THESIS

Design of a
Fatigue Testing Machine

by

V. E. Farmer.

Class of Nineteen Hundred and Sixteen

Department of Mechanical Engineering .

THROOP COLLEGE OF TECHNOLOGY
Pasadena, California.

1916 .

CONTENTS.

I. Introduction.

The Testing of Materials Laboratory at Throop College of Technology is equipped with a White-Souther fatigue testing machine. The machine is of the revolving arm type and the specimen is loaded as a cantilever. The specimen can be loaded up to its elastic limit or even higher but the range for test is from seventy to one hundred percent. The time of a test is between two and three weeks as a maximum; therefore the machine is of importance in the College or research laboratory only.

The objections to the White-Souther machine are as follows.

1- The time required to run a series of tests is very long, because of the fact that only two specimens are tested at the same time.

2- The specimen is costly and must be made up by a machinist.

3- An empirical formula is used to determine the stresses in the material.

4- The specimen is loaded as a cantilever and therefore the maximum stress occurs at a fixed point and it will always break at this fixed point, independently of any local weakness that exists,

5- The specimen is long and therefore a series of tests may not (because of changes that may occur in a bar) give comparative results.

6- Because of the shape of the specimen the piece cannot be tested in tension after it has been partially fatigued.

The present type of design is of the revolving beam. The specimen is subject to a uniform bending moment over the entire length of the part under test. The range of loading is from fifty percent. to one hundred percent. of the elastic limit. The time of test is cut down in as much as ten specimens can be tested at once. The machine is adapted to College or Research Laboratories. Commercial tests are made in a very short time and give very good comparative results for the acceptance of new materials. If one is studying the effects of repetition of stress in a specimen loaded inside of the elastic limit of the material, this machine is adapted to his work. The machine as designed is an attempt to use the good points of the old machine and combine with these the correction of the worst of its faults.

The following paragraphs show how the faults of the White-Souther machine were corrected and used in the new design.

The time of a single test will take two or three weeks as a maximum. This depends on the relation of the load impressed to that required to stress the piece to its elastic limit. A piece stressed to its elastic limit will not run for as many alternations of stress as one loaded beneath the elastic limit. If a series of tests are conducted several pieces are cut from the same rod and tested at various proportions of the elastic limit. In case six tests were made from fifty percent. to one hundred percent. of the elastic limit, by variation of ten percent. each there would be six specimens to be tested. Two specimens can be tested at the same time in the White-Souther machine. In order to make such a series of tests the time required would be nearly six weeks. In case check runs were made another six weeks would be required. If the new design, which has ten spindles, were used the time would be cut down to the length of time required to run the longest test (namely, two weeks). If a check run were required, four of the second set could be tested at the same time as the first. Although the time per specimen is not reduced the total time is cut down by testing ten specimens at a time.

The cost of the White-Souther specimen is between three dollars and four dollars. This is due to the extreme care required in getting the dimensions absolutly exact. Any machine or file marks near the dangerous section decrease the life of the piece. This is overcome in the new design by the use of a simple specimen reduced in area for part of its length in order not to have any bending in the chucks. The reduced section is circular in shape and may be any length, one inch being suggested for a suitable length. The radius of the fillet between the reduced and large sections need not be an accurate circular arc. It can be made up with any tools that are on hand and a diameter of an eighth of an inch is suggested. This simplicity makes it possible for anyone with an ordinary knowledge of a lathe to make up the specimens.

The use of an empirical formula to determine the stresses in the material is not objectional in itself. It is due to the fact that if any slight change is made in the chape of the specimen a change would be made in the stress caused by given loading. Thus any slight change in the dimensions as specified by the maker, would render the stresses, as determined by the formula, somewhat in error. This is due to the fact that the formula was derived from results obtained by testing pieces made in exact accordance with the working drawings of the piece. In the present design this is overcome by subjecting the specimen to a uniform bending moment over the entire length of its reduced section. The stress can be easily calculated from the formula $M = pI/e$.

M = bending moment impressed on the piece expressed in inch-pounds.

p = stresses in the material expressed in pounds per square inch.

I - moment of inertia of the section.

e = this distance of the outside fiber to the neutral axis.

With a certain moment the value of "p" depends on the values of "I" and "e". These in turn depend on the cross-section of the piece alone. Thus the influence of the length and the care of getting the dimensions exact have been eliminated.

A cantilever specimen is subject to the maximum stress in one section only. This means that, if there is any irregularity in the metal in any other section, the break would not be affected by this. This is due to the fact that the piece is not under maximum stress at this point. In this way high values would often be obtained. By taking a piece subject to a uniform bending moment over its entire length this can be overcome. It is thus overcome in the new specimen. The values thus obtained would be uniformily lower than those obtained with the old machine. This is an advantage in as much as it shows values at the weakest point in the specimen. In case there were any irregularities the weakest section would necessarily give way first. This lower value obtained will therefore give more uniform results of the tests.

A bar of any material may vary greatly from one end to the other. The use of a long specimen which has a maximum stress at one point only increases the danger of missing the weak places in the bar. If several tests are made on pieces from the same bar and each piece is loaded to stress the material to different values the results may not show results that should compare with the loadings, i.e. the results may not be in accordance with the loadings or proportional to the loadings. In a long specimen this discrepancy is due to the change in composition of the bar itself. By using short pieces this chance for a change in composition is reduced to a minimum. Two complete specimens in the old machine have a length of between fifteen and sixteen inches. The new specimens may be made as short as three and one-half inches thereby getting nearly five instead of two from the same length of bar and by this lessening the danger of a difference in composition in the various specimens.

Another test that can be made with the specimens of the new design is as follows;- a piece that has been partially fatigued may be tested in tension and comparative values of tension obtained for different degrees of fatigue. This is valuable to determine how a piece should be loaded after it had been subjected to a given number of reversals of stress. This will be of interest in determining the factor of safety for various work. Nothing like this could be done with the old specimen because of its shape.

II. Formulae and Data of Design.

Lever arm - the maximum weight - 25 lbs.

The length of the lever arm is to be such that a one pound weight will put a stress of two thousand (2000) pounds per square inch into the specimen.

$$M = \frac{p\ I}{e} \qquad I = \frac{\pi d^4}{64}$$

$$p = \frac{P\ l \times 64\ d}{\pi d^4 \times 2} \qquad e = \frac{d}{2} = \frac{1}{4} \text{ inch.}$$

P - one pound

$$\therefore l = \frac{2000 \times \pi \times (\frac{1}{2})^3}{32} \qquad p = 2000 \text{ lb/in}^2$$

l = 24.54 inches - length of lever arm.

Make the arm of steel seamless tubing. Use a one inch tube one-sixteenth inch thick.

$$\frac{I}{e} = \frac{\pi[(d_1)^4 - (d_2)^4]}{64 \times \frac{d}{2}} \qquad e = \frac{d}{2} = \frac{1}{2} \text{ inch.}$$

$$\frac{I}{e} = \frac{\pi[(1)^4 - (\frac{7}{8})^4]}{32}$$

d_1 = one inch.

d_2 = 7/8 inch.

$$\frac{I}{e} = 0.0411$$

Section Modulus required

$$M = \frac{p\ I}{e}$$

M = P l - 24.54" x 25 lbs.

$$\therefore \frac{I}{e} = \frac{25 \times 25}{16000} = 0.0391 \qquad p = 16000 \text{ lb/in}^2$$

This tube is sufficiently strong. Because it must be threaded at its weakest section a sleeve is inserted into the tube at this point with a slight press fit. The thickness of the straightening sleeve must be at least one-sixteenth inch. A piece of three-quarter inch extra strong pipe turned down to 0.8755 inch outside diameter gives the required thickness.

The bearings. Ball bearings to be used. Four per spindle. Thrust load to be carried by the bearings.

M = 625 inch-pounds.

Assume bearings as three inches apart.

Radial thrust on bearing : $\frac{625}{3} = 208.3$ pounds

Axial thrust - Weight of head and weights assume to be equal to thirty (30) pounds.

Equivalent radial load = 300 pounds.

Total radial load = 510 pounds.

Use Norma - Light Series - No. 206.

(Bore = 1.1811 inches
(
(Outside Diameter = 2.4410 inches.
(
(Width = 0.6299 inches

Chuck for holding specimen.

Reamed with No. 7 Brown and Sharpe taper reamer; taper ½ inch to one foot. - Diameter at large end = 13/16".

Required thickness of sleeve.

Assume force used when inserting specimen into chuck = 60 pounds.

$$\tan^{-1}\theta = \frac{1}{24} = 0.0417$$

$$\therefore \theta = 2^{\circ} - 21.9'$$

$$\frac{\theta}{2} = 1^{\circ} - 10.95'$$

$$N = P \csc. \frac{\theta}{2} = 60 \times 48.9. \quad \csc 1^{\circ}-10.95' = 48.9.$$

$$N = 60 \times 48.9 = 2840 \text{ lbs.}$$

$$\text{Area} = \left(\frac{13}{16}\right) \pi \times 2 = 5.10 \text{ square inches.}$$

$$P = \frac{2840}{5.10} = 567 \text{ lbs. per square inch.}$$

Assume 600 pounds because the hole is not 13/16 inches in diameter throughout the entire length.

Hoop Tension in hollow cylinder.

$$p = \frac{dW}{2h}$$

$$h = \frac{.8125 \times 600}{2 \times 14000}$$

$$h = 0.0174 \text{ inch}$$

$p = 14000$ lbs/in^2.
$W = 600$ lbs/in^2.
$d = 0.8125$ inch
h = thickness

$\therefore$ The chuck need only be slightly over 1/64 inch thick to withstand the driving to place.

Driving gears.

Driving gears. (Continued)

Using one to one ratio - 45° Helical gears - Both left handed (to get desired direction of rotation).

Maximum outside diameter = 2,4410 inches

Mimimum inside " = 1.5000 "

Assume : Diametral pitch = 12

18 teeth.

True normal helix = $\frac{18}{12}$ = 1.50

Pitch Diameter = $\frac{1.5}{.7071}$ = 2.120 inches

Outside diameter $\left(\frac{-2 \text{ in.}}{\text{dia P}}\right)$ = 2.287 inches

Drive shaft - 1500 r.p.m.

No calculations could be made as to the power required to drive the machine, because it is not known how much power is consumed in deforming the specimen. It has been estimated that the total power would be between three and five horse power. A one inch shaft will carry this load at 1500 r.p.m.

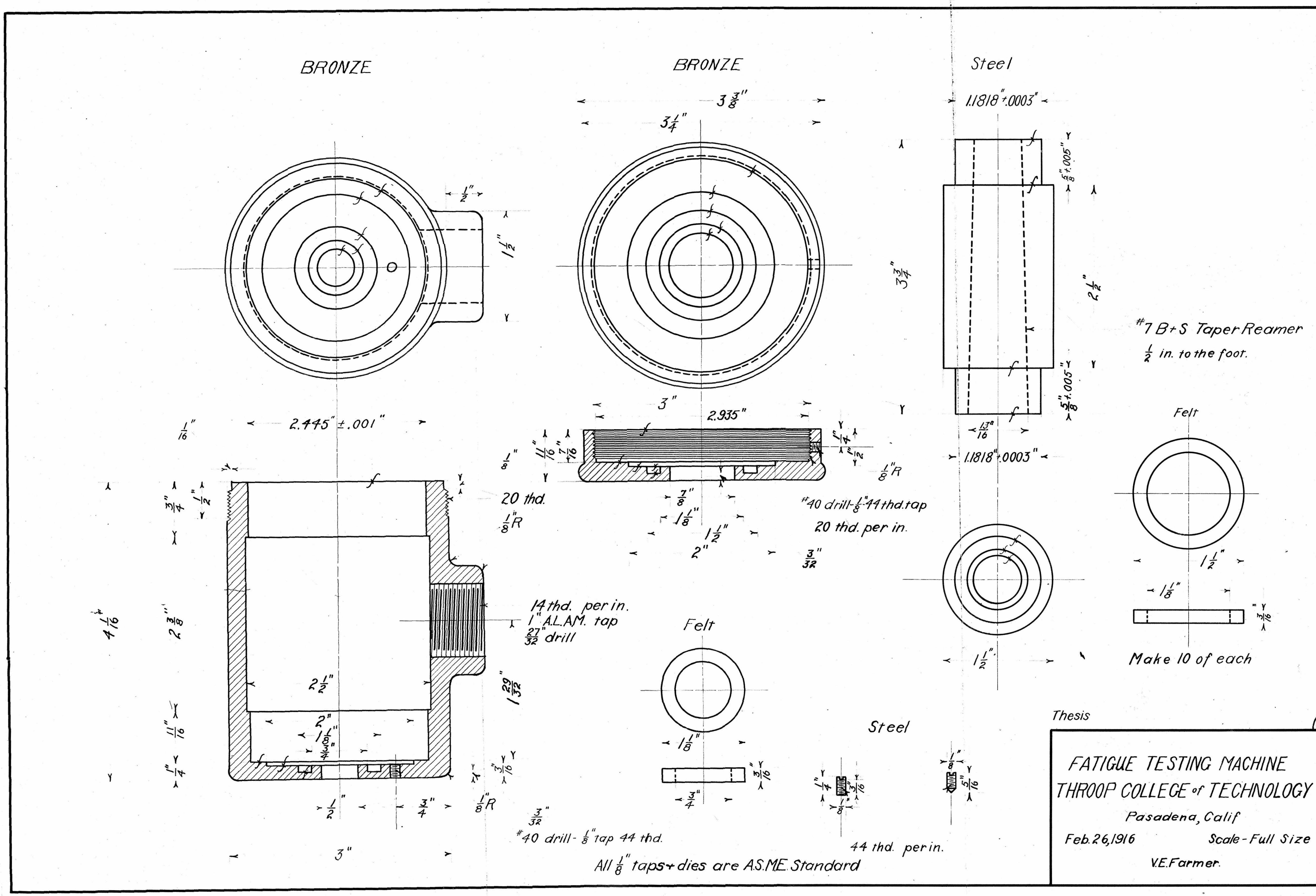
The counting mechanism.

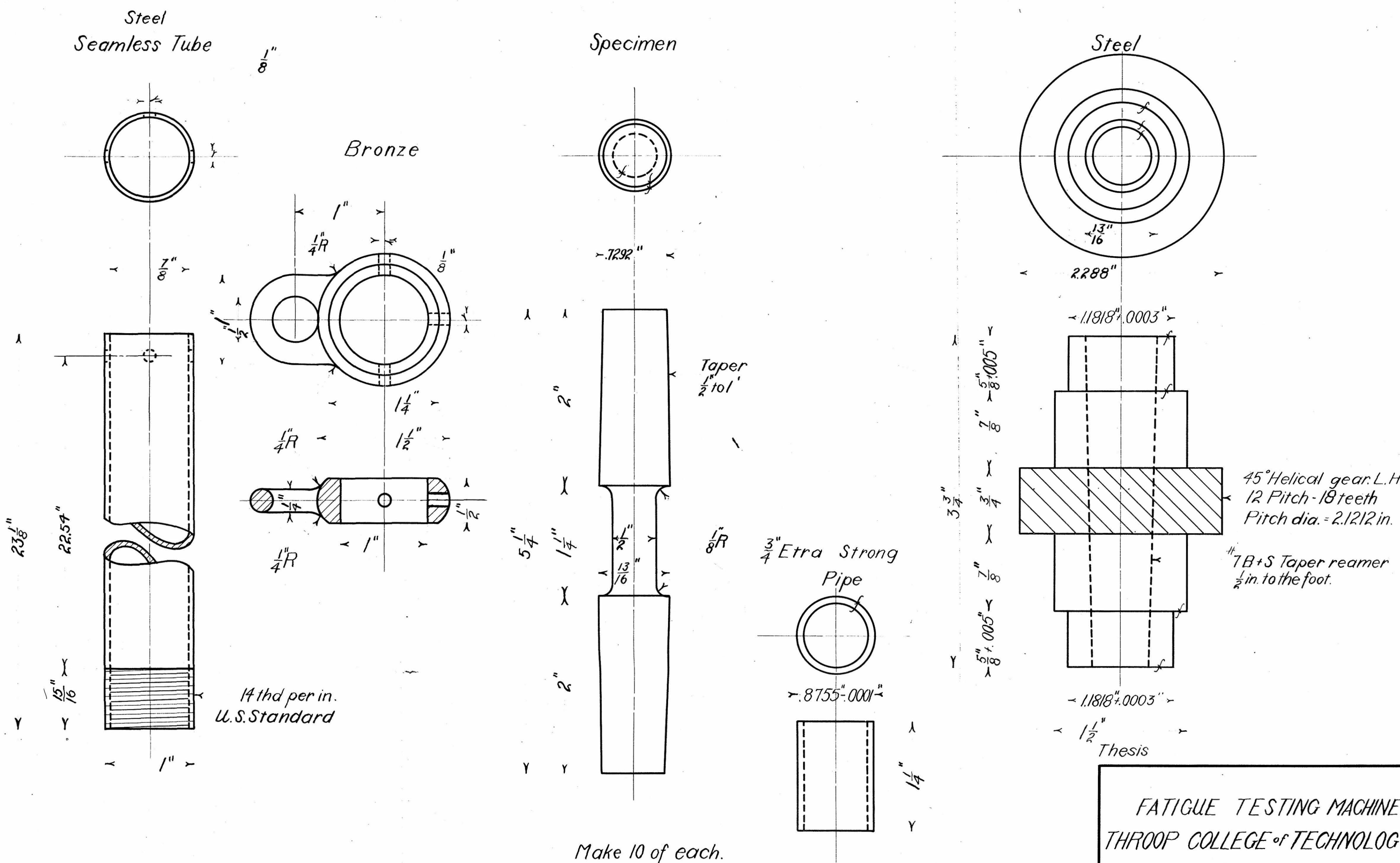
By mounting a five figure counter on the head of each spindle the need of a reducing gear is eliminated. Veeda counters, which register once every complete turn are used. These must be equipped with a five point star wheel, and therefore the readings on the counter must be multiplied by five to give correct results. One end of each specimen will have to be drilled and tapped for a one-fourth inch bolt. The depth of thread required is one-half inch.

The space left for the counter may be used for the switch for the driving motor. Mount the switch on a one-half inch piece of fiber eight inches square. One-half inch holes are drilled in each corner one inch from the sides.

The machine is to be mounted on one of the tables in the Testing Laboratory.

The motor is to be direct connected to the shaft by some form of flexible coupling.


BRONZE
BRONZE
Steel
#7 B+S Taper Reamer
1/2 in. to the foot.
Felt
Make 10 of each
20 thd.
#40 drill - 1/8" - 44 thd. tap
20 thd. per in.
14 thd. per in.
1" A.L.A.M. tap
27/32" drill
Felt
Steel
#40 drill - 1/8" tap 44 thd.
44 thd. per in.
All 1/8" taps + dies are A.S.M.E. Standard
Thesis
FATIGUE TESTING MACHINE
THROOP COLLEGE of TECHNOLOGY
Pasadena, Calif
Feb. 26, 1916
Scale - Full Size
V.E. Farmer.



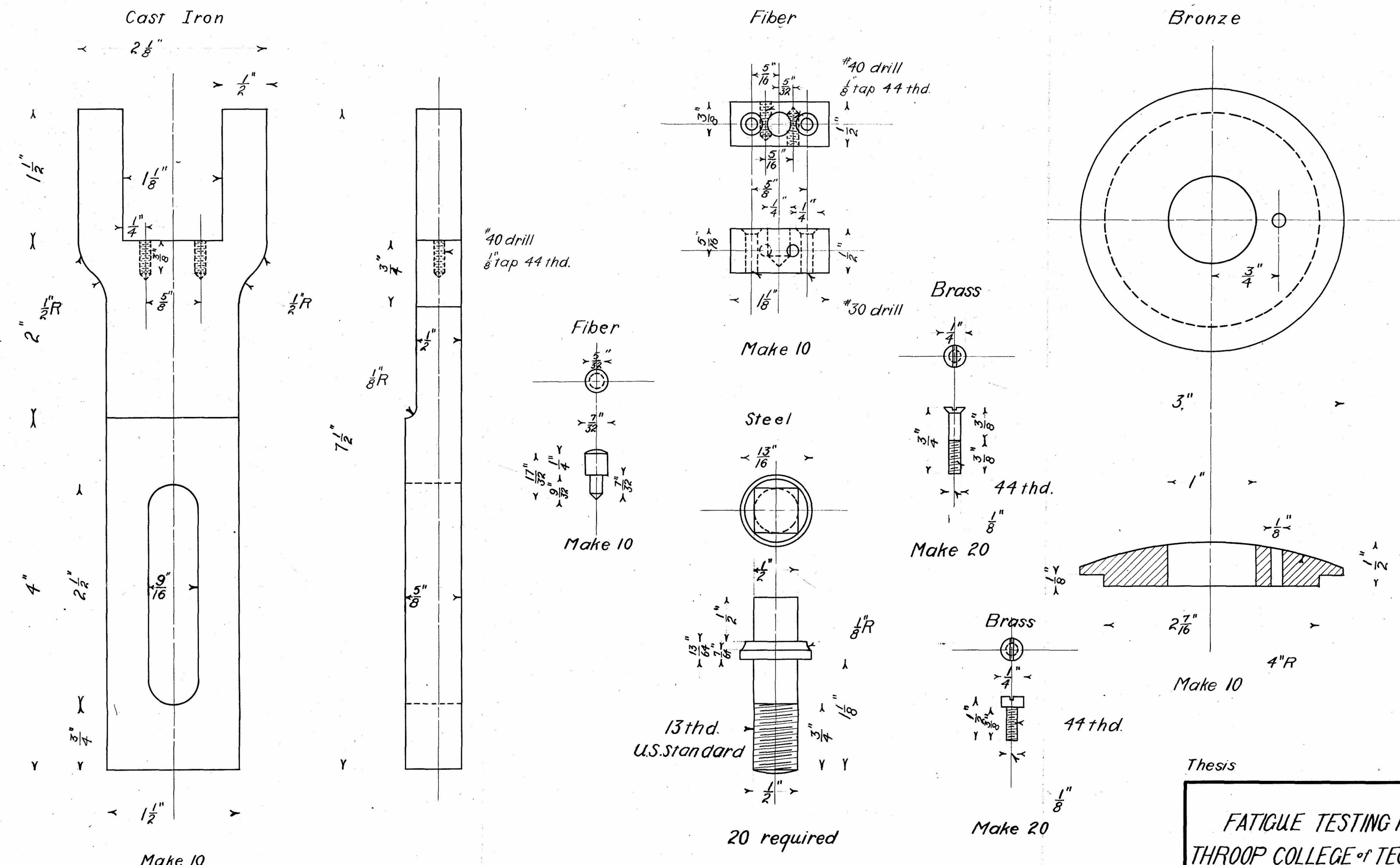
FATIGUE TESTING MACHINE

THROOP COLLEGE of TECHNOLOGY

Pasadena, Calif

March 18, 1916 Scale - Full Size

V.E. Farmer



Thesis

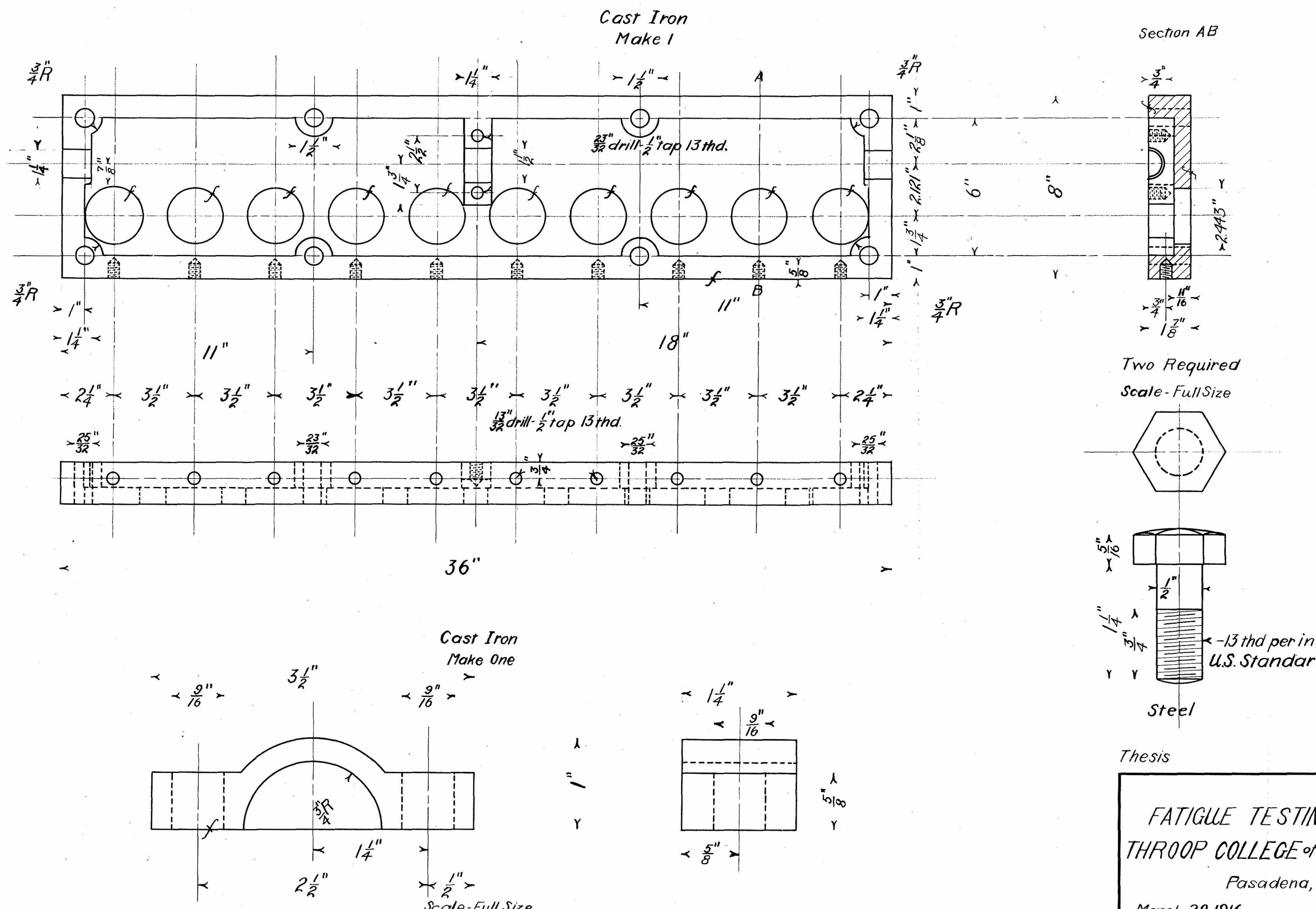
FATIGUE TESTING MACHINE

THROOP COLLEGE of TECHNOLOGY

Pasadena, Calif.

March 27, 1916 Scale - Full Size

V.E.Farmer

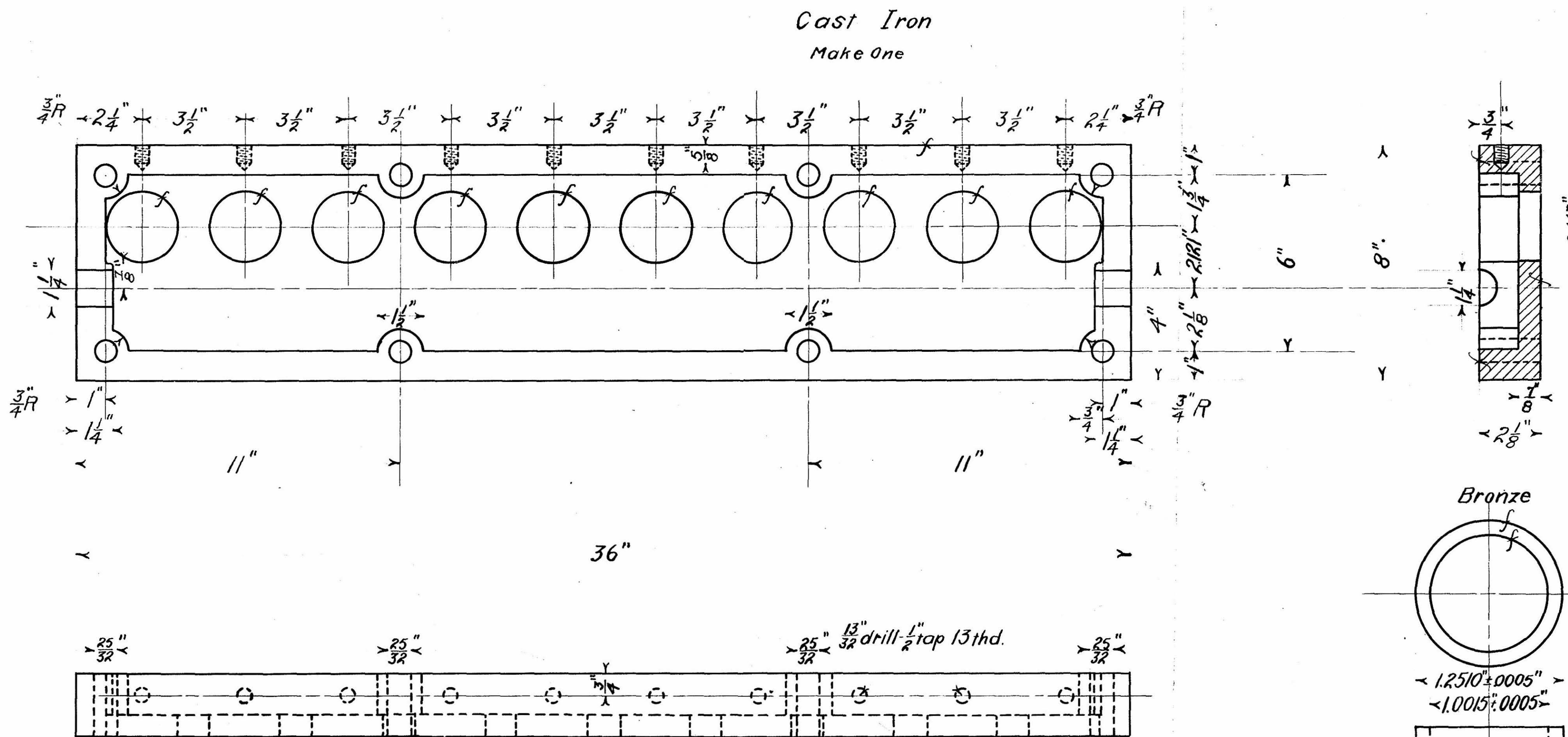


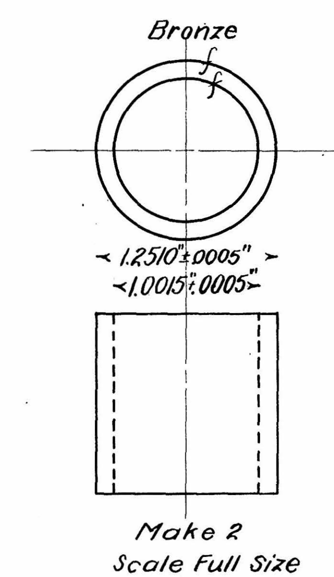
Thesis

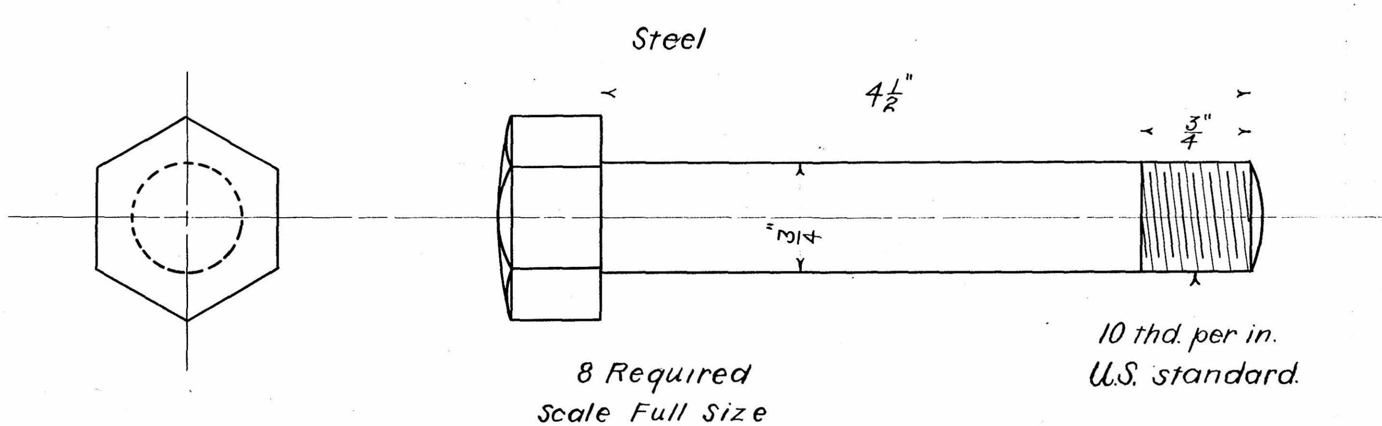
FATIGUE TESTING MACHINE
THROOP COLLEGE of TECHNOLOGY
Pasadena, Calif.

March 29, 1916 Scale - 1/4" = 1"

V.E. Farmer.







Thesis

5

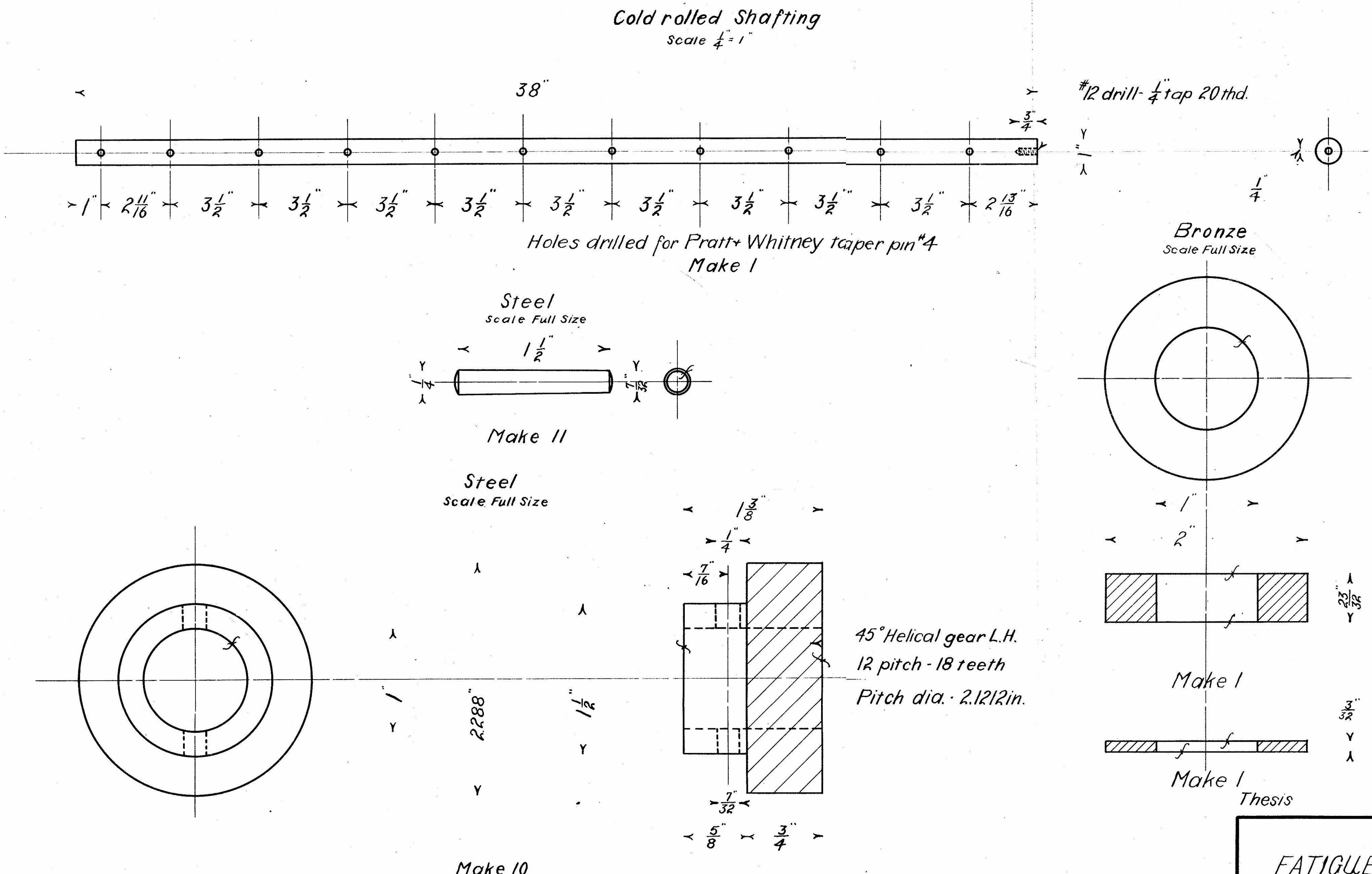
FATIGUE TESTING MACHINE

THROOP COLLEGE of TECHNOLOGY

Pasadena, Calif.

March 29, 1916 Scale - 1/4" = 1"

V. E. Farmer.



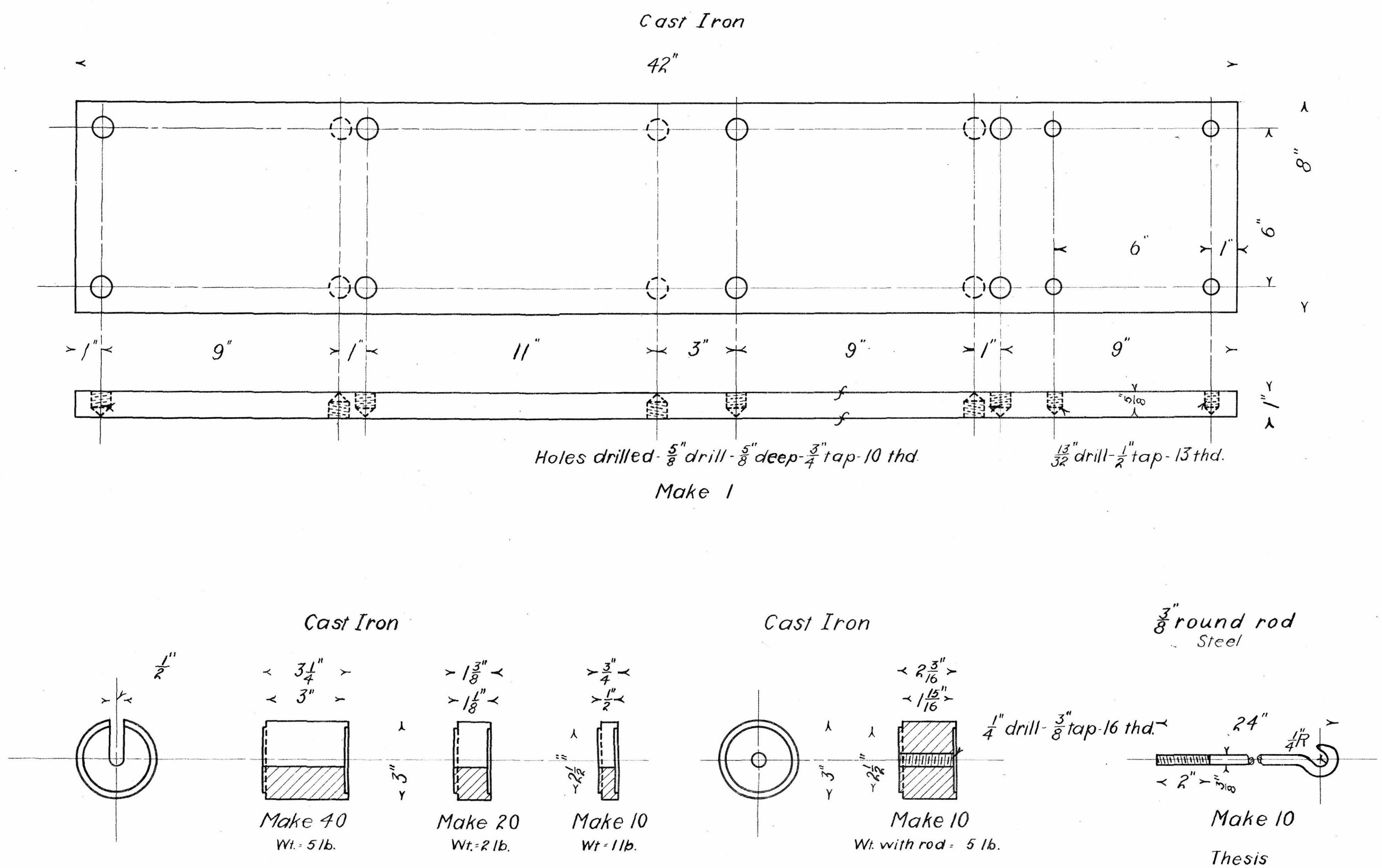
Thesis

6

FATIGUE TESTING MACHINE
THROOP COLLEGE of TECHNOLOGY
Pasadena, Cal.

April 8, 1916 Scale - shown

V.E. Farmer.



7

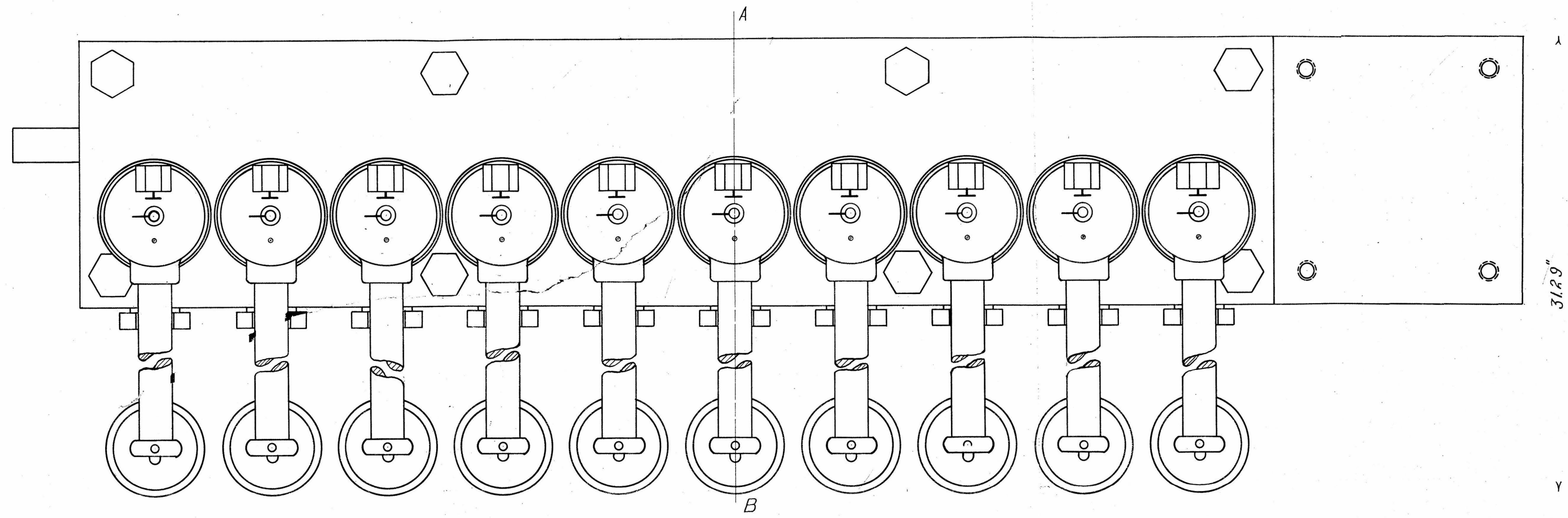
FATIGUE TESTING MACHINE

THROOP COLLEGE of TECHNOLOGY

Pasadena, Calif.

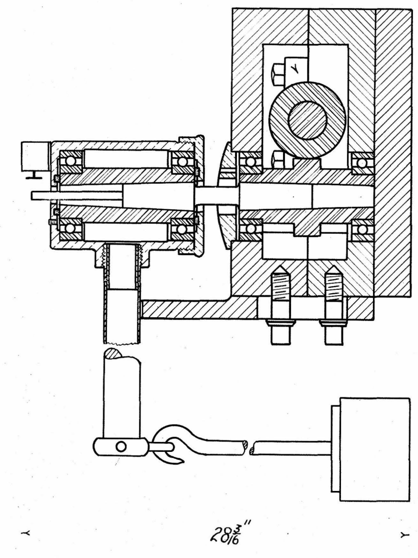
April 10, 1916 Scale - 1/4" = 1"

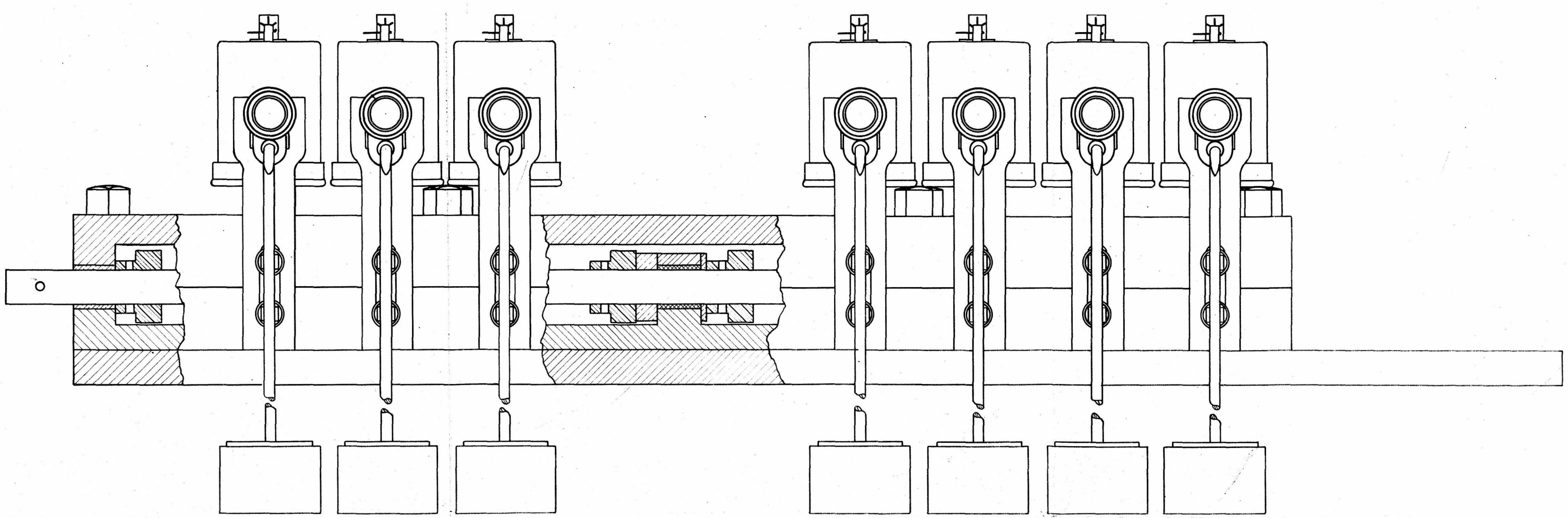
V. E. Farmer.



Section AB

Center bearing babbitted in position.





Thesis

Assembly

FATIGUE TESTING MACHINE
THROOP COLLEGE of TECHNOLOGY
Pasadena, Calif.

May 23, 1916

Scale - 3/8" = 1"

V.E. Farmer