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A SIMPLE-BEAM DIAMETER TRANSDUCER FOR TENSILE TESTING OF ROUND SPECIMENS AT CONSTANT TRUE STRAIN RATES

by

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Pinawa, Manitoba
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Transducteur diamétral à poutrelle unique pour effectuer des essais de traction sur des spécimens ronds à des taux de contraintes véritables

par

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Résumé

On a développé un transducteur diamétral à poutrelle unique pour faire subir des essais de traction à des spécimens ronds à des taux constants de contraintes véritables. Le concept adopté comprend une paire de poutrelles minces en acier à ressorts courbées au-dessus du milieu du spécimen et pivotant à leurs extrémités. Une jauge de contrainte est fixée sur la surface extérieure au centre de l'une des poutrelles. Si les points d'articulation et la ligne de centre verticale du spécimen se trouvent dans le même plan, la contrainte mesurée sur la poutrelle variera linéairement avec le diamètre du spécimen. En pratique, cette nécessité géométrique est satisfaite par la méthode de construction et la linéarité a été confirmée par des expériences.

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ABSTRACT

A simple-beam diameter transducer was developed for tensile testing of round specimens at constant true strain rates. The design adopted consists of a pair of thin beams of spring steel bent across the specimen mid-point and hinged at their extremities. A strain gauge is bonded to the outer surface at the mid-length of one of the beams. If the hinge points and vertical centre line of the specimen lie in the same plane, the strain measured on the beam will vary linearly with the diameter of the specimen. In practice, this geometric requirement is satisfied by the method of construction, and linearity was confirmed by experiment.

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1. INTRODUCTION

During a series of tests investigating the relationships between true stress, and true strain it became necessary to perform tensile tests in which the true strain rates remain constant up to the point of fracture. Also, it was required that the specimen surface be marked with a grid to confirm analytical results from a finite element, elasto-plastic stress analysis.

True strain in a tensile specimen undergoing uniform deformation can be defined as:

$$\varepsilon_t = \int_{l_o}^{l_i} \frac{dl}{l} = \ln \frac{l_i}{l_o}$$

where l_o is the unstrained length and l_i is the instantaneous length at any time. For a specimen of circular cross section it can be shown that, assuming constant volume,

$$\frac{l_i}{l_o} = \left(\frac{d_o}{d_i}\right)^2$$

and therefore

$$\varepsilon_t = \ln\left(\frac{d_o}{d_i}\right)^2$$

where d_o is the unstrained diameter and d_i is the instantaneous diameter during the test. This latter expression is valid even for the case of plastic non-uniform deformation which occurs during necking of the specimen. Thus true strain, ε_t, and true strain rate, $\dot{\varepsilon}_t$, are functions of the instantaneous diameter, d_i.

A device which will follow the "neck", electronically monitor the "neck" diameter, and provide an output linearly proportional to the "neck" diameter can therefore be used to provide the necessary feedback signal.

2. EXISTING DIAMETRAL GAUGE DESIGNS

The tests required a diametral gauge capable of following the "neck" and measuring the minimum diameter, providing a linear output with respect to diameter, with rapid response characteristics for use at high strain rates, simple and cheap to construct, and unobstructive to photographic work.

A literature search to determine approaches to this problem by other experimenters revealed that three basic types of diametral gauge have been employed. All are relatively cumbersome, expensive, and unsuitable for our purposes. The stationary monitor type(1) does not follow the vertical translation of the neck. The light integrator type(2) is not compatible with the lighting required for photography and the multiple leaf type(3,4) obstructed the view of the camera.

3. IMPROVED DIAMETRAL GAUGE DESIGN

When a constant diameter tensile specimen is being tested, the precise location of the "neck" cannot be predicted prior to the test. A double tapered specimen was devised to ensure necking at the mid-point (see Figure 1).

The diametral gauge design adopted consists of a pair of thin beams of spring steel bent across the specimen mid-point and hinged at their extremities. A strain gauge was bonded to the outer surface at the mid-length of one of the beams. Provided that the hinge points and the vertical centre line of the specimen lie in the same plane, the strain measured on the beam will vary linearly with the diameter of the specimen. In practice, this geometric requirement is satisfied by the method of construction indicated in Figure 2, and linearity was confirmed by experiment.

The design is based on simple beam-bending theory (see Appendix A). It is of interest to note that the measured strain is independent not only of the Young's Modulus of the beam material but also of the Moment of Inertia of the beam section. Thus the cross section of the beam may be modified to ensure point contact at the root of the "neck" without affecting the linear relationship between specimen diameter and measured strain.

4. CALIBRATION AND OPERATION

Linearity of the device was confirmed using drill bits of various diameters to produce a plot of diameter against amplifier output. However, in application the device is used without calibration. Since the true strain is a function of a diameter ratio, it is only necessary to set the amplifier output to zero in the unstrained condition, and to ± 10 volts with the device installed on the specimen.

Figure 3 shows the system arrangement in block schematic form. A program command signal, together with set point, or datum, is compared with the feedback signal from the diameter sensing device. The algebraic difference, or error signal, is amplified and used to drive the servovalve to move the actuator in such a way as to cause the feedback to equal the command.

Programming is by means of the Data-Trak* Arbitrary Function Generator integral with the MTS** system. This device commands the hydraulic actuator according to a program drawn in graph form on a chart mounted on a rotating drum.

The graph axis across the drum width represents the required transducer output signal in volts. Full scale of 10 volts represents d_o, the initial diameter. Other diameters, d_i, will be represented by $\frac{d_i^2}{d_o}$ x 10 volts.

The graph axis around the circumference of the drum represents time, and the distance from zero corresponding to any given diameter d_i is calculated from:

$$x = \frac{s\varepsilon_i}{\dot{\varepsilon}} \text{ mm}$$

where s = speed of drum mm/min
ε_i = strain corresponding to d_i
$\dot{\varepsilon}$ = true strain rate required.

$$\text{So} \quad x = \frac{2s}{\dot{\varepsilon}} \ln\left(\frac{d_o}{d_i}\right).$$

5. ADVANTAGES & DISADVANTAGES

Advantages

1) The device is cheap, quick and easy to manufacture. The narrow strain gauges which are now readily available permit the use of

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[*] Trade mark: Research, Incorporated, Minneapolis, Minnesota, U.S.A.

[**] Mechanical Testing System, manufactured by MTS Systems Corporation, Minneapolis, Minnesota, U.S.A.

narrow beams which will follow the "neck" accurately. The gauges used were type EA-06-230DS-120 manufactured by Micro-Measurements. This type of gauge is 0.762 mm wide at maximum and mounted on a plastic backing approximately 3.2 mm wide. This backing may be trimmed flush with the edge of the beam after the gauge is mounted. The beams described were 2.5 mm wide, but narrower beams, say 1.5 mm, could be used.

2) Calibration is simple, only a matter of setting the transducer amplifier output to zero with the beams in the unstrained condition, and to ± 10 volts with the device installed on the specimen.

3) Since the device is not positively located relative to stationary parts of the testing machine, it will follow any vertical movement of the "neck" relative to such stationary parts.

4) The device will follow the "neck" all the way to specimen fracture.

Disadvantages

1) The specimen may not start to "neck" at the exact section at which the beams are located. Attempts to relocate the beams after "necking" has begun will result in the hydraulic actuator "backing-up", putting the specimen into compression. However, tapered specimens such as those used in these tests allow the point of "necking" to be closely predicted, thus reducing this disadvantage.

2) When the specimen fractures, the transducer output will rapidly tend to zero, thus outpacing the program. This will result in the hydraulic actuator "backing-up", putting the specimen into compression, or forcing the fractured ends together. However, by careful setting of

the error detectors of the MTS system, the hydraulic system will shut down at specimen fracture and damage to the fracture surfaces can be minimized.

3) A beam of rectangular cross section will not accurately follow the curved surface of the "neck". This may be overcome by grinding the face of the beam which contacts the specimen so that a D-Section is obtained.

4) In its present form, the device is not suitable for high temperature work. While a weldable, high temperature gauge might allow work up to 350°C, the length of the device would require that a very large diameter furnace be used.

6. REFERENCES

1. Powell, G.W., Marshall, E.R., and Backofen, W.A., ASTM Proceedings 55 (1955), 797-809.

2. Bartholomew, E.L., Krystyan, K.J., Millar, D.A.J., and Wulff, J. Rev. Sci. Inst. 24 (1953), 196-202.

3. Jur, T.A., J. of Eng. Mat. and Tech. Trans. A.S.M.E. 96 Ser. H. (1974) 195-200.

4. De Sisto, T.S. and Driscoll, D.E., ASTM Bulletin, 228, (1958) 46-49.

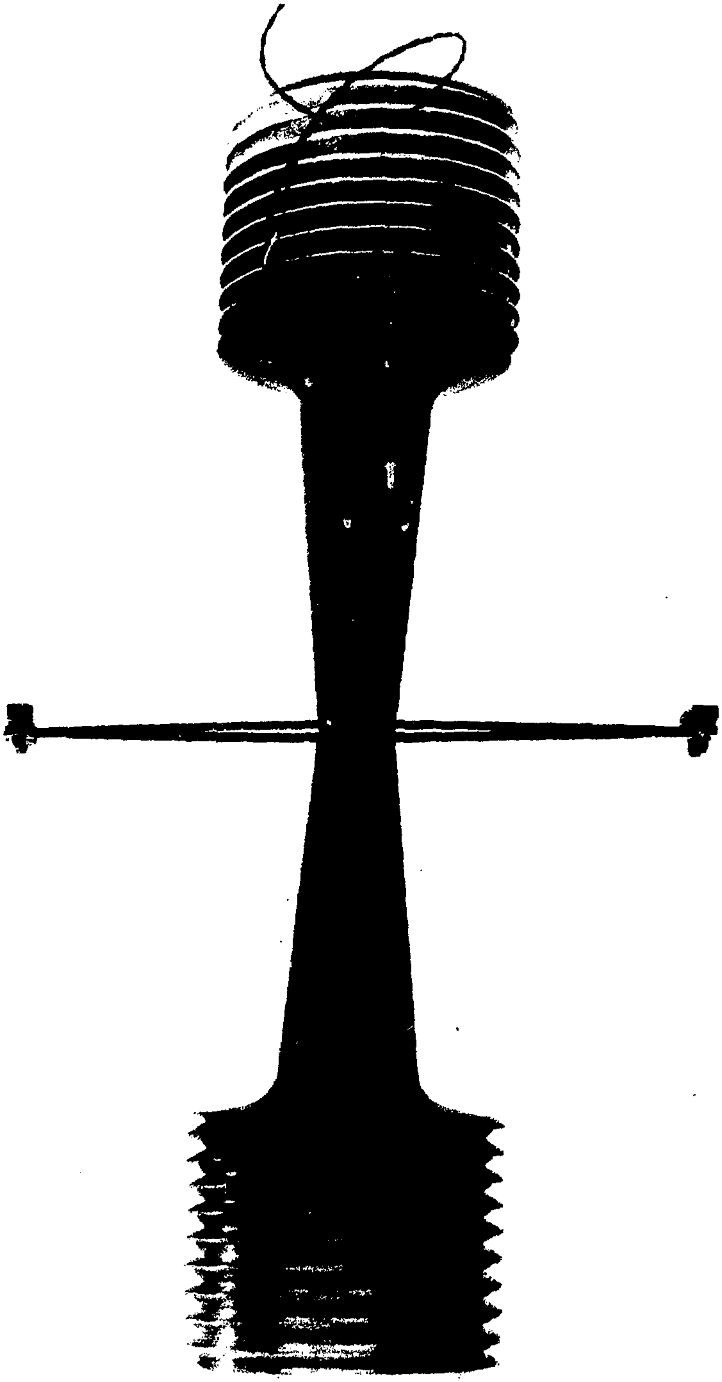
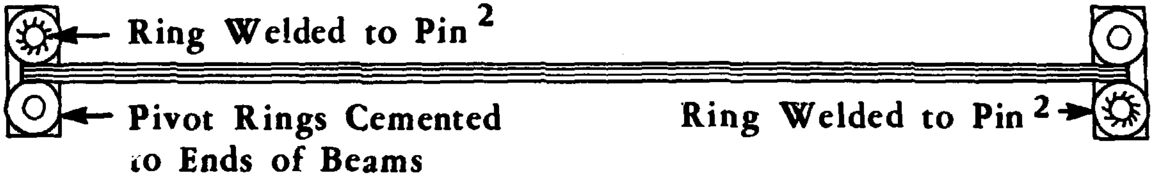


FIGURE 1



Notes:

1. Lengths of beams selected according to diameter to be measured strain should be approx. 2000-3000 μ strain
2. Diagonally opposing rings welded to pins to avoid beams from being locked in the bent position

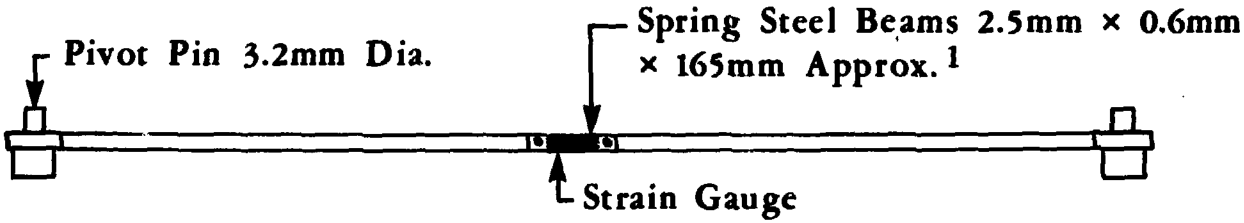


FIGURE 2 Bent Beams System for Diameter Measurement

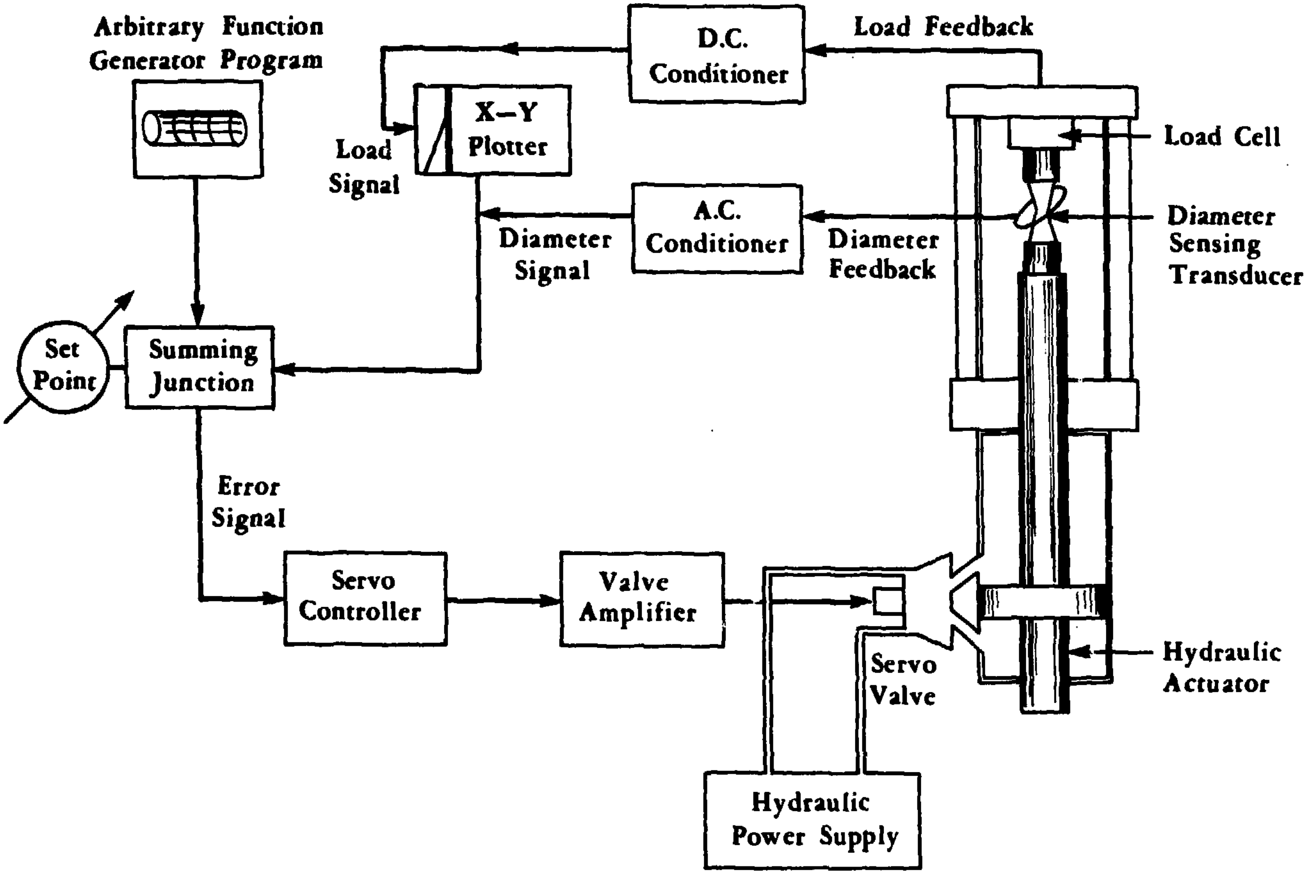


FIGURE 3 Material Testing System With True Strain Control by Continuous Diameter Measurement

APPENDIX A

Consider a beam of spring material of rectangular cross section to be bent around the specimen as shown in Figure A1.

By simple beam bending theory,

$$\frac{E}{R} = \frac{M}{I} = \frac{\sigma}{y} \qquad \text{A.1}$$

where E = Young's modulus for the spring material
R = radius of curvature of the bent beam
M = bending moment at any section along the beam
I = second moment of area of the beam cross section
σ = stress in the beam material at a distance y from the neutral axis.

From A.1, $\sigma = \frac{Ey}{R}$, but $E = \frac{\sigma}{\varepsilon_b}$ is the strain in the beam material. Therefore,

$$\varepsilon_b = \frac{\sigma}{E} = \frac{y}{R}. \qquad \text{A.2}$$

Also, from bending theory,

$$EI.\,\frac{d^2s}{dx^2} = M$$

where s is the displacement at a distance x from one support (see Figure A1). Also, from (A.1) above, $M = \frac{\sigma I}{y}$, therefore

$$\frac{d^2s}{dx^2} = \frac{\sigma}{Ey}\,.$$

Integrating, $\frac{ds}{dx}$ = slope of the beam at any section

$$= \frac{\sigma x}{Ey} + c_1$$

when $x = \frac{L}{2}, \frac{ds}{dx} = 0$, and $c_1 = \frac{-\sigma L}{2Ey}$.

Therefore, $\frac{ds}{dx} = \frac{\sigma x}{Ey} - \frac{\sigma L}{2Ey}$.

By integration, $s = \frac{\sigma x^2}{2Ey} - \frac{\sigma L}{2Ey} + C_2$

when $x = 0$, $s = 0$, and $C_2 = 0$.

Therefore, $s = \frac{\sigma}{2Ey} \{x^2 - Lx\}$.

Hence, at the mid-point, $s = \frac{-L^2\sigma}{8Ey}$.

Since $\varepsilon_b = \frac{\sigma}{E}$ (Equation A.2), $s = \frac{-L^2\varepsilon_b}{8y}$

In the case of the beam bent around a tensile specimen of diameter d_o prior to straining, $s = \frac{d_o}{2}$ provided that the support points are in the plane of the specimen vertical centre line,

At any instant, $s_i = \frac{d_i}{2}$

or $d_i = 2s_i = \frac{-L^2\varepsilon_b}{4y}$

Since L is constant and y can be assigned as the distance from the neutral axis to the outer surface of the beam, which remains essentially constant for $\varepsilon_b < 3000$ μm strain, $d_i \propto \varepsilon_b$. That is, the diameter of the tensile sample at any instant will be proportional to the strain measured at the beam surface. Note that the expression is independent of the Young's modulus of the beam material and also independent of the second moment of area of the beam section.

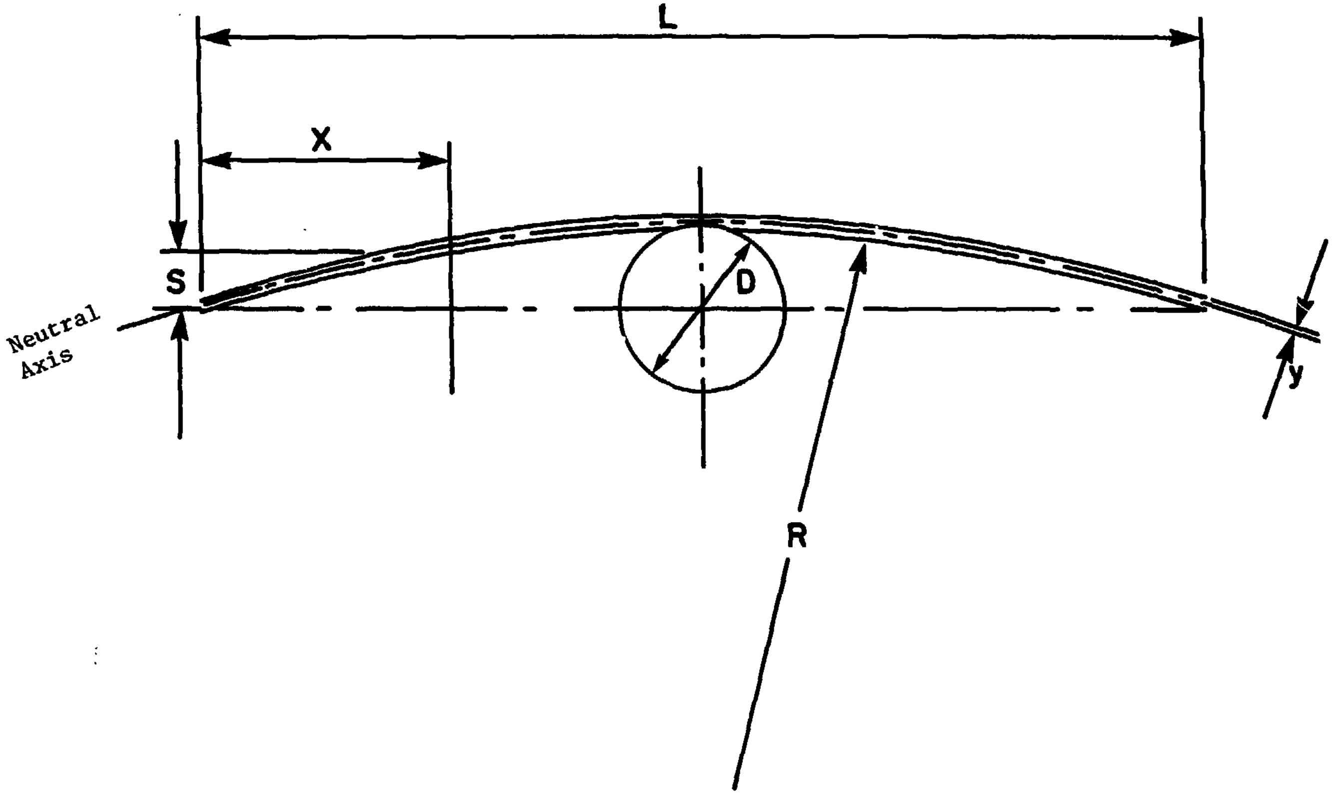


FIGURE A.1

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