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COMPUTERIZED MICROSTRAIN TEST SYSTEM

by J. W. Lyons, H. C. Pambookian, J. P. Krawiec, and T. P. Curran

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Cambridge, Mass.

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16. Abstract
A computerized microstrain measuring system is described. The system utilizes an automatic absolute capacitance measuring bridge with either an analog or hybrid computer to measure plastic deformation, hysteresis loop areas, and total strain energy at microinch sensitivities over a 7500-μ in. strain range in conventional load-unload tensile tests. Details of the system, including computer simulation, calibration, and error sources, are discussed. Microyield, elastic limit, specific damping energy, and internal friction results obtained with 52100 steel, 6061-T6 aluminum, and 6Al-4V titanium alloys are presented. Examples of additional capabilities are mentioned.

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COMPUTERIZED MICROSTRAIN TEST SYSTEM

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SUMMARY

A computerized microstrain test system is described, which processes strain signals from an automatic capacitance bridge and load signals from a constant loading rate tensile machine in either an analog or hybrid computer. The basic objective of the system is to measure the microstrain properties of materials in tensile load-unload tests. Plastic deformation, hysteresis loop areas, and total strain energy can be measured at microinch sensitivities over total strain ranges as large as 7500 μ in. A full discussion of the computer simulation, calibration procedure, and error sources of the system is given. Preliminary results of microyield, elastic limit, specific damping energy, and internal friction determinations on 52100 steel, 6AL-4V titanium, and 6061 T6 aluminum are presented.

INTRODUCTION

In order to achieve the accuracy and reliability required in precision instruments, such as the gyroscopes and accelerometers in inertial guidance systems, the materials used in their construction must perform predictably and consistently. A prime design criterion for these instruments is that the materials used behave truly elastically. Dimensional instabilities in materials due singularly or to combinations of stress, time, and temperature can have deleterious effects on the drift characteristics of gyroscopes, and cause bias and null shifts in accelerometers. In most high precision inertial instruments and telescopes, any permanent dimensional change greater than 10^{-6} in./in. can seriously impair performance and reliability.

Various experimental techniques, utilizing optical (Tuckerman) extensometers, resistance strain gauges, differential transformers (LVDT's) and capacitance gauges, have been used to detect nonrecoverable permanent (plastic) deformation under load. Each technique has its limitations, however. The strain range is limited and speed of testing and recording are slow with optical gauges. Bonding agents used with resistance strain gauges can modify the surface structure of the material, and have limited range and questionable stability due to creep and moisture absorption. LVDT's are one order of magnitude less sensitive than optical and resistance gauges and about two orders of magnitude less sensitive than capacitance gauges. Capacitance gauges have a nonlinear output with plate spacing, and depending on the capacitance measuring instrument used, can have questionable stability and limited range at 1×10^{-6} in. (or less) sensitivity. On the other hand, greater effectiveness and accuracy can be achieved with the capacitance gauge since it measures bulk behavior, has high sensitivity (10^{-7} to 10^{-8} in., depending on the strain range or type of information required) and good dynamic response, and can be used at temperatures ranging from cryogenic to about 200°F, which covers the range of temperatures precision instruments might experience. A good review of the experimental techniques utilizing capacitance gauges for microstrain evaluations is covered in detail by Brown (ref. 1), Roberts et al. (ref. 2), and Rutherford et al. (ref. 3). Briefly stated, the procedures involve the measurement of relative capacitance changes by capacitance proximity meters or micrometers with a gauge consisting of one "live" and one grounded plate. Permanent (plastic) strain and material hysteresis are usually determined and measured from visual plots of stress-strain curves in load-unload tension (or compression) tests. Hysteresis loop areas are measured with a planimeter. In the referenced works, strain calibration is rather tedious and is required for each evaluation since relative capacitance changes are employed.

A more satisfactory procedure is found in the microstrain technique, to be described, where the precision material evaluations are carried out with the use of absolute capacitance differences to measure strain and the inclusion of a computer, either analog or hybrid, into the system. This measuring system utilizes an automatic capacitance bridge and analog computer in load-unload tests. Its salient features include (1) linear strain ranges of 5000 μ in. or greater, permitting the microstrain characteristics of low-modulus, high-strength aerospace materials to be determined, (2) determination of permanent plastic deformation of 1×10^{-6} in. or less, (3) measurement of microstrain hysteresis loop areas and total strain energy during a single test. This system can also be used to investigate low- and medium-frequency high-amplitude internal friction (specific damping), undirectional fatigue, and nonelastic strain recovery of materials at both the microstrain and macrostrain levels with the appropriate strain transducer. Finally, the system can be adapted to a hybrid (analog plus digital) computer for greater versatility and more flexibility than is possible with just the analog computer.

MICROSTRAIN MEASURING SYSTEM

General Description

The essential elements of the microstrain test apparatus developed at ERC are shown in Figure 1. The functions of the various elements are described as follows.

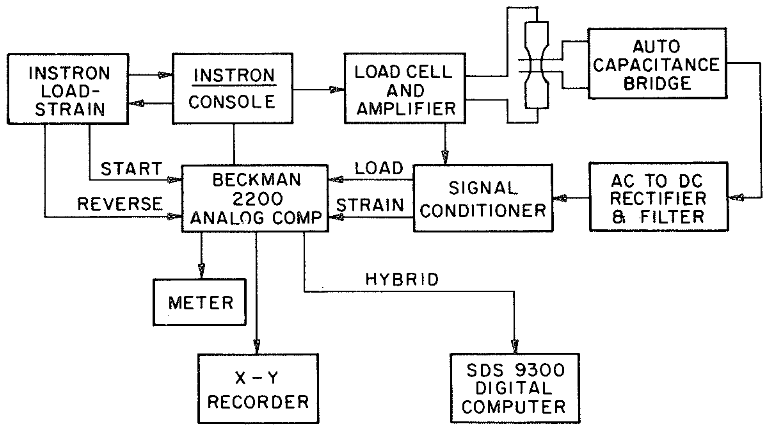


Figure 1.- Block diagram of computerized microstrain test system

<u>Load signal</u>.- The load signal from the load cell and load cell amplifier, exclusive of the recorder, is obtained from the Instron console. This load voltage, which also drives the Instron X-Y recorder, is about 1 Vdc at full capacity of the cell and full scale deflection of the recorder. This signal is buffered, filtered, and amplified 10 times in the signal processor before being transmitted to the analog computer. The Instron load-strain console loads the specimen at a selectable uniform rate ranging from 2 lb/min to 10,000 lb/min with the Instron 1000-lb load cell. The constant loading rate is utilized for integration of the hysteresis loop areas and the strain energy under the stress-strain curve. Integration in the computer is initiated by a pulse generated by the "increase" (start) button on the load-strain console at the beginning of a load-unload cycle. Integration is reversed on a pulse from the "decrease" (unload) button when the unloading part of the cycle or run is started. The end of the run is controlled by the computer which uses logic to insure that the computation stops when the unload-load voltage is equal to the initial load voltage at the start of the run.

<u>Strain signal</u>.- The strain (opening of the capacitance plates comprising the gauge on the specimen , Figure 2) is

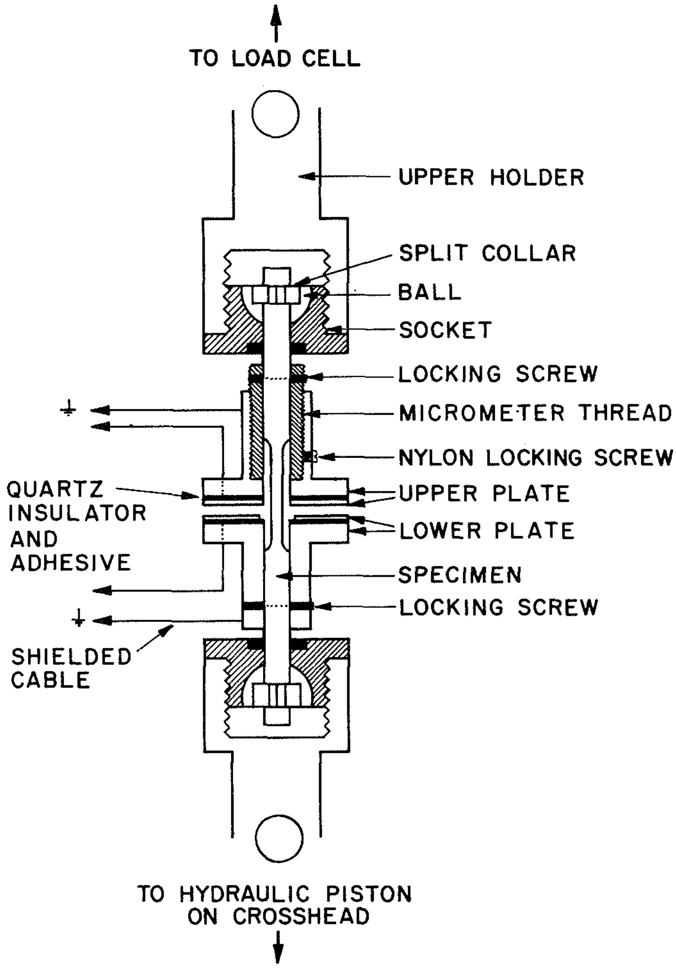


Figure 2.- Capacitance gauge assembly showing specimen, three terminal wiring connection and grips

measured by the General Radio Type 1680 automatic capacitance bridge assembly. An ac signal from the counters of this unit is rectified to dc. This signal is then buffered and filtered in the signal processor for transmission to the computer. In range 1 of the capacitance bridge, capacitance is proportional to the voltage and ranges from about 2.8 Vdc at 150 pico-farad (pf) to 0.1 Vdc at 30 pf. The accuracy of the bridge is 0.1 percent, the resolution of the counters is ± 1 count (0.01 pf), and in continuous track at 1 kHz the speed of balance is 1.1 sec for 7 percent full-scale change of the unknown or about 10 pf/sec. At high capacitance values the speed of balance is a factor to be considered when high loading rates are employed, since very small changes in plate opening cause very large changes in capacitance.

The parabolic shaped capacitance versus gap (or displacement) curve is linearized using a function generator (DFG) in the computer to provide constant scaling over the entire strain range and to permit the stress-strain curve to be plotted. The plot is used primarily to check that the system is working properly. Figure 3 shows the linearized curve from 147 pf (2.8 V) to 30.5 pf (0.12 V) for a 5000-μ in. strain range. It is evident that smaller strain ranges with higher sensitivities and larger strain ranges with lower sensitivity can be selected to permit the evaluation of high-and low-modulus materials, respectively.

Computer simulation.- The basic operation of the analog or hybrid computer is to process the load and strain signals from the load weighing system and the capacitance bridge. It may also serve as a dynamic check of the hardware system. Since elastic materials obey Hooke's law, true elastic specimen behavior can be easily simulated on the computer. This "perfect specimen" simulation is used in parallel with the same computer control circuits employed in "real" specimen analysis as a reference and check on the accuracy and repeatability of the overall microstrain measuring system. The analog computer used in developing the system was the Beckman 2200 computer, which is a 100-V machine with an accuracy of 0.01 percent. The hybrid computer consisted of the Beckman 2200 and the Scientific Data System 9300 digital computer. A block diagram of the computer simulation is shown in Figure 4. A schematic diagram of the overall computer simulation of "real" and "perfect" specimen behavior is presented in the Appendix.

Strain signal: The parabolic shaped capacitance versus gap voltage curve, Figure 2, is linearized and amplified 35 times in the analog computer by a function generator and amplifier. With the hybrid system, the voltage goes directly to the digital computer where linearization is carried out. The hybrid system provides greater ease in selecting different maximum strain ranges for high-and low-modulus materials, since the analog computer requires a separate function generator for each strain range. The smallest strain range practical for the material being evaluated is desired since greater strain resolution is achieved.

Before the start of a load-unload cycle, and with the load-strain in hold at a selected preload to maintain alignment, the strain signal in the computer is balanced to zero. When the start (increase) button is pushed, integration of the strain voltage starts, and track and hold units track both the integrated area and strain. At the desired load (or strain level), the reverse (decrease) button of the load-strain unit is pushed, which activates control logic to measure and hold the total area or strain energy. Also at this point reverse integration of the

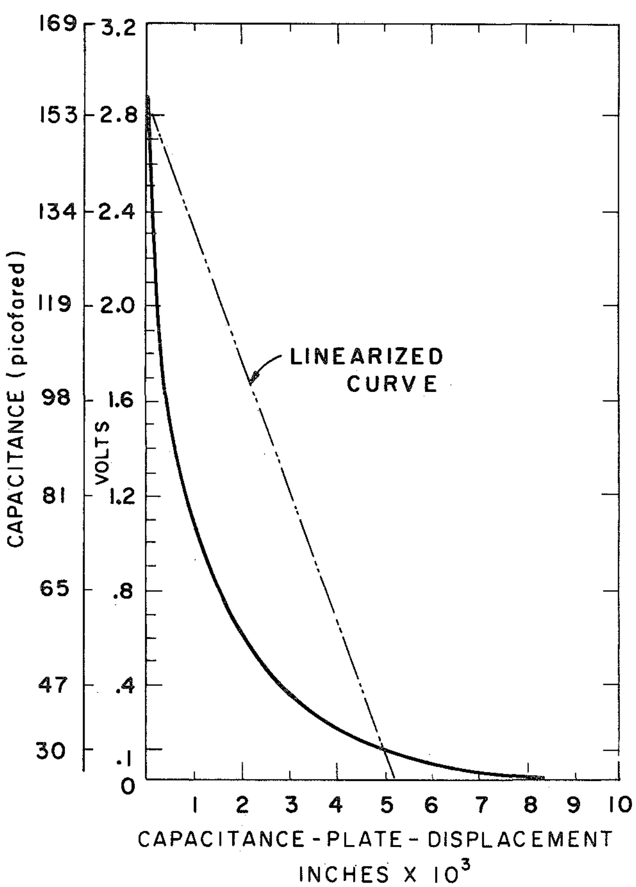


Figure 3.- Strain calibration curve showing voltage (and capacitance) versus displacement and linearized curve

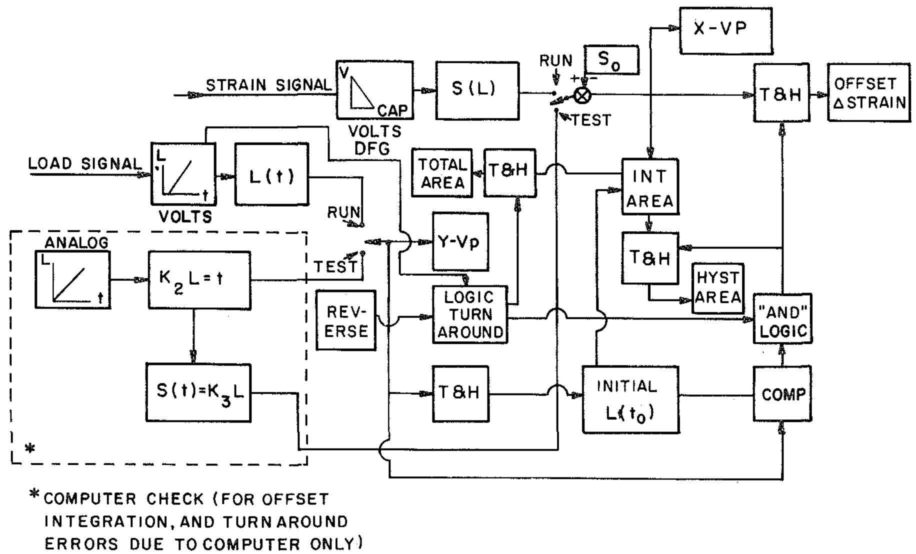


Figure 4.- Block diagram showing processing of load and strain signals in computer

strain signal starts as the specimen is unloaded. When the load reaches its initial preload voltage, the computer stops and the tracked hysteresis area and strain voltages are held in a hold mode until read and cleared.

Integration: The area under a load versus strain curve can be given by

$$A = \int_{L1}^{L2} \varepsilon \, dL$$

where

A = area

ε = strain (deflection) in inches

L = load in pounds.

Since the loading rate is constant

$$L = RT$$

$$dL = T \, dT$$

where

R = constant loading rate in pounds per minute

T = times in minutes.

Therefore, by substitution

$$A = \int_{T1}^{T2} \varepsilon \, R \, dT = R \int_{T1}^{T2} \varepsilon \, dT$$

Since the computer integrator automatically integrates a measured variable with respect to time

$$A = R\varepsilon T \Big]_{T1}^{T2}$$

Turn around: The integration error at reverse (turn-around) loading must be corrected since the turn-around time for 7075 T6 aluminum alloy, for example, has been measured as 0.25±0.05 sec over a strain range of about 5000 μ in. at a loading rate of 500 lb/min. At the end of 2 min a 0.25-sec error would cause an integration error of about 0.04 in.-lb. The logic to eliminate the turn-around error uses the differentiation of load versus time during the run and a pulse emanating from the reverse (decrease) button. This pulse signals the beginning of the turn-around, stops the area integration, and starts to integrate the dL/dT signal. The sign of the integrated value will change from positive to negative during the turn-around period, as the load starts to decrease. The computer logic is implemented such that an "AND" gate controls the integration of the area computation. The time interval between the turn-around signal pulse and the attainment of a negative value of the integrated dL/dT function specifies the time which the hysteresis area integration is suspended. This correction essentially eliminates the area integration error at turn-around, by ensuring that all computations are carried out at constant rate load operation during the load-unload cycle. The turn-around error time is reduced to about 0.01 sec with this technique.

Calibration

Load.- The load calibration procedure is similar to that used to calibrate the Instron load weighing system. With the signal conditioner balanced out to zero volts on the load channel and with no load on the load weighing system, the calibration weights are added. The signal conditioner load channel is then adjusted with the gain knob to read 10.00 V measured with a digital voltmeter (DVM). The Instron chart is also calibrated for full scale. When the calibration weights are removed and the holders, specimen, and gauge assembly are hung on the weighing system, the Instron balance knob and the balance knob of the signal processor are used to remove this voltage in order to rezero the Instron recorder and the signal processor.

Strain.- Figures 5 and 3 show the voltage-capacitance and the voltage (capacitance)-displacement relationships, respectively.

Figure 5 was obtained by setting capacitance values on the bridge with variable capacitance standards (General Radio types 1422-CC and 1412-BC) and reading the corresponding voltage at the signal processor with a digital voltmeter (DVM). Figure 3 was obtained by mounting the capacitance gauge on a specimen (split in center of gauge length) adapted for use in a high-magnification extensometer calibration micrometer (Instron Type G55-1) and concurrently reading the capacitance and voltage for increasing

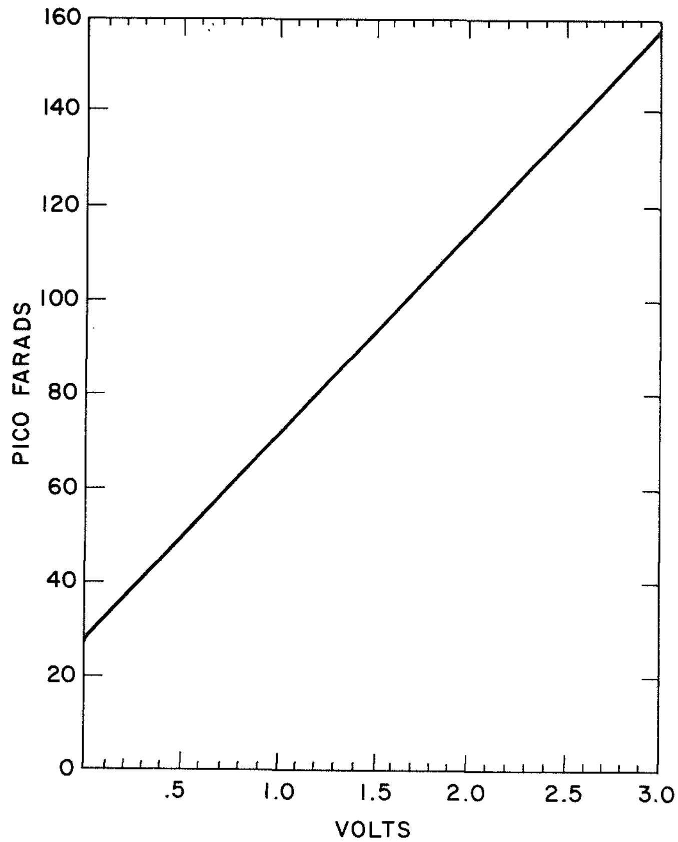


Figure 5.- Capacitance versus voltage after rectifying voltage from automatic capacitance bridge

settings or openings on the micrometer. The minimum (zero) gap and corresponding capacitance value were arbitrarily selected as the first readings that could be obtained after breaking electrical contact of the two capacitance plates by opening the micrometer. Both the General Radio hand-operated Type 1620 (0.01 percent accurate) and the automatic Type 1680 (0.1 percent accurate) capacitance measuring assemblies were used on successive runs in a constant temperature-humidity room to establish the capacitance versus gap relationship shown in Figure 3. Both capacitance assemblies yielded the same curve, thus indicating the high degree of accuracy, repeatability, and stability with this measuring technique. Since the strain-measuring technique is based on absolute values, calibration of the strain signal is simply a matter of setting a gap on the gauge (usually done with some preload on the specimen) and adjusting the gain on the strain channel of the signal conditioner (previously balanced to zero volts) to the corresponding voltage of the capacitance reading, Figure 5.

Microstrain system.- Calibration of the overall system consists of loading and unloading an elastic calibration specimen at low loads (in the elastic and/or anelastic region) and comparing

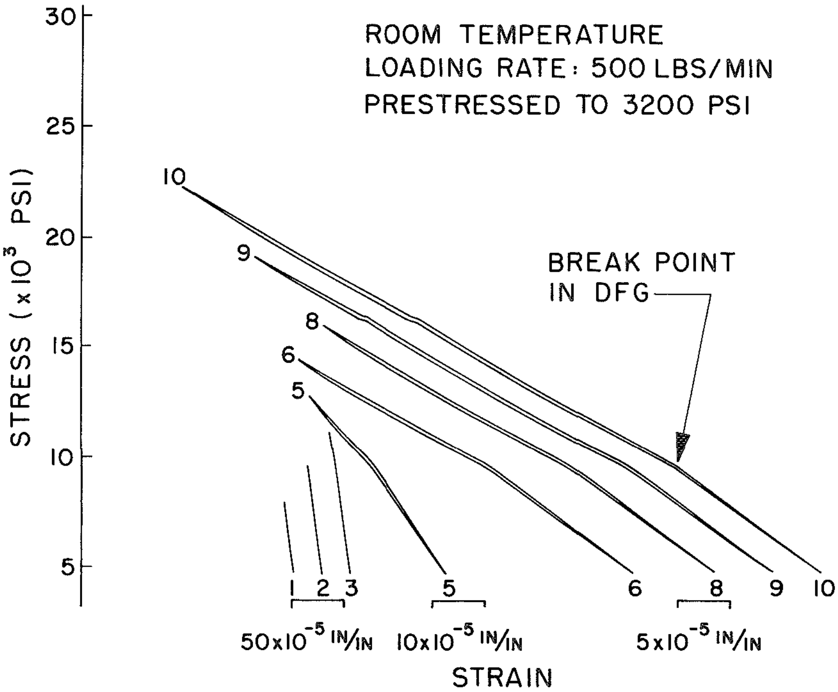


Figure 6.- Stress microstrain curve for 52100 steel

the computed offset (plastic deformation), hysteresis, and strain energy values with those obtained from highly magnified visual plots. Figure 6 is a plot of stress-strain curve obtained with a hardened (RC 65), tempered, and stress-relieved 52100 steel specimen used as a calibration standard. Runs 1, 2, and 3 (1" = 500 x 10^{-6} in.) do not show any yielding or hysteresis. Run 5 (1" = 100 x 10^{-6} in.) and runs 6, 8, 9, and 10 (1" = 50 x 10^{-6} in.) also indicate no yielding, but hysteresis is present. In all eight runs the computed offset values did not indicate any residual strain (offset), but did yield definite hysteresis values. Further discussion of the microstrain characteristics of this specimen is covered in the section "Results." Planimeter measurements of the hysteresis areas were carried out and agree within 25 percent (or less) of the computed values. The total area as determined from the plots was within 10 percent (or less) of the computed values. The computed offset values were within the error of the system (± 0.5 μ in. for steel), which is substantiated by the plots. The computed hysteresis and total area values are considered to be much more reliable than those obtained with a planimeter or other area measurements from the plot directly because of the greater strain and stress sensitivities used in the computation in contrast to the inherent limitations of the X-Y plotter, the width of the ink trace lines, etc.

System Error Sources, Sensitivity, and Repeatability

Considering the main components of the microstrain measuring system separately, the computer is the least source of error. In the "perfect specimen" simulation mode a very high sensitivity and repeatability are achieved. This mode utilizes an operational amplifier to simulate strain, constant rate integration to simulate load, and high-speed electronic switches to simulate start, reverse, and stop command controls. The repeatability of the "offset" is within 0.1 μ in. and the hysteresis area is of the order of 5×10^{-5} in. The same components and controls are used for "real" specimen tests utilizing the Instron load signal and the capacitance bridge strain signal.

Strain signal.- The Type 1680 automatic capacitance bridge has a ±0.01-pf resolution and a ±0.02-pf repeatability in range 1 at 1000 Hz. A capacitance gauge with a plate area of about 1 $in.^2$ at a capacitance of 150 pf has a sensitivity (slope of the capacitance versus gap curve) of about 0.11 pf/μ in. or 2 mV/μ in. Resolution of strain at 150 pf is at least $\pm 1 \times 10^{-7}$ in. and repeatable to within $\pm 2 \times 10^{-7}$ in. Greater sensitivities are possible with higher capacitance values. At 200 pf, for example, the sensitivity would be about 0.2 pf/μ in. (4 mV/μ in.) and the resolution would increase to about $\pm 5 \times 10^{-8}$ in. In the computer these voltages are amplified 35 times and, therefore, at 150 pf, a sensitivity of 0.07 V/μ in. is achieved. Since the computer is accurate to 0.01 V, a strain sensitivity of about 0.15 μ in. seems possible.

Load signal.- Since the amount of residual plastic strain (offset) is highly dependent on the ability of the computer to detect the original preload voltage during the unload cycle, the repeatability of the load cell and load cell amplifier was determined. The 1000-lb Instron D cell was loaded and unloaded in 100-lb increments, from a preload of 100 lb to the maximum load of 1000 lb, three consecutive times. The load cell amplifier voltage was amplified 10 times with the signal processor, and the preload voltage before and after each loading cycle was read with a digital voltmeter. For the well-exercised load cell the repeatability of the preload voltage was ±0.005 V or ±0.5 lb. This means, for example, that for cylindrical specimens having a gauge length diameter of 0.200 in. the residual plastic strain (offset) error for an aluminum specimen with a 10×10^6 psi modulus is about ±1.5 μ in.; or about ±0.5 μ in. for a 30×10^6 psi modulus steel specimen. Smaller errors would result with more precise load cells.

Overall microstrain system.- Repeated tests with the hardened and tempered 52100 steel calibration specimen show that the residual plastic strain (offset) error is about ± 1 μ in. and that the error in the hysteresis area calculation is about 100×10^{-6} lb/in.

RESULTS

The microyield strength, work done (plastic hysteresis energy), and internal friction of 52100 steel, 6061-T6 aluminum, and 6AL-4V titanium are shown in Figures 6, 7, 8, and 9, respectively. The steel specimen (0.200-in. gauge length diameter) was rough-machined from bar stock quench, tempered, and finished machined; then it was stress-relieved to RC 65 hardness. This specimen had been prestressed to 1000 lb on several occasions. The aluminum titanium specimens were machined from 0.5 in. diameter bar stock with 0.125 in. gauge length diameter and had no subsequent heat treatment or prestressing (prestraining). All three specimens had 0.5-in. gauge lengths.

The steel specimen, which was also used to calibrate the microstrain system, as illustrated by Figure 6, exhibits no microyielding (permanent plastic deformation of 1×10^{-6} in./in. or greater) up to stress levels of about 22,000 psi (1540 kg/cm^2). Figure 7 shows that hysteresis areas or work done (ΔW) is linear over the stress range shown. The internal friction, $\Delta W/W$, where W = total area under the curve, decreases gradually with increasing stress to a value of about 3×10^{-2}.

The elastic limit and the microyield stress are theoretically considered to be the beginning of reversible bowing of dislocations from pinning points, and the irreversible breaking away of dislocation from pinning points, respectively. Extrapolation of ΔW to zero area or energy should then yield the elastic limit, the first departure from true linear elastic behavior. This extrapolation yields an elastic limit of about 7000 psi (490 kg/cm^2) for 52100 steel.

The microyield strength of the 6061-T6 aluminum, Figure 8, is about 26,000 psi (1820 kg/cm^2), which is consistent with other values reported for this alloy. The hysteresis energy is linear up to the microyield strength and then increases nonlinearly with increasing stress. Extrapolation yields an elastic limit of about 9,000 psi (630 kg/cm^2) for this alloy. The internal friction decreases to the microyield stress and then increases

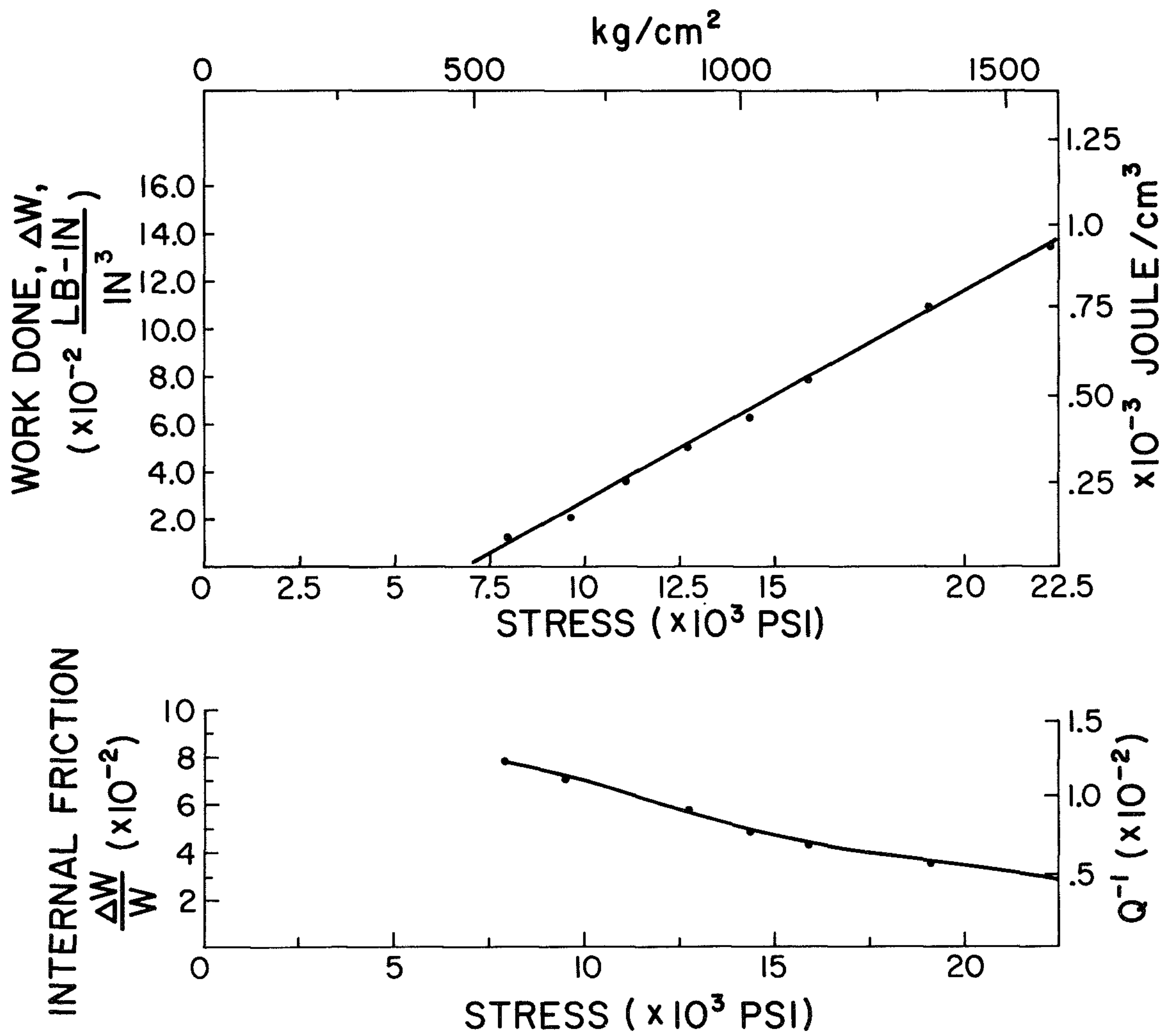


Figure 7.- Hysteresis energy and internal friction of 52100 steel versus stress

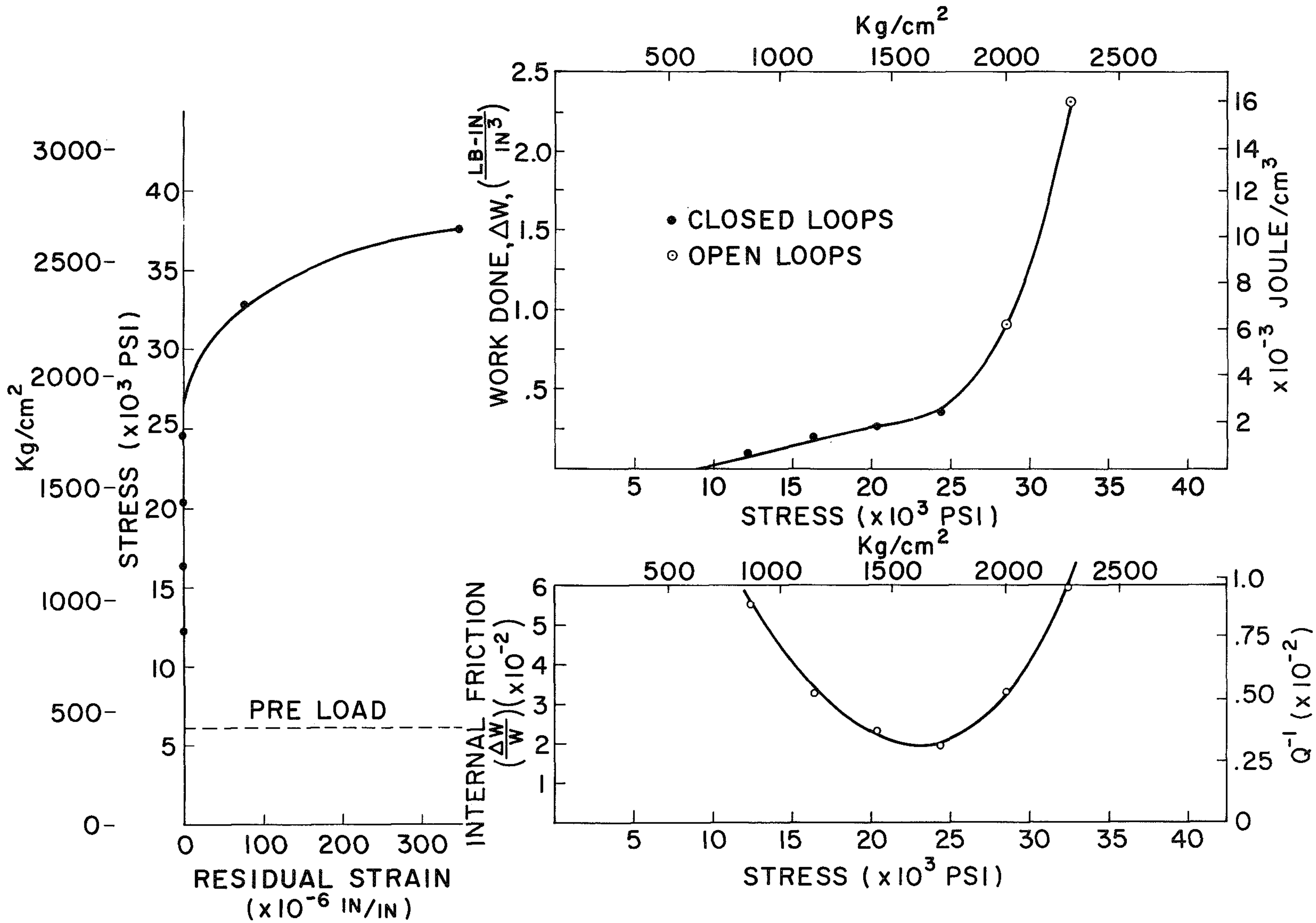


Figure 8.- Residual microstrain, hysteresis energy, and internal friction of 6061 T6 aluminum versus stress

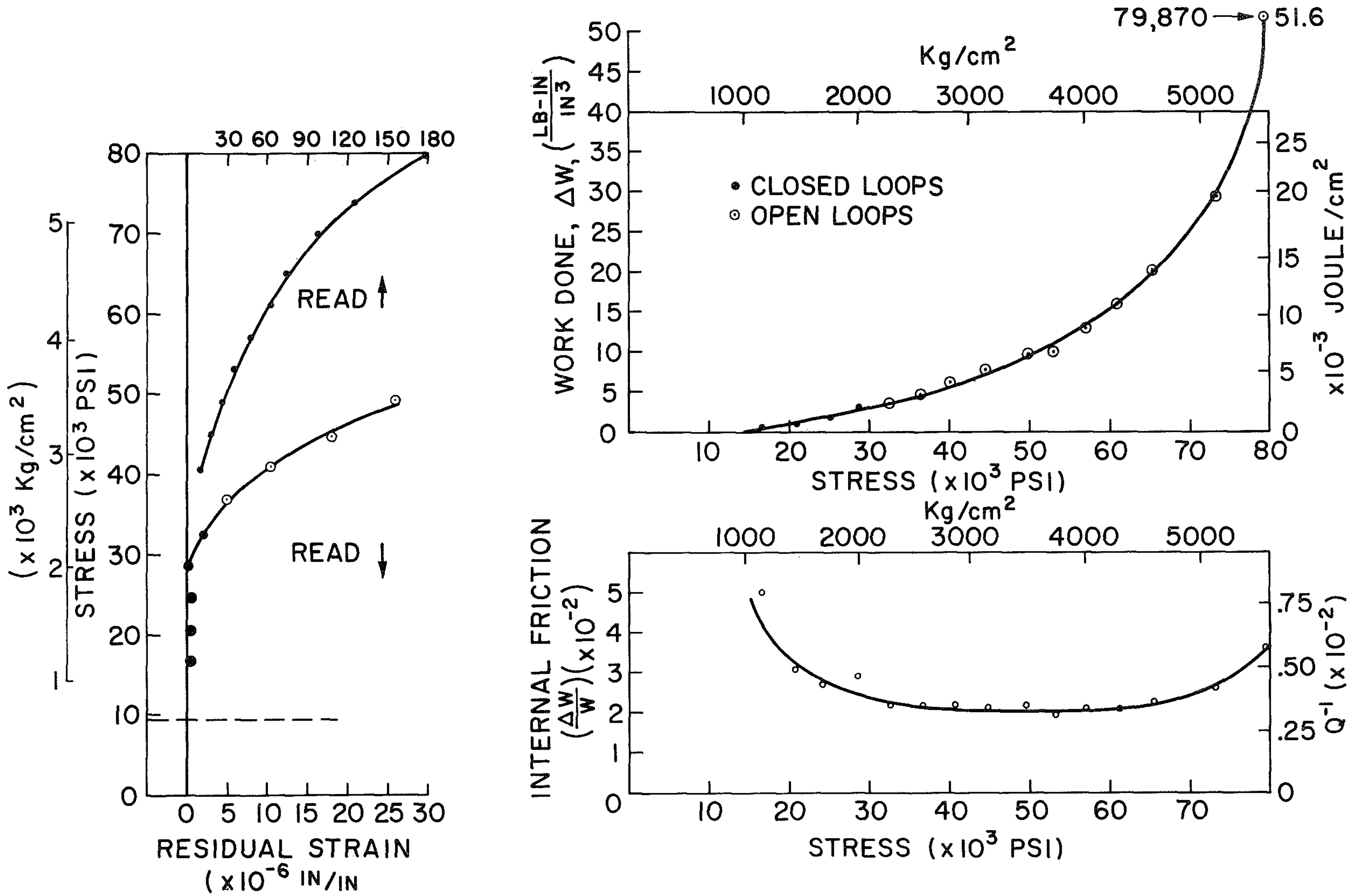


Figure 9.- Residual microstrain, hysteresis energy, and internal friction of 6AL-4V titanium versus stress

rather rapidly with increasing stress. The sharp increase in the internal friction of 7075 T6 aluminum alloy at strains of 10^{-3} has been reported by Mason (ref. 4), who attributes it to the generation of new dislocations.

Figure 9 shows that the titanium alloy has a microyield strength of about 28,000 psi (1960 kg/cm^2), which is considerably less than the nominal macroyield strength of about 120,000 psi (8400 kg/cm^2). The hysteresis area (ΔW) is linear up to microyield strength and slowly increases nonlinearly with increasing stress. The linear portion extrapolates to an elastic limit of about 15,000 psi; the loop energy of the titanium alloy is about 10 times larger than that of the steel at 20,000 psi (1400 kg/cm^2). The internal friction decreases gradually to a plateau level of 2×10^{-2}, which remains essentially constant from 30,000 psi (2100 kg/cm^2) to about 65,000 psi (4550 kg/cm^2) and then increases with increasing stress levels up to 80,000 psi (5600 kg/cm^2).

This long internal friction plateau has been noted by Mason (ref.4), who attributes it to closely pinned dislocations which are prevented from breaking away until a critical strain level of about 10^{-3} is reached. Wood (ref. 5) also has reported that this alloy does not strain harden efficiently and attributes the cause to the inability of interstitial and impurity atoms to pin mobile dislocation generated by microyielding.

FUTURE DEVELOPMENT

The microstrain test system can be readily and easily improved to provide greater computer control and yield additional microstrain information. For example, the microyield and microstrain hardening characteristics could be obtained in a single test by measuring the change of slope during extension. This technique might lead to establishing microyield characteristics at sensitivities much less than 10^{-6} or 10^{-7} in. Also, cyclic stress-strain curves, which may be vastly different from monotonic stress-strain curves, could be obtained at microstrain sensitivities to determine steady-state cyclic deformation resistance. Finally, cyclic fatigue studies are possible (and, in fact, are presently being carried out) to determine the relation of plastic hysteresis energy, microplastic deformation, and internal friction to fatigue damage.

REFERENCES

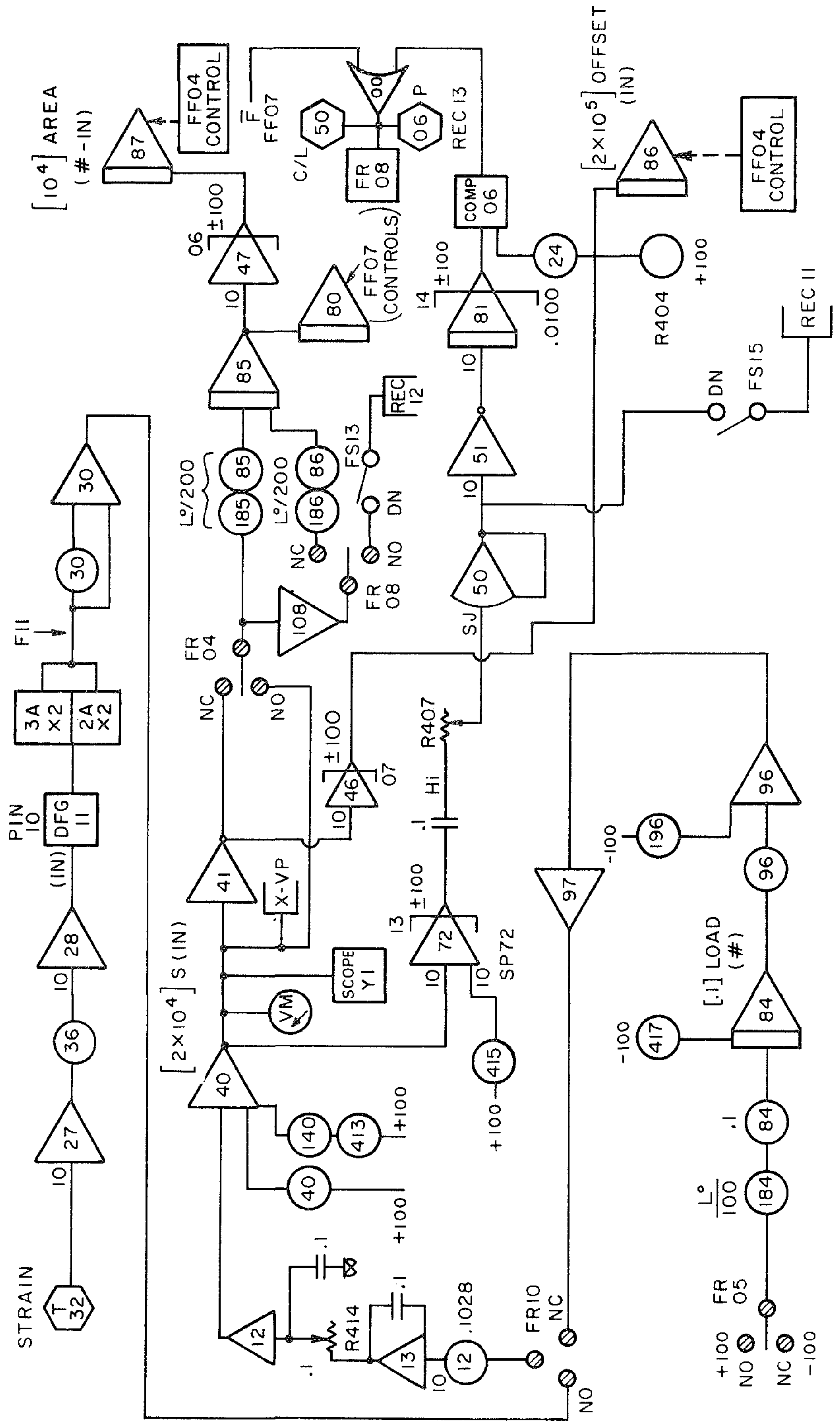
1. Brown, Norman: Observations of Microplasticity. Microplasticity. C. J. McMahon Jr., ed., John Wiley and Sons, N. Y., 1968.

2. Roberts, J. M., Herring, R. B., and Hartman, D. E.: The Use of Capacitance Gauge Sensors to Make Precision Mechanical Property Measurements. Proceedings of the Interamerican Conference on Materials Technology, San Antonio, Texas, May 20-24, 1968. New York, American Society of Mechanical Engineers, 1968, pp. 87-96.

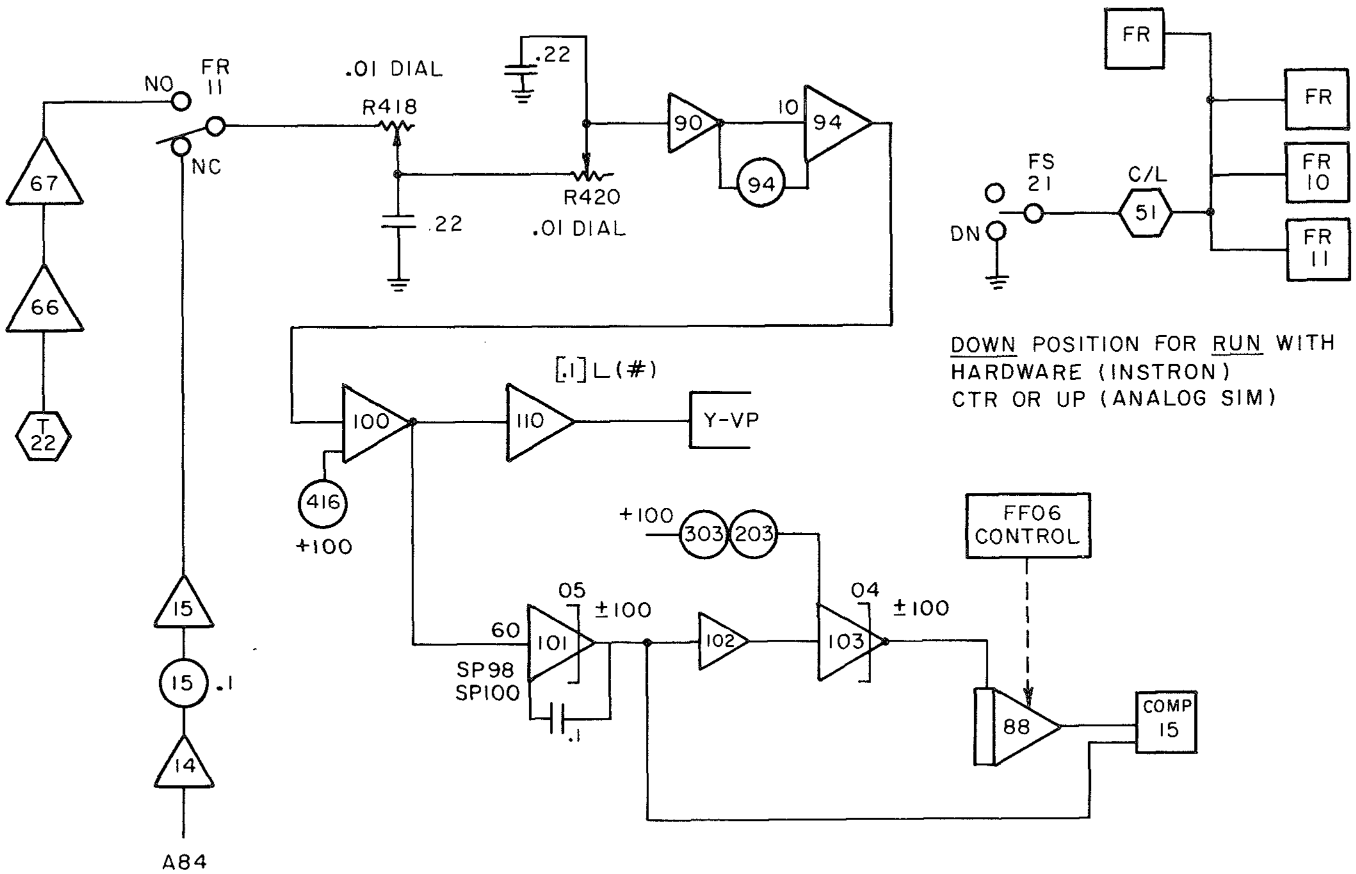
3. Rutherford, J. L., and Swain, W. B.: Research on Materials For Gas-Lubricated Gyro Bearings. NASA NAS 12-90, Research Center, Aerospace Group, General Precision, Inc., Little Falls, N. J., October 31, 1966.

4. Mason, W. P.: Internal Friction Measurements in Solids. Microplasticity. C. J. McMahon, Jr., ed., John Wiley and Sons, N. Y., 1968, pp. 360-361.

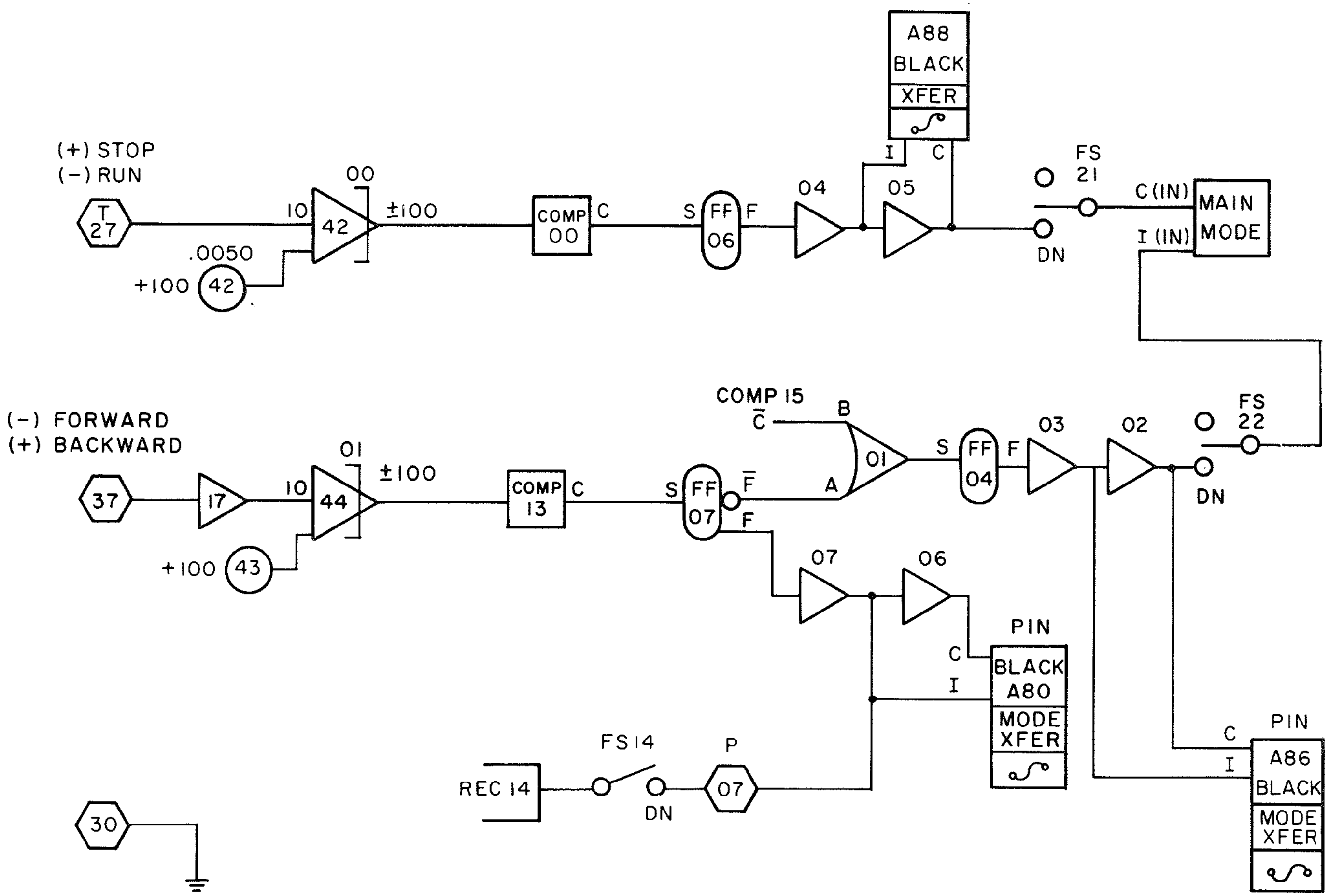
5. Wood, W. A.: Instability of Titanium and Ti 6AL-4V Alloy at Room Temperature. Department of Civil Engineering and Engineering Mechanics, Columbia University, contract no. NONR 266 (91), project no. NR 064-470, technical report no. 45, April 1967.



STRAIN SIMULATION



LOAD SIMULATION



START AND REVERSING CONTROL LOGIC FOR HYSTERESIS SIMULATION

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