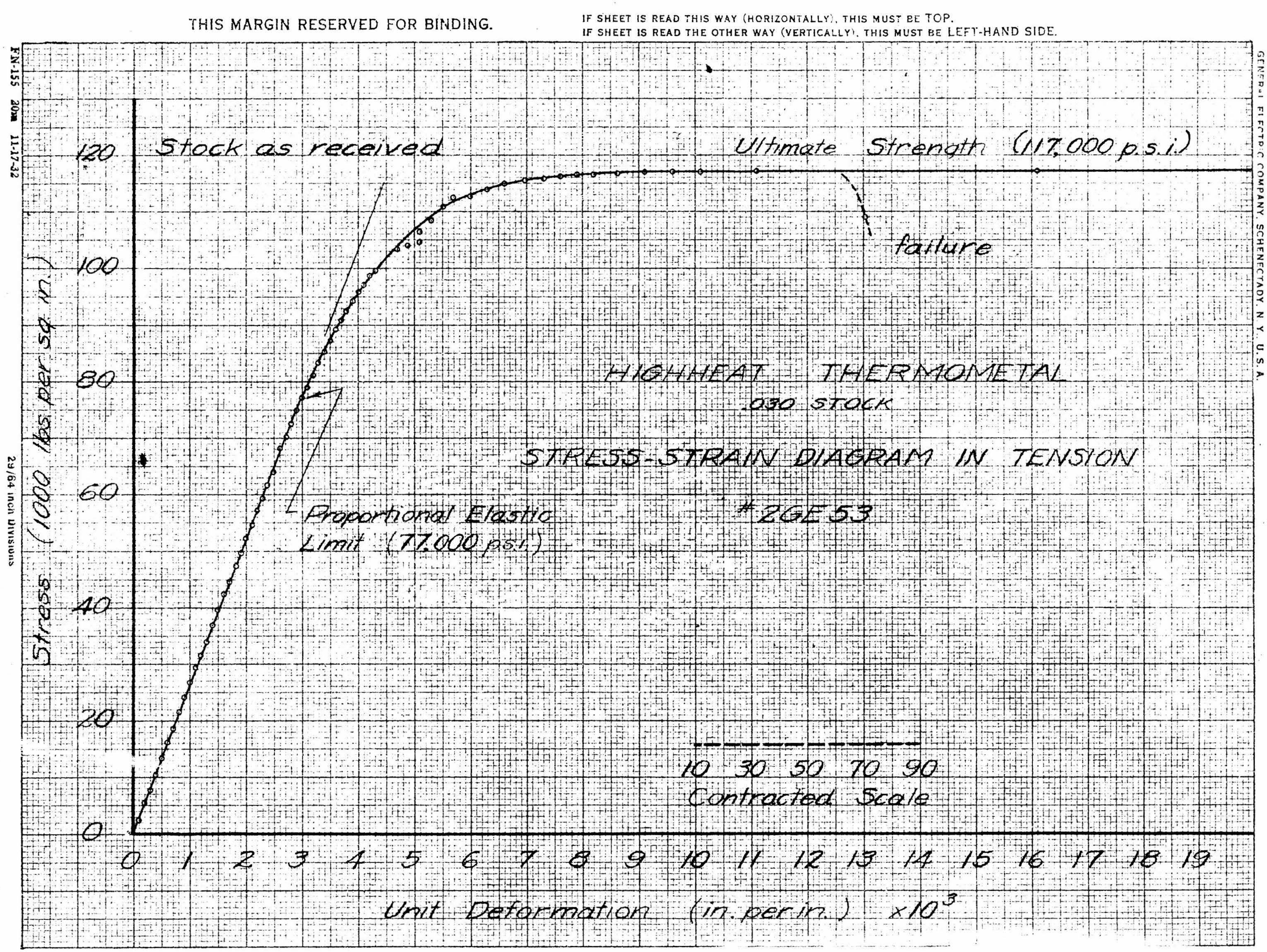

HIGHHEAT THERMOMETAL
.030 STOCK
HEAT #5147 + HEAT #7384
OUTER FIBER STRESS-STRAIN
DIAGRAM
Heated
1 hr at 650°F
#2-HD
Cantilever loading
Steel side in tension
Stress (1000 lbs per sq in)
100
80
60
40
20
0
Proportional Elastic
Limit (39,000 p.s.i.)
Δ Set Curve
.001"
Set
0
1
2
3
4
5
6
Unit Deformation (in per in) x 10^3


LOW EXPANDING STEEL
.080 STOCK
HEAT #7384
OUTER FIBER STRESS-STRAIN DIAGRAM
#1-3D
Heated
1 hr. at 650°F.
Cantilever loading
Stress (1000 lbs per sq in)
100
80
60
40
20
0
Proportional Elastic Limit (33,000 p.s.i)
Δ Set Curve
.001"
Set
0
1
2
3
4
5
6
Unit Deformation (in per in) x 10^3

APPENDIX B

DIRECT TENSION CURVES


GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A.
THIS MARGIN RESERVED FOR BINDING.
IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.
HIGHHEAT THERMOMETAL
.030 STOCK
STRESS-STRAIN DIAGRAM IN TENSION
#1 GE 52
Stock as received
Failure
Ultimate Strength
(75,000 psi)
Proportional Elastic
Limit (20,000 psi)
10 30 50 70 90 110 130 150
Contracted Scale
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Unit Deformation (in. per in.) x 10^5
0 20 40 60 80 100
Stress (1000 lbs per sq in)
FN-155 20m 11-17-32
29/64 inch Divisions

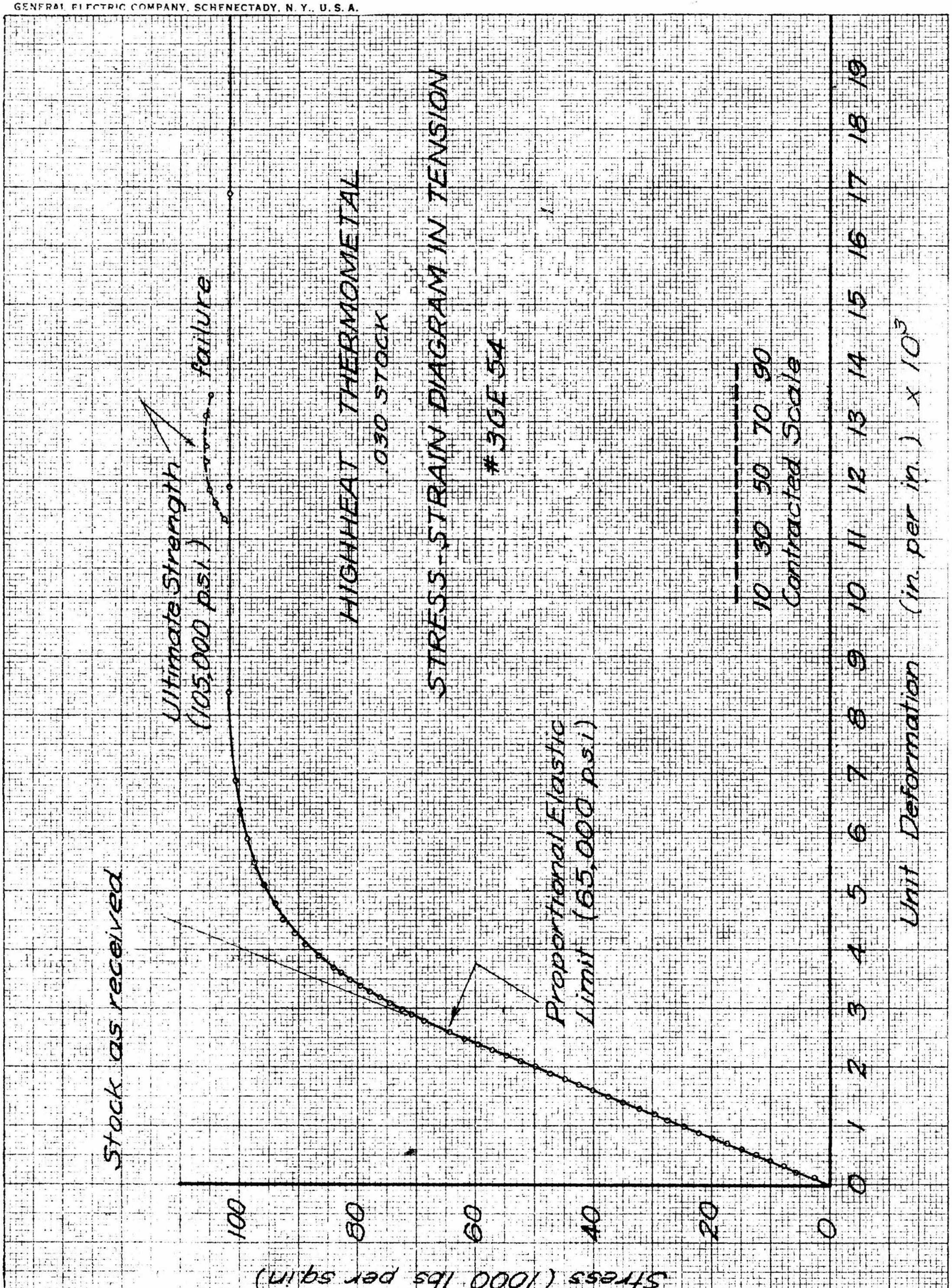


THIS MARGIN RESERVED FOR BINDING.
IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.
GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A.
Stock as received
Ultimate Strength (117,000 p.s.i.)
failure
HIGHHEAT THERMOMETAL
.030 STOCK
STRESS-STRAIN DIAGRAM IN TENSION
#2GE53
Proportional Elastic Limit (77,000 p.s.i.)
10 30 50 70 90
Contracted Scale
Stress (1000 lbs per sq in.)
0
20
40
60
80
100
120
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Unit Deformation (in. per in.) x10^3
FN-155 20m 11-17-32
29/64 inch Divisions

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A.

THIS MARGIN RESERVED FOR BINDING.

IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.



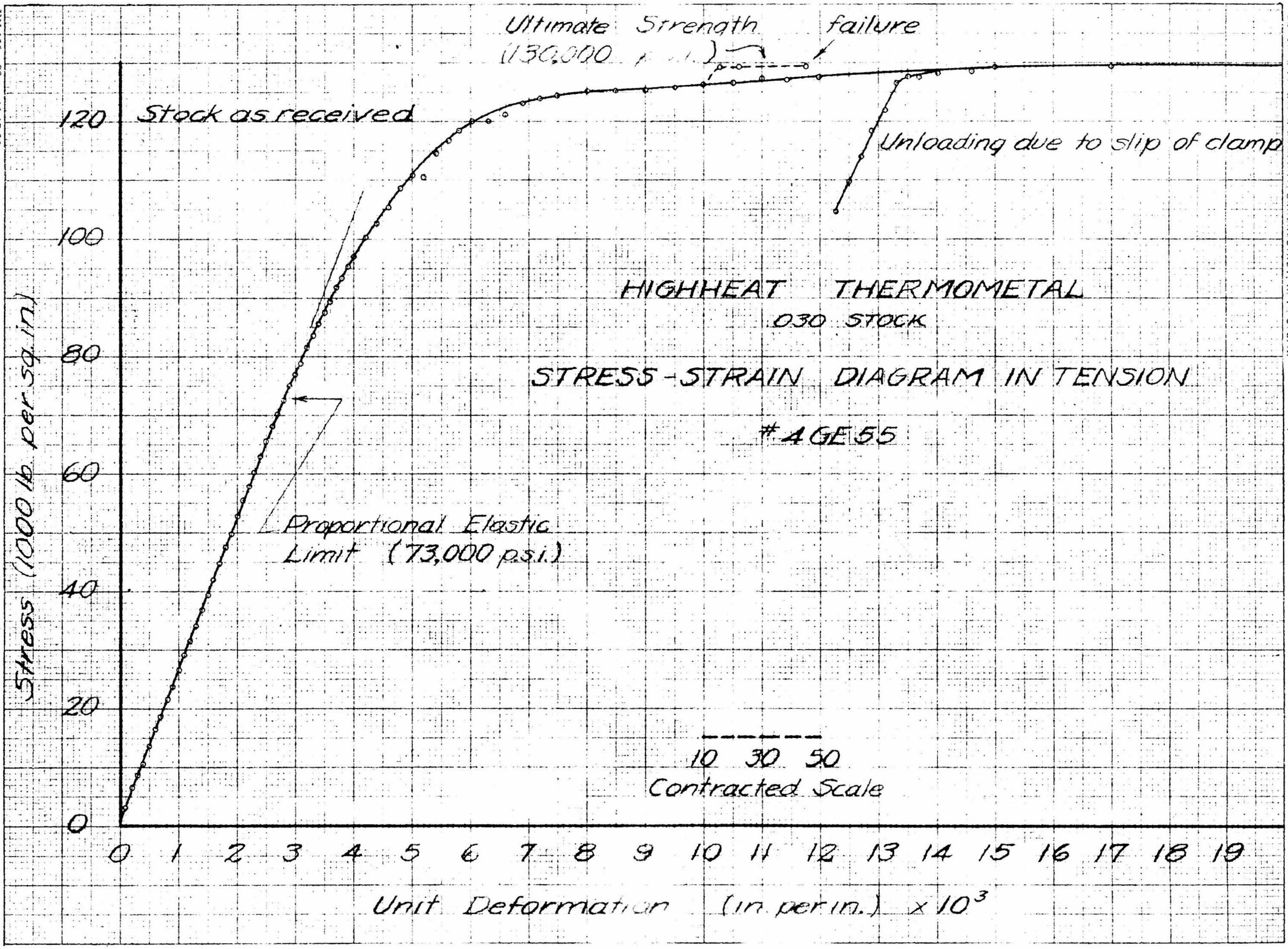
FN-155 20m 11-17-3

29/64 Inch Divisions

THIS MARGIN RESERVED FOR BINDING.

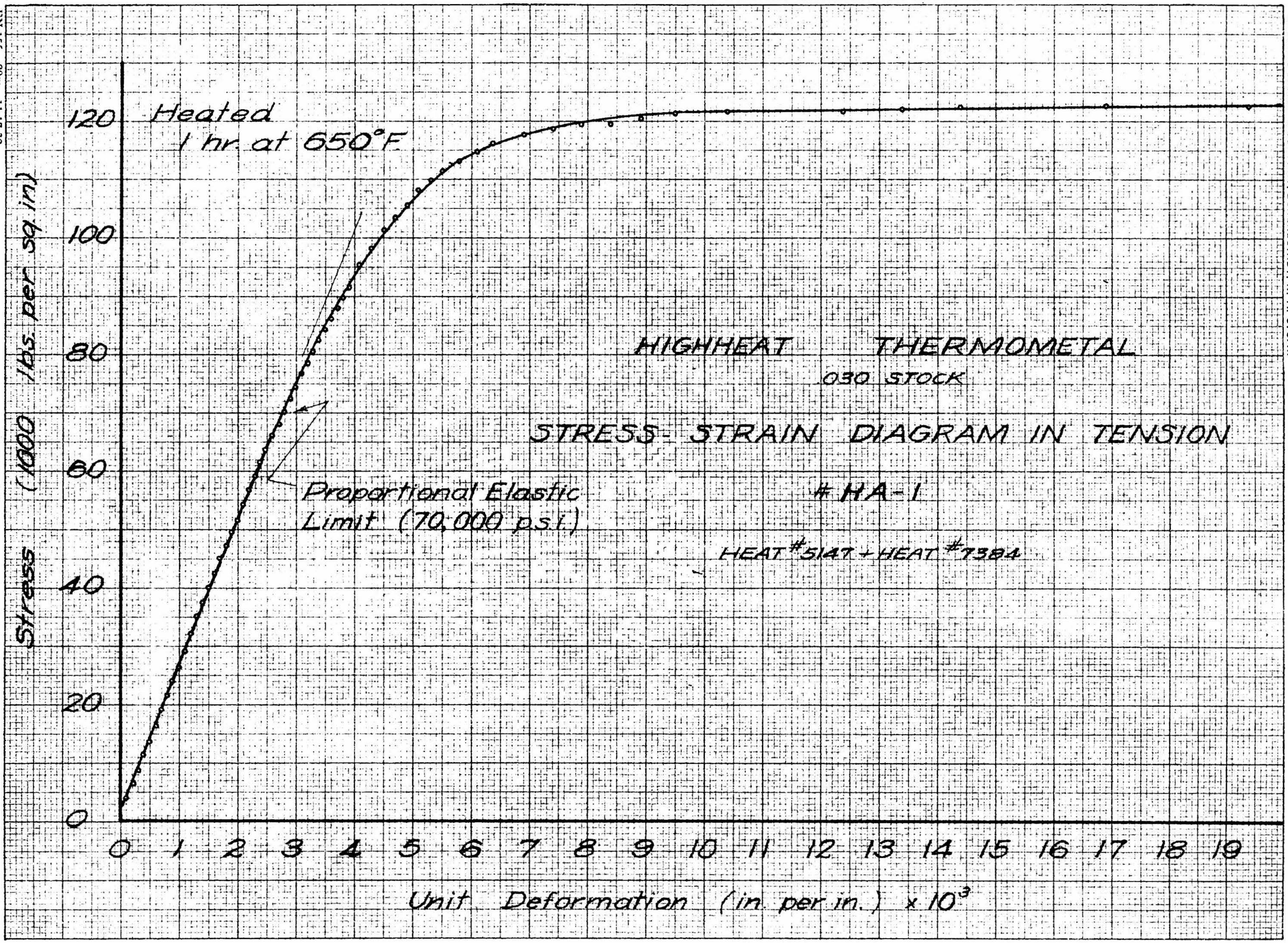
IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.

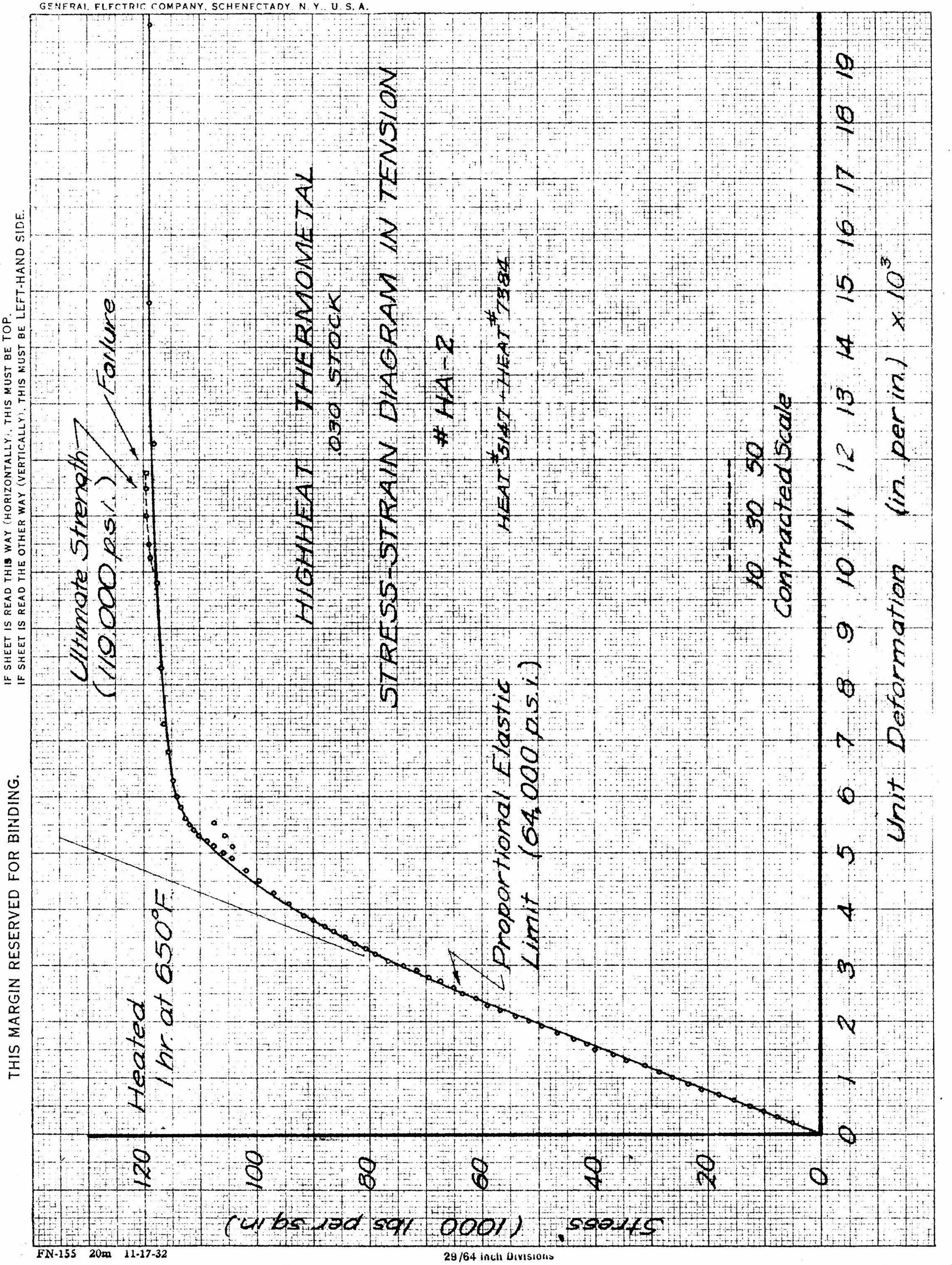
GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A.

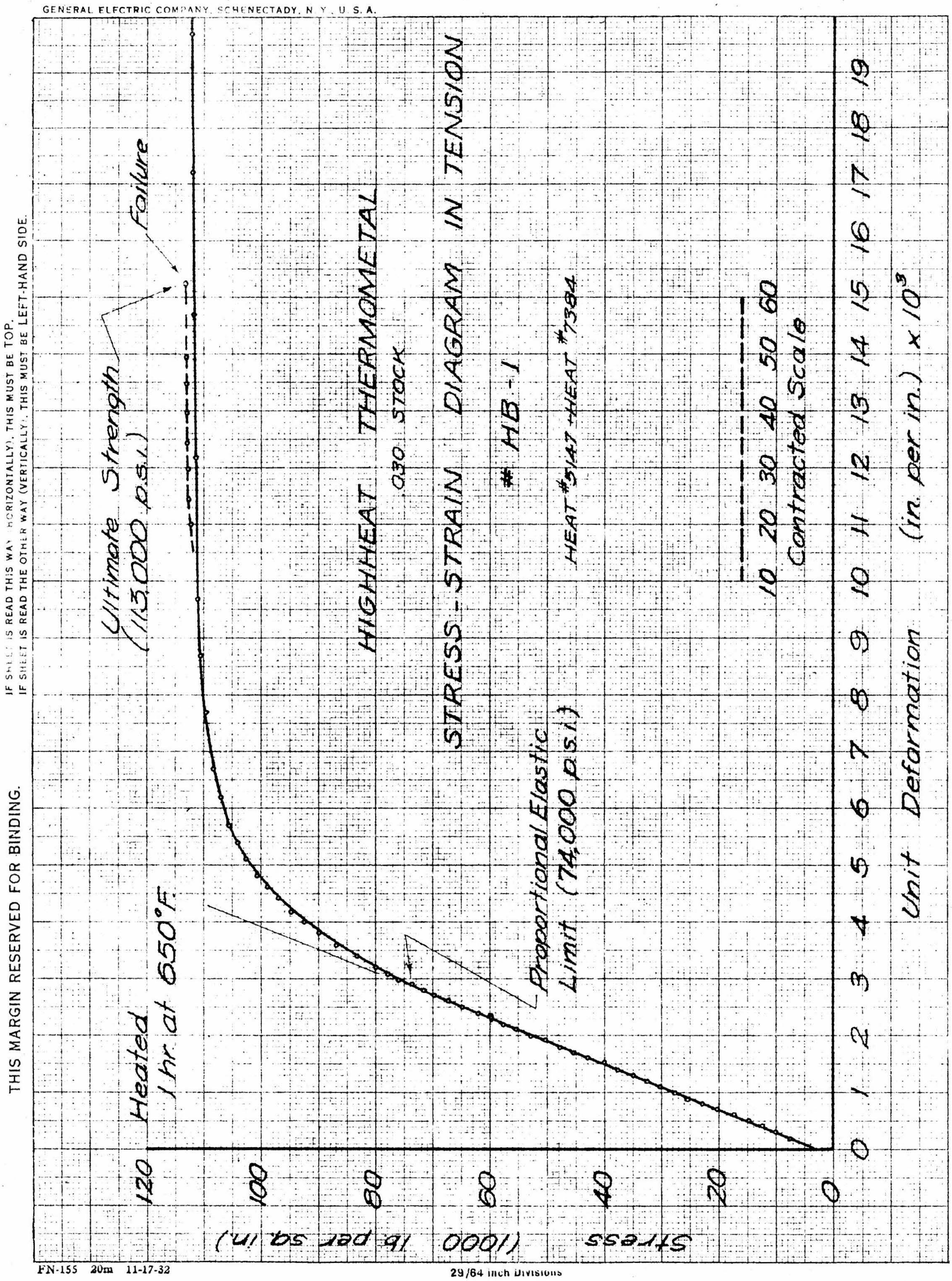


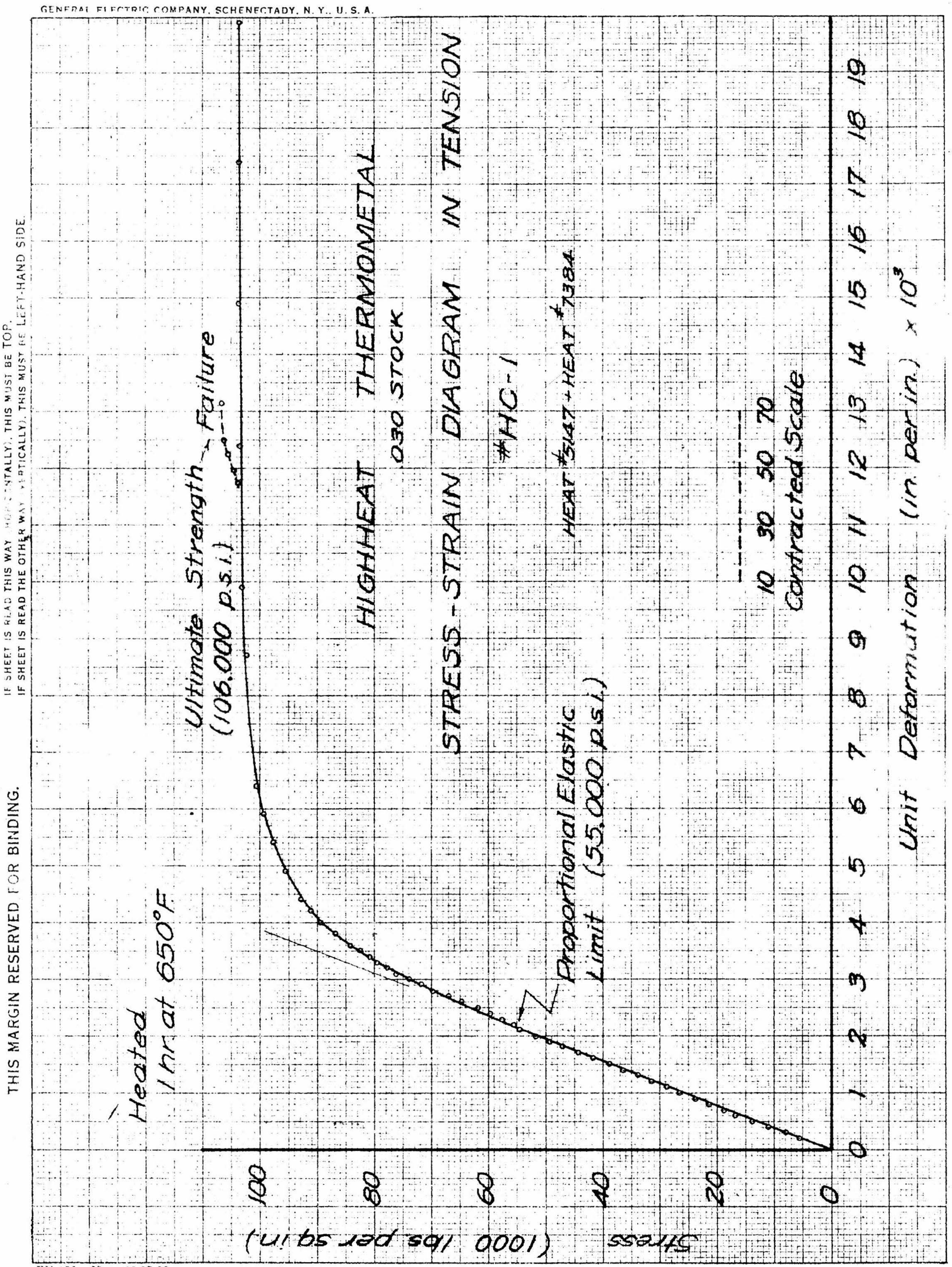
FN-155 20m 11-17-32

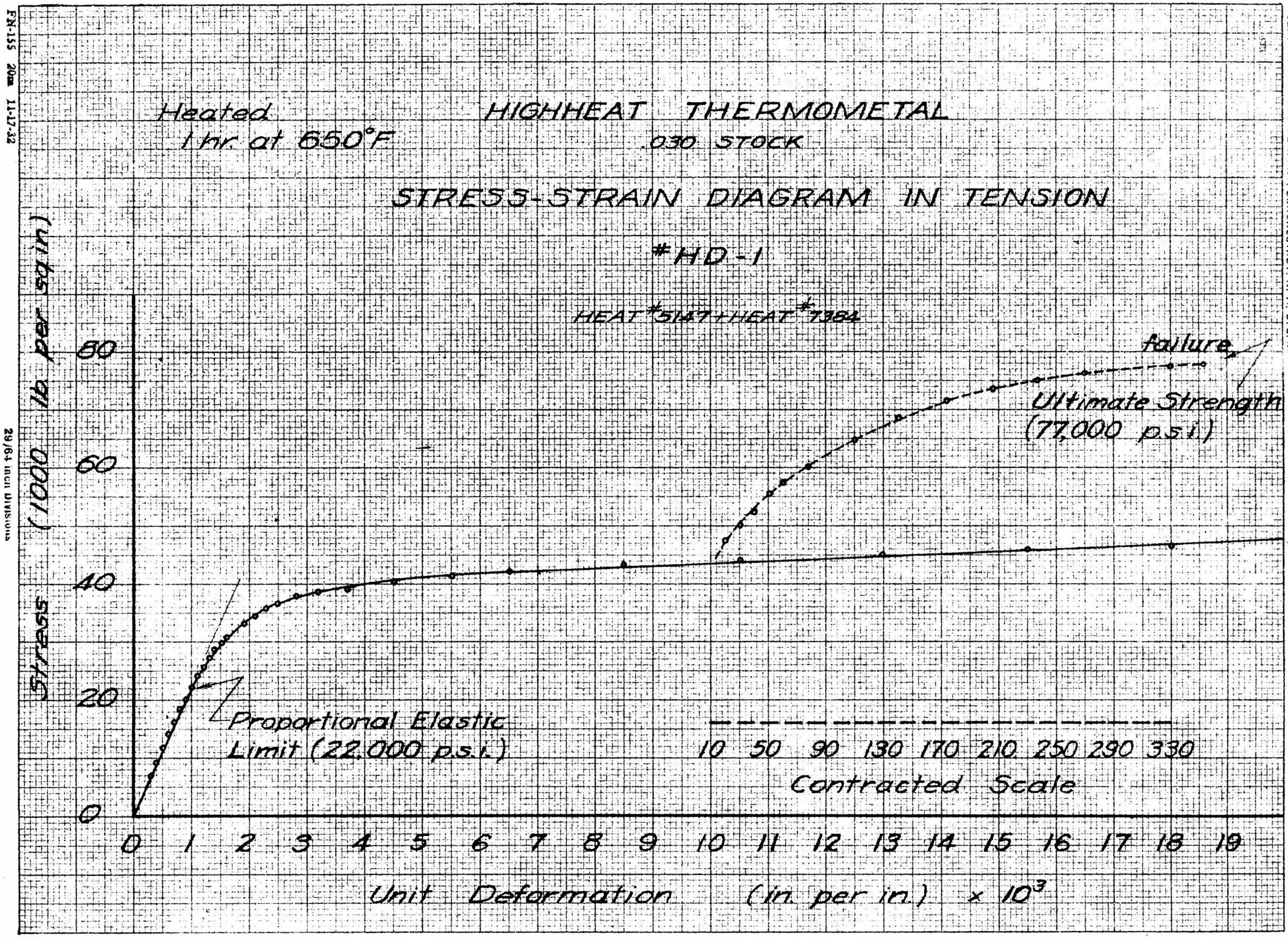
29/64 inch Divisions

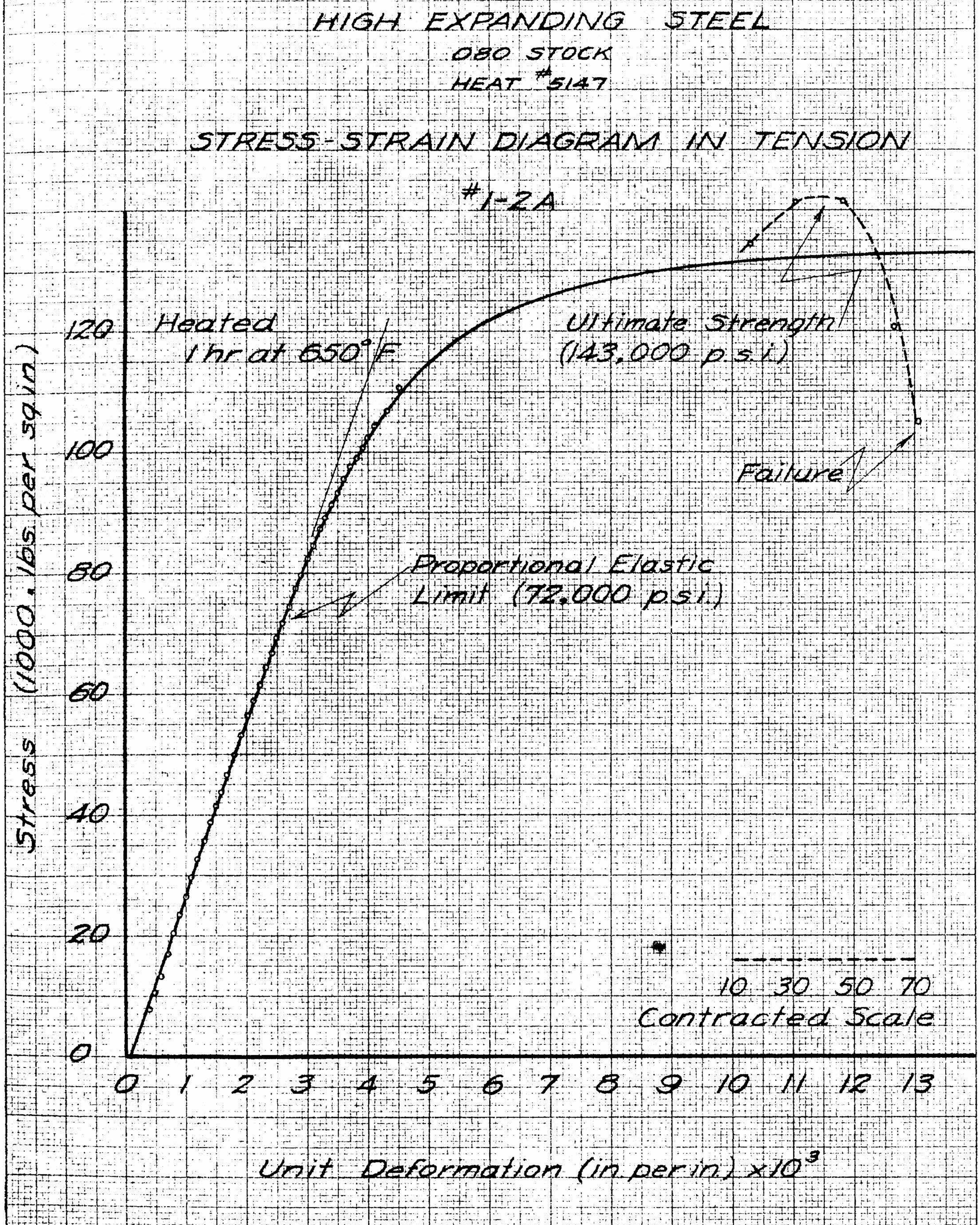

HIGHHEAT THERMOMETAL
.030 STOCK
STRESS- STRAIN DIAGRAM IN TENSION
HA-1
HEAT #5147 + HEAT #7384
Heated
1 hr. at 650°F
Proportional Elastic
Limit (70,000 p.s.i.)
Stress (1000 lbs. per sq. in.)
0
20
40
60
80
100
120
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Unit Deformation (in. per in.) x 10^3


GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A.
THIS MARGIN RESERVED FOR BINDING.
IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.
HIGHHEAT THERMOMETAL
.030 STOCK
STRESS-STRAIN DIAGRAM IN TENSION
HA-2
HEAT # 5147 - HEAT # 7384
Heated
1 hr. at 650°F
Ultimate Strength
(119,000 p.s.i.)
Failure
Proportional Elastic
Limit (64,000 p.s.i.)
10 30 50
Contracted Scale
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Unit Deformation (in. per in.) x 10³
0 20 40 60 80 100 120
Stress (1000 lbs per sq in.)
FN-155 20m 11-17-32
29/64 inch Divisions


GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A.
THIS MARGIN RESERVED FOR BINDING.
IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.
HIGHHEAT THERMOMETAL
.030 STOCK
STRESS - STRAIN DIAGRAM IN TENSION
HB-1
HEAT #5147 - HEAT #7384
Heated 1 hr. at 650°F.
Ultimate Strength (113,000 p.s.i.)
Failure
Proportional Elastic Limit (74,000 p.s.i.)
Contracted Scale
10 20 30 40 50 60
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Unit Deformation (in. per in.) x 10^3
0 20 40 60 80 100 120
Stress (1000 lb per sq. in.)
FN-155 20m 11-17-32
29/64 inch Divisions

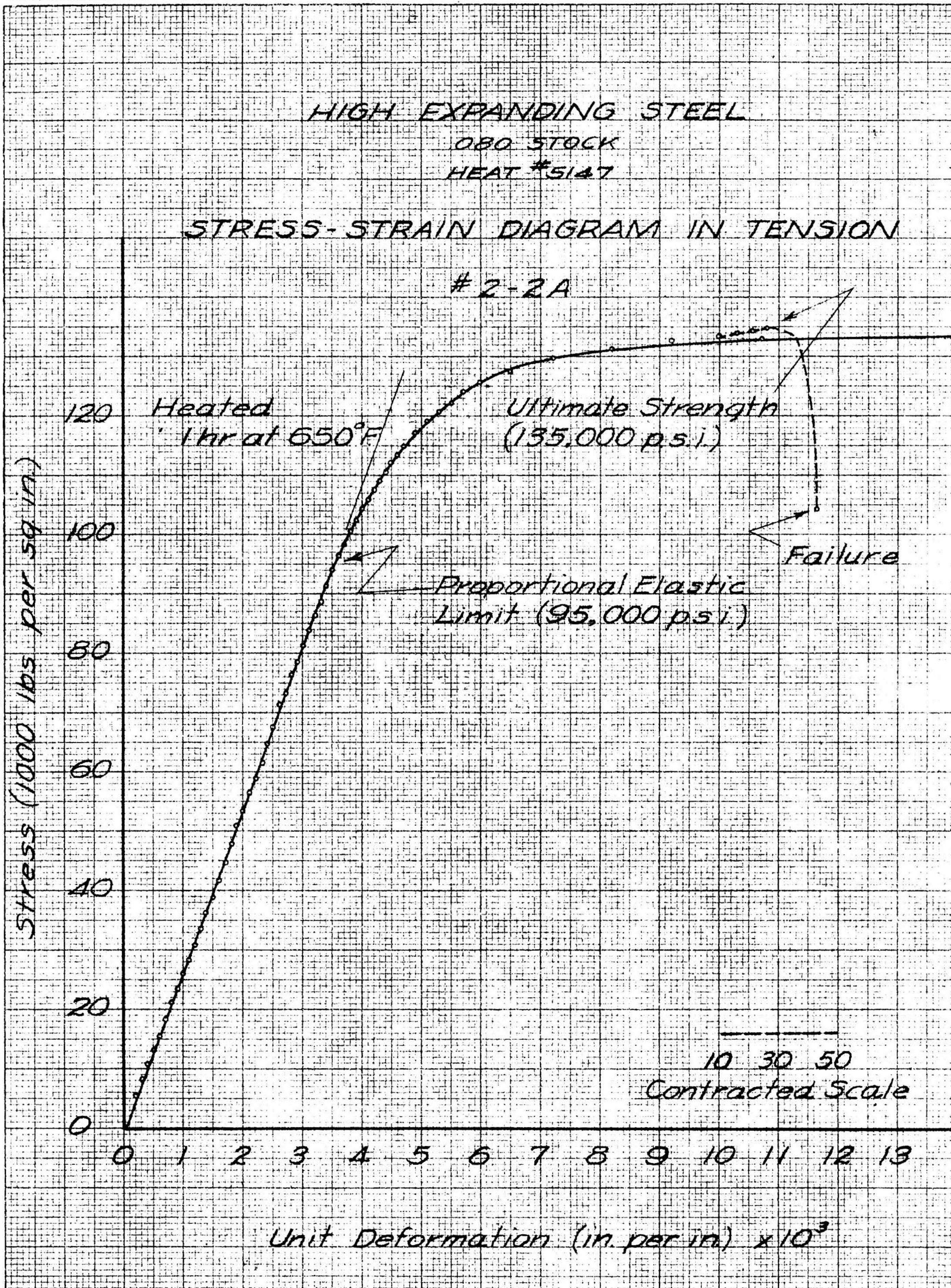

GENERAL ELECTRIC COMPANY, SCHENECTADY, N.Y., U.S.A.
THIS MARGIN RESERVED FOR BINDING.
IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.
HIGHHEAT THERMOMETAL
030 STOCK
STRESS-STRAIN DIAGRAM IN TENSION
#HC-1
HEAT #5147 + HEAT #7384
Heated 1 hr at 650°F
Ultimate Strength (106,000 p.s.i.)
Failure
Proportional Elastic Limit (55,000 p.s.i.)
10 30 50 70
Contracted Scale
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Unit Deformation (in. per in.) x 10³
0 20 40 60 80 100
Stress (1000 lbs per sq in.)
FN-155 20m 11-17-32
29/64 inch Divisions

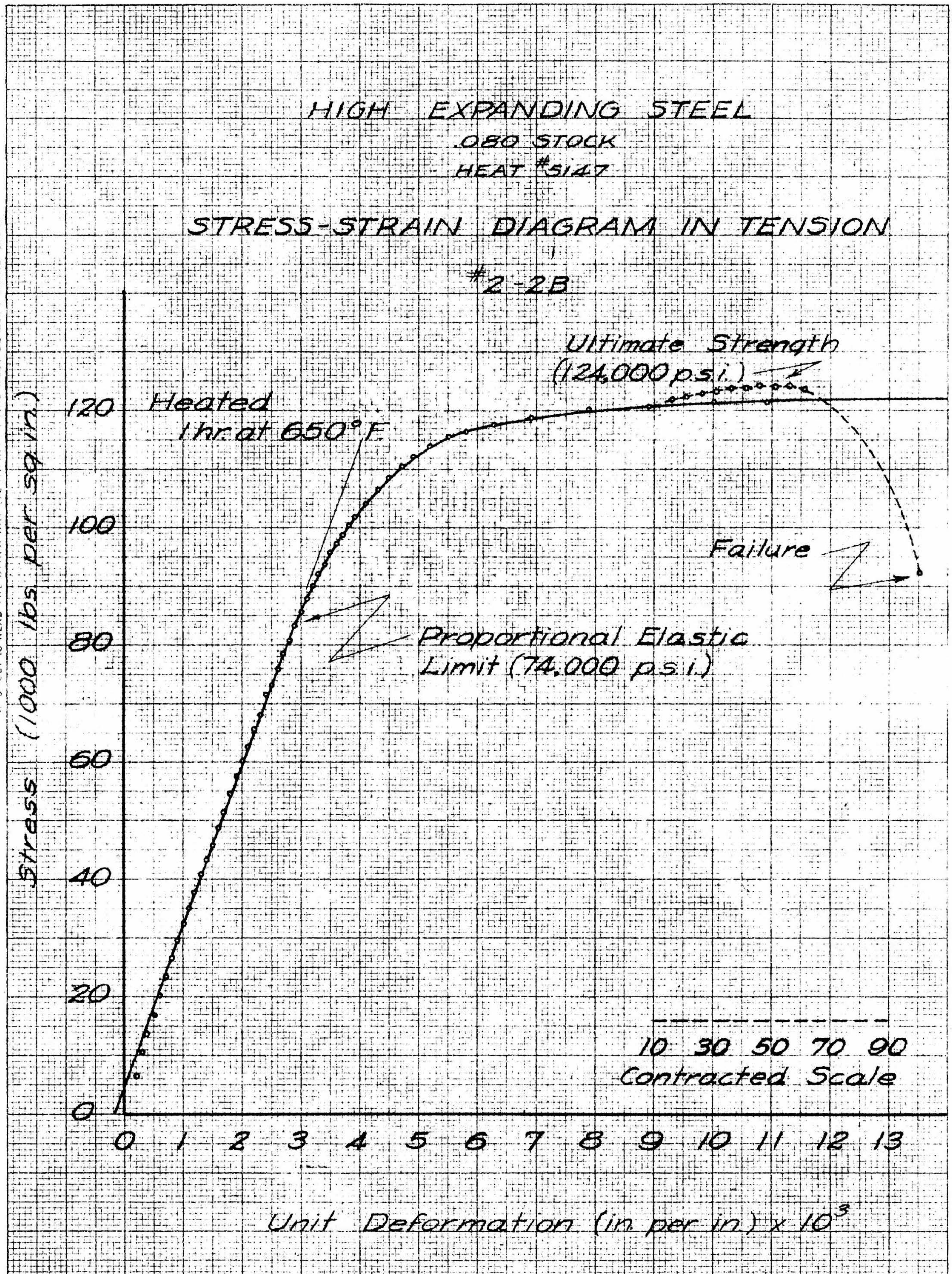

Heated
1 hr. at 650°F
HIGHHEAT THERMOMETAL
.030 STOCK
STRESS-STRAIN DIAGRAM IN TENSION
#HD-1
HEAT #5147 + HEAT #7384
failure
Ultimate Strength
(77,000 p.s.i.)
Proportional Elastic
Limit (22,000 p.s.i.)
10 50 90 130 170 210 250 290 330
Contracted Scale
Stress (1000 lb per sq in)
0 20 40 60 80
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Unit Deformation (in. per in.) x 10^3

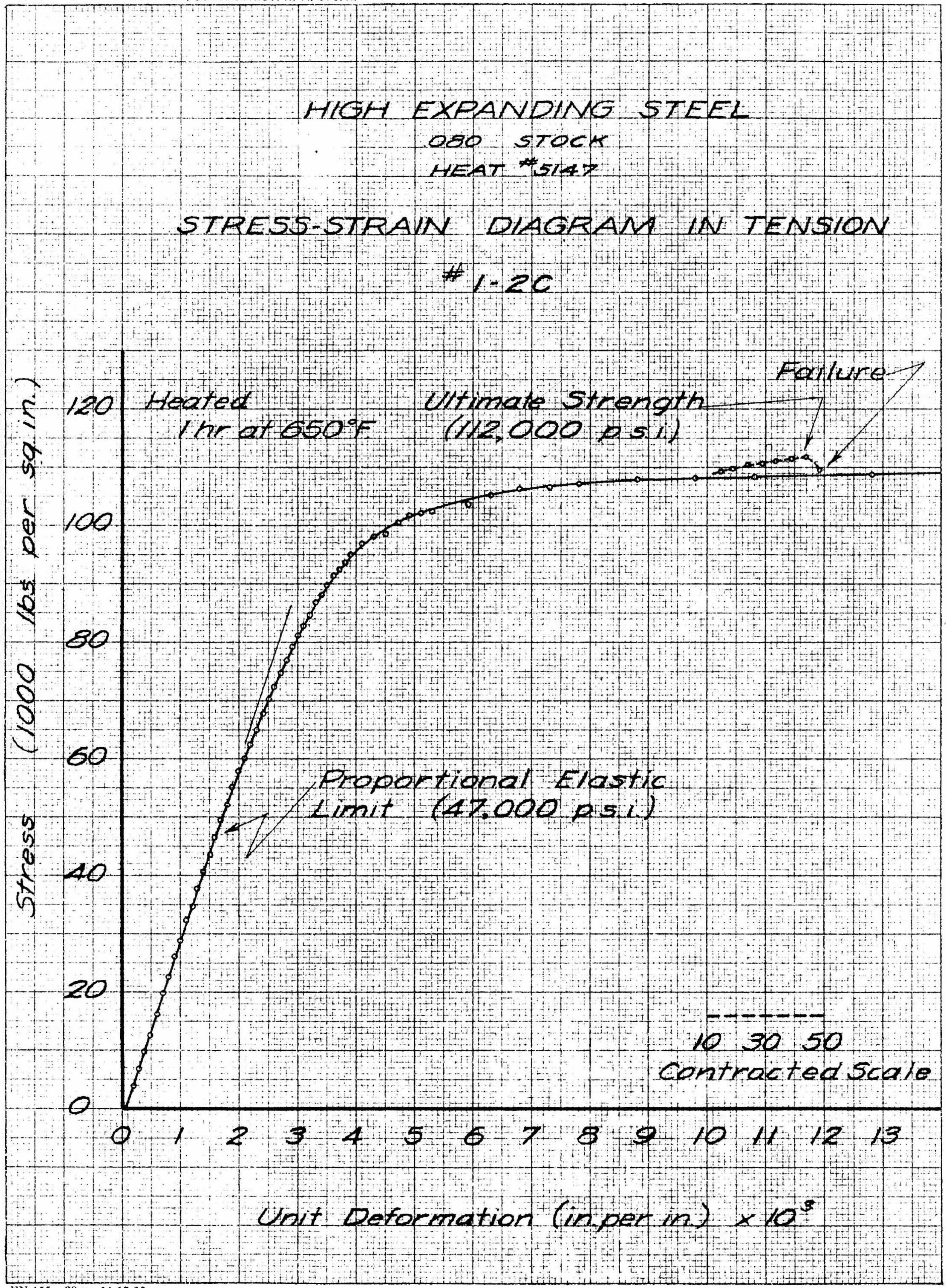

HIGH EXPANDING STEEL
.080 STOCK
HEAT #5147
STRESS-STRAIN DIAGRAM IN TENSION
#1-2A
Heated
1 hr at 650° F
Ultimate Strength
(143,000 p.s.i.)
Failure
Proportional Elastic
Limit (72,000 p.s.i.)
Stress (1000 lbs per sq in)
0
20
40
60
80
100
120
10 30 50 70
Contracted Scale
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Unit Deformation (in per in) x10^3

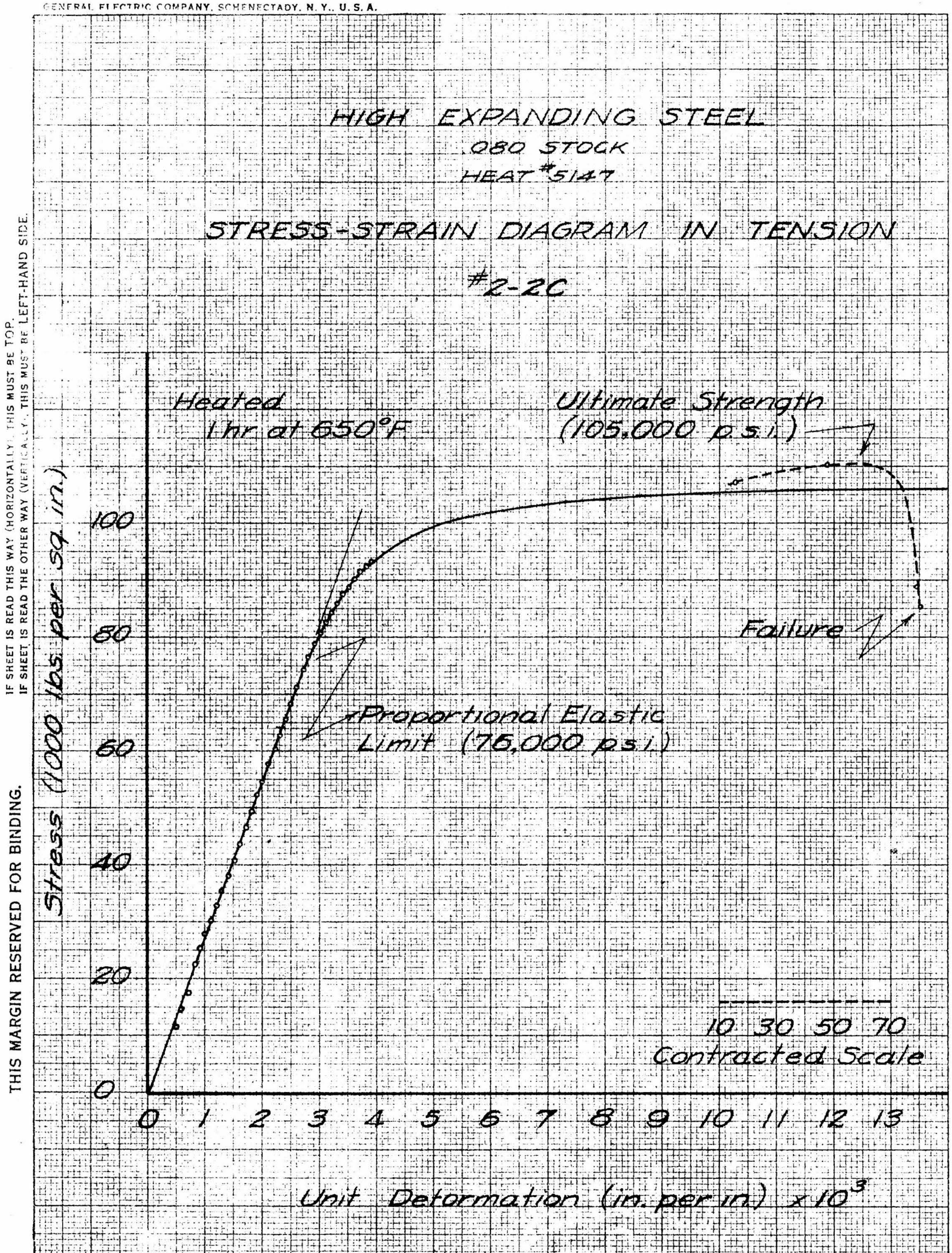
IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.

THIS MARGIN RESERVED FOR BINDING.




HIGH EXPANDING STEEL
.080 STOCK
HEAT #5147
STRESS-STRAIN DIAGRAM IN TENSION
#2-2B
Heated 1hr. at 650° F.
Ultimate Strength (124,000 p.s.i.)
Failure
Proportional Elastic Limit (74,000 p.s.i.)
Stress (1000 lbs per sq in.)
0
20
40
60
80
100
120
0 1 2 3 4 5 6 7 8 9 10 11 12 13
10 30 50 70 90
Contracted Scale
Unit Deformation (in per in) x 10³


HIGH EXPANDING STEEL
.080 STOCK
HEAT #5147
STRESS-STRAIN DIAGRAM IN TENSION
1-2C
Heated
1 hr at 650°F
Ultimate Strength
(112,000 p.s.i.)
Failure
Proportional Elastic
Limit (47,000 p.s.i.)
10 30 50
Contracted Scale
Stress (1000 lbs per sq in.)
0
20
40
60
80
100
120
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Unit Deformation (in.per in.) x 10^3


GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A.
HIGH EXPANDING STEEL
.080 STOCK
HEAT #5147
STRESS-STRAIN DIAGRAM IN TENSION
#2-2C
Heated
1hr at 650°F
Ultimate Strength
(105,000 p.s.i.)
Failure
Proportional Elastic
Limit (76,000 p.s.i.)
Stress (1000 lbs per sq. in.)
0
20
40
60
80
100
10 30 50 70
Contracted Scale
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Unit Deformation (in. per in.) x 10^3
THIS MARGIN RESERVED FOR BINDING.
IF SHEET IS READ THIS WAY (HORIZONTALLY) THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY) THIS MUST BE LEFT-HAND SIDE.
FN-155 20m 11-17-32
28/64 inch Divisions

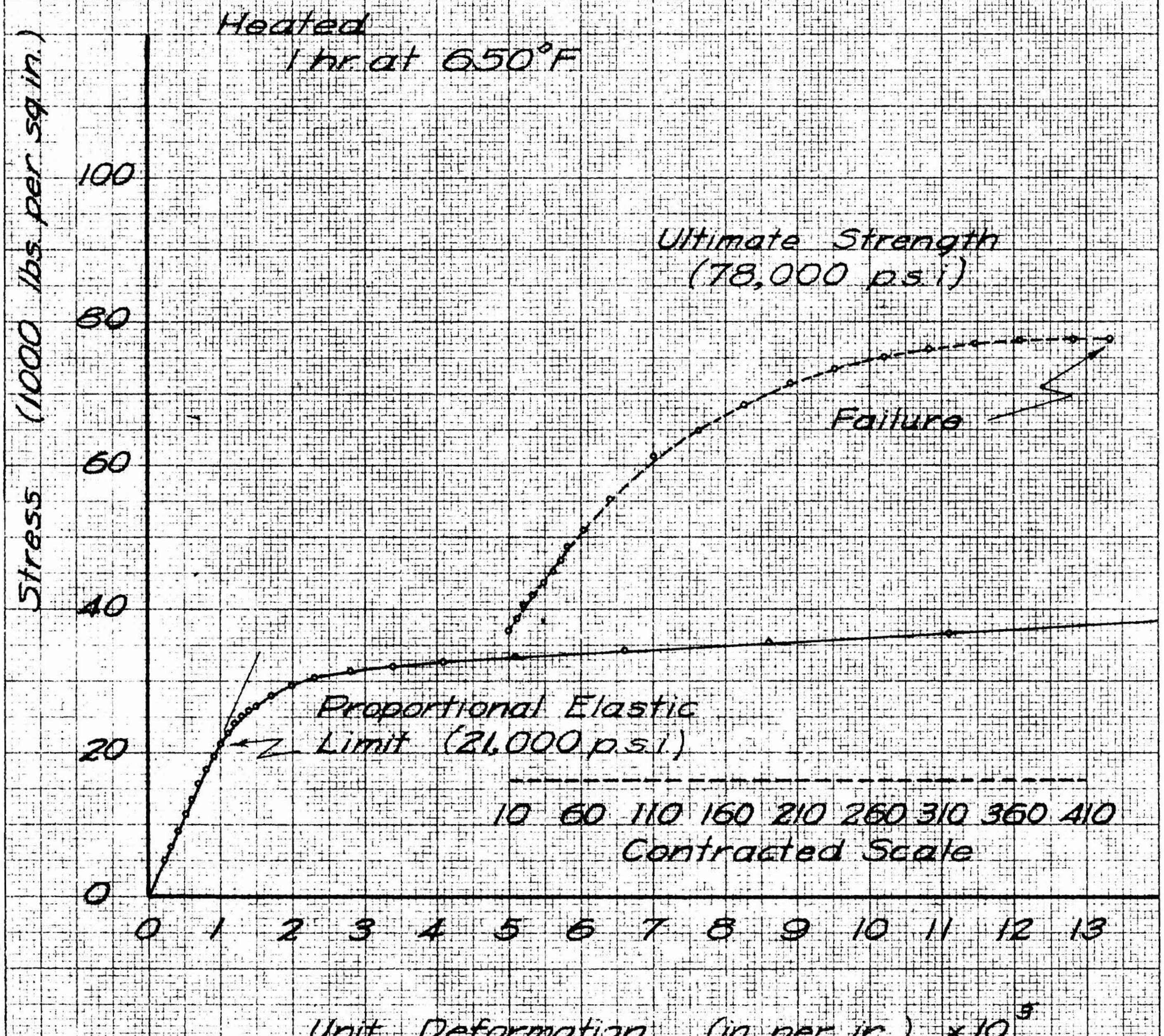
HIGH EXPANDING STEEL

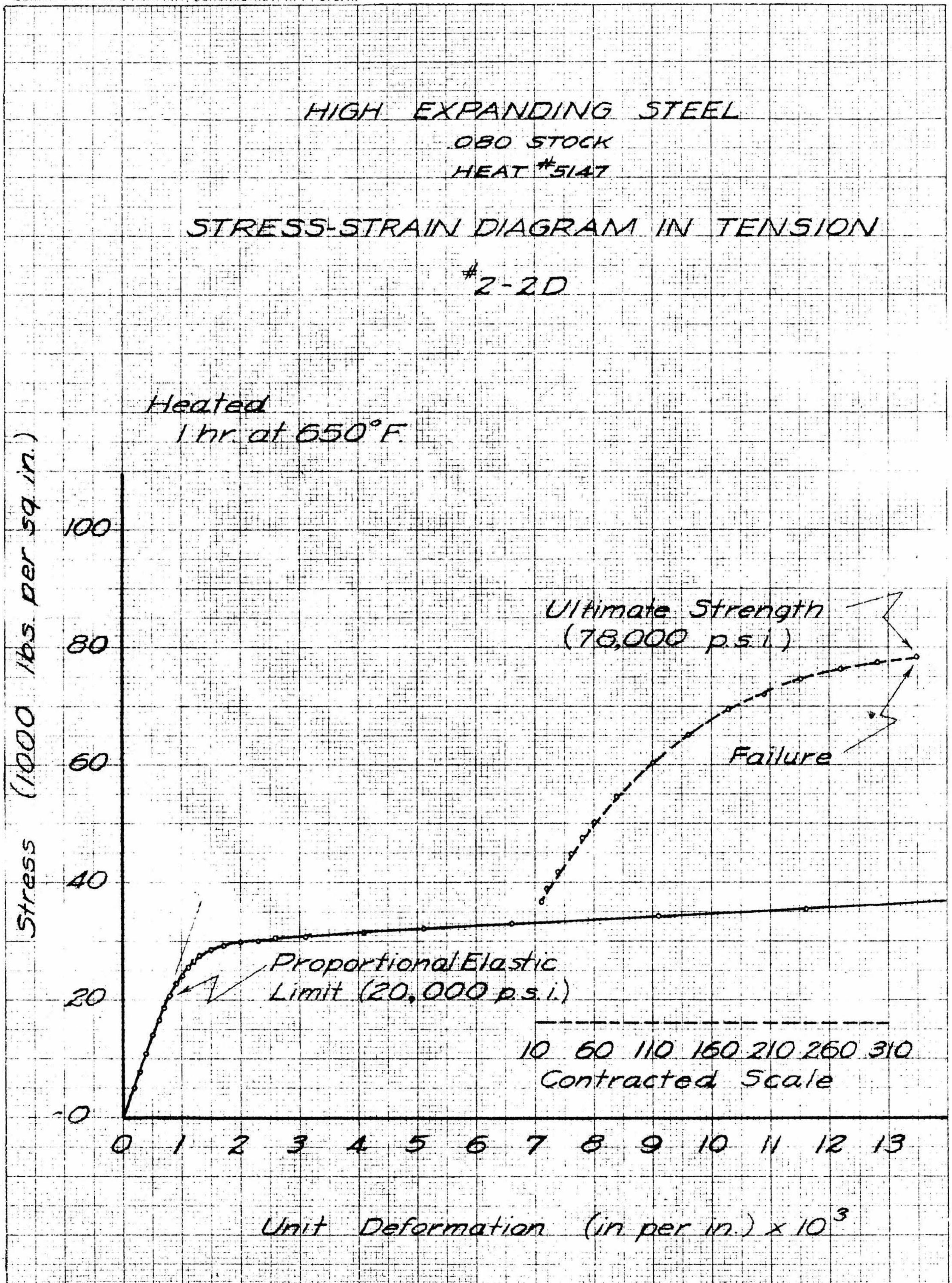
.080 STOCK

HEAT #5147

STRESS-STRAIN DIAGRAM IN TENSION

#1-2D




HIGH EXPANDING STEEL
.080 STOCK
HEAT #5147
STRESS-STRAIN DIAGRAM IN TENSION
#2-2D
Heated
1 hr. at 650°F.
Stress (1000 lbs. per sq. in.)
100
80
60
40
20
0
Ultimate Strength
(78,000 p.s.i.)
Failure
Proportional Elastic
Limit (20,000 p.s.i.)
10 60 110 160 210 260 310
Contracted Scale
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Unit Deformation (in per in.) x 10^3

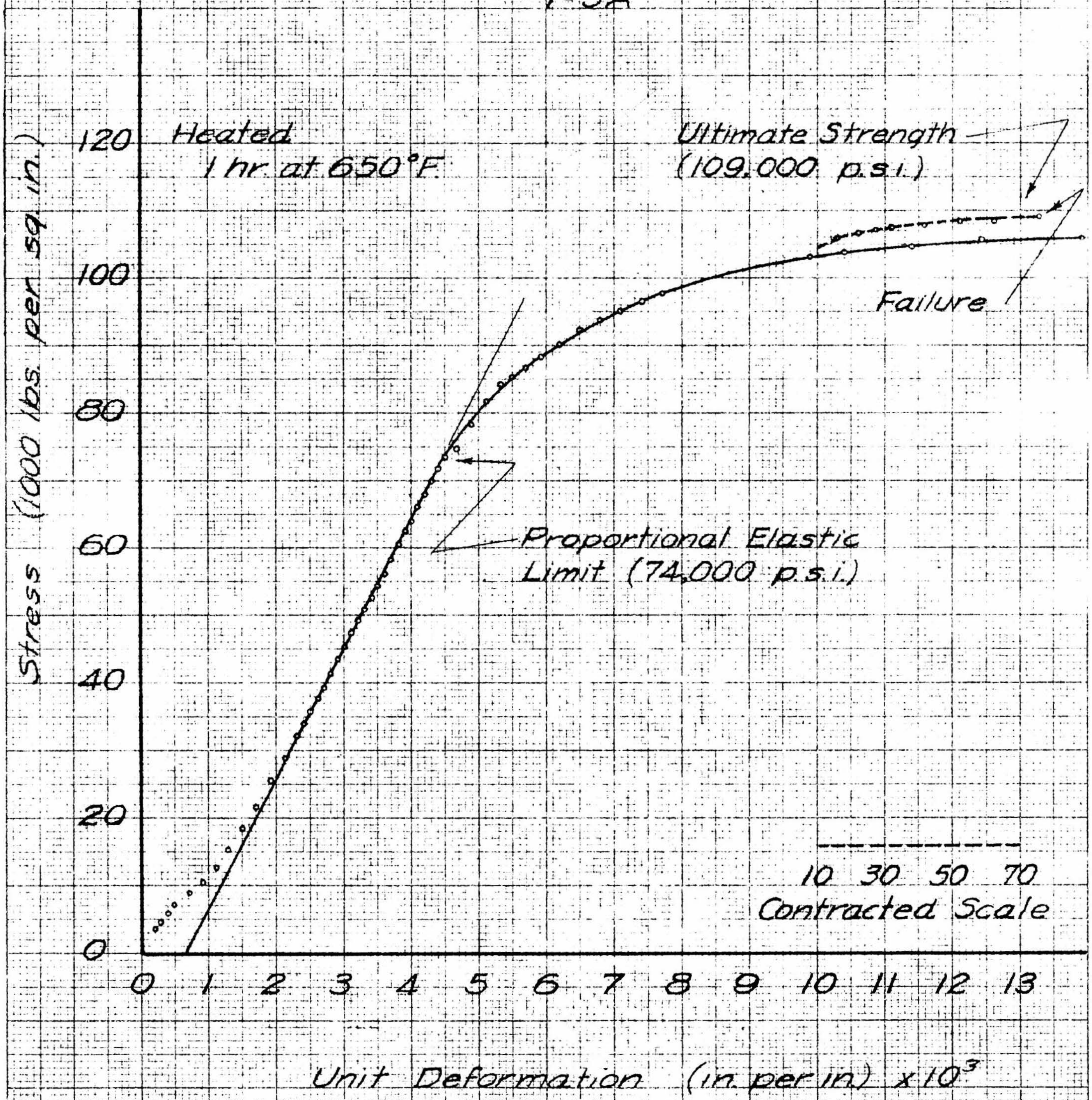
LOW EXPANDING STEEL

.080 STOCK

HEAT #7384

STRESS-STRAIN DIAGRAM IN TENSION

#1-3A



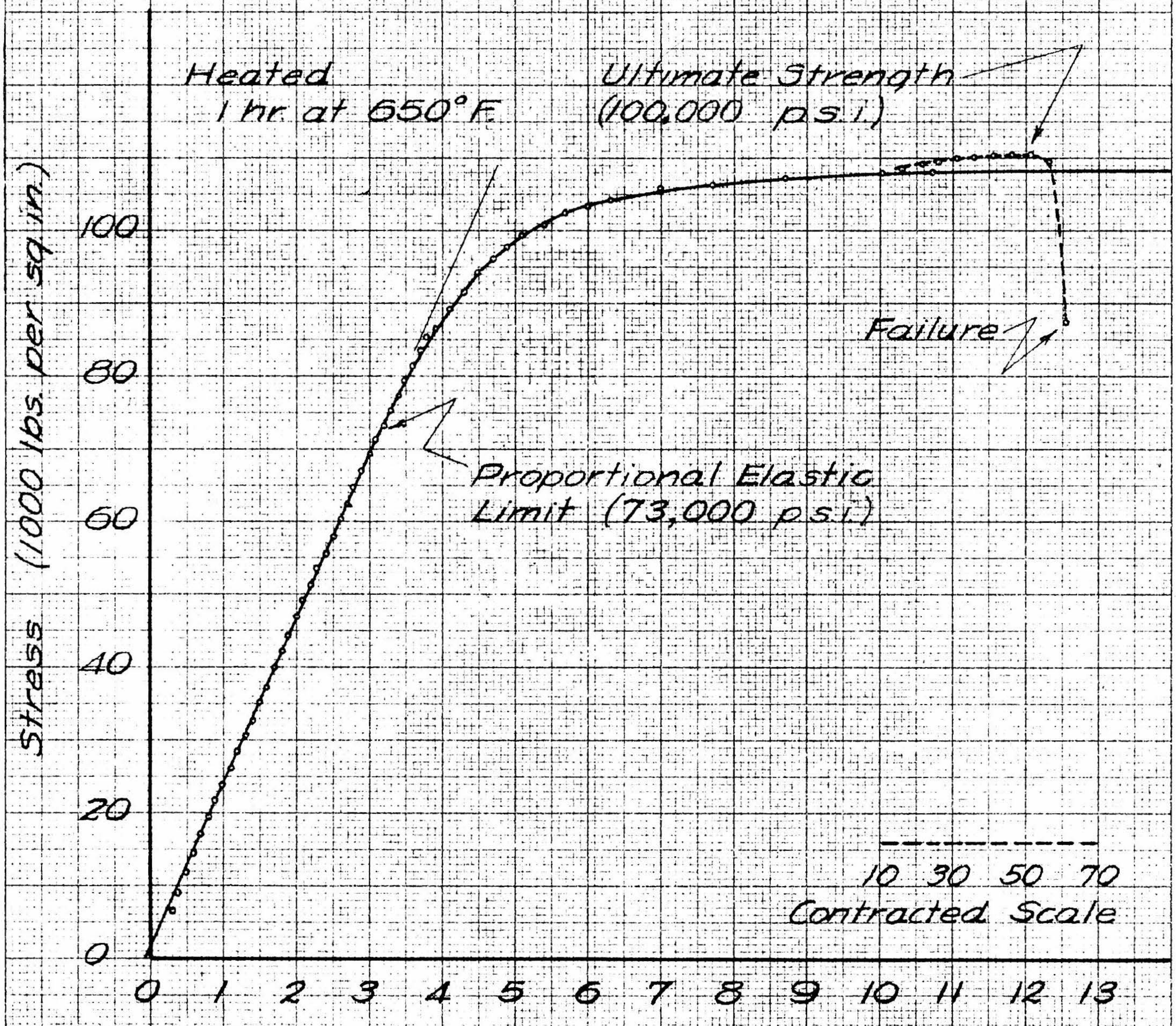
LOW EXPANDING STEEL

.080 STOCK

HEAT #7384

STRESS-STRAIN DIAGRAM IN TENSION

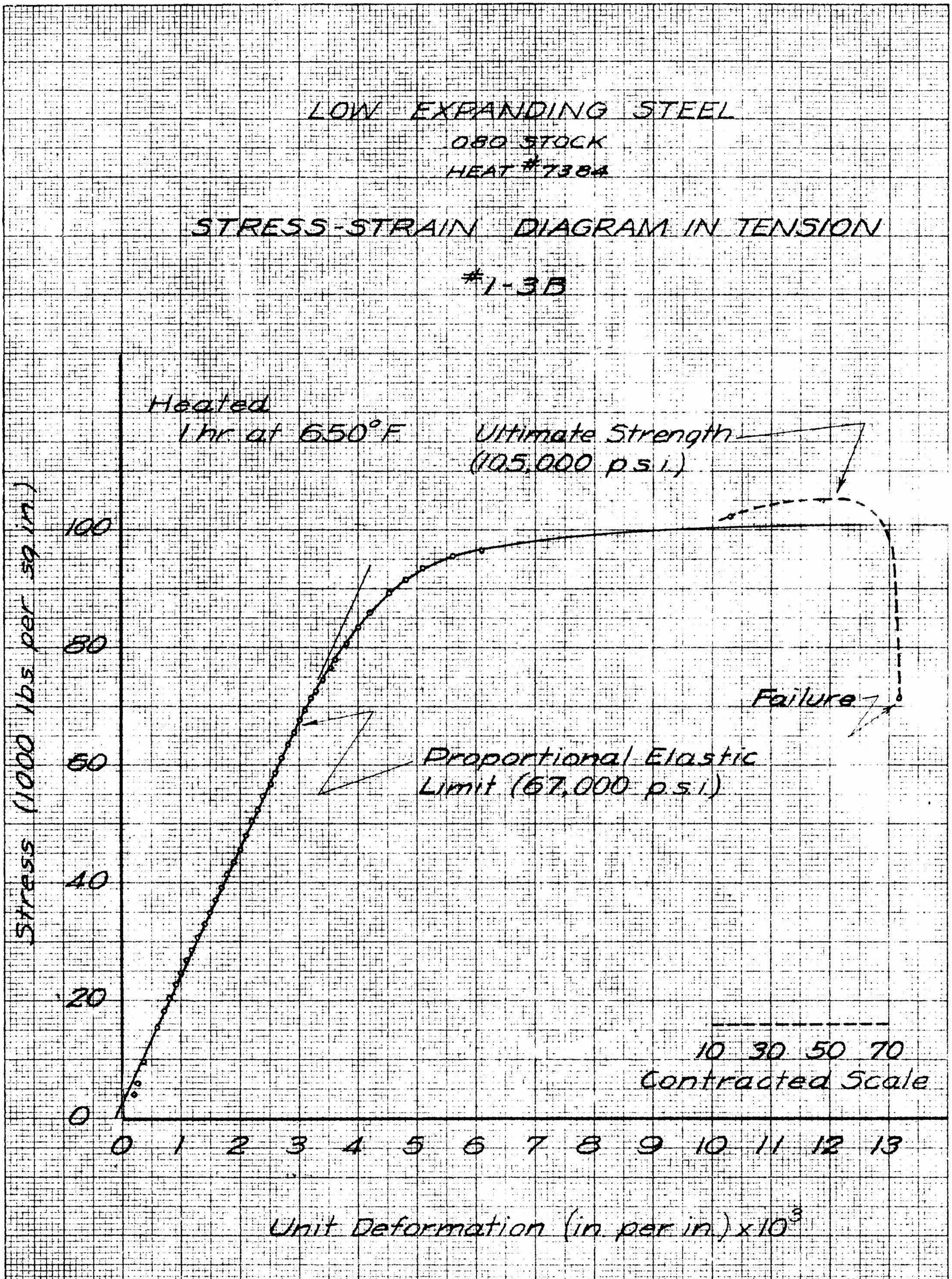
#2-3A



GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A

IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.

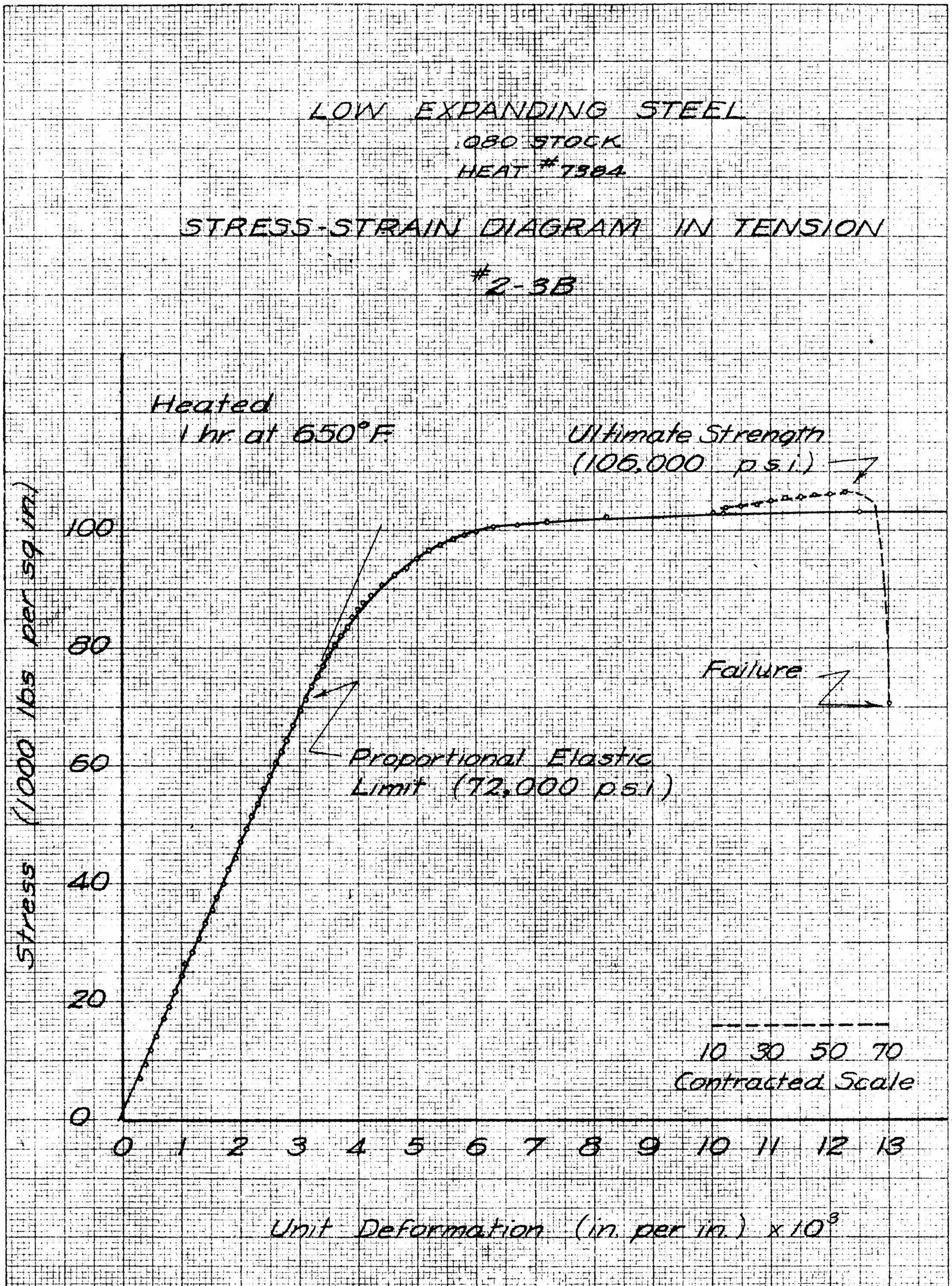
THIS MARGIN RESERVED FOR BINDING.



FN-155 20m 11-17-32

29/64 inch Divisions

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A



IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.

THIS MARGIN RESERVED FOR BINDING.

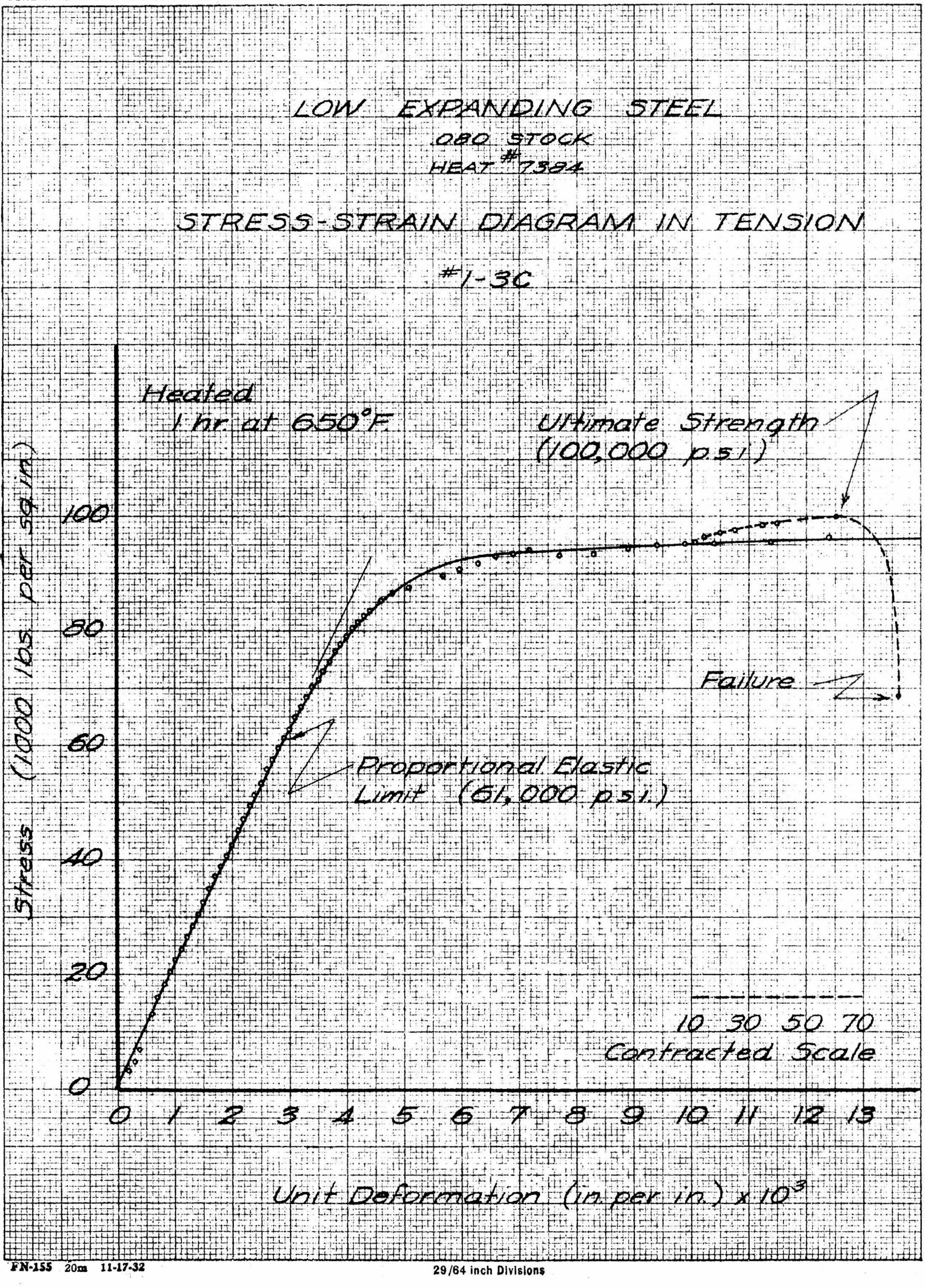
FN-155 20m 11-17-32

29/64 inch Divisions

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A

THIS MARGIN RESERVED FOR BINDING.

IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.

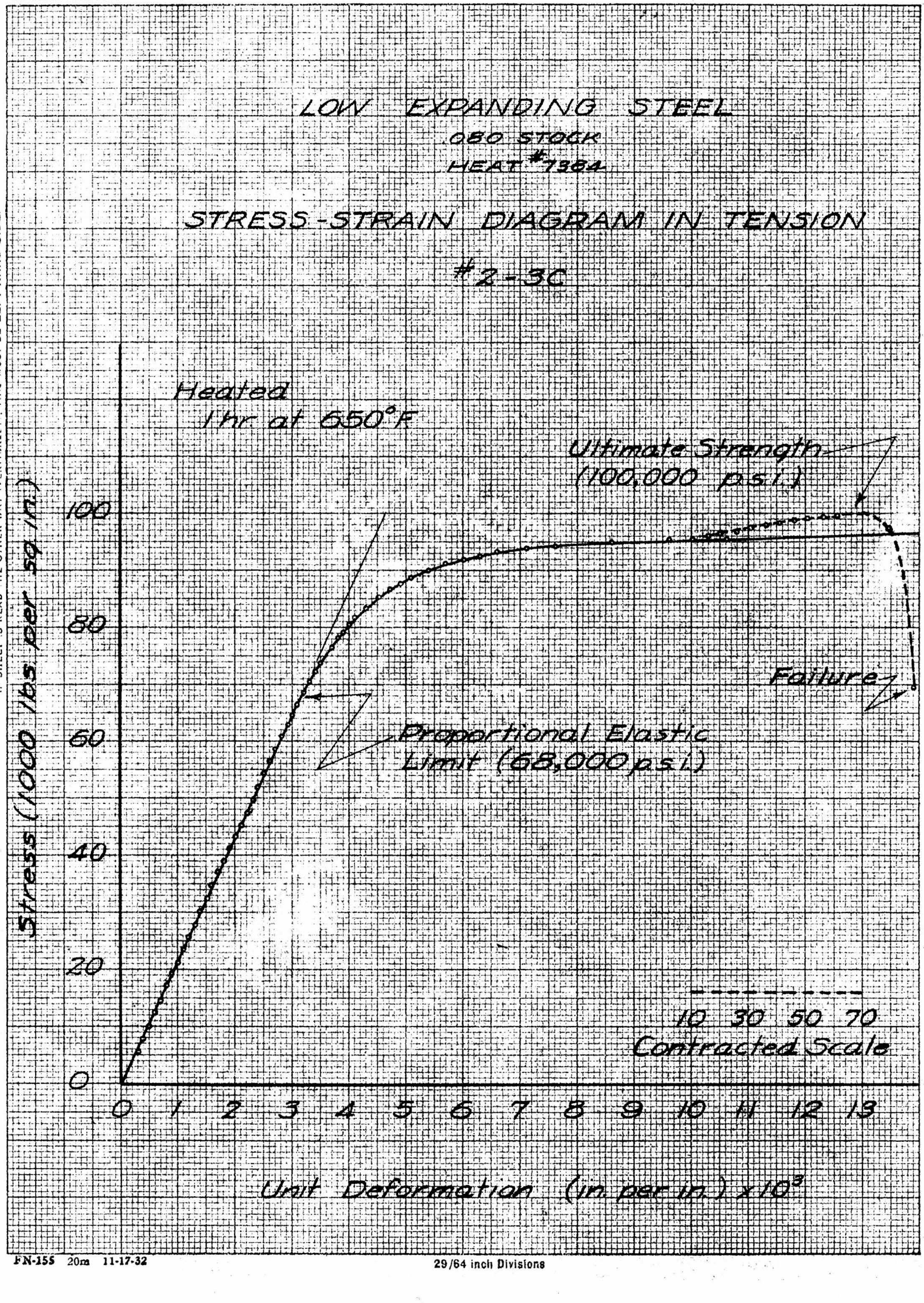


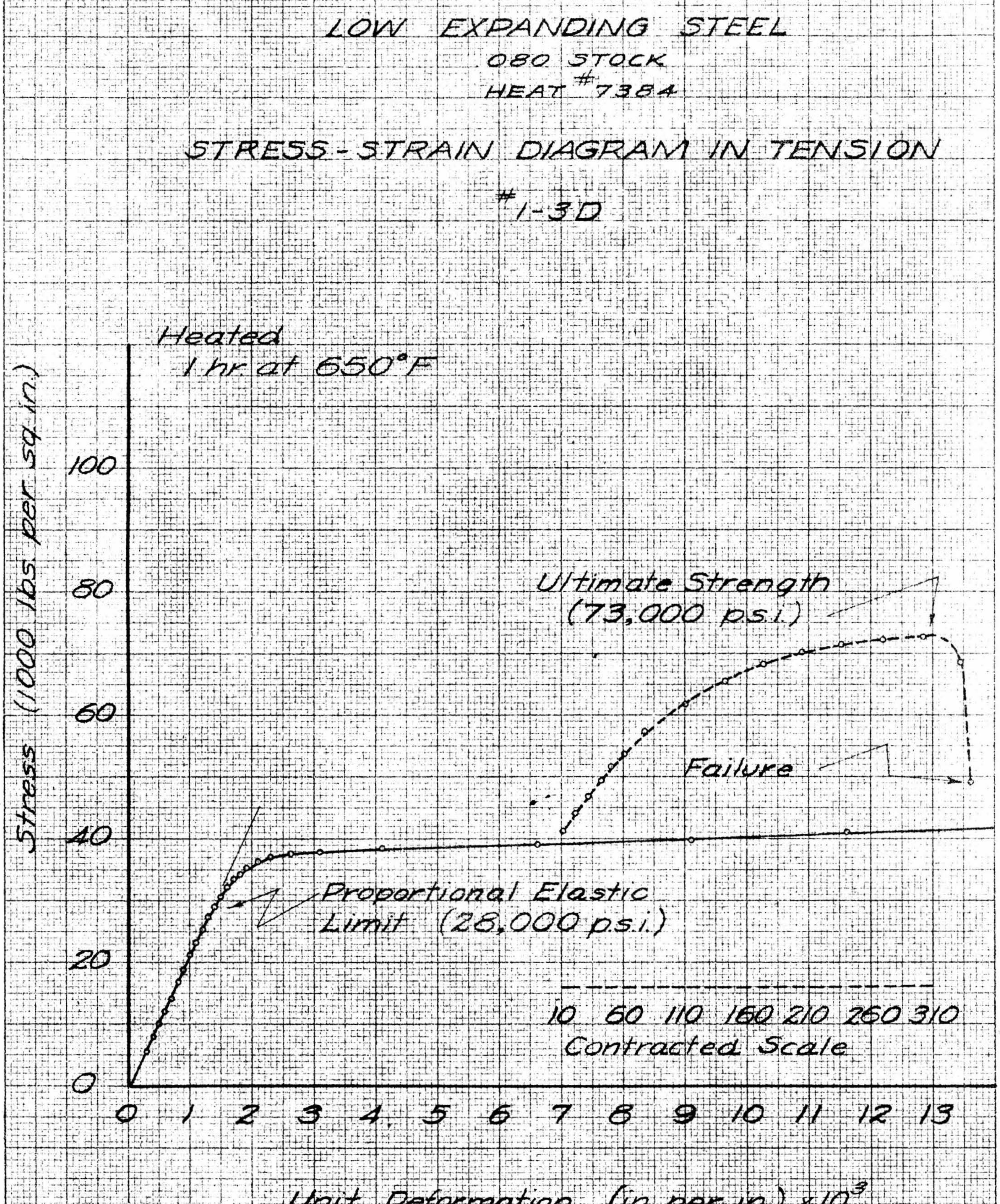
FN-155 20m 11-17-32

29/64 inch Divisions

THIS MARGIN RESERVED FOR BINDING.

IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.

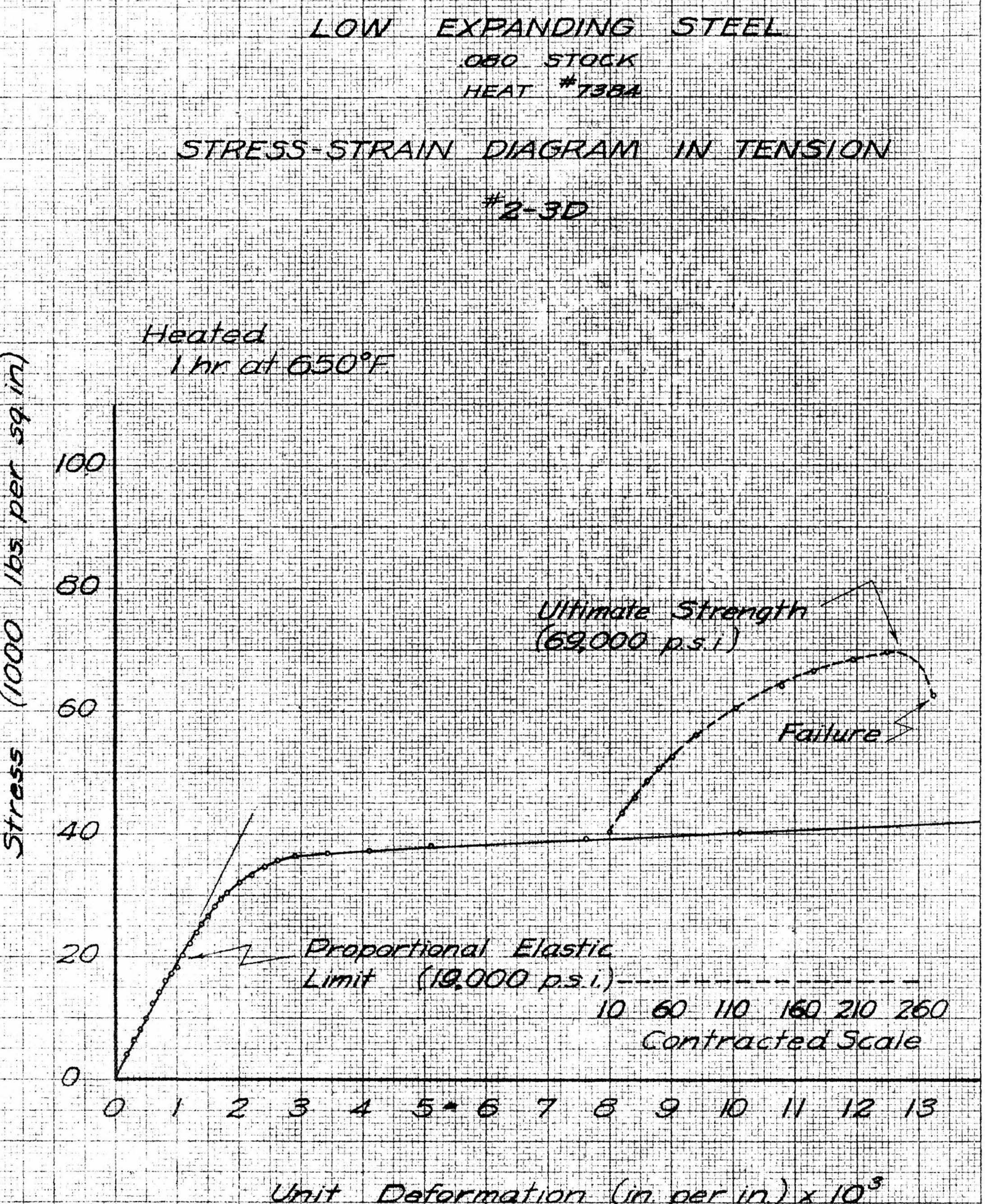



LOW EXPANDING STEEL
.080 STOCK
HEAT #7384
STRESS-STRAIN DIAGRAM IN TENSION
#1-3D
Heated
1 hr at 650°F
Stress (1000 lbs per sq in.)
100
80
60
40
20
0
Ultimate Strength
(73,000 p.s.i.)
Failure
Proportional Elastic
Limit (28,000 p.s.i.)
10 60 110 160 210 260 310
Contracted Scale
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Unit Deformation (in. per in.) x10³

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A.

IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.

THIS MARGIN RESERVED FOR BINDING.



FN-155 20m 11-17-32

29/64 inch Divisions

APPENDIX C

TRANSVERSE BENDING DATA

THERMOMETAL .030 # 1-IC

tension in steel
width = .760"
zero load = 8 oz.

stock as received
Curvature = .0089

gage length = 1 3/4"
center on steel side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.502	91 1/2	7,700	.00037	0
2		4	.489+	92	11,500	.00056	
3		0	.501 1/2				1/2
4		8	.477	92 1/2	15,300	.00074	
5		0	.501				1/2
6		12	.464+	93	19,200	.00093	
7		0	.501-				1/3
8	1	0	.452-	94	23,000	.00110	
9		0	.500				2/3
10	1	4	.439	94 1/2	27,000	.00129	
11		0	.499				1
12	1	8	.426	95	30,800	.00148	
13		0	.498				1
14	1	12	.412	96	34,700	.00169	
15		0	.496+				1 2/3
16	2	0	.397	96 1/2	38,500	.00190	
17		0	.493+				3
18	2	4	.381	97	42,500	.00214	
19		0	.489				4 1/3
20	2	8	.364	98	46,500	.00239	
21		0	.485				4
22	2	12	.343	98 1/2	50,400	.00269	
23		0	.478				7
24	3	0	.322	99 1/2	54,300	.00299	
25		0	.468	93	7,700	.00087	10
26	3	4	.291	100 1/2	58,500	.00344	
27		0	.452				16
28	3	8	.245	102 1/2	63,100	.00409	
29		0	.423				29
30	3	12	.194	104 1/2	67,700	.00480	
31		0	.384				39
32	4	0	off dial				
33		0	.213	102	7,900	.00452	

THERMOMETAL .030 # 1-IT

tension in invar
width = .755"
zero load = 8 oz.

stock as received
Curvature = .0017

gage length = $1\frac{3}{4}$"
center on invar side

No.	Load lb.	oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.492	91½	7,700	.00037	0
2		4	.479	92	11,600	.00056	
3		0	.492				0
4		8	.467	92½	15,500	.00074	
5		0	.492-				1/3
6		12	.455	93	19,300	.00091	
7		0	.492-				0
8	1	0	.442+	94	23,300	.00110	
9		0	.492-				0
10	1	4	.429-	94½	27,200	.00129	
11		0	.490				1 2/3
12	1	8	.413	95½	31,100	.00153	
13		0	.487				3
14	1	12	.396	96	35,000	.00177	
15		0	.483				4
16	2	0	.380	97	38,900	.00200	
17		0	.479-	92	7,700	.00056	4 1/3
18	2	4	.361	98	43,000	.00228	
19		0	.471+				7 1/3
20	2	8	.338	99	47,000	.00261	
21		0	.461+				10
22	2	12	.310	100	51,000	.00302	
23		0	.448-		7,700	.00102	13 2/3
24	3	0	.278	101	55,300	.00350	
25		0	.428				19 2/3
26	3	4	.225	103½	60,100	.00422	
27		0	.391		7,700	.00185	37

THERMOMETAL .030 # 2-IC

tension in steel
width = .765"
zero load = 8 oz.

stock as received
Curvature = .0160

gage length = 1 3/4"
center on steel side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.505	90	7,600	.00034	0
2		4	.493+	90 1/2	11,400	.00051	
3		0	.505				0
4		8	.481+	91	15,200	.00069	
5		0	.505-				1/3
6		12	.470-	91 1/2	19,100	.00086	
7		0	.505-				0
8	1	0	.458+	92	22,900	.00103	
9		0	.505-				0
10	1	4	.447	92 1/2	26,700	.00119	
11		0	.504+				1/3
12	1	8	.436	93	30,500	.00135	
13		0	.504+				0
14	1	12	.424+	93 1/2	34,400	.00153	
15		0	.504+				0
16	2	0	.413-	94	38,300	.00169	
17		0	.504				1/3
18	2	4	.401	94 1/2	42,100	.00186	
19		0	.504				0
20	2	8	.389+	95 1/2	46,000	.00204	
21		0	.504				0
22	2	12	.378+	96	49,800	.00220	
23		0	.504-				1/3
24	3	0	.367+	96 1/2	53,700	.00235	
25		0	.504-				0
26	3	4	.356	97	57,600	.00252	
27		0	.503+				1/3
28	3	8	.343	97 1/2	61,500	.00270	
29		0	.503				1/3
30	3	12	.332	98 1/2	65,500	.00286	
31		0	.503-				1/3
32	4	0	.320-	99	69,500	.00304	
33		0	.502+				1/3
34	4	4	.308	99 1/2	73,600	.00321	
35		0	.502+				0
36	4	8	.296	100	77,600	.00338	
37		0	.502				0
38	4	12	.284	100 1/2	81,700	.00355	
39		0	.503				0
40	5	0	.273	101	85,600	.00371	
41		0	.502+				0
42	5	4	.260	101 1/2	89,800	.00390	
43		0	.502+				0
44	5	8	.247	102	94,000	.00407	

2-10

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
45		0	.502-				2/3
46	5	12	.235	102 1/2	98,200	.00424	
47		0	.501+				1/3
48	6	0	.221	103	102,200	.00444	
49		0	.501-				2/3
50	6	4	.208	103 1/2	106,400	.00463	
51		0	.500				2/3
52	6	8	.194	104	111,000	.00482	
53		0	.499+				2/3
54	6	12	.182	104 1/2	115,200	.00498	
55		0	.499-				2/3
56	7	0	.167	105 1/2	119,800	.00518	
57		0	.498				2/3
58	7	4	.152	106 1/2	124,500	.00540	
59		0	.496+				1 2/3
60	7	8	.135	107	129,200	.00562	
61		0	.494				2 1/3
62	7	12	.120	108	134,000	.00583	
63		0	.492				2
64	8	0	.099	108 1/2	139,000	.00610	
65		0	.487	90 1/2	7,600	.00060	5

THERMOMETAL .030 # 4-II

tension in invar
width = .768"
zero load = 8 oz.

stock as received
Curvature = .0067

gage length = 1 3/4"
center on invar side

No.	Load lb.	oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.505	91	7,600	.00034	
2		4	.494	91 1/2	11,400	.00050	
3		0	.505				0
4		8	.483-	92	15,200	.00066	
5		0	.505				0
6		12	.471	92 1/2	19,000	.00084	
7		0	.505				0
8	1	0	.460-	93	22,800	.00100	
9		0	.505				0
10	1	4	.448-	94	26,700	.00118	
11		0	.505				0
12	1	8	.436-	94 1/2	30,500	.00135	
13		0	.504				1
14	1	12	.425-	95	34,300	.00151	
15		0	.503+				2/3
16	2	0	.412	95 1/2	38,200	.00170	
17		0	.502				1 2/3
18	2	4	.399	96	42,100	.00190	
19		0	.500+				1 2/3
20	2	8	.387	96 1/2	45,900	.00207	
21		0	.498				2 1/3
22	2	12	.372+	97	49,800	.00228	
23		0	.496				2
24	3	0	.360-	97 1/2	53,600	.00246	
25		0	.495-				1 1/3
26	3	4	.344	98 1/2	57,600	.00269	
27		0	.491+		7,600	.00054	3 1/3
28	3	8	.328	99 1/2	61,700	.00292	
29		0	.488+				3
30	3	12	.314	100	65,600	.00312	
31		0	.486				2 1/3
32	4	0	.299	100 1/2	69,700	.00334	
33		0	.483-				3 1/3
34	4	4	.284	101 1/2	73,900	.00355	
35		0	.479-				4
36	4	8	.268	102	78,000	.00377	
37		0	.475				3 1/3
38	4	12	.252	102 1/2	82,100	.00400	
39		0	.471				4
40	5	0	.231	103 1/2	86,500	.00429	
41		0	.466				5
42	5	4	.214	104 1/2	90,800	.00453	
43		0	.461				5
44	5	8	.195	105	95,300	.00479	

2-IT

No.	Load lb. oz.		Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in	Set .001"
45		0	.456				5
46	5	12	.172	106	99,900	.00511	
47		0	.448				8
48	6	0	.150	107	104,500	.00540	
49		0	.442				6
50	6	4	.133	108	109,300	.00563	
51		0	.436				6
52	6	8	.109	109	114,200	.00547	
53		0	.428				8
54	6	12	.085	110	120,300	.00625	
55		0	.419				9
56	7	0	.054	111 1/2	125,000	.00667	
57		0	.407				12
58	7	4	.016	112 1/2	130,800	.00712	
59		0	.391	95 1/2	7,600	.00202	16

THERMOMETAL .030 # 3-IC

tension in steel
width = 0.762"
zero load = 8 oz.

Stock as received
Curvature = .0089

Gage length = 1 3/4"
center on steel side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.494	91	7,600	.00035	0
2		4	.482−	91½	11,500	.00053	
3		0	.494−				1/3
4		8	.469+	92	15,300	.00072	
5		0	.494−				0
6		12	.458−	92½	19,200	.00089	
7		0	.494−				0
8	1	0	.446−	93	23,000	.00106	
9		0	.493+				1/3
10	1	4	.434	93½	26,900	.00123	
11		0	.493+				0
12	1	8	.422	94	30,700	.00141	
13		0	.493				1/3
14	1	12	.410	94½	34,600	.00159	
15		0	.493−				1/3
16	2	0	.398	95	38,500	.00177	
17		0	.493−				0
18	2	4	.386	95½	42,400	.00194	
19		0	.492				2/3
20	2	8	.374−	96½	46,200	.00212	
21		0	.492−				1/3
22	2	12	.361+	97	50,100	.00230	
23		0	.491				2/3
24	3	0	.349	97½	54,100	.00247	
25		0	.490+				2/3
26	3	4	.335	98	58,000	.00268	
27		0	.489+				1
28	3	8	.321	98½	62,000	.00288	
29		0	.489−				2/3
30	3	12	.309	99	66,000	.00305	
31		0	.489−				0
32	4	0	.296	100	70,100	.00324	
33		0	.487+				1 1/3
34	4	4	.282	100½	74,100	.00343	
35		0	.487−				2/3
36	4	8	.268	101½	78,400	.00364	
37		0	.485+				1 1/3
38	4	12	.253	102	82,500	.00385	
39		0	.484				1 1/3
40	5	0	.239	102½	86,600	.00404	
41		0	.483−				1 1/3
42	5	4	.224	103½	90,900	.00426	
43		0	.481+				1 1/3
44	5	8	.206	104	95,200	.00451	

3-IC

No.	Load lb.	oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
45		0	.479				2 1/3
46	5	12	.190	104½	99,600	.00473	
47		0	.477				2
48	6	0	.173	105½	104,100	.00497	
49		0	.474-				3 1/3
50	6	4	.158	106½	108,800	.00516	
51		0	.471				2 2/3
52	6	8	.131	107½	113,500	.00554	
53		0	.464				7
54	6	12	.112	108½	118,500	.00579	
55		0	.458-				6 1/3
56	7	0	.082	109½	123,700	.00619	
57		0	.447-	92½	7,700	.00105	11

THERMOMETAL .030 # 3-IT

tension in invar
width = .768″ stock as received gage length = $1\frac{3}{4}$"
zero load = 8 oz. Curvature = .0062 center on invar side

No.	Load lb.	oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.490	91½	7,600	.00037	0
2		4	.477	92	11,300	.00056	
3		0	.490-				1/3
4		8	.464+	92½	15,200	.00075	
5		0	.489+				1/3
6		12	.452	93	19,000	.00093	
7		0	.489+				0
8	1	0	.440-	93½	22,800	.00111	
9		0	.489+				0
10	1	4	.427+	94	26,700	.00129	
11		0	.489				1/3
12	1	8	.415	94½	30,400	.00147	
13		0	.489				0
14	1	12	.403	95½	34,300	.00165	
15		0	.489-				1/3
16	2	0	.391-	96	38,100	.00182	
17		0	.489-				0
18	2	4	.378	96½	42,000	.00201	
19		0	.489-				0
20	2	8	.367	97	45,800	.00216	
21		0	.488+				1/3
22	2	12	.354	97½	49,700	.00235	
23		0	.488				1/3
24	3	0	.341+	98½	53,600	.00254	
25		0	.488-				1/3
26	3	4	.328	99	57,500	.00273	
27		0	.487				2/3
28	3	8	.315	99½	61,500	.00292	
29		0	.486				1
30	3	12	.301	100	65,500	.00312	
31		0	.485-				1 1/3
32	4	0	.287	100½	69,500	.00332	
33		0	.483-				2
34	4	4	.271	101	73,600	.00355	
35		0	.480-				3
36	4	8	.256	102	77,700	.00376	
37		0	.477-				3
38	4	12	.238	102½	81,900	.00402	
39		0	.472				4 2/3
40	5	0	.216	104	86,400	.00433	
41		0	.467				5
42	5	4	.199	104½	90,800	.00455	
43		0	.462		7,600	.00078	5

THERMOMETAL .030 # 4-IC

tension in steel
width = .767"
zero load = 8 oz

stock as received
Curvature = .0222

gage length = $1\frac{3}{4}$"
center on invar side

No.	Load lb.	oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.505	94	7,600	.00031	0
2		4	.494 +	94	11,400	.00047	
3		0	.505 –				1/3
4		8	.484 –	94½	15,200	.00062	
5		0	.505 –				0
6		12	.473	95	19,100	.00078	
7		0	.505 –				0
8	1	0	.462 +	95½	22,900	.00094	
9		0	.505 –				0
10	1	4	.451	96	26,700	.00110	
11		0	.504 +				1/3
12	1	8	.441	96½	30,600	.00125	
13		0	.504 +				0
14	1	12	.430	97	34,500	.00141	
15		0	.504 +				0
16	2	0	.418 +	97½	38,400	.00158	
17		0	.504				1/3
18	2	4	.408	98	42,300	.00173	
19		0	.504 –				1/3
20	2	8	.396	98½	46,200	.00190	
21		0	.503 +				1/3
22	2	12	.384	99½	50,100	.00207	
23		0	.503				1/3
24	3	0	.373	100	54,000	.00224	
25		0	.503 –				1/3
26	3	4	.361	100½	58,000	.00241	
27		0	.502				2/3
28	3	8	.349	101	62,000	.00258	
29		0	.501 +				2/3
30	3	12	.336	101½	66,000	.00276	
31		0	.501 –				2/3
32	4	0	.324	102	70,000	.00293	
33		0	.500 +				1/3
34	4	4	.311	102½	74,200	.00312	
35		0	.500 –				1/3
36	4	8	.298 +	103	78,300	.00330	
37		0	.499				2/3
38	4	12	.286	103½	82,400	.00347	
39		0	.498 +				2/3
40	5	0	.274	104	86,500	.00364	
41		0	.498 –				2/3
42	5	4	.260	104½	90,700	.00384	
43		0	.497				2/3
44	5	8	.298	105½	95,200	.00401	

4-IC

No.	Load lb. oz.		Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
45		0	.446 +				2/3
46	5	12	.235	106	99,500	.00418	
47		0	.496 –				2/3
48	6	0	.223	106½	103,000	.00431	
49		0	.495				2/3
50	6	4	.208	107	108,200	.00456	
51		0	.494				1
52	6	8	.194	107½	112,800	.00475	
53		0	.493				1
54	6	12	.179	108	117,200	.00495	
55		0	.492 +				2/3
56	7	0	.164	109	122,100	.00515	
57		0	.491				1 1/3
58	7	4	.148	110	127,000	.00537	
59		0	.490 –				1 1/3
60	7	8	.133	110½	131,800	.00556	
61		0	.488 +				1 1/3
62	7	12	.117	111	136,600	.00578	
63		0	.487				1 1/3
64	8	0	.097	112	142,000	.00604	
65		0	.485 –				2 1/3
66		0	.486 –	taken	after five	minutes	-1
67	8	4	.077	113	147,300	.00629	
68		0	.482				3 2/3
69	8	8	.054	113½	152,700	.00659	
70		0	.479 –				3 1/3
71	8	12	.031	114½	158,500	.00690	
72		0	.474				4 2/3
73	9	0	.007 –	117	166,400	.00735	
74		0	.463		7,600	.00093	11

THERMOMETAL .030 # 4-IT

tension in invar
width = .760"
zero load = 8 oz.

stock as received
Curvature = .0076

gage length = 1¾"
center on invar side

No.	Load lb.	oz.	Dial. in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.494	90	7,700	.00034	0
2		4	.483 -	90½	11,500	.00050	
3		0	.494				0
4		8	.471	91½	15,300	.00068	
5		0	.494				0
6		12	.460 -	92	19,200	.00084	
7		0	.494				0
8	1	0	.448 +	92½	23,000	.00101	
9		0	.494				0
10	1	4	.437	93	27,000	.00118	
11		0	.494				0
12	1	8	.426	93½	30,700	.00134	
13		0	.494 -				1/3
14	1	12	.415 -	94	34,600	.00150	
15		0	.494 -				0
16	2	0	.403 -	94½	38,500	.00168	
17		0	.494 -				0
18	2	4	.392	95	42,400	.00184	
19		0	.494 -				0
20	2	8	.381	95½	46,300	.00200	
21		0	.494 -				0
22	2	12	.369 +	96	50,200	.00216	
23		0	.493 +				1/3
24	3	0	.358	96½	54,100	.00232	
25		0	.493				1/3
26	3	4	.347	97	58,100	.00249	
27		0	.492 +				2/3
28	3	8	.335	97½	62,000	.00266	
29		0	.492				1/3
30	3	12	.323 -	98	66,000	.00284	
31		0	.492 -				1/3
32	4	0	.308	98½	70,000	.00305	
33		0	.490 +				1 1/3
34	4	4	.294	99½	74,200	.00325	
35		0	.489 +				1
36	4	8	.280	100	78,300	.00345	
37		0	.488				1 1/3
38	4	12	.267	100½	82,400	.00364	
39		0	.486 +				1 2/3
40	5	0	.251	101½	86,700	.00386	
41		0	.483				3 1/3
42	5	4	.238	102	90,800	.00405	
43		0	.480 +				2 2/3
44	5	8	.223	102½	95,200	.00426	

4-IT

No.	Load lb. oz.		Dial in.		Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
45		0	.477	-				3 2/3
46	5	12	.203		103½	99,500	.00454	
47		0	.472	-				5
48	6	0	.179		104½	104,100	.00487	
49		0	.465	-				7
50	6	4	.159		105	108,700	.00514	
51		0	.458					6 2/3
52	6	8	.139		106	113,500	.00541	
53		0	.452	-				6 1/3
54	6	12	.115		107½	118,700	.00572	
55		0	.444					7 2/3
56	7	0	.092		108	123,300	.00606	
57		0	.434					10
58	7	4	.059		110	129,300	.00634	
59		0	.422					12
60	7	8	.021		111	135,300	.00698	
61		0	.405	+	93½	7,700	.00164	16 2/3

THERMOMETAL .030 # 233

tension in invar
width = .402"
zero load = 8 oz.
thickness = .030"

1 hr. at 650 deg. F.
3 hr. at 600 deg. F.
Curvature ± .0044

gage length = 1 3/4"
center on invar side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.503	92	14,500	.00068	0
2		2	.492−	92½	18,200	.00084	
3		0	.503				0
4		4	.480	93	21,800	.00101	
5		0	.503−				1/3
6		6	.468+	93½	25,400	.00119	
7		0	.503−				0
8		8	.457	94	29,100	.00135	
9		0	.503−				0
10		10	.446	94½	32,800	.00152	
11		0	.503−				0
12		12	.434	95	36,500	.00169	
13		0	.502+				1/3
14		14	.423+	95½	40,100	.00185	
15		0	.502+				0
16	1	0	.411	96	43,800	.00202	
17		0	.502−				2/3
18	1	2	.400−	96½	47,600	.00219	
19		0	.502−				0
20	1	4	.388	97½	51,300	.00236	
21		0	.501+				1/3
22	1	6	.377−	98	55,000	.00252	
23		0	.501−				2/3
24	1	8	.364	98½	58,800	.00270	
25		0	.500				2/3
26	1	10	.352+	99	62,600	.00287	
27		0	.499				1
28	1	12	.338+	99½	66,400	.00308	
29		0	.498				1
30	1	14	.325	100½	70,400	.00326	
31		0	.497−				1 1/3
32	2	0	.312	101	74,200	.00345	
33		0	.495−				2
34	2	2	.297	101½	78,200	.00366	
35		0	.493				1 2/3
36	2	4	.283−	102½	82,200	.00386	
37		0	.491−				2 1/3
38	2	6	.268−	103	86,200	.00407	
39		0	.488				2 2/3
40	2	8	.251+	103½	90,300	.00431	
41		0	.484+				3 2/3
42	2	10	.234	104½	94,500	.00454	
43		0	.481−				3 2/3
44	2	12	.215−	105	98,700	.00481	
45		0	.476	93	14,500	.00107	4 2/3

THERMOMETAL .030 # 2B4

tension in steel
width = .397"
zero load = 8 oz.
thickness = .0295"

1 hr. at 600 deg. F.
3 hr. at 600 deg. F.
Curvature = .0009

gage length = 1$\frac{3}{4}$"
center on invar side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.502	98	15,200	.00066	0
2		2	.491−	98$\frac{1}{2}$	19,000	.00083	
3		0	.502				0
4		4	.479	99	22,800	.00100	
5		0	.502−				1/3
6		6	.468−	99$\frac{1}{2}$	26,600	.00116	
7		0	.502−				0
8		8	.456+	100	30,500	.00132	
9		0	.502−				0
10		10	.445	100$\frac{1}{2}$	34,300	.00149	
11		0	.501+				1/3
12		12	.433	101$\frac{1}{2}$	38,200	.00166	
13		0	.501+				0
14		14	.421+	102	42,100	.00183	
15		0	.501+				0
16	1	0	.409	102$\frac{1}{2}$	46,000	.00200	
17		0	.501				1/3
18	1	2	.397+	103	49,900	.00217	
19		0	.501				0
20	1	4	.386	103$\frac{1}{2}$	53,800	.00233	
21		0	.501				0
22	1	6	.375−	104	57,800	.00249	
23		0	.501				0
24	1	8	.363	104$\frac{1}{2}$	61,700	.00266	
25		0	.501−				1/3
26	1	10	.351+	105	65,700	.00283	
27		0	.501−				0
28	1	12	.338	105$\frac{1}{2}$	69,700	.00301	
29		0	.501−				0
30	1	14	.326+	106	73,700	.00317	
31		0	.501−				0
32	2	0	.314	106$\frac{1}{2}$	77,800	.00334	
33		0	.500+				1/3
34	2	2	.301+	107$\frac{1}{2}$	82,000	.00353	
35		0	.500				1/3
36	2	4	.288	108	86,200	.00371	
37		0	.500−				1/3
38	2	6	.275+	109	90,500	.00388	
39		0	.500−				0
40	2	8	.261+	109$\frac{1}{2}$	94,600	.00407	
41		0	.499				2/3
42	2	10	.248+	110	98,800	.00424	
43		0	.499−				1/3
44	2	12	.234	110$\frac{1}{2}$	103,100	.00444	

2B4

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
45		0	.498				2/3
46	2	14	.220 +	111	107,300	.00463	
47		0	.498 −				1/3
48	3	0	.206	112	112,300	.00482	
49		0	.497 −				1
50	3	2	.190 −	112½	116,700	.00504	
51		0	.495 +				1 1/3
52	3	4	.174 +	113½	121,200	.00524	
53		0	.494				1 1/3
54	3	6	.158 −	114	126,000	.00546	
55		0	.492 −				2 1/3
56	3	8	.141 −	114½	130,800	.00568	
57		0	.489 −				3
58	3	10	.117	115½	136,000	.00600	
59		0	.484				4 2/3
60	3	12	.092	116½	141,300	.00631	
61		0	.477	100*	15,200	.00102	7

*Estimated after test.

THERMOMETAL .030 # 2F1

tension in invar
width = .406"
zero load = 8 oz.
thickness = .0295"

1 hr. at 650 deg. F.
504 hr. at 600 deg. F.
Curvature = .0120

gage length = 1 3/4"
center on invar side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.502	90½	14,800	.00065	0
2		2	.491	91	18,600	.00081	
3		0	.502				0
4		4	.479+	91½	22,300	.00098	
5		0	.502				0
6		6	.468+	92	26,000	.00114	
7		0	.502				0
8		8	.457-	92½	29,800	.00130	
9		0	.502				0
10		10	.445+	93	33,500	.00147	
11		0	.502				0
12		12	.434-	93½	37,300	.00163	
13		0	.502-				1/3
14		14	.422+	94	41,000	.00180	
15		0	.502-				0
16	1	0	.409-	94½	44,800	.00199	
17		0	.501+				1/3
18	1	2	.398+	95	48,600	.00215	
19		0	.501				1/3
20	1	4	.387	95½	52,400	.00231	
21		0	.500+				2/3
22	1	6	.375	96	56,200	.00248	
23		0	.500				1/3
24	1	8	.363	96½	60,000	.00265	
25		0	.499+				2/3
26	1	10	.351-	97½	64,000	.00282	
27		0	.499-				2/3
28	1	12	.338-	98	67,800	.00300	
29		0	.498				2/3
30	1	14	.326	98½	71,800	.00317	
31		0	.497-				1 1/3
32	2	0	.312	99	75,700	.00337	
33		0	.495				1 2/3
34	2	2	.298-	99½	79,600	.00356	
35		0	.493				2
36	2	4	.283	100½	83,700	.00377	
37		0	.491-				2 1/3
38	2	6	.268	101	87,900	.00398	
39		0	.488+				2 1/3
40	2	8	.251	101½	92,000	.00422	
41		0	.485				3 1/3
42	2	10	.235+	102½	96,300	.00443	
43		0	.482-				3 1/3
44	2	12	.217	103½	100,500	.00468	
45		0	.477+				4 1/3
46	2	14	.198-	104	104,900	.00494	
47		0	.472				5 1/3
48	3	0	.176+	104½	109,200	.00523	
49		0	.466-	92*	14,900	.00117	6 1/3

*Estimated after test

THERMOMETAL .030 # 2F4

tension in invar
width = .395"
zero load = 8 oz.
thickness = .0295"

1 hr. at 650 deg. F.
504 hr. at 600 deg. F.
Curvature = .0084

gage length = 1 3/4"
center on invar side

No.	Load lb.	oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.500	91	15,300	.00068	0
2		2	.489−	91½	19,100	.00084	
3		0	.500−				1/3
4		4	.477−	92	23,000	.00101	
5		0	.500−				0
6		6	.465	92½	26,800	.00119	
7		0	.500−				0
8		8	.453+	93	30,600	.00136	
9		0	.500−				0
10		10	.442	93½	34,500	.00151	
11		0	.499+				1/3
12		12	.430+	94½	38,400	.00168	
13		0	.499+				0
14		14	.419	95	42,300	.00184	
15		0	.499+				0
16	1	0	.406+	95½	46,200	.00203	
17		0	.499+				0
18	1	2	.394+	96	50,200	.00219	
19		0	.499+				0
20	1	4	.383	96½	54,200	.00236	
21		0	.499+				0
22	1	6	.370+	97	58,200	.00253	
23		0	.499+				0
24	1	8	.358+	97½	62,100	.00271	
25		0	.499				1/3
26	1	10	.346+	98	66,200	.00288	
27		0	.499				0
28	1	12	.333	99	70,400	.00306	
29		0	.499				0
30	1	14	.321−	99½	74,400	.00323	
31		0	.499−				1/3
32	2	0	.307	100	78,500	.00342	
33		0	.499−				0
34	2	2	.295−	100½	82,600	.00359	
35		0	.499−				0
36	2	4	.283	101	86,900	.00375	
37		0	.499−				0
38	2	6	.270	101½	91,100	.00393	
39		0	.498+				1/3
40	2	8	.255−	102½	95,600	.00414	
41		0	.498				1/3
42	2	10	.241	103	99,900	.00432	
43		0	.498				0
44	2	12	.229−	104	104,300	.00450	

2F4

No.	Load lb.	oz.	Dial in.	Ang A deg.	Stress 3/sq.in.	Strain in./in.	Set .001"
45		0	.498 −				1/3
46	2	14	.215 +	104½	108,700	.00467	
47		0	.497 +				1/3
48	3	0	.200 +	105	113,200	.00487	
49		0	.497 −				2/3
50	3	2	.185 +	105½	117,900	.00507	
51		0	.495 +				1 1/3
52	3	4	.169 +	106	122,400	.00528	
53		0	.494				1 1/3
54	3	6	.154 −	107	127,300	.00548	
55		0	.493 −				1 1/3
56	3	8	.137 −	108	132,500	.00571	
57		0	.490				2 2/3
58	3	10	.111	109	137,900	.00605	
59		0	.485				5
60	3	12	.082 −	110	143,600	.00641	
61		0	.476 +	92	15,300	.00102	8 2/3

THERMOMETAL .030 # 3B2

tension in steel
width = 0.394"
zero load = 8 oz.
thickness = .0305"

1 hr. at 650 deg. F.
3 hr. at 600 deg. F.
Curvature = .0018

gage length = 1 3/4"
center on inner side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.500	94½	14,300	.00063	0
2		2	.490-	95	17,900	.00078	
3		0	.500				0
4		4	.479	95½	21,500	.00094	
5		0	.500				0
6		6	.468+	96	25,100	.00110	
7		0	.500				0
8		8	.458-	96½	28,700	.00126	
9		0	.500				0
10		10	.447	97	32,300	.00142	
11		0	.500-				1/3
12		12	.436-	97½	36,000	.00158	
13		0	.500-				0
14		14	.425-	98	39,600	.00175	
15		0	.499+				1/3
16	1	0	.413	98½	43,200	.00193	
17		0	.499+				0
18	1	2	.402+	99	46,900	.00208	
19		0	.499+				0
20	1	4	.390+	99½	50,600	.00225	
21		0	.499				1/3
22	1	6	.380-	100	54,300	.00242	
23		0	.499				0
24	1	8	.368+	100½	58,000	.00258	
25		0	.499-				1/3
26	1	10	.357	101	61,700	.00275	
27		0	.498+				1/3
28	1	12	.345+	101½	65,500	.00292	
29		0	.498+				0
30	1	14	.334-	102½	69,400	.00308	
31		0	.498+				0
32	2	0	.321	103	73,200	.00327	
33		0	.498				1/3
34	2	2	.309+	103½	77,100	.00344	
35		0	.498-				1/3
36	2	4	.297	104	80,900	.00362	
37		0	.497+				1/3
38	2	6	.285	104½	84,800	.00379	
39		0	.497-				2/3
40	2	8	.272-	105	88,700	.00398	
41		0	.496+				1/3
42	2	10	.259+	105½	92,800	.00416	
43		0	.495+				1
44	2	12	.244+	106½	96,900	.00437	

3B2

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
45		0	.494				1 1/3
46	2	14	.231	107	100,900	.00456	
47		0	.492				2
48	3	0	.215+	108	105,200	.00478	
49		0	.490−				2 1/3
50	3	2	.197−	108½	109,400	.00503	
51		0	.486				3 2/3
52	3	4	.178−	109	113,800	.00530	
53		0	.481				5
54	3	6	.158	110	118,300	.00556	
55		0	.476−	96*	14,400	.00099	5 1/3

* Estimated after test

THERMOMETAL .030 # 3B4

tension in invar
width = .416"
zero load = 8 oz.
thickness = .031"

1 hr. at 650 deg. F.
3 hr. at 600 deg. F.
Curvature = .0040

gage length = 1¾"
center on steel side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.502	92½	13,100	.00061	0
2		2	.492	93	16,400	.00076	
3		0	.502				0
4		4	.482 −	93½	19,700	.00091	
5		0	.502 −				1/3
6		6	.472	94	23,000	.00106	
7		0	.502 −				0
8		8	.462 −	94½	26,300	.00122	
9		0	.502 −				0
10		10	.452 −	95	29,600	.00137	
11		0	.501 +				1/3
12		12	.441 +	95½	33,000	.00153	
13		0	.501 +				0
14		14	.431 +	96	36,300	.00168	
15		0	.501				1/3
16	1	0	.421	96½	39,600	.00183	
17		0	.501				0
18	1	2	.411	97	43,000	.00198	
19		0	.501 −				1/3
20	1	4	.400	97½	46,400	.00214	
21		0	.500 +				1/3
22	1	6	.390	98	49,800	.00230	
23		0	.500				1/3
24	1	8	.379 +	98½	53,200	.00246	
25		0	.500 −				1/3
26	1	10	.369	99	56,600	.00261	
27		0	.499 +				1/3
28	1	12	.358 −	99½	60,000	.00278	
29		0	.499 −				2/3
30	1	14	.346	100	63,500	.00295	
31		0	.498 +				1/3
32	2	0	.334	100½	67,100	.00313	
33		0	.498 −				2/3
34	2	2	.323	101	70,500	.00330	
35		0	.496 +				1 1/3
36	2	4	.310	101½	74,000	.00348	
37		0	.495				1 1/3
38	2	6	.298	102½	77,700	.00366	
39		0	.494				1
40	2	8	.285 +	103	81,400	.00384	
41		0	.492				2
42	2	10	.272 +	103½	85,100	.00403	
43		0	.490 −				2 1/3
44	2	12	.259 −	104	88,700	.00423	

3B4

No.	Load lb.	oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
45		0	.488 -				2
46	2	14	.244	104½	92,400	.00444	
47		0	.485 -				3
48	3	0	.229	105	96,200	.00466	
49		0	.481 +				3 1/3
50	3	2	.213	105½	100,000	.00490	
51		0	.477+				4
52	3	4	.196	106½	104,000	.00512	
53		0	.472	94	13,200	.00106	5 1/3

THERMOMETAL .030 # 3F3

tension in steel
width = 0.409"
zero load = 8 oz.
thickness = .031"

1 hr. at 650 deg. F.
504 hr. at 600 deg. F. gage length = 1 3/4"
Curvature = .0013 center on invar side

No.	Load lb.	oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.503	89½	13,300	.00061	0
2		2	.493+	90	16,700	.00076	
3		0	.503				0
4		4	.483−	90½	20,100	.00091	
5		0	.503				0
6		6	.473	91	23,400	.00106	
7		0	.503−				1/3
8		8	.463	91½	26,800	.00121	
9		0	.503−				0
10		10	.453	92	30,200	.00136	
11		0	.502+				1/3
12		12	.443−	92½	33,600	.00152	
13		0	.502+				0
14		14	.433−	93	36,900	.00167	
15		0	.502+				0
16	1	0	.422	93½	40,300	.00183	
17		0	.502+				0
18	1	2	.412	94	43,700	.00198	
19		0	.502+				0
20	1	4	.401	94½	47,200	.00214	
21		0	.502+				0
22	1	6	.391	95	50,600	.00229	
23		0	.502				1/3
24	1	8	.380+	95½	54,000	.00246	
25		0	.502				0
26	1	10	.370+	96	57,500	.00261	
27		0	.502				0
28	1	12	.360−	96½	61,000	.00276	
29		0	.502−				1/3
30	1	14	.349+	97	64,500	.00292	
31		0	.502−				0
32	2	0	.339−	97½	68,100	.00308	
33		0	.501+				1/3
34	2	2	.328−	98	71,600	.00324	
35		0	.501+				0
36	2	4	.317−	98½	75,200	.00340	
37		0	.501+				0
38	2	6	.306+	99	78,800	.00356	
39		0	.501				1/3
40	2	8	.295+	99½	82,400	.00372	
41		0	.501−				1/3
42	2	10	.285−	100	86,000	.00387	
43		0	.501−				0
44	2	12	.274−	102½	89,700	.00403	

3F3

No.	Load lb. oz.		Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
45		0	.500 +				1/3
46	2	14	.265	101	93,500	.00419	
47		0	.500 −				2/3
48	3	0	.251 +	101½	97,200	.00436	
49		0	.499				2/3
50	3	2	.239	102	101,000	.00453	
51		0	.498 +				2/3
52	3	4	.227 −	102½	104,800	.00471	
53		0	.497				1 1/3
54	3	6	.216 −	103	108,600	.00487	
55		0	.495 +				1 2/3
56	3	8	.202 −	103½	112,500	.00505	
57		0	.494 −				1 2/3
58	3	10	.187 +	104	116,400	.00526	
59		0	.491				2 2/3
60	3	12	.171	104½	120,700	.00549	
61		0	.487				4
62	3	14	.153	105½	125,000	.00573	
63		0	.482				5
64	4	0	.133	106½	129,500	.00601	
65		0	.475	91*	13,400	.00113	7

* Estimated after test.

THERMOMETAL .030 # 3F4

tension in invar
width = .401"
zero load = 8 oz.
thickness = .0305"

1 hr. at 650 deg. F.
504 hr. at 600 deg. F.
Curvature = .0049

gage length = 1 3/4"
center on invar side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.502	96½	14,100	.00064	0
2		2	.492-	97	17,600	.00079	
3		0	.502				0
4		4	.481-	97½	21,100	.00096	
5		0	.502-				1/3
6		6	.470	98	24,600	.00112	
7		0	.502-				0
8		8	.459	98½	28,200	.00129	
9		0	.501+				1/3
10		10	.448+	99	31,800	.00145	
11		0	.501				1/3
12		12	.437	99½	35,300	.00161	
13		0	.501-				1/3
14		14	.427-	100	38,900	.00177	
15		0	.501-				0
16	1	0	.416-	100½	42,400	.00193	
17		0	.501-				0
18	1	2	.405+	101	46,100	.00209	
19		0	.500+				1/3
20	1	4	.394	101½	49,600	.00225	
21		0	.500				1/3
22	1	6	.383-	102	53,300	.00242	
23		0	.500-				1/3
24	1	8	.372	102½	56,900	.00258	
25		0	.499+				1/3
26	1	10	.361	103½	60,700	.00274	
27		0	.499				1/3
28	1	12	.349+	104	64,300	.00290	
29		0	.498+				2/3
30	1	14	.337	104½	68,100	.00309	
31		0	.498				2/3
32	2	0	.325+	105	71,800	.00326	
33		0	.497-				1
34	2	2	.313	105½	75,500	.00344	
35		0	.496-				1
36	2	4	.299+	106	79,300	.00363	
37		0	.494+				1 1/3
38	2	6	.286	106½	83,100	.00382	
39		0	.492+				2
40	2	8	.272	107	86,900	.00402	
41		0	.490+				2
42	2	10	.257	108	91,000	.00423	
43		0	.487+				3
44	2	12	.243-	108½	94,800	.00443	
45		0	.485-				2 2/3
46	2	14	.228	109	98,800	.00465	
47		0	.481				3 2/3
48	3	0	.210	110	103,200	.00490	
49		0	.476	98	14,100	.00103	5

THERMOMETAL .030 — # 4B1

tension in invar
width = .3875"
zero load = 8 oz.
thickness = .030"

1 hr. at 650 deg. F.
3 hr. at 600 deg. F.
Curvature = .0089

gage length = $1\frac{3}{4}$"
center on invar side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.504	92	15,000	.00069	0
2		2	.493-	92½	18,800	.00086	
3		0	.504				0
4		4	.480+	93	22,600	.00104	
5		0	.504				0
6		6	.469-	93½	26,400	.00121	
7		0	.504				0
8		8	.457	94½	30,200	.00138	
9		0	.504-				1/3
10		10	.445	95	34,000	.00156	
11		0	.504-				0
12		12	.433	95½	37,800	.00173	
13		0	.504-				0
14		14	.422-	96	41,600	.00190	
15		0	.503+				1/3
16	1	0	.409	96½	45,400	.00208	
17		0	.503+				0
18	1	2	.397-	97	49,300	.00226	
19		0	.503				1/3
20	1	4	.384-	98	53,200	.00244	
21		0	.502+				2/3
22	1	6	.372	98½	57,000	.00262	
23		0	.502				1/3
24	1	8	.358+	99	61,000	.00282	
25		0	.501-				1 1/3
26	1	10	.345-	99½	64,900	.00301	
27		0	.499+				1 1/3
28	1	12	.330+	100	68,900	.00322	
29		0	.498-				1 2/3
30	1	14	.316+	101	72,900	.00342	
31		0	.496				1 2/3
32	2	0	.300-	101½	77,000	.00365	
33		0	.493+				2 2/3
34	2	2	.285-	102½	81,200	.00387	
35		0	.490+				3
36	2	4	.269	103	85,400	.00409	
37		0	.487				3 1/3
38	2	6	.251	104	89,700	.00434	
39		0	.483				4
40	2	8	.229	105	94,100	.00465	
41		0	.477				6
42	2	10	.209	106	98,600	.00492	
43		0	.472	93½	15,100	.00116	5

THERMOMETAL .030 # 4B3

tension in steel
width = .397"
zero load = 8 oz.
thickness = .030"

1 hr. at 650 deg. F.
3 hr. at 600 deg. F.
Curvature = .0022

gage length = 1 3/4"
center on invar side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.504	95	14,700	.00066	0
2		2	.493	95½	18,400	.00082	
3		0	.504				0
4		4	.481+	96	22,100	.00100	
5		0	.504−				1/3
6		6	.470+	96½	25,800	.00116	
7		0	.504−				0
8		8	.459	97	29,500	.00132	
9		0	.503+				1/3
10		10	.448	98	33,200	.00148	
11		0	.503+				0
12		12	.437−	98½	36,900	.00164	
13		0	.503+				0
14		14	.426−	99	40,700	.00180	
15		0	.503				1/3
16	1	0	.414	99½	44,400	.00197	
17		0	.503				0
18	1	2	.403	100	48,200	.00214	
19		0	.503				0
20	1	4	.391−	100½	52,000	.00231	
21		0	.503−				1/3
22	1	6	.380	101	55,700	.00247	
23		0	.503−				0
24	1	8	.369−	101½	59,600	.00264	
25		0	.502+				1/3
26	1	10	.357	102	63,400	.00280	
27		0	.502+				0
28	1	12	.345−	102½	67,300	.00298	
29		0	.502				1/3
30	1	14	.333	103	71,200	.00314	
31		0	.502				0
32	2	0	.321	103½	75,200	.00331	
33		0	.502				0
34	2	2	.309−	104½	79,200	.00349	
35		0	.502−				1/3
36	2	4	.295+	105	83,200	.00368	
37		0	.502−				0
38	2	6	.283+	105½	87,200	.00385	
39		0	.501+				1/3
40	2	8	.269−	106	91,200	.00405	
41		0	.501−				2/3
42	2	10	.257	106½	95,400	.00422	
43		0	.500+				1/3
44	2	12	.244+	107	99,500	.00441	

4B3

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
45		0	.500				1/3
46	2	14	.231−	108	103,700	.00458	
47		0	.499+				2/3
48	3	0	.217	108½	107,900	.00476	
49		0	.499−				2/3
50	3	2	.201	109	112,200	.00498	
51		0	.498				2/3
52	3	4	.189	109½	116,700	.00515	
53		0	.497+				2/3
54	3	6	.175−	110	120,800	.00534	
55		0	.496				1 1/3
56	3	8	.160+	111	125,700	.00554	
57		0	.495+				1 1/3
58	3	10	.141	112	130,500	.00579	
59		0	.492				2 2/3
60	3	12	.120	113	135,600	.00606	
61		0	.488				4
62	3	14	.097−	114	140,800	.00636	
63		0	.483−				5 1/3
64	4	0	.070	115	146,200	.00673	
65		0	.475	97*	14,700	.00108	7 2/3

* Estimated after test.

THERMOMETAL .030 # 4F2

tension in invar
width = .386"
zero load = 8 oz.
thickness-0.030"

1 hr. at 650 deg. F.
504 hr. at 600 deg. F.
Curvature = .0093

gage length = 1 3/4"
center on invar side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.502	96	15,100	.00069	0
2		2	.490+	96½	18,900	.00087	
3		0	.502				0
4		4	.479−	97	22,700	.00103	
5		0	.502				0
6		6	.467−	97½	26,500	.00121	
7		0	.502				0
8		8	.455−	98	30,300	.00138	
9		0	.502−				1/3
10		10	.443	99	34,100	.00156	
11		0	.502−				0
12		12	.431−	99½	37,900	.00173	
13		0	.501+				1/3
14		14	.419	100	41,700	.00190	
15		0	.501+				0
16	1	0	.406+	100½	45,600	.00209	
17		0	.501+				0
18	1	2	.394+	101	49,500	.00227	
19		0	.501				1/3
20	1	4	.382−	102	53,400	.00245	
21		0	.501−				1/3
22	1	6	.375	102½	57,200	.00262	
23		0	.500				2/3
24	1	8	.355−	103	61,200	.00282	
25		0	.499+				2/3
26	1	10	.342+	103½	65,200	.00302	
27		0	.499−				2/3
28	1	12	.329−	104	69,200	.00321	
29		0	.497+				1 1/3
30	1	14	.315−	105	73,200	.00341	
31		0	.496−				1 2/3
32	2	0	.299+	105½	77,400	.00363	
33		0	.494−				2
34	2	2	.283+	106½	81,500	.00386	
35		0	.491−				3
36	2	4	.266	107	85,700	.00411	
37		0	.487+				3 1/3
38	2	6	.248+	108	90,000	.00435	
39		0	.483+				4
40	2	8	.230	108½	94,300	.00460	
41		0	.478+				5
42	2	10	.215	109½	98,800	.00489	
43		0	.473				5 1/3
44	2	12	.189	110½	103,200	.00517	
45		0	.467	97½	15,100	.00120	6

tension in steel | THERMOMETAL .030 | # 4F3
width = 0.389" | 1 hr. at 650°F |
zero load = 8 oz. | 504 hr. at 600°F | gage length = $1\frac{3}{4}$"
thickness = .030" | Curvature = .0062 | center on invar side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.503	92½	15,000	.00068	0
2		2	.492	93	18,700	.00084	
3		0	.503				0
4		4	.480	93½	22,500	.00101	
5		0	.503				0
6		6	.469	94	26,300	.00118	
7		0	.503-				1/3
8		8	.457+	94½	30,100	.00135	
9		0	.503-				0
10		10	.447-	95	33,900	.00150	
11		0	.503-				0
12		12	.434	95½	37,600	.00168	
13		0	.502+				1/3
14		14	.422	96	41,500	.00186	
15		0	.502				0
16	1	0	.409	96½	45,400	.00205	
17		0	.502				1/3
18	1	2	.397	97	48,200	.00222	
19		0	.502				0
20	1	4	.385+	97½	53,100	.00240	
21		0	.502				0
22	1	6	.373+	98	56,900	.00257	
23		0	.502				0
24	1	8	.361+	98½	60,900	.00274	
25		0	.502				0
26	1	10	.349	99	64,800	.00292	
27		0	.502				1/3
28	1	12	.335+	100	68,800	.00311	
29		0	.501-				1/3
30	1	14	.324-	100½	72,800	.00327	
31		0	.501+				0
32	2	0	.310	101	76,900	.00347	
33		0	.501				1/3
34	2	2	.297-	101½	81,000	.00365	
35		0	.501-				1/3
36	2	4	.284	102	85,000	.00384	
37		0	.500+				1/3
38	2	6	.270+	103	89,200	.00403	
39		0	.500+				0
40	2	8	.257	103½	93,400	.00421	
41		0	.500				1/3
42	2	10	.244-	104	97,500	.00439	
43		0	.500-				1/3
44	2	12	.231	104½	101,800	.00458	
45		0	.499+				1/3
46	2	14	.218	105	106,100	.00475	
47		0	.499-				2/3
48	3	0	.204-	106	110,600	.00495	
49		0	.498				2/3
50	3	2	.188	106½	115,200	.00516	

4F3

No.	Load lb.	oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
51		0	.497				1
52	3	4	.175-	107	119,700	.00537	
53		0	.496-				1 1/3
54	3	6	.155	108	124,400	.00561	
55		0	.494-				2
56	3	8	.138+	109	129,300	.00584	
57		0	.491+				2 1/3
58	3	10	.119-	109½	134,200	.00608	
59		0	.488-				3 2/3
60	3	12	.090-	111	140,000	.00645	
61		0	.481-				7
62	3	14	.060-	112	145,600	.00685	
63		0	.472-	93+	15,000	.00109	9
64	4	0	.028-	113½	152,000	.00726	
65		0	.460	93½	15,000	.00131	11 2/3

THERMOMETAL .030 # 1-HA

tension in steel
width = .369"
zero load = 8 oz.
thickness = .0305"

1 hr. at 650° F.
Curvature = .0009

gage length = 1 3/4"
center on invar side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.502	95 1/2	15,300	.00072	0
2		2	.490 +	96	19,100	.00090	
3		0	.502				0
4		4	.478 -	96 1/2	23,000	.00108	
5		0	.502				0
6		6	.466 -	97	26,800	.00126	
7		0	.502				0
8		8	.454 -	97 1/2	30,700	.00144	
9		0	.502				0
10		10	.442	98	34,500	.00161	
11		0	.502 -				1/3
12		12	.429	98 1/2	38,400	.00180	
13		0	.501 +				1/3
14		14	.418 -	99	42,300	.00197	
15		0	.501 +				0
16	1	0	.405	100	46,200	.00216	
17		0	.501 +				0
18	1	2	.393	100 1/2	50,200	.00234	
19		0	.501 +				0
20	1	4	.381	101	54,100	.00252	
21		0	.501 +				0
22	1	6	.369	101 1/2	58,100	.00269	
23		0	.501 +				0
24	1	8	.356 +	102	62,100	.00287	
25		0	.501 +				0
26	1	10	.344	103	66,200	.00305	
27		0	.501				1/3
28	1	12	.331 -	103 1/2	70,300	.00325	
29		0	.501 -				1/3
30	1	14	.318 +	104	74,400	.00343	
31		0	.501 +				0
32	2	0	.305 -	104 1/2	78,500	.00362	
33		0	.501 -				0
34	2	2	.292 -	105	82,600	.00381	
35		0	.500 +				1/3
36	2	4	.277	106	87,000	.00402	
37		0	.500 +				0
38	2	6	.264	106 1/2	91,200	.00421	
39		0	.500 +				1/3
40	2	8	,249	107	95,400	.00441	
41		0	.500				1/3
42	2	10	.236 -	107 1/2	99,700	.00461	
43		0	.500				0
44	2	12	.221	108 1/2	104,200	.00482	

1-HA

No.	Load lb. oz.		Dial in.		Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
45		0	.500	-				1/3
46	2	14	.206	-	109	108,700	.00503	
47		0	.500	-				0
48	3	0	.192		110	113,200	.00521	
49		0	.499	+				1/3
50	3	2	.178		110 1/2	117,800	.00541	
51		0	.499	-				2/3
52	3	4	.164		111	122,400	.00560	
53		0	.498	+				1/3
54	3	6	.144		112	127,300	.00586	
55		0	.497	+				1
56	3	8	.123		113	132,700	.00615	
57		0	.495					2 1/3
58	3	10	.099		114	137,900	.00640	
59		0	.491					4
60	3	12	.071		115	143,700	.00684	
61		0	.485	-	96*	15,300	.00097	6 1/3
62	3	14	.036		116	149,700	.00730	
63		0	.474		96 1/2	15,300	.00103	10 2/3

* Estimated after test.

THERMOMETAL .030 # 2-HA

tension in invar
thickness = .0305"
width = .370"
1 hr. at 650 deg. F.
gage length = $1\frac{3}{4}$"
zero load = 8 oz.
Curvature = .0009
center in invar side

No.	Load lb.	Load oz.	Dial in.		Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.502		$94\frac{1}{2}$	15,300	.00073	0
2		2	.490		95	19,100	.00091	
3		0	.502	–				1/3
4		4	.477	+	96	22,900	.00110	
5		0	.502	–				0
6		6	.465	+	$96\frac{1}{2}$	26,800	.00128	
7		0	.501	+				1/3
8		8	.453		97	30,600	.00146	
9		0	.501					1/3
10		10	.441		$97\frac{1}{2}$	34,500	.00164	
11		0	.501	–				1/3
12		12	.428		98	38,400	.00183	
13		0	.500	+				1/3
14		14	.416		$98\frac{1}{2}$	42,300	.00201	
15		0	.500					1/3
16	1	0	.403		99	46,200	.00220	
17		0	.499	+				2/3
18	1	2	.390	–	$99\frac{1}{2}$	50,100	.00240	
19		0	.498	+				1
20	1	4	.377	–	$100\frac{1}{2}$	54,100	.00259	
21		0	.497	+				1
22	1	6	.364		101	58,100	.00278	
23		0	.496					1 1/3
24	1	8	.349		102	62,100	.00300	
25		0	.494	+				1 2/3
26	1	10	.335	+	$102\frac{1}{2}$	66,100	.00319	
27		0	.493	–				1 2/3
28	1	12	.320		103	70,200	.00342	
29		0	.490					2 2/3
30	1	14	.305		$103\frac{1}{2}$	74,400	.00363	
31		0	.488	–				2 1/3
32	2	0	.289	–	104	78,500	.00387	
33		0	.484	+				3 1/3
34	2	2	.271	–	105	82,800	.00412	
35		0	.481	–				3 2/3
36	2	4	.253		106	87,200	.00438	
37		0	.477	–				4
38	2	6	.235		107	91,700	.00462	
39		0	.472	+				4 1/3
40	2	8	.218		$107\frac{1}{2}$	96,000	.00487	
41		0	.468		96	15,300	.00124	4 1/3

THERMOMETAL .030 # 1-HB

tension in steel
width = .363"
zero load = 8 oz.
thickness = .0310"

1 hr. at 650 deg. F.
Curvature = .0218

gage length = 1¾"
center on steel side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.498	93	15,000	.00073	0
2		2	.487	93½	18,800	.00090	
3		0	.498				0
4		4	.475 -	94	22,600	.00108	
5		0	.498				0
6		6	.463	94½	26,400	.00126	
7		0	.498				0
8		8	.451	95	30,100	.00144	
9		0	.498				0
10		10	.439	96	33,900	.00162	
11		0	.498				0
12		12	.427	96½	37,700	.00181	
13		0	.498 -				1/3
14		14	.415 +	97	41,500	.00198	
15		0	.498 -				0
16	1	0	.403 -	97½	45,300	.00217	
17		0	.498 -				0
18	1	2	.391	98	49,100	.00235	
19		0	.497 +				1/3
20	1	4	.379	98½	53,000	.00253	
21		0	.497 +				0
22	1	6	.367 +	99	56,900	.00271	
23		0	.497 +				0
24	1	8	.355 +	99½	60,700	.00289	
25		0	.497 +				0
26	1	10	.343 +	100	64,600	.00307	
27		0	.497				1/3
28	1	12	.331 -	101	68,600	.00325	
29		0	.497				0
30	1	14	.319	101½	72,600	.00343	
31		0	.497 -				1/3
32	2	0	.306	102	76,600	.00362	
33		0	.497 -				0
34	2	2	.294	102½	80,600	.00380	
35		0	.497 -				0
36	2	4	.281	103½	84,700	.00398	
37		0	.496 +				1/3
38	2	6	.268	104	88,800	.00417	
39		0	.496 +				0
40	2	8	.255 -	104½	92,900	.00437	
41		0	.496				1/3
42	2	10	.242	105	97,000	.00456	
43		0	.496				0
44	2	12	.228	105½	101,100	.00476	

1-HB

No.	Load lb.	oz.	Dial in.		Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
45		0	.496	–				1/3
46	2	14	.215		106	105,300	.00495	
47		0	.495	+				1/3
48	3	0	.203	–	107	109,700	.00511	
49		0	.494	+				1
50	3	2	.187		108	114,200	.00534	
51		0	.493	+				1
52	3	4	.170		108½	118,700	.00558	
53		0	.491	+				2
54	3	6	.155		109	123,200	.00580	
55		0	.489	–				2 2/3
56	3	8	.136		110	127,900	.00605	
57		0	.485					4
58	3	10	.111	–	111	133,000	.00640	
59		0	.478					6 2/3
60	3	12	.078		112	138,400	.00690	
61		0	.468	–	94	15,000	.00119	10 1/3

THERMOMETAL .030 # 2-HB

tension in invar
width = .368"
zero load = 8 oz.
thickness = .0310"

1 hr. at 650 deg. F.
Curvature = .0187

gage length = 1¾"
center on steel side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.498	97½	14,900	.00073	0
2		2	.487 –	98	18,600	.00090	
3		0	.498				0
4		4	.474 +	98½	22,400	.00109	
5		0	.498 –				1/3
6		6	.462 +	99	26,100	.00127	
7		0	.498 –				0
8		8	.450 +	99½	29,900	.00145	
9		0	.498 –				0
10		10	.439	100	33,700	.00162	
11		0	.497 +				1/3
12		12	.427	100½	37,500	.00180	
13		0	.497 +				0
14		14	.415	101	41,300	.00197	
15		0	.497				1/3
16	1	0	.403 –	101½	45,100	.00216	
17		0	.497				0
18	1	2	.390 +	102	49,000	.00235	
19		0	.497 –				1/3
20	1	4	.378 –	102½	52,800	.00254	
21		0	.496 +				1/3
22	1	6	.366	103½	56,800	.00271	
23		0	.496 –				2/3
24	1	8	.352 –	104	60,700	.00291	
25		0	.495				2/3
26	1	10	.339 –	104½	64,700	.00311	
27		0	.494				1
28	1	12	.325	105	68,700	.00332	
29		0	.493				1
30	1	14	.311	106	72,800	.00352	
31		0	.492				1
32	2	0	.295 +	106½	76,800	.00375	
33		0	.490				2
34	2	2	.281	107	80,900	.00398	
35		0	.488 +				1 2/3
36	2	4	.264	108	85,200	.00420	
37		0	.486				2 1/3
38	2	6	.249	108½	89,400	.00442	
39		0	.484 –				2 1/3
40	2	8	.230 –	109½	93,900	.00468	
41		0	.480 +				3 1/3
42	2	10	.210	110½	98,500	.00496	
43		0	.476 +				4
44	2	12	.187	111	103,100	.00535	
45		0	.471 –	98	14,900	.00104	5 2/3

THERMOMETAL .030 # 1-HC

tension in invar
width = .364"
zero load = 8 oz.
thickness = .0300"

1 hr. at 650 deg. F.
Curvature = .0080

gage length = 1¾"
center on steel side

No.	Load lb.	oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.502	94½	16,100	.00079	0
2		2	.489	95	20,100	.00098	
3		0	.502 -				1/3
4		4	.475	95½	24,100	.00119	
5		0	.501				2/3
6		6	.462 +	96½	28,200	.00138	
7		0	.501				0
8		8	.449 -	97	32,300	.00157	
9		0	.501 -				1/3
10		10	.435	97½	36,400	.00177	
11		0	.500 +				1/3
12		12	.422 -	98	40,500	.00196	
13		0	.500 +				0
14		14	.408	99	44,600	.00217	
15		0	.500				1/3
16	1	0	.394 -	99½	48,700	.00237	
17		0	.500 -				1/3
18	1	2	.381 -	100	52,900	.00256	
19		0	.500 -				0
20	1	4	.367	101	57,100	.00276	
21		0	.499 +				1/3
22	1	6	.353	101½	61,400	.00295	
23		0	.499 -				2/3
24	1	8	.338	102	65,600	.00317	
25		0	.498				2/3
26	1	10	.323	103	70,000	.00338	
27		0	.497				1
28	1	12	.307	103½	74,400	.00361	
29		0	.496 -				1 1/3
30	1	14	.290	104	78,700	.00385	
31		0	.494 +				1 2/3
32	2	0	.272 -	105	83,300	.00410	
33		0	.492				2 1/3
34	2	2	.254	106	88,100	.00435	
35		0	.489				3
36	2	4	.234	107	92,700	.00462	
37		0	.485 +				3 2/3
38	2	6	.214	108	97,600	.00489	
39		0	.481 +				4
40	2	8	.185	109	102,700	.00529	
41		0	.473	95½	16,100	.00122	8 1/3

THERMOMETAL .030 # 2-HC

tension in steel
width = .367"
zero load = 8 oz.
thickness = .0300"

1 hr. at 650° F.
Curvature = .0107

gage length = 1 3/4"
center on steel side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.502	93	15,900	.00075	0
2		2	.489 -	93 1/2	19,900	.00094	
3		0	.502 -				1/3
4		4	.476 -	94 1/2	23,900	.00113	
5		0	.501 +				1/3
6		6	.463 +	95	27,900	.00132	
7		0	.501 +				0
8		8	.451 -	95 1/2	31,900	.00150	
9		0	.501 +				0
10		10	.438 +	96 1/2	35,900	.00169	
11		0	.501 +				0
12		12	.425	97	40,000	.00188	
13		0	.501				1/3
14		14	.413	97 1/2	44,000	.00205	
15		0	.501				0
16	1	0	.399	98	48,100	.00225	
17		0	.501 -				1/3
18	1	2	.386 +	98 1/2	52,200	.00244	
19		0	.501 -				0
20	1	4	.373 +	99 1/2	56,300	.00263	
21		0	.500 +				1/3
22	1	6	.361	100	60,400	.00281	
23		0	.500 +				0
24	1	8	.347	100 1/2	64,600	.00300	
25		0	.500 -				2/3
26	1	10	.333 +	101	68,800	.00320	
27		0	.500 -				0
28	1	12	.319	102	73,100	.00341	
29		0	.499 +				1/3
30	1	14	.305 +	102 1/2	77,300	.00360	
31		0	.499 -				2/3
32	2	0	.290	103 1/2	81,700	.00382	
33		0	.498 +				1/3
34	2	2	.275 -	104	86,100	.00402	
35		0	.498 -				2/3
36	2	4	.260	104 1/2	90,500	.00423	
37		0	.497				2/3
38	2	6	.245 -	105 1/2	95,000	.00445	
39		0	.496				1
40	2	8	.228 -	106	99,500	.00469	
41		0	.494 +				1 2/3
42	2	10	.209	107	104,300	.00494	
43		0	.492				2 1/3
44	2	12	.189	108	109,200	.00521	

2-HC

No.	Load lb.	oz.	Dial in.	Ang. A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
45		0	.488+				3 2/3
46	2	14	.171+	108 1/2	113,900	.00546	
47		0	.485-				3 2/3
48	3	0	.150	109 1/2	119,000	.00574	
49		0	.479-				6
50	3	2	.124	110 1/2	124,300	.00609	
51		0	.471	94 1/2	15,900	.00120	7 2/3

THERMOMETAL .030 # 1-HD

tension in invar
width = .363"
zero load = 8 oz.
thickness = .0310"

1 hr. at 650° F.
Curvature = .0178

gage length = 1 3/4"
center on steel side

No.	Load lb.	oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.504	94	15,000	.00073	0
2		2	.492 +	94 1/2	18,900	.00091	
3		0	.504				0
4		4	.480	95	22,700	.00109	
5		0	.504				0
6		6	.468	95 1/2	26,500	.00127	
7		0	.503 +				2/3
8		8	.454	96	30,300	.00148	
9		0	.501 +				2
10		10	.439	96 1/2	34,100	.00171	
11		0	.499 -				2 2/3
12		12	.423 -	97 1/2	38,000	.00195	
13		0	.494 +				4 1/3
14		14	.404	98 1/2	42,000	.00223	
15		0	.487 +				7
16	1	0	.381	99 1/2	45,900	.00258	
17		0	.478				9
18	1	2	.351	100 1/2	50,000	.00302	
19		0	.461	95 1/2	15,100	.00138	17

THERMOMETAL .030 # 2-HD

tension in steel
width = .365"
zero load = 8 oz.
thickness = .0310"

1 hr. at 650° F.
Curvature = .0218

gage length = 1 3/4"
center on steel side

No.	Load lb.	Load oz.	Dial in.	Ang. A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.500	87 1/2	15,000	.00072	0
2		2	.489-	88	18,700	.00090	
3		0	.500				0
4		4	.477-	88 1/2	22,500	.00108	
5		0	.500				0
6		6	.465	89	26,200	.00126	
7		0	.500-				1/3
8		8	.453-	89 1/2	30,000	.00145	
9		0	.499+				1/3
10		10	.441	90	33,700	.00163	
11		0	.499+				0
12		12	.429-	90 1/2	37,500	.00181	
13		0	.499				1/3
14		14	.416-	91 1/2	41,300	.00201	
15		0	.498-				1 1/3
16	1	0	.400	92	45,100	.00225	
17		0	.494				3 2/3
18	1	2	.383	93	49,000	.00250	
19		0	.488+				5 2/3
20	1	4	.360	93 1/2	52,900	.00284	
21		0	.478				10 1/3
22	1	6	.334	94 1/2	56,800	.00324	
23		0	.464	89	15,000	.00128	14

LOW EXPANDING STEEL # 1-3D

tension in numbered side
width = .422"
zero load = 8 oz.
thickness = .0805"

1 hr. at 650 deg. F. gage length = $4\frac{1}{2}$"
Curvature = .0013 center on unnumbered side

No.	Load lb.	Load oz.	Dial in.	Ang A deg.	Stress #/sq.in.	Strain in./in.	Set .001"
1		0	.499	92½	4,900	.00027	0
2		4	.477-	93	7,400	.00041	
3		0	.499				0
4		8	.454	93½	9,900	.00054	
5		0	.499				0
6		12	.431	94	12,600	.00068	
7		0	.499-				1/3
8	1	0	.408	94½	14,800	.00082	
9		0	.499-				0
10	1	4	.385	95	17,300	.00095	
11		0	.498+				1/3
12	1	8	.363	95½	19,800	.00108	
13		0	.498+				0
14	1	12	.340+	96	22,300	.00122	
15		0	.498				1/3
16	2	0	.318	96	24,800	.00135	
17		0	.498				0
18	2	4	.296	96½	27,200	.00148	
19		0	.498-				1/3
20	2	6	.272	97	29,700	.00162	
21		0	.497-				1
22	2	12	.249	97½	32,300	.00176	
23		0	.495+				1 1/3
24	3	0	.226	98	34,800	.00190	
25		0	.493+				2
26	3	4	.201	98½	37,300	.00205	
27		0	.490+				3
28	3	8	.174	99	39,900	.00221	
29		0	.486-				4 2/3
30	3	12	.146	99½	42,500	.00237	
31		0	.479				6 2/3
32	4	0	.115	100	45,000	.00255	
33		0	.470-				7 1/3
34	4	4	.078	100½	47,600	.00276	
35		0	.456	93½	4,900	.00053	13 2/3

APPENDIX D

DIRECT TENSION DATA

#1 GE52

HIGHHEAT THERMOMETAL .030
width = .253"
thickness = .030"

Gage length = 3.94"
Final length = 5 13/64"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.	No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	16	1023	2,100	.0001	51	375	700	49,400	.0324
2	29	1022	3,800	.0002	52	383	650	50,500	.0374
3	46	1021	6,100	.0003	53	393	600	51,700	.0424
4	64	1020	7,400	.0004	54	401	550	52,800	.0474
5	79	1019	10,400	.0005	55	411	500	54,100	.0524
6	94	1018	12,400	.0006	56	421	450	55,400	.0574
7	109	1017	14,400	.0007	57	429	400	56,500	.0624
8	123	1016	16,200	.0008	58	436	350	57,500	.0674
9	137	1015	18,000	.0009	59	444	300	58,500	.0724
10	149	1014	19,600	.0010	60	451	250	59,400	.0774
11	163	1013	21,500	.0011	61	459	200	60,500	.0824
12	175	1012	23,100	.0012					
13	185	1011	24,400	.0013					
14	196	1010	25,800	.0014		575	failure	75,700	.32
15	205	1009	27,000	.0015					
16	214	1008	28,200	.0016					
17	222	1007	29,200	.0017					
18	230	1006	30,300	.0018					
19	243	1004	32,000	.0020					
20	253	1002	33,300	.0022					
21	263	999	34,600	.0025					
22	272	995	35,800	.0029					
23	282	990	37,100	.0034					
24	287	985	37,800	.0039					
25	293	980	38,600	.0044					
26	300	975	39,500	.0049					
27	302	970	39,700	.0054					
28	305	965	40,200	.0059					
29	310	960	40,800	.0064					
30	313	955	41,200	.0069					
31	314	950	41,300	.0074					
32	316	945	41,600	.0079					
33	319	940	42,000	.0084					
34	320	935	42,100	.0089					
35	322	930	42,400	.0094					
36	324	925	42,700	.0099					
37	326	920	42,900	.0104					
38	327	915	43,100	.0109					
39	328	910	43,200	.0114					
40	330	905	43,500	.0119					
41	332	900	43,700	.0124					
42	333	890	43,800	.0134					
43	337	880	44,300	.0144					
44	340	860	44,700	.0164					
45	345	840	45,400	.0184					
46	350	820	46,100	.0204					
47	356	800	46,900	.0224					
48	359	775	47,200	.0249					
49	364	750	47,900	.0274					
50	370	725	48,700	.0299					

#2 GE53

HIGHHEAT THERMOMETAL .030
width = .253"
thickness = .030"

Gage length = 3.94"
Final length = 4 13/64"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.	No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	19	1010	2,500	.0001	51	855	954	112,500	.0057
2	42	1009	5,500	.002	52	857	951	112,800	.0060
3	60	1008	7,900	.0003	53	866	948	114,000	.0063
4	80	1007	10,500	.0004	54	873	945	115,000	.0066
5	101	1006	13,300	.0005	55	876	941	115,300	.0070
6	123	1005	16,200	.0006	56	879	938	115,700	.0073
7	143	1004	18,800	.0007	57	884	935	116,200	.0076
8	165	1003	21,700	.0008	58	886	932	116,600	.0079
9	184	1002	24,200	.0009	59	886	929	116,600	.0082
10	203	1001	26,800	.0010	60	887	925	116,800	.0086
11	223	1000	29,400	.0011	61	889	920	117,000	.0091
12	241	999	31,800	.0012	62	889	915	117,000	.0096
13	259	998	34,100	.0013	63	889	910	117,000	.0101
14	281	997	37,000	.0014	64	890	900	117,100	.0111
15	303	996	39,900	.0015	65	890	850	117,100	.0161
16	322	995	42,400	.0016	66	890	800	117,100	.0211
17	341	994	44,900	.0017	67	890	750	117,100	.0261
18	361	993	47,500	.0018	68	890	700	117,100	.0311
19	379	992	49,900	.0019	69	890	400	117,100	.0611
20	396	991	52,200	.0020	70	829	300	109,000	.0711
21	415	990	54,600	.0021	71	Failure	280		.0731
22	434	989	57,100	.0022					
23	449	988	59,100	.0023					
24	469	987	61,800	.0024					
25	486	986	64,000	.0025					
26	517	985	68,100	.0026					
27	534	984	70,300	.0027					
28	550	983	72,500	.0028					
29	567	982	74,700	.0029					
30	585	981	77,100	.0030					
31	600	980	79,000	.0031					
32	616	979	81,100	.0032					
33	632	978	83,300	.0033					
34	647	977	85,200	.0034					
35	661	976	87,100	.0035					
36	677	975	89,200	.0036					
37	691	974	91,000	.0037					
38	704	973	92,700	.0038					
39	715	972	94,200	.0039					
40	728	971	96,000	.0040					
41	738	970	97,200	.0041					
42	750	969	98,800	.0042					
43	756	968	99,600	.0043					
44	760	967	100,100	.0044					
45	785	964	103,300	.0047					
46	790	962	104,000	.0049					
47	808	960	106,300	.0051					
48	795	960	104,700	.0051					
49	824	958	108,300	.0053					
50	842	956	110,900	.0055					

HIGHHEAT THERMOMETAL .030

#3 GE54 width = .253" Gage length = 3.94"
thickness = .030" Final length = 4 1/4"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.	No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	20	1018	2,600	.0001	51	777	650	102,300	.0369
2	42	1017	5,500	.0002	52	790	600	104,000	.0419
3	60	1016	7,900	.0003	53	797	550	105,000	.0469
4	76	1015	10,000	.0004	54	787	500	103,600	.0519
5	96	1014	12,600	.0005	55	800	450	105,300	.0569
6	113	1013	14,900	.0006	56	800	400	105,300	.0619
7	132	1012	17,400	.0007	57	800	300	105,300	.0719
8	152	1011	20,000	.0008	58	781	4 7/32	102,800	.071
9	169	1010	22,200	.0009	59	796	4 1/4	104,800	.079
10	188	1009	24,800	.0010	60	failure			.079
11	208	1008	27,400	.0011					
12	226	1007	29,800	.0012					
13	246	1006	32,400	.0013					
14	266	1005	35,100	.0014					
15	285	1004	37,500	.0015					
16	305	1003	40,200	.0016					
17	324	1002	42,700	.0017					
18	342	1001	45,000	.0018					
19	361	1000	47,500	.0019					
20	379	999	49,900	.0020					
21	397	998	52,300	.0021					
22	416	997	54,800	.0022					
23	433	996	57,100	.0023					
24	453	995	59,700	.0024					
25	471	994	62,000	.0025					
26	489	993	64,400	.0026					
27	523	991	68,900	.0028					
28	538	990	70,900	.0029					
29	551	989	72,500	.0030					
30	567	988	74,700	.0031					
31	579	987	76,200	.0032					
32	592	986	78,000	.0033					
33	604	985	79,600	.0034					
34	617	984	81,300	.0035					
35	628	983	82,800	.0036					
36	638	982	84,100	.0037					
37	658	980	86,700	.0039					
38	676	978	89,000	.0041					
39	689	976	90,700	.0043					
40	703	974	92,600	.0045					
41	714	971	94,000	.0048					
42	728	968	95,900	.0051					
43	738	964	97,300	.0055					
44	747	960	98,400	.0059					
45	757	955	99,700	.0064					
46	763	950	100,500	.0069					
47	773	935	101,800	.0084					
48	773	900	101,800	.0119					
49	773	850	101,800	.0169					
50	773	700	101,800	.0319					

HIGHHEAT THERMOMETAL

#4 GE55

width = .253"
thickness = .030"

Gage length = 3.94"
Final length = 4 1/16"

No.	Load Lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.	No.	Load Lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	23	1019	3,000	.0001	51	912	957	120,000	.0063
2	49	1018	6,500	.0002	52	921	954	121,200	.0066
3	67	1017	8,800	.0003	53	935	951	123,100	.0069
4	87	1016	10,400	.0004	54	941	948	123,900	.0072
5	105	1015	13,800	.0005	55	944	945	124,200	.0075
6	125	1014	16,500	.0006	56	950	940	125,100	.0080
7	143	1013	18,800	.0007	57	950	935	125,100	.0085
8	163	1012	21,500	.0008	58	951	930	125,200	.0090
9	181	1011	23,800	.0009	59	956	925	125,800	.0095
10	199	1010	26,200	.0010	60	960	920	126,300	.0100
11	220	1009	29,000	.0011	61	964	915	126,900	.0105
12	239	1008	31,500	.0012	62	966	910	127,200	.0110
13	258	1007	34,000	.0013	63	969	900	127,500	.0120
14	280	1006	36,900	.0014	64	795	897	104,700	.0123
15	300	1005	39,500	.0015	65	834	895	109,800	.0125
16	319	1004	42,000	.0016	66	866	893	114,000	.0127
17	339	1003	44,600	.0017	67	898	891	118,200	.0129
18	360	1002	47,400	.0018	68	927	889	122,000	.0131
19	378	1001	49,800	.0019	69	955	887	126,700	.0133
20	401	1000	52,800	.0020	70	968	885	127,300	.0135
21	421	999	55,400	.0021	71	968	883	127,300	.0137
22	440	998	57,900	.0022	72	973	880	128,100	.0140
23	457	997	60,200	.0023	73	976	874	128,500	.0146
24	478	996	63,000	.0024	74	982	870	129,300	.0150
25	496	995	65,400	.0025	75	982	850	129,300	.0170
26	516	994	68,000	.0026	76	982	800	129,300	.0220
27	532	993	70,000	.0027	77	982	750	129,300	.0270
28	550	992	72,500	.0028	78	982	700	129,300	.0320
29	568	991	74,900	.0029	79	982	650	129,300	.0370
30	584	990	76,900	.0030	80	982	600	129,300	.0420
31	598	989	78,800	.0031	81		570	Failure	.0450
32	617	988	81,300	.0032					
33	633	987	83,400	.0033					
34	649	986	85,500	.0034					
35	665	985	87,600	.0035					
36	679	984	89,500	.0036					
37	695	983	91,600	.0037					
38	711	982	93,600	.0038					
39	725	981	95,500	.0039					
40	736	980	97,000	.0040					
41	761	978	100,200	.0042					
42	780	976	102,700	.0044					
43	799	974	105,200	.0046					
44	825	972	108,600	.0048					
45	842	970	110,900	.0050					
46	840	968	110,700	.0052					
47	870	966	114,500	.0054					
48	887	964	116,800	.0056					
49	899	962	118,300	.0058					
50	912	960	120,000	.0060					

#H-A1

HIGHHEAT THERMOMETAL
width = .501"
thickness = .030"

Gage length = 3.94"
Final length =

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.	No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	57	993	3,800	.0001	51	1768	925	117,600	.0069
2	100	992	6,600	.0002	52	1785	920	118,700	.0074
3	138	991	9,200	.0003	53	1797	915	119,500	.0079
4	175	990	11,600	.0004	54	1798	910	119,600	.0084
5	211	989	14,000	.0005	55	1810	905	120,400	.0089
6	250	988	16,600	.0006	56	1821	899	121,200	.0095
7	288	987	19,200	.0007	57	1827	890	121,500	.0104
8	327	986	21,800	.0008	58	1828	880	121,600	.0114
9	363	985	24,100	.0009	59	1830	870	121,800	.0124
10	397	984	26,400	.0010	60	1835	860	122,000	.0134
11	438	983	29,100	.0011	61	1839	850	122,300	.0144
12	483	982	32,100	.0012	62	1841	825	122,500	.0169
13	528	981	35,100	.0013	63	1841	800	122,500	.0194
14	565	980	37,600	.0014	64	1841	750	122,500	.0244
15	602	979	40,100	.0015	65		710		
16	641	978	42,600	.0016		Failure in lower clamp			
17	679	977	45,200	.0017					
18	713	976	47,400	.0018					
19	745	975	49,600	.0019					
20	778	974	51,800	.0020					
21	817	973	54,400	.0021					
22	853	972	56,800	.0022					
23	891	971	59,300	.0023					
24	924	970	61,400	.0024					
25	959	969	63,800	.0025					
26	994	968	66,100	.0026					
27	1024	967	68,100	.0027					
28	1057	966	70,300	.0028					
29	1089	965	72,400	.0029					
30	1120	964	74,500	.0030					
31	1150	963	76,500	.0031					
32	1178	962	78,400	.0032					
33	1212	961	80,700	.0033					
34	1242	960	82,700	.0034					
35	1268	959	84,300	.0035					
36	1296	958	86,200	.0036					
37	1324	957	88,000	.0037					
38	1351	956	89,800	.0038					
39	1375	955	91,400	.0039					
40	1432	953	95,300	.0041					
41	1479	951	98,300	.0043					
42	1521	949	101,200	.0045					
43	1559	947	103,500	.0047					
44	1581	945	105,300	.0049					
45	1626	943	108,100	.0051					
46	1651	941	109,800	.0053					
47	1677	939	111,500	.0055					
48	1702	936	113,200	.0058					
49	1724	933	114,800	.0061					
50	1745	930	116,000	.0064					

HA-2

HIGHHEAT THERMOMETAL
width = .500"
thickness = .030"

Gage length = 3.94"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	75	987	5,000	.0002
2	115	986	7,700	.0003
3	152	985	10,100	.0004
4	190	984	12,700	.0005
5	230	983	15,300	.0006
6	270	982	18,000	.0007
7	313	981	20,900	.0008
8	353	980	23,500	.0009
9	390	979	26,000	.0010
10	430	978	28,700	.0011
11	466	977	31,100	.0012
12	514	976	34,300	.0013
13	552	975	36,800	.0014
14	583	974	39,900	.0015
15	620	973	41,300	.0016
16	658	972	43,800	.0017
17	702	971	46,700	.0018
18	739	970	49,300	.0019
19	777	969	51,800	.0020
20	810	968	54,000	.0021
21	851	967	56,700	.0022
22	885	966	59,00	.0023
23	915	965	61,000	.0024
24	951	964	63,400	.0025
25	977	963	65,100	.0026
26	1009	962	67,300	.0027
27	1045	961	69,600	.0028
28	1078	960	71,800	.0029
29	1110	959	74,000	.0030
30	1149	958	76,600	.0031
31	1184	957	78,900	.0032
32	1210	956	80,700	.0033
33	1240	955	82,700	.0034
34	1263	954	84,300	.0035
35	1294	953	86,200	.0036
36	1319	952	87,900	.0037
37	1349	951	90,000	.0038
38	1374	950	91,600	.0039
39	1416	948	94,400	.0041
40	1455	946	97,000	.0043
41	1494	944	99,600	.0045
42	1528	942	101,800	.0047
43	1564	940	104,300	.0049
44	1563	938	104,200	.0051
45	1585	936	105,700	.0053
46	1613	934	107,600	.0055
	Failure at bottom clamp			
New clamping and new gage points				
47	1561	949	104,100	.0049
48	1587	948	105,800	.0050
49	1610	947	107,300	.0051
50	1630	946	108,700	.0052
51	1652	945	110,200	.0053
52	1665	944	111,000	.0054
53	1678	943	111,800	.0055
54	1689	942	112,500	.0056
55	1702	940	113,400	.0058
56	1712	938	114,000	.0060
57	1721	935	114,700	.0063
58	1734	930	115,600	.0068
59	1744	925	116,300	.0073
60	1753	915	116,900	.0083
61	1762	900	117,500	.0098
62	1770	875	118,000	.0123
63	1778	850	118,600	.0148
64	1784	800	118,900	.0198
65	1791	700	119,300	.0298
66	1791	600	119,300	.0398
67	Failure	550		.0448

HIGHHEAT THERMOMETAL

#HB-1

width = .502"
thickness = .031"

Gage length = 3.94"
Final length = 4 11/64"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	116	995	7,500	.0002
2	155	994	10,000	.0003
3	192	993	12,300	.0004
4	232	992	14,900	.0005
5	270	991	17,400	.0006
6	315	990	20,300	.0007
7	356	989	22,900	.0008
8	397	988	25,500	.0009
9	433	987	27,800	.0010
10	473	986	30,400	.0011
11	510	985	32,800	.0012
12	544	984	35,000	.0013
13	588	983	37,800	.0014
14	625	982	40,200	.0015
15	670	981	43,100	.0016
16	704	980	45,300	.0017
17	745	979	47,900	.0018
18	784	978	50,400	.0019
19	825	977	53,00	.0020
20	858	976	55,200	.0021
21	890	975	57,200	.0022
22	927	974	59,600	.0023
23	967	973	62,100	.0024
24	1009	972	64,800	.0025
25	1046	971	67,200	.0026
26	1084	970	69,700	.0027
27	1116	969	71,700	.0028
28	1144	968	73,600	.0029
29	1178	967	75,800	.0030
30	1206	966	77,500	.0031
31	1237	965	79,600	.0032
32	1296	963	83,200	.0034
33	1350	961	86,800	.0036
34	1399	959	90,000	.0038
35	1436	957	92,300	.0040
36	1473	955	94,700	.0042
37	1508	953	97,000	.0044
38	1538	951	98,800	.0046
39	1562	949	100,500	.0048
40	1597	946	102,500	.0051
41	1619	943	104,000	.0054
42	1642	940	105,500	.0057
43	1664	935	107,000	.0062
44	1681	930	108,200	.0067
45	1704	920	109,600	.0077
46	1718	910	110,500	.0087
47	1725	900	111,000	.0097
48	1729	875	111,200	.0122
49	1738	850	111,800	.0147
50	1740	825	111,900	.0172
51	1744	800	112,200	.0197
52	1746	750	112,300	.0247
53	1754	700	112,600	.0297
54	1758	650	113,000	.0347
55	1758	600	113,000	.0397
56	1758	550	113,000	.0447
57	1758	400	113,000	.0597
58		4 3/16		
59	0	4 11/64	Failure	.058

HIGHHEAT THERMOMETAL

#HC-1

width = .500"
thickness = .0305"

Gage length = 3.94"
Final length = 4 15/64"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.	No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	84	997	5,500	.0002	51	1580	750	103,600	.0249
2	121	996	7,900	.0003	52	1580	700	103,600	.0299
3	168	995	11,000	.0004	53	1580	650	103,600	.0349
4	209	994	13,700	.0005	54	1580	600	103,600	.0399
5	254	993	16,600	.0006	55	1580	550	103,600	.0449
6	288	992	18,900	.0007	56	1594	500	104,500	.0499
7	325	991	21,300	.0008	57	1610	450	105,500	.0549
8	365	990	23,900	.0009	58	1621	400	106,200	.0599
9	402	989	26,300	.0010	59	0	4 15/64	Failure	.074
10	441	988	28,800	.0011					
11	479	987	31,400	.0012					
12	517	986	33,900	.0013					
13	555	985	36,400	.0014					
14	592	984	38,800	.0015					
15	634	983	41,600	.0016					
16	675	982	44,200	.0017					
17	717	981	47,000	.0018					
18	755	980	49,400	.0019					
19	790	979	51,800	.0020					
20	829	978	54,300	.0021					
21	845	977	55,300	.0022					
22	882	976	57,700	.0023					
23	912	975	59,700	.0024					
24	945	974	61,900	.0025					
25	988	973	64,700	.0026					
26	1021	972	66,900	.0027					
27	1066	971	69,800	.0028					
28	1094	970	71,700	.0029					
29	1128	969	74,000	.0030					
30	1160	968	76,100	.0031					
31	1186	967	77,700	.0032					
32	1211	966	79,400	.0033					
33	1232	965	80,800	.0034					
34	1260	964	82,600	.0035					
35	1282	963	84,100	.0036					
36	1323	961	86,700	.0038					
37	1361	959	89,200	.0040					
38	1390	957	91,100	.0042					
39	1415	955	92,800	.0044					
40	1455	950	95,400	.0049					
41	1489	945	97,600	.0054					
42	1513	940	99,200	.0059					
43	1530	935	100,400	.0064					
44	1538	924	100,900	.0075					
45	1555	912	102,000	.0087					
46	1570	900	103,000	.0099					
47	1575	875	103,300	.0124					
48	1580	850	103,600	.0149					
49	1580	825	103,600	.0174					
50	1580	800	103,600	.0199					

HIGHHEAT THERMOMETAL

#H-D1

thickness = .0315"
width = .502"

Gage length = 3.94"
Final length = 5 5/16"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	79	1003	5,000	.0002
2	109	1002	6,900	.0003
3	144	1001	9,100	.0004
4	183	1000	11,600	.0005
5	218	999	13,800	.0006
6	252	998	16,000	.0007
7	289	997	18,300	.0008
8	314	996	19,900	.0009
9	349	995	22,100	.0010
10	379	994	24,000	.0011
11	403	993	25,500	.0012
12	426	992	26,900	.0013
13	449	991	28,400	.0014
14	470	990	29,700	.0015
15	485	989	30,700	.0016
16	524	986	33,100	.0019
17	547	984	34,600	.0021
18	565	982	35,700	.0023
19	579	980	36,600	.0025
20	594	977	37,600	.0028
21	610	973	38,600	.0032
22	621	968	39,200	.0037
23	636	960	40,200	.0045
24	653	950	41,300	.0055
25	665	940	42,100	.0065
26	682	920	43,200	.0085
27	697	900	44,100	.0105
28	712	875	45,100	.0130
29	726	850	45,900	.0155
30	739	825	46,700	.0180
31	753	800	47,600	.0205
32	774	750	49,000	.0255
33	794	700	50,200	.0305
34	816	650	51,600	.0355
35	832	600	52,600	.0405
36	854	550	54,000	.0455
37	874	500	55,300	.0505
38	890	450	56,300	.0555
39	906	400	57,300	.0605
40	950	4 1/4	60,200	.0787
41	1026	4 3/8	64,900	.1103
42	1088	4 1/2	68,800	.1422
43	1131	4 5/8	71,600	.1740
44	1165	4 3/4	73,700	.2055
45	1187	4 7/8	75,100	.2370
46	1210	5	76,600	.2690
47	1223	5 1/4	77,400	.3330
48			Failure	.348

HIGH EXPANDING STEEL

#1-2A

width = .257"
thickness = .0795"

Gage length = 3.94"
Final length = 4 13/64"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	162	997	7,900	.0004
2	214	996	10,500	.0005
3	273	995	13,400	.0006
4	349	994	17,100	.0007
5	417	993	20,400	.0008
6	479	992	23,400	.0009
7	542	991	26,500	.0010
8	607	990	29,700	.0011
9	668	989	32,700	.0012
10	730	988	35,700	.0013
11	796	987	38,900	.0014
12	842	986	41,200	.0015
13	897	985	43,900	.0016
14	959	984	46,900	.0017
15	1019	983	49,900	.0018
16	1082	982	53,000	.0019
17	1150	981	56,300	.0020
18	1203	980	58,900	.0021
19	1260	979	61,600	.0022
20	1315	978	64,300	.0023
21	1367	977	66,800	.0024
22	1422	976	69,600	.0025
23	1475	975	72,200	.0026
24	1525	974	74,700	.0027
25	1579	973	77,300	.0028
26	1631	972	79,800	.0029
27	1683	971	82,400	.0030
28	1731	970	84,700	.0031
29	1781	969	87,200	.0032
30	1824	968	89,300	.0033
31	1864	967	91,200	.0034
32	1906	966	93,300	.0035
33	1955	965	95,700	.0036
34	1993	964	97,600	.0037
35	2023	963	99,000	.0038
36	2063	962	101,000	.0039
37	2096	961	102,500	.0040
38	2128	960	104,200	.0041
39	1931	944	94,600	.0037
40	2016	942	98,700	.0039
41	2135	940	104,500	.0041
42	2182	938	106,900	.0043
43	2266	936	111,000	.0045
44	2749	4"	134,500	.016
45	2785	4 1/16"	141,500	.031
46	2785	4 1/8"	141,500	.047
47	2466	4 3/16"	120,800	.063
48	2150	Failure	105,000	.068

#2-2A

HIGH EXPANDING STEEL
width = .258"
thickness = .079"

Gage length = 3.94"
Final length = 4 3/32"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	113	1005	5,500	.0002
2	167	1004	8,200	.0003
3	212	1003	10,800	.0004
4	268	1002	13,200	.0005
5	320	1001	15,700	.0006
6	372	1000	18,300	.0007
7	429	999	21,100	.0008
8	479	998	23,500	.0009
9	527	997	25,900	.0010
10	574	996	28,200	.0011
11	630	995	30,900	.0012
12	684	994	33,600	.0013
13	737	993	36,200	.0014
14	794	992	39,000	.0015
15	852	991	41,800	.0016
16	912	990	44,800	.0017
17	973	989	47,700	.0018
18	1035	988	50,800	.0019
19	1088	987	53,500	.0020
20	1146	986	56,200	.0021
21	1201	985	58,900	.0022
22	1255	984	61,600	.0023
23	1315	983	64,600	.0024
24	1373	982	67,400	.0025
25	1437	981	71,600	.0026
26	1488	980	73,100	.0027
27	1550	979	76,200	.0028
28	1603	978	78,700	.0029
29	1656	977	81,300	.0030
30	1707	976	83,800	.0031
31	1758	975	86,400	.0032
32	1805	974	88,600	.0033
33	1858	973	91,300	.0034
34	1913	972	94,000	.0035
35	1965	971	96,500	.0036
36	2006	970	98,600	.0037
37	2047	969	100,600	.0038
38	2088	968	102,600	.0039
39	2124	967	104,300	.0040
40	2158	966	106,000	.0041
41	2187	965	107,500	.0042
42	2220	964	109,100	.0043
43	2255	963	110,800	.0044
44	2284	962	112,300	.0045
45	2313	961	113,600	.0046
46	2339	960	115,000	.0047
47	2385	958	117,200	.0049
48	2422	956	119,000	.0051
49	2459	954	120,900	.0053
50	2490	952	122,400	.0055
51	2522	950	124,000	.0057
52	2557	947	125,700	.0060
53	2595	942	127,500	.0065
54	2640	935	129,700	.0072
55	2672	925	131,200	.0082
56	2699	915	132,700	.0092
57	2716	900	133,300	.0107
58	2729	850	134,000	.0157
59	2736	800	134,300	.0207
60	2745	750	134,900	.0257
61	2120	Failure	104,200	.0391

HIGH EXPANDING STEEL

#2-2B

width = 0.251"

thickness = .080"

Gage length = 3.94"

Final length = 4 15/64"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	131	1007	6,500	.0002
2	215	1006	10,700	.0003
3	278	1005	13,800	.0004
4	341	1004	17,000	.0005
5	403	1003	20,000	.0006
6	471	1002	23,400	.0007
7	528	1001	26,300	.0008
8	591	1000	29,400	.0009
9	648	999	32,200	.0010
10	708	998	35,200	.0011
11	759	997	37,700	.0012
12	816	996	40,600	.0013
13	873	995	43,300	.0014
14	924	994	45,900	.0015
15	981	993	48,700	.0016
16	1033	992	51,400	.0017
17	1097	991	54,600	.0018
18	1154	990	57,400	.0019
19	1204	989	59,900	.0020
20	1261	988	62,700	.0021
21	1317	987	65,500	.0022
22	1369	986	68,100	.0023
23	1420	985	71,600	.0024
24	1470	984	73,200	.0025
25	1525	983	75,800	.0026
26	1576	982	78,400	.0027
27	1626	981	80,800	.0028
28	1677	980	83,400	.0029
29	1722	979	85,600	.0030
30	1767	978	87,900	.0031
31	1809	977	90,000	.0032
32	1849	976	92,000	.0033
33	1886	975	93,800	.0034
34	1922	974	95,700	.0035
35	1954	973	97,200	.0036
36	1987	972	98,800	.0037
37	2022	971	100,500	.0038
38	2052	970	102,000	.0039
39	2097	968	104,200	.0041
40	2143	966	106,600	.0043
41	2183	964	108,500	.0045
42	2220	962	110,400	.0047
43	2253	960	112,000	.0049
44	2290	957	113,900	.0052
45	2320	954	115,400	.0055
46	2341	951	116,400	.0058
47	2369	946	117,700	.0063
48	2391	940	118,900	.0069
49	2416	930	120,200	.0079
50	2430	920	120,800	.0089
51	2442	900	121,400	.0109
52	2457	850	122,100	.0159
53	2466	800	122,500	.0209
54	2477	750	123,000	.0259
55	2482	700	123,500	.0309
56	2487	650	123,700	.0359
57	2491	600	123,800	.0409
58	2497	550	124,100	.0459
59	2498	500	124,100	.0509
60	2498	450	124,100	.0559
61	2489	400	123,700	.0609
62	1850	Failure	92,100	.074

HIGH EXPANDING STEEL

#1-2C

width = .247"
thickness = .081"

Gage length = 3.94"
Findal length = 4 7/64"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.	No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	80	986	4,000	.0002	51	2157	900	107,800	.0088
2	138	985	6,900	.0003	52	2162	890	108,100	.0098
3	195	984	9,800	.0004	53	2169	880	108,400	.0108
4	252	983	12,600	.0005	54	2175	860	108,800	.0128
5	325	982	16,200	.0006	55	2184	840	109,200	.0148
6	400	981	20,000	.0007	56	2190	820	109,500	.0168
7	455	980	22,700	.0008	57	2196	800	109,800	.0188
8	519	979	26,000	.0009	58	2202	750	110,100	.0238
9	578	978	28,900	.0010	59	2211	700	110,600	.0288
10	645	977	32,300	.0011	60	2219	650	111,000	.0338
11	699	976	34,900	.0012	61	2227	600	111,400	.0388
12	755	975	37,700	.0013	62	2234	550	111,700	.0438
13	810	974	40,500	.0014	63	2183	500	109,200	.0488
14	872	973	43,600	.0015	64			failure	.042
15	933	972	46,600	.0016					
16	991	971	49,600	.0017					
17	1044	970	52,200	.0018					
18	1101	969	55,000	.0019					
19	1153	968	57,600	.0020					
20	1204	967	60,200	.0021					
21	1251	966	62,500	.0022					
22	1297	965	64,800	.0023					
23	1352	964	67,600	.0024					
24	1403	963	70,200	.0025					
25	1450	962	72,500	.0026					
26	1494	961	74,700	.0027					
27	1539	960	76,900	.0028					
28	1581	959	79,100	.0029					
29	1621	958	81,200	.0030					
30	1657	957	82,800	.0031					
31	1696	956	84,800	.0032					
32	1730	955	86,500	.0033					
33	1762	954	88,100	.0034					
34	1794	953	89,700	.0035					
35	1823	952	91,200	.0036					
36	1851	951	92,600	.0037					
37	1877	950	93,800	.0038					
38	1901	949	95,000	.0039					
39	1931	947	96,600	.0041					
40	1960	945	98,000	.0043					
41	1969	943	98,300	.0045					
42	2006	941	100,300	.0047					
43	2033	939	101,600	.0049					
44	2040	937	102,000	.0051					
45	2044	935	102,200	.0053					
46	2072	929	103,600	.0059					
47	2099	925	105,000	.0063					
48	2123	920	106,200	.0068					
49	2131	915	106.500	.0073					
50	2142	910	107,100	.0078					

#2-2C

HIGH EXPANDING STEEL
width = 0.253"
thickness = .081"

Gage length = 3.94"
Final length = 4 1/4"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	241	995	11,800	.0005
2	299	994	14,600	.0006
3	354	993	17,300	.0007
4	463	992	22,600	.0008
5	519	991	25,300	.0009
6	574	990	28,000	.0010
7	621	989	30,200	.0011
8	675	988	32,900	.0012
9	728	987	35,500	.0013
10	782	986	38,100	.0014
11	838	985	40,800	.0015
12	891	984	43,400	.0016
13	952	983	46,400	.0017
14	1011	982	49,300	.0018
15	1070	981	52,200	.0019
16	1124	980	54,800	.0020
17	1184	979	57,800	.0021
18	1237	978	60,300	.0022
19	1288	977	62,800	.0023
20	1343	976	65,600	.0024
21	1395	975	68,100	.0025
22	1453	974	70900	.0026
23	1520	973	74,200	.0027
24	1565	972	76,300	.0028
25	1617	971	78,800	.0029
26	1657	970	80,800	.0030
27	1694	969	82,700	.0031
28	1729	968	84,300	.0032
29	1758	967	85,700	.0033
30	1794	966	87,600	.0034
31	1821	965	88,800	.0035
32	1847	964	90,200	.0036
33	1873	963	91,500	.0037
34	1992	962	92,400	.0038
35	1914	961	93,500	.0039
36	1788	955	87,300	.0045
37	1896	953	92,600	.0047
38	1981	951	96,800	.0049
39	2007	949	97,700	.0051
40	2023	947	98,800	.0052
41	2038	945	99,500	.0055
42	2194	4"	107,100	.016
43	2259	4 1/8"	110,200	.047
44	1825	4 1/4"	89,000	.079
45	1750	Failure	85,300	.079

#1-2D

HIGH EXPANDING STEEL
width = .250"
thickness = .0805"

Gage length = 3.94"
Final length = 5 11/16"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	102	1009	5,100	.0002
2	139	1008	6,900	.0003
3	184	1007	9,200	.0004
4	230	1006	11,400	.0005
5	273	1005	13,600	.0006
6	315	1004	15,700	.0007
7	356	1003	17,700	.0008
8	395	1002	19,600	.0009
9	432	1001	21,500	.0010
10	458	1000	22,800	.0011
11	487	999	24,200	.0012
12	507	998	25,300	.0013
13	523	997	26,000	.0014
14	535	996	26,600	.0015
15	562	994	28,000	.0017
16	589	991	29,300	.0020
17	611	988	30,400	.0023
18	629	983	31,300	.0028
19	643	977	32,000	.0034
20	657	970	32,700	.0041
21	673	960	33,500	.0051
22	691	945	34,400	.0066
23	714	925	35,500	.0086
24	740	900	36,800	.0111
25	779	850	38,700	.0161
26	817	800	40,600	.0211
27	844	750	42,000	.0261
28	877	700	43,600	.0311
29	904	650	45,000	.0361
30	933	600	46,400	.0411
31	959	550	47,700	.0461
32	980	500	48,800	.0511
33	1005	450	50,000	.0561
34	1025	400	51,000	.0611
35	1110	4 1/4	55,300	.0788
36	1215	4 3/8	61,500	.1103
37	1303	4 1/2	64,800	.1421
38	1368	4 5/8	68,200	.1738
39	1433	4 3/4	71,300	.2055
40	1476	4 7/8	73,500	.2370
41	1506	5	75,000	.2690
42	1529	5 1/8	76,100	.3010
43	1542	5 1/4	76,800	.3330
44	1551	5 3/8	77,200	.3640
45	1556	5 1/2	77,400	.3960
46	1556	5 5/8	77,400	.4280
47			failure	.443

HIGH EXPANDING STEEL

#2-2D

width = .253"
thickness = .0785"

Gage length = 3.94"
Final length = 5 25/64"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.	No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	97	991	4,900	.0002	51		Failure		.341
2	153	990	7,700	.0003					
3	208	989	10,500	.0004					
4	259	988	13,000	.0005					
5	282	987	14,200	.0006					
6	322	986	16,200	.0007					
7	366	985	18,400	.0008					
8	399	984	21,000	.0009					
9	Started over								
10	214	987	10,800	.0004					
11	279	986	14,000	.0005					
12	328	985	16,500	.0006					
13	373	984	18,800	.0007					
14	414	983	20,800	.0008					
15	454	982	22,900	.0009					
16	480	981	24,200	.0010					
17	506	980	25,500	.0011					
18	529	979	26,600	.0012					
19	545	978	27,500	.0013					
20	571	976	28,700	.0015					
21	583	974	29,400	.0017					
22	593	971	29,900	.0020					
23	601	968	30,300	.0023					
24	608	965	30,600	.0026					
25	614	960	30,900	.0031					
26	624	950	31,400	.0041					
27	637	940	32,100	.0051					
28	654	925	32,900	.0066					
29	680	900	34,300	.0091					
30	705	875	35,500	.0116					
31	730	850	36,800	.0141					
32	747	825	37,600	.0166					
33	768	800	38,700	.0191					
34	798	750	40,200	.0241					
35	829	700	41,700	.0291					
36	860	650	43,300	.0341					
37	891	600	44,800	.0391					
38	922	550	46,400	.0441					
39	944	500	47,500	.0491					
40	971	450	48,900	.0541					
41	995	400	50,100	.0591					
42	1084	4 1/4"	54,600	.0788					
43	1196	4 3/8"	60,200	.1103					
44	1292	4 1/2"	65,100	.1421					
45	1378	4 5/8"	69,400	.1738					
46	1429	4 3/4"	72,000	.2055					
47	1484	4 7/8"	74,700	.2370					
48	1514	5"	76,300	.2690					
49	1537	5 1/8"	77,400	.3010					
50	1550	5 1/4"	78,100	.3330					

LOW EXPANDING STEEL

#1-3A

width = .253"
thickness = .080"

Gage length = 3.94"
Final length = 4 15/64"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	73	1017	3,600	.0002
2	97	1016	4,800	.0003
3	125	1015	6,200	.0004
4	145	1014	7,200	.0005
5	162	1013	8,000	.0006
6	184	1012	9,100	.0007
7	218	1010	10,800	.0009
8	262	1008	12,900	.0011
9	314	1006	15,500	.0013
10	374	1004	18,500	.0015
11	440	1002	21,700	.0017
12	514	1000	25,400	.0019
13	585	998	28,900	.0021
14	654	996	32,300	.0023
15	691	995	34,100	.0024
16	727	994	35,900	.0025
17	765	993	37,800	.0026
18	803	992	39,600	.0027
19	840	991	41,500	.0028
20	878	990	43,400	.0029
21	919	989	45,400	.0030
22	958	988	47,400	.0031
23	994	987	49,100	.0032
24	1032	986	50,900	.0033
25	1063	985	52,400	.0034
26	1100	984	54,300	.0035
27	1139	983	56,200	.0036
28	1177	982	58,100	.0037
29	1225	981	60,500	.0038
30	1265	980	62,500	.0039
31	1301	979	64,200	.0040
32	1340	978	66,200	.0041
33	1381	977	68,200	.0042
34	1420	976	70,100	.0043
35	1454	975	71,800	.0044
36	1490	974	73,600	.0045
37	1513	972	74,700	.0047
38	1585	970	78,300	.0049
39	1655	968	81,700	.0051
40	1700	966	84,000	.0053
41	1729	964	85,400	.0055
42	1756	962	86,700	.0057
43	1787	960	88,200	.0059
44	1828	957	90,200	.0062
45	1867	954	92,300	.0065
46	1900	951	93,800	.0068
47	1928	948	95,300	.0071
48	1958	945	96,700	.0074
49	1983	942	97,900	.0077
50	1903	936	94,000	.0083
51	2011	930	99,300	.0089
52	2063	925	101,900	.0094
53	2088	920	103,200	.0099
54	2105	915	104,000	.0104
55	2120	905	104,700	.0114
56	2134	895	105,600	.0124
57	2147	880	106,000	.0139
58	2153	860	106,200	.0159
59	2161	830	106,800	.0189
60	2167	800	107,000	.0219
61	2174	750	107,300	.0269
62	2179	700	107,500	.0319
63	2187	600	108,100	.0419
64	2197	500	108,500	.0519
65	2197	400	108,500	.0619
66	2225	Failure	109,700	.0746

LOW EXPANDING STEEL

#2-3A

width = .250"
thickness = .0805"

Gage length = 3.94"
Final length = 4 11/64"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.	No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	133	1004	6,600	.0003	51	2170	900	108,000	.0107
2	181	1003	9,000	.0004	52	2184	850	108,700	.0157
3	239	1002	11,900	.0005	53	2195	800	109,200	.0207
4	289	1001	14,400	.0006	54	2206	750	109,600	.0257
5	342	1000	17,000	.0007	55	2211	700	110,000	.0307
6	389	999	19,400	.0008	56	2215	650	110,200	.0357
7	436	998	21,700	.0009	57	2219	600	110,300	.0407
8	481	997	23,900	.0010	58	2222	550	110,500	.0457
9	525	996	26,100	.0011	59	2222	500	110,500	.0507
10	573	995	28,500	.0012	60	2104	450	109,500	.0557
11	616	994	30,600	.0013	61	1750	400	87,100	.0607
12	656	993	32,600	.0014	62	1415	Failure	70,400	.0598
13	705	992	35,100	.0015					
14	750	991	37,300	.0016					
15	801	990	39,800	.0017					
16	847	989	42,100	.0018					
17	894	988	44,400	.0019					
18	937	987	46,600	.0020					
19	985	986	49,000	.0021					
20	1029	985	51,200	.0022					
21	1072	984	53,400	.0023					
22	1117	983	55,600	.0024					
23	1164	982	57,900	.0025					
24	1213	981	60,300	.0026					
25	1259	980	62,600	.0027					
26	1306	979	64,900	.0028					
27	1347	978	67,000	.0029					
28	1395	977	69,400	.0030					
29	1435	976	71,400	.0031					
30	1473	975	73,300	.0032					
31	1516	974	75,400	.0033					
32	1555	973	77,400	.0034					
33	1598	972	79,500	.0035					
34	1640	971	81,600	.0036					
35	1674	970	83,300	.0037					
36	1711	969	85,200	.0038					
37	1738	968	86,500	.0039					
38	1793	966	89,200	.0041					
39	1843	964	91,700	.0043					
40	1889	962	94,100	.0045					
41	1933	960	96,200	.0047					
42	1968	958	98,000	.0049					
43	1998	956	99,400	.0051					
44	2033	953	101,000	.0054					
45	2064	950	102,600	.0057					
46	2085	947	103,800	.0060					
47	2104	944	104,600	.0063					
48	2129	937	106,000	.0070					
49	2145	930	106,600	.0077					
50	2158	920	107,300	.0087					

#1-3B

LOW EXPANDING STEEL
width = .254"
thickness = .0805"

Gage length = 3.94"
Final length = 4 15/64"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.	No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	86	1004	4,200	.0002					
2	139	1003	6,800	.0003					
3	195	1002	9,500	.0004					
4	266	1001	13,000	.0005					
5	318	1000	15,600	.0006					
6	373	999	18,200	.0007					
7	423	998	20,700	.0008					
8	469	997	22,900	.0009					
9	505	996	24,700	.0010					
10	550	995	26,900	.0011					
11	592	994	28,900	.0012					
12	630	993	30,800	.0013					
13	676	992	33,100	.0014					
14	716	991	35,000	.0015					
15	757	990	37,100	.0016					
16	801	989	39,100	.0017					
17	847	988	41,400	.0018					
18	888	987	43,400	.0019					
19	932	986	45,600	.0020					
20	977	985	47,800	.0021					
21	1026	984	50,200	.0022					
22	1066	983	52,200	.0023					
23	1115	982	54,500	.0024					
24	1165	981	57,000	.0025					
25	1205	980	58,900	.0026					
26	1251	979	61,200	.0027					
27	1299	978	63,600	.0028					
28	1341	977	65,600	.0029					
29	1380	976	67,500	.0030					
30	1415	975	69,200	.0031					
31	1455	974	71,200	.0032					
32	1486	973	72,700	.0033					
33	1530	972	74,800	.0034					
34	1566	971	76,600	.0035					
35	1592	970	77,900	.0036					
36	1648	968	80,600	.0038					
37	1703	966	83,300	.0040					
38	1759	964	86,000	.0042					
39	1822	961	89,100	.0045					
40	1878	958	91,900	.0048					
41	1917	955	93,800	.0051					
42	1951	950	95,500	.0056					
43	1976	945	96,700	.0061					
44	Slips in bottom clamp								
45	2097	4"	102,400	.016					
46	2146	4 1/8"	105,000	.047					
47	1465	Failure	71,600	.074					

#2-3B

LOW EXPANDING STEEL
width = .252"
thickness = .080"

Gage length = 3.94"
Final length = 4 13/64"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.	No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	139	999	6,900	.0003	51	2037	935	101,000	.0067
2	190	998	9,400	.0004	52	2047	930	101,700	.0072
3	241	997	12,000	.0005	53	2061	920	102,300	.0082
4	290	996	14,400	.0006	54	2074	900	103,000	.0102
5	344	995	17,100	.0007	55	2087	850	103,700	.0152
6	389	994	19,300	.0008	56	2097	800	104,100	.0202
7	439	993	21,800	.0009	57	2105	750	104,300	.0252
8	485	992	24,100	.0010	58	2114	700	105,000	.0302
9	534	991	26,400	.0011	59	2125	650	105,400	.0352
10	579	990	28,700	.0012	60	2130	600	105,600	.0402
11	622	989	30,800	.0013	61	2139	550	106,100	.0452
12	672	988	33,300	.0014	62	2146	500	106,300	.0502
13	716	987	35,500	.0015	63	2149	450	106,600	.0552
14	761	986	37,700	.0016	64	2085	400	103,100	.0602
15	805	985	39,900	.0017	65	1415	Failure	70,200	.0668
16	850	984	42,200	.0018					
17	895	983	44,300	.0019					
18	946	982	46,900	.0020					
19	997	981	49,400	.0021					
20	1036	980	51,400	.0022					
21	1081	979	53,600	.0023					
22	1129	978	56,000	.0024					
23	1175	977	58,200	.0025					
24	1218	976	60,400	.0026					
25	1258	975	62,400	.0027					
26	1302	974	64,600	.0028					
27	1345	973	66,700	.0029					
28	1392	972	69,000	.0030					
29	1438	971	71,300	.0031					
30	1478	970	73,300	.0032					
31	1516	969	75,200	.0033					
32	1553	968	77,100	.0034					
33	1588	967	78,700	.0035					
34	1620	966	80,400	.0036					
35	1651	965	81,800	.0037					
36	1683	964	83,500	.0038					
37	1713	963	85,100	.0039					
38	1741	962	86,400	.0040					
39	1768	961	87,700	.0041					
40	1791	960	88,800	.0042					
41	1827	958	90,700	.0044					
42	1861	956	92,300	.0046					
43	1892	954	93,800	.0048					
44	1920	952	95,300	.0050					
45	1948	950	96,700	.0052					
46	1967	948	97,600	.0054					
47	1983	946	98,400	.0056					
48	1998	944	99,200	.0058					
49	2013	942	99,800	.0060					
50	2025	939	100,500	.0063					

#1-3C

LOW EXPANDING STEEL
width = .2515"
thickness = .080"

Gage length = 3.94"
Final length = 4 1/4"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	66	1002	3,300	.0002
2	95	1001	4,700	.0003
3	139	1000	6,900	.0004
4	201	999	10,000	.0005
5	265	998	13,200	.0006
6	320	997	15,900	.0007
7	369	996	18,400	.0008
8	413	995	20,600	.0009
9	453	994	22,500	.0010
10	494	993	24,600	.0011
11	534	992	26,600	.0012
12	573	991	28,500	.0013
13	616	990	30,700	.0014
14	660	989	32,900	.0015
15	703	988	35,000	.0016
16	746	987	37,100	.0017
17	781	986	38,900	.0018
18	821	985	40,800	.0019
19	862	984	42,900	.0020
20	901	983	44,800	.0021
21	941	982	46,800	.0022
22	991	981	49,300	.0023
23	1029	980	51,200	.0024
24	1070	979	53,200	.0025
25	1102	978	54,800	.0026
26	1154	977	57,400	.0027
27	1194	976	59,400	.0028
28	1229	975	61,100	.0029
29	1262	974	62,700	.0030
30	1307	973	65,000	.0031
31	1344	972	66,900	.0032
32	1383	971	68,700	.0033
33	1415	970	70,400	.0034
34	1437	969	71,500	.0035
35	1468	968	73,100	.0036
36	1503	967	74,800	.0037
37	1537	966	76,500	.0038
38	1562	965	77,700	.0039
39	1589	964	79,100	.0040
40	1618	963	80,600	.0041
41	1641	962	81,700	.0042
42	1667	961	82,900	.0043
43	1684	960	83,800	.0044
44	1710	958	85,200	.0046
45	1735	956	86,400	.0048
46	1753	953	87,200	.0051
47	1799	947	89,600	.0057
48	1824	944	90,800	.0060
49	1845	941	91,800	.0063
50	1870	938	93,100	.0066
51	1881	935	93,600	.0069
52	1893	932	94,200	.0072
53	1868	927	93,000	.0077
54	1874	921	93,300	.0083
55	1897	915	94,400	.0089
56	1910	910	95,100	.0094
57	1918	905	95,400	.0099
58	1921	900	95,600	.0104
59	1926	890	95,800	.0114
60	1932	880	96,200	.0124
61	1935	859	96,300	.0145
62	1945	839	96,800	.0165
63	1950	820	97,100	.0184
64	1952	800	97,200	.0204
65	1970	750	98,000	.0254
66	1978	650	98,500	.0354
67	1989	600	99,000	.0404
68	2003	500	99,700	.0504
69	2003	400	99,700	.0604
70	2098		104,300	
71	1380	Failure	68,700	.079

#2-3C

LOW EXPANDING STEEL
width = .251"
thickness = .080"

Gage length = 3.94"
Final length = 4 9/32"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.	No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	109	1003	5,400	.0003	51	1904	920	94,800	.0086
2	156	1002	7,800	.0004	52	1911	910	95,200	.0096
3	199	1001	9,900	.0005	53	1917	900	95,400	.0106
4	251	1000	12,500	.0006	54	1924	875	95,800	.0131
5	294	999	14,600	.0007	55	1932	850	96,200	.0156
6	345	998	17,200	.0008	56	1937	800	96,500	.0206
7	386	997	19,200	.0009	57	1946	750	96,800	.0256
8	427	996	21,200	.0010	58	1958	700	97,500	.0306
9	474	995	23,600	.0011	59	1969	650	98,000	.0356
10	517	994	25,700	.0012	60	1975	600	98,300	.0406
11	562	993	27,900	.0013	61	1982	550	98,700	.0456
12	610	992	30,300	.0014	62	1989	500	99,000	.0506
13	656	991	32,600	.0015	63	1997	450	99,400	.0556
14	700	990	34,800	.0016	64	2002	400	99,600	.0606
15	745	989	37,100	.0017	65	1954	4 1/4"	97,300	.0788
16	786	988	39,100	.0018	66	1400	Failure	69,700	.0866
17	832	987	41,400	.0019					
18	873	986	43,400	.0020					
19	919	985	45,700	.0021					
20	957	984	47,600	.0022					
21	1003	983	49,900	.0023					
22	1044	982	52,000	.0024					
23	1097	981	54,600	.0025					
24	1139	980	56,700	.0026					
25	1181	979	58,800	.0027					
26	1224	978	60,900	.0028					
27	1266	977	62,900	.0029					
28	1302	976	64,700	.0030					
29	1337	975	66,500	.0031					
30	1377	974	68,500	.0032					
31	1417	973	70,500	.0033					
32	1452	972	72,300	.0034					
33	1484	971	73,800	.0035					
34	1540	969	76,600	.0037					
35	1571	968	78,200	.0038					
36	1593	967	79,300	.0039					
37	1617	966	80,500	.0040					
38	1640	965	81,600	.0041					
39	1673	963	83,300	.0043					
40	1709	961	85,100	.0045					
41	1738	959	86,500	.0047					
42	1764	957	87,800	.0049					
43	1785	955	88,800	.0051					
44	1807	952	90,000	.0054					
45	1827	949	91,000	.0057					
46	1845	946	91,800	.0060					
47	1861	943	92,600	.0063					
48	1872	940	93,200	.0066					
49	1883	935	93,700	.0071					
50	1891	930	94,200	.0076					

LOW EXPANDING STEEL

#1-3D

width = .251"
thickness = .081"

Gage length = 3.94"
Final length = 5 17/64"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	113	1003	5,600	.0003
2	156	1002	7,700	.0004
3	203	1001	10,000	.0005
4	247	1000	12,200	.0006
5	287	999	14,100	.0007
6	341	998	16,800	.0008
7	381	997	18,800	.0009
8	428	996	21,100	.0010
9	470	995	23,100	.0011
10	510	994	25,100	.0012
11	553	993	27,300	.0013
12	584	992	28,800	.0014
13	621	991	30,600	.0015
14	651	990	32,100	.0016
15	678	989	33,400	.0017
16	697	988	34,300	.0018
17	714	987	35,200	.0019
18	735	985	36,200	.0021
19	751	983	37,000	.0023
20	760	980	37,400	.0026
21	771	975	38,000	.0031
22	783	965	38,600	.0041
23	795	950	39,100	.0066
24	811	925	39,900	.0091
25	833	900	41,100	.0116
26	867	850	42,700	.0166
27	899	800	44,300	.0216
28	927	750	45,600	.0266
29	955	700	47,000	.0316
30	982	650	48,300	.0366
31	1006	600	49,500	.0416
32	1028	550	50,600	.0466
33	1052	500	51,800	.0516
34	1075	450	52,900	.0566
35	1093	400	53,800	.0616
36	1163	4 1/4"	57,200	.0788
37	1257	4 3/8"	61,800	.1103
38	1330	4 1/2"	65,500	.1421
39	1387	4 5/8"	68,300	.1738
40	1427	4 3/4"	70,200	.2055
41	1451	4 7/8"	71,500	.2370
42	1470	5"	72,400	.2690
43	1475	5 1/8"	72,600	.3010
44	1387	5 1/4"	68,300	.3330
45	1000	Failure	49,200	.3370

LOW EXPANDING STEEL

#2-3D

width = .248"
thickness = .081"

Gage length = 3.94"
Final length = 5"

No.	Load lbs.	Dial 1/10,000	Stress #/in.^{2}	Strain in/in.
1	82	999	4,000	.0002
2	129	998	6,300	.0003
3	166	997	8,100	.0004
4	203	996	10,000	.0005
5	252	995	12,400	.0006
6	291	994	14,200	.0007
7	326	993	16,000	.0008
8	352	992	17,200	.0009
9	375	991	18,400	.0010
10	416	990	20,400	.0011
11	447	989	21,900	.0012
12	490	988	24,000	.0013
13	519	987	25,400	.0014
14	545	986	26,700	.0015
15	573	985	28,100	.0016
16	598	984	29,300	.0017
17	620	983	30,400	.0018
18	660	981	32,300	.0020
19	677	979	33,200	.0022
20	706	977	34,600	.0024
21	723	975	35,500	.0026
22	740	972	36,300	.0029
23	752	967	36,900	.0034
24	762	960	37,300	.0041
25	777	950	38,100	.0051
26	798	925	39,100	.0076
27	820	900	40,200	.0101
28	851	850	41,600	.0151
29	884	800	43,300	.0201
30	910	750	44,600	.0251
31	938	700	45,900	.0301
32	966	650	47,300	.0351
33	991	600	48,600	.0401
34	1013	550	49,600	.0451
35	1035	500	50,800	.0501
36	1056	450	51,700	.0551
37	1077	400	52,700	.0601
38	1147	4 1/4"	56,100	.0802
39	1237	4 3/8"	60,600	.1120
40	1308	4 1/2"	64,100	.1440
41	1363	4 5/8"	66,700	.1760
42	1398	4 3/4"	68,500	.2070
43	1422	4 7/8"	69,600	.2390
44	1284	5"	62,800	.2710
45			Failure	.27