1.3

UNITED KINGDOM ATOMIC ENERGY AUTHORITY
DOUNREAY NUCLEAR POWER DEVELOPMENT ESTABLISHMENT

WORKING GROUP ON HOT LABS AND REMOTE HANDLING
21st PLENARY MEETING
PETTEN
JUNE 1983

THE IN-CELL USE OF LASER MICROMETERS

BY
R R BROWN

UNITED KINGDOM ATOMIC ENERGY AUTHORITY
DOUNREAY NUCLEAR POWER DEVELOPMENT ESTABLISHMENT

INTRODUCTION

Core components in all types of reactor undergo some degree of distension and this is usually monitored inside the core or during post-irradiation examination. Well proven reactor systems require minimum surveillance while the performance of a new design in a fast reactor demands detailed monitoring at all stages of irradiation. The degree of allowable distension is usually no more than a few per cent and a variety of techniques are available to measure these changes; for example, linear variable differential transformer transducers, eddy current transducers or optical devices using diffraction gratings. The level of accuracy required is dependent on several factors but the diametral measurement of fast reactor fuel pins and other components which have been exposed to fast neutron fluxes typically requires accuracies of ± 0.1% (± 0.005 mm for a 6 mm diameter fast reactor fuel pin).

The introduction of low powered laser beams offers a new technique for the dimensional measurement of reactor components in a hot cell. The technique can have advantages over some of the more traditional methods in terms of absolute accuracy but its practical value lies in the reduction of the number of the sources of error which are introduced by the conventional in-cell measurement machine hardware.

This paper describes the use of two types of laser operated gauge which have been used for the post-irradiation measurement of test pieces previously irradiated in a fast reactor. The limitations and advantages compared with more conventional systems are also given and plans for a new installation where all measurement equipment is situated outside the hot cell are described.

LASER INTERFEROMETER TECHNIQUE

The technique of laser interferometry is not new but its incorporation into a fully automatic machine for the very precise measurement of irradiated pre-pressurised tubes is novel. The machine was built by Westinghouse at their Hanford Engineering Development Laboratories at Richland, Washington, USA and it is fully described in Reference 1. Small pre-pressurised tubes manufactured from a variety of materials of interest are loaded into the machine via a chute and, using a series of motors and pneumatic pistons, the specimen is first introduced between pads for length measurement and then between sapphire styluses for detailed diameter measurement. After measurement is complete the specimen is automatically discharged into a hopper for collection in a storage tube. Dimensional change of the specimen is reflected in movement of the pads or sapphire-faced anvils. In the case of diameter measurement, the specimen is rotated and lowered while held between the anvils and measurement is made at precise points on the spiral path. Movement of pads or anvils is detected by a Hewlett Packard 5501A laser interferometer system; the laser beam detects the movement of retroreflectors which are attached to each measurement anvil or pad. This interferometer system is described in detail in the manufacturer's operating and service manual (Reference 2).

The fundamental measurement concept is illustrated in Figure 1 showing a single axis measurement system. The system requires a source of beam (the laser head), an interferometer/retroreflector combination and a receiver. The system detects only relative position change between the interferometer and the retroreflector. It does not measure absolute position. A block diagram showing a simple system with only one moving reflector is shown in Figure 2. This illustration also describes the function of each of the components used in the measurement sytem.

The laser head is of the helium-neon type producing a 1 milli-watt beam; this beam is made up of two frequencies separated by approximately 2 MHZ, one polarised vertically and one horizontally. A small fraction of both frequencies is split off to generate a reference frequency but the major portion is passed on to the interferometer system (Figure 2). The beam is split into two frequencies and each is directed to a reflector, one of which is fixed relative to the interferometer. Consider each of the separate beams. That which is directed to the fixed reflector returns to the interferometer station unchanged but that which strikes the movable reflector suffers a change in frequency; movement of the reflector causes a doppler shift in the frequency of the returning beam and the sign of this shift is dependent on the direction of motion. The two beams are made to recombine and interfere with one another - this interference signal is the basis for measurement. This new beam is directed to a receiver (photodetector) where an electrical signal is generated. This signal is compared cycle by cycle with that generated from the reference frequency and an up or down output pulse is produced whenever one of the signals gets one half cycle ahead or behind the other. Each pulse corresponds to a reflector movement of one quarter wave length of light. These pulses are accumulated, shown on the display unit and stored in a computer memory. After specimen measurement is completed the accumulated values are transferred from the memory to magnetic tape.

The configuration of beam splitters, interferometers, retroreflectors and receivers used in the American machine are shown in Figure 3 - each anvil of the diameter measurement and length stations is fitted with a moving retroreflector although the beam is only being used for diameter or length measurement at any given time.

The laser interferometer machine can give very accurate measurement of specimen dimensions; its resolution is $\frac{1}{4}\ \lambda$ of light although, in practice, its accuracy is ± 0.0006 mm (2 σ value) for diameter measurement. In addition to investigating the effects of neutron induced voidage swelling it aims to show the very early effect of irradiation creep. Trials with the machine at Dounreay have shown that it is capable of achieving the claimed levels of accuracy - many hundreds of specimens have been measured and re-measured. For specialised applications where extremely high accuracies are required and a separate hot cell or area of hot cell can be constructed, this system is worthy of consideration. This is the case at Dounreay where a special cell has been built to house the measurement machine (Reference 3). The portion of the cell which contains the machine has a roll out door which opens into an active area. The machine sits in a frame mounted to the inside of this removable door and access to the machine is readily achieved. Although the machine can operate for long periods without any adjustment it has been found that optimum performance of the laser system requires occasional re-alignment of the components and re-setting of the anvils and contact pads. Cleaning of the beam benders and reflectors is necessary if the intensity of the laser beam reaching the receivers is not to fall.

The Biaxial Creep Measurement Machine, manufactured by HEDL, USA is an essential part of a large materials surveillance and irradiation creep programme being carried out at Dounreay. The machine's specialised design means that it is able to provide highly accurate automated measurements from large numbers of irradiated pre-pressurised tubes. For this application radiation "hardening" of the measuring equipment was not undertaken. Control of the number of irradiated specimens in close proximity to the machine will ensure that radiation dose will not adversely affect the equipment.

LASER SHADOWGRAPH TECHNIQUE

The laser shadowgraph technique does not offer extremely high levels of measurement accuracy - its resolution is similar to that offered by more conventional techniques. Its value lies in its simplicity of use.

The laser beam, once again Helium-Neon type, is used in a completely different way from the interferometer. The laser beam is merely a convenient and coherent source of parallel light which can be used to provide a scanning beam. The laser gauge used was manufactured by the Techmet Company of Dayton, Ohio, USA and its machines bear the trademark "Lasermike". A model 50 was initially used for in-cell dimensional measurement but more recently a model 500 with increased resolution has been purchased. An illustration of the Lasermike gauge head is given in Figure 4.

The measurement system is made up of a gauge head and a digital readout unit connected together by one cable. In a hot cell application, only the gauge unit is installed in the cell and mains voltage is supplied to the display unit outside the cell. See Figure 5 for a schematic diagram of the gauge head components. The Lasermike gauge head contains a 0.25 milli-watt helium-neon laser which emits a parallel beam of light approximately 0.8 mm in diameter. This beam is converted to a radially scanning beam by a motor driven double sided mirror operating at approximately 3,000 revolutions per minute. Because two scans occur per motor revolution, 100 scans per second are produced and this radially scanning beam is converted to a parallel scanning beam by using a lens positioned so that its focal point is coincident with the rotating mirror surface. The parallel beam has an effectively constant scanning velocity and this provides the basis for making measurements. Any object placed in the working area of the scanner interrupts the beam for a period proportional to its profile along the scan path. This interrupted beam is collected by the receiver lens and focussed onto a photodetector. This time of the interruption is counted and displayed as a dimension on the readout unit. The main advantage of the laser shadowgraph technique is its non-contacting method of measurement. A large number of errors can be introduced by the inclusion of the more usual anvil system where knife-edged probes rub against the surface of the object being measured. The anvils must be straight and parallel and in the same plane and they must not wear unevenly along their length. A major problem with such contacting systems is the possible accumulation of foreign matter between the anvils and the object. Thus one dirty area of the specimen can lead to more than one false reading - the foreign matter can be pulled on through successive measurement stations. The "Lasermike" gives a direct reading of the cross-section scanned while conventional methods usually show the difference between a known standard and the object being measured. In hot cell applications the effect of contamination and radiation on the laser machine must be considered separately. Contamination would not normally create problems in the operation of the instrument - the in-cell gauge head can be wrapped in a protective plastic gaiter to prevent dust entering the unit. The laser beam is comparatively weak (¼ mW) and trials have shown that the protective covering must be omitted from the lens apertures. However the lens areas are sealed and ingress of contamination should not occur. High radiation fields are more likely to cause failure. The machine is not designed for use in a high radiation environment and after long exposures it is likely that the unit will fail due to darkening of glass lenses or damage to the electronics.

A model 50 "Lasermike" has been undergoing trials inside a B γ hot-cell at Dounreay for 5 months. Before positioning in the hot cell the unit was wrapped in a layer of PVC with small cut outs to allow the beam to pass unhindered. The space between the laser transmitter and receiver is fixed ($\sim$ 225 mm) with the "pass line" (the fixed position between transmitter and receiver where maximum accuracy is obtained) only 50 mm from the receiver. This limits the amount of lead shielding which can be applied. A lead shoe with a slot sufficient to allow passage of the 0.8 mm diameter beam was positioned between the transmitter and receiver and 50 mm thick lead blocks were built around the machine to reduce radiation from sources outside the measurement area.

The "Lasermike" has been used to measure the diameter of a large number of components ranging from 22 mm diameter absorber pins to 2.3 mm diameter materials test specimens. The estimate dose accumulated to date is modest at approximately 3,000 Gy (30,000 Rads) and no adverse effects have been observed. The repeatability of standard measurement remains the same as that of the new unit at ± 0.005 mm. No maintenance has been required during the period in-cell.

IMPROVEMENTS TO THE TECHNIQUE AND PLANS FOR A NEW INSTALLATION IN THE HOT CELL

The "Lasermike" machine has worked well inside a hot cell but the glass and electronic components make it vulnerable to high radiation fields. The construction of the machine makes it difficult to shield vital components effectively. Any increase in separation of the laser transmitter and receiver would allow greater shielding but there are practical reasons which tend to limit the beam path length. For long path lengths, the optics of the system must be of very high quality especially if a range of sizes is to be measured. Although the laser light is coherent and interference at the edges of the object is very low, error can be introduced by imperfections in beam parallelism magnified by long path lengths. Increasing the distance between transmitter and receiver therefore carries a cost penalty. Because measurement is made without contacting the object, it is feasible to abandon the familiar configuration of having the measuring hardware inside the hot cell but the thick shield walls would require laser path lengths of at least 4 metres in high-gamma concrete shielded facilities. However the great majority of hot cells are large multi-purpose facilities and it would be valuable to adapt the existing technology to these installations. In the high B γ Post-Irradiation Examination Building at Dounreay a scheme has been drawn up for the installation of shadowgraph laser outside the existing hot cell. Objects to be measured will be moved past a laser scanning beam using a conventional translation bed driven by computer controlled stepping motors. Only the laser scanning beam will be present within the cell - the laser transmitter and receiver will be positioned below the cell floor. A diagram of the layout is shown in Figure 6. The shadowgraph laser used will be the "Zygo" model 120F which has a variable transmitter to receiver distance of up to 2 metres. The high quality optics required for the machine makes its cost four times that of the "Lasermike" model 50 machine. The underside of the cell floor is readily accessible and the Zygo unit and the local lead shielding should be installed without difficulty. The laser scanning system will be contained within a strong steel frame which will support the 200 mm thick layer of lead required to shield the Zygo from radiation sources within the cell. Lighter (100 mm) shielding will be used for side shielding and these side walls will be so constructed as to allow access from the side nearest the man access hatch. The laser scanning system will sit on a horizontal stainless steel plate to assist permanent alignment of the scanning beam.

Within the cell, two 45° high efficiency mirrors will straddle slots cut in the cell floor. These slots (2 mm x 50 mm) will have upturned edges to minimise the passage of swarf and other small particulate matter. If found to be necessary, the slots may be covered by small sections of stabilised impact resistant glass. The angles of reflection for the in-cell mirrors will be fully adjustable using commercially available optic mounts.

These laser scanning systems have only one moving part (the rotating mirror) and they are known to be extremely reliable in operation. After initial alignment has been achieved and the in-cell mirrors secured in position it is expected that the system will operate without further attention for long periods. The in-cell mirrors will be the only vulnerable part of the system and they will be readily replaceable.

The "Zygo" laser shadowgraph has a maximum beam power of 1 mW; this linked with a good quality optics system allows the object to be measured to be positioned at any point in the 2 metre gap between transmitter and receiver. At present this is the longest beam path available in a commercial scanning laser system (this limit may be imposed by safety as well as cost considerations because the units are normally used in factories and workshops).

In the future a higher powered scanning laser (say 4 mW) with high quality optics may become available, albeit at increased cost. This unit could have a laser path length in excess of 7 metres and it could be positioned on the cell operating face with the beam directed to the measurement station using paths at high level through the thick concrete walls and a system of mirrors within the cave.

REFERENCES

1. KIRCHNER, T L. "Laser Interferometer System for the Measurement of Creep in Pressurised Tubes" HEDL-SA-1101 1976.

2. HEWLETT-PACKARD Co Inc. 5501A Laser Transducer System - Operating and Service Manual. HP Manual No 05501-00013 Printed Sept 1977.

3. SWANSON, K M et al. "Recent Experience with Post-Irradiation Examination Facilities at Dounreay". ANS Proc of the 29th Conference on Remote Systems Technology. Vol 1 Summer 1981. Bal Harbour, Florida.

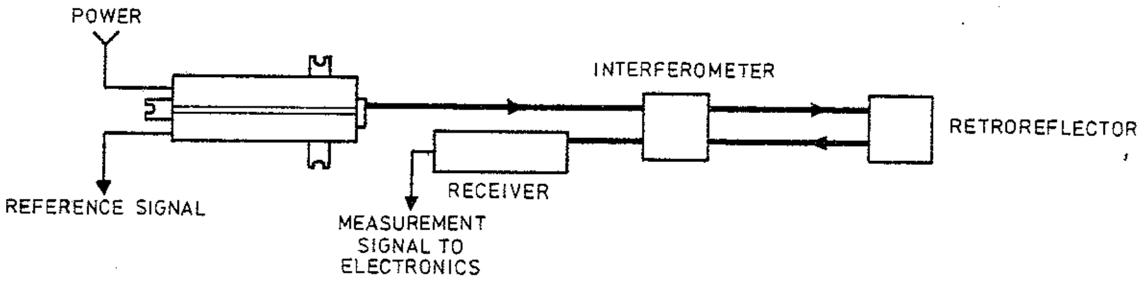
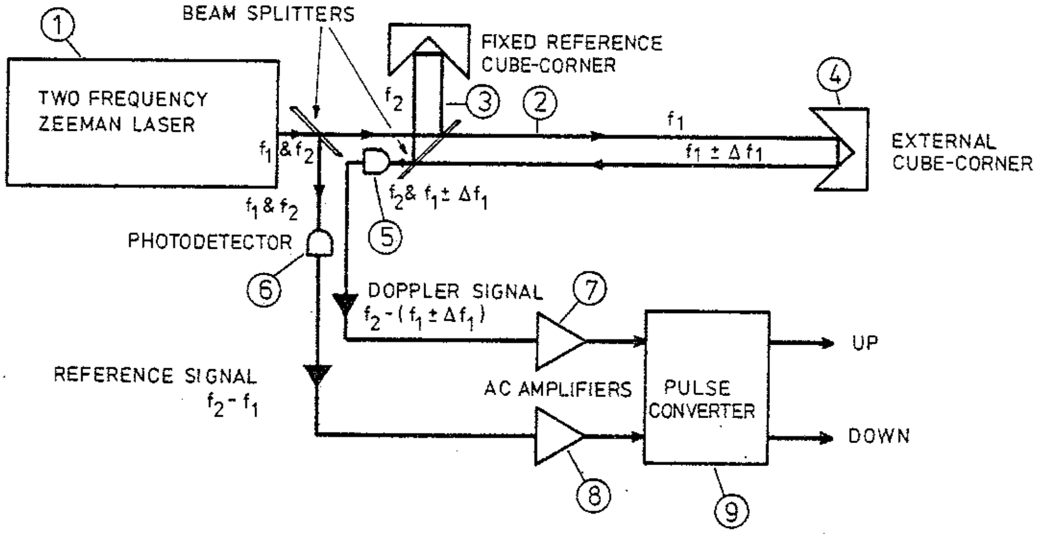


FIGURE 1 SINGLE AXIS LASER INTERFEROMETER MEASUREMENT SYSTEM



❶ Laser generates light of two slightly different frequencies with opposite circular polarizations.

❷ One of the two frequencies f_1, is optically separated and sent to the movable external cube-corner reflector.

❸ The second frequency, f_2, is optically separated and sent to a fixed reflector and then rejoins f_1 at the beam splitter to produce an interference signal at about 2 MHz.

❹ If the movable reflector moves, the returning beam frequency will be Doppler-shifted slightly up or down by Δf_1 depending on direction of motion.

❺ Photodetector changes f_2 and $(f_1 \pm \Delta f_1)$ to electrical signal.

❻ Photodetector changes reference beam, f_1 and f_2, to electrical signal.

❼ AC amplifier separates measurement frequency difference signal $f_2 - (f_1 \pm \Delta f_1)$.

❽ AC amplifier separates reference frequency difference signal $f_2 - f_1$.

❾ Pulse converter extracts Δf_1 and outputs one pulse per quarter wavelength of motion.

FIGURE 2 DIAGRAM OF HEWLETT-PACKARD LASER INTERFEROMETER SYSTEM

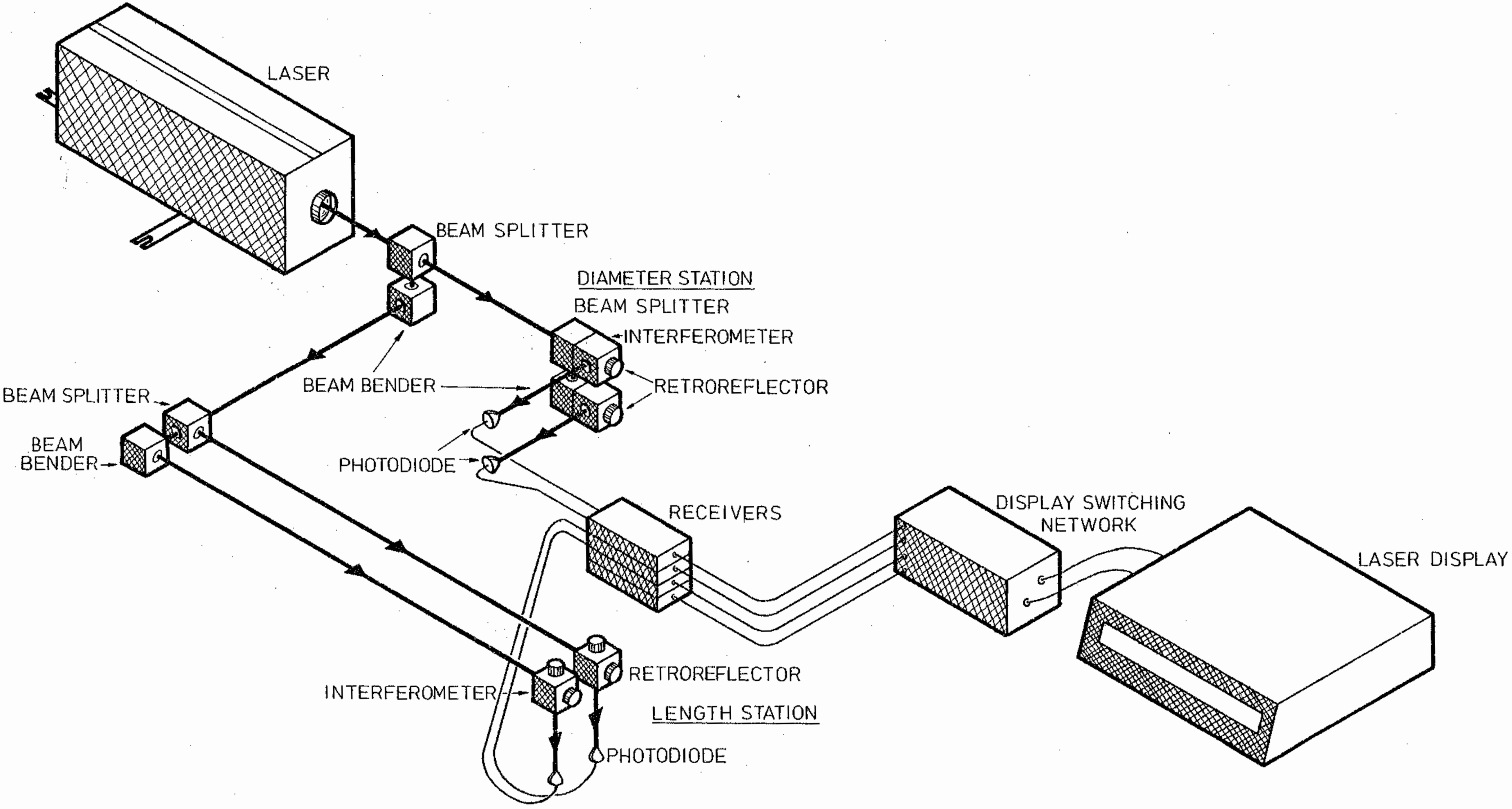


FIGURE 3 LAYOUT OF THE BIAXIAL CREEP MEASUREMENT MACHINE COMPONENTS

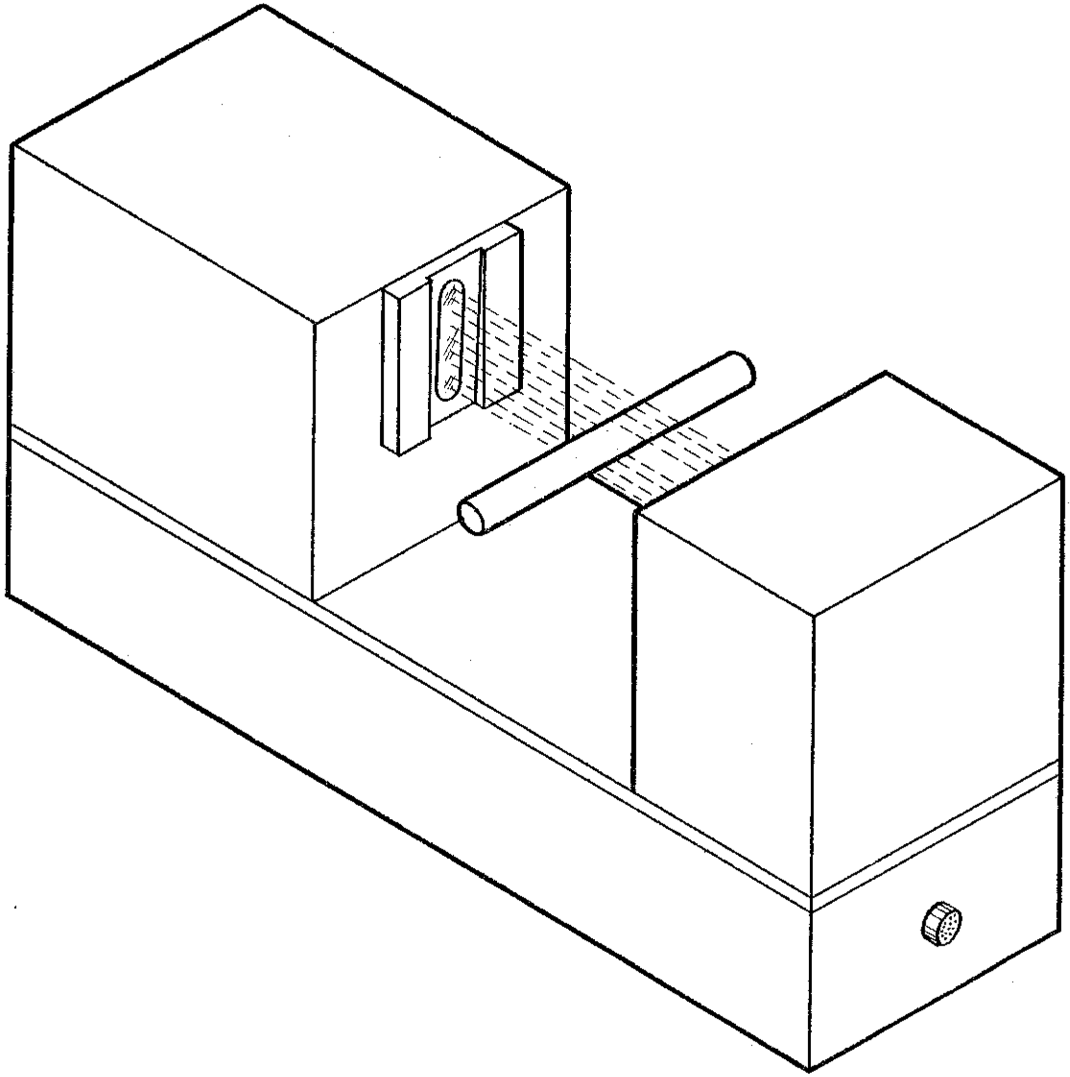


FIGURE 4 LASERMIKE GAUGE HEAD

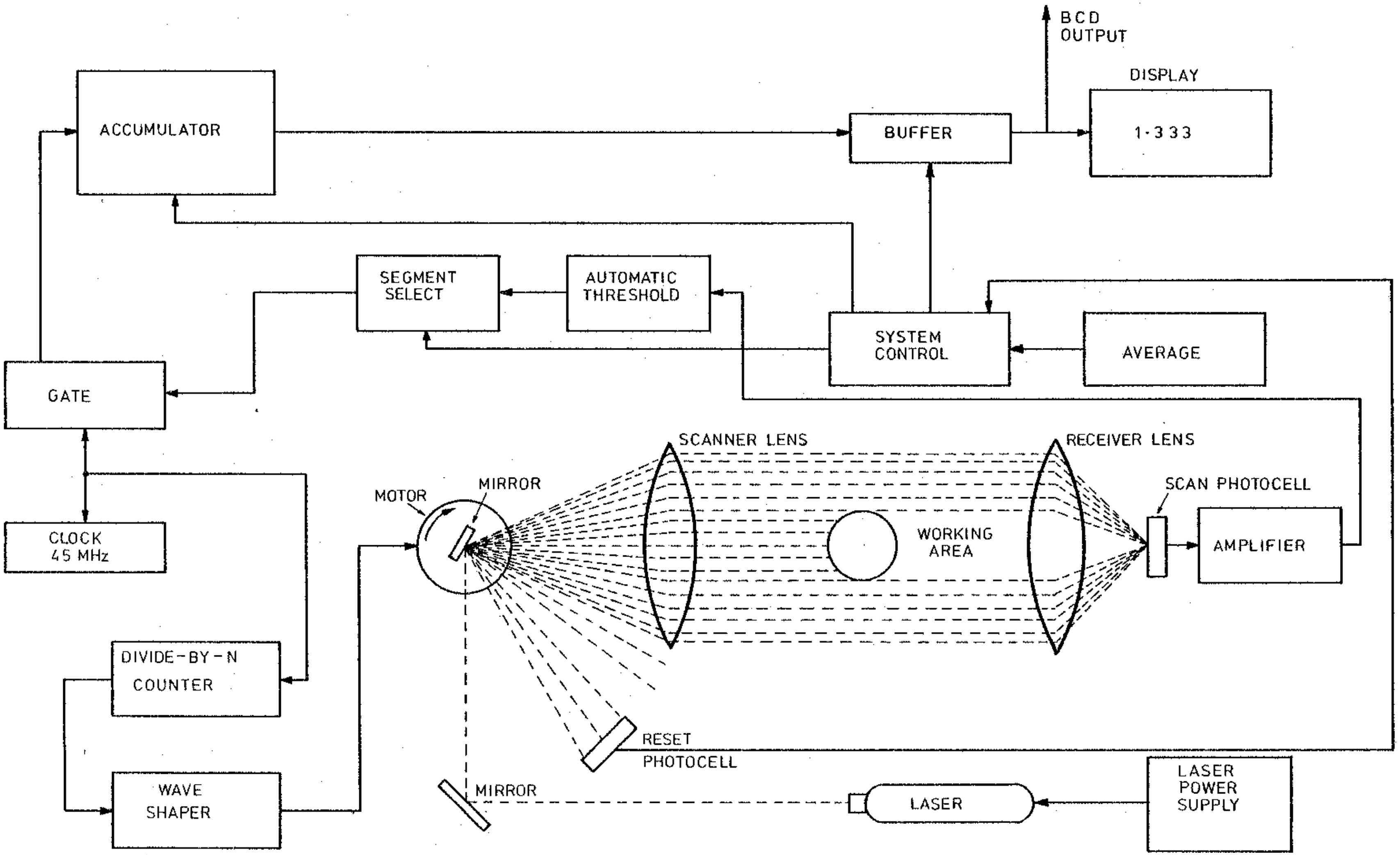


FIGURE 5 DIAGRAM OF LASER SHADOWGRAPH MEASUREMENT SYSTEM

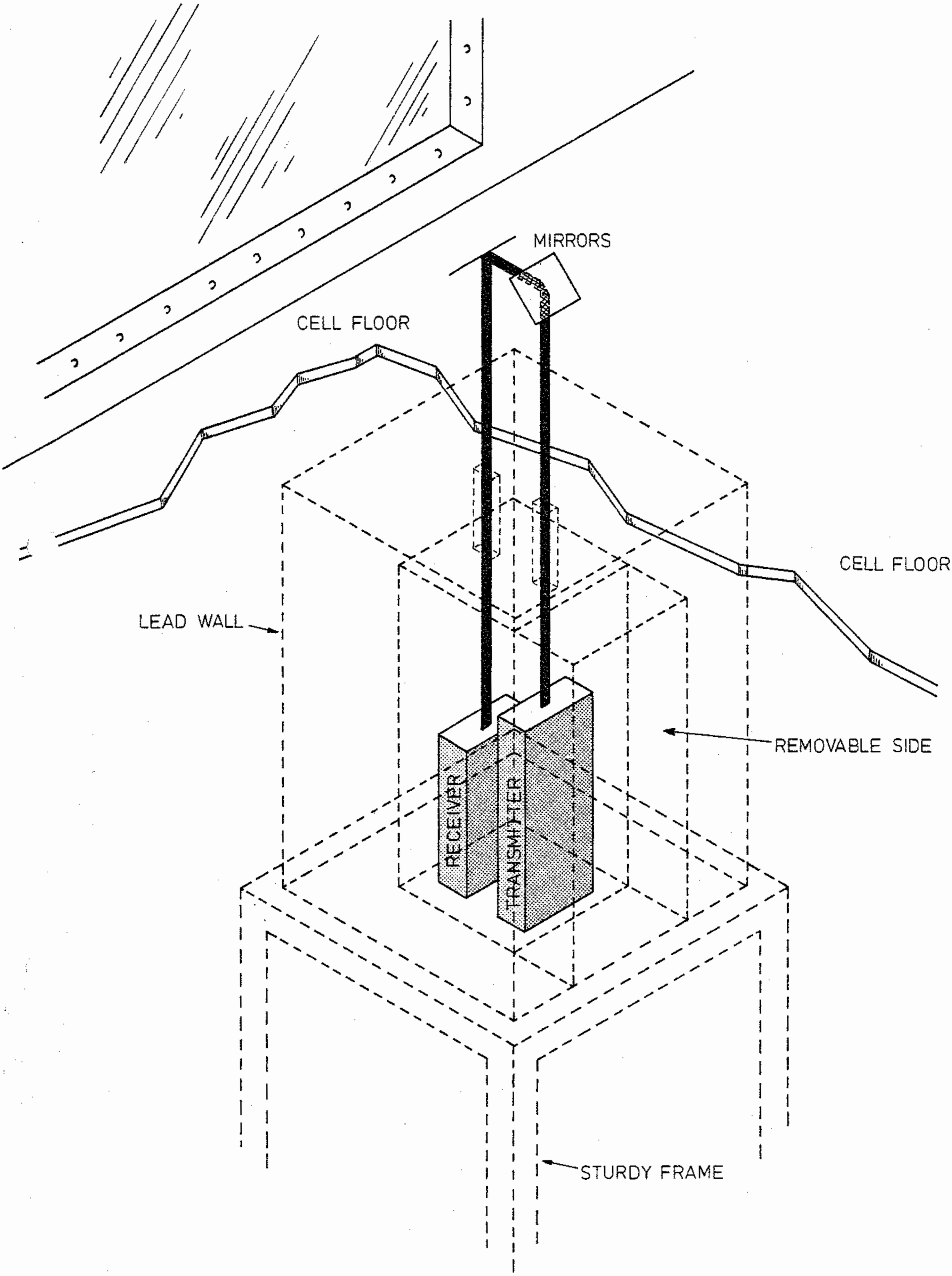


FIGURE 6 PROPOSED INSTALLATION OF LASER SHADOWGRAPH IN THE HOT CELL