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High Temperature Creep- and Stress-Rupture Apparatus for Remote Application

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HIGH TEMPERATURE
CREEP- AND STRESS-RUPTURE APPARATUS
FOR REMOTE APPLICATION

ABSTRACT

This report describes a machine in current application at Battelle-Northwest that will perform creep and stress-rupture tests to 1600°F with loads to 1500 pounds in inert gas and air environments. The machine is compact, lightweight, and designed for remote operation in an irradiation hot cell; its cost is less than one-third that of commercially available test apparatus.

INTRODUCTION

The comprehensive investigation of the mechanical properties of candidate reactor structural and fuel cladding materials requires a thorough knowledge of creep and stress-to-rupture properties of these materials in the postirradiation condition.

ASTM has designated standards (E 139-66T) for this type of testing; remotized operation in the small confines of an irradiation hot cell makes additional demands. The result is the following design criteria for a machine to perform these tests:

- Loading accuracy: 1% over load range.
- Temperature control: $\pm$ 3°F total specimen variation from setpoint.
- Less than 15% bending moment across the specimen.
- Must be light, compact, and remotely operable.
- Temperatures to 1600°F.
- Loads to 1500 pounds.
- Must accept all designs of miniaturized uniaxial solid samples.
- Inert gas and air environments, with easy modification to low vacuum.

To meet these testing requirements, a search was made of commercially available testing equipment. Most (Figure 1) were rejected because of size alone; others did not offer suitable environment or remote handling capabilities.

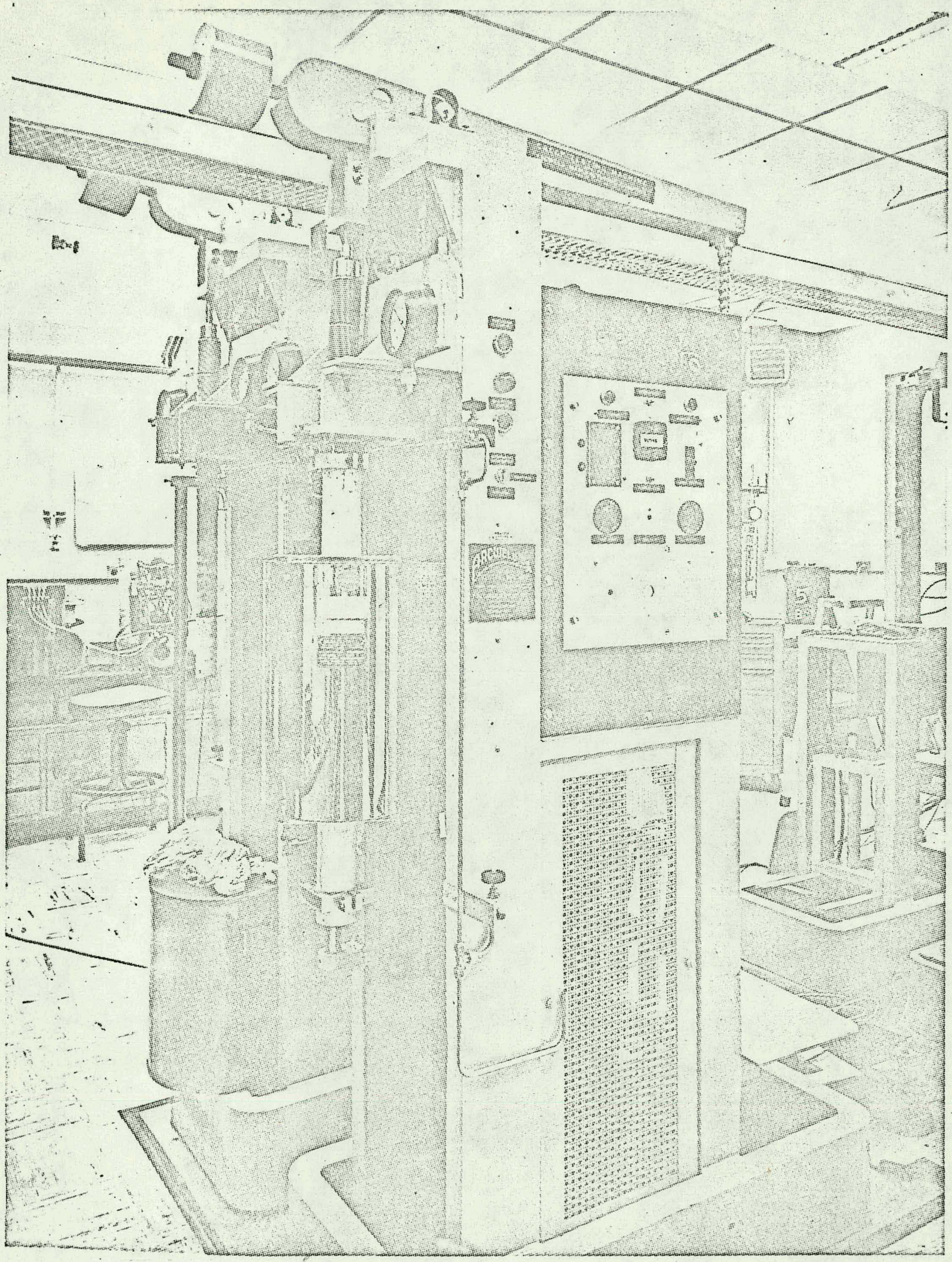

Figure 1

Typical Commercial Creep-Rupture Apparatus

A pressurized gas rig previously designed at Battelle-Northwest (BNWL 137) seemed to offer the best possibilities. While the machine had proven marginally satisfactory for bench testing, it has never been widely used due to certain conceptual design deficiencies.

The machine described in this report, then, is a totally different approach to the concept of gas loaded creep and stress-rupture testing.

DISCUSSION

The machine is shown in its most complete form in Figures 2 and 3. Operation is quite simple: a differential pressure is applied across a rolling diaphragm air cylinder, and the resultant force acts on the specimen. Briefly, the apparatus incorporates the following design features:

1. Since low pressure fittings, valves, and lines are easier to handle and less expensive, the apparatus satisfies design criteria with gas pressures under 125 psig.

2. To minimize connections that must be made and broken remotely, and to reduce cost, the pressure gas on the load applying device and the specimen environment are common.

3. To eliminate the spring constant and low stroke associated with a bellows and friction present in a conventional air cylinder, a rolling diaphragm air cylinder is used.

4. To achieve the best possible alignment of load train, the entire compression assembly is machined as a unit after welding and heat treating.

5. Rubber or viton O-ring seals are used when possible for easy assembly and disassembly.

6. Heat is provided by an economical three zone, 110 volt furnace wound on the outside of the retort.

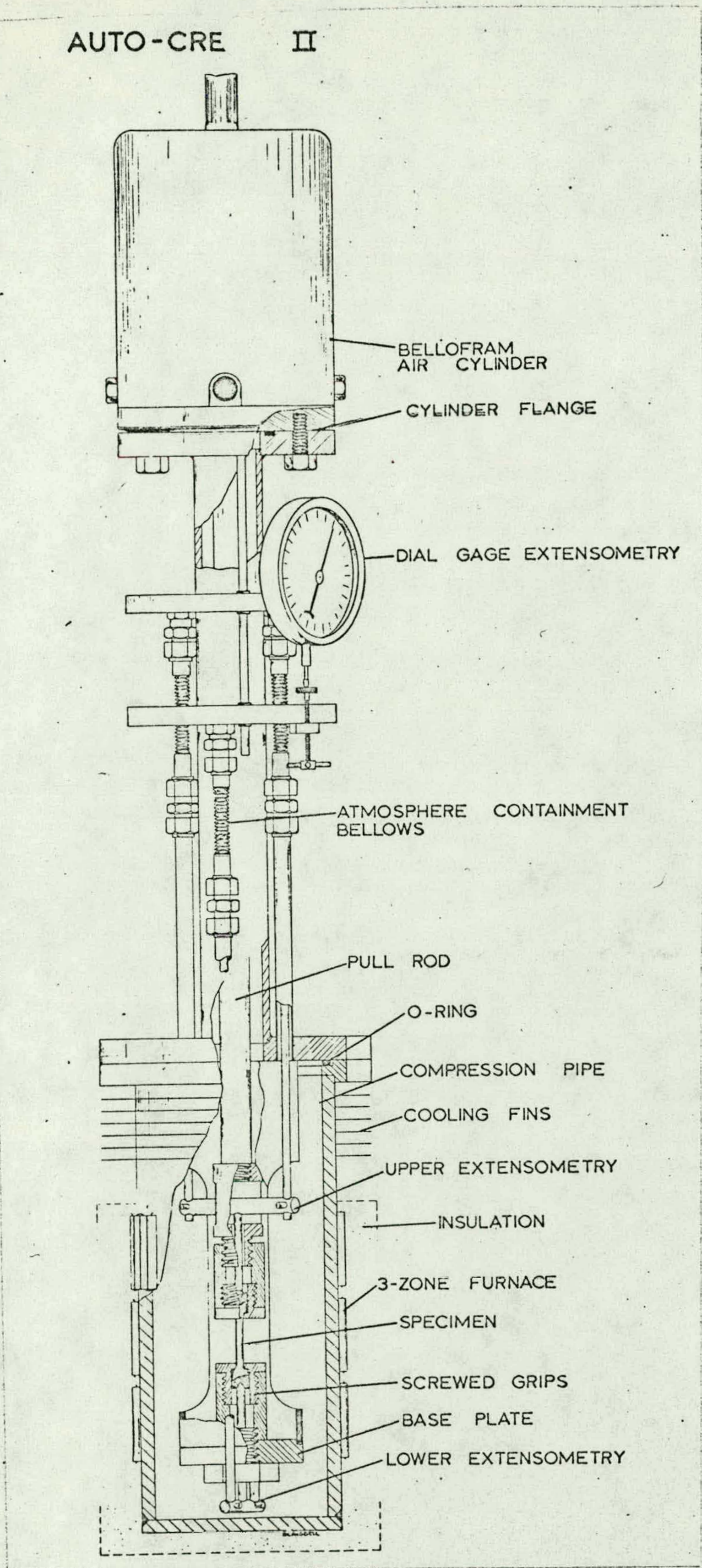

Figure 2 "Autocreep II" Remotized Creep Rupture Apparatus

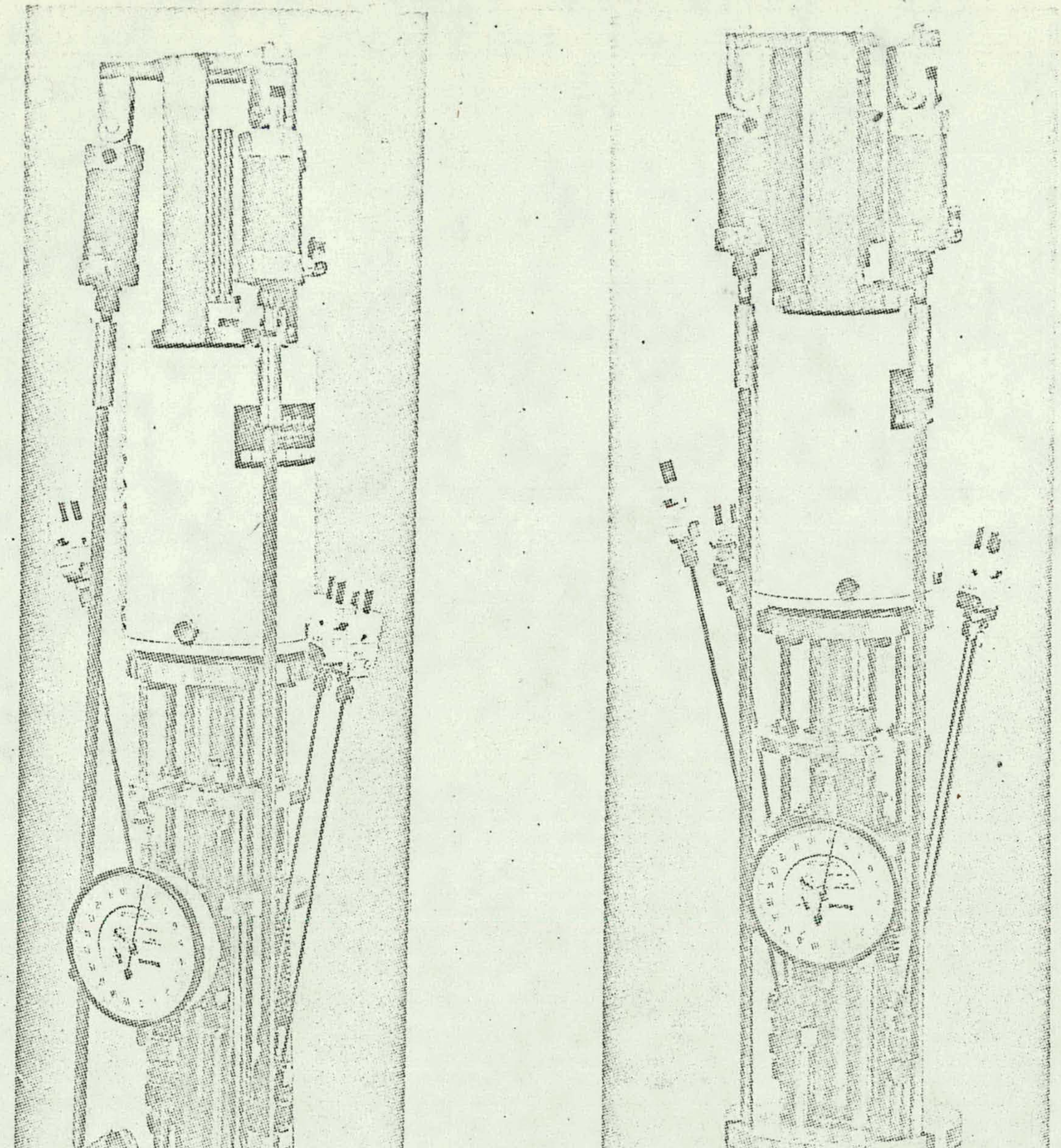

Figure 3 "Autocreep II" During Assembly

7. Since some deformation may occur in the load bearing system, the extension of the sample is measured as the difference in movement of two plates referenced through low stress rods to each end of the specimen.

8. Room is provided for dial gage as well as LVDT measurement of extension.

9. Alignment is further enhanced with the use of precision linear ball bushings in the diaphragm air cylinder.

10. Stroke (2-1/2 inches) is long enough to allow virtually any kind of miniature grip that can be handled remotely.

Two additional forms of the basic machine have been developed for special application:

1. Since the vast majority of materials to be tested have a reasonable ductility, and since bench tests have shown (Figure 4) the measurement of the movement of the load bearing system adequate in these instances, one model of the machine is in operation without the expense and complication of the endpoint extensometer system.

2. Furnace holes of a small (3 inch diameter) size were in existence in a remote facility at Battelle-Northwest; the retort has been further reduced (Figures 5 and 6) to meet this requirement.

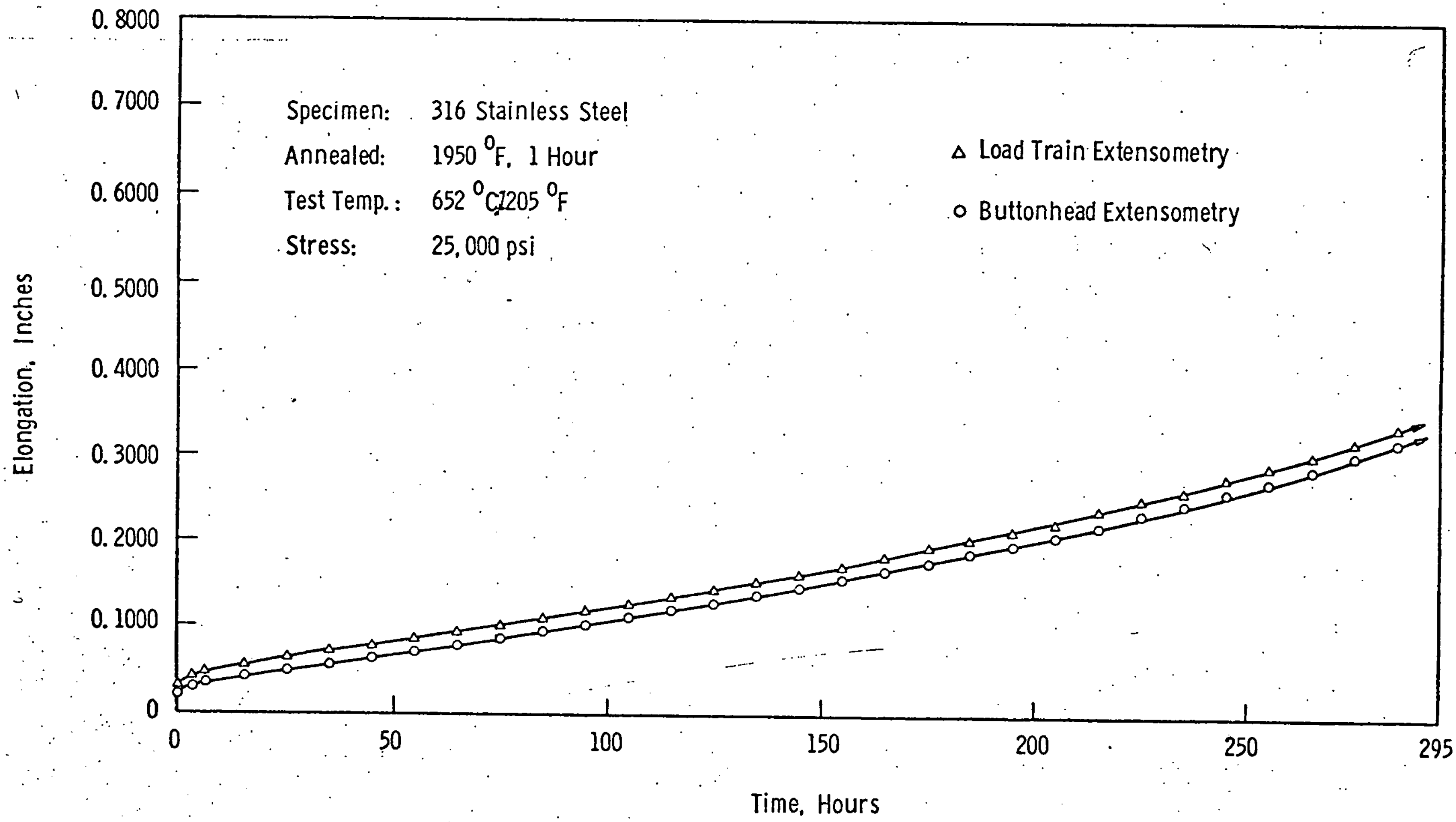

Figure 4

Extension of a 316 SS Specimen As Measured By End Point Displacement and Movement of Load Bearing Rods

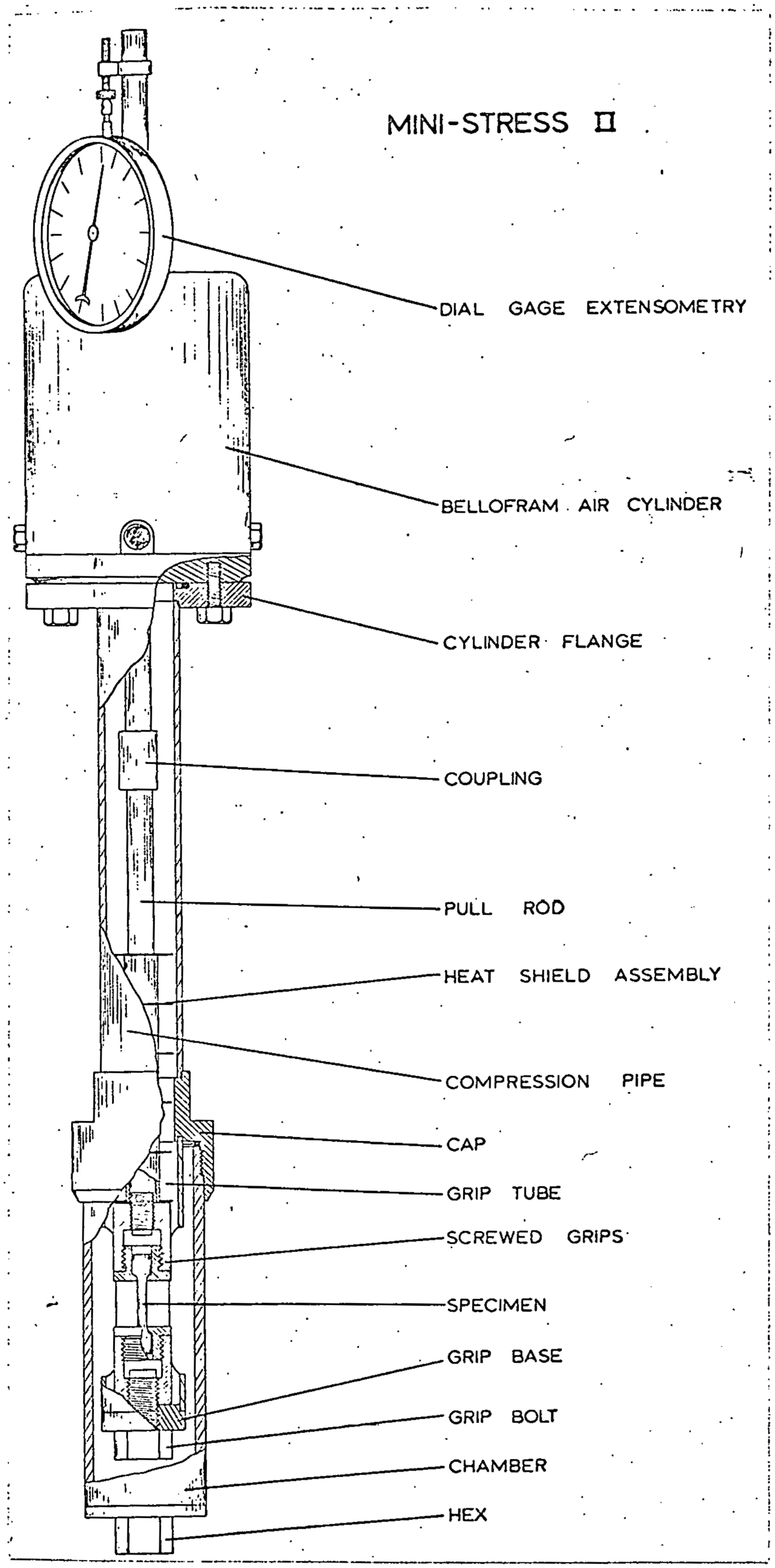

Figure 5 "Mini-Stress II" Remotized Stress-Rupture Apparatus

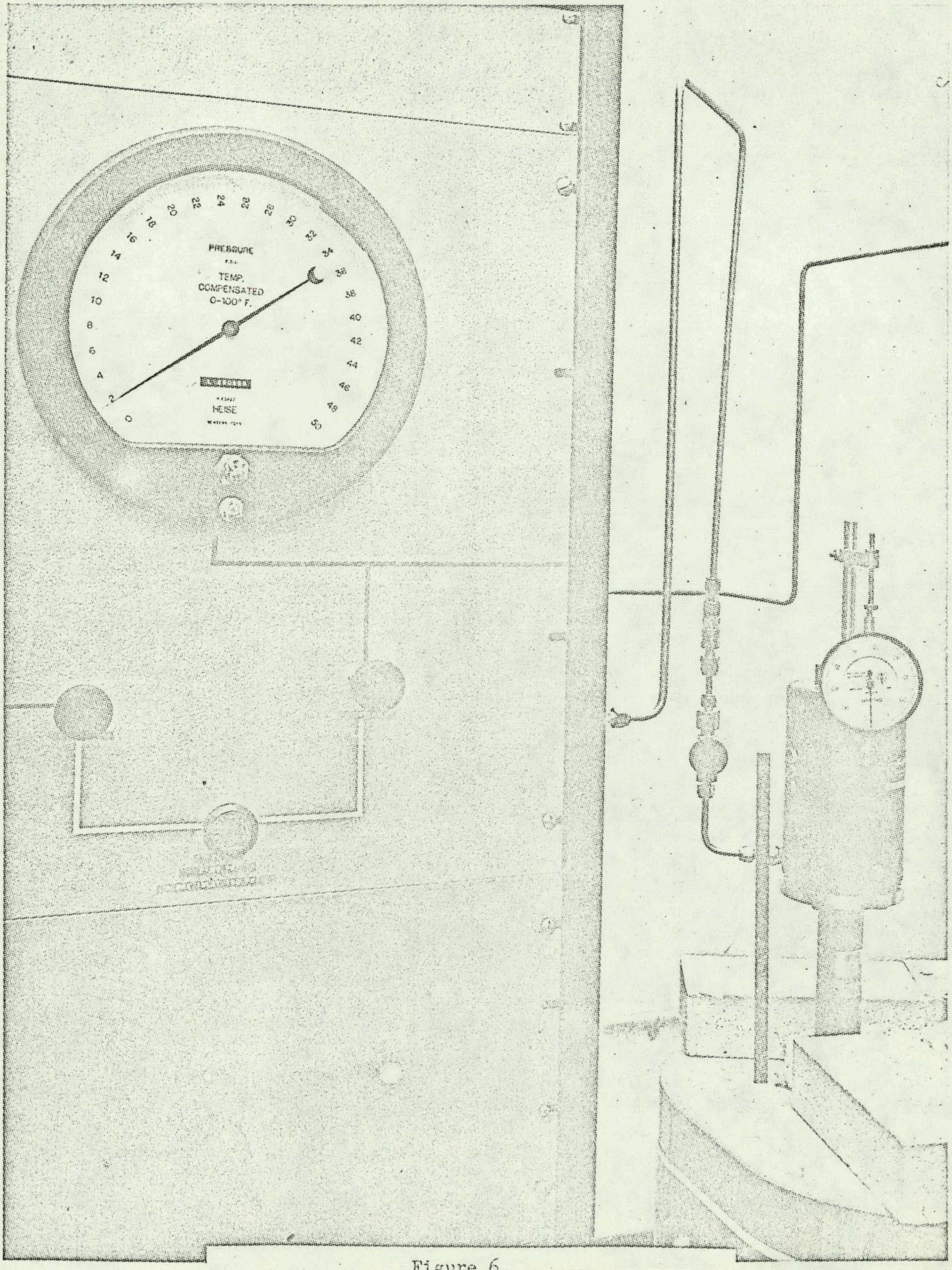

Figure 6

"Ministress II" and Gas System
Just Prior to Test Startup

EVALUATION

Following design and fabrication, a rigorous program of evaluation was begun. The tests were as follows:

A. Temperature Profile

ASTM E 139-66T states that the indicated temperature shall vary not more than ± 3°F over the length of the specimen for temperatures from 0-1800°F, and that maximum system deviation from the setpoint shall not exceed 3°F. This criterion implies a fairly sophisticated temperature control system. On the other hand, systems giving too fine a control are to be avoided due to the costs involved. A pleasant compromise was found in the system shown in Figure 7. It consists of a high-low controller with variable cycle time. The power alternates between variable auto-transformers adjusted to operate just above and just below the desired temperature.

Using the best available techniques for measuring thermocouple milli-voltage, there was no detectable difference in the indicated temperature over the length of the specimen at 1200°F. The system temperature was found to drift 3/4°F total while cycling at the same temperature.

B. Furnace Reliability

Some doubt was raised as to the long term reliability of the Kanthol furnace elements. An element was brought to 1400°F and allowed to cycle

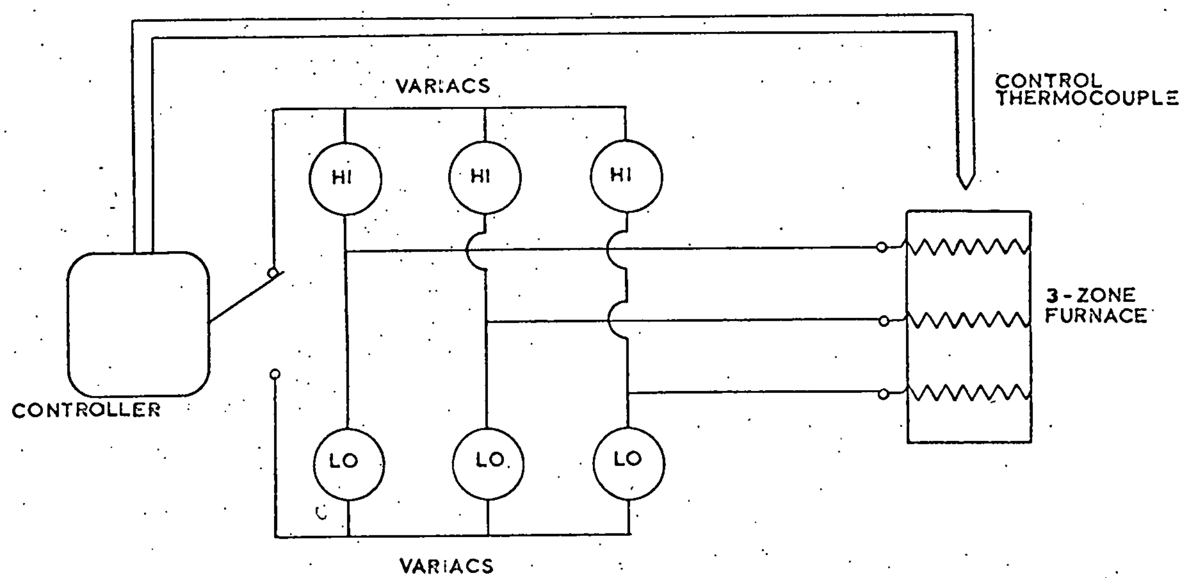

Figure 7 Temperature Control System Schematic

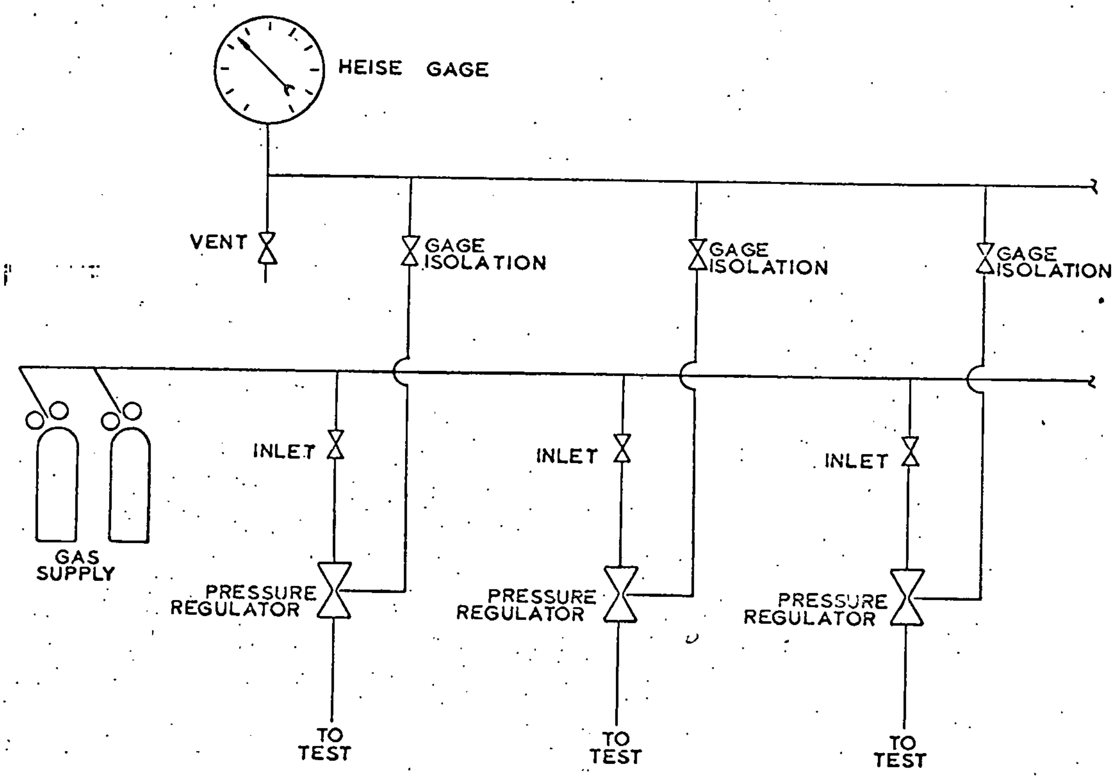

Figure 8 Pressure Gas System Schematic

between 70% power and off at approximately 5 seconds per cycle for seven weeks. A failure was noted at that time due to oxide buildup on the retort. Subsequent furnaces have been properly protected; longer term tests are scheduled.

C. Alignment

One of the most critical requirements for the testing of materials of low ductility concerns alignment of the load system. A bending moment can be caused by an uneven stress distribution across the specimen due to misalignment. ASTM E 139-66T allows a 15% variation in this distribution.

A stainless steel specimen with four bonded strain gages was inserted in the machine as received from fabrication. The strain across the specimen diameter was found to vary from 5 to 7 percent as the specimen was reinserted and rotated. It is believed that even this figure could be improved using precise alignment techniques, such as lapping the grips.

D. Calibration--Load Repeatability

In order to provide meaningful data, some correlation must be known between gas pressure and pounds force on the load system. To this end, the machine was placed, sans specimen, as shown in Figure 9, in an Instron tensile machine and the upper cylinder rod allowed to push against a load cell. A calibration curve (Figure 10) was drawn, and a few pressures selected at random. These pressures were in turn applied to the cylinder, and the load

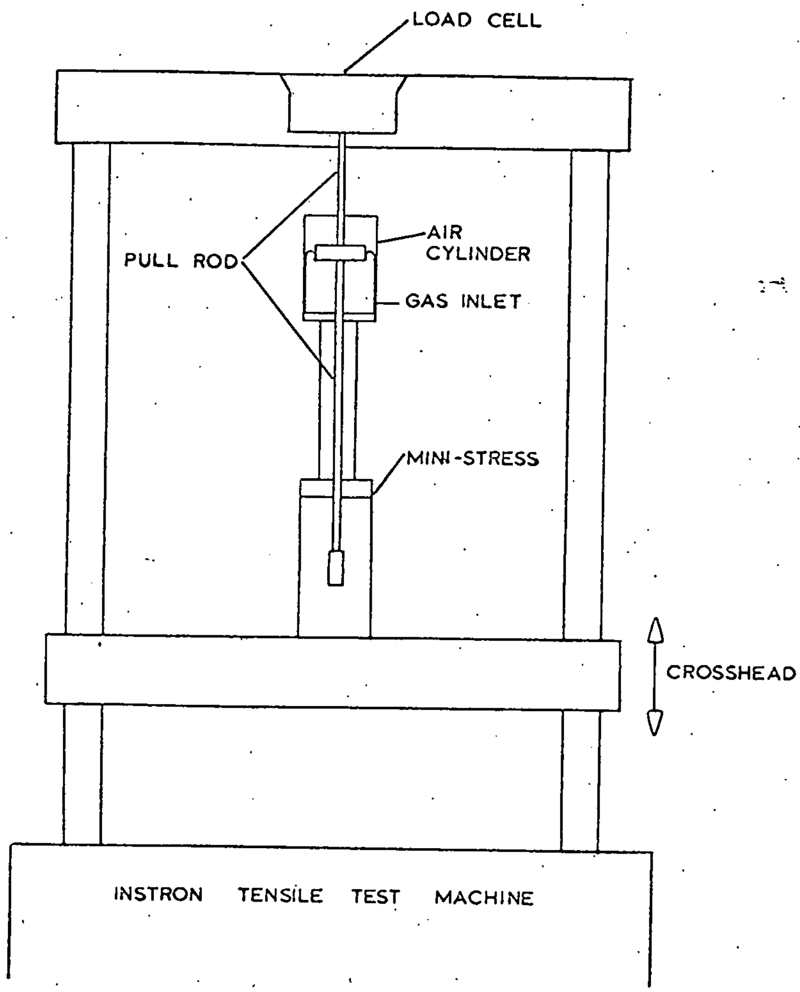

Figure 9 Test Configuration for Load Calibration

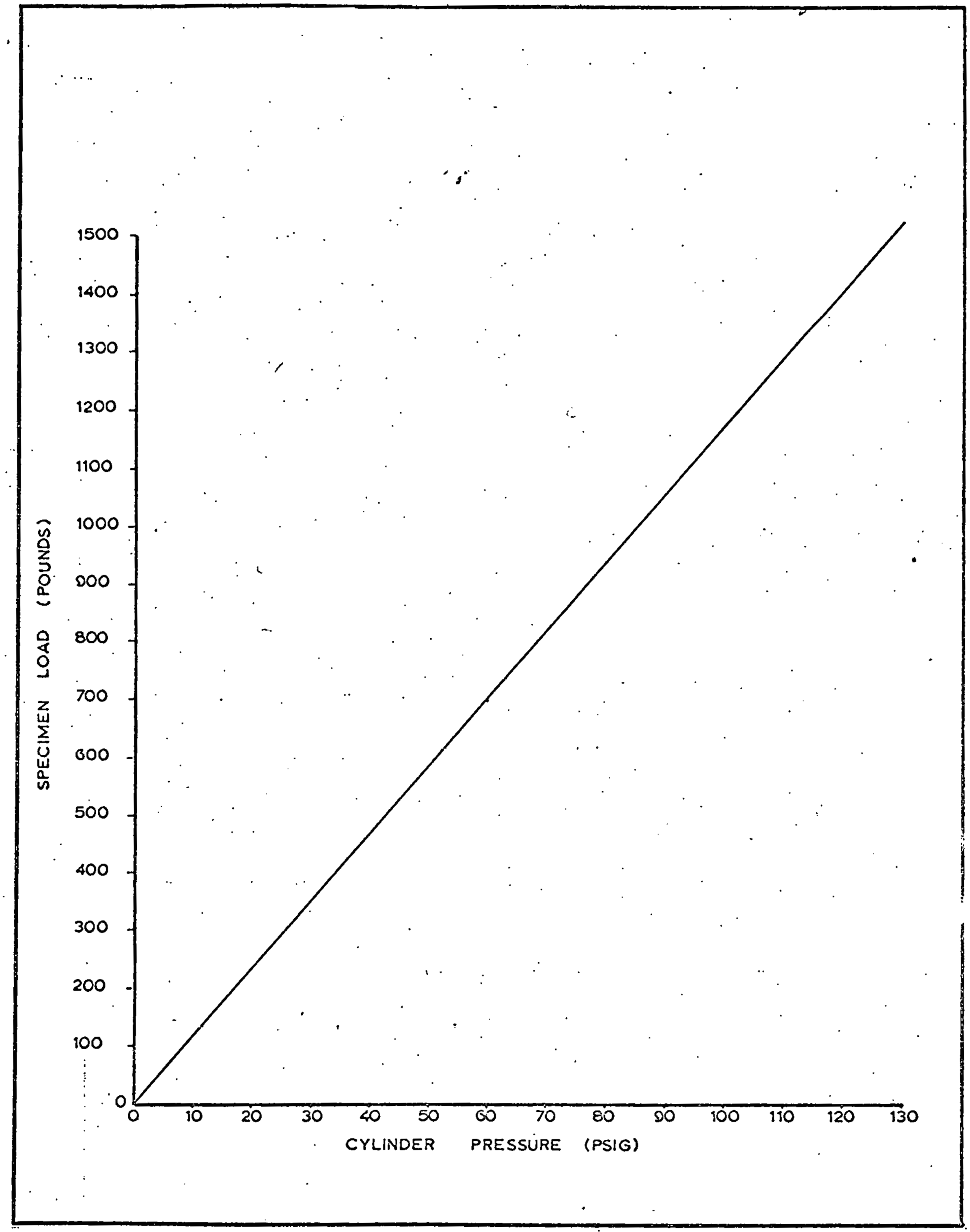

Figure 10 Typical Load Calibration Curve

recorded from the load cell compared with the predicted value from the curve. The combined error in all cases did not exceed 1/3%. This compares favorably with the ASTM 1% requirement.

E. System Friction--Load Fluctuation

The system's ability to maintain a constant load over the stroke of the machine was examined. This test was performed in the same apparatus (Figure 9) as the load calibration, only the cross head of the Instron was allowed to move down with a constant pressure in the cylinder. The cross head rate was varied from 0.001 to 0.05 inches per minute, stopped, restarted, and finally allowed to run at a constant speed of 0.05 inches per minute for the length of the stroke. In all cases, the load varied less than 1/3%.

CONCLUSIONS

Development efforts aimed at providing a compact creep rupture machine for remote applications have also, through design innovations, provided a means of performing non-irradiated tests in inert gas and air at a far more reasonable price than was previously possible with commercial apparatus.

In addition, application of the load by gas pressure allows that parameter to be varied or programmed. This is a versatility not easily shared with dead-weight loaded machines.