

Methods and Appliances for Testing Materials for Machinery – Reading and Interpreting Stress Curves

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Abstract

In this paper, it is showcased that a designer of machinery must be familiar with all the properties of materials used as the materials need to be able to withstand stresses and strains of the machinery's regular operation. The materials are subjected to various tests, after which stress curves are plotted which must be understood by a machine designer looking to ascertain its capacity to manage stress.

The aim of these tests is to determine various strength parameters of materials, such as elasticity, ductility, etc. This is essential to determine the magnitude of load it can take safely as part of a machine.

Keywords: Test Curves, Stress Curves, Test Peices

INTRODUCTION

The stresses to which the parts of a machine are most commonly subjected are those producing: tension, compression, and flexure. Consequently, the greater number of tests is made to determine the strengths of materials subjected to these stresses. In some machines, the parts are subjected to torsion and shearing, but these are usually of less importance than the others, so that tests for strength in torsion and in shearing are less frequently made.

TEST PIECES

Selection of Test Pieces

In making a physical test of a material, a bar of that material is taken and subjected to the kind of stress under which its strength is desired to be known. The bar thus taken is known as a test piece or test specimen. This piece should be selected with care in order that it may represent the average quality of the material of which it is a specimen. It is not uncommon to find variations of quality in the same piece of material, as, for example, in a boiler plate.

It is unwise, therefore, to depend on the results obtained from the testing of a single specimen; a number of tests should be made and the average of the results taken. This will give a more nearly correct idea of what may be expected of the material in actual service.

Forms of Test Pieces for Tension

Some of the forms of specimens used in tensile tests are shown in Fig. 1, in which (a) is a rolled (a) or square bar taken just as it comes from the rolls; (b) is a round rolled bar; (c) is a specimen cut from a plate; (d) is a specimen that has been turned down in the middle so as to give a uniform section for a considerable portion of its length; and (e) is a circular bar having a sectional area at the middle of about 1 square inch.

For ordinary work, specimens of square, round, or flat bars are cut directly from the rolled stock and used without further preparation. In all such cases, the least sectional area of the piece must be accurately measured and recorded. If the specimen is cut from a plate, the usual form is that shown in Fig. 1 (c). The front and back surfaces are rolled and are not machined in any way. The edges, however, are machined so as to make them parallel and about $1^{1/2}$ inches apart. For testing pieces from large bars, the middle part of the specimen is turned down, as in Fig. 1 (d). The large ends thus form convenient places to grip the test piece in the testing machine, while the break in the piece must occur somewhere between the larger ends, because of the reduction in cross-section.

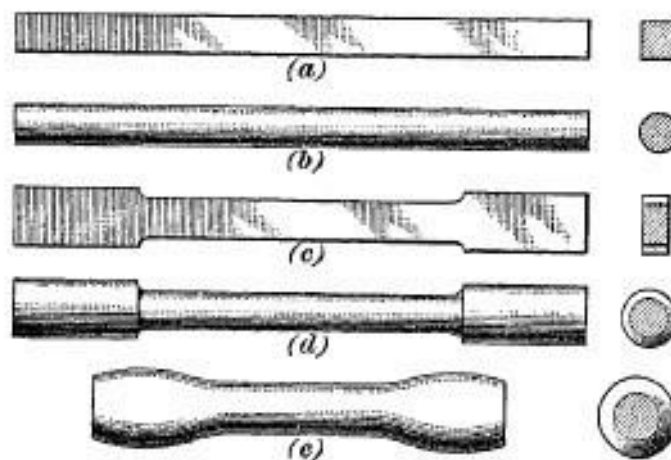


Figure 1

Test Piece with Threaded Ends

A test piece with threaded ends is shown in Fig. 2. This form is adopted by the American section of the International Association for Testing Materials. For steel forgings, the dimensions of the test piece are as shown in the figure. The ends are threaded with United States standard threads, ten to the inch.

The advantages of this form of specimen for steel forgings are as follows:

- (1) It is shorter than other forms and less material is wasted.
- (2) Less time and labor are required to prepare a small specimen.
- (3) The testing of a number of short specimens gives, at equal cost, a better idea of the quality of the material than the testing of one long specimen.

(4) The shorter piece can be taken from parts of a forging that will not give a long piece.

(5) The elastic limit, elongation, and reduction of area of cross-section in tension, can be determined quite as accurately by short as by long specimens.

There is no generally accepted standard form of test piece for tension. It has been found, however, that pieces having the same relative dimensions or of similar shapes have the same percentages of elongation and the same strengths per square inch, so that under these conditions comparisons of the materials tested may be made without error. A rule that may be safely followed is to make the length of the test piece eight times the diameter, in case of a round bar, and nine times the thickness in case of a square bar. A bar 8 inches long and 1 inch in diameter is used quite commonly in practice.

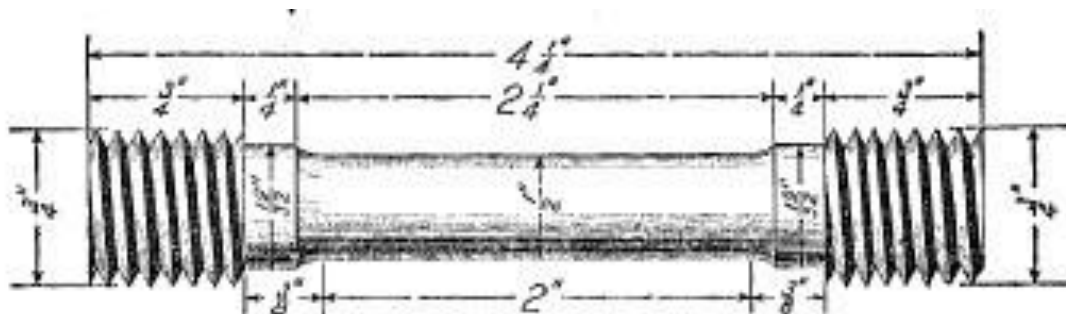


Figure 2

Test Pieces for Compression

There are a number of forms of test pieces for compression, but when it is Desired to find the compressive strength only, the length of the piece should not exceed ten times its least transverse dimension. Short square blocks are sometimes used for compression specimens, but the most common form is a short cylinder. There are two convenient sizes of this form, one being 1 inch in diameter by 2 inches in height, and the other .798 inch" in diameter by 1 inch in height. The area of cross-section of the first is .7854 square inch, while that of the latter is $\frac{1}{2}$ square inch, which is very convenient in calculating the stress per square inch. In preparing test pieces for compression, great care must be taken to have the ends quite flat and parallel, as well as at right angles to the sides of the piece. The pressure should be applied in a direction

parallel to the sides. If the ends are not at right angles to the sides, or if they are not flat, the load will not be distributed uniformly and the results of the test will be less trustworthy.

Test Pieces for Flexure

Test pieces for flexure are ordinarily made of square or of rectangular cross-section and of any convenient length. The small specimens of wrought iron and steel used in the testing machine are usually taken from bars 1 inch square, just as they come from the rolls, and are not machined or finished. Cast-iron specimens are also 1 inch square in section and are used just as they come from the mold, except that the sand is brushed off them. Larger test pieces maybe made of rolled shapes, and full-sized beams may be tested, provided that a machine of ample size is available.

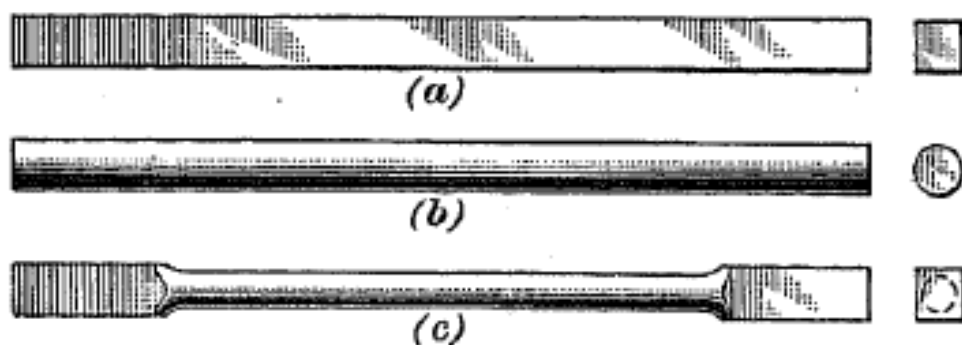


Figure 3.

Test Pieces for Torsion and Shearing

Test pieces of convenient sizes for torsion tests are shown in Fig. 3. That shown at (a) is a bar about 20 inches in length and 1 inch square; that at (b) is of the same length, but is cylindrical and 1 inch in diameter; that shown at (c) is a piece formed from a square bar turned down at the middle to 6 inch diameter. It is of the same length as the others.

Shearing tests of bars are seldom made. However, tests are sometimes made to determine the shearing strength of rivets. To do this, a test piece like that shown in Fig. 4 is employed. It consists of two plates riveted together. The plates are made of such strength that the rivets will fail first, by shearing off, when the entire piece is subjected to tension.

APPARATUS FOR TESTING MATERIALS

The Testing Machine

Physical tests of materials are usually made by means of a machine called a testing machine, although there are a few simple tests that can be made with ordinary tools, such, for example, as bending a piece of iron or steel while cold to determine its toughness

and ductility, or dropping a weight on a bar of cast iron to determine its ability to resist shocks. The important tests, however, are accomplished by special machines designed for the purpose, one of which is shown in Fig. 5. This machine may be used to test materials in tension, compression, or flexure. As shown in the illustration, the machine is fitted up to make a tension test.

The bar to be tested is held firmly by its ends in jaws or clamps at b and c. The lower clamp b is attached to the movable head d, which is raised and lowered by the turning of two heavy screws, one at each side of the head d.

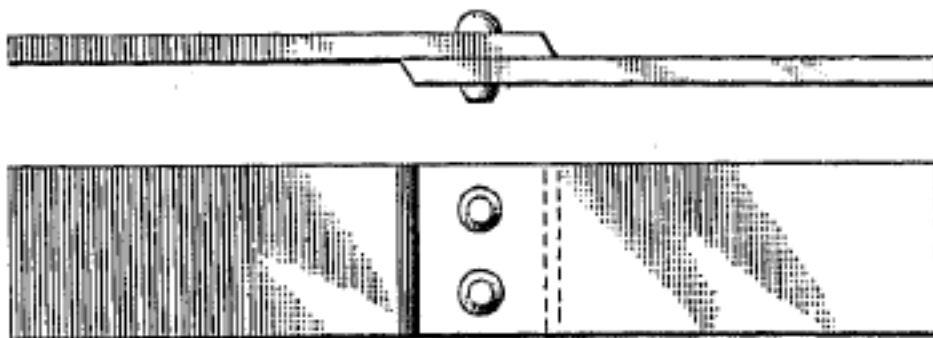


Figure 4.

One of these screws is shown at e. Large nuts are rigidly held in the head and the screws pass through them. Hence, when the screws are turned by the gears in the base of the One of these screws is shown at e. Large nuts are rigidly held in the head and the screws pass through them.

Hence, when the screws are turned by the gears in the base of the machine, the head d is moved vertically. The upper clamp c is held immovable in the fixed head f, which is supported on the columns g. These columns are secured to the weighing platform h, which rests on knife-edge bearings on the lever i. This lever is fulcrumed on knife edges that are supported by the box frame j. Consequently, when the head d descends, so as to exert a tensile force on the piece a, this force is transmitted to the head f and through it to the columns g, which in turn press downwards on the weighing platform h.

This pressure is then transmitted through the levers i and k to the scale beam l, which is graduated so that the load on the test piece can be read directly by moving the poise m to the point at which the scale beam floats or balances. This poise is moved by means of a long screw extending along the top of the scale beam.

The screw may be rotated by means of the hand wheel n, or it may be operated automatically. A battery o is connected to an electromagnet, which operates a clutch through which the screw may be caused to rotate by power from the driving mechanism of the machine. The battery is so connected that when the scale beam rises the finger p closes the battery circuit by touching the beam, and the clutch is instantly operated by the magnet.

The weight or poise is then moved out along the beam until the beam falls, breaking the contact at A releasing the clutch, and stopping the outward movement of the poise.

This action is repeated until the maximum load is reached. The poise must then be run back by turning the hand wheel n. To return the poise to the zero mark, a lever at the top of the poise is pressed down, releasing the nut which engages with the screw on the scale beam. The poise may then be moved by hand.

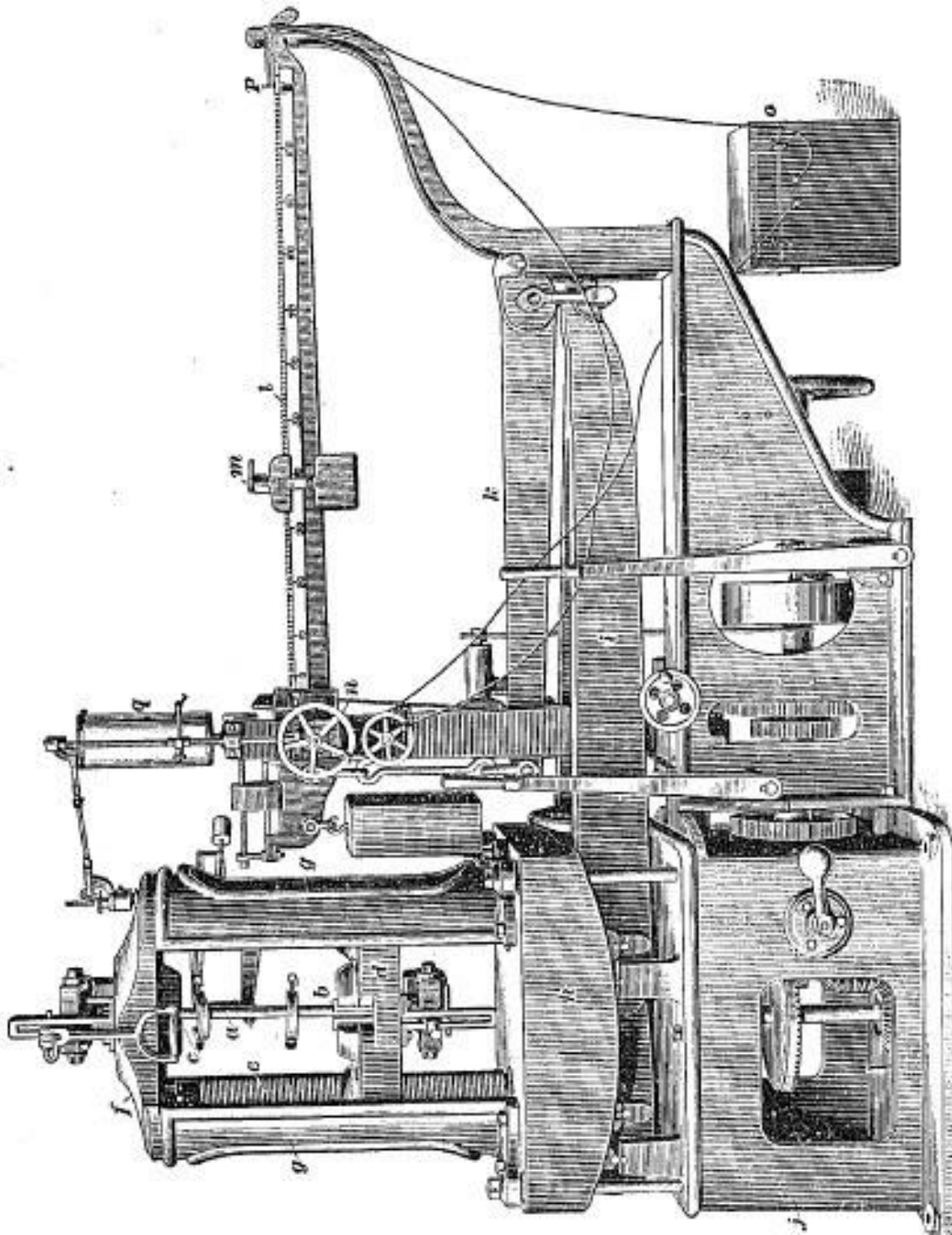


Figure 5

AUXILIARY APPARATUS

Jaws for Holding Test Specimens

When a test piece is subjected to tension in a testing machine, it should be acted on only by a force applied in the direction of its axis. That is, the ends of the piece should be so held that there will be no tendency to bend the test piece. In Fig. 6 (a) is shown a test piece held in ball-and-socket jaws intended to counteract any tendency to bend. The upper end of the test piece *a* is held firmly between the jaws *b* *t* *b* in the fixed head of the machine, while the lower end is held by similar jaws *c*, *c* in the movable head. The jaws press against blocks *d*, *d* that have ball-and-socket bearings at *e*, *e*; such jaws permit the piece to be stretched without

inducing any side stresses or bending forces. The jaws are wedge-shaped, and fit into tapered rectangular holes in the fixed and movable heads. On account of this wedging action, any increase in tension causes the piece to be held more firmly. The faces of the jaws are roughened into filelike surfaces that hold the test piece tightly and prevent slipping. In Fig. 6 (b) is shown the roughened face of an ordinary jaw for holding a flat test piece, like that shown in Fig. 6 (a).

In Fig. 6 (c) is illustrated a jaw used for the purpose of holding test pieces with round ends. As in the previous types, the gripping surfaces are roughened so as to take firm hold of the test piece.

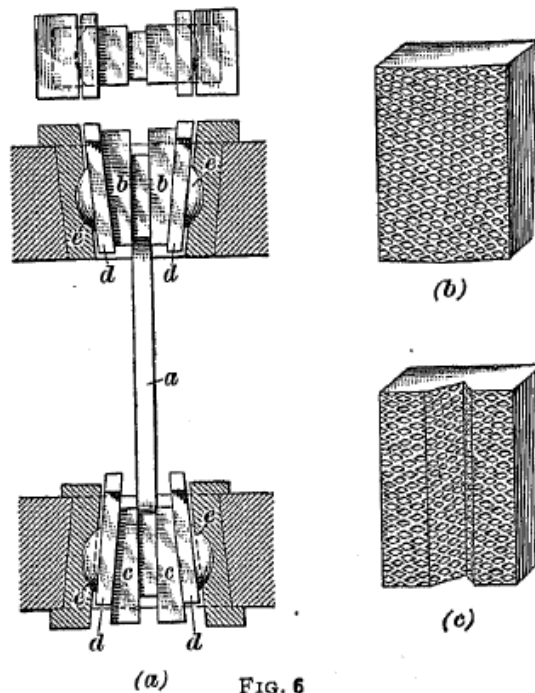


FIG. 6

The Micrometer Caliper

Before a test piece is placed in the testing machine, it is measured, so that its diameter, if it is a round specimen, or its breadth and thickness, if it is rectangular, is known: These measurements should be made very accurately. In Fig. 7 is shown one kind of measuring instrument used for this purpose; it is known as a micrometer caliper, and is capable of giving very accurate results. It really consists of two micrometers, a and b, fastened to one base c. The piece to be measured is placed between the fixed point d and the movable point e, and the latter is then screwed up by means of the knurled wheel f until it

rest slightly against the piece. The reading is then taken from the graduated scale on the bar g and the edge of the wheel f.

In measuring rectangular specimens, it is advantageous to have a double micrometer, as shown, so that one may be set for the width and the other for the thickness. These micrometers are graduated so as to read to 1/1000 inch, and may be used for measurements up to 2 ½ inches. This instrument is used also in determining the size of the test piece after it is tested, as in tension or compression tests the dimensions of the test piece are slightly altered.

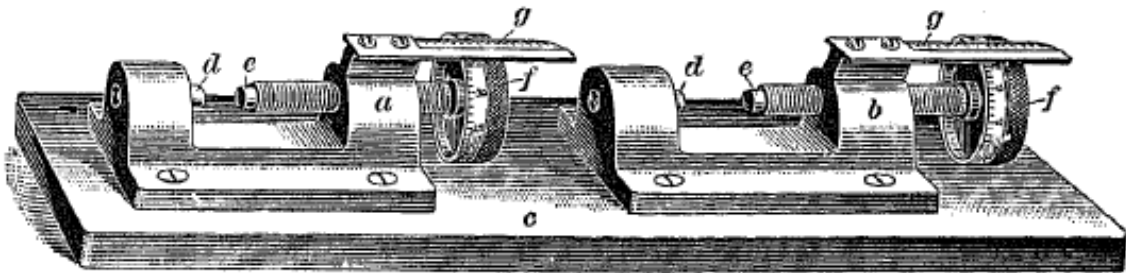


Figure 7

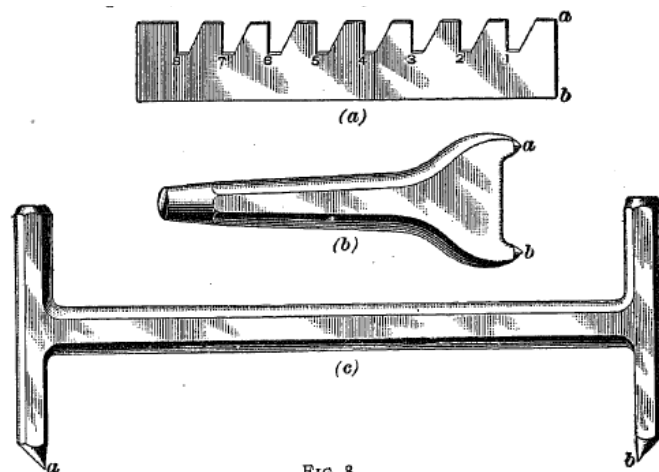


FIG. 8

Figure 8

Spacing Instruments

In a tension test on an 8-inch test piece, it is customary to divide the length into eight equal parts. After the test, the elongation of the piece is measured on this marked portion of the bar. An instrument adapted to the division of a test piece as described is shown in Fig. 8 (a). It consists of a steel rule having eight notches along its edge. The sides of these notches that lie parallel to the end a b are exactly 1 inch apart. Hence, by laying this rule on a flat test piece and making a scratch along each of the edges named the piece is easily marked off into eight Equal divisions.

If the test piece is round, the division may be accomplished by the use of the instrument shown in Fig. 8 (). It is simply a prick punch with two points instead of one, the points a and b being exactly 1 inch apart. Having scratched a straight line along the side of the piece, the eight 1-inch divisions are laid off by placing the prick punch in successive positions and tapping it lightly with a hammer. The marks thus left are permanent, whereas simple scratches on the piece may easily become effaced. The purpose of laying off these divisions is to locate the point where the test piece fractures or breaks; in some tests, also, it

is customary to measure the elongation in each inch of the piece.

In case two marks 8 inches apart are all that are desired, a double punch of the form shown in Fig. 8 (c) may be used. Its points a and b are 8 inches apart, and it is only necessary to place the points in position and tap each punch lightly with a hammer.

The Micrometer Extensometer

A form of instrument used to measure the elongation of a piece is shown in Fig. 9. It is known as the micrometer extensometer, since the measurements are taken by means of micrometer screws. The instrument is tightly clamped to the test piece by clamps at a and b. The points that hold the clamps to the test piece are kept exactly 8 inches apart by the distance bars c, one on either side. The upper ends of these are hook-shaped; after the instrument is firmly fastened to the test piece the hooked ends are disengaged and moved to one side, as shown in the illustration. To the lower clamp is fastened a frame carrying two micrometer screws d, d attached to index wheels e, e. The same frame also carries the graduated scales f, f. The upper clamp carries a frame to which are attached posts g, g that are adjusted so as to come directly opposite the points h, h

of the micrometer screws. These posts *g*, *g* are insulated from the other metallic parts of the instrument and are connected by wires to one pole of a battery *z*. Another wire connects the other pole of the battery

to the lower clamp *b*, through an electric bell *j*. It is evident, therefore, that if the point *h* of one screw touches the corresponding post *g*, the bell will ring.

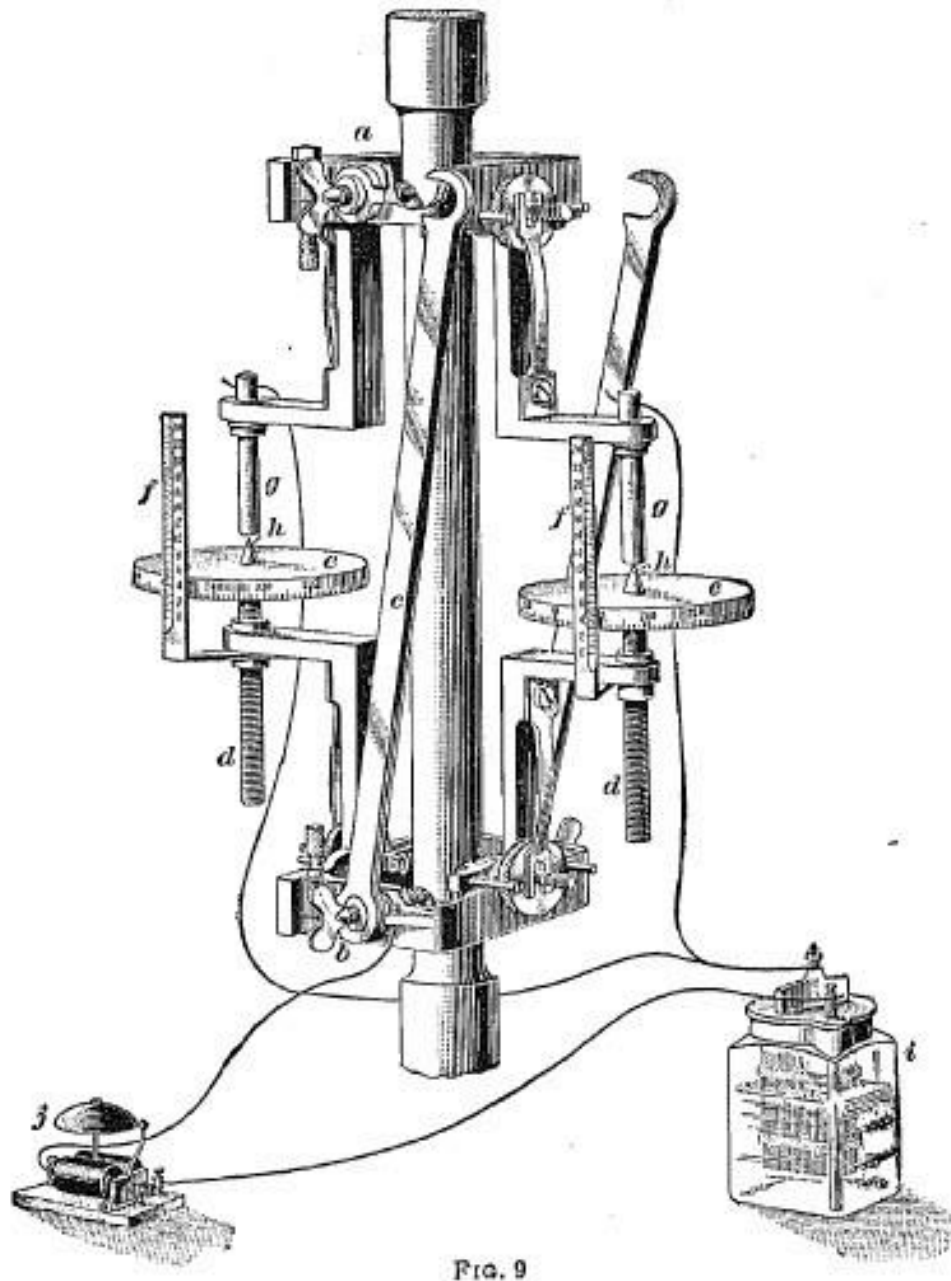


Figure 9

In order to measure the extension of a piece, the reading of each micrometer is taken before any load is applied. Then, when a certain load is put on the test piece, it will elongate somewhat, thus separating the post g from the point h. The wheels e, e are then turned until the points 7z, h just fail to touch the posts g,g, and the reading of each is again taken. The difference between the average of the first two and the average of the last two readings is the elongation. This operation is repeated for each load, or as often as it is desired to take readings. In order to be certain that the point h just fails to touch g, the screw is turned upwards until the bell rings and then turned back slowly until the bell ceases to ring.

The index wheels are graduated into 250 equal divisions and the screws have forty threads per inch. Hence, for each movement of one division on the index wheel, the vertical movement of the screw is $\frac{1}{40} \times \frac{1}{250} = \frac{1}{1000}$ inch; that is, the instrument will read to $\frac{1}{1000}$ inch. The readings from both micrometers should be taken as nearly at the same instant as possible, which may be accomplished by having an observer to manipulate each screw. It is usually desirable to have a bell for each micrometer, so that there may be no possibility of error.

The extensometer should always be removed from the test piece before fracture occurs, as the jar due to the recoil after the rupture may damage the instrument. Frequently, the elongation beyond the elastic limit may be measured roughly with a pair of dividers after the extensometer has been removed. These measurements can be taken nearly up to the breaking point, and while probably not accurate to less than $\frac{1}{1000}$ inch, they nevertheless may be used in determining the elongation near the point of rupture.

The Compressometer

In a compression test or in a transverse test, it is desirable to know the amount by which the piece shortens or by which it deflects under various loads. An instrument known as a compressometer, one form of which is shown in Fig. 10, is used for this purpose. It contains two micrometer screws a and b, having the same number of threads per inch and connected by the gears c, d, and e, so that when one screw is turned, the other turns an equal amount in the same direction. These screws are supported by the base / and carry the frame g, which, having once been set level, remains so, as the micrometer screws move equally.

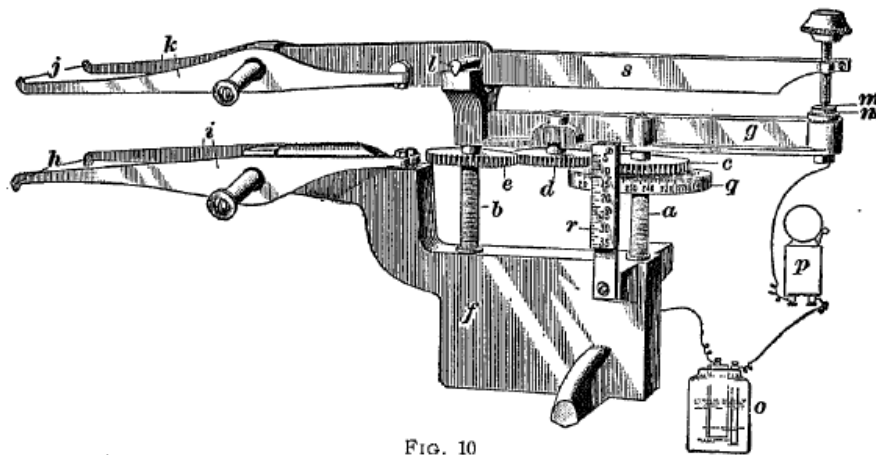


FIG. 10

Figure 10

In using this instrument, the points *h* of the rigid arms *i* are placed in contact with the platform of the machine, or with a block of convenient thickness lying on the weighing platform; these points do not have any vertical movement. The points *j* of the arms *k* are placed beneath the compression head of the machine and in contact with it. The arms *k* are fastened to a bar *s*, pivoted at *l*, which carries a thumbscrew at its end, the point *m* of the screw being opposite an insulated metal block *n* held in the frame *g*. The block *n* is connected to one terminal of a battery *o* through a bell *p*, the other terminal of the battery being connected to the frame of the instrument. Hence, if the point *m* touches *n*, the bell will ring.

Now, as the movable head of the testing machine descends, it depresses the points *j* and turns the bar on the fulcrum *l*, separating the points *m* and *n*. The screw *a*

is then turned down by means of the index wheel *q*, lowering the fulcrum *l* until the point *m* touches *n* and rings the bell. The amount the fulcrum *l* is lowered is measured by the index wheel *q* and the scale *r*. This measurement represents the amount the test piece is compressed. There are 250 divisions on the index wheel, and each micrometer screw has forty threads per inch, so that this instrument may be used to measure compression to 1/10000 inch. When used in connection with a transverse test, an instrument of this form is sometimes termed a deflectometer.

The Autographic Recording Apparatus

At *q*, Fig.5, is shown an autographic attachment by means of which the stress in a test piece and the corresponding deformation are automatically recorded throughout the test. An enlarged view of this apparatus is shown in Fig. 11.

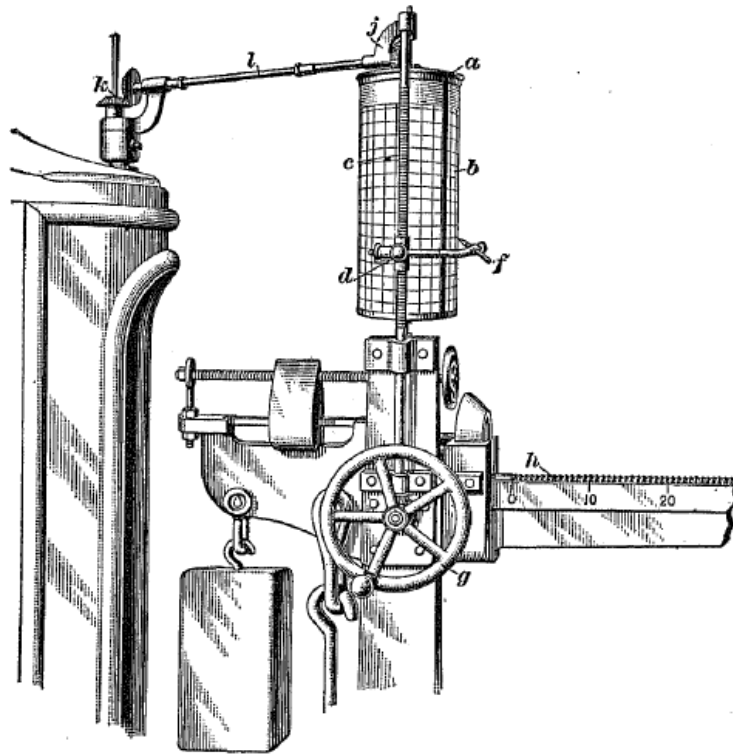


Figure 11

At a is a cylindrical drum, mounted on a vertical shaft supported by the frame of the machine. This drum has a sheet of paper b fastened tightly around it, the paper being divided into squares by horizontal and vertical lines equally spaced. Beside the drum and parallel to its axis is a vertical standard and a screw c, on which is a nut, at d, carrying an arm to which is attached a pencil f. This screw has a bevel gear on its lower end, which meshes with another gear on the shaft of the hand wheel g. Hence, any movement of the screw h on the scale beam will cause a corresponding vertical movement of pencil f. In other words, the vertical

movement of the pencil is proportional to the distance traveled by the poise in, Fig. 5, and hence proportional to the load on the test piece.

The drum a is given a rotary motion by means of bevel gears at l and k and the shaft l. This rotation is due to the deformation of the test piece. By means of gearing, the amount of deformation of the test piece is transformed into motion of the shaft l, causing rotation of the drum. Thus the amount of rotation of the drum, is at all times proportional to the deformation of the test specimen. In making a test, the pencil is set at the point on the paper b

corresponding to zero load and zero deformation. Then, as the test progresses and the load and deformation increase, the pencil rises vertically and the drum turns, and there is drawn on the sheet a curve that at all times represents the load and its corresponding deformation.

TENSION TEST

Method of Making The Test

Preparations for the Tension Test

The test piece having been first prepared and given a uniform cross section, the area of this section is carefully determined by the use of the micrometer calliper. Next, if it is an 8-inch specimen, the piece is marked off into eight divisions of 1 inch each, care being taken to have this length of 8 inches extend over that portion of the piece that is uniform in cross-section. When the piece is thus marked with prick

punch marks, it will appear somewhat as shown in Fig. 12.

The extensometer is then attached and the piece is placed in the jaws of the machine. At first, it will fit loosely, and in order to set the jaws firmly the machine is started and the movable head allowed to descend until the scale beam tips up, the poise having been previously placed at zero and the machine balanced. There is now a very slight tension in the test piece but it is so small that it will not affect the piece appreciably. In case the autographic attachment is to be used, it is now attached, and the pencil is set at zero on the sheet. The latter should fit snugly to the drum, and there should be no lost motion in any of the attachments. This completes the preparation of the machine for the test.



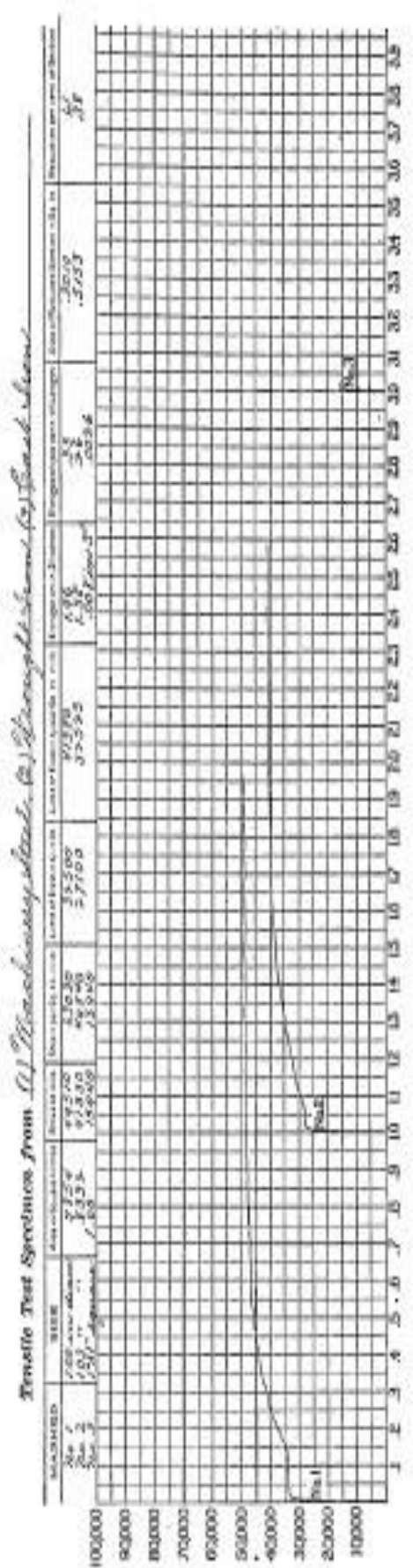
Figure 12

Conducting the Test

The readings of the scale beam and of the extensometer should be taken at the same instant. The interval between readings is not fixed, but may be assumed at pleasure. Some engineers prefer to take readings at intervals of 2,000 pounds; that is, to take a reading each time the tension becomes 2,000 pounds greater than at the preceding reading. Others take readings on a time basis, say every 1/2 minute.

The machine should be run very slowly until the piece is stretched beyond the elastic limit, after which it may be speeded up. The application of the load to the test specimen should be gradual and increase uniformly. There should be no shocks or jerks. Neither should the test be made too quickly. At ordinary temperatures, a tension test covering several minutes will give practically the same results as those obtained by applying the load much more slowly. But a very rapid application of the load tends to give too high values for the elastic limit and the ultimate strength. The testing machine is so constructed that from four to seven speeds are obtainable, to suit different conditions.

Card of Tensile Tests and Reports of Same TESTING DEPARTMENT



RECORDS OF THE TEST

The Autographic Diagram

When the autographic attachment is used in making a test, the diagram produced by it is known as an autographic diagram or a stress curve. Three of these diagrams, for three tension tests, are shown in Fig. 13j recorded on one sheet. The sheet on which the records are drawn is generally called a card. The three curves, together with the data at the top of the sheet, give full information concerning the tests.

Curve No. 1 is for machinery steel, No. 2 is for wrought iron, and No. 3 is for cast iron. The specimens of steel and wrought iron are 6 inches long, and of cast iron 3 inches long. The sheet is divided into squares, and each division on the vertical scale represents a load of 5,000 pounds, while each division on the horizontal scale represents an elongation of .05 inch.

It will be observed that in the test of machinery steel, as represented by curve No. 1, the curve is approximately a straight line, until a stress of about 32,500 pounds is reached. This means that up to this point the load and the elongation are in the same ratio, or directly proportional to each other.

Beyond this load, the elongation increases much more rapidly than the load, as shown by the approach of the curve to a horizontal line.

The point where this sudden change of direction occurs is the elastic limit, since it is the point beyond which the elongation is no longer directly proportional to the load. The area of the test piece being .7854 square inch and the stress at the elastic limit being 32,500 pounds, the elastic limit of the material must be $32,500 / .7854 = 41,380$ pounds per square inch.

The diagram also shows a total elongation of 1.96 inches, but as this is the elongation in 6 inches of length, the elongation per inch is $1.96 / 6 = .33$ inch, nearly, or practically 33 per cent. The area of the section at the point of rupture, measured after the piece is broken, is .3019 square inch. Consequently, the reduction of area, as compared with the original cross-section, is

$$\frac{.7854 - .3019}{.7854} = .61, \text{ or } 61 \text{ per cent}$$

Test of Wrought Iron Specimen Mark 9
Material from Greenway Iron and Steel Co
Form of Section Circular Machine used #1
Initial: Length 1 in. Dimensions of Cross Section 1 in. Area 78.54 sq. in.
Final: " 10 " " " " 35 " " 4794 " "
Position of Fracture Middle Character of Fracture Fibrous
Load per sq. in.: El. 1,00,555 Max. 51,037 Breaking 48,841
Elongation % 75 Reduction of Area % 37 Modulus of Elasticity 26,000,000

No.	LOAD		EXTENSOMETER READING			ELONGATION		
	Actual P	Per Sq. In. S. A.	1	2	Mean	Actual	Diff.	Per In.
1	0	0	.0645	.1356	1.0005	0	0	0
2	4000	5093	.0661	.1368	1.0145	.00140	.00140	.000175
3	8000	10186	.0673	.1386	1.0295	.00290	.00150	.000363
4	12000	15279	.0685	.1403	1.0455	.00450	.00160	.000563
5	16000	20372	.0707	.1417	1.0595	.00535	.00135	.000800
6	20000	25465	.0720	.1433	1.0765	.00760	.00170	.000950
7	24000	30558	.0759	.1434	1.0765	.00960	.00200	.001200
8	24810	31589	.0930	.1590	1.2550	.02545	.01585	.003191
9	25540	32518	.1430	.1944	1.6870	.06865	.04320	.008581
10	26660	33944	.1680	.2255	1.9675	.09670	.03805	.012088
11	28910	36809	.2188	.2800	2.4940	.14935	.05265	.015669
12	31540	40043	.3070	.3850	3.4350	.24345	.09410	.030431
13	33370	42487	.3945	.5000	4.4725	.34720	.10375	.043400
14	35310	44958	.5370	.6054	5.7120	.47115	.12395	.058894
15	36520	46498	.6788	.7054	6.6710	.56705	.09590	.070881
16	37470	47708	.7235	.8100	7.6675	.66670	.09965	.083338
17	38500	49020	.8870	.9650	9.2600	.82595	.15925	.103244
18	39000	49656	.9836	1.0757	10.2965	.92960	.10365	.116200
19	39850	50102	1.1400	1.1902	1.16510	1.06505	.13545	.133131
20	39660	50497	1.2250	1.3000	1.26250	1.16245	.09740	.145306
21	40260	51261	Extensometer			1.30000	.13755	.162500
22	40320	51337	Removed			1.60000	.30000	.200000
23	40070	51019				1.90000	.30000	.237500
24	38360	48111				2.00000	.10000	.250000

Date _____

Observers _____

10

FIG. 14

Figure 14

The records on the card show similar data for both the wrought-iron and the cast-iron specimens. The point of zero stress for all of the curves has been taken on the base line of the diagram, but the point of zero elongation has been shifted to the right in the case of curves No. 2 and No. 3 in order that the curves may not intersect and thus become confused.

In any case, the total elongation is found by subtracting the reading at the beginning of the test from the reading at the point of rupture. In the case of the wrought-iron specimen, the total elongation is $2.58 - 1.00 = 1.58$ inches, while in the case of the cast-iron specimen it is but .008 Inch.

Log of a Tension Test

The record of a test, frequently termed the log of a test, may be kept in a number of convenient forms, one of which is illustrated in Fig. 14. It consists of a sheet divided into several columns, with blank spaces in which are written the data observed during the entire test.

The first column at the left gives the numbers of the readings, and the second gives the corresponding loads as read from the scale beam. In the third column are given the loads per square inch of section, these results being found by dividing the

load P in the second column by the area A of the cross-section of the test piece, in square inches.

In the test from which this record was taken, the elongation was determined by the use of an extensometer like that shown in Fig. 9, and the poise on the scale beam was operated by hand. The fourth and fifth columns contain the readings of the two micrometers on the extensometer, the mean of each pair of readings being given in the sixth column, found by taking one-half of the sum of the two readings at any instant. In the seventh column are given the actual elongations corresponding to the separate readings.

The actual elongation at any instant is equal to the mean extensometer reading for that instant minus the first mean reading of the extensometer. Thus, for the eighth reading, the elongation is $.12550 - .10005 = .02545$ inch; for the seventeenth reading, it is $.92600 - .10005 = .82595$ inch.

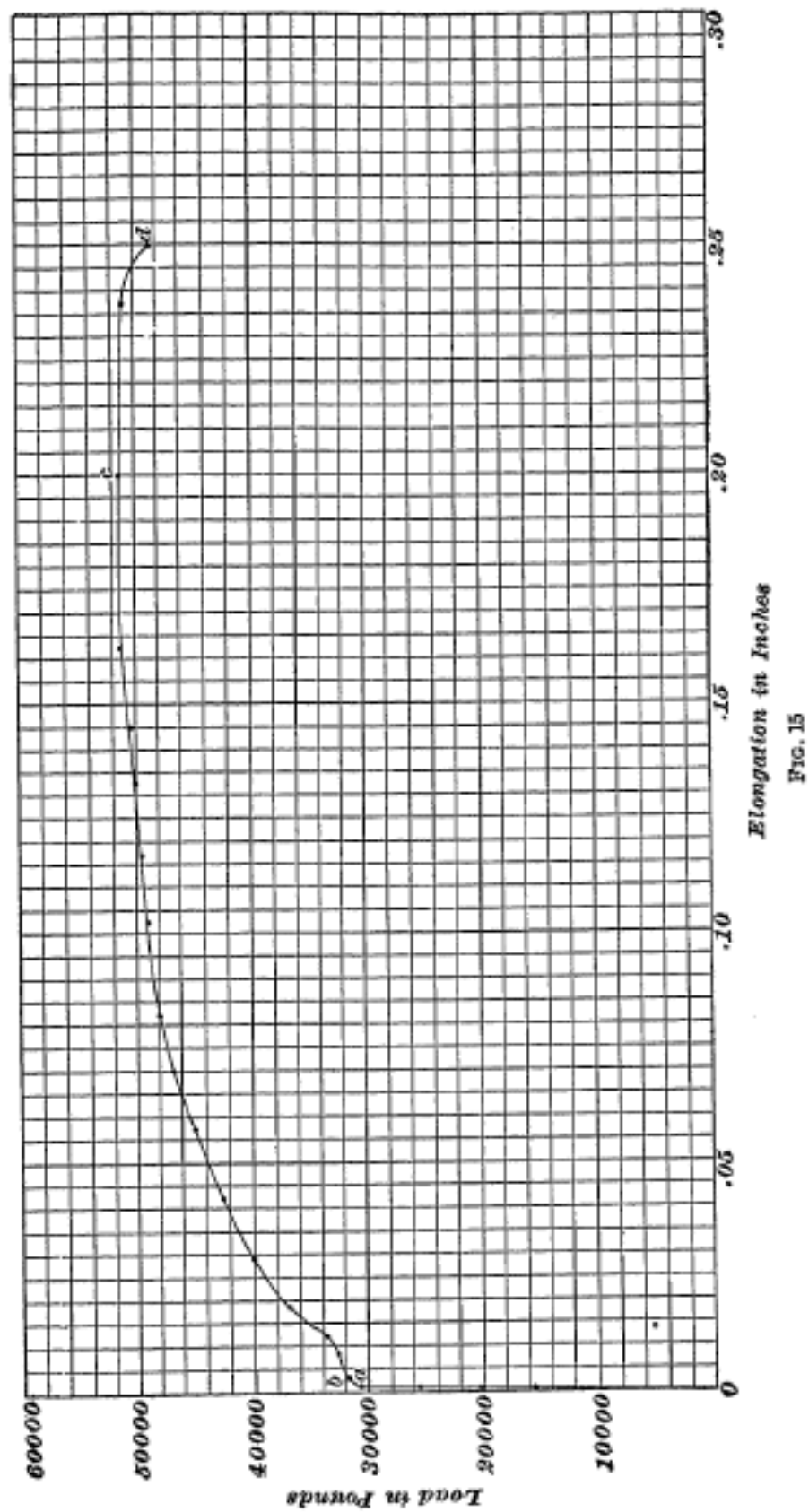


Figure 15.

The last four readings in this column were secured by measuring the test piece with the aid of a pair of dividers after the extensometer was removed.

The eighth column gives the differences of elongation, each of which is found by subtracting from its corresponding actual elongation the preceding actual elongation. Thus, at the tenth reading, the difference of elongation is equal to $.09670 - .06865 = .02805$ inch. The last column gives the actual elongations per inch of length of the piece, these being found by dividing the values in the seventh column by 8, the length of the test piece, in inches.

The notes on the upper part of the report explain themselves, to a large extent. The final length is equal to the original length plus the total elongation up to the point of rupture of the piece. The final area of cross-section is determined by measuring the dimensions of the piece at the point where it broke. The percentage of elongation is found by dividing the total elongation by the original length of the piece; thus, $2 - 1.75 = .25 = 25$ per cent. The percentage of reduction of area is found by dividing the difference between the initial and final areas by the initial area; thus, $(.7854 - .4794) \div .7854 = .3896$, or say 39 per cent.

The terms modulus of elasticity, maximum and breaking loads, and load at the elastic limit, will be explained later, in connection with the curve of stresses and elongations.

Plotting the Stress Curve

After the log of the test has been prepared, as in Fig. 14, the stress curve may be plotted as shown in Fig. 15. This should be done on sheets, ruled into small squares, known as cross-section paper or squared paper, since it is very convenient to use.

The first step is to decide on the scales of stress and elongation. Suppose that each vertical division represents a load of 2,000 pounds, and each horizontal division an elongation of .005 inch per inch of length of the test piece.

Taking the data given in the third and ninth columns in Fig. 14, the stresses are laid off in Fig. 15 as ordinates and the corresponding elongations as abscissas, and through the points thus located a curve is drawn; this curve is stress curve. It may not be possible to draw a small curve to pass through all the points located. This is usually due to errors in observing the readings, and in such a case, the curve should be drawn so as to represent,

approximately the mean of the locations of the points.

CONCLUSION:

Reading the Test Curves

In connection with curve No. 1, Fig. 18, it was shown that the elastic limit is represented by the point at which the curve first takes a decided slope from the vertical. In Fig.15, the point represents the elastic limit of the material, since that is the point where the curve rapidly departs from the straight line Oa. At the point b, there is a still more decided departure from the vertical trend; this point is known as the yield point. It is at this point that the test piece begins to fail rapidly, showing that its structure is being broken down. The point c at which the curve is farthest above the base line indicates the point of ultimate strength of the material; that is, the point of maximum load per square inch. At d, the end of the curve, the piece fractures, and the height of this point above the base line represents the breaking load, which may or may not be equal to the ultimate strength.

The falling of the curve from c to d indicates that there is a rapid decrease of load on the test piece during this period of the test. After passing the point of ultimate strength c, the elongation becomes very

rapid, and in order to keep the scale beam floating or balanced, it is necessary to move the poise backwards along the beam, which results in a gradual falling of the curve on the autographic record. As the piece yields, its area of cross-section rapidly diminishes. If the testing machine were so made that the load at c could be maintained steadily, the piece would break at that point. Hence, the fiber stress at the point c is called the maximum fiber stress, or ultimate strength, of the material. Inspection of the stress curve and the test report shows that the load per square inch at the elastic limit a is 30,558 pounds. The maximum load, at c, is 51,337 pounds per square inch, while the breaking load, at d, is only 48,841 pounds per square inch. The modulus of elasticity is equal to the load per square inch, at any point below the elastic limit, divided by the elongation per inch at that load. That is, divide any value in the third column of Fig. 14, up to the elastic limit, by the corresponding value in the ninth column to obtain the modulus of elasticity.

The module of elasticity calculated from several readings will not agree exactly, but by taking the average of several results a close approximation to the true modulus may be secured. Thus, taking the corresponding readings in the fourth line of Fig. 14,

$15,279 - .000563 = 27,140,000$, nearly;

taking the fifth line,

$20,372 + .0008 = 2,5,460,000$;

taking the sixth line,

$25,465 \sim .00095 = 26,800,000$;

taking the seventh line,

$30,558 \sim .0012 = 25,460,000$

The average of these four results is 26,215,000, so that the modulus of elasticity may be taken, approximately, as 26,000,000.

Important Points in a Tension Test

There are six important points or factors to be determined by a tension test, of which a record should be kept by means of a suitable report or record, or by a diagram, or still better, by both. These factors are the modulus of elasticity, the elastic limit, the yield point, the ultimate strength, the percentage of elongation, and the percentage of reduction of area of cross-section.

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