ASD TECHNICAL REPORT 61-168

A TENSILE TESTING APPARATUS FOR SHORT FINE FILAMENTS WITH OPTICAL-MECHANICAL STRAIN MEASUREMENT

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SEPTEMBER 1961

PROJECT No. 7021
TASK No. 73653

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

400 - December 1961 - 15-601 & 602

FOREWORD

This technical report was prepared by Mssrs. J.E. Emrick and H.L. Gegel, project engineers for the work covered by this report. The work was initiated by the Advanced Metallurgical Studies Branch under Project No. 7021, "Solid State Research and Properties of Matter," and Task No. 73653, "Mechanisms of Flow and Fracture of Metallic and Nonmetallic Crystalline Substances." This program was administered under the direction of the Metals and Ceramics Laboratory, Directorate of Materials and Processes, Deputy for the Advanced Systems Technology, Aeronautical Systems Division.

This report covers the period of work from June 1958 through October 1959.

We wish to acknowledge the assistance in design and construction of the apparatus by Mr. E. Beutel, and extend appreciation to Drs. J.A. Herzog, H. Weik, and P. Stark for their suggestions and criticisms.

ABSTRACT

An apparatus was designed and built, which will obtain relatively accurate stress-strain curves of fine metallic filaments and whiskers. The principle of operation is based upon extension of a calibrated spring to apply the load. The strain is measured optically by projecting the gauge marks on two ground-glass plates attached to dial indicators. The magnitude of error in load and strain measurements is very slight. Stress-strain measurements of elastic moduli for two filament metals were made as a final check.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

J. Read Holland

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INTRODUCTION

An increased interest in the mechanical properties of thin metallic filaments and whiskers has made it necessary to develop mechanical instruments capable of applying axial loads and detecting consequent changes in strain in this size area. There are no commercial instruments available suitable for measuring the mechanical properties of metals whose effective diameters range from 1 to 50 microns and are approximately one centimeter in length.

Previous work in this field (1, 2, 3, and 5) has contributed greatly to the development of whisker testing instruments, but instruments used by these investigators to measure tensile strength did not necessarily give the most comprehensive results. S.S. Brenner (1) had an estimated error in strain of ±.001. His instrument had a solenoid for applying the loads, and the specimen was mounted on rigid grips. P.J. Shlichta (3) measured strain with a differential transformer which measured elongation between the heads. The grips were a ball and socket design. The load was applied by a quartz helix spring controlled by an analytical balance arrangement. H. Weik (4) used the "dead load" method and did not measure elongation.

In designing a suitable instrument, simple mechanical methods of loading and strain measuring, centricity of the specimen and the elongation measurement between gauge marks, and immediate strain detection were important goals. The apparatus which we designed approaches these requirements.

PRINCIPLE OF OPERATION

The load is applied to the tensile specimen by extending a calibrated spring. The spring is attached to the end of a depth micrometer (figure 1) by a ball bearing joint and secured by knife edge guides to prevent rotation of the spring. Strain is measured by optically observing the differential movement of two gauge marks attached to the specimen. Shadows of the gauge marks are magnified to obtain the accuracy required for strain measurements.

DESIGN AND CONSTRUCTION

The test apparatus consists principally of a power unit, light source, mounting fixture, lens system, spring loading system, dial indicator, micrometer, and projection screen.

The supporting unit for the specimen shown in figure 2a is affixed to a cross beam which is supported by columns from a base plate and is not adjustable. The micrometer mechanism is adjustable to allow for springs of various lengths. It is supported from a cross beam attached to two precision bronze bearings, which slide up and down on 1/2-inch drill-rod journals. The bearings may be adjusted by a screw mounted in the base plate and tapped through the micrometer cross beam. A dial indicator, attached to one of the supporting columns, permits adjustment of the micrometer head to obtain the free

Manuscript released by the authors 1 June 1961 for publication as an ASD Technical Report.

length of the spring. The calibrated springs are made of music wire and have a spring index of approximately 25, maximum design stress of 60,000 psi, and shear modulus of 12,000,000 psi. The spring design is a double-wound helix, with two identical springs attached 180° out of phase at the fixed ends. This design minimizes the twisting moment applied to the specimen by the extended spring. Each spring has a hook on one end and a "boss" on the other (figure 2a). The boss is used to attach the spring to the micrometer, and the spring is secured by two small screws. The grips, for the specimen, are made from annealed iron wire (its size depends on the specimen strength) which are formed into loops by means of a special jig which produces a trough when the free ends meet (figure 1). Mounted horizontally in a fixture* (figure 2b), they assure close axial alignment of the specimen, which is secured to the grips with an epoxy resin or Duco cement thinned with acetone and applied with a hypodermic needle.

The fixture with the mounted specimen is placed in a vertical position, and secured to the testing apparatus (figure 2a). The fixture prevents extraneous loading of the specimen caused by handling and securing it in the loading apparatus. Gauge marks on the specimen are bits of whiskers which are affixed to the specimen with a special mixture of rosin. (Formerly, the gauge marks used were slivers of aluminum foil which had been dipped in a low viscosity mixture of benzene and rubber cement and allowed to stick to the specimen.) The optical system (figure 3) is a standard Zeiss projection lens which magnifies the gauge marks when projected on ground-glass screens. The screens, which have a hair line scribed on them, are attached to 0.001-inch dial indicators that are adjusted to the change in gauge length.

PERFORMANCE

This apparatus affords many advantages over earlier methods. It is adaptable to filaments of various sizes. The arrangement of the specimen in the trough of the preformed grips minimizes the degree of misalignment of the specimen. The effective length of the specimen is increased by the wire grips. The maximum moment of an axially aligned specimen then occurs at the end of the loops and not at the point of adhesion of the specimen as it does in rigid grips. The elongation of the specimen is measured on the specimen and not at the grips or point of adhesion. Similarly, in tests where small beads of material are affixed to the specimen clearly defined gauge lengths are not available.

A disadvantage of the apparatus is the change in load caused by extensive elongation of the specimen, but high strength filaments do not generally deform extensively.

CALIBRATION AND ERRORS

Elongation of the specimen can be measured to $\pm 5 \times 10^{-6}$ inches. The loads produced by the extension of one of the calibrated springs having a spring constant of 18 grams per inch are accurate to within ± 18 mg. The spring constant was determined by the "dead load versus deflection" method using gram weights for applying the load and a traveling microscope for measuring the deflection. Figure 4 shows the calibration curve of the spring used for loading whiskers of micron size. The calibration was repeated several times to show sensitivity and reproducibility. The spring constant was also double

* A similar fixture was used by H. Weik for tests with iron whiskers (4).

checked by applying a load to the spring through use of the "Instron" tensile machine.

Results were comparable to within less than 1-percent error. For the aforementioned spring, the systematic error in the load measurement introduced by the compliance of the mounting loops is less than 0.1 percent. There is a slight hysteresis effect during the time period of testing, but this is found to be recoverable with time. The systematic error due to compliance of the specimen in the elastic range can be corrected, since the elongation of the specimen can be calculated. With increasing strength properties and relative decrease in strain the correction becomes negligible. Comparable load checks on whiskers have been obtained by use of the Instron machine. Experience has established, however, that the "Instron" is not versatile enough to measure elongation on short fibers or on specimens such as whiskers.

The optical flatness of the projected light field was determined at approximately 200x magnification by projecting a calibrated scale onto a screen. No variation was found in the distances between the divisions across the diameter of the field.

The major source of the error in any tests on thin filaments or whiskers is in the determination of the cross-sectional area. Figure 5 presents the relationship between the change of the modulus of elasticity with respect to the cross-sectional area.

In the future we anticipate automatic recording of the load and elongation to be incorporated in this apparatus. This will be through the use of photoelectric cells and an X-Y recorder, which will simplify the recording operation.

MODULUS MEASUREMENTS

The moduli of elasticity of iron and magnesium were measured to investigate the accuracy of the apparatus. Typical stress-strain curves are presented in figure 6. The values of the moduli determined for iron and magnesium were 31.2×10^6 and 6.7×10^6 psi, respectively. These moduli of elasticity measured for iron and magnesium filaments, whose diameters were approximately 0.002 inch, agree quite closely with the accepted bulk moduli of elasticity for the respective metals.

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2. S.S. Brenner, J. Appl. Phys. Vol 28, P. 1023, 1957.

3. P.J. Schlichta, Growth and Perfection of Crystals, John Wiley and Sons, Inc. P. 217, 1958.

4. H. Weik, Metal, WADC TN 58-369, Vol. 13, P. 114, 1959.

5. R. L. Eisner, Acta Metallurgica, Vol. 3, No. 4, 1955.

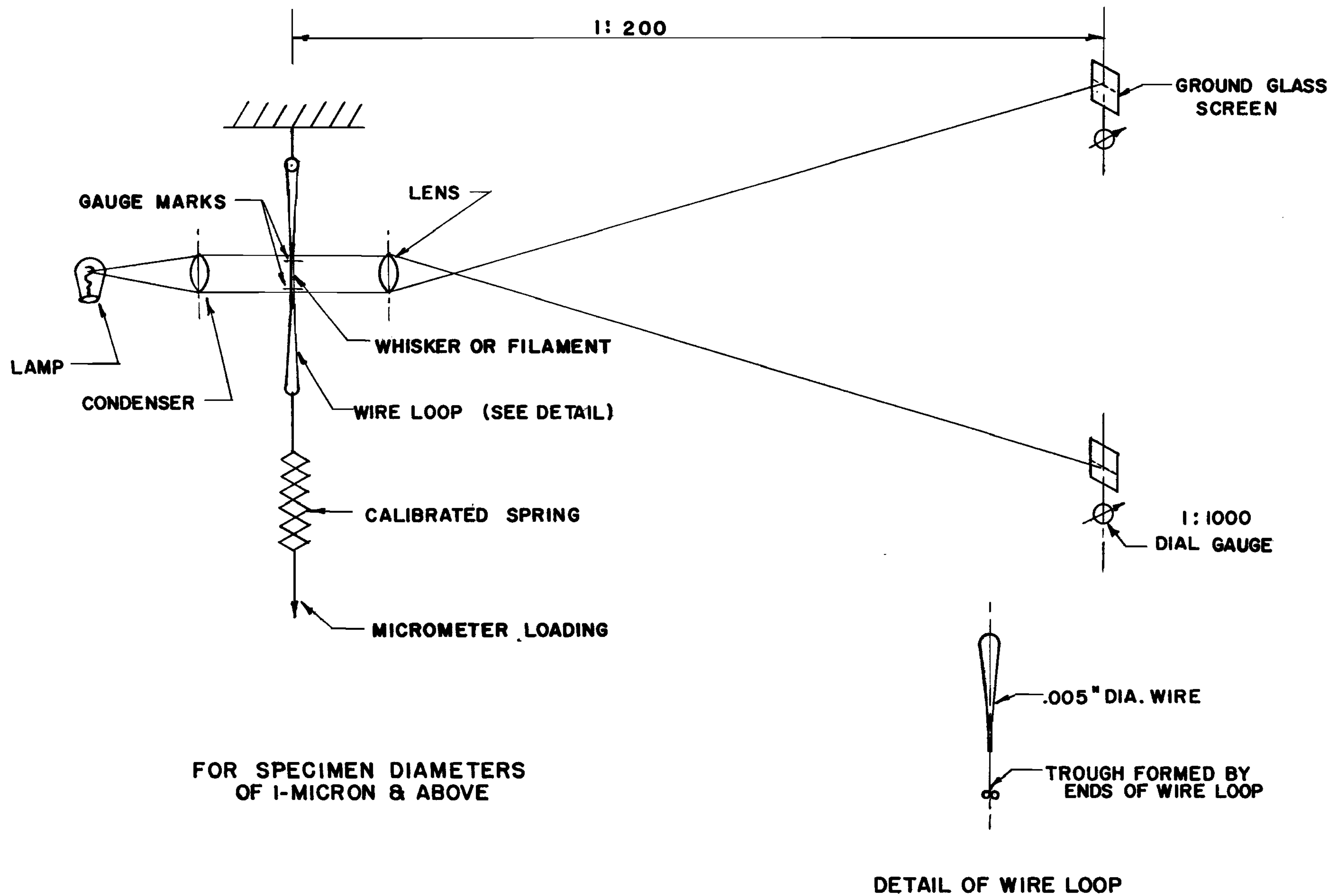

Figure 1. Schematic of Tensile Testing Apparatus for short, fine filaments with optical-mechanical strain measurement.

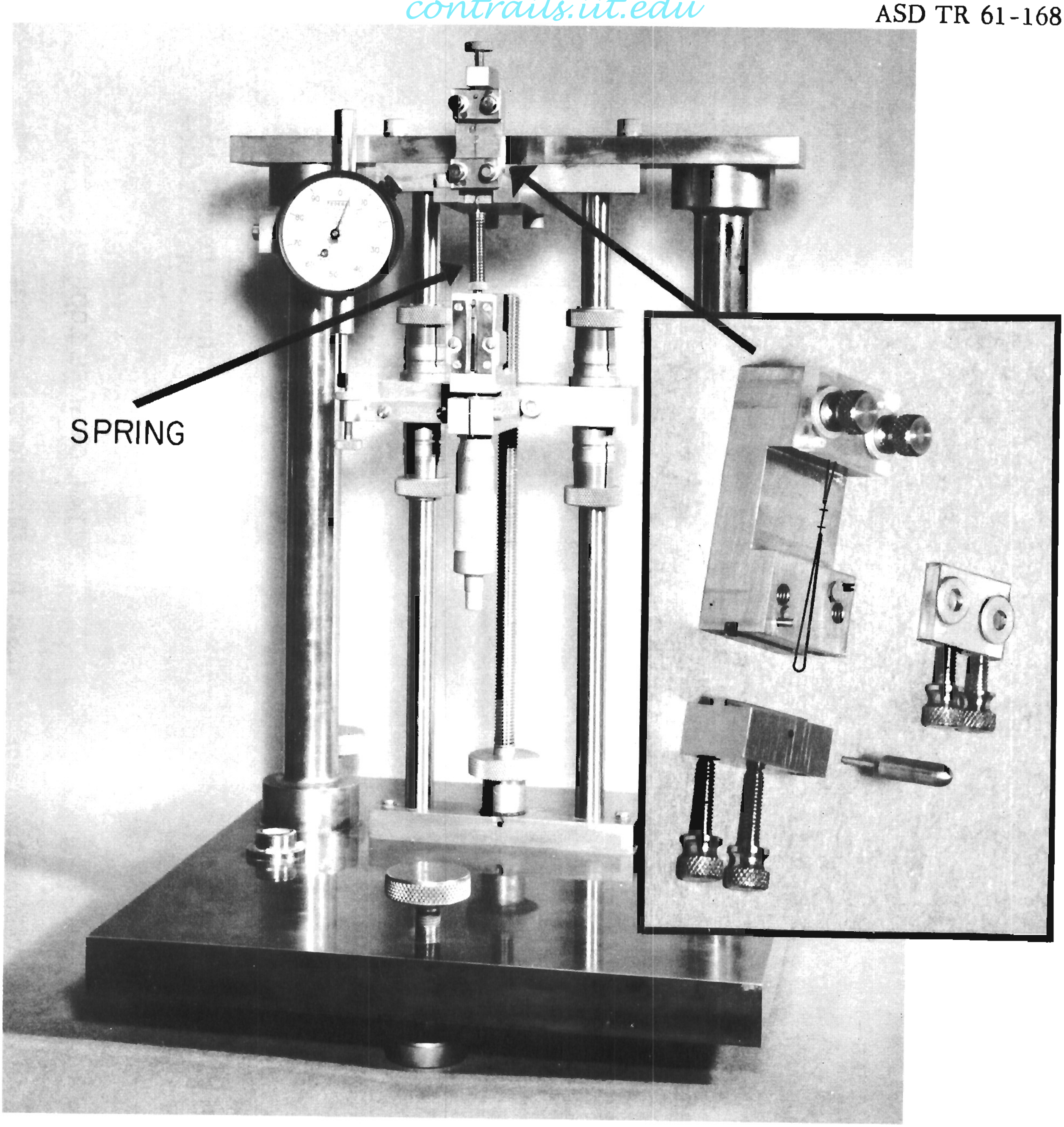

Figure 2. (a) The apparatus used to apply a tensile load to the specimen.

(b) An exploded view of the mounting fixture used to ready the specimen for tensile test.

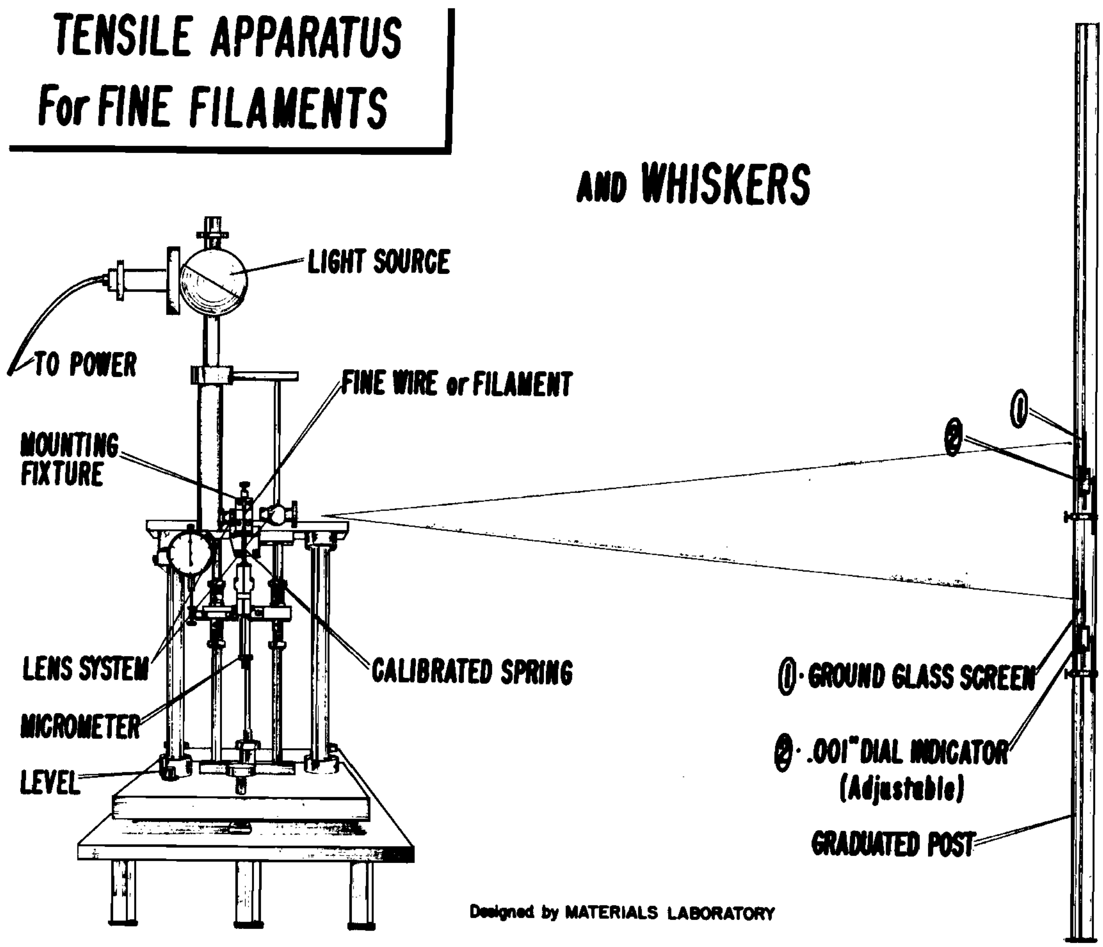

Figure 3. Sketch of the complete tensile testing apparatus.

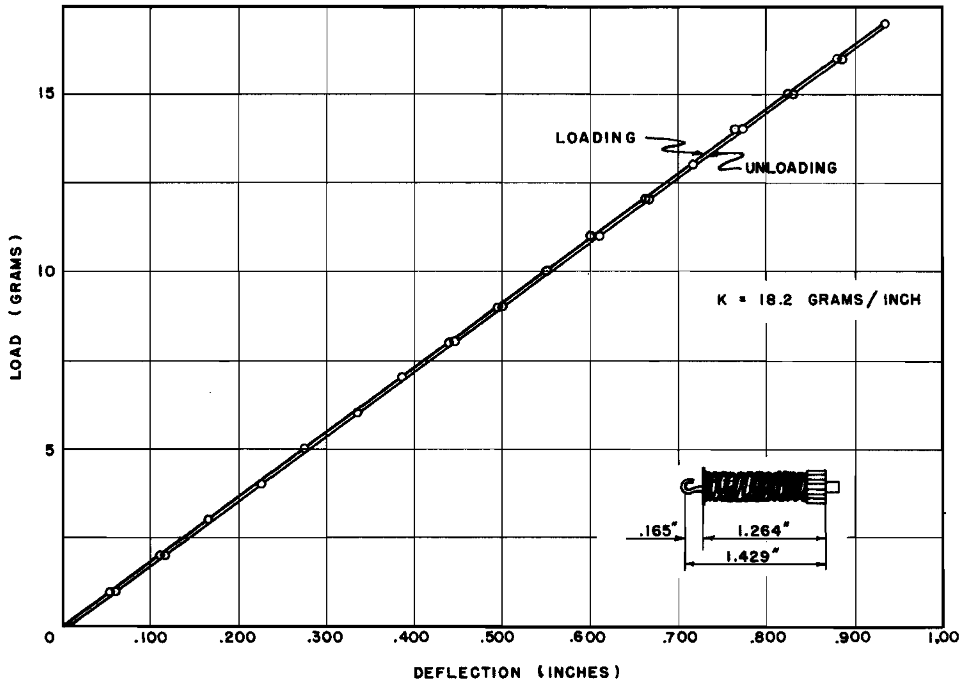

Figure 4. Load versus deflection curve for a calibrated helical spring.

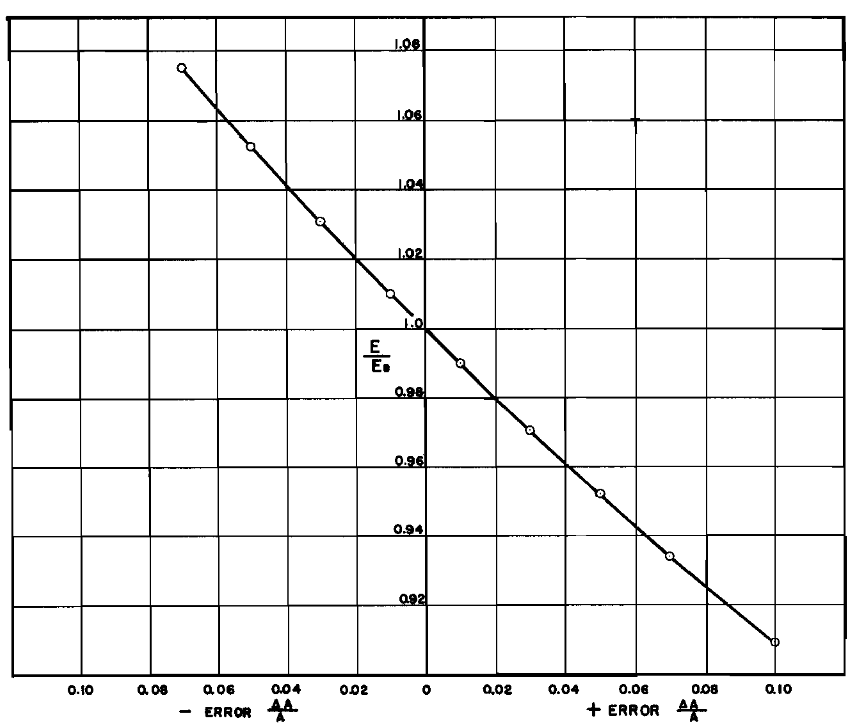

Figure 5. Relationship of error in modulus versus error in area.

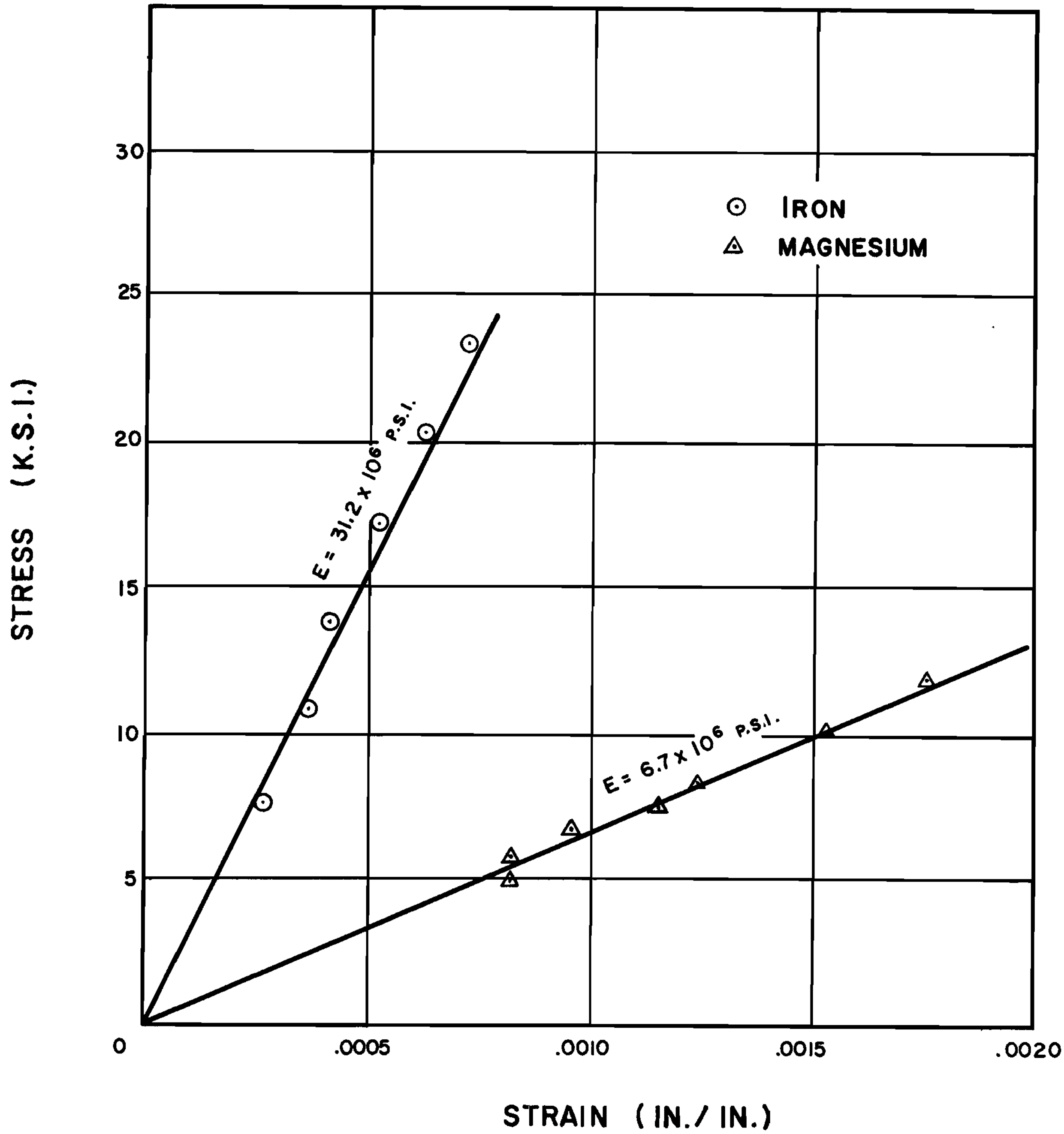

Figure 6. Stress-strain measurements and moduli of elasticity for two filament materials $\approx$ .002 inch diameter.