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100,000 HOURS OPERATION OF THE ECN, PETTEN, SHIELDED CREEP TESTING FACILITY

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Paper to be presented at the Meeting of Groupe de Travail "Laboratoires Chauds et Télémanipulation" at Brasimone, Italy, May 21-23, 1986.

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ABSTRACT

After the realization in 1973 of the shielded creep facility, about four hundred creep tests on irradiated material have been performed. The facility consists of a line with ten creep testing machines, including furnaces and extensometer systems, shielded with 7" lead. At one end of the line an assembly cell equipped with manipulators and tools is built. From this cell the individual creep machines are fed with specimens in loading bars and extensometry with a transport cart.

The creep testing machines are of constant load dead weight type with automatic lever levelling. Test loads up to 30 kN can be applied; test temperatures are in the range of 700 K to 1300 K. Each furnace has three independently controlled zones.

This paper describes the approach for the design and construction of the shielded facility and its supporting systems. Operational experience of the facility itself as well as the auxiliary remote handling equipment for creep testing is reviewed.

Attention is also given to a number of modifications for using the creep machines and data acquisition in a lead shielded facility. After 100,000 hours of operation, the shielded facility for creep testing has been proven successfully.

CONTENTS

1. INTRODUCTION

The design and building of the shielded creep testing facility at the Netherlands Energy Research Foundation (ECN), Petten, was started in 1971. Realization took place in 1973 and was put into operation in the same year.
Most creep tests have been performed within the framework of the Liquid Metal Fast Breeder Reactor Programme (LMFBR), but creep data for other applications have also been generated.

The facility consists of 10 creep testing machines.
Early data collection was done manually by reading dial gauges and typing in the relevant data. With constantly advancing data logging technology, this procedure was improved to the present computer controlled data acquisition system.
This paper describes the approach for the design and construction of the shielded facility and its supporting systems such as temperature control, data acquisition and climate system.
Operational experience of the facility itself as well as the auxiliary remote handling equipment for creep testing is reviewed. Attention is also given to a number of modifications necessary for the creep machines and data acquisition in a lead shielded facility.

2. DESIGN OF THE SHIELDED FACILITY

The shielded creep testing facility is located in the Laboratory for Strongly radioactive Objects (LSO), where most post-irradiation research is performed.

The facility consists of a medium activity cell, of which the shielding is obtained from 7" lead bricks and a roof shield assembled from steel plates. The whole assembly is enclosed by a steel frame work. The inside dimensions are 700 x 140 x 250 cm (length x width x height). The cell is provided with two Central Research Laboratory (CRL) Model G Compact Masterslaves, situated on the front face of the assembly part of the cell. In this part the posting port is also situated. This port is designed to accommodate a specially modified ECN container with a shutter, 160 mm in diameter.

A second access, 400 mm in diameter, is located in the work surface with dimensions of 140 x 140 cm. Through this posting port all low activity materials, like defective furnaces and pullrods, can be removed. This posting port also allows personel access for in-cell maintenance and repair activities in a pressure suit.

On the work surface two lead shielded boxes, including a cover, are available for specimen storage. The specimens are stored in stainless steel tubes embedded in lead. One box can contain 36 cylindrical specimens, whereas the other box is used for tested specimens. The latter can contain 10 broken specimens.

A lead glass viewing window, 400 x 600 x 400 mm, completes this front face.

On the side face eleven tongs, operating through ball-joints, are installed, as well as ten lead glass windows 270 x 180 mm (length x width) in order to assist in loading procedures on the test machines. On the other side the lever of the creep testing machines is protruding the wall. The passage is closed by a gas-tight box.

Figures 1 and 2 give an impression of the facility.

The cell is connected to an air-conditioning system with a capacity of 3500 m^3 air per hour. For safety reasons this system is a duplex system. An air extract system, operating through in-cell filters, maintains a depression of 20 mm water gauge within. The air-conditioning system controls the amount of air-inlet and air temperature and is capable to maintain the in-cell temperature to 20 °C, whereas the temperature limit is set to 25 °C. If the temperature or depression limit exceed their limits, an alarm is triggered and is recognized by a computer system. This system calls a service engineer.

3. TESTING EQUIPMENT AND PERIPHERALS

3.1. General

All creep test machines are manufactured by MAYES and include furnaces and extensometers as well. Before installing in the hot cell some parts of the frame, like furnace suspension and motor drive, have been modified. Over the years modifications of furnace control, loading bars, lever levelling system have been modified as well. Load is applied through the specimen by a loading bar, which is connected to a lever. This lever is penetrating one cell wall, so that it is possible to place the dead weights outside the cell. The lever ratio is 20:1, which corresponds to a maximum load capacity of the machine of 30 kN. This value is calibrated during servicing and maintenance of the cell (which is every three years) with a high accuracy electronic load cell connected to the loading bars. Experiments in the range of 700 K to 1300 K can be conducted and rupture times over 10,000 hours have been obtained.

Strain measurements are made with Hottinger Baldwin Messtechnik (HBM) linear variable differential transformers (LVDT), type W.TK. Each transformer is supplied with an amplifier which signal is read with advanced data acquisition equipment.
The maximum deviation of linearity of the transformers/amplifier combination is 0.1%. Displacement readings have a resolution of 1 micron. A special calibration device has been adopted and described [1] to calibrate the transformers before every test. Considering the stability of the amplifiers and the calibration quality, an accuracy of 2-3 μm can be obtained in displacement measurements.

The furnaces are of the resistance wire, 3-zones type, and controlled by using Eurotherm TCS 6358, 8-loop Programmable Controllers. Temperature fluctuations can be held to within ± 1 K.

Data processing and analyzing is done fully automatically. Signals of all transducers, temperatures and times are scanned periodically by a Hewlett Packard (HP) 3497 Data Acquisition and Control Unit, which is connected to a HP 87 XM Microprocessor. The progress of every test can be observed daily using a Tektronix 4051 Graphics Computing System. All data are stored in a CYBER computer.
A software package has been developed to perform all necessary calculations and analyses. The data processing meets the requirements according to the American Society for Testing and Materials (ASTM) Standard E139.

3.2. Adaptations for remote operation

Operating a shielded facility produces radioactive contamination inside the cell. A number of technical precautions are taken to limit the occurrence of contamination. Paper cloth is used to cover the work surface during mounting and dismounting the loading bar assembly. Periodically contamination tests are executed to determine the radiation level.
After the specimens are taken out of the irradiation capsule they are degreased in Inhibisol. In case of the sodium filled capsule the sodium remnants are removed first. This is followed by a cleaning procedure in a solution of water and soft soap. The contamination level of the fluid is kept as low as possible (< 1 millirem). Then the transport to the testing facility takes place. An in-cell contamination check on the specimens is executed before definite acceptance to the facility. Whenever possible, parts of the testing equipment requiring servicing and maintenance, are placed outside the cell. Since the creep testing machines have a simple structure, the technical requirements are easy to fulfil.
On the creep testing machines some adaptations concerning remote handling conditions are required. The machines were originally provided with an automatic levelling system powered by a motor, housed in a cabinet below the loading bar and controlled by a mercury switch

on the lever. In the test set-up this motor has been placed outside the cell in front of the wall and the worm drive of the loading system has been extended. To enable automatic as well as manual lever levelling a hand-wheel, including a clutch, is connected to the worm drive. The idea of placing the motor outside the cell is to reduce handling problems associated with service activities.
Since the motor has proven to be very reliable over a long period of service this idea is dropped for a newly built facility. The mercury switches, used for the automatic lever levelling system, suffer from aging after a long period of service, which causes unreliable switching. Therefore, they have been replaced by IFM Electronic Ltd., inductive proximity switches, type IGA 2008 ABOW/IG 0009 (Fig. 3) outside the cell. These switches consist of an LC with oscillator which operates an electronic circuit. A high frequency alternating field is set up with an open shell core with coil. This field is termed the active zone. If an electrically conductive material (e.g. metal) is introduced into the active zone, the oscillator circuit loses energy. This leads to the break-down of the oscillation. These two states, oscillator on and off, are passed to the output stage. In this way the motor can be controlled for the automatic levelling system. These switches work contactlessly, switching is done by electronic components. These switches are situated outside the lead shield, thus, checks and maintenance become easier.

Every machine has its own service panel inside the cell, mainly existing of connections for furnace power supply as well as for the control and measuring thermocouples.

The positioning of the furnace is done by using a so-called cradle. Two guide bushes on the two front columns of the testing machine are connected to each other in horizontal and vertical direction with brackets and steelstrips. This results in a half cage construction. At the height of the bushes conical pins are fitted.

The furnace is connected with the lower pins on the cradle, whereas on the upper pins a steel cable is fitted. This steel cable is coupled through a number of sheaves to a pulley, which on its turn is connected to a wind-up and wind-off system. With the manually driven pulley the cradle and furnace can be moved up and down.

A loading and unloading rig is used to bring the loading assembly (pull rods, specimen and extensometer assembly) into the creep testing machine. The loading and unloading rig is connected to a transporter, which will be described in chapter 4. The rig and loading assembly, when in front of a test machine, are pushed forward, by which the upper pull rod is connected to the upper grip. The lower pull rod is positioned in the lower grip and arrested by a slide. Thereafter the rig can be removed and a horizontal position of the lever is achieved by the automatic levelling system.
In Figs 4A and 4B the previous respectively present lower grip assembly is shown.

3.3. Technical adaptations

The standard furnace is of the three zone electrical resistance type with a silica tube, using a master-slave control principle.
In the course of the years all furnaces are renovated.
The main adjustments consist of a quartz tube on which the insulated windings are fixed.
The control thermocouples are fitted as close as possible to the windings and are placed in austenitic stainless steel mini-tubes.
The master-slave control principle has been changed into three independently fed zones. These measures have resulted in a more stable temperature control in a narrower band. At the same time, 10 mm thick stainless steel slide valves are placed on top and bottom of the furnace to prevent the chimney effect. The original ceramic valves regularly fractured, which required a lot of repair time. The thick steel valves might seem rather transparent for furnace heat, but measurements do not show a significant energy consumption increase.

The reasons are probably the more tight fit of the steel valves, which reduces leaks of hot air in the furnace through gaps. In this way the temperature gradient in the middle of the furnace is within the standards and a standard deviation of 0.1-0.2 K at 700-1000 K is achieved.

Three calibrated K-type measurement thermocouples, supplied by Rössel Messtechnik, are used per specimen and renewed after every test lasting more than 2000 hours. One thermocouple is located in the centre of the specimen, the others are located near the top and bottom of the gauge length respectively.

4. SPECIAL FEATURES

The most complex in-cell operation is mounting of the specimen in the machine.

For this purpose a special device is developed, which comprises:

- an assembly template,
- a loading and unloading rig,
- a transport system.

To mount a specimen, the pull rods and the extensometer are placed in the assembly template. The specimen is connected to the pull rods by means of swivels. Then the extensometer is put on the specimen, including the thermocouples.

Finally the calibrated LVDT's are adjusted to the extensometer.

This whole assembly is put into the loading and unloading rig which in its turn is connected to the transport system. The system is basically a carriage, driven by a chain transmission along a horizontal rail, parallel to the side face of the cell.

The rig can be moved perpendicular to the cell wall. This movement is necessary to load and unload the specimen assembly into and out of the creep testing machines.

The transport system can also be employed for remote replacement of defected furnaces.

In a recently realized new creep testing facility the lifting of the template is performed by a hydraulic/pneumatic lifting and rotation device. The template is connected to this device which enables the template to be lifted 90 °C until a vertical position is reached and to rotate in the horizontal plane over 90 °C.

Figure 5 shows the creep loading assembly including the extensometer system, whereas in Fig. 6 the loading assembly, including the assembly template is placed in the transport system.

5. MAINTENANCE AND SERVICING

After every three years of operation a maintenance and servicing period is carried out for the creep testing facility. The main objective is to decontaminate and to overhaul in-cell equipment.
At the same time components can be replaced and repaired, whereas newly developed techniques can also be built in. In this period all in-cell active materials are taken out and the facility is decontaminated. The maximal average contamination level found over the years is 1500 pCi dm^{-2}, whereas the average contamination level on the work surface is 5000 pCi dm^{-2}.
In principle all mechanical equipment is overhauled and all rotating parts are lubricated.
It is observed that all vinyl cables of the extensometer systems and thermocouples suffer from aging and should therefore be renewed.
Further the lever ratio of the creep testing machines is calibrated.

6. DATA ACQUISITION

When the creep testing facility came into operation, creep extensions were measured with dial gauges and typed on punch cards for the analysis by computer. For an accurate analysis, a larger number of data per short test (t_r < 500 h) had to be generated 24 hours a day, 7 days a week.

Therefore automatic data processing and handling are useful. The change from analogue to digital processing was done step by step.

The first change was the introduction of HBM inductive displacement transformers for strain measurements, combined with an HBM measuring and scanning unit. Data was then stored on paper punch tape and printed out by an ASR 301 Teleprinter.

Daily progress and further analysis is done by a Tektronix 4051 Graphics Computer System using a FACIT punch tape reader.

Finally the CYBER Computer is used to perform the complete creep analysis per experiment and the complex multi experiment analysis.

Advancing technology gives the possibility to supersede the HBM measuring and scanning unit by a HP 3497 A Data Acquisition and Control Unit combined with a HP 87 XM Microprocessor.

All relevant data from the extension measurements, test temperature, time and extensometer calibration are scanned at predetermined intervals and stored on $5\frac{1}{4}$" floppy discs.

The final step is to communicate the results with the HP system directly to the CYBER.

A schematic diagram of the data acquisition system is given in Figs 7 and 8.

It is evident that a number of programmes has been developed for the data processing and handling. The course of elongation (ε) and test temperature (T) as a function of test duration (t) is plotted. Standard deviations (s) of test temperature are calculated and if necessary corrections can be made. The actual situation per test can also be visualized and control actions can then be taken. After this the daily obtained data are stored. After a test has been completed all data of the test are analysed and the graphs of the concerning test can be plotted.

The main analysis is done by the CYBER Computer.

All available data of stress (σ) and time to failure (t_r) are also stored. Comparisons between different heats and test conditions can thus be obtained by which predictions of stress and time to failure for future tests can also be made.

Example of the different output is given in Table 1 and Figs 9 to 11.

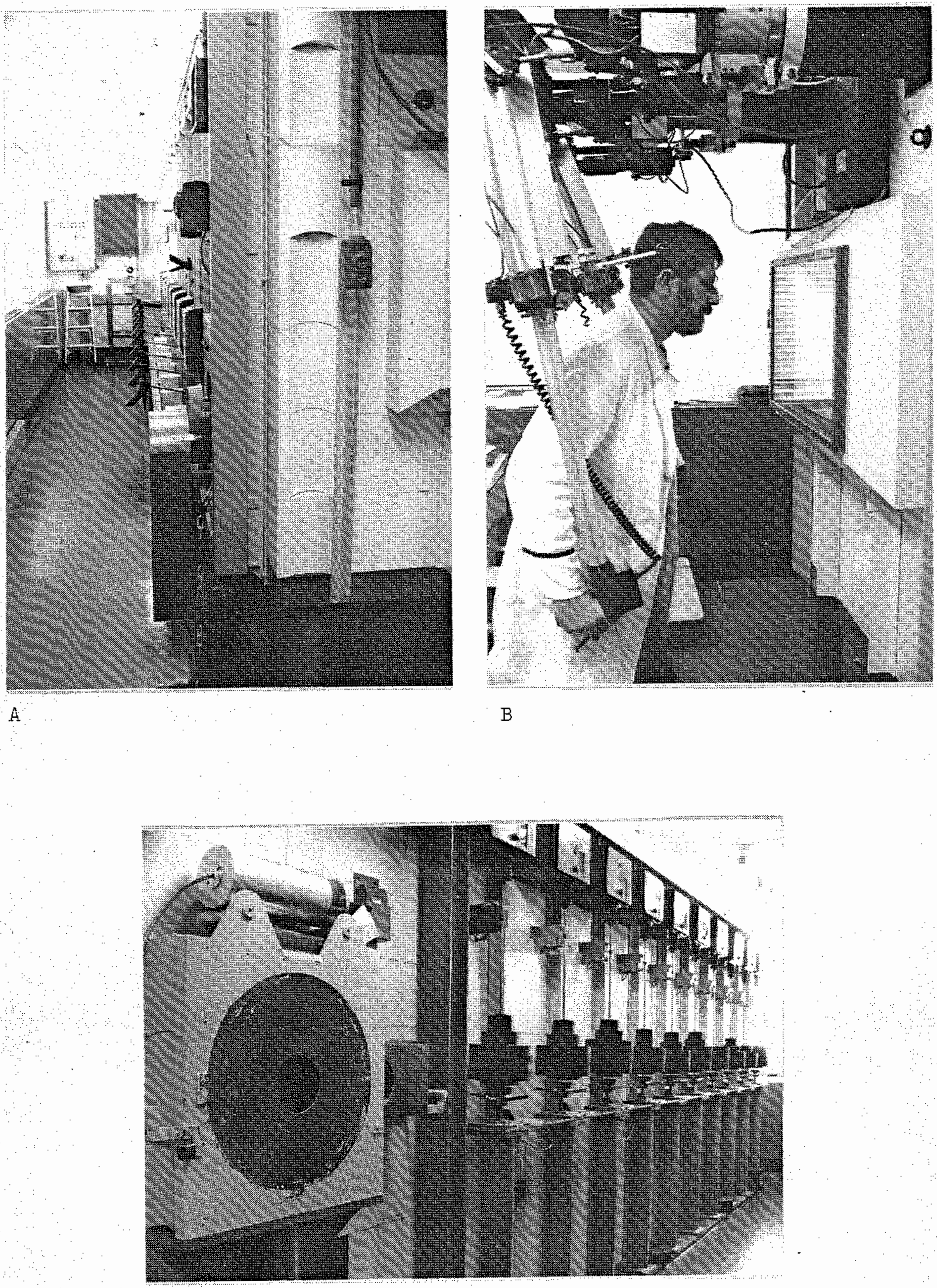
7. CONCLUSIONS

This paper covers a period of $12\frac{1}{2}$ years or 100,000 hours of operation of 10 machines, thus over 1 million hours of creep machine operation. The facility has been used succesfully for creep tests on radioactive materials at test loads up to 20 kN and test temperatures in the range of 700 K to 1100 K. The specially developed experimental techniques for remote control have proved to be reliable. However, during the course of operation a number of adjustments have been realized to improve quality, efficiency and reduce contamination. During periodical servicing and maintenance activities on the facility, it became clear that working under present conditions prevents malfunctioning.

Servicing and maintenance activities were limited after every three years of operation depending on the number of repairs of in-cell equipment and improvement of equipment.

8. REFERENCES

[1] Tjoa, G.L., Boef, R. den,
A Remote Controlled Calibration Device for Displacement Transducers. ECN-173, November 1985. The Netherlands Energy Research Foundation, ECN, Petten, The Netherlands.



A

B

C

Fig. 1. Impression of the shielded creep testing facility, showing the side faces of the hot cell (A and C) and front face (B).

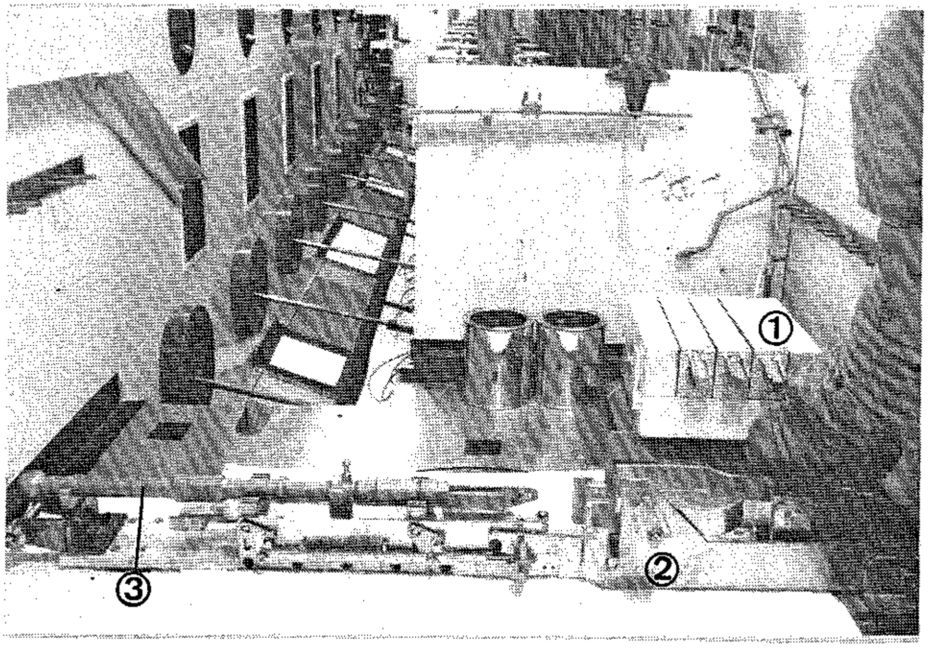


Fig. 2. Interior of the cell showing the work surface on which the specimen storage boxes (1), the assembly template (2) and the lower pull rod (3) are placed.

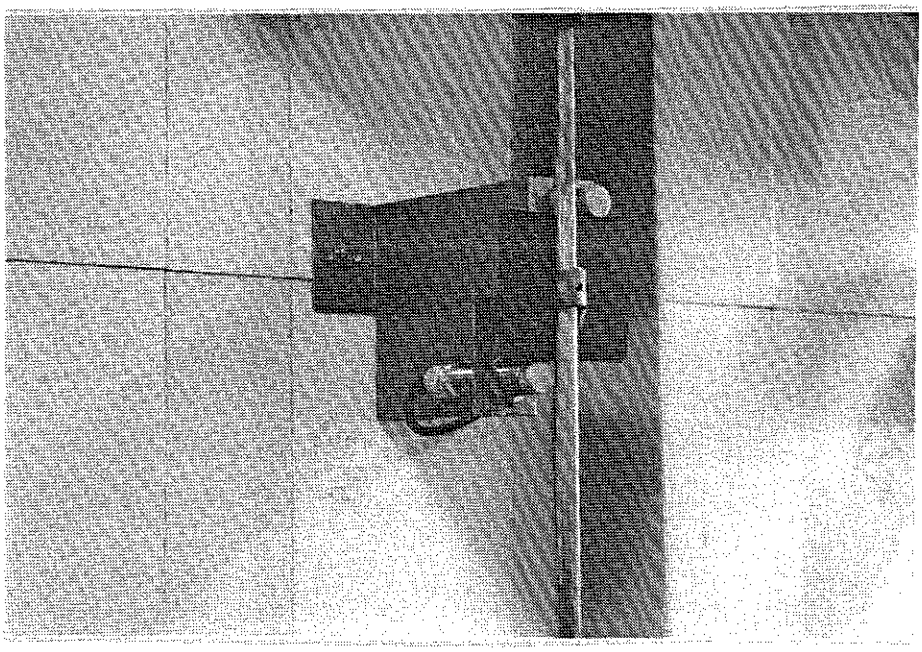
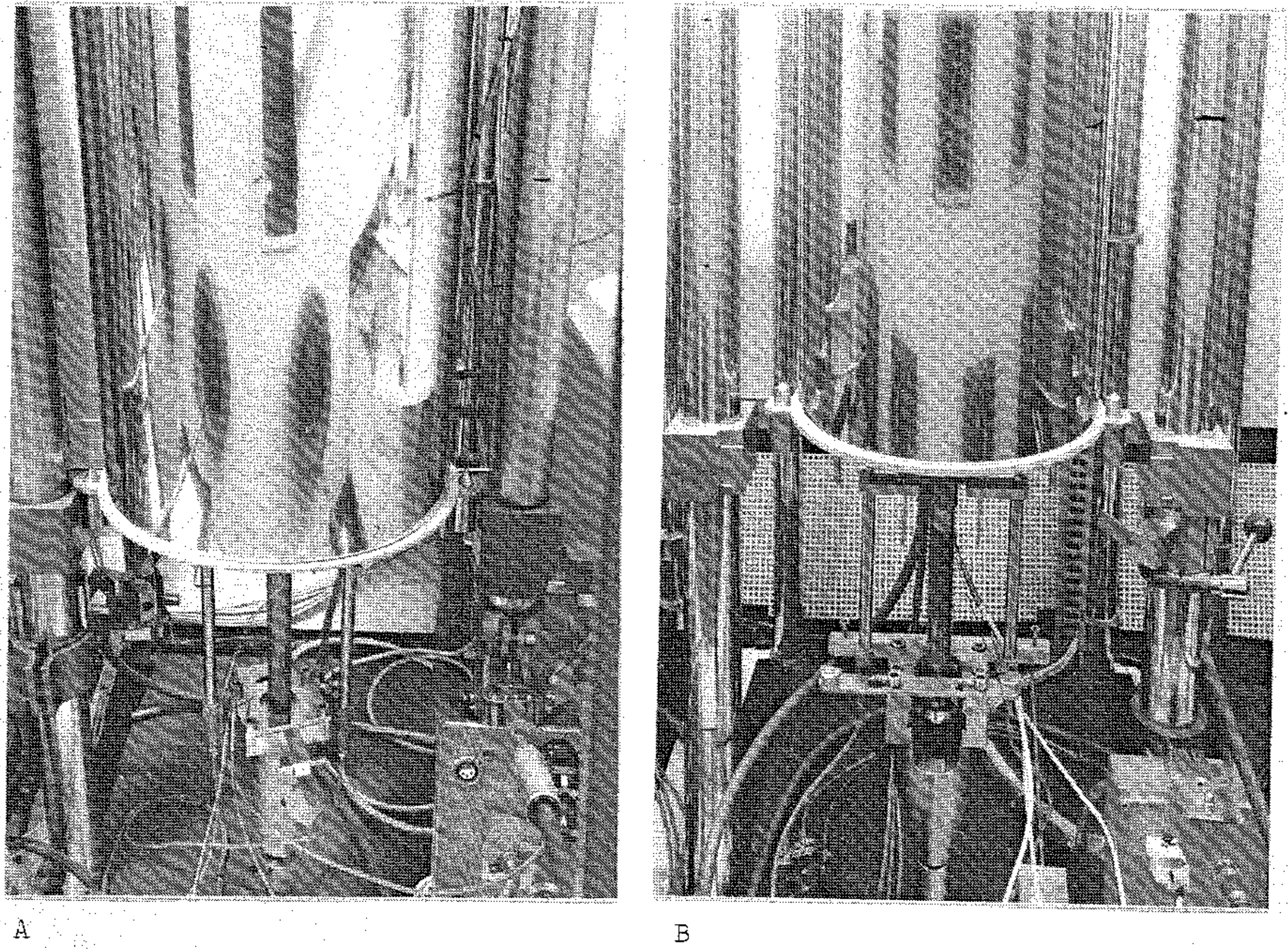


Fig. 3. Close-up of the proximity switch


A

B

Fig. 4. The previous (A) and present lower grip assembly.

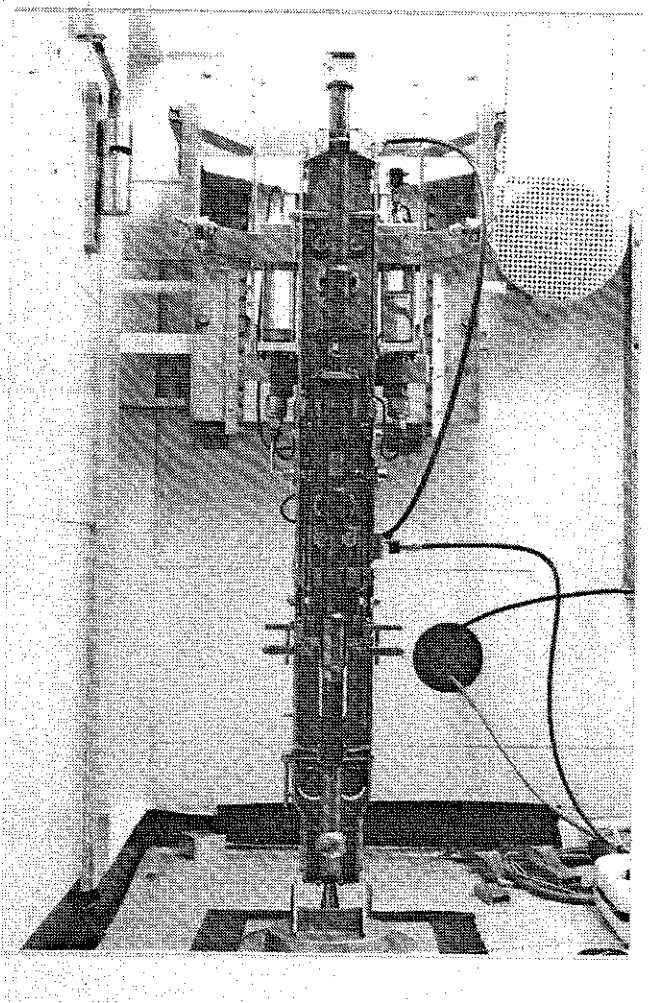


Fig. 6. The transport system including assembly template and loading assembly.

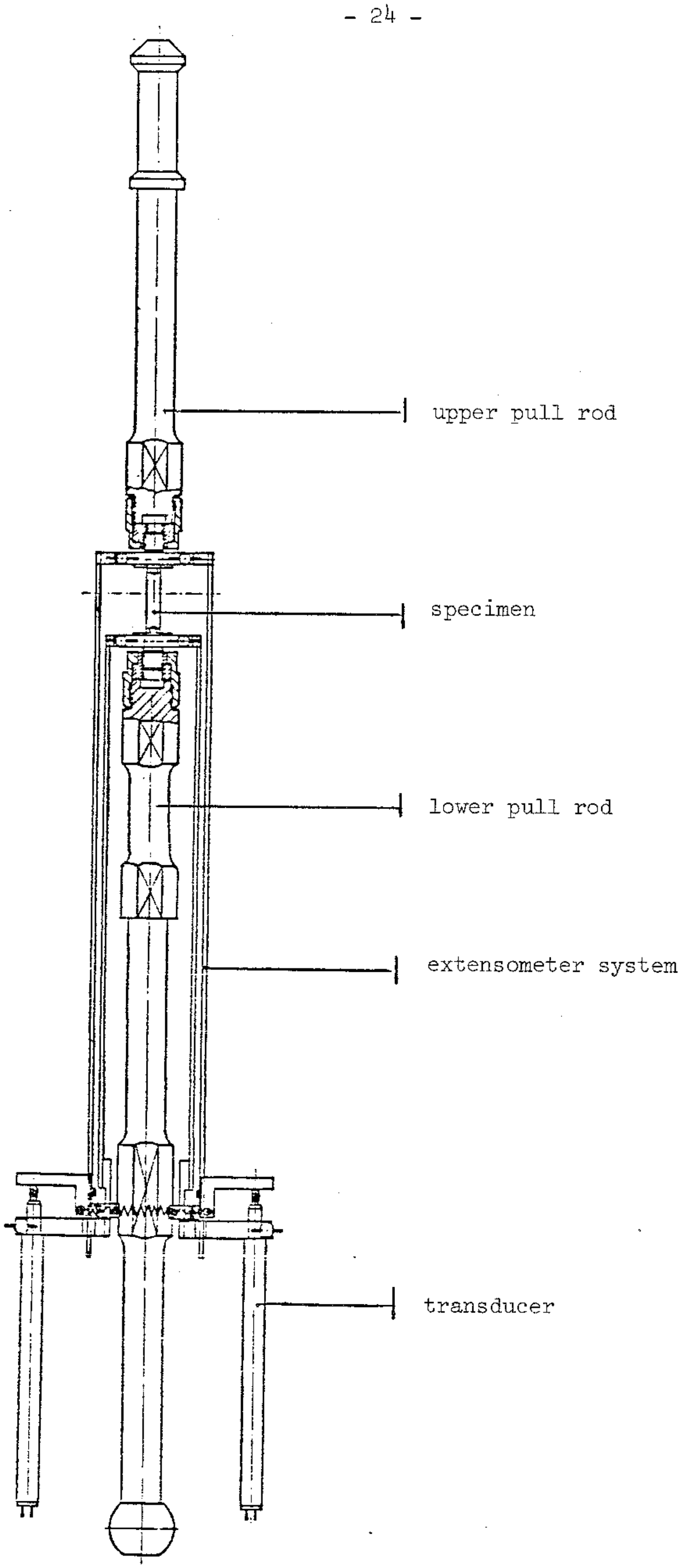


Fig. 5. The loading assembly including extensometer system.

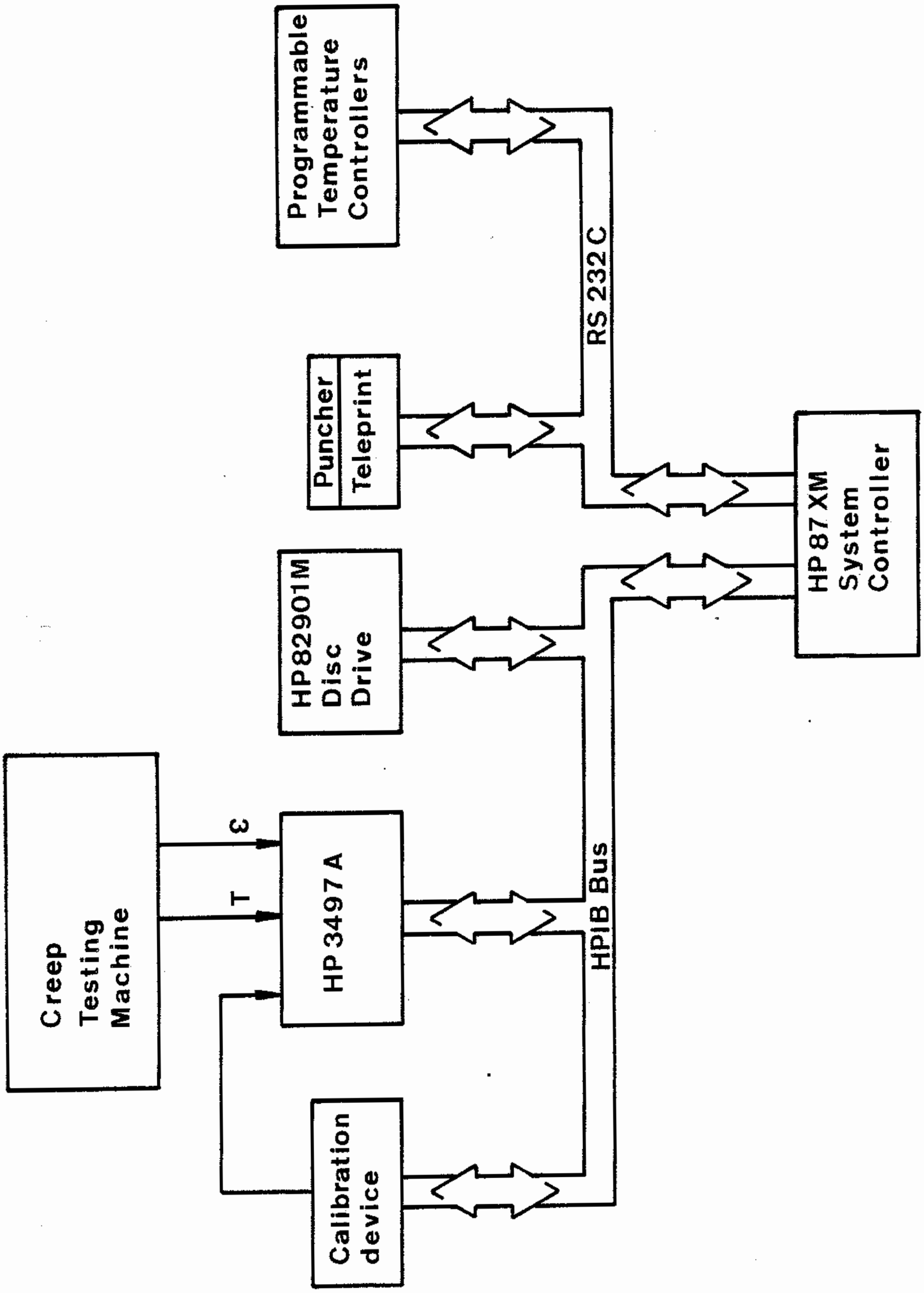


Fig. 7. Schematic diagram of the data acquisition system.

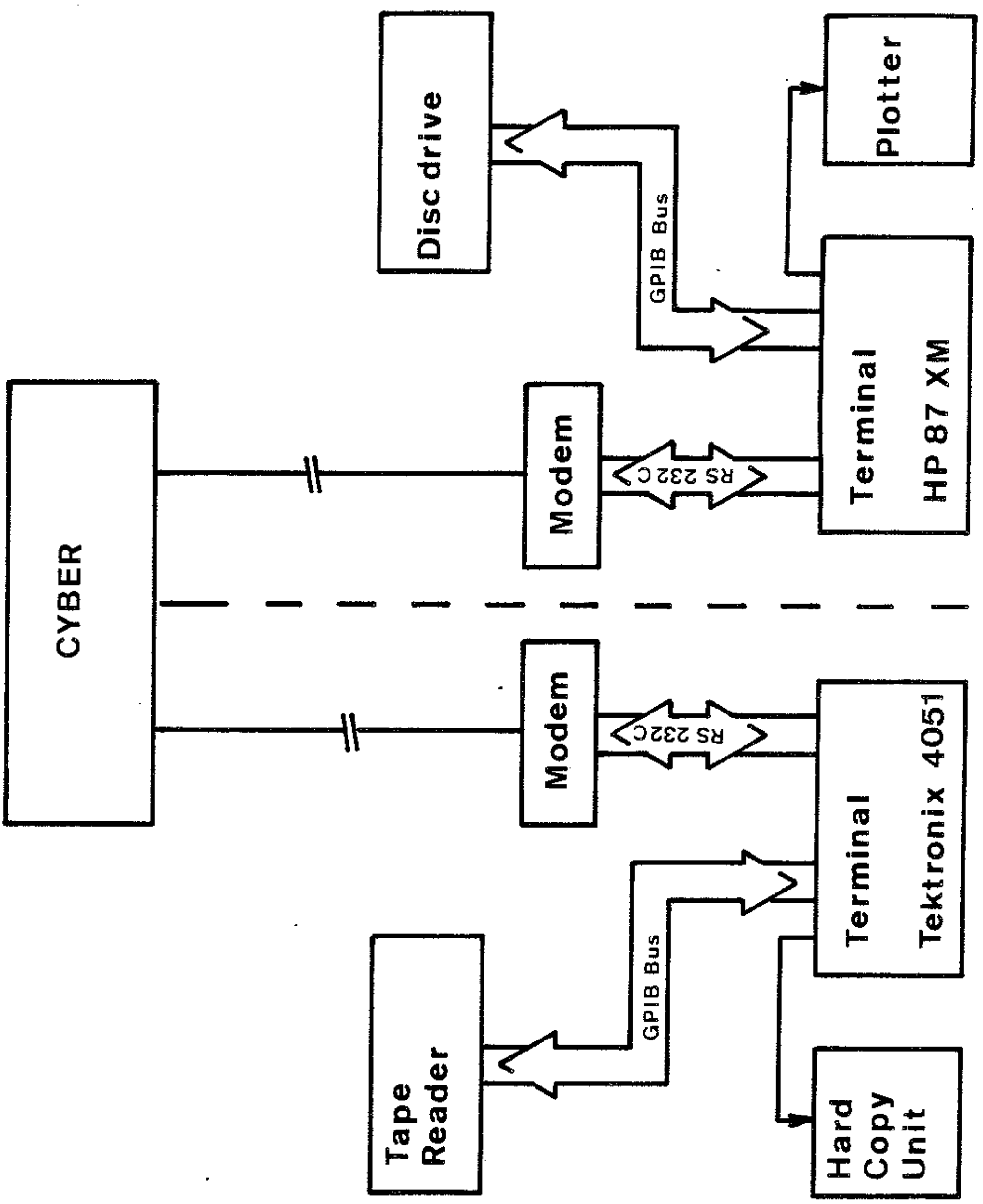


Fig. 8. Schematic diagram of the data analysis system to obtain the daily results.

MACHINE NUMBER	AVERAGE TEMP. IN ^{o}C			STAND. DEV. OF TEMP.			NUMBER OF MEASURING POINTS		
	BOTTOM	MIDDLE	TOP	BOTTOM	MIDDLE	TOP			
301	599.9	600.0	600.2	0.1	0.1	0.1	46	46	46
302	500.3	500.0	500.2	0.1	0.2	0.1	46	46	46
303	601.2	600.8	600.9	0.2	0.1	0.1	46	46	46
304	550.0	550.4	549.8	0.1	0.1	0.1	46	46	46
305	600.8	600.4	600.7	0.1	0.1	0.1	46	46	46
306	500.2	499.8	500.8	0.1	0.1	0.1	46	46	46
307	550.2	550.4	549.6	0.1	0.1	0.1	46	46	46
308	550.1	549.6	550.3	0.1	0.1	0.1	46	46	46
309	600.9	600.3	600.3	0.1	0.2	0.1	46	46	46
310	550.6	549.9	550.7	0.1	0.0	0.1	46	46	46
311	550.4	550.3	550.2	0.2	0.2	0.2	46	46	46
312	550.8	550.7	550.8	0.2	0.2	0.1	46	46	46
313	550.7	550.4	550.7	0.2	0.1	0.2	46	46	46
314	19.2	20.8	21.3	0.2	0.1	0.1	46	46	46

Table 1. Temperature history of all machines determined from 30-03-1986, 10.00 hours to 01-04-1986, 07.00 hours.

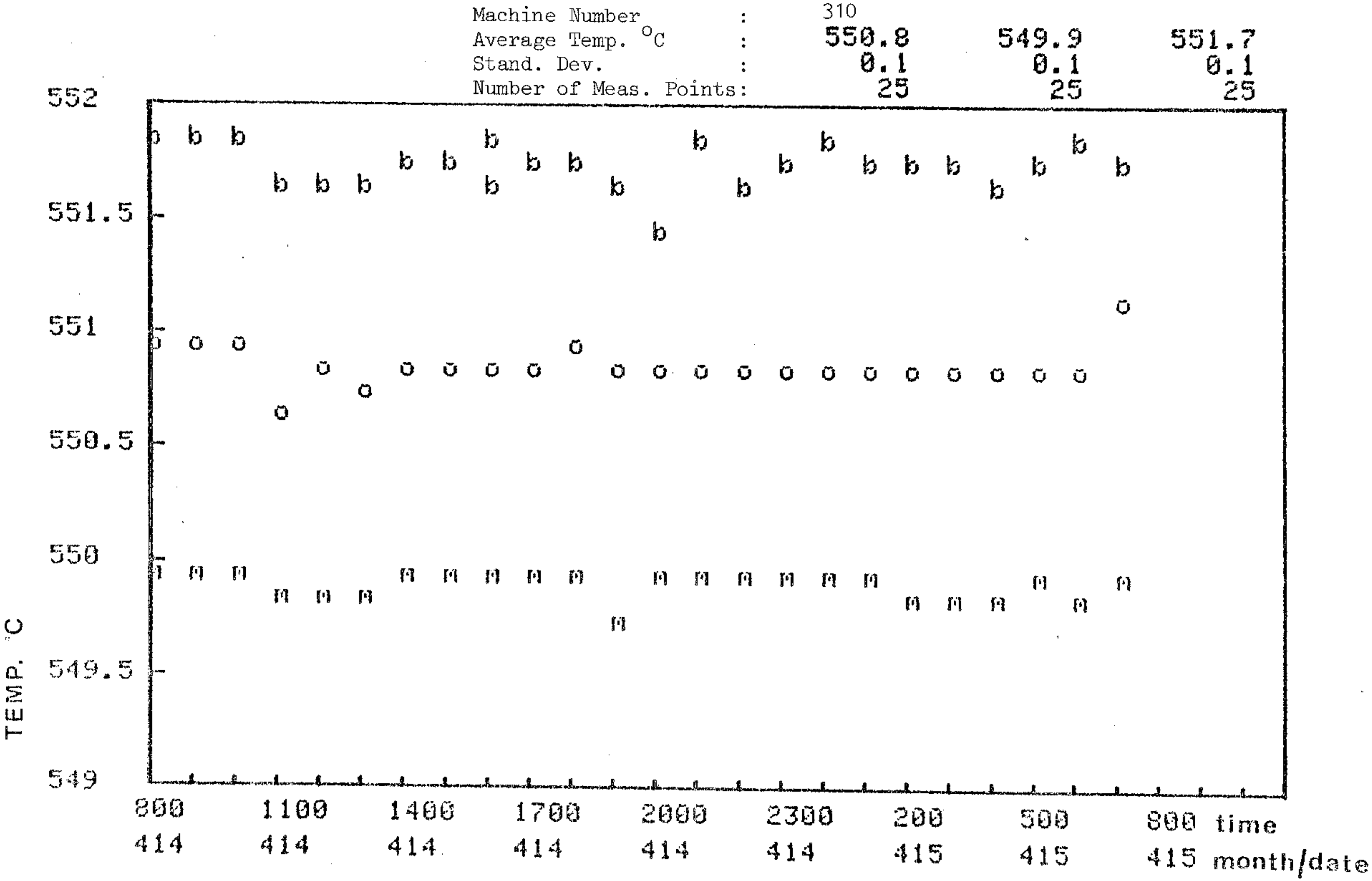


Fig. 9. Temperature history over 24 hours.

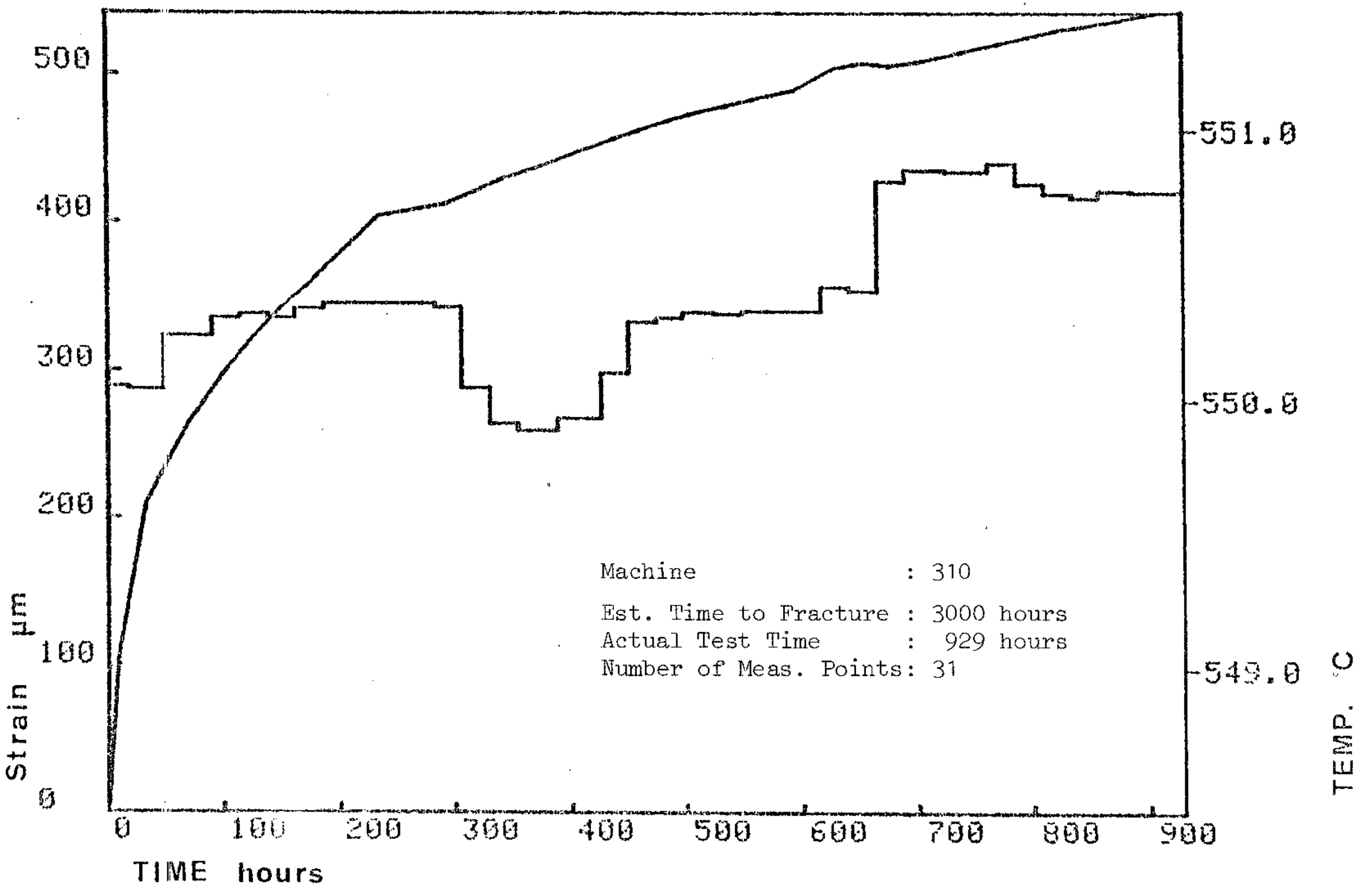


Fig. 10. Preliminary creep strain and creep temperature plot.

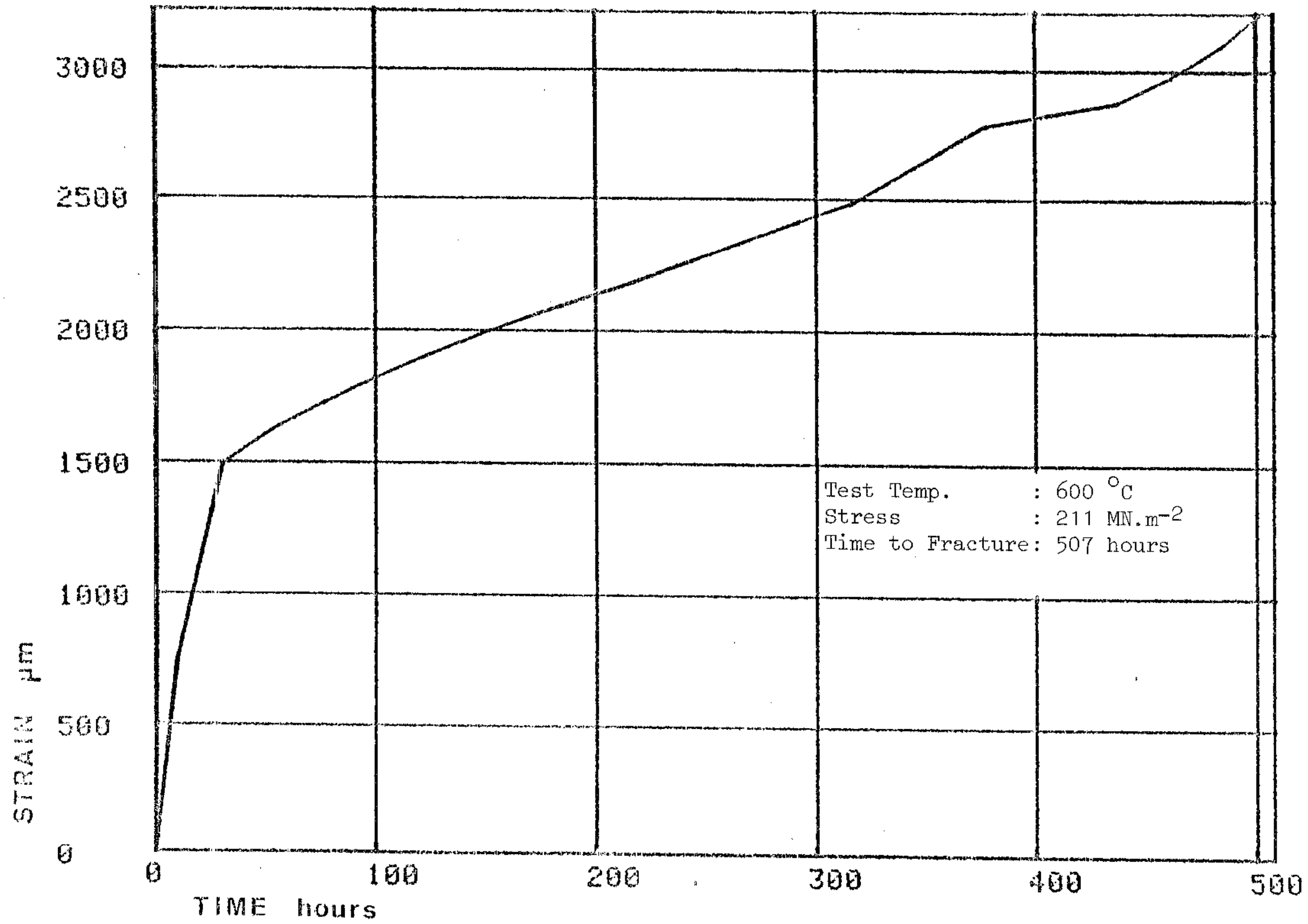


Fig. 11. Creep time versus creep strain plot after fracture.