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Abstract
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A HIGH-TEMPERATURE VACUUM EXTENSOMETER

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J. R. Bohn and Glenn Murphy

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at
Iowa State University of Science and Technology
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A HIGH-TEMPERATURE VACUUM EXTENSOMETER

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ABSTRACT

An autographic extensometer for use at temperatures up to 1000°C is described. Strain information is obtained from within a high vacuum enclosure by a unique application of linear variable differential transformers which provides great versatility in strain magnification and range. Important details of the vacuum test chamber and extensometer are given. Typical high temperature stress-strain records for uranium and tantalum are included to illustrate the performance of the equipment.

INTRODUCTION

Current interest in materials for high temperature applications has pointed out the need for a reliable means of determining high temperature tensile properties of materials. This is particularly evident when the materials to be tested do not in themselves possess the ability to withstand oxidation at temperatures where test information is desired. For such materials contaminating environments must be prevented from coming in contact with the surface of the specimen during testing. This may be accomplished by enclosing the specimen in a controlled environment container; however, the effectiveness of such a method depends on the integrity of the means used to transmit the necessary strain information from within the controlled environment enclosure without interfering with the function of the container. This presents the problem of transferring relative mechanical movement through the container walls by means of an appropriate flexible seal arrangement. In any case, no functional compromise should be made between the facilities provided for strain measurement and oxidation protection.

An effective method of protecting tensile creep specimens has been developed which involves encapsulating the specimen in a flexible capsule capable of withstanding prolonged exposure in elevated temperature corrosive conditions.* Strain measurements in this case are transmitted through the capsule walls by means of a compound knife-edge arrangement. This technique can be applied to short-time tensile testing; however, the cost of a capsule, which is expendable, is usually unwarranted for tests lasting only several minutes, as contrasted to long time creep testing.

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* Bohn, J. R., Uhrig, R. E. and Murphy, Glenn. A method of specimen corrosion protection for high temperature creep testing. USAEC Report IS-48, 1959.

This investigation deals with the development of equipment and techniques for oxidation protection and strain measurements of specimens subjected to short-time elevated temperature tensile tests. Test results on uranium and tantalum demonstrate the performance of the equipment at high temperature, vacuum and strain magnification.

DESCRIPTION OF THE TEST FACILITY

The majority of the system components used in conjunction with the high temperature vacuum test chamber and extensometer were standard commercial items. They included a 60,000-lb tensile testing machine for load application, an x-y recorder for load-strain recording, vacuum pumping and measuring devices, and temperature indicating and recording potentiometers. Temperature control was accomplished using an electronic proportioning furnace controller designed for this specific application, where temperature sensing for control was provided by a platinum resistance thermometer wound integrally with the furnace heater windings. Temperature measurements were made using chromel-alumel thermocouples at four points along the gage length of the specimen. A sketch of the high temperature vacuum test chamber and extensometer is given in Fig. 1. Figure 1 serves as schematic illustration of the functional mechanical components of the system and also provides an index of description for the various components discussed in the text.

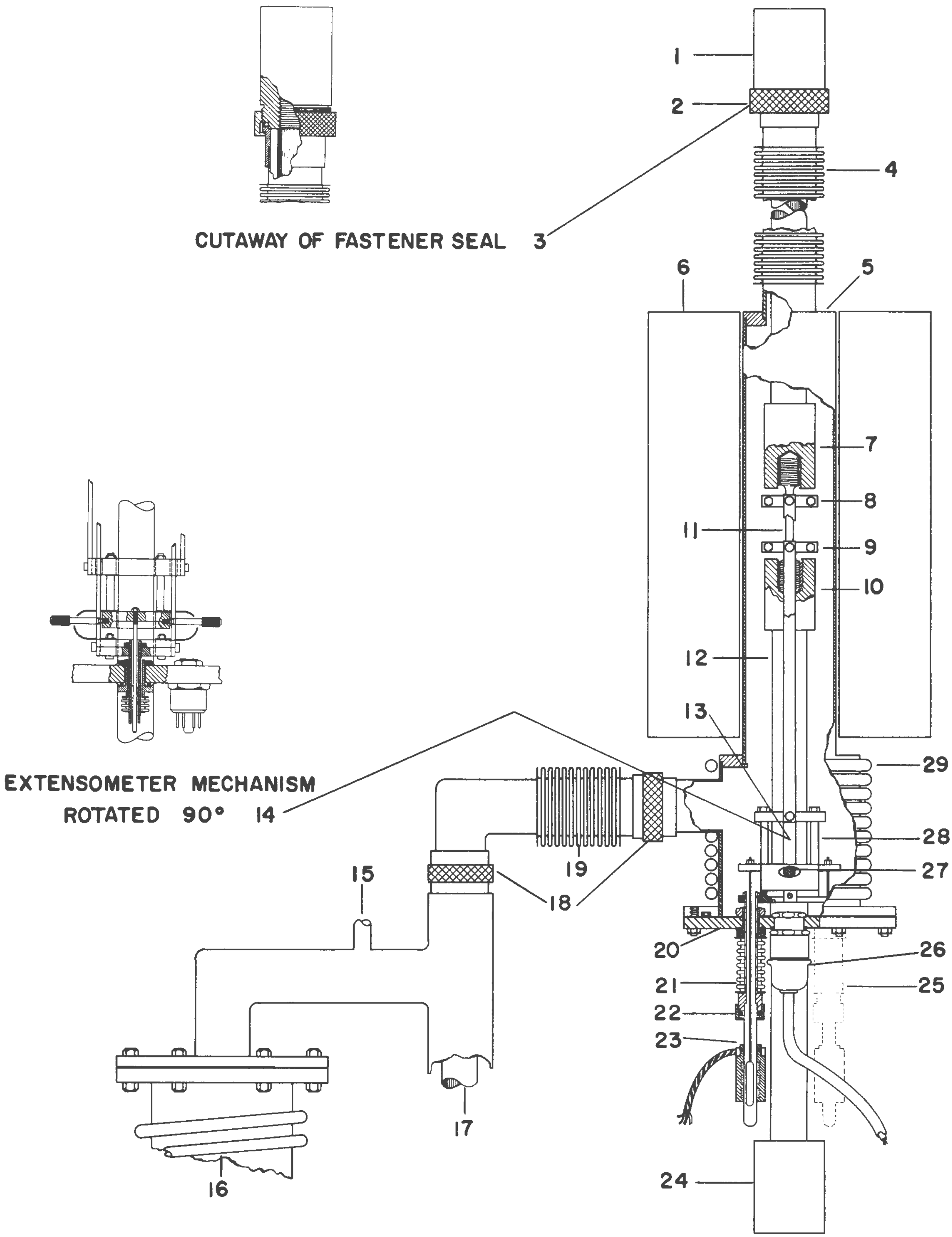

FIG. I HIGH TEMPERATURE-VACUUM TEST CHAMBER AND EXTENSOMETER

LEGEND

1. Upper cross-head fastener
2. Cross-head fastener vacuum seal
3. Cutaway of fastener seal
4. Chamber extension bellows
5. Test chamber
6. Resistance furnace
7. Specimen adaptor grip (upper)
8. Upper knife edge
9. Lower knife edge
10. Specimen grip (lower)
11. Tensile specimen
12. Tensile load rod
13. Extensometer mechanism
14. Extensometer mechanism - rotated 90°
15. Vacuum ion gage
16. Oil diffusion pump
17. Nitrogen cooled cold trap
18. Vacuum couplings
19. Alignment bellows
20. Lower test chamber flange
21. Flexible extensometer well arrangement
22. Glass to metal vacuum coupling
23. LVDT assembly
24. Lower cross-head fastener
25. Auxiliary extensometer assembly
26. Thermocouple seal assembly
27. Gage length positioning screws
28. Gage length spacer rods
29. Cooling coil

TEST CHAMBER

A vacuum chamber, which provides the corrosion barrier for oxidation protection, houses the specimen and allied extensometer fixtures. The chamber is rigidly attached to the lower load application rod which is mounted in the lower stationary cross-head of the tensile machine. Thus, the weight of the test chamber does not affect the tare weight of loading. Elongation of the test chamber during loading is allowed by a bellows which is attached to the top of the chamber and coupled to the upper cross-head fastener and load rod through an "O" ring seal. The system is designed to accommodate specimens of three sizes: 0.252-in. diameter by 1.0-in. gage length, 0.357-in. diameter by 1.5-in. gage length and 0.505-in. diameter by 2.0-in. gage length. The over-all length between cross heads is maintained constant for specimens of the various gage lengths by changing the length of the upper specimen grip. The chamber is evacuated through an outlet in the side of the chamber which is coupled to the vacuum pumping system with a Cenco vacuum seal. The strain and temperature measuring fixtures located on the bottom flange of the chamber are mounted with fittings incorporating "O" ring seals. A detachable water-cooled coil placed around the lower chamber provides cooling for the vacuum seals. The furnace tube portion of the test chamber is constructed of inconel and the majority of the other components are type 316 stainless steel.

The pumping system, which consists of a mechanical fore pump, an oil diffusion pump and a nitrogen cooled cold trap, is consistently capable of producing pressures between 1 and 5 x 10^{-6} mm Hg. Pressure measurements are taken in the vacuum line between the cold trap and the test chamber. The diffusion pump and the cold trap are mounted on the vertical support screw of the lower cross head. This mounting permits the diffusion pump and cold trap to be swung out of position when not in use. The flexible coupling in the vacuum line between the cold trap and test chamber provides easy alignment when setting up a test. A separating member between the cold trap and the test chamber fixes the length of the bellows which would otherwise tend to collapse upon evacuating the system. Figure 2 shows the apparatus less the cooling coil and cold trap, mounted in the tensile machine.

EXTENSOMETER

Strain measurements are transferred through the vacuum wall of the test chamber by a unique application of linear variable differential transformers (LVDT) and appropriate mechanical linkages. The windings of the LVDT are attached to the exterior of a flexible well extending through the bottom of the test chamber. The movable core of the LVDT is positioned on the inside of the well. With this arrangement electrical coupling between the primary and secondary winding of the LVDT is accomplished

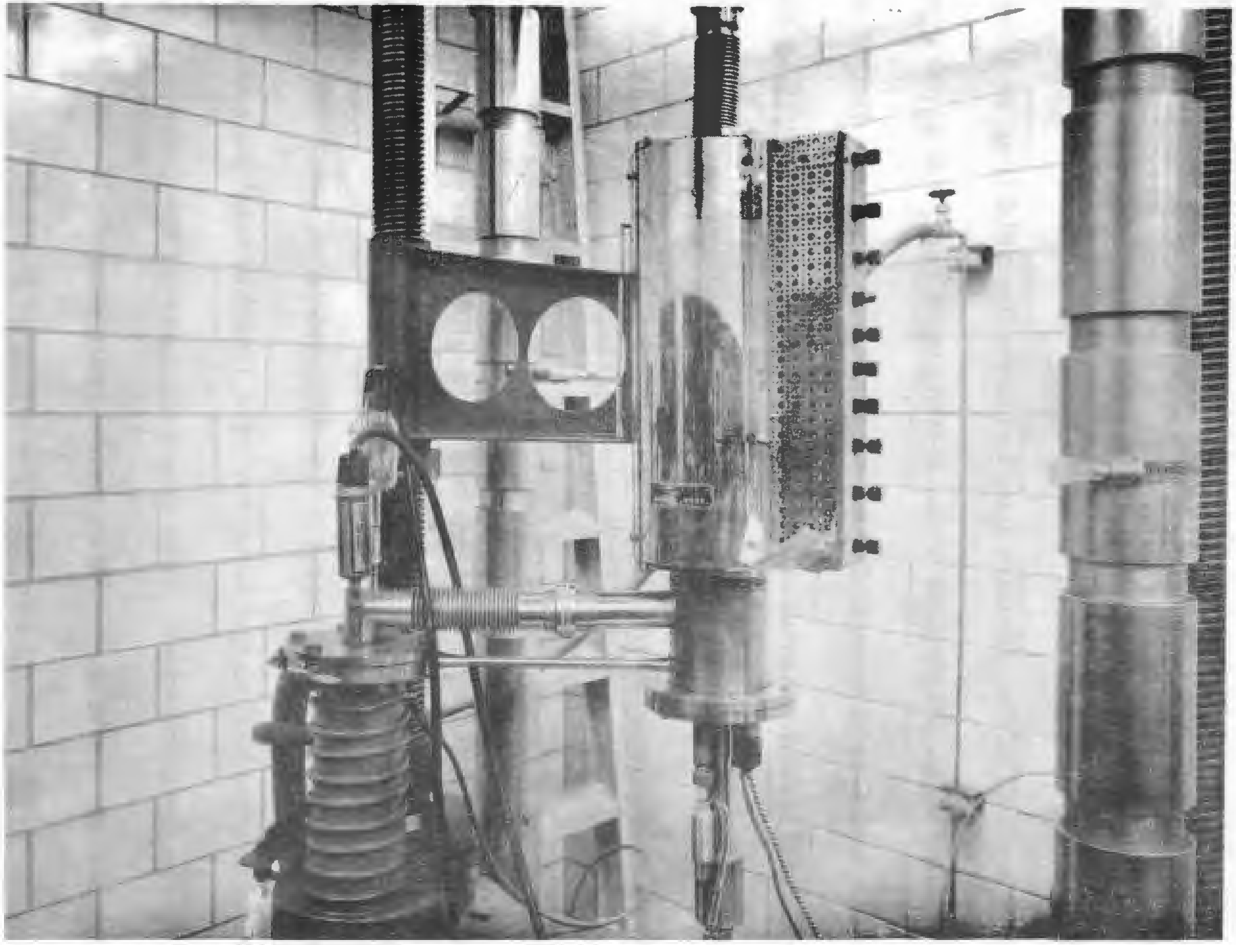

Fig. 2. Test chamber mounted in the tensile machine

by the core through the vacuum wall of the well. The voltage which is developed in the secondary winding is proportional to the relative positions of the core and the windings. Two extensometer wells were provided to maintain symmetry in the forces developed by the bellows (flexible well coupling) which are resisted by the extensometer linkages. The two well arrangement provides the necessary facilities for dual strain recording applications.

Knife edges which attach directly to the specimen gage length reference movement and provide the source of strain measurement. Movement of the lower knife edge is transferred to the bottom flange of the extensometer assembly and then to the walls of the extensometer well. A bellows which is attached to the side of the well and to the bottom of the test chamber provides flexible vacuum seal and permits the strain initiated movement of the lower knife edge to be transmitted to the exterior of the test chamber. This strain movement is developed between the lower specimen grip and knife edge, a distance of about 3/8 of an inch. The elongation of a specimen over this distance is small, imposing a correspondingly small dimensional change in the extensometer well bellows. Movement of the upper knife edge is transferred to the top and middle flanges of the extensometer assembly, and then to the LVDT core by a rod which passes through the bellows into the extensometer well.

The LVDT core support rod is nonmagnetic and makes no physical contact other than its point of suspension from the middle flange of the extensometer assembly.

The four spacer rods which connect the upper and the middle flange of the extensometer assembly can be replaced to accommodate specimens of varying gage lengths. The same knife edges are used with the 0.357-in. diameter, 1.5-in. gage length and the 0.505-in. diameter, 2.0-in. gage length specimens by increasing the length of the spacer rods 1/2 in. The 0.252-in. diameter, 1.0-in. gage length specimens require a special set of knife edges. Gage length positioning screws reference the upper and lower knife edge linkages at the middle extensometer flange in order initially to establish the exact specimen gage length before setting the knife edges. After the gage length is established these screws are removed. The hair-pin-shaped spring provides lateral alignment stability of the extensometer assembly.

LOAD SENSING

An LVDT is attached directly to the load cell of the tensile machine in parallel with the load indicator linkage. This provides the advantage of using range and scale switching facilities built into the load indicator, in addition to those provided in the LVDT measuring circuit.

RECORDING

A number of techniques are available for recording the ac output voltage of an LVDT. Several of the more common methods are: (1) direct ac recording with an ac potentiometer, (2) the use of specially designed null balance type servo bridges, where the active and compensating legs of the bridge are LVDT's, and (3) dc recording of the rectified output of the LVDT. In this investigation the third method was employed since it was desired to sense both load and strain with LVDT's which required x-y recording, thus eliminating the possibility of utilizing method (2) which is most commonly employed in strain-recording applications. The circuit diagram shown in Fig. 3 illustrates the electrical treatment given the primary source voltage and the ac output of the LVDT for dc recording. The same circuitry is used for both strain and load recording. Line voltage is stabilized and transformed to provide a range of 0 to 10 volts to supply the primaries of the load and strain sensing LVDT's in parallel. The LVDT's used have a linear range of 0.125 in. on either side of null; however, the phase sensitive rectification circuit employed eliminates the null output inherent to the LVDT and doubles the useful range providing an output signal of a given polarity over a range of 0.250 in. The output signal is attenuated for a given magnification using a ten-turn helipot. Helipot dial setting

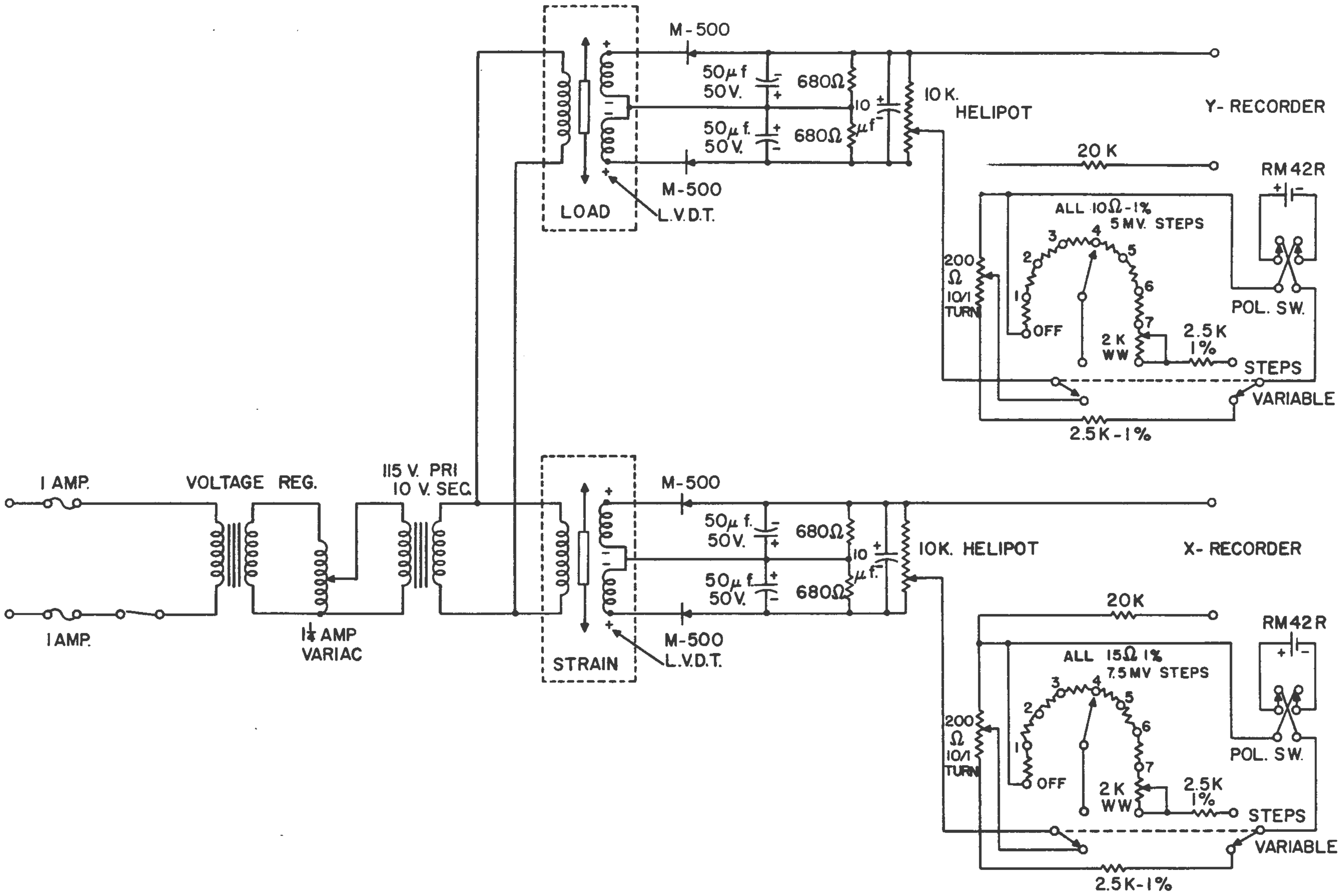

Fig. 3. Load-strain measuring circuit

versus magnification is linear. A maximum magnification of 2500x is possible with an input voltage to the LVDT primary of 6.3 volts; however, proportionately high magnifications can be obtained by increasing the input voltage upward to 10 volts.

A bucking voltage in series with the output signal to the recorder is provided as a means of extending the recording range. The bucking signal is provided for both the load and strain axes and can be utilized in two ways, continuously variable or in steps of 7.5 mv on the x-axis and 5 mv on the y-axis. These values correspond to full-scale deflection on the respective scales of the x-y recorder used.

In calibration tests of the load-strain measuring system, both linearity and stability showed deviations of less than 1% for periods less than one-half hour. Instrument warm-up periods of at least an hour are necessary to assure these conditions, since temperature compensation of the LVDT's can not be provided.

PROCEDURE

Setting up a test initially involves the three components shown in Fig. 4. The specimen is inserted in the lower grip and the lower knife edge is fastened to it. Then the gage point screws are set after which the upper knife is attached. This establishes the gage length

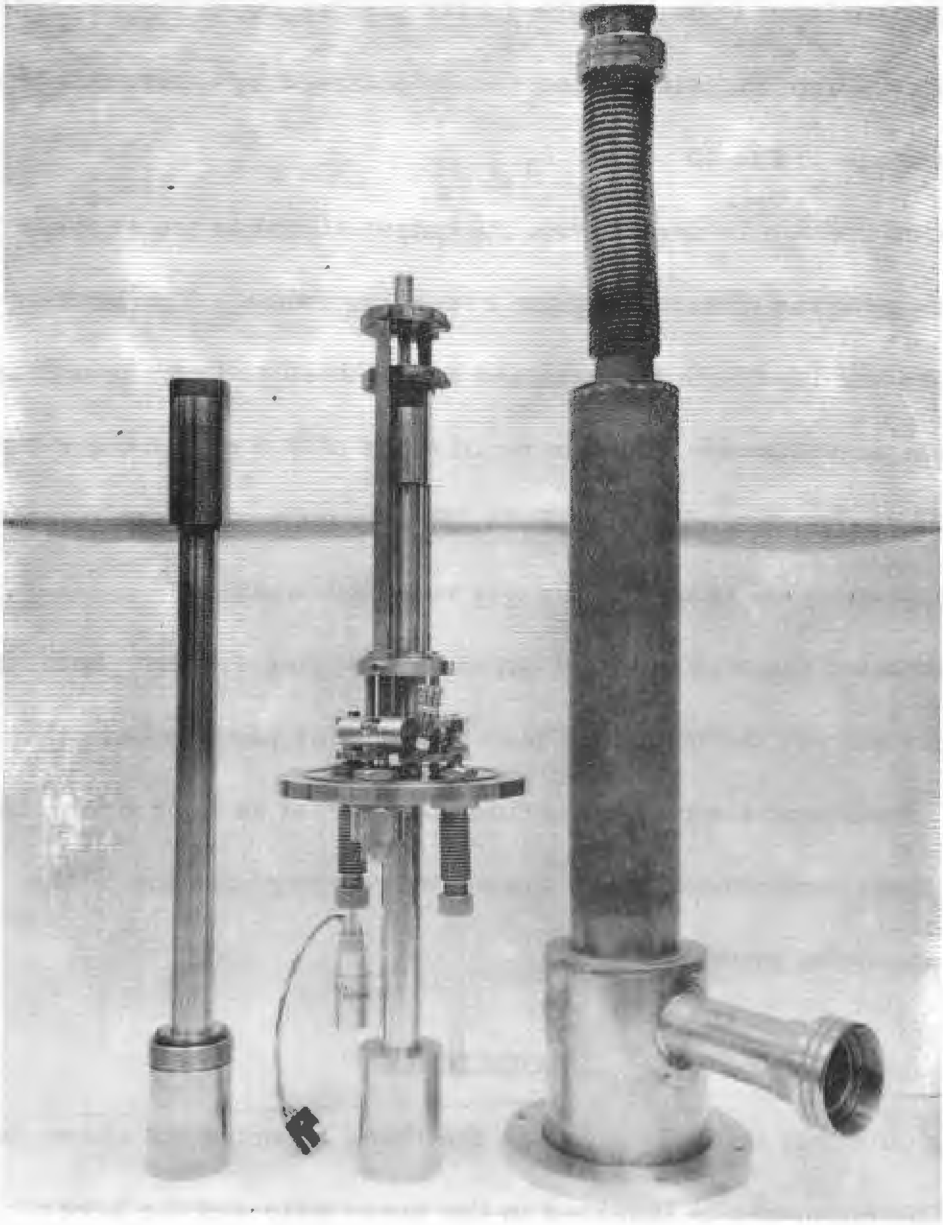

Fig. 4. Components of the test chamber and extensometer

after which the gage point set screws are removed. The four thermocouples are attached, the upper load rod is screwed onto the specimen and the vacuum chamber is placed over the assembly and secured to the bottom flange with six cap screws. Next, the seal is made between the bellows and the upper cross-head fastener. The test chamber assembly is now ready to be mounted in the tensile machine. The test chamber assembly is supported in the spherical joint of the lower cross head only which prevents the tare weight of the assembly from adding to the load to be placed on the specimen. The remainder of the procedure is a matter of making the necessary connections, pumping the vacuum and establishing the desired temperature conditions. Running the test is routine.

TEST RESULTS

Autographic load-strain records for uranium and tantalum have been included in Figs. 5, 6 and 7 as the basis for illustrating the effectiveness of the testing apparatus. For these tests 0.357-in. diameter, 1.5-in. gage length specimens were used. These specimens have a cross-sectional area of 0.10 sq. in., hence the engineering stress may be conveniently calculated as 10 times the load. Strain as indicated is the total strain over the 1.5-in. gage length; thus, unit strain is the total strain divided by 1.5. The small extrapolations which appear near the

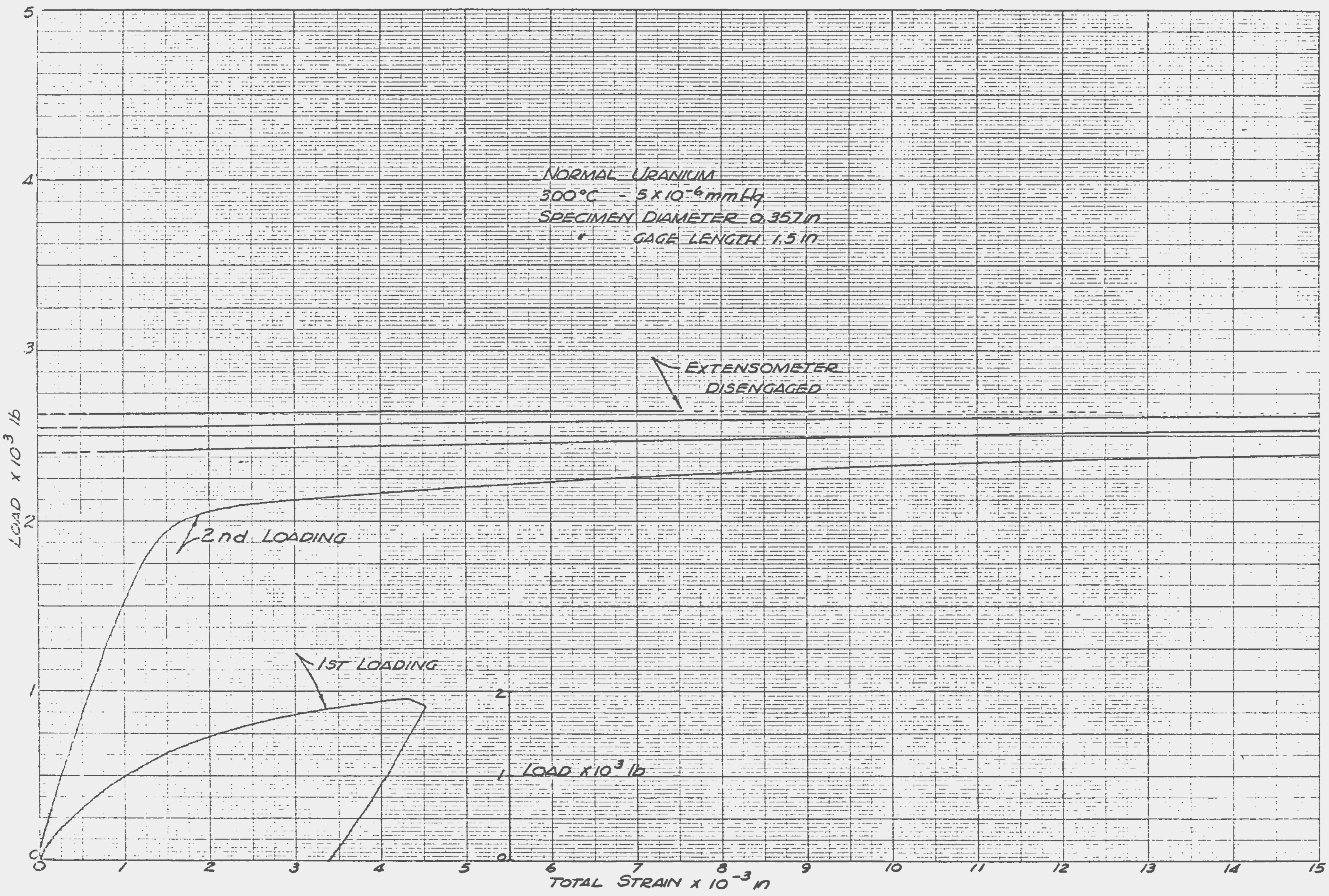

Fig. 5. Load-strain curve of uranium at 300°C

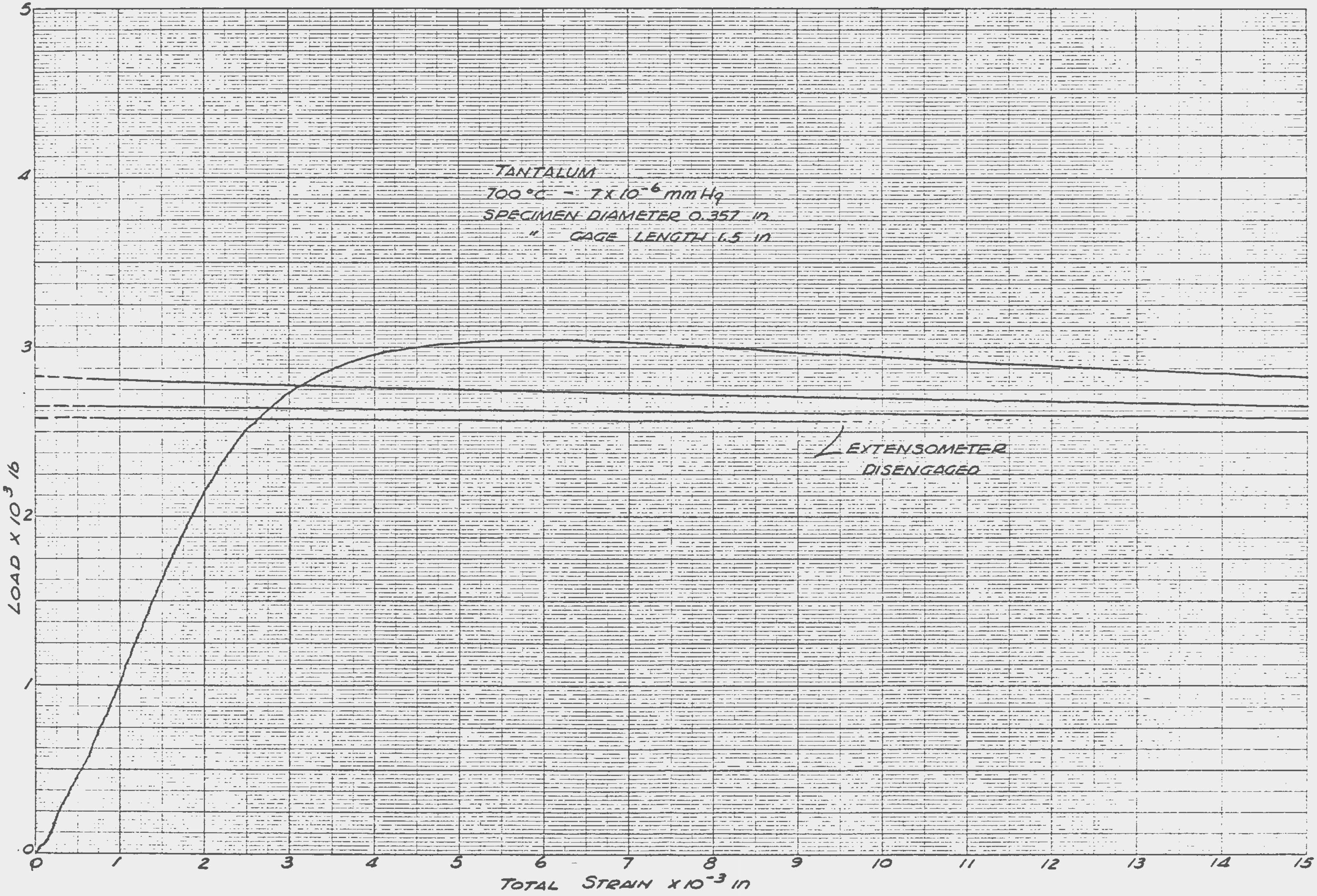

Fig. 6. Load-strain curve of tantalum at 700°C

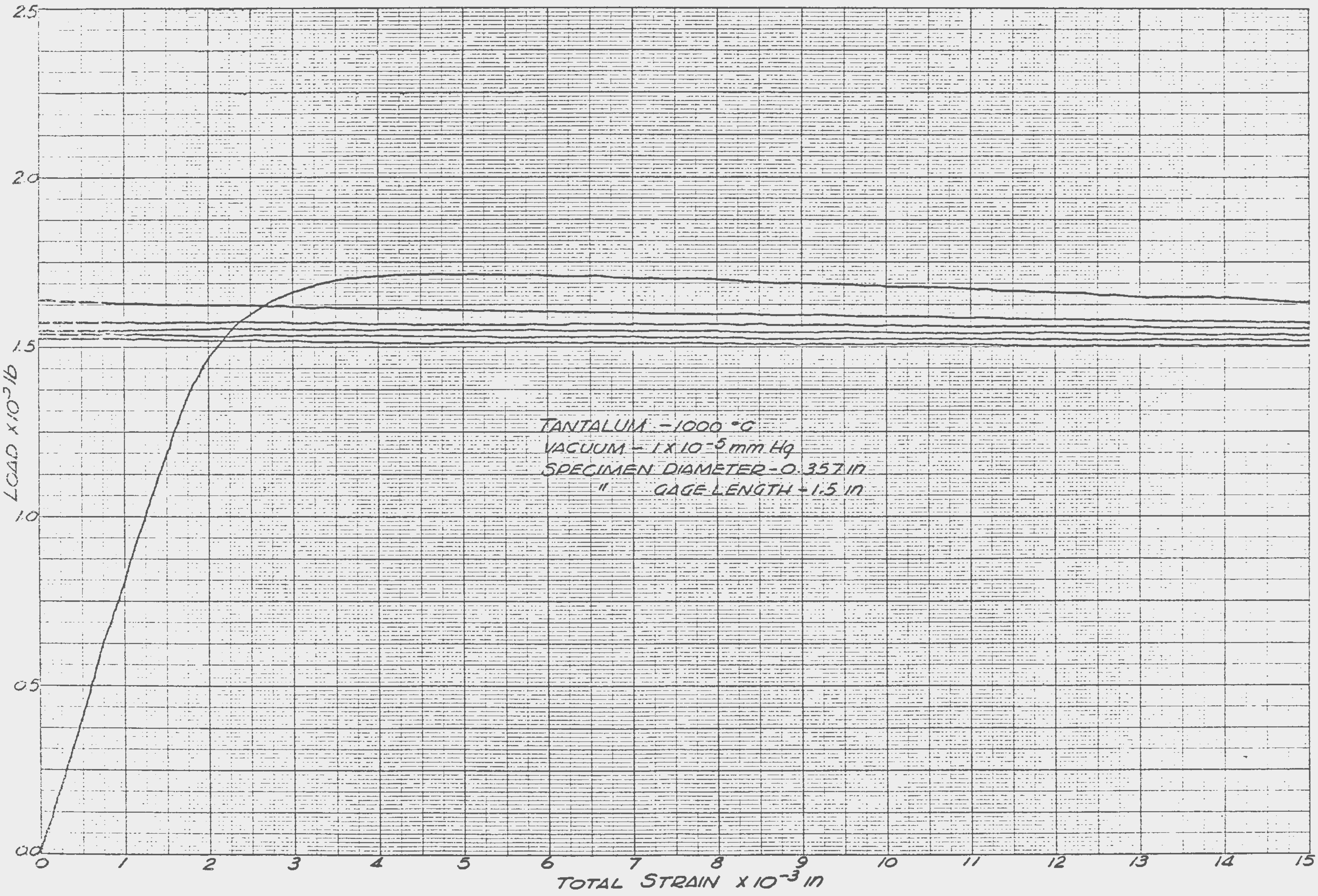

Fig. 7. Load-strain curve of tantalum at 1000°C

abscissa are the result of expanding the strain axis, and are caused by the time lapse of full scale pen travel. Recording was terminated as indicated by the notation, "extensometer disengaged". Disengagement of the extensometer occurs when necking-down of the specimen causes uncoupling of the knife edges.

CONCLUSIONS AND SUMMARY

The elastic properties of materials do not adequately describe the stress-strain properties of materials which behave in a semi-plastic manner. In elevated temperature applications it is particularly desirable to have available the actual stress-strain records for the material. Reproducible autographic recordings greatly simplifies such a task.

The performance of the test equipment described is considered excellent for intended applications. It is believed that testing at temperatures greater than 1000°C could be achieved by improving the materials of construction and providing the heat from within the vacuum chamber. Strain magnifications up to 3000 are possible over a range of 0.250 in. High magnification and extended range provides great versatility for most stress-strain applications. In addition, the provisions for dual strain sensing provides the advantage of dual range recording. One recorder might measure over a wide range of strain while another would greatly magnify a portion of the stress-strain curve of particular interest. Another outstanding feature of the strain measuring apparatus is its ability to give a continuous record to fracture without necessitating uncoupling or other special precautions.