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DESCRIPTION OF PATERSON HIGH-PRESSURE HIGH-TEMPERATURE (HPT) TESTING SYSTEM

The system provides basically an environment of confining pressure to 500 MPa and temperature to 1600 K in argon gas for experimental purposes. This facility can, in itself, be used for hot isostatic pressing (HIP), materials synthesis or other applications requiring a high-pressure, high-temperature environment, such as experimental petrology. However, its main application is to provide an environment for mechanical testing and associated studies at high P–T. For this purpose, testing modules can be added for the following functions:

— mechanical testing in compression and extension
— mechanical testing in torsion
— experiments involving pore fluids
— measurement of physical properties

BASIC HIGH-PRESSURE HIGH-TEMPERATURE SYSTEM

Housing

The steel housing serves both as the framework for the complete machine and as its protective shielding. The high-pressure parts are entirely enclosed in a "box" consisting of steel walls attached to a strong welded frame of angle sections. The steel walls are of multiple construction, consisting of three plates of 12, 3 and 3 mm thickness, respectively, positioned so that there are small gaps between them. The function of this multiple arrangement is to attenuate any possible blast waves from a pressure vessel failure to a level that is conservatively safe for ears. Access to the working space is provided by two sliding doors at the back and one sliding door at the top. Access to the top door is provided by a platform attached to the side of the machine, with appropriate stairs. The doors are provided with door locks that prevent the opening of the doors when the pressure is raised above a certain level, usually set at 30 MPa. The locks remain effective even if there is loss of mains power.

The basic electrical wiring required for the operation of the pressure and temperature facilities is incorporated in the housing, as well as provision for the power requirements of the mechanical testing and pore fluid modules. The mains supply of 220-240V AC is introduced through a switch located under the operator's desk at the front of the machine. However, the electrical instrumentation is, in general, powered by a 24 V AC common supply, eliminating the requirement for 240 V lines within the operational spaces. The basic electrical circuitry, with auxiliary transformers, fuses and bus-bars, are located in a compartment in the front of the main housing, shielded from the high-pressure space, and closed by two doors at the front. The right-hand door functions as the control panel for the pressure system and the left hand door functions as the control panel for the temperature system.

Pressure vessel and pumping system

The main pressure vessel is of duplex construction and is arranged with axis vertical. The hardened steel inner cylinder, of 230 mm external diameter and 65 mm internal diameter, provides a high pressure working space of 360 mm length. The outer soft steel cylinder of 270 mm outside diameter is shrunk on to the inner cylinder and serves as a safety sleeve; it also incorporates cooling coils for removal of the furnace heat. The volume of gas at high pressure is minimized in the interests of safety. With a solid-ceramic-insulated furnace and internal load cell fitted, the free gas volume in the pressure vessel is about 200 ml. The cylinder is tested to over 700 MPa and is intended for routine usage to a maximum of 500 MPa.

Two-stage pumping is provided by a Haskel gas booster pump followed by a 10:1 oil-driven intensifier. Control facilities mentioned below enable the pressure to be controlled manually, or maintained automatically, or programmed from an external computer, as required. The high pressure plumbing consists of Nova-Swiss valves and tubing. There is a pneumatically-controlled bleed valve in the intensifier oil line for automatic pressure reduction when required. Rupture disks are fitted to prevent accidental over-pressuring of the different stages of the pumping system, and door interlocks prevent pumping to high pressure when the safety doors are open. A bubbler system is provided for quick location of any leaks from the O-ring seals in the high-pressure system.

Furnace

High temperatures are produced with an internal furnace. The use of an internal furnace permits relatively rapid heating and cooling while maintaining the pressure vessel walls close to ambient temperature. The furnace is attached to the top closure plug of the pressure vessel. This plug is fitted with electric feed-throughs for the furnace windings and thermocouples. The specimen assembly can be inserted or removed without disturbing the furnace. The temperature distribution is monitored with an externally-controlled traversing thermocouple in a special calibrating assembly.

The furnace is of special design for minimizing convective losses associated with operation in the relatively high-density gas medium. It is furnished with three molybdenum windings which permit temperatures of up to 1600 K (1300°C) to be used. The power to each winding is provided by a separate thyristor unit, powered from a common 55 V secondary winding on the furnace power transformer. Current limiters in the thyristors are set to about 16 A. By carefully adjusting the relative power to the three windings, a uniform temperature can be established over approximately 50 mm length to within ±1 or 2 K. The internal diameter of the furnace is usually 21 mm but a larger-bore furnace can be provided if required, with some compromise in maximum temperature.

Thermocouples are provided adjacent to each winding and it is usual to incorporate a further thermocouple in the specimen assembly for accurate indication of the specimen temperature. Any one of the various thermocouples can be selected at will for feed-back to the control system which is described below.

Pressure control system

The control panel for the pressure system has the following features:

— On/off switch for the power to all the control panels (with the exception of the main pressure gauge, which is always powered up when the main power switch is on)

— Control switches for the gas booster used in priming the gas system to about 100 MPa, for the intensifier used to pump to the final working pressure, and for the bleed valve used to prevent the pressure exceeding a set value (for example, if the temperature is raised after reaching the desired pressure level). These switches can be set for manual control, for automatic control through the setpoints in the pressure gauge, or for control by an external control system.
— Digital pressure gauge indicating the pressure in the gas confining medium. When the pumps are set to AUTO control, this instrument provides the setpoints for the pressure target during pumping up and the bleed target for bleeding back. There is provision for retransmission of the pressure signal for external recording or control purposes.
— Analogue pressure gauge indicating the pressure in the oil of the intensifier (this is displayed in bars and, since the intensifier ratio is 10:1, the display also indicates approximately the gas pressure in MPa)
— Oil level indicator, which serves to indicate the position in the intensifier stroke
— Bubblers for indicating the location of leaks at O-ring seals

The mV/V calibration provided by the transducer manufacturer (Broser, Germany) is used for the pressure gauge calibration.

Temperature control system

The control panel for the temperature system has the following features:

— A Eurotherm 903 self-tuning and programming controller which permits control using feedback from a furnace or specimen thermocouple, as chosen from a selector switch adjacent to the controller. There is a separate temperature indicator from which all thermocouples can be monitored, as chosen by a separate selector switch. The readings of all thermocouples can therefore be scanned without interfering with the control thermocouple.
— An ammeter and a voltmeter for each of the three windings. These meters are of moving iron type which give rms readings and from which the power consumption can therefore be directly calculated. A push-button adjacent to one of the voltmeters also enables the output voltage of the furnace power transformer to be checked.
— On/off switches for the furnace power. The power can only be switched on when there is a small gas pressure present and the cooling water is flowing, there being a flow switch in the water line. Loss of gas pressure or of cooling water flow will therefore cause the furnace power to be interrupted.
— The output or control signal (0-10 V) from the Eurotherm controller is connected in parallel to the three thyristors through three rheostats adjacent to the respective voltmeters and ammeters. These rheostats serve to attenuate the output signal to the particular windings and so permit the adjustment of the power to the windings for optimum temperature distribution in the furnace.

AXIAL DEFORMATION MODULE

General arrangement

The axial deformation module permits mechanical tests to be carried out in both compression and extension under rate, force or displacement control. The bottom closure plug of the pressure vessel is furnished with a pressure-compensated piston for applying axial load to the specimen assembly. The pressure compensation is achieved by arranging for the confining pressure to be applied to an annular ring on the piston, of the same cross-sectional area as the main piston, in the direction to oppose the force of the confining pressure on the piston itself. The main piston is of 30 mm diameter.

Below the pressure vessel, a stirrup is attached to the pressure-compensated loading piston so that access is available to the bore of this piston for introduction of electrical leads and pore fluid connections. An external load cell is attached, in turn, to the stirrup. The external load cell serves several purposes: (1) it gives, as a check, an approximate measure of the force on the specimen assembly when allowance for friction is made, (2) it can be used for calibrating the internal load cell in the absence of an internal calibrating spring, (3) it permits the setting of maximum load limits through alarms in the indicating unit. The external load cell is connected, finally, to the actuator applying the load.

Because of the pressure compensation, the applied force required to move the piston assembly consists only of the force applied to the specimen itself plus some friction (several kN, depending mainly on the level of the confining pressure). This force is provided by a servocontrolled electromechanical actuator of 100 kN capacity, connected through the external load cell and stirrup to the pressure-compensated loading piston. The actuator is based on a ball-screw of 10 mm pitch that is driven by a Printed Motors servomotor, powered from a Copley servoamplifier. The servoamplifier is operated under tachogenerator feedback to ensure constant speed for a given demand signal to the amplifier. Reduction gearing of 1000:1 is provided so that one revolution of the motor normally advances the ball-screw by 10 µm. The maximum rate of advance is then around 0.5 mm per second and the minimum around 2 mm per hour with standard gearing. A 100:1 speed changer is also normally fitted so that, when engaged, the ball screw advances 0.1 µm per motor revolution; then the minimum displacement rate is 0.02 mm per hour. The displacement range for the loading piston is 30 mm. The actuator shaft can also be moved down a further 20 mm for servicing purposes.

Internal load cell

In order to measure the force applied to the specimen assembly without effects from friction, which are notoriously variable, an internal load cell is used. This cell is attached to the pressure-compensated loading piston. The load cell serves for measurement of both axial force and torque (in the case that a torsion actuator is fitted). Further, it also has provision for the measurement of the axial displacement. The measurement of axial displacement inside the pressure vessel has the advantage of substantially reducing the corrections for elastic distortion when calculating the strain in the specimen. There are six LVDT's located in the load cell, functioning under pressure as follows:

1. Two commercial (RDP) LVDT's measure the axial displacement over a total range of 30 mm. These units are located 180 degree apart so as to give compensation for bending errors.
2. Two LVDT's of special construction are used for measuring the axial force, again located so as to minimize bending errors.

3. Two LVDT's of special construction are used for measuring the torque in case a torsion actuator is fitted.

All six LVDT's are excited from a common power supply and the signals of each pair are connected in series. There are therefore eight pressure-tight feed-throughs in the body of the load cell for the electrical connections: one pair for the common excitation and one pair each for axial displacement, axial force and torque signals. The armatures of the LVDT's for axial force and torque are connected to the elastic element of the load cell through flexure pivots, which give a mechanical amplification of about four times.

The signal conditioning for the LVDT's is done by means of Solatron two-channel oscillator/demodulator cards. One card serves for the axial displacement and axial load channels. In the case where a torsion actuator is fitted, a second card, located in the torsion control unit, is used for the torque channel. It may be noted that the same load cell is used whether or not a torsion module is fitted since the only addition needed for the torque measurement is the fitting of the torque LVDT's themselves.

There is an opening in the bottom of the load cell body giving access to a central space in the load cell. This permits the following arrangements:

1. If the hole is blanked off, the load cell is useable in compression mode only and other unnecessary complications are avoided.
2. The internal space can be fitted with a connection to the specimen assembly for venting it to atmospheric pressure or to an external pore fluid system. This connection consists of a flexible pipe so as not to affect the internal load detection. It allows extensional force to be applied to the load cell in extension testing and ensures maximum friction for torsional loading.
3. Alternatively, the internal space can be fitted with a flexible electrical feedthrough for connection to a thermocouple located on the bottom side of the specimen (as an addition to the usual thermocouple on the top side of the specimen) or for use with other internal transducers.

The internal load cell is designed to operate under forces up to 100 kN full scale. However, the signal can be scaled to smaller ranges, giving higher sensitivity if required, by at least an order of magnitude. In the most sensitive setting, the full scale range is of the order of 5 kN or somewhat less.

Axial deformation control unit

The axial deformation control unit is fitted in a rack to the left of the temperature and pressure control panels. It contains the following features:

— A model 2604 Eurotherm process controller for actuator control through displacement feed-back. The input to this controller is the signal of ±10 V range from the Solatron card channel for the axial displacement. The output, also of ±10 V range, provides the demand signal for the Copley amplifier driving the axial actuator motor when in axial displacement mode.
— A second model 2604 Eurotherm process controller for actuator control through axial force feed-back. The input is the signal of ±10 V range from the Solatron card channel for axial force. The ±10 V output provides the demand signal for the Copley amplifier driving the axial actuator motor when in axial force mode.
— Either process controller can be used in manual mode to drive the actuator at a chosen constant speed (rate mode).

- Each of the Eurotherm controllers is provided with alarm settings that can be used to limit, respectively, the displacement range and the force range to which the specimen assembly is subjected. In this way protection can be provided for the experiment itself, in addition to the protection of the machine provided by trip switches at the extremes of the displacement and force ranges.
- A three-way mode switch by means of which either one of the controller outputs or a demand signal from an external control source is connected to the Copley amplifier driving the axial actuator motor.
- A digital meter displaying the output of the external load cell. This meter provides the excitation and signal conditioning for the external force measurement. It also contains alarms that are set to stop the motor if the force exceeds the maximum allowable force of 100 kN.
- A further digital meter that displays the displacement rate. The input to this meter is the tachogenenrator output from the motor and the display is calibrated to give the displacement rate in $\mu m\ s^{-1}$.
- A switch for activating the 100:1 speed reducer.
- On/off switches for connecting the demand signal from the mode switch to the Copley motor amplifier, that is, for starting or stopping the axial actuator.
- Trim-pots for adjusting the zero and span (calibration) for the axial force and axial displacement readings. These are connected to the Solatron card, which is located in the control box. Coarser adjustments of zero and range are provided by jumpers on the Solatron card.

The displacement indication is calibrated by observing the readings on a dial gauge attached to the axial actuator assembly. The internal force indication is calibrated either by comparing readings of internal and external load cells, allowing for friction, or by observing the change of length of the special calibrating spring whose spring constant has been independently determined. The calibrating spring can be used in both compression and extension.

All parameters are re-transmitted at the ±10 V or 0-10 V level to terminals mounted on the side of the machine, from which connection can be made to a recorder or other data-logging device. Digital connections to the Eurotherm controllers and external force meter are also available for external use. Thus these outputs can be used as feed-backs for an external control system, if desired.

High sensitivity internal load cell

A special internal load cell can be provided for measuring forces smaller than can be readily measured with the standard internal load cell described in the previous section. This device is currently under development but is expected to provide ranges from about 2 kN down to around 10-20 N full scale. It differs from the standard load cell in that, instead of using the body of the load cell as the elastic element for sensing the force, the force is sensed from the deflection of leaf springs located within a slightly modified load cell body. Again, special LVDT's are used to sense the deflection of the force-sensing element under the axial force. Four LVDT's are used in order to gain maximum sensitivity by connecting their signals in series. Torque measurement is not possible with this load cell.

The load cell is attached to the pressure-compensated loading piston in the same way as the standard load cell and it also has the same provision for the measurement of the axial displacement. Again all six LVDT's are excited from a common power supply, the same feed-through arrangement is used, and the signal conditioning for the LVDT's is done by means of a Solatron two-channel oscillator/demodulator card. However, in this case there is no opening in the bottom of the load cell body giving access to a central space in the load cell.

The high sensitivity load cell will be interchangeable with the standard load cell. In fact, either of the load cells could be selected as the primary internal load cell and the other used as an alternative internal load cell. The alternative internal load cell will need an additional Solatron conditioning card which will be housed in a separate box with its associated trimpots for calibration and zero adjustments, together with change-over switches. However, in order to permit easy interchange between load cells, it is recommended that a separate bottom plug and loading piston be purchased for use with the additional load cell. This arrangement facilitate quick interchange of the load cells, avoiding the dis-assembly that would otherwise be required for taking one load cell out of the bottom plug and mounting the other.

TORSION TESTING MODULE

General arrangement

The addition of torsion testing greatly extends the range of deformation experimentation. Large shearing strains and shear localization phenomena can be studied in torsion tests. Also, with simultaneous application of axial load, all three principal stresses can be varied independently for fully determining rheological laws.

The torsion module consists of an actuator, internal and external torque cells, rotary displacement transducer, calibrating bars, specimen assembly components, and control system. The servocontrolled electromechanical actuator applies torque to the top of the specimen assembly, independently of the axial actuator, which acts on the bottom of the assembly. The torsion actuator is driven through reduction gearing of 54,600:1 by a Printed Motors motor powered from a Copley servoamplifier. A further 100:1 reduction is possible with the speed changer on the motor. The servoamplifier is operated under tachogenerator feedback to ensure constant speed for a given demand signal to the amplifier. The magnitude of the twist is measured with a Schaevitz DC-RVDT, which gives a linear output in the range $\pm$ 10 V DC for an angular range of 1.4 radians. The use of 5:1 gears allows for this range to be either 0.28 or 7 radians. For larger ranges, the number of cycles can be counted. There is no limit to the amount of twist that can be applied so long as the specimen assembly remains intact.

The maximum torque is 1000 N m. The rates of twist can be varied over a range from about 0.01 radians per second to 0.04 radians per hour with the standard gearing and down to 0.0004 radians per hour with the 100:1 speed changer.

An external torque cell is incorporated in the torsion actuator. This cell serves the following purposes: (1) it gives, as a check, an approximate measure of the torque on the specimen assembly when allowance for friction is made, (2) it permits the setting of maximum torque limits through alarms in the indicating unit.

Internal torque measurement

The internal load cell used for axial force measurement is also used for the internal torque measurement, as described above under "Axial Deformation Module". A separate pair of LVDT’s provides the torque signal. The signal conditioning for these LVDT's is done by means of a Solatron oscillator/demodulator card fitted in the torsion control unit.

It is desirable that the vent assembly be fitted in the internal load cell so that zero internal fluid pressure is ensured in the specimen assembly. The reason for this requirement is that the torque is transmitted to the torque loading pistons in the specimen assembly by the friction on their ends, arising from the action of the confining pressure on the jacketed assembly.

The internal load cell is designed to operate under torques up to 1000 N m full scale. However, the signal can be scaled to smaller ranges, giving higher sensitivity if required, by at least an order of magnitude.

Torsion control unit

The torsion control panel is fitted in a rack to the left of the temperature and pressure control panels, usually above the axial deformation control panel. It contains the following features:

— A model 2604 Eurotherm process controller for actuator control through twist displacement feed-back using the ±10 V signal from the RVDT. The control output, also of ±10 V range, is used as the demand signal for the Copley amplifier driving the torsion actuator motor when in torsional displacement mode.
— A second model 2604 Eurotherm process controller for control through torque feed-back. The input is the signal of ±10 V range from the Solatron card channel for torque. The ±10 V output is used as the demand signal for the Copley amplifier driving the torsion actuator motor when in torque mode.
— Either process controller can be used in manual mode to drive the actuator at a chosen constant speed.
— Each of the Eurotherm controllers is provided with alarm settings that can be used to limit, respectively, the twist range and the torque range to which the specimen assembly is subjected. In this way protection can be provided for the experiment itself, in addition to the protection of the machine provided by trip switches at the extremes of the torque range, as mentioned below.
— A three-way mode switch by means of which either one of the controller outputs or a demand signal from an external control source is connected to the Copley amplifier driving the torsion actuator motor.
— A digital meter displaying output of the external torque cell. This meter provides the excitation and signal conditioning for the external torque measurement. It also contains alarms that are set to stop the motor if the torque exceeds the maximum allowable value of 1000 N m.
— A further digital meter that displays the twist rate. The input to this meter is the tachogenenrator output from the motor and the display is calibrated to give the displacement rate in μrad s^{-1}.
— On/off switches for connecting the demand signal from the mode switch to the Copley motor amplifier, that is, for starting or stopping the torsion actuator.
— Trim-pots for adjusting the zero and span (calibration) for the internal torque readings. These are connected to the Solatron card, which is located in the control box. . Coarser adjustments of zero and range are provided by jumpers on the Solatron card.

The twist indication is scaled by using the calibration supplied with the RVDT. The internal torque indication is calibrated by observing the amount of twist of special calibrating bars whose elastic properties can be calculated.

All parameters are re-transmitted at the ±10 V or 0-10 V level to terminals mounted on the side of the machine, from which connection can be made to a recorder or other data-logging device. Digital connections to the Eurotherm controllers and external torque meter are also available for external use. Thus these outputs can be used as feed-backs for an external control system, if desired.

PORE-FLUID MODULE

General arrangement

The pore-fluid module consists of a volumometer driven by a servocontrolled electromechanical actuator, with upstream and downstream pressure transducers, and plumbing connections to the specimen assembly. It is suitable for argon or water at pressures up to 500 MPa, and is fitted with pressure and displacement transducers. The volumometer can be used in conjunction with axial or torsion testing, or independently.

The volumometer cylinder and piston are made of stainless steel for corrosion resistance. The piston is of precisely 7 mm diameter, with 50 mm stroke. It thus sweeps out a total volume of approximately 2000 mm^3. The piston is driven by an actuator based on a ball-screw of 5 mm pitch that is driven by a Printed Motors servomotor, powered from a Copley servoamplifier. The servoamplifier is operated under tachogenerator feedback to ensure constant speed for a given demand signal to the amplifier. Reduction gearing of 160:1 is provided so that one revolution of the motor advances the volumometer piston by 31 µm. The maximum rate of fluid delivery is thus around 60 mm^3 per second and the minimum around 70 mm^3 per hour with the standard gearing. Trip switches are fitted at each end of the piston travel to prevent over-run and damage to the actuator.

The volumometer cylinder is fitted with a Precise Sensors pressure transducer, located in such a way as to minimize any "dead" volume. The piston displacement is measured with a Schaevitz LVDT located within the ball-screw, on the axis of the actuator. Thus both displaced volume and pressure of pore fluid can be monitored.

The volumometer is provided with plumbing connection to the upper end of the specimen assembly. Provision is also made for the insertion of a metal-sheathed thermocouple to monitor the temperature at the top side of the specimen.

Downstream arrangements

A downstream Precise Sensors pressure transducer is also supplied. This is mounted in a connector block from which two outlets are provided. One outlet is for connection to the bottom end of the specimen assembly, allowing flow-through observations for permeability determinations. The other outlet is connected through a valve to the upstream pore fluid system, allowing initial filling and later isolation. Determination of very low permeabilities may require special adaptations such as filling the bores of the downstream connecting tubes with wires to minimize downstream volume, and providing additional amplification for the downstream pressure signal. These special developments are left to the user to implement according to requirements.

Pore fluid control unit

The pore fluid control unit is fitted in a rack to the left of the temperature and pressure control panels and usually above such axial and torsion control panels as may be fitted.. The panel contains the following features:

— A model 2604 Eurotherm process controller for volumometer control through displacement feed-back. The input to this controller is the signal of ±10 V range from the Solatron card channel for the piston displacement. The output, also of ±10 V range, is the demand signal for the Copley amplifier driving the volumometer motor when in displacement mode.

— A second model 2604 Eurotherm process controller for volumometer control through pore fluid pressure feed-back. The input is the signal of ±10 V range from the other Solatron card channel that is used for the pore fluid pressure. The ±10 V output is the demand signal for the Copley amplifier driving the volumometer motor when in pressure mode.
— Either process controller can be used in manual mode to drive the volumometer actuator at a chosen constant speed.
— Each of the Eurotherm controllers is provided with alarm settings that can be used to limit, respectively, the volumetric displacement range and the pressure range to which the specimen assembly is subjected. In this way protection can be provided for the experiment itself, in addition to the protection of the machine provided by trip switches at the extremes of the displacement and pore fluid pressure ranges.
— A three-way mode switch by means of which either one of the controller outputs or a demand signal from an external control source is connected to the Copley amplifier driving the volumometer motor.
— A digital meter displaying output of the downstream pore pressure transducer. This meter provides the excitation and signal conditioning for this transducer. It also contains alarms that are set to stop the motor if the pore pressure exceeds the maximum allowable of 500 MPa..
— A further digital meter that displays the volumetric displacement rate of the volumometer. The input to this meter is the tachogenenrator output from the motor and the display is calibrated to give the displacement rate in mm^3 s^{-1}.
— On/off switches for connecting the demand signal from the mode switch to the Copley motor amplifier, that is, for starting or stopping the volumometer drive.
— Trim-pots for adjusting the zero and span (calibration) for the volumometer displacement and pressure readings. These are connected to the Solatron card, which is located in the control box.

The displacement indication is calibrated by observing the readings on a dial gauge attached to the volumometer actuator assembly. The pore fluid pressure indication is calibrated either by comparing readings with the confining pressure readings when the systems are interconnected, or by inputting the mV/V supplied with the transducer to the indicating instrument.

All parameters are re-transmitted at the ±10 V or 1-10 V level to terminals mounted on the side of the machine, from which connection can be made to a recorder or other data-logging device. Digital connections to the Eurotherm controllers and downstream pressure meter are also available for external use. Thus these outputs can be used as feed-backs for an external control system, if desired.

PHYSICAL PROPERTIES MEASUREMENT AND OTHER APPLICATIONS

The high-pressure, high-temperature facility also lends itself to the measurement of physical properties and to other applications such as hot isostatic pressing (HIP). Some electrical connections can be made through the top end of the specimen assembly, and a special bottom closure plug can be provided for an additional eight or more electrical feedthroughs to the bottom end of the specimen assembly. The feedthrough connections are flexibly mounted so that no axial force is generated in the specimen assembly from compression and thermal expansion.. Thus complex measurements such as those of thermal properties, seismic wave speeds, permeability etc are possible. Enquiries regarding specific requirements are welcome.