CANADA

DEPARTMENT OF
ENERGY, MINES AND RESOURCES
MINES BRANCH
OTTAWA

CAM PLASTOMETER OPERATION MANUAL INCLUDING THEORY AND DESIGN

M. J. STEWART

PHYSICAL METALLURGY DIVISION

JUNE 27, 1974

Research Report R 282

Price: $1.00

Available by mail from Information Canada, Ottawa, K1A 0S9
and at the following Information Canada bookshops:

HALIFAX
1683 Barrington Street

MONTREAL
640 St. Catherine Street West

OTTAWA
171 Slater Street

TORONTO
221 Yonge Street

WINNIPEG
393 Portage Avenue

VANCOUVER
800 Granville Street

or through your bookseller

Price: $1.00 Catalogue No. M38-1/282

Price subject to change without notice

Information Canada
Ottawa, 1974

Mines Branch Research Report R 282

CAM PLASTOMETER THEORY, DESIGN AND OPERATION

by

M.J. Stewart*

ABSTRACT

A Cam Plastometer is a compression testing machine used in studying the hot-working behaviour of metals. The deformation of cylindrical specimens is controlled by a shaped cam which maintains the true strain rate constant throughout the hot-working test. This report describes the recently completed Cam Plastometer at the Mines Branch, Ottawa, Canada. The theory of design and the operating procedures are also discussed.

Tests can be conducted at constant strain rates between 0.1 and 160 per sec. The maximum load is 0.45 MN (100,000 lb) and the maximum test temperature is 1300°C.

*Research Scientist, Metal Forming Section, Physical Metallurgy Division, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

Direction des Mines

Rapport de Recherches R 282

THEORIE, CONCEPTION ET FONCTIONNEMENT DU PLASTOMETRE A CAME

par

M. J. Stewart*

RESUME

Un Plastomètre à Came est une machine d'essais de compression qui étudie le comportement des métaux qui travaillent à chaud. La déformation d'échantillons cylindriques est controllée par une came spécialement usiner pour maintenir constant le taux réel de déformation durant l'essai à chaud. Ce rapport d'écrit le Plastomètre à Came récemment achevé à la Direction des Mines, Ottawa, Canada. La théorie de la conception et les procédés d'opération y sont aussi expliqués.

Ces essais peuvent être menés à taux de déformation constant entre 0.1 et 160 par seconde. La force de compression maximum est de 0.45 MN (100,000 lbs) et la température maximale est de 1300°C.

---

*Chercheur Scientifique, Section du Formage des Métaux, Division de la Métallurgie Physique, Direction des Mines, Ministère de l'Energie, Mines et des Ressources, Ottawa, Canada.

CONTENTS

cont'd.

CONTENTS (cont'd)

CAM PLASTOMETER OPERATION MANUAL INCLUDING THEORY AND DESIGN

by

M. J. Stewart

1. PURPOSE OF MACHINE AND THEORY OF OPERATION

1.1. Introduction

A Cam Plastometer is a high-speed compression testing machine. The machine deforms a metal sample such that the true strain rate is constant throughout the total deformation of the sample.

The deformation stress of metals deformed at high temperatures (greater than one-half of the absolute melting point) is very dependent on the temperature and the applied strain rate. For calculations involving the force requirements in metal forming it is required to know the true flow stress as a function of strain, strain rate, and temperature.

The way in which the load is applied - by torsion, tension, or compression - can also vary the applied loads during hot deformation. If the mode of deformation during the test is not similar to that of the metal-forming process being considered, further errors are introduced. Since most metal-forming operations, such as rolling, forging and extrusion, are under compressive forces, the most accurate experimental simulation can be conducted using compressive deformation.

The microstructural changes that occur during and after hot deformation are also a function of the strain and strain rate. Since these changes are local effects, the true strain, true stress, and true strain rate are the only relevant parameters to characterize these changes. This is very important at high temperatures where the effect of strain rate is very large.

It is therefore necessary in hot deformation studies to conduct the experimental tests under conditions of constant true strain rate. The rates of deformation must also correspond to the rates encountered in metal forming processes. With a high speed constant true strain rate Cam Plastometer, these criteria can be met.

1.2. General Operation of Machine

The metal sample is deformed between two flat dies, contained within the heavy two column machine frame (Fig.1). The lower die is caused to move upwards by a cam follower riding up a cam lobe. This upwards movement of the lower die compresses the sample. The cam is driven by a motor through two variable speed transmissions (Fig. 2). The whole of the deformation is completed during one pass of the cam lobe past the cam follower which in turn is connected to the lower die.

For a test, the cam is driven at a predetermined speed and at a precise moment the cam follower is inserted between the cam and the lower die. The lobe pushes the follower and die upwards deforming the sample. The cam follower is then retracted before the lobe can again hit the follower. Depending on the cam rotation speed, the strain rate can be varied.

The energy of the deformation is transmitted through the cam to the sample. At high speeds a large flywheel stores sufficient energy for the deformation without an appreciable loss in speed. At low speeds the flywheel energy is not sufficient and the drive motor maintains the cam speed.

2. DESIGN OF MACHINE

2.1. Cam Profile

2.1.1. Theory of Cam Design

The nomenclature used in this section is:

C = machine elastic deformation constant
h = sample height
h_f = final sample height
h_o = original sample height
K = constant true strain rate value (sec^{-1})
r = cam radius
r_o = cam base radius
t = time
t^1 = total time duration of the deformation
Δh_t = total sample deformation ($h_f - h_o$)
ε = true strain
ε_t = total true strain of the deformation
$\dot{\varepsilon}$ = true strain rate (sec^{-1})
θ = angle from the start of the cam lobe
θ_m = total angle subtended by the cam lobe
ω = cam speed (rotational).

True strain for compressive deformation is defined by

$$\varepsilon = -\ln\left(\frac{h_o}{h}\right) \tag{1}$$

and the true strain rate is therefore

$$\frac{d\varepsilon}{dt} = \dot{\varepsilon} = \frac{1}{h}\frac{dh}{dt} . \tag{2}$$

For the Cam Plastometer since the true strain rate is constant during the deformation

$$\dot{\varepsilon} = \frac{1}{h}\frac{dh}{dt} = K . \tag{3}$$

The profile of the cam lobe determines how the strain rate varies as the deformation proceeds. In the Cam Plastometer the lobe is designed such that the deformation is defined by equation (3). Since K is the constant true strain rate

$$\varepsilon = Kt = -\ln \frac{h_o}{h} \quad . \qquad (4)$$

Therefore the height of the sample at any instant during the deformation is

$$h = h_o e^{Kt} \quad . \qquad (5)$$

It should be noted that since the strain is negative that K is a negative quantity.

The height of the cam lobe is equal to the decrease in sample height at that point in the deformation. Taking r as the cam radius at any point and r_o as the base radius of the cam

$$r = r_o + (h_o - h) \quad . \qquad (6)$$

Then from equation (5) and (6)

$$r = r_o + h_o \, (1 - e^{Kt}) \quad . \qquad (7)$$

Taking θ_m as the total angle subtended by the cam lobe and ω as the speed of the cam rotation the time for the complete deformation, t^1 is

$$t^1 = \frac{\theta_m}{\omega} \qquad (8)$$

and the time at any point during the deformation is

$$t = \frac{\theta}{\omega} \quad . \qquad (9)$$

where θ is the angle from the start of the cam lobe. Therefore combining equation (7) and (9) the cam profile is defined as

$$r = r_o + h_o \left(1 - e^{\frac{K\theta}{\omega}}\right) . \tag{10}$$

For a particular cam, r_o, h_o, and θ_m is fixed. Also the ratio K/ω is a constant for a particular cam.

For $\theta = \theta_m$, $r = r_o + |\Delta h_t|$ where Δh_t is the total reduction in sample height for the test. Substituting into (10)

$$h_f = h_o \, e^{\frac{K\theta_m}{\omega}} \tag{11}$$

where h_f is the final sample height. Therefore

$$\frac{K}{\omega} = \frac{\varepsilon_t}{\theta_m} \tag{12}$$

where ε_t is the total true strain. Therefore the cam profile may be calculated from

$$r = r_o + h_o \left(1 - e^{\frac{\varepsilon_t \theta}{\theta_m}}\right) . \tag{13}$$

This equation assumes that the machine and sample have no elastic deformation. This is not true and must be corrected for in the cam lobe. The actual cam profile is taken as

$$r = r_o + h_o \left(1 - e^{\frac{\varepsilon_t \theta}{\theta_m}}\right) + C\theta \tag{14}$$

where C is the elastic deformation constant. This equation is used to design the cams for the Cam Plastometer.

2.1.2. 45° Cam Design

The 45° cam has a lobe subtending a 45° angle on the cam. This is the high speed cam since there is an arc of

315° during which time the cam follower can be inserted without interfering with the lobe. The theoretical design parameters for this cam are:

$$h_o = 0.770 \text{ in. } (19.6 \text{ mm})$$
$$h_f = 0.382 \text{ in. } (9.70 \text{ mm})$$
$$\varepsilon_t = 0.700$$
$$r_o = 5.000 \text{ in. } (127. \text{ mm})$$
$$\theta_m = 45° .$$

A total elastic deformation and mating surface gaps allowance of 0.037 in. is allowed for in the design of the cam. From equation (14) the cam profile is defined by

$$r = 5.770 - 0.770\, e^{-\left(\frac{0.700}{45}\right)\theta} + \left(\frac{0.037}{45}\right)\theta . \qquad (15)$$

Appendix I gives the actual cam profile as it was machined.

2.1.3. 225° Cam Design

The 225° Cam has a lobe subtending a 225° angle on the cam. This is the low speed cam since the drive train can be rotating much faster for the same deformation rate as with the 45° cam. This allows more energy to be in the system before testing. The theoretical design parameters for this cam are:

$$h_o = 0.770 \text{ in. } (19.6 \text{ mm})$$
$$h_f = 0.382 \text{ in. } (9.70 \text{ mm})$$
$$\varepsilon_t = 0.700$$
$$r_o = 5.000 \text{ in. } (127. \text{ mm})$$
$$\theta_m = 225° .$$

A total elastic deformation of 0.037 in. (0.94 mm) is allowed for in the design of the cam. From equation (14) the cam profile is defined by

$$r = 5.770 - 0.770\, e^{-\frac{0.700}{225}\theta} + \frac{0.037}{225}\theta. \quad (16)$$

Appendix II gives the actual cam profile as it was machined.

2.2. General Machine Specifications

Standard specimen height: 0.770 in., (19.56mm)
Maximum specimen diameter: 1.000 in., (25.4mm)
True strain rate range (design): 0.1 to 250 sec^{-1}
Testing temperature (present capacity): RT to 500°C
Maximum testing load: 100,000 lbs. (0.45 MN)
Cam speed: 0 to 2500 RPM
dc Motor: 40 h.p. (30 KW) variable speed 0-1200 rpm
Gear ratios: 39 speeds 0.47:1 to 25.29:1 overall ratios.

2.3. Machine Description

2.3.1. Drive Train

2.3.1.1. Description and Operation

The cam plastometer drive train consists of a dc motor driving the cam and flywheel through two automotive type multiple speed transmissions. This is shown schematically in Fig. 3.

The dc motor is rated at 40 h.p. (30 KW) from 300 to 1200 rpm and is driven from a motor-generator (MG) set. There is a friction brake on one output shaft to prevent freewheeling of the motor when in the off position. The motor is controlled from the main plastometer control panel (Fig. 4). A closeup of the motor controls is shown in Fig. 5.

The ammeter monitors the total dc current to the motor. The right hand side switch sets the run mode of the motor, either RUN, OFF, or JOG. In the OFF position the motor is held from rotating by the brake. The RUN position is used during a test and in this mode the speed control, the large central rheostat, is used to set the desired motor speed. In the JOG position the brake is released when the JOG DIRECTION control is used. The JOG DIRECTION control jogs the motor in either direction at a fixed speed. The centre control, BRAKE, activates the motor brake at any time in any motor mode.

The motor drives directly into a 13 speed transmission (Fuller, Model RT00 9513). The gearshift pattern is shown in Figure 6. This transmission must have a supply of 80 psi (550 kPa) compressed air to shift ranges.

The main transmission drives directly into a 3 speed auxiliary transmission (Fuller, Model 3-A92). The gearshift pattern is shown in Figure 7. The overall gear ratios of the drive train are listed in Table I. There is a total of 39 speeds. The table also lists the RPM ranges of each gear ratio.

The auxiliary transmission drives the plastometer flywheel through a universal joint coupling. The flywheel supplies the energy of deformation at high speeds. Due to the large quantity of energy stored at high speeds in the flywheel, the machine should always be gradually brought to operating speed and also gradually decreased in speed after a test to prevent undue loads in the drive train.

The flywheel is connected to the cam through a shear coupling. The shear coupling consists of ten shear pins and is designed to shear at an 8000 lb-ft (10850 Nm) torque when all shear pins are in place.

The rotational speed of the cam is measured by a magnetic pickup located beside a 120-tooth sprocket on the flywheel shaft. The magnetic pickup is an ELECTRO, Model 3030 AN. This sensor gives an electrical pulse as each sprocket tooth passes the senser head. Since there are 120 teeth, the number of pulses per second is equal to double the cam rotations per minute (rpm). See section 2.3.1.2. for measurement of these pulses.

> **Note**: There is a large multiplication of torque through the drive train. The system is designed such that the drive train torque cannot exceed the design limit except in 1st gear, where this limit may be exceeded substantially. Great care must therefore be used when operating the machine in 1st gear to prevent damage.

2.3.1.2. Data Acquisition

The drive train rotation speed is measured by analysing the pulses from the magnetic pickup located on the plastometer. A direct rpm reading is obtained by feeding the pulse signal into an electronic counter (Transistor Specialties Model 500). The magnitude of the electric pulse from the pickup is a function of the rate at which the sprocket tooth passes the pickup. At low speeds the pulse is very weak and must be externally amplified. This is done by connecting the pulse output (Fig.4) to the operational amplifier (Type 3A8) in the power supply cabinet (Type 129). The amplified signal is passed to the electronic counter. For higher rotational speeds the pulse becomes stronger and the amplification can be reduced. Table II lists the proper amplifier and counter settings for each strain rate.

The magnetic pickup pulse is also connected to a tachometer (ELECTRO Mini Tach, Model 1-75404). This module converts the pulses to a voltage proportional to the rpm The output is 0 - 5 volts dc for 0-2500 rpm. This output may be used for permanent recording of the cam rotational speed. This system will show the cam slowdown during the testing of a specimen. The output of the Mini Tach is on the front of the main control panel and labeled TACH OUTPUT.

2.3.2. Cam Follower Activation System

2.3.2.1. Description and Operation

For a compression test to be completed the cam follower must make contact with the cam lobe for one pass of the lobe only. If the cam follower remains in place the lobe will again make contact and this can cause serious mishaps, since after the initial deformation of the sample the dies are out of position. The end cooling blocks (see Section 2.3.5.) are in a position also where a second blow from the cam could cause serious machine damage. The purpose of the cam follower activation system is, therefore, to insert the follower, allow the deformation to occur, and then retract the follower before the lobe comes around again.

Figure 8 is a schematic and Figure 9 a photo of cam follower and the double-acting cylinder that controls the follower movement. When the follower is in the rest position (not making contact with the cam lobe, Fig. 9a) the normally closed three-way solenoid valve is off, and the follower side of the piston is vented to atmosphere. The far side of the piston is pressurized up to 250 psi (1720 kPa). On signal, the three-way solenoid valve opens and allows up to 500 psi (3450 kPa) pressure into the follower side of the piston. This overbalances the piston and moves the follower into the activated position (Fig. 9b). A large surge tank is placed in both the high- and low-pressure lines to prevent drops or rises during activation of the system. For retracting the follower, the solenoid valve is turned off and the high pressure side exhausts, allowing the lower pressure to return the follower to the rest position. Bottles of compressed nitrogen gas are used to supply the gas pressure.

The high and low pressures used for moving the piston vary with the cam rotational speed. Table II lists the pressures that must be used. The pressures are controlled from the high pressure regulators on the gas bottles to the left of the machine drive train.

2.3.2.2. Activation Control

The activation control panel for activating the solenoid valve is located on the master cam plastometer control console. The electronic control is completely solid-state except for the solenoid valve. A complete description is obtained in the separate manual entitled "Electronic Control for the Cam Plastometer". The control is designed so that the circuit cannot be activated again until it is reset. Photo transistors on the plastometer give the initial pulse to the control unit for insertion of the cam follower. Similarly the photo-transistor gives a pulse to the control unit for removal of the cam. On activation, the control unit also produces a signal to trigger the storage oscilloscope and the transient recorder for the recording of the test data.

Preparation of the control for activation (Fig. 10 is a closeup of the panel) is as follows: ensure that the surge capacitor switch is on DISCHARGE and that the ARM and ACTIVATE switches are in the off position before turning on the power. The numbers on the panel are in step by step order. The activation procedure is as follows:

1. Turn power on.
2. Set delay time for correct cam rpm (Table II).
3. Push reset #1.
4. Push reset #2 (first blue light comes on).
5. Set surge capacitor switch to charge.

6. Set lobe selector to centre position.
7. Push lobe #1 selector.
8. Set surge capacitor switch to ready (second blue light comes on).
9. Set ARM switch.
10. To activate, set ACTIVATE switch.
11. When activation has been completed, set capacitor surge switch to discharge; arm and activate switches to off.

> Note:
> 1. Both blue lights must be ON before activation.
> 2. The operating instructions must be carefully followed or accidental activation of the solenoid may results.

2.3.3. Load Measurement

The load during the deformation is measured with the use of a strain gauge load cell. This cell is bolted to the underside of the main screwdown. The cell has a rating of 100,000 lb (0.45 MN) with a 200% overload capacity. There are four strain gauges (Micro-Measurements, EA-06-187BB-120) forming a full bridge on the load cell. The wiring diagrams and pin numbering is shown in Appendix III. The gauges were attached with adhesive (M-Bond 610).

The load is recorded with the use of a Bridge Amplifier Meter (BAM). This gives a dc signal to the strain gauge bridge. The system has been calibrated on an hydraulic testing machine A digital voltmeter (Hewlett-Packard, Model No. 3470) is used to calibrate the BAM.

The output signal from the BAM is fed to channel #1 of the storage oscilloscope and the transient recorder (Biomation, 802). Table III gives the settings for various full-scale deflections corresponding to the calibration setting of the BAM.

The BAM instrument is operated in the "meter out" position during the compression test and calibration. This is important in high-speed tests due to the damping effect of the BAM indicating gauge. Figure 11 shows a layout of the load measuring system.

2.3.4. Displacement Measurement

The displacement of the lower die blocks can be recorded during a test and for calibrating the lobe profile. A linear variable differential transformer (LVDT) is mounted in the pressure pad and the transformer core is mounted to the transfer block (Fig. 12). This device produces an electrical output proportional to the displacement of the movable core.

The LVDT is a Schaevitz Type 500 MHR connected to a signal conditioner (Schaevitz, Model SCM-025 RLT). The signal conditioner is mounted on the main plastometer control panel. The output from the signal conditioner is a dc signal proportional to the core displacement and in this case proportional to the lower die movement. This signal is fed to channel #2 of the storage oscilloscope, set at 2.0 volts/division.

2.3.5. Furnace Description and Control

2.3.5.1. Low-Temperature Furnace

The Cam Plastometer specimens can be heated "in situ" by a resistance-winding split-tube furnace mounted on the pressure pad. For room-temperature testing the whole furnace can be swung forward out of the way. The 4.25-in.(108 mm) long carbide dies are used with the furnace in place. To protect the load cell and the lower transfer mechanism from excessive heating, a water-cooled block is positioned between the upper platen and the load cell and between the lower platen and the transfer blocks.

Water must be circulating through these during furnace operation.

The furnace has three vertical zones which can be controlled to obtain the desired specimen temperature.

The plastometer furnace is controlled from the main control panel (Fig. 13). The furnace is controlled by a proportioned controller (Thermo Electric, Model 32431). One control thermocouple is used and the controller is calibrated for a Pt vs Pt 10% Rh type couple. A control thermocouple is embedded in the furnace windings for controlling the furnace temperature. The systems can be more accurately controlled by having the control thermocouple attached directly to the test specimen. When this is not feasible or desired the furnace thermocouple must be used.

The temperature controller output is a 0-5 mA signal proportional to the deviation from setpoint. This is fed into three ac SCR power controllers. The power controllers provide time proportioned power to the furnace depending on the milliamp output of the proportional controller. Each of the power controllers control one of the three furnace zones. The average power to each individual zone can be independently varied by adjusting the variable resistance in the temperature controller output circuit to each zone. These controls are on the main panel and are marked as TOP ZONE, MIDDLE ZONE, and BOTTOM ZONE. The input to the power controllers is monitored by the three milliamp meters.

For furnace operation, the master furnace switch and the master dc switch must be turned on. The furnace mode switch is normally on AUTOMATIC. The zone proportional settings should be adjusted to the correct readings as determined from prior calibration testing. Due to the open-winding furnace construction and the very low thermal mass within the furnace, the heating rate is very rapid and overshoot is possible. The setpoint should, therefore, initially be set substantially below the final desired setpoint and then manually increased to the final setpoint carefully monitoring the actual furnace temperature. The 0-5 mA meters can be used to indicate when the system is under control. During heat up the control current should be below 0.8 mA to each zone.

Caution: The split furnace should not be opened when the furnace control is ON and the control thermocouple is attached to the specimen.

2.3.5.2. High Temperature Furnace

For high temperature tests, the sample is heated in a globar furnace independent from the plastometer. To eliminate a temperature drop of the sample during the transfer from the globar furnace to the plastometer, a portable unit is used. The sample is mounted between the lubricated dies in the portable unit while it is being heated (Fig. 14). The portable unit is designed by the use of two radiation barriers, to reduce the temperature loss of the sample on the transfer. The transfer must be made within thirty seconds to avoid appreciable temperature drop. A thermocouple can be welded to the specimen with this technique for monitoring the specimen temperature and calibrating the globar furnace.

Just before the transfer to the plastometer, a dummy block is placed on the transfer block in the pressure plate. The dummy block is preheated to the test temperature and is used to reduce heat loss from the portable heater. Similarly a cold dummy block is placed on top of the upper die (separated by mica layers) on removal of the portable unit from the globar furnace. This protects the load cell when the main screwdown is tightened.

To eliminate delay while the screwdown is tightened, the activation system should be armed and the cam should be at speed during the portable unit transfer.

<u>Caution:</u> It is imperative for safety that the person loading the plastometer must also activate the system, to prevent the system from being activated while the portable heater is being put into place.

2.3.6. Data Acquitision

2.3.6.1. Oscilloscope Operation

A complete description of the operation of the oscilloscope is obtained in the following Tektronix instruction manuals:

(a) Type RM 564 Oscilloscope.
(b) Type 129 Power Supply Plug-In Unit.
(c) Type 3B3 Plug-In Unit Time Base.
(d) Type 3A74 Plug-In Unit Four Trace Amplifier.
(e) Type 3A8 Operational Amplifier Plug-In Unit.
(f) Oscilloscope Camera C-12.

Four Oscilloscope channels are available to record four events simultaneously during the deformation test. Normally, Channel #1 is used for the load and Channel #2 for the lower platen displacement. The other two channels are available to record the specimen temperature or to monitor the cam-lobe position and the cam-follower position. For normal testing the LVDT output is inverted so the load and displacement curves cannot coincide.

For a test, the activation control circuit provides a signal which triggers the scope to make a single sweep recording the test results.

2.3.6.2. Chart Recorders

Two chart recorders are used with the machine to record sample temperature and cam rotational speed. For operating instructions refer to the Hewlett-Packard, Model 7100B Instruction Manual and the Hewlett-Packard Model 7004A Manual.

There are output jacks on the main control panel for the sample temperature, LVDT displacement output and the cam rotational speed.

2.3.6.3. Load Data Acquisition (Fig. 11)

A transient recorder (Biomation, Model 802) is used to store the load versus time event of the test. This recorder stores the digital equivalent of the output from the BAM in 1024 memory locations. For proper recording, the instrument must be set to the proper sweep delay and sweep-time settings listed in Table II; the recorder must be in the Delayed Sweep mode. Refer to the Biomation, Model 802 Operating and Service Manual for a complete description of the instrument.

The transient recorder can be fed into an Y-t recorder for a visual curve of the load versus time by pushing the PLOT button on the front panel. The most accurate output is to the 33ASR teletypewriter. The teletype prints the 1024 data points in rows of ten giving 103 lines of print. The teletype can also produce punched tape of the result for direct computation. The computer program for converting the data to true stress - true strain curves is obtained in a separate report "Computation of Cam Plastometer Data".

A data coupler (Datacap, Model B207) is used to interface the transient recorder and the teletypewriter. (Refer to Operating Manual for a complete description.) This interface also controls the output to the teletype. For transferring the solid state memory onto the punched tape or printed format, the start switch is pressed. The writing will stop automatically after the 1024 points are recorded. The printing can be stopped at any time by pressing the reset button.

3. OPERATING PROCEDURES

3.1. Specimen Lubrication

The barrelling of the specimen during the compression deformation can be nearly or completely eliminated with the proper lubrication. A system of grooves is machined into the sample ends to stop the lubricant from being rejected during the deformation. The groove system varies with the sample material, lubricant and temperature. Table IV gives the combinations that have been developed, and Fig. 15 shows the groove geometry.

3.2. Thermocouple Placement

Thermocouples are placed directly onto the specimen for the most accurate monitoring of the test temperature. This also allows monitoring of the adiabatic heating during the deformation.

Two methods may be used to fix the thermocouple to the sample. The first involves drilling a small hole in the specimen and inserting a beaded thermocouple into the hole. The hole edge is then peened over to lock in the thermocouple head. The second method involves welding the thermocouple onto the side of the specimen. A capacitor discharge miniature welder is used and the welding can be done after the specimen is mounted in the plastometer.

3.3. Test Procedure Check List

The following check list should be carefully followed for a test. Full explanation of each step is given in the relevant section of this manual.

1. Turn on dc master switch (pilot light).
2. Turn on tachometer switch.
3. Turn on electronic counter (pilot light).
4. Turn on LVDT signal conditioner (pilot light).
5. Turn on Tektronix oscilloscope and power supply (pilot lights).
6. Turn on Biomation transient recorder.
7. Turn on Datacap interface.
8. Turn on teletypewriter.
9. Turn on all recorders.
10. Turn on BAM (see section 2.3.3.).
11. Turn on activation control panel (see section 2.3.2.2.).
12. Position LVDT trace on scope (channel #2 inverted, 2.0 volts/division).
13. Position load trace on scope (channel #1, see Table IV).
14. Mount specimen thermocouples (see section 3.2.).
15. Lubricate die faces (see section 3.1.).
16. Calibrate BAM meter (see Table III).
17. Insert specimen between dies.
18. Close furnace (see section 2.3.5.).
19. Turn on platen cooling water.
20. Prepare thermocouple cold junction.
21. Connect and check thermocouple operation.
22. Set furnace zone proportional controls (see section 2.3.5.1.).

23. Turn on furnace.
24. Release main press screw as thermal expansion loads specimen.
25. Turn on motor-generator set for dc power.
26. Turn on plastometer motor.
27. Select proper gear ratio (Table II).
28. Dial in proper activation delay time on control panel (see Table II).
29. Turn on dc activation control light.
30. For the oscilloscope:
    (a) Dial in proper delay time (Table II).
    (b) Set sweep rate and delayed sweep rate (Table II).
    (c) Set time base to delayed sweep.
    (d) Set sweep control to single sweep.
    (e) Set slope control to +.
    (f) Set coupling to dc.
    (g) Set source control to external.
    (h) Reset scope trigger.
31. For the transient recorder:
    (a) Set sweep time (Table II).
    (b) Set delay time (Table II).
    (c) Set to delayed sweep.
    (d) Set to single sweep.
    (e) Set slope to +.
    (f) Set trigger to dc.
    (g) Make sure the input signal is not causing the off scale light to glow.
    (h) Arm.
32. Increase cam to test speed.
33. Test activation control (see section 2.3.2.2.).
34. Both transient recorder and scope should have triggered. Check proper scope trace has appeared.
35. Disarm activation circuit.
36. Pressurize surge tanks (Table II).
37. Arm activation circuit.
38. Reset oscilloscope and transient recorder triggers.

39. Clear oscilloscope screen.
40. Turn on chart recorders to test sweep rates.
41. Activate system - test occurs.
42. Stop chart recorders.
43. Bring cam to rest.
44. Disarm activation system (see section 2.3.2.2.).
45. Turn furnace off.
46. Depressurize surge tanks.
47. Photograph test result, or print out result on teletype.
48. Turn off dc activation control light.
49. Open furnace and remove specimen.

> Note: If another test is to be conducted return to Step 14 in this procedure at this point.

50. Turn off dc master switch.
51. Turn off electronic counter.
52. Turn off LVDT signal conditioner.
53. Turn off oscilloscope.
54. Turn off all recorders.
55. Turn off BAM.
56. Turn off activation control panel.
57. Turn off motor-generator set.
58. Turn off platen cooling water, after dies are cool.

3.4. Test Data Sheet

A standard test data sheet is used to record the machine and sample test conditions and partial test results. The data sheet is shown in Fig. 16.

4. MACHINE MAINTENANCE

The following maintenance schedule should be followed for proper care of the machine. The intervals stated between maintenance procedures are considered maximums.

Every ten (10) tests:

1. Check integrity of the cam follower block holder and ensure "roll-pin" in piston rod is undisturbed.
2. Check lubrication on the cam surface.
3. Check the condition of the cam follower shock absorption pads. Replace as required.

Every week:

1. Completely clean machine.
2. Lubricate cam and flywheel bearings (bearing grease).
3. Lubricate universal joint coupling (bearing grease).

Every Month:

1. Lubricate main screw down (oil plus MoS_2).
2. Check integrity of all couplings in the drive train.

Every twenty-five (25) tests:

1. Lubricate cam follower block and transfer block (oil plus MoS_2).

5. SUPPLEMENTARY INSTRUCTION MANUALS

The following instruction manuals should be used in conjunction with this manual.

1. Transistor Specialties, Incorporated, 500 Series Modular Electronic Counter.
2. Thermo Electric Indicating Thermocouple Controller Model 32431.
3. Hewlett Packard Recorder Model 7100B.
4. Hewlett Packard Recorder Model 7004A.
5. Tektronix Oscilloscope Camera C-12.
6. Tektronix Type 3A8 Operational Amplifier Plug-In Unit.
7. Tektronix Type 3B3 Plug-In Unit.
8. Tektronix Type RM 564 Oscilloscope.
9. Tektronix Type 129 Power Supply Plug-In Unit.

10. Tektronix Type 3A74 Plug-In Unit.
11. Electronic Control for Cam Plastometer.
12. BAM - 3A Bridge Amplifier Meter
13. Intertechnology Instructions for the Installation of Strain Gauges.
14. Schaevitz Engineering Technical Bulletin - AA-1b.
15. Electro Products Laboratories Inc. Bulletin - MPB-269.
16. Biomation Model 802 Transient Recorder.
17. Datacap Model B207 Data Coupler.
18. Hewlett-Packard Model 3470 Measurement System.

ACKNOWLEDGEMENTS

The Physical Metallurgy Division is indebted to John Hockett of Los Alamos Scientific Laboratories on whose plastometer our machine is based.

MS:gt

TABLE 1

Overall Gear Ratios and RPM Ranges

Gear No.	RTOO -9513 Gear (Range)	3-A-92 Gear	Overall Ratio	rpm Maximum
1	Low	1	25.29	47
2	1(LO)	1	15.22	78
3	Low	2	12.10	99
4	2(LO)	1	10.66	112
5	Low	3	9.08	132
6	3(LO)	1	7.71	115
7	1(LO)	2	7.28	164
8	4(LO)	1	5.64	212
9	1(LO)	3	5.64	219
10	2(LO)	2	5.10	235
11	5(DIR)	1	4.12	291
12	2(LO)	3	3.83	313
13	3(LO)	2	3.69	325
14	5(OD)	1	3.47	345
15	6(DIR)	1	2.88	416
16	3(LO)	3	2.77	433
17	4(LO)	2	2.70	444
18	6(OD)	1	2.42	495
19	7(DIR)	1	2.09	574
20	4(LO)	3	2.03	591
21	5(DIR)	2	1.97	609
22	7(OD)	1	1.76	681
23	5(OD)	2	1.66	722
24	8(DIR)	1	1.53	784
25	5(DIR)	3	1.48	810
26	6(DIR)	2	1.38	869
27	8(OD)	1	1.30	923
28	5(OD)	3	1.25	960
29	6(OD)	2	1.16	1034
30	6(DIR)	3	1.04	1153
31	7(DIR)	2	1.00	1200
32	6(OD)	3	0.87	1379
33	7(OD)	2	0.84	1428
34	7(DIR)	3	0.75	1600
35	8(DIR)	2	0.73	1643
36	7(OD)	3	0.63	1904
37	8(OD)	2	0.62	1935
38	8(DIR)	3	0.55	2181
39	8(OD)	3	0.47	2553

TABLE II

A. Machine Settings 45° Cam

Strain Rate (sec^{-1})	rpm	ms per pulse	Gear	Pressures (psi)	Activation Delay (sec)
3.0	28.12	17.781	1	150/75	0.05
3.5	32.81	15.24	1	150/75	0.05
5.0	46.9	10.66	1	150/75	0.05
10.0	93.7	5.33	4	150/75	0.05
20.0	187.5	2.666	8	150/75	0.22
30.0	281.2	1.778	21	150/75	0.16
40.0	375.0	1.333	26	150/75	0.16
50.0	468.7	1.067	26	200/100	0.07
60.0	562.5	0.889	31	200/100	0.065
70.0	656.2	0.762	31	250/125	0.045
80.0	750.0	0.667	33	250/125	0.040
90.0	843.7	0.593	35	250/125	0.032
100.0	937.5	0.533	39	300/150	0.019
120.0	1125.0	0.444	39	300/150	0.0081
140.0	1312.5	0.381	39	400/200	0.0061
160.0	1500.0	0.3333	39		
180.0	1687.5	0.2963	39		
200.0	1875.0	0.2666	39		

TABLE II A (Cont'd)

Strain Rate (sec^{-1})	Oscilloscope Trigger Delay (units)	Oscilloscope Sweep Time (ms)	802 Recorder Delay (units)	802 Recorder Sweep Time (ms)	Amplifier Setting Zi	Amplifier Setting Zf	Tach Setting
3.0	1.55	500/50	1.80	500	0.1	0.5	10^{-5}
3.5			1.50	500	0.1	0.5	10^{-5}
5.0	2.50	200/20	1.00	500	-	-	10^{-6}
10.0	1.60	100/20	1.20	200	-	-	10^{-6}
20.0	4.75	50/10	2.75	100	-	-	10^{-6}
30.0	3.30	50/5	3.70	50	-	-	10^{-6}
40.0	1.20	50/5	2.00	50	-	-	10^{-6}
50.0	5.20	20/5	2.50	50	-	-	10^{-6}
60.0	4.80	20/2	5.30	20	-	-	10^{-6}
70.0	4.50	20/2	5.05	20	-	-	10^{-6}
80.0	7.60	10/2	4.20	20	-	-	10^{-6}
90.0	7.60	10/1	3.90	20	-	-	10^{-6}
100.0	7.60	10/1	3.90	20	-	-	10^{-6}
120.0	6.80	10/1	7.15	20	-	-	10^{-6}
140.0	5.90	10/1		10	-	-	10^{-7}
160.0					-	-	10^{-7}
180.0							
200.0							

TABLE II B. Machine Settings 225° Cam

Strain Rate (sec^{-1})	rpm	ms per pulse	Gear	Pressures (psi)	Activation Delay (sec)	Tach Setting
0.1	5	100.0	1	150/75	9.999	10^{-4}
0.2	10	50.00	1	150/75	4.5	10^{-5}
0.5	25	20.00	1	150/75	1.80	10^{-5}
1.0	50	10.00	2	150/75	0.89	10^{-5}
2.0	100	5.00	3	150/75	0.35	10^{-6}
3.0	150	3.333	7	150/75	0.24	10^{-6}
3.5	175	2.857	7	150/75	0.20	10^{-6}
5.0	250	2.000	11	150/75	0.13	10^{-6}
10.0	500	1.000	26	250/125	0.05	10^{-6}

Strain Rate (sec^{-1})	Oscilloscope		802 Recorder		Amplifier Setting	
	Trigger Delay	Sweep Time (ms)	Delay (units)	Sweep Time (ms)	Zi	Zf
0.1	-	1000	0.5	10 sec	0.1	0.5
0.2	-	1000	0.52	5 sec	0.1	0.5
0.5	-	500	0.4	2000	0.1	0.5
1.0	-	200	0.4	1000	0.1	0.5
2.0	-	100	0.5	500	-	-
3.0	-	100	0	500	-	-
3.5	-	50	0	500	-	-
5.0	-	50	0.55	200	-	-
10.0	-	20	0.7	100	-	-

TABLE III

Load Measuring System Calibration Factors

The BAM Meter is calibrated with the Hewlett-Packard digital voltmeter reading 0.0xx millivolts on the meter "out" position and 0.5000 volts on the calibration position.

"802" Full Scale Setting	Load Factor "802" Unit	Maximum Load (lb)	Maximum Load (KN)
2 volts	441.2	100,000+	445+
1 volt	220.6	55,000	245
500 mv	110.3	27,000	120
200 mv	44.12	11,000	49
100 mv	22.06	5,500	25
50 mv	11.03	2,800	12

TABLE IV

Specimen Lubrication Chart

Material	Temperature	Die Material	Lubricant
Al-1.5% Cu	450° C	Crodi	Silicon oil +graphite
	500°+	Si_3N_4 Crodi	Pb-borate glass
Zn-22% Al	<350° C	Crodi	Teflon sheet
Steel (carbon)	500-600° C	Si_3N_4	Pb-borate glass
	600-1050° C	Si_3N_3	GCF-81 glass
	800° C	SiC	3419 glass
	900-1000° C	SiC	XF-105 glass
	1100° C	Steel	Soda-Lime glass

Note: Numbered Glasses have been obtained from Ferro Enamels (Canada) Ltd.

APPENDIX I

CAM PROFILE 45°

Angle Around Cam (deg)	Radius (in.)	Y-Dimension (in.)	X-Dimension (in.)
315	5.0000	+3.5356	-3.5356
316	5.0132	+3.6055	-3.4818
317	5.0261	+3.6758	-3.4278
318	5.0389	+3.7446	-3.3717
319	5.0514	+3.8123	-3.3140
320	5.0638	+3.8791	-3.2550
321	5.0760	+3.9448	-3.1944
322	5.0879	+4.0093	-3.1324
323	5.0996	+4.0727	-3.0690
324	5.1112	+4.1351	-3.0043
325	5.1226	+4.1962	-2.9382
326	5.1338	+4.2561	-2.8708
327	5.1449	+4.3149	-2.8021
328	5.1557	+4.3723	-2.7321
329	5.1664	+4.4285	-2.6609
330	5.1769	+4.4834	-2.5885
331	5.1872	+4.5368	-2.5148
332	5.1974	+4.5890	-2.4400
333	5.2074	+4.6398	-2.3641
334	5.2173	+4.6893	-2.2871
335	5.2270	+4.7373	-2.2090
336	5.2365	+4.7838	-2.1300
337	5.2459	+4.8289	-2.0497
338	5.2551	+4.8724	-1.9686
339	5.2642	+4.9146	-1.8865
340	5.2732	+4.9552	-1.8035
341	5.2820	+4.9942	-1.7197
342	5.2907	+5.0318	-1.6349
343	5.2992	+5.0676	-1.5493
344	5.3076	+5.1020	-1.4630
345	5.3158	+5.1346	-1.3758
346	5.3240	+5.1658	-1.2880
347	5.3320	+5.1953	-1.1994
348	5.3398	+5.2231	-1.1102
349	5.3476	+5.2494	-1.0204
350	5.3552	+5.2739	-0.9299
351	5.3627	+5.2967	-0.8389
352	5.3701	+5.3178	-0.7474
353	5.3773	+5.3372	-0.6553
354	5.3845	+5.3550	-0.5628
355	5.3915	+5.3710	-0.4699
356	5.3984	+5.3852	-0.3766
357	5.4052	+5.3978	-0.2829
358	5.4119	+5.4086	-0.1889
359	5.4185	+5.4177	-0.0946
360	5.4250	+5.4250	0
1 to 314	5.0000	-	-

APPENDIX II

225° CAM COORDINATES

Cam Profile Coordinates

Angle Around Cam (deg)	Radius (in.)	X-Dimension (in.)	Y-Dimension (in.)
1 to 134	5.0000	-	-
135	5.0000	+3.5356	-3.5356
136¼	5.0033	+3.4598	-3.6142
137½	5.0066	+3.3824	-3.6913
138¾	5.0099	+3.3032	-3.7666
140	5.0132	+3.2224	-3.8403
141¼	5.0164	+3.1399	-3.9122
142½	5.0197	+3.0558	-3.9824
143¾	5.0229	+2.9701	-4.0507
145	5.0261	+2.8829	-4.1171
146¼	5.0293	+2.7941	-4.1817
147½	5.0325	+2.7040	-4.2444
148¾	5.0357	+2.6124	-4.3051
150	5.0389	+2.5195	-4.3638
151¼	5.0420	+2.4756	-4.4205
152½	5.0452	+2.3296	-4.4751
153¾	5.0483	+2.2328	-4.5277
155	5.0514	+2.1348	-4.5781
156¼	5.0545	+2.0357	-4.6264

Angle Around Cam (deg)	Radius (in.)	X-Dimension (in.)	Y-Dimension (in.)
157½	5.0576	+1.9354	-4.6726
158¾	5.0607	+1.8342	-4.7166
160	5.0638	+1.7319	-4.7584
161¼	5.0668	+1.6287	-4.7979
162½	5.0699	+1.5245	-4.8353
163¾	5.0729	+1.4195	-4.8702
165	5.0759	+1.3137	-4.9029
166¼	5.0787	+1.2071	-4.9331
167½	5.0819	+1.0999	-4.9615
168¾	5.0849	+0.9920	-4.9872
170	5.0879	+0.8835	-5.0106
171¼	5.0908	+0.7744	-5.0315
172½	5.0938	+0.6649	-5.0502
173¾	5.0967	+0.5549	-5.0664
175	5.0996	+0.4444	-5.0802
176¼	5.1025	+0.3337	-5.0916
177½	5.1054	+0.2227	-5.1005
178¾	5.1083	+0.1114	-5.1071

Angle Around Cam (deg)	Radius (in.)	X-Dimension (in.)	Y-Dimension (in.)
180	5.1112	0	-5.1112
181¼	5.1141	-0.1115	-5.1129
182½	5.1169	-0.2232	-5.1120
183¾	5.1198	-0.3348	-5.1135
185	5.1226	-0.4464	-5.1031
186¼	5.1254	-0.5580	-5.0950
187½	5.1282	-0.6694	-5.0843
188¾	5.1310	-0.7805	-5.0713
190	5.1338	-0.8915	-5.0558
191¼	5.1366	-1.0021	-5.0379
192½	5.1393	-1.1124	-5.0175
193¾	5.1421	-1.2222	-4.9947
195	5.1449	-1.3316	-4.9696
196¼	5.1476	-1.4405	-4.9420
197½	5.1503	-1.5487	-4.9119
198¾	5.1530	-1.6564	-4.8795
200	5.1557	-1.7634	-4.8448
201¼	5.1584	-1.8696	-4.8077

Angle Around Cam (deg)	Radius (in.)	X-Dimension (in.)	Y-Dimension (in.)
202½	5.1611	-1.9750	-4.8682
203¾	5.1637	-2.0797	-4.7264
205	5.1664	-2.1834	-4.6824
206¼	5.1690	-2.2862	-4.6359
207½	5.1717	-2.3880	-4.5873
208¾	5.1743	-2.5405	-4.5345
210	5.1769	-2.5885	-4.4834
211¼	5.1795	-2.6870	-4.4280
212½	5.1821	-2.7843	-4.3705
213¾	5.1846	-2.8804	-4.3108
215	5.1872	-2.9753	-4.2491
216¼	5.1898	-3.0688	-4.1853
217½	5.1923	-3.1609	-4.1193
218¾	5.1949	-3.2516	-4.0514
220	5.1974	-3.3408	-3.9814
221¼	5.1999	-3.4285	-3.9095
222½	5.2024	-3.5147	-3.8356
223¾	5.2049	-3.5992	-3.7598

Angle ARound Cam (deg)	Radius (in.)	X-Dimension (in.)	Y-Dimension (in.)
225	5.2074	-3.6822	-3.6822
226¼	5.2099	-3.7634	-3.6027
227½	5.2124	-3.8430	-3.5214
228¾	5.2148	-3.9207	-3.4383
230	5.2173	-3.9967	-3.3536
231¼	5.2197	-4.0707	-3.2671
232½	5.2221	-4.1430	-3.1790
233¾	5.2246	-4.2133	-3.0894
235	5.2270	-4.2817	-2.9981
236¼	5.2294	-4.3481	-2.9053
237½	5.2318	-4.4124	-2.8110
238¾	5.2341	-4.4747	-2.7153
240	5.2365	-4.5350	-2.6183
241¼	5.2389	-4.5931	-2.5200
242½	5.2412	-4.6490	-2.4201
243¾	5.2436	-4.7028	-2.3192
245	5.2459	-4.7544	-2.2170
246¼	5.2482	-4.8037	-2.1137

Angle Around Cam (deg)	Radius (in.)	X-Dimension (in.)	Y-Dimension (in.)
247½	5.2505	-4.8508	-2.0093
248¾	5.2529	-4.8958	-1.9039
250	5.2552	-4.9383	-1.7974
251¼	5.2574	-4.9784	-1.6899
252½	5.2597	-5.0163	-1.5816
253¾	5.2620	-5.0518	-1.4725
255	5.2642	-5.0848	-1.3625
256¼	5.2665	-5.1156	-1.2517
257½	5.2687	-5.1438	-1.1404
258¾	5.2710	-5.1697	-1.0283
260	5.2732	-5.1931	-0.9157
261¼	5.2754	-5.2140	-0.8025
262½	5.2776	-5.2324	-0.6889
263¾	5.2798	-5.2484	-0.5748
265	5.2820	-5.2619	-0.4603
266¼	5.2842	-5.2729	-0.3456
267½	5.2863	-5.2813	-0.2306
268¾	5.2885	-5.2872	-0.1153

Angle Around Cam (deg)	Radius (in.)	X-Dimension (in.)	Y-Dimension (in.)
270	5.2907	-5.2907	0
271¼	5.2928	-5.2915	+0.1154
272½	5.2949	-5.2899	+0.2310
273¾	5.2971	-5.2858	+0.3464
275	5.2992	-5.2790	+0.4618
276¼	5.3013	-5.2698	+0.5772
277½	5.3034	-5.2580	+0.6923
278¾	5.3055	-5.2437	+0.8071
280	5.3076	-5.2270	+0.9217
281¼	5.3097	-5.2076	+1.0359
282½	5.3117	-5.1858	+1.1500
283¾	5.3138	-5.1615	+1.2630
285	5.3158	-5.1367	+1.3764
286¼	5.3179	-5.1074	+1.4887
287½	5.3199	-5.0737	+1.5997
288¾	5.3219	-5.0395	+1.7107
290	5.3240	-5.0029	+1.8209
291¼	5.3260	-4.9639	+1.9304

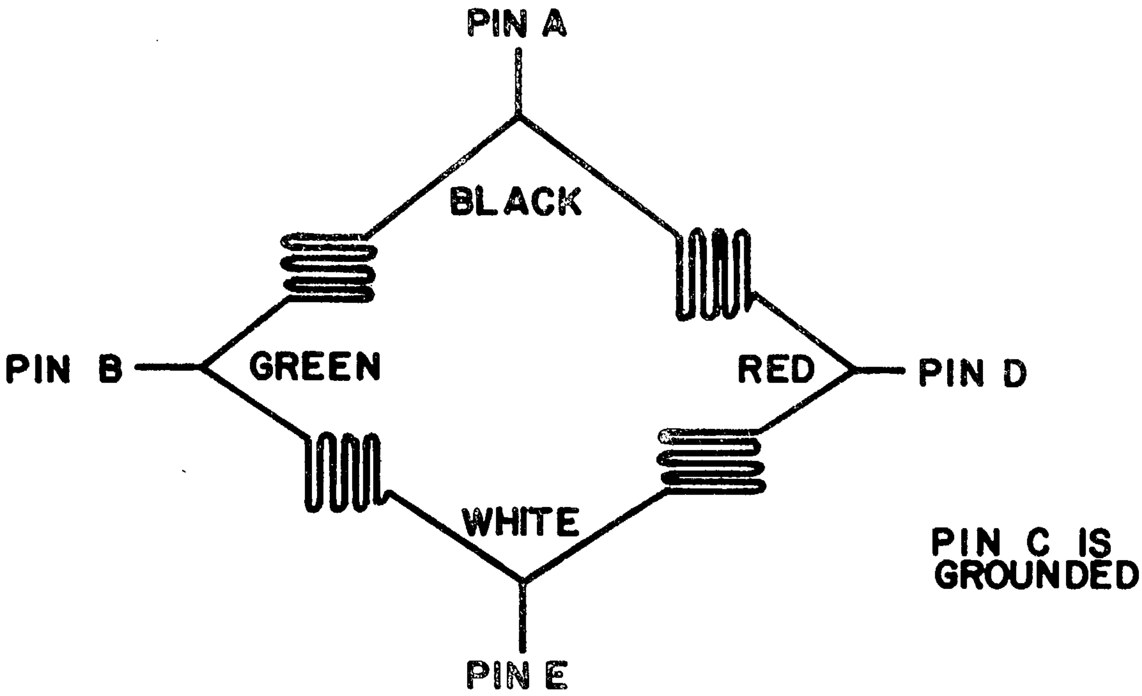
Angle Around Cam (deg)	Radius (in.)	X-Dimension (in.)	Y-Dimension (in.)
292½	5.3280	-4.9224	+2.0389
293¾	5.3300	-4.8786	+2.1467
295	5.3320	-4.8324	+2.2534
296¼	5.3339	-4.7838	+2.3591
297½	5.3359	-4.7330	+2.4639
298¾	5.3371	-4.6792	+2.6205
300	5.3398	-4.6244	+2.6699
301¼	5.3418	-4.5668	+2.7712
302½	5.3437	-4.5068	+2.8712
303¾	5.3457	-4.4448	+2.9699
305	5.3476	-4.3805	+3.0673
306¼	5.3495	-4.3141	+3.1632
307½	5.3514	-4.2455	+3.2577
308¾	5.3533	-4.1749	+3.3507
310	5.3552	-4.1023	+3.4423
311¼	5.3571	-4.0277	+3.5322
312½	5.3590	-3.9511	+3.6205
313¾	5.3608	-3.8724	+3.7070

Angle Around Cam (deg.)	Radius (in.)	X-Dimension (in.)	Y-Dimension (in.)
315	5.3627	-3.7920	+3.7920
316¼	5.3645	-3.7096	+3.8751
317½	5.3664	-3.6255	+3.9565
318¾	5.3682	-3.5395	+4.0360
320	5.3701	-3.4518	+4.1137
321¼	5.3719	-3.3624	+4.1894
322½	5.3737	-3.2713	+4.2632
323¾	5.3755	-3.1786	+4.3350
325	5.3773	-3.0843	+4.4048
326¼	5.3791	-2.9885	+4.4726
327½	5.3809	-2.8912	+4.5382
328¾	5.3827	-2.7924	+4.6017
330	5.3846	-2.6923	+4.6632
331¼	5.3862	-2.6446	+4.7222
332½	5.3880	-2.4879	+4.7792
333¾	5.3898	-2.3839	+4.8339
335	5.3915	-2.2786	+4.8864
336¼	5.3932	-2.1721	+4.9364

Angle Around Cam (deg)	Radius (in.)	X-Dimension (in.)	Y-Dimension (in.)
337½	5.3950	-2.0646	+4.9843
338¾	5.3967	-1.9560	+5.0298
340	5.3984	-1.8464	+5.0728
341¼	5.4001	-1.7358	+5.1135
342½	5.4018	-1.6243	+5.1518
343¾	5.4035	-1.5121	+5.1876
345	5.4052	-1.3990	+5.2210
346¼	5.4069	-1.2851	+5.2519
347½	5.4086	-1.1706	+5.2804
348¾	5.4103	-1.0555	+5.3063
350	5.4119	-0.9398	+5.3297
351¼	5.4136	-0.8235	+5.3506
352½	5.4152	-0.7068	+5.3688
353¾	5.4169	-0.5897	+5.3847
355	5.4185	-0.4722	+5.3979
356¼	5.4201	-0.3545	+5.4085
357½	5.4218	-0.2365	+5.4166
358¾	5.4234	-0.1183	+5.4221
360	5.4250	0	+5.4250

APPENDIX III

Load Cell Wiring Diagram



Load Cell to BAM Cable Identification

Wire Colour	Load Cell End	BAM End
Green	PIN B	PIN A
White	PIN E	PIN D
Red	PIN D	PIN B
Black	PIN A	PIN C
Shield	PIN C	PIN E

List of Figures

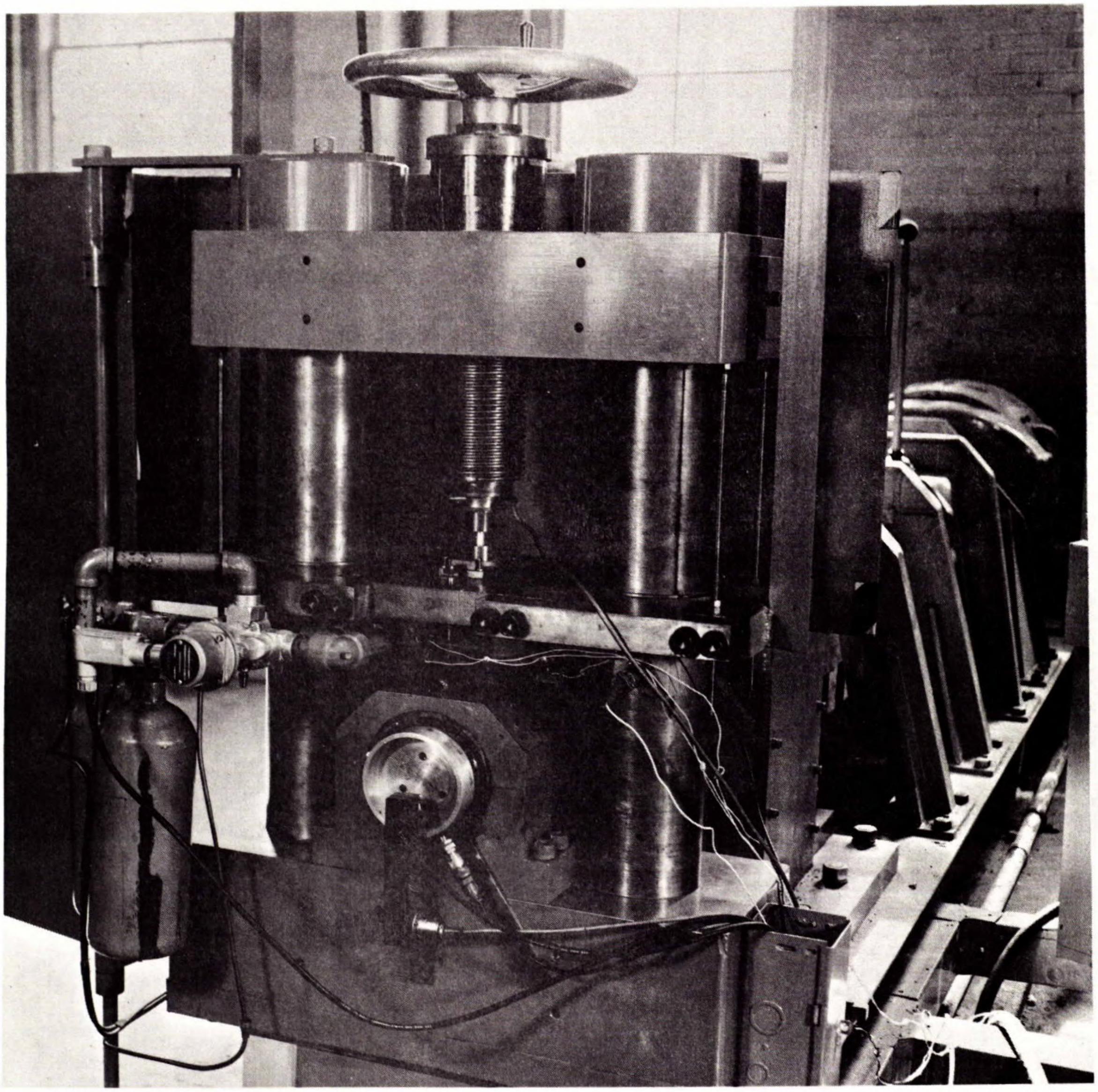


Fig. 1. Front view of Cam Plastometer showing load frame.

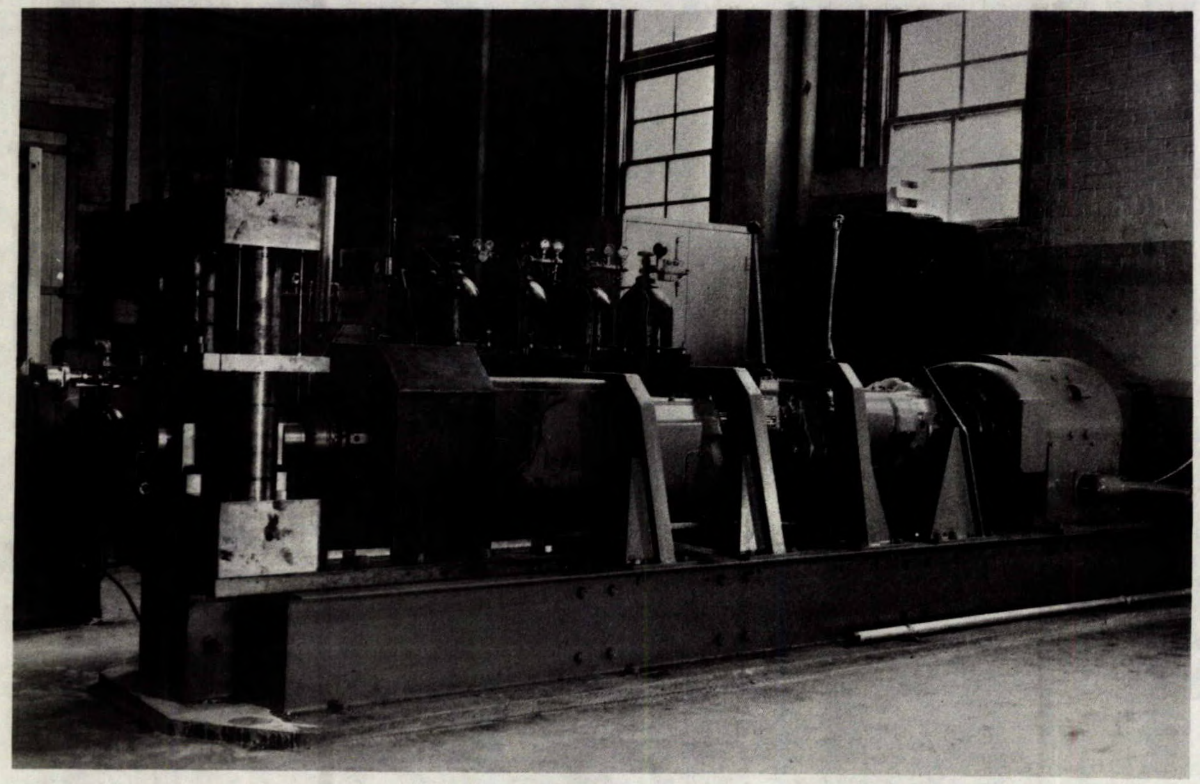


Fig. 2. Side view of Cam Plastometer (construction picture).

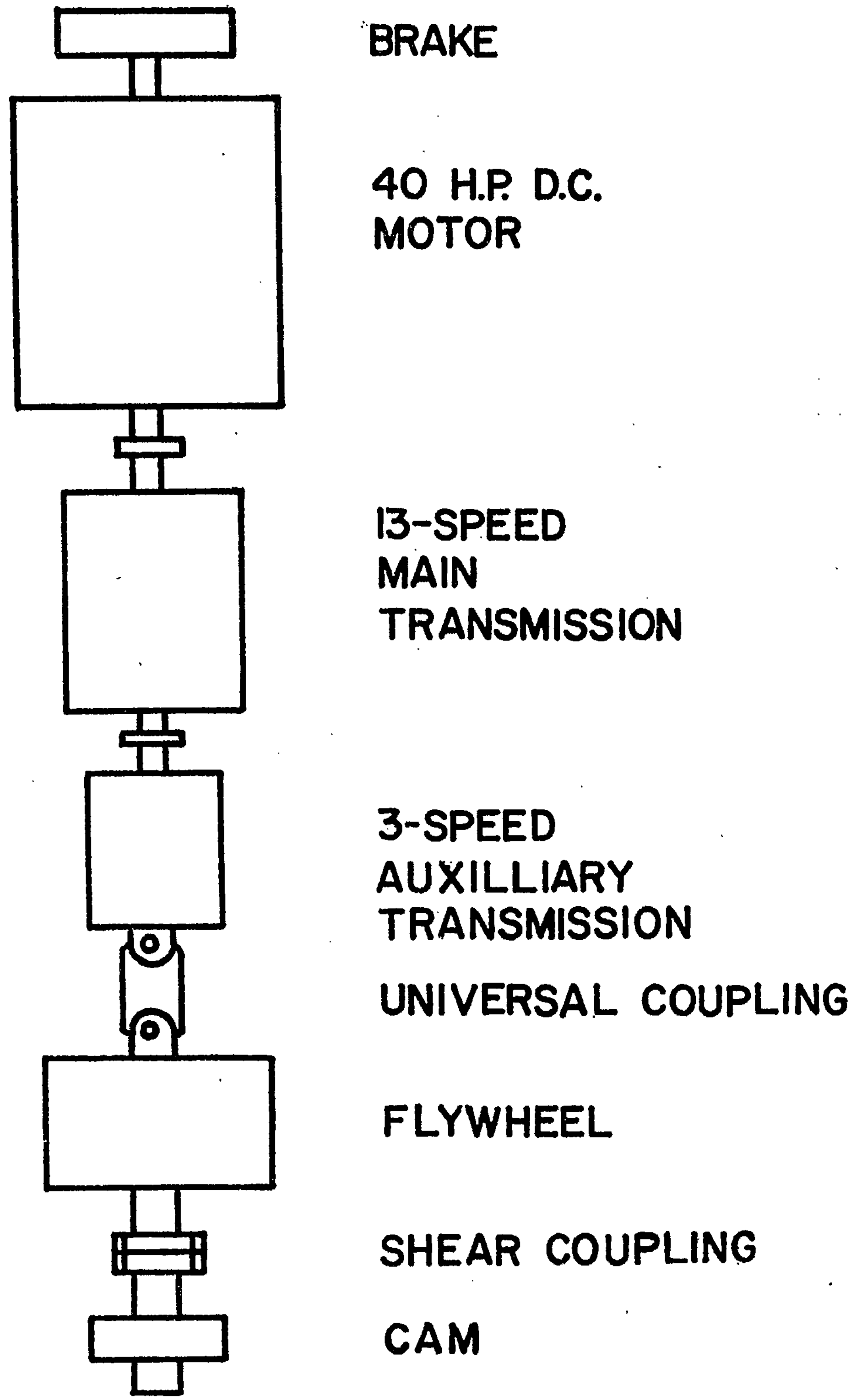


Fig. 3. Schematic of plastometer drive train.

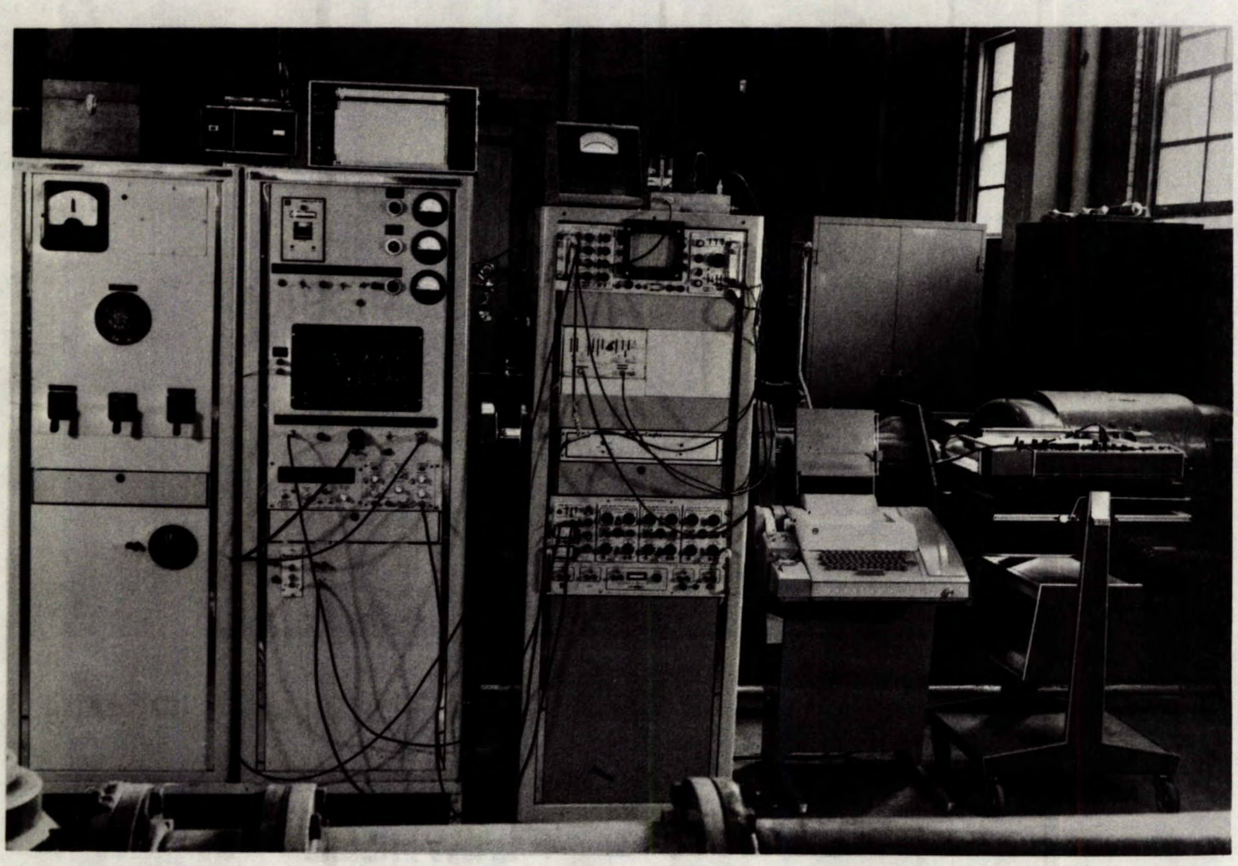


Fig. 4. Control panel, main plastometer

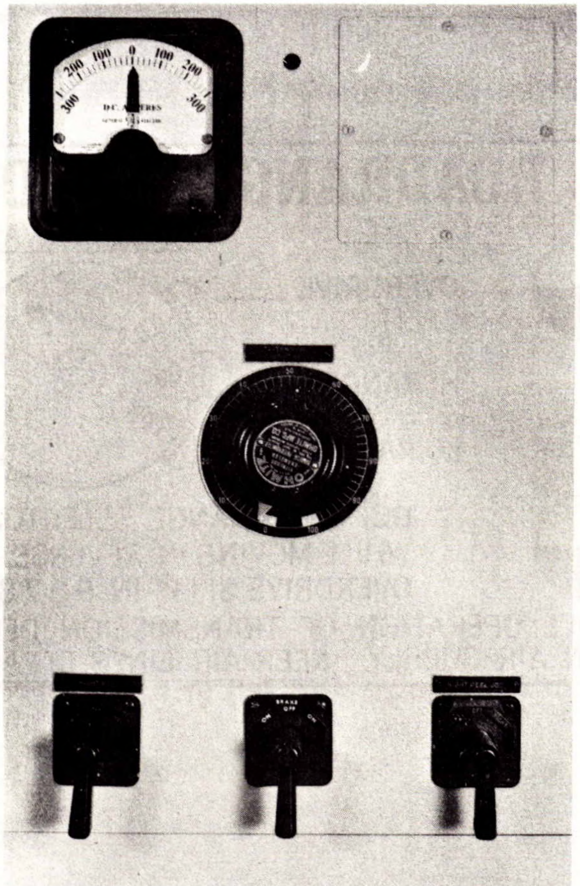


Fig. 5. Control panel, 40-hp dc motor.

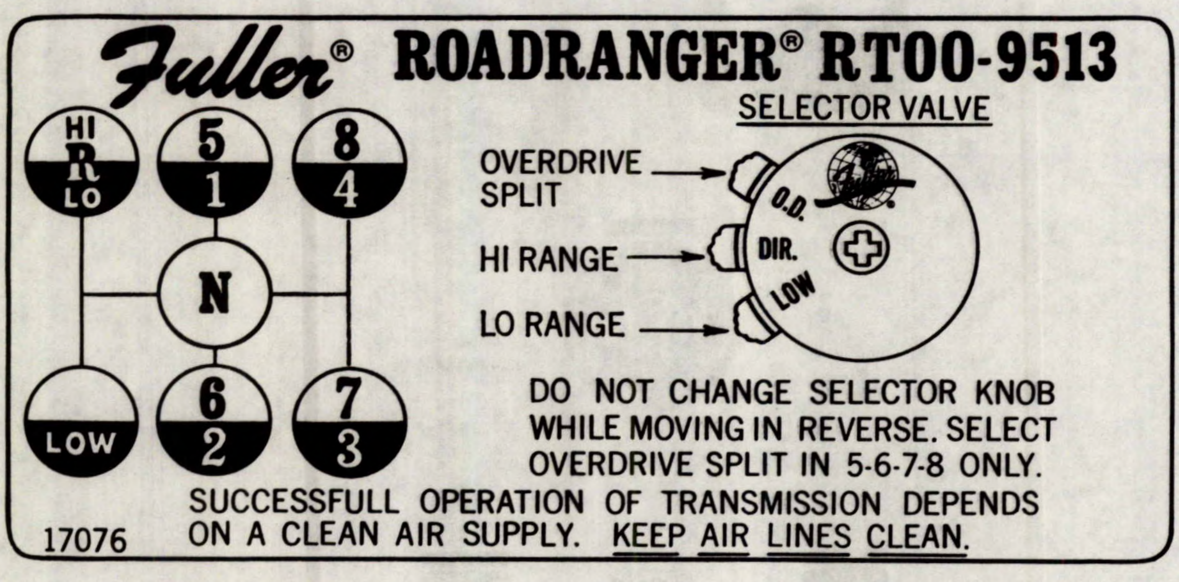


Fig. 6. Gear shift pattern for 13-speed main transmission.

3-A-92 TRANSMISSION

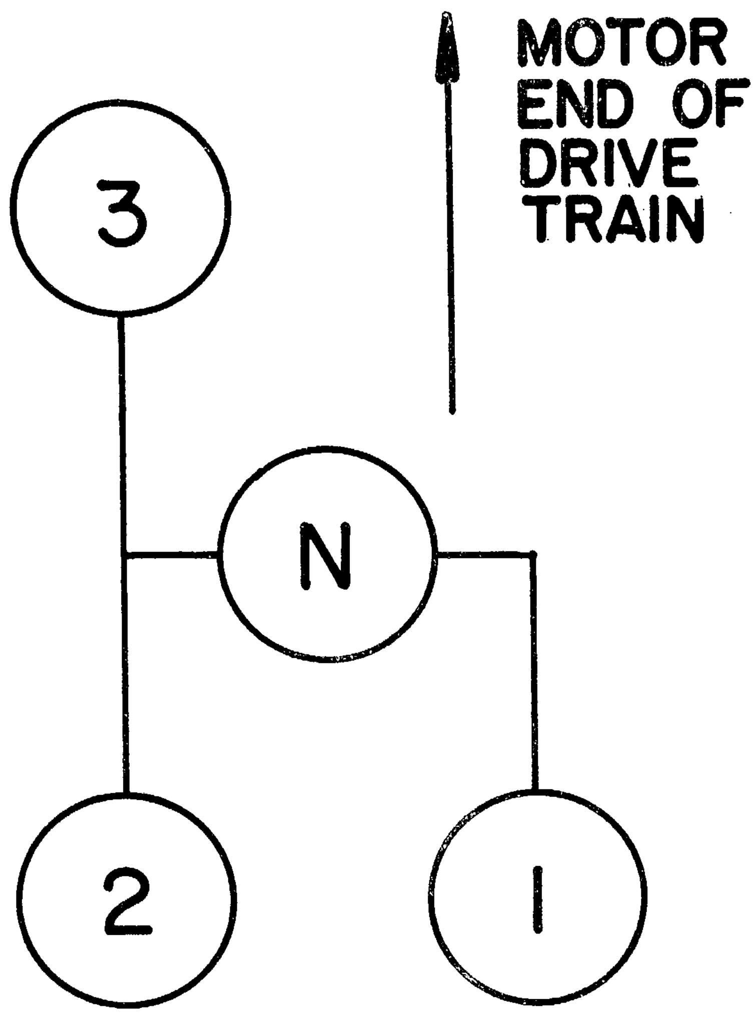
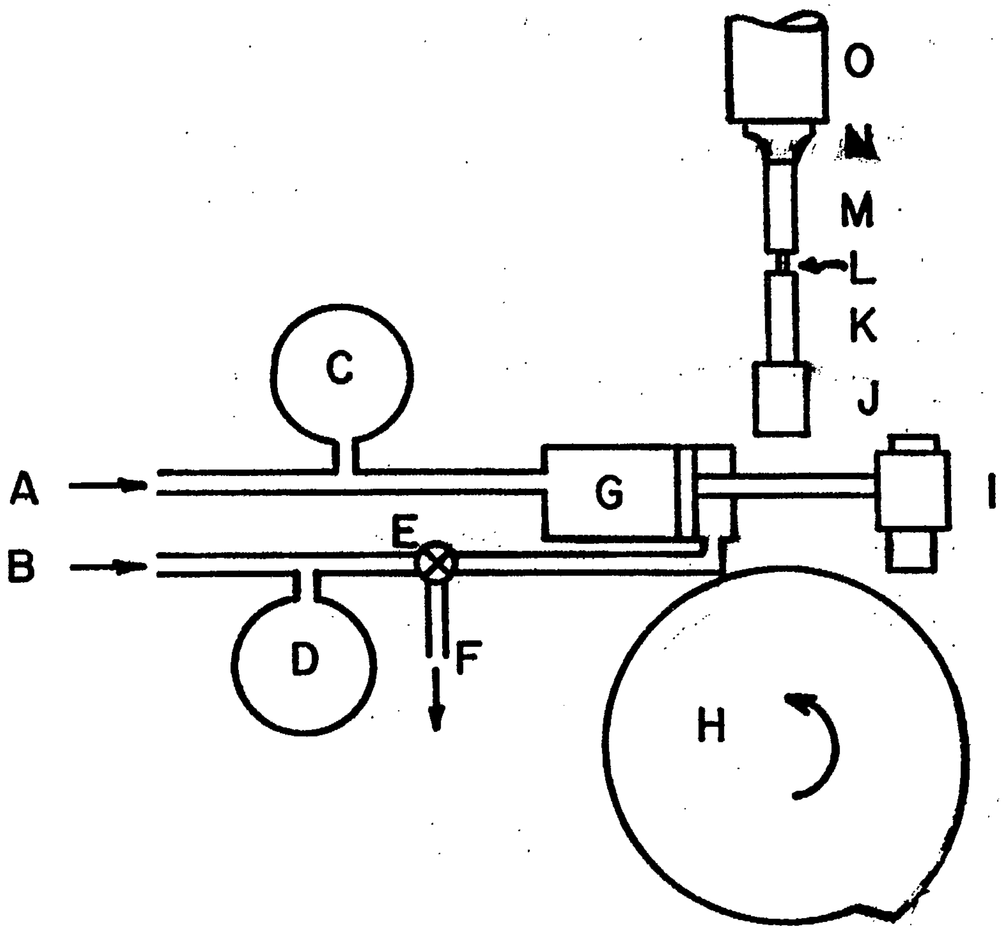


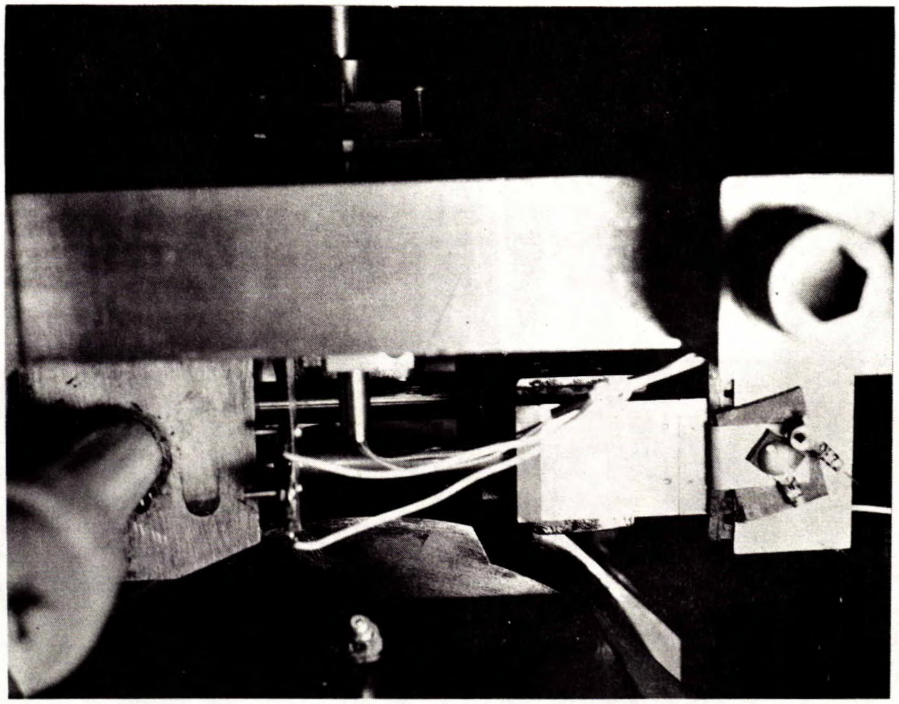
Fig. 7. Gear shift pattern for 3-speed auxiliary transmission.



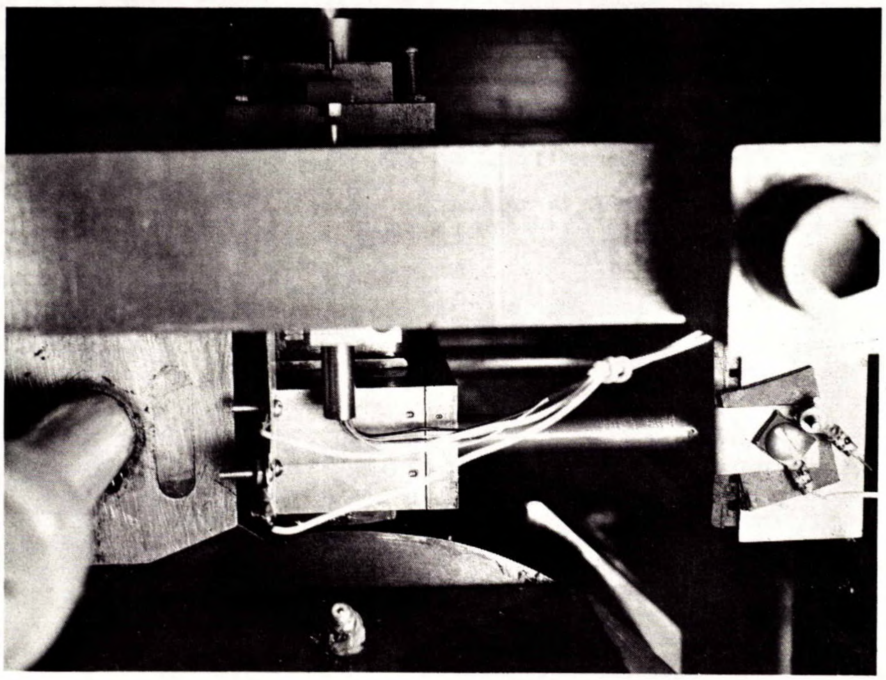
A- LOW PRESSURE IN
B- HIGH PRESSURE IN
C- SURGE TANK
D- SURGE TANK
E- SOLENOID VALVE
F- EXHAUST
G- CYLINDER

H- CAM
I - CAM FOLLOWER
J - TRANSFER BLOCK
K- LOWER DIE
L- SPECIMEN
M- UPPER DIE
N- LOAD CELL
O- PRESS SCREW

Fig. 8. Schematic diagram of cam follower insertion mechanism.



(a)



(b)

Fig. 9. Cam follower in (a) rest position and (b) contact position.

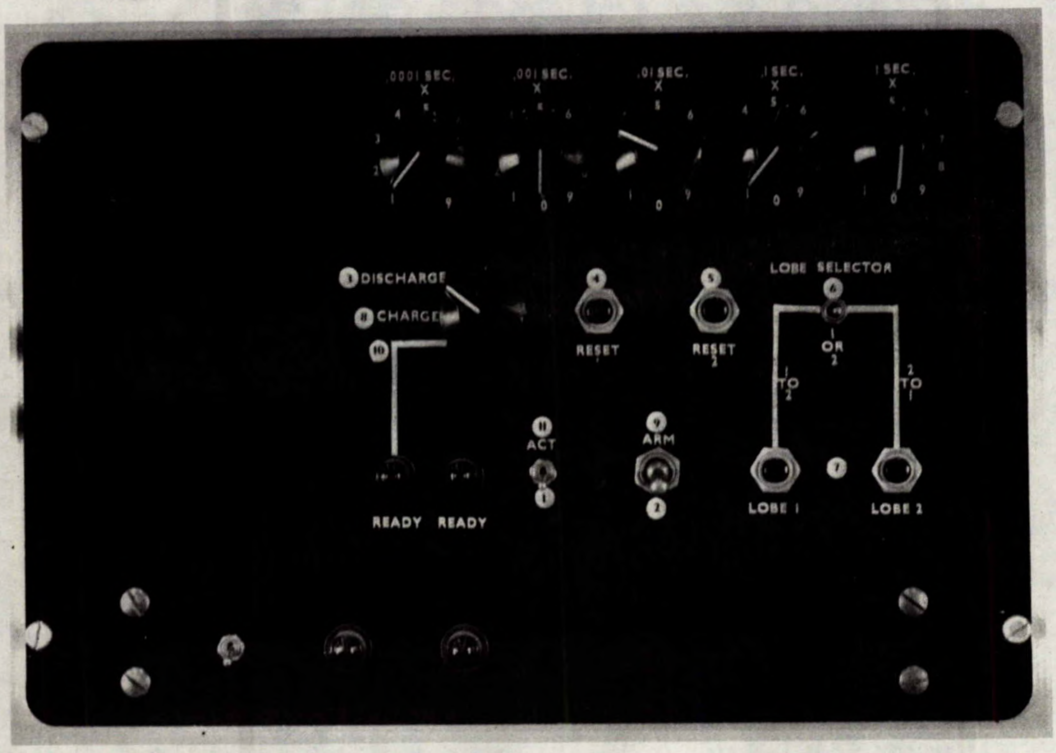


Fig. 10. Electronic control panel for inserting cam follower.

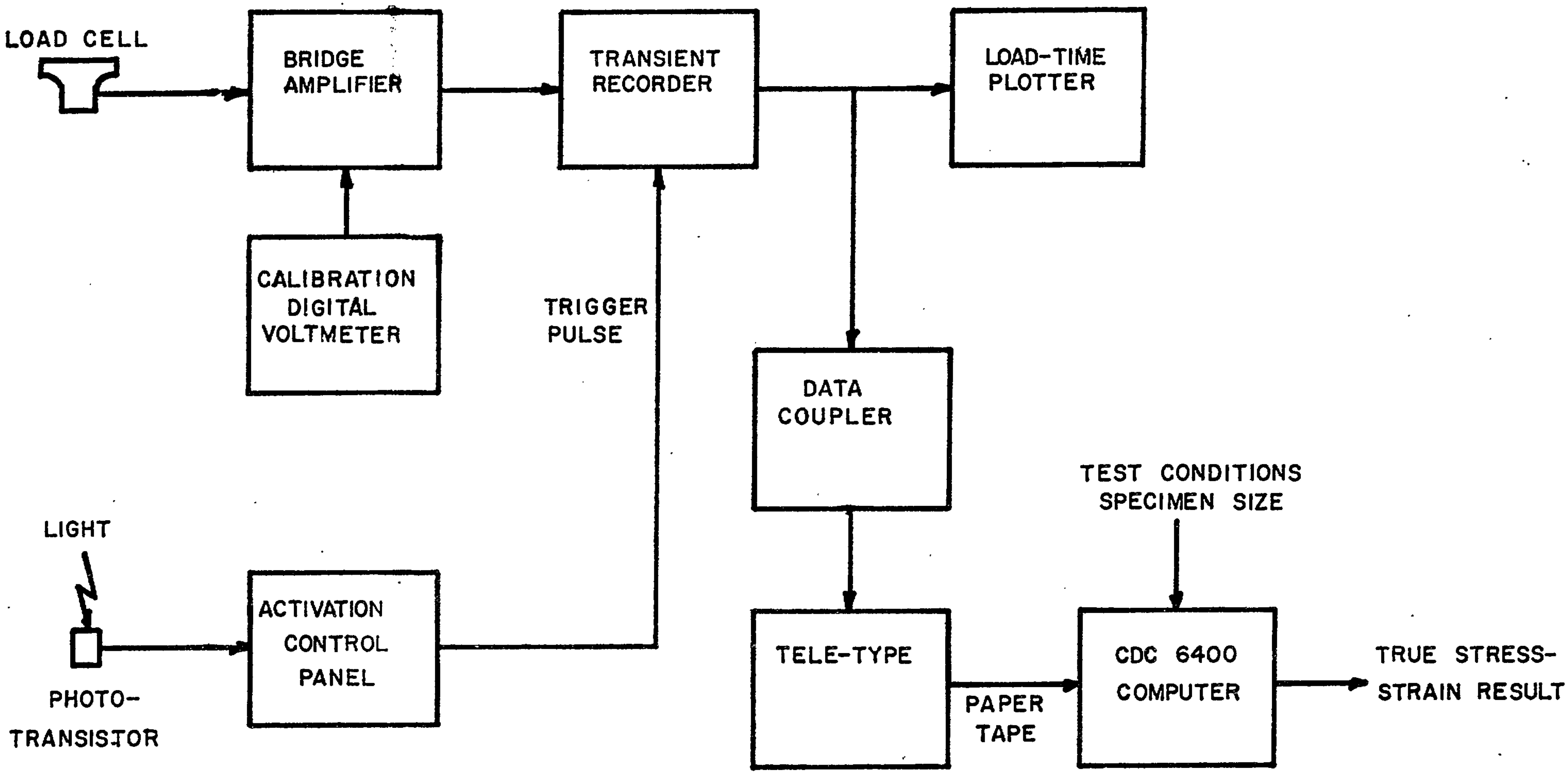


Fig. 11. Load measuring system.

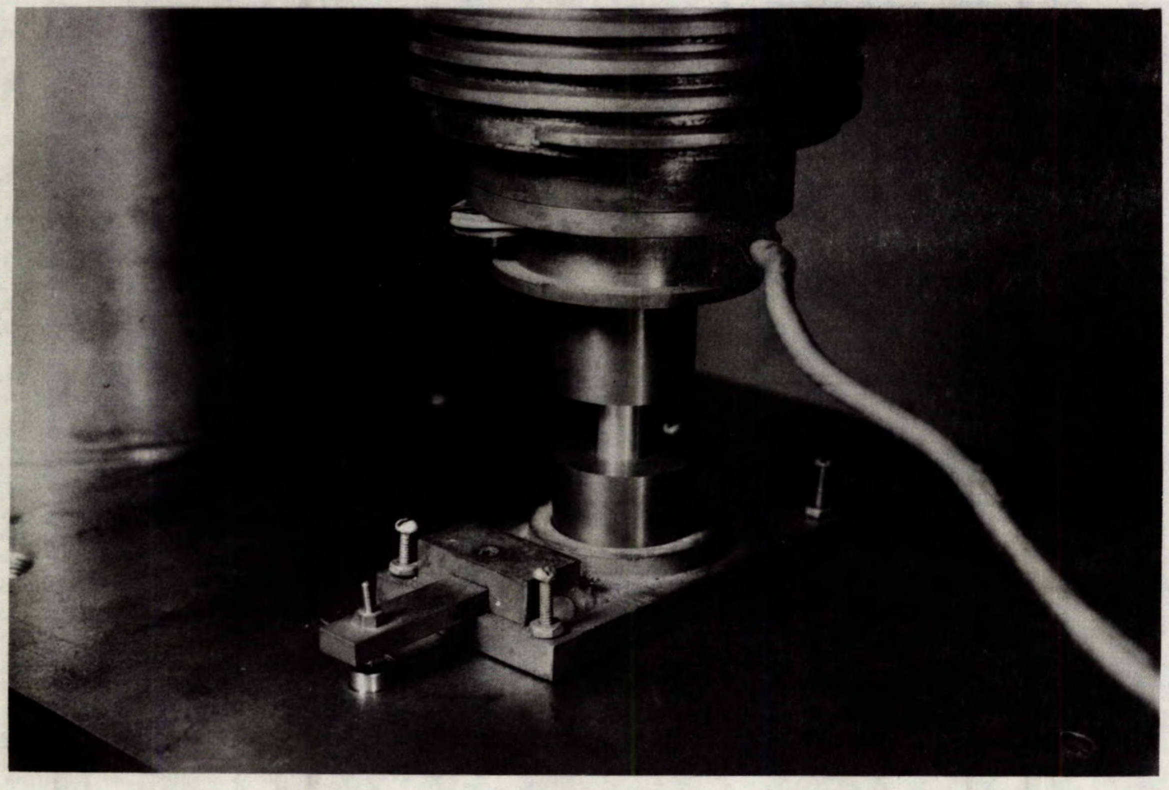


Fig. 12. Close-up view of transfer block, LVDT, specimen, and load cell.

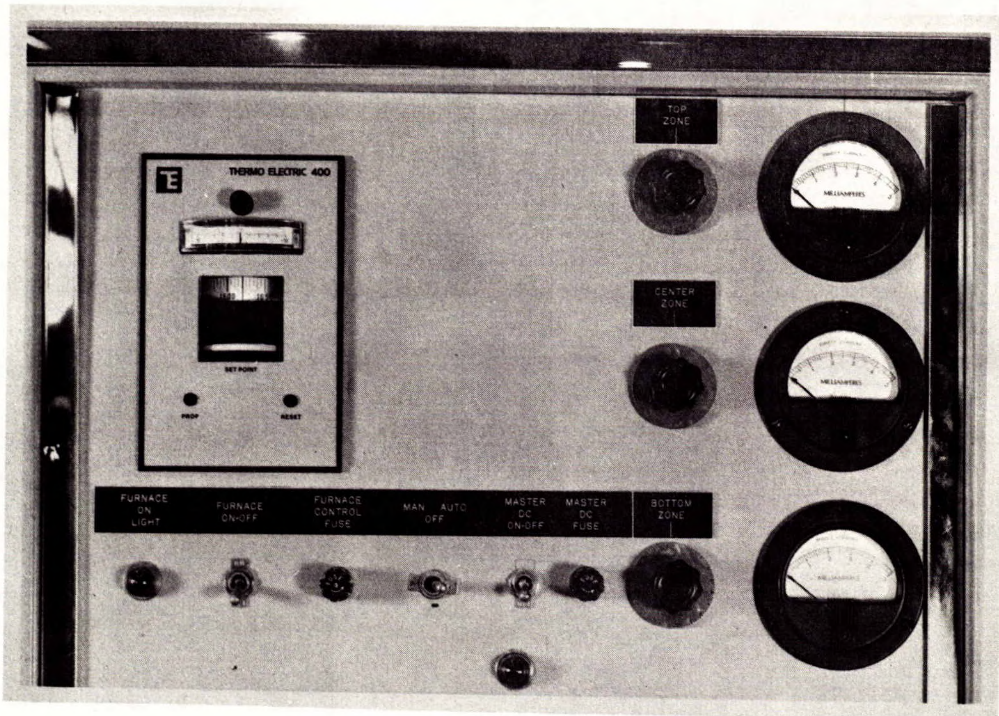


Fig. 13. Control panel, plastometer furnace.

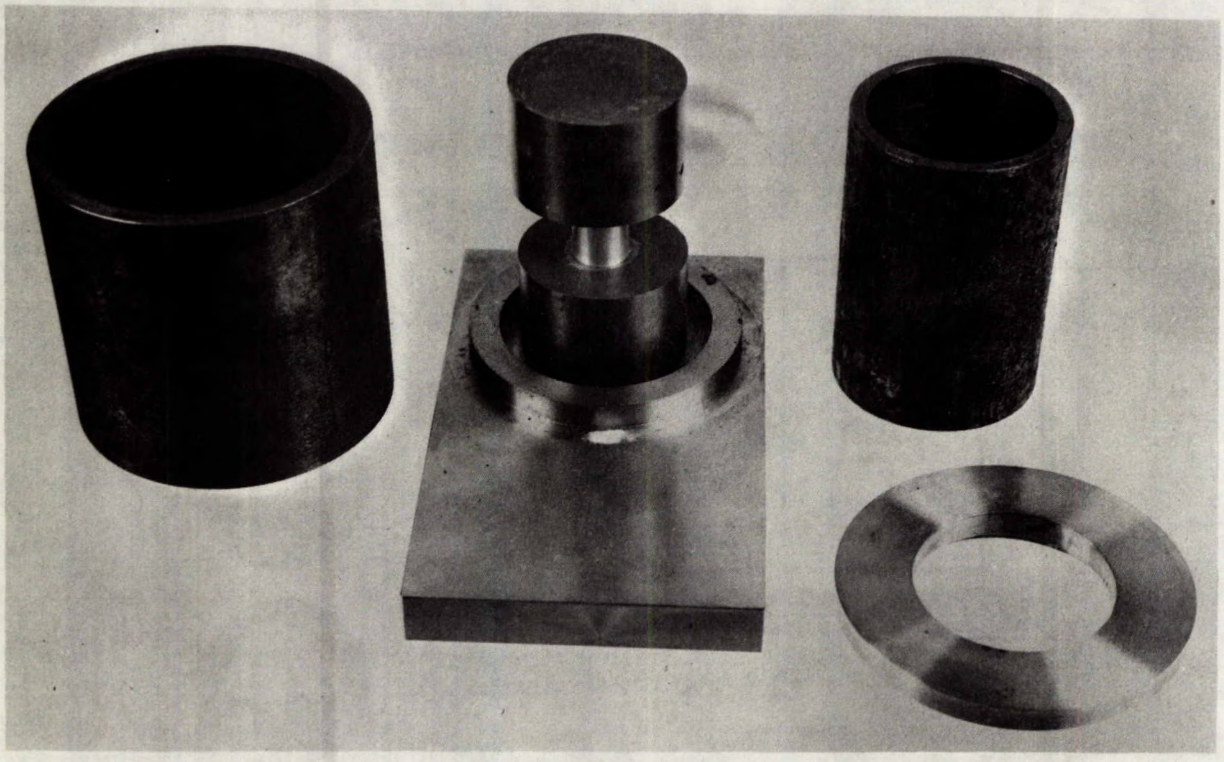
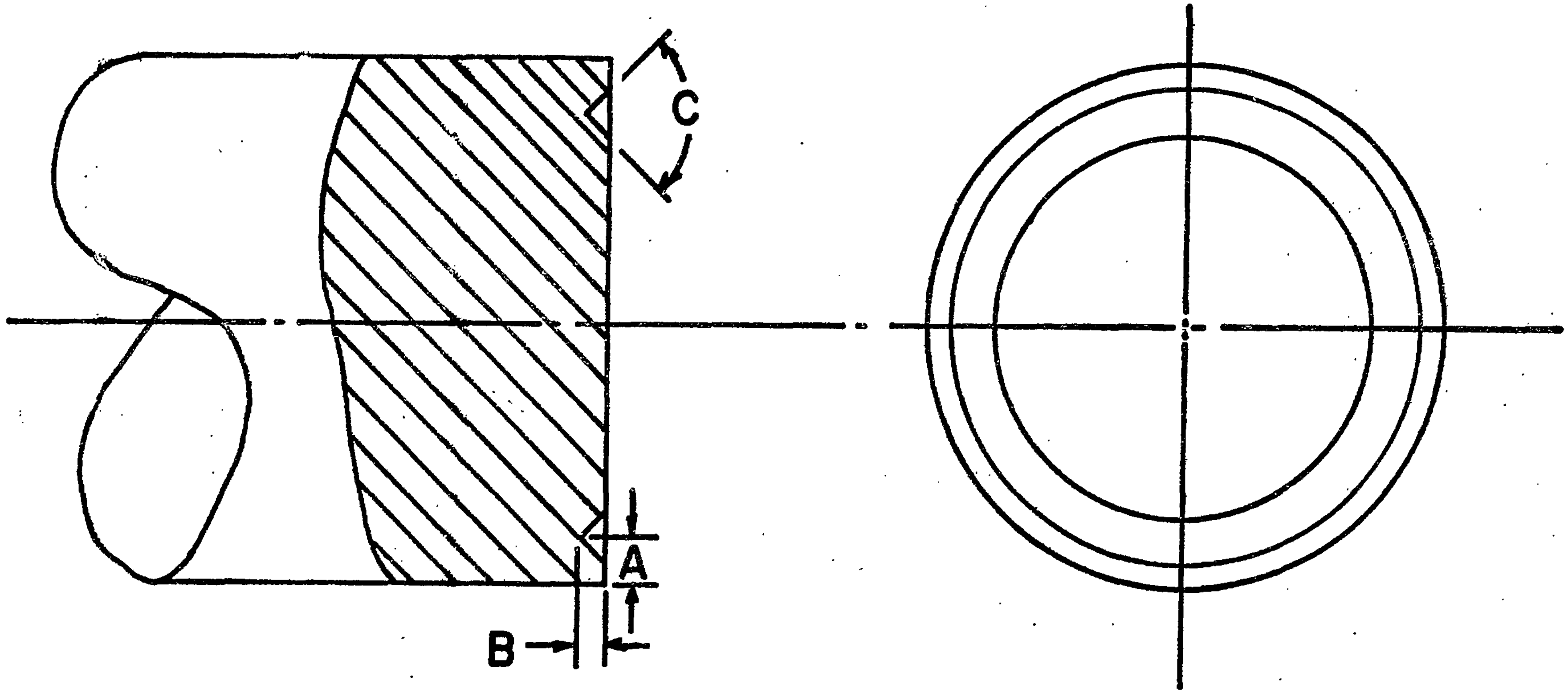


Fig. 14. Portable unit used to transfer heated specimen.



DIMENSION

	A	B	ANGLE C
(a) ALUMINUM	0.38mm (0.015")	0.20mm (0.008")	80°
(b) STEEL	0.51mm (0.020")	0.25mm (0.010")	80°

Fig. 15. Groove specifications for proper lubrication.

CAM PLASTOMETER TEST DATA

TEST NUMBER:__________ DATE:________

SAMPLE: CAM: 45 225 COMPUTER? YES NO

CPCALC CPCALC2

LUBRICATION: GROOVES: 1 2 3 CY=1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

DIES: STEEL CARBIDE INCONEL SIC Si_3N_4 FURNACE: SATEC BLUEM LINDBERG

STRAIN RATE:______SEC^{-1} PH: 1 2 3 4 5 6 7 8 9

TEST SPEED:_______RPM (_______MSEC)

TEST GEAR:______ TEST PRESSURES:_____/______PSI

ACTIVATION DELAY:_______SEC. GAS: Ar H_2 RATE:_______UNITS

BAM: ON VOLTMETER - ZERO = _______, CALIBRATE = __________

OSCILLOSCOPE:

LOAD TRACE CHANNEL NO.____AT_____VOLTS/DIVISION

LVDT TRACE CHANNEL NO.____AT_____VOLTS/DIVISION

SCOPE TRIGGER DELAY:_______UNITS

TRACE SPEED:_____SEC/DIVISION TO______MSEC/DIVISION

TRANSIENT RECORDER:

LOAD TRACE = __________MVOLTS LOAD FACTOR = __________

SWEEP TIME = __________MSEC. J = ________B(J) = __________

DELAY TIME = __________UNITS K = ________B(K) = __________

SAMPLE IN FURNACE AT:______________, TEST AT:___________. B(J) = __________

FURNACE SET POINT: __________°C, SAMPLE TEMPERATURE:________°C

SATEC SETTINGS: TOP_____% MID_____% BOTTOM______%

SAMPLE TEMPERATURE: TOP______, MID________, BOTTOM_______.

TEMPERATURE RISE:________°C

CAM SLOWDOWN:________/_________ = _________%

SAMPLE DIMENSIONS: D_o = __________IN. H_o = __________IN.

D_f = __________, ________IN., H_f = _________IN.

BARRELLING: A B C D E F

CHECK LINES:____________

Fig. 16. Test data sheet.