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**A SYSTEM FOR EVALUATING THE
DEFORMATION OF VARIOUS
MATERIALS UNDER COM-
PRESSIVE LOADS**

R. A. Gallman

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A SYSTEM FOR EVALUATING THE DEFORMATION OF VARIOUS MATERIALS UNDER COMPRESSIVE LOADS

R. A. Gallman

Laboratory Development Department
Y-12 Development Division

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Oak Ridge Y-12 Plant

P. O. Box Y, Oak Ridge, Tennessee 37830

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ABSTRACT

A test system has been developed in two versions which can determine the deformation of various materials under selectable, uniaxial, compressive loads. The field model is an inexpensive, rugged, easily operated instrument intended for production use; whereas, the instrumented model is an accurate instrument, with analog and digital outputs, intended for use as a certification tool.

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SUMMARY

A system has been developed which can measure the deformation of various materials under selectable, uniaxial, compressive loads. Two versions of this load-deformation test system are available. The field model is an inexpensive, rugged instrument which is operationally simple and easily transported; the instrumented model is an easily operated instrument which has a high degree of accuracy and is equipped with analog and digital outputs of load and deformation.

The maximum bias and precision (95% confidence interval) for the field model are 2.0 and ± 4.5 N, respectively, on the load and 13.0 and ± 14.0 μm , respectively, on the deformation. The maximum bias and precision (95% confidence interval) of the instrumented model are 0.25 and ± 1.0 N, respectively, on the load and 5.0 and ± 5.0 μm , respectively, on the deformation.

INTRODUCTION

All substances deform under applied loads. Two phenomena occur when a substance is subjected to such loads: (1) distortion, which is any change in shape, and (2) dilatation, which is any change in density. The summed effect of these two phenomena is called "deformation". Deformation is defined as any change in the configuration of a substance. Experience shows that within the elastic range the relation between deformation and applied stress is linear, being known as Hooke's law. Beyond the elastic range, the material acquires a permanent set which is known as "plastic deformation". The deformation characteristics of a material are significant factors which affect the use of that material and the design of components to be fabricated from that material.

The purpose of this report is to describe a specialized testing system developed to perform deformation studies on various materials under low, uniaxial, compressive loads. The system must satisfy the following criteria: (1) must be inexpensive; (2) must be rugged; (3) must be easily transported; (4) must be simple to operate; (5) must make measurements rapidly; (6) must have a sample pressure range from 14 to 350 kPa; (7) must have a 25-mm clearance between the loading platens; (8) the deformation measurement must have sufficient accuracy to make the measurement of value, and (9) the system must be able to accommodate instrumented readout options. The Oak Ridge Y-12 Plant^(a) has a need for just such a testing system to study the deformation of various materials under uniaxial, compressive loads. Presently, deformation evaluation of this type requires the use of a universal testing machine, a position gage, and a deflectionometer. This system has several drawbacks: (1) it is large and expensive; (2) it is a complicated system to operate, requiring a trained technician; (3) a long setup period prior to testing makes it a time-consuming measurement, and (4) the data must be interpreted from load-displacement analog readouts.

(a) Operated by the Union Carbide Corporation's Nuclear Division for the US Energy Research and Development Administration.

DEFORMATION EVALUATION SYSTEM

USE OF THE SYSTEM

The load-deformation test system is to be used in two different environments. One environment requires a cheap, rugged instrument which is operationally simple, can be easily transported, and can make rapid measurements. In this situation, a high degree of accuracy on the load and deformation values is not required. These requirements are dictated by production needs for a quick, easy, on-site check of material deformation. The other environment is for a certification test. Here, the system must have variable load capabilities, a high degree of accuracy on the load and deformation values, and analog and digital readouts of load and deformation. These differing requirements indicate a need for two versions of the load-deformation test system.

FIELD MODEL OF THE TEST SYSTEM

Equipment

A view of the field model of the load-deformation test system, which is intended for use in a production area, is presented in Figure 1. To achieve sturdy construction and a low cost, a

Figure 1. FIELD MODEL OF THE LOAD-DEFORMATION TEST SYSTEM.

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commercial cast arbor stand with a modified base is used as the basic load frame. Attached vertically to the arbor stand is a gas-driven piston with a valve which applies the compressive load. The piston has a 25-mm stroke and is operated by any clean gas supply. Actuation of the piston is accomplished through the control unit which provides power and switching to the piston valve. The load is applied to a sample by a pressure foot attached to the piston. The pressure foot is available in three area sizes (644, 1291, and 2579 mm²) to cover the desired sample pressure range. Smaller pressure feet will allow higher pressures on the sample without increasing the load above 250 N. A 25-mm travel dial indicator is mounted on the arbor stand parallel to the load axis. This instrument indicates movement of the piston via its traveling arm which rides a steel bar attached to the piston. The dial indicator measures liftoff from the sample base. Figure 2 is a block diagram of the field-model test system. The gas regulator adjusts the gas pressure delivered to the piston, thereby regulating the load delivered to the sample; the control unit supplies power to the system and gives an accurate reading of gas pressure; the foot switch actuates the piston. The estimated cost of the field model of the load-deformation test system is \$600.

Figure 2. COMPONENTS OF THE FIELD MODEL OF THE LOAD-DEFORMATION TEST SYSTEM.

This version of the test system is easy to operate. After applying power by a front panel switch on the control units, the gas regulator is adjusted to deliver the proper gas pressure in order to get the desired load. With the pressure foot seated against the sample base, the dial indicator is adjusted for a zero reading; then the pressure foot is raised, a sample introduced, and the pressure foot lowered. The amount of deformation for a given load and pressure foot (load/pressure foot area equals sample pressure) is found by comparing the dial indicator thickness with the independently determined, unloaded thickness of the same sample.

Performance

For the field model of the load-deformation test system to be useful, a measurement of the load delivered by the piston must be provided. This requirement can be met in two ways: (1) use a force gage to measure the load directly prior to testing while adjusting the gas pressure, or (2) use a predetermined calibration of load as a function of gas pressure. Use of a force gage is preferred because it is a direct measurement and because it is used shortly before testing. However, if such a gage is not available it becomes necessary to have a load/gas pressure calibration. Such a calibration was obtained for this system using a load cell mounted atop the sample base to give load values. The results of this calibration are presented in Table 1 and Figure 3 (the solid line indicates a linear least-squares fit to the data). The maximum bias of the load is dependent upon the measuring technique used, but is generally within two newtons of the known value. Two problems were encountered during testing: (1) there exists a minimum gas pressure (20 kPa) below which the piston cannot be actuated, meaning a minimum load of about 25 N; (2) during the first 15 seconds after piston actuation, the load decreases by as much as 7% (Table 2). This time lag requires a minimum delay, after the piston is lowered, of 15 seconds before taking any readings. The repeatability of load value was studied also with the result that, for 25 measurements, the 95% confidence interval amounted to ± 4.5 N.

Table 1
LOAD VALUES TO THE PISTON AS A
FUNCTION OF GAS PRESSURE

Gas Pressure (kPa)	Load Cell Output(1) N
138	200
131	187
124	178
117	169
110	165
103	151
96	142
90	131
83	120
76	109
69	100
62	87
55	78
48	69
41	60
34	49
28	40
24	36
21	31

(1) Values obtained 15 seconds after piston actuation.

The bias of the dial indicator was studied using thickness standards which would not deform significantly under low loads. Ten thickness values per standard were taken and an average found. These data are presented in Table 3. The maximum bias of the dial indicator was found to be $13.0 \mu\text{m}$. The precision of the dial indicator was studied in a series of tests at three loads. Twenty values were obtained at each load. The standard deviation was found to

be $7\text{ }\mu\text{m}$; hence, a 95% confidence interval of $\pm 14\text{ }\mu\text{m}$. Of the 60 values collected, the maximum difference was $25\text{ }\mu\text{m}$.

Table 2
LOAD VALUES TO THE PISTON AS A
FUNCTION OF TIME AFTER
ACTUATION

Elapsed Time (sec)	Load Cell Output (N) at Various Gas Pressures (kPa)			
	34.5	69.0	103.4	137.9
0	50.35	102.93	151.72	207.72
15	46.93	95.45	147.01	207.05
30	46.53	94.03	145.85	206.03
45	46.35	93.32	145.09	205.19
60	46.30	92.83	145.00	204.56
75	46.21	92.52	144.38	204.16
90	46.17	92.30	144.12	203.81
105	46.17	92.16	143.89	203.36
120	46.13	91.98	143.67	203.18

222.5 N so that the gas pressure should never be great enough to give a load above this value. A stainless steel disc is attached to its upper surface to serve as a seat for the pressure foot. The LVDT has 25 mm of travel with a gaging range of $\pm 2.5\text{ mm}$. Both the LVDT and load cell control units have digital displays as well as analog and digital outputs.

A block diagram of the instrumented model is given in Figure 5. This version of the load-deformation test system is operated similarly to the field model; the only differences are that direct load readings are obtained during the test from the load cell and the LVDT provides the deformation measurement. The same problems of minimum gas pressure to actuate the piston and decreasing load during the first 15 seconds apply to this version. Both readouts can be interfaced to a strip-chart recorder or a computer. The estimated cost of the instrumented model of the load-deformation test system is \$3200.

Performance

To develop confidence in the load and thickness values obtained from the instrumented model, the bias and precision of the load cell and the LVDT were determined under normal operating conditions and under conditions designed to maximize error and variability.

INSTRUMENTED MODEL OF THE TEST SYSTEM

Equipment

The instrumented model of the load-deformation test system, intended for use as a certification tool, can be seen in Figure 4. The instrumented model is similar to the field model, but with two important differences: (1) a load cell is mounted atop the sample base, replacing the plastic platen seen in Figure 1, and (2) a linear variable differential transformer (LVDT) is mounted on the arbor stand in place of the dial indicator. The load cell has a capacity of

Figure 3. LOAD VALUES TO THE PISTON AS A FUNCTION OF THE GAS PRESSURE.

Table 3
DIAL INDICATOR BIAS DATA FOR THE FIELD MODEL

Actual Thickness (μm)	Dial Indicator Readings (μm)										Mean ($\pm 1 \sigma$)
	1	2	3	4	5	6	7	8	9	10	
0.0	0.0	0.0	2.5	2.5	5.0	5.0	2.5	2.5	2.5	0.0	2.5 ± 2.5
127.0	127.0	127.0	124.5	127.0	127.0	132.0	127.0	127.0	129.5	127.0	127.0 ± 2.5
254.0	264.2	259.1	254.0	254.0	254.0	256.5	259.1	256.5	254.0	259.1	256.5 ± 2.5
381.0	383.5	381.0	383.5	381.0	386.1	381.0	386.1	381.0	386.1	383.5	383.5 ± 2.5
508.0	510.5	497.8	502.9	497.8	500.4	505.5	500.4	502.9	500.4	502.9	502.9 ± 2.5
635.0	635.0	632.5	632.5	635.0	637.5	635.0	635.0	635.0	635.0	632.5	635.0 ± 2.5
762.0	756.9	744.2	744.2	746.8	744.2	756.9	749.3	754.4	746.8	754.4	749.3 ± 5.0

Figure 4. INSTRUMENTED MODEL OF THE LOAD-DEFORMATION TEST SYSTEM.

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The bias of the load cell was determined using calibrated weights known to $\pm 0.1\%$ and was found to be within the limit of error of the calibrated weights over its operating range (0 - 222.5 N). The load-cell precision was studied at several different gas pressures. Two sets of data were taken, one under normal operating conditions and the other under the adverse operating conditions mentioned earlier. Table 4 lists these results for a gas pressure of 34.5 kPa. In normal operation, the difference between the maximum and minimum load values was 1.2 N, with the 95% confidence interval amounting to ± 1.0 N. Under adverse operating conditions, the difference between the maximum and minimum load values was 17.1 N, with the 95% confidence interval being ± 9.8 N. The results were

similar at the other gas pressures. Also, for a given gas pressure, the load was found to increase as the area of the pressure foot increased, but the increase was always less than 4.5 N. The stability of the load cell was examined over a two-week period and it was found that the output varied no more than 0.1 N.

The bias and precision of the LVDT were determined when used with the instrumented model of the load-deformation test system. The bias of the LVDT alone, separate from the test system, was found to be no more than $2.5\ \mu\text{m}$ over its gaging range. It is probably better than that, but the LVDT control unit can be read only to the nearest $2.5\ \mu\text{m}$. The bias of the LVDT used in conjunction with the test system was determined using thickness standards that covered its gaging range. Under normal operating conditions, the maximum bias of the LVDT was found to be $5.0\ \mu\text{m}$; under adverse operating conditions, it was $15.0\ \mu\text{m}$. The precision of the LVDT for a given load was found. Two data sets were generated, one under normal operating conditions and the other under adverse operating conditions. Table 5 summarizes these results for a load of 50.0 N. In normal operation, the

Figure 5. COMPONENTS OF THE INSTRUMENTED MODEL OF THE LOAD-DEFORMATION TEST SYSTEM.

Table 4

LOAD CELL REPEATABILITY DATA AT A
GAS PRESSURE OF 34.5 kPa

Run	Load Cell Reading (N)(1)	
	Normal Conditions	Adverse Conditions
1	44.9	50.4
2	45.4	50.0
3	45.3	49.6
4	45.2	48.8
5	45.0	48.7
6	45.0	51.9
7	45.0	50.9
8	45.0	43.9
9	45.8	43.0
10	45.6	44.0
11	45.6	44.3
12	45.5	45.3
13	45.1	43.8
14	45.7	42.9
15	45.5	38.3
16	45.7	37.4
17	45.9	42.3
18	45.9	52.6
19	46.0	52.6
20	46.1	52.5
21	45.8	54.5
22	45.8	53.7
23	45.9	52.8
24	45.7	53.4
25	45.5	48.0
Standard Deviation	0.5	4.9

Table 5

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER
REPEATABILITY DATA AT A LOAD OF 50.0 N

Run	LVDT Reading (μm)	
	Normal Conditions	Adverse Conditions
1	22.9	22.9
2	27.9	22.9
3	27.9	22.9
4	27.9	35.6
5	27.9	35.6
6	25.4	25.4
7	27.9	25.4
8	22.9	25.4
9	25.4	26.4
10	25.4	35.6
11	22.9	22.9
12	22.9	22.9
13	25.4	22.9
14	27.9	22.9
15	25.4	22.9
16	25.4	38.1
17	25.4	38.1
18	25.4	33.0
19	25.4	35.6
20	22.9	38.1
21	30.5	22.9
22	27.9	22.9
23	27.9	22.9
24	25.4	17.8
25	25.4	27.9
Standard Deviation	2.6	0.5

(1) Values obtained about 15 seconds after piston
actuation.

difference between the maximum and minimum LVDT readings was $7.6 \mu\text{m}$, with the 95% confidence interval being $\pm 5.0 \mu\text{m}$. Under adverse operating conditions, the difference between the maximum and minimum LVDT readings was $20.3 \mu\text{m}$, with a 95% confidence interval of $\pm 13.0 \mu\text{m}$. The stability of the LVDT was studied over a two-week period. Results show that its output varied less than 1%.

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