<u>THE DESIGN AND COMMISSIONING OF A NON DESTRUCTIVE EXAMINATION (NDE) FACILITY FOR THE IN-POOL TESTING OF LIGHT WATER REACTOR (LWR) FUEL RODS.</u>

<u>VOLUME ONE</u>

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A Thesis Submitted To The Faculty Of Engineering of The University Of Glasgow For The Degree Of Master Of Science (Engineering).

To my Father, the memory of my Mother
and my Aunt.

ACKNOWLEDGMENTS

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List Of Abreviations Used In This Thesis.

AERE	Atomic Energy Research Establishment
ASM	American Society of Metals
BWR	Boiling Water Reactor
ECT	Eddy Current Testing.
EMAT	ElectroMagnetic Acoustic Transducer
EPRI	Electric Power Research Institute
HFR	High Flux Reactor
IAEA	International Atomic Energy Agency
IPD	Impedance Plane Diagram
JRC	Joint Research Centre
KWU	KraftWerk Union
LVDT	Linear Variable Displacement Transducer
LWR	Light Water Reactor
MFEC	Multi Frequency Eddy Current
NDE	Non Destructive Examination
NDT	Non Destructive Testing
NFD	Nippon Fuel Development
PEC	Pulsed Eddy Current
PIE	Post Irradiation Examination
PE	Pulse Echo.
PWR	Pressurised Water Reactor
SAFT	Synthetic Aperture Focusing Technique
TOFD	Time Of Flight Diffraction
UT	Ultrasonic Testing.

1.0 INTRODUCTION AND SUMMARY

The work described in this thesis details the design and commissioning of a Non Destructive Examination facility (NDE) for Light Water Reactor (LWR) fuel rod testing. The facility will be located in the High Flux Reactor (HFR) of the Commission of the European Communities Joint Research Centre at Petten in The Netherlands. When fully installed in the HFR the system will replace an existing system which has been in use since 1977 and performed approximately 600 examinations.

The initial stages of the work concerned a Literature Survey and Design Review which is contained in Chapter Two. The scope of the Literature Survey covers not only methods which are used in the new design, but also encompasses a variety of techniques which are currently used elsewhere in the Non Destructive Examination of Light Water Reactor Fuel Rods.

The first section of the chapter examines eddy current testing techniques. It describes the theory and test equipment involved in a basic eddy current test and also describes more advanced testing techniques such as multi-frequency or pulsed eddy current examinations.

Although not subsequently incorporated into the new design, a short review into the different methods of Ultrasonic NDE is given in the second section.

The final section of the Literature Review discusses the application of various inspection techniques to the NDE of nuclear fuel rods.

In the Design Review, Chapter 2.4, an analysis was conducted on four systems currently employed for in-pool NDE of LWR fuel rods. The aim of the review was to evaluate the operational capabilities of other systems and to try to identify any beneficial features which could be subsequently incorporated into the design.

As a result of information drawn from the Literature Survey and Design Review, a Specification for the overall system design was generated and this is documented in Chapter Three. The specification was created in order that it could act as a guide and a focus for descision making throughout the entire design process.

Closely related to the Design Specification is the Design Selection which is described in Chapter Four. The purpose of the Design Selection was to generate and evaluate different design solutions against the initial Design Specification resulting in the final design. A photograph of the chosen design showing the facility in the test pool at Petten can be seen in figure 1.1 whilst the associated computers and electronic equipment is shown in figure 1.2.

The experimental work conducted during the course of the project is detailed in Chapter Five. This covers both the laboratory work concerned with determining optimum test parameters for the new system, and the commissioning trials conducted in the test pool at Petten which were used to confirm the functionality of the complete system. A more comprehensive description of the laboratory work is given in the Laboratory Report which is contained in the Appendix.

The final chapter, Chapter Six, contains a list of conclusions, recommendations for design changes and further work.

In order to enable a systematic and disciplined approach to be taken, the Design Process shown in figure 1.3 was devised. Using these stages as a guide, it was proposed to compile the thesis in a modular format, completing each module after each stage of the Design Process had been concluded. By following this approach it was hoped that it would considerably simplify the final thesis write up.

At the start of the project, a work plan was constructed detailing all the individual tasks within the project. Figure 1.4 shows the main tasks contained in this planning. Unfortunately, due to a combination of inaccuracies and unexpected delays this was not achievable within the available time period. The actual work plan is shown in Figure 1.5.

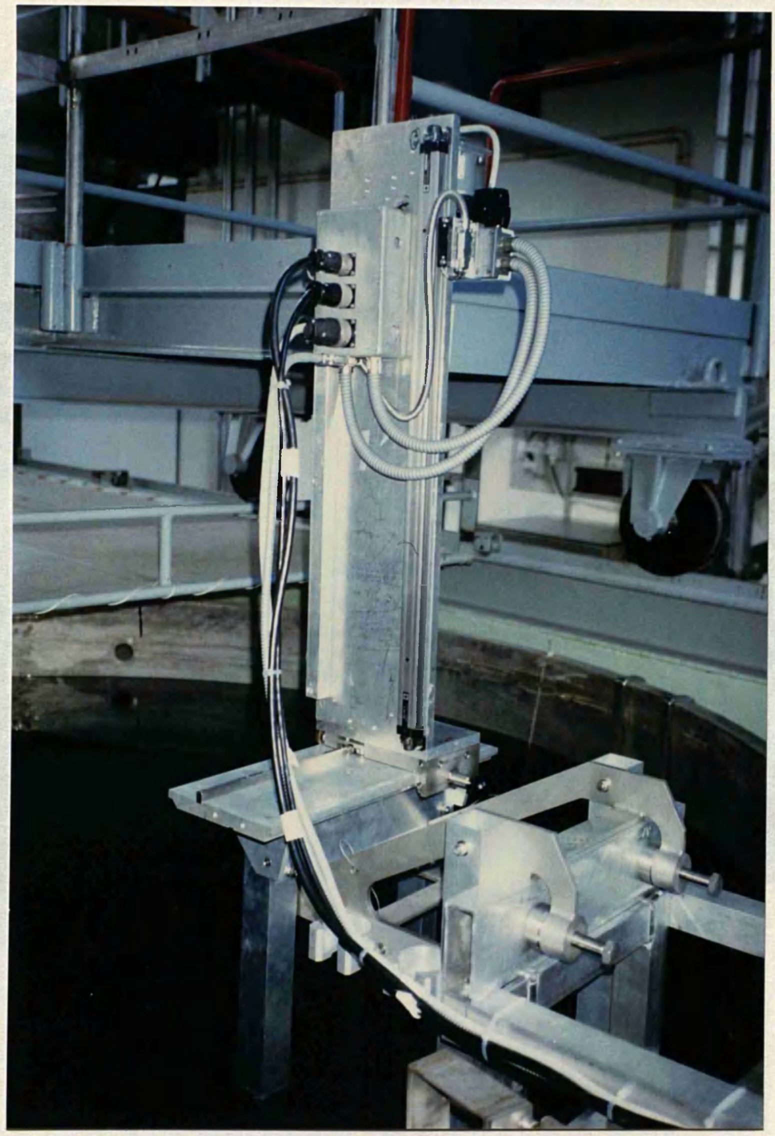

Figure 1.1 - Photograph Of Facility At Petten Test Pool

Figure 1.2 - Photograph Of Computers And Electrical Equipment At Petten Test Pool.

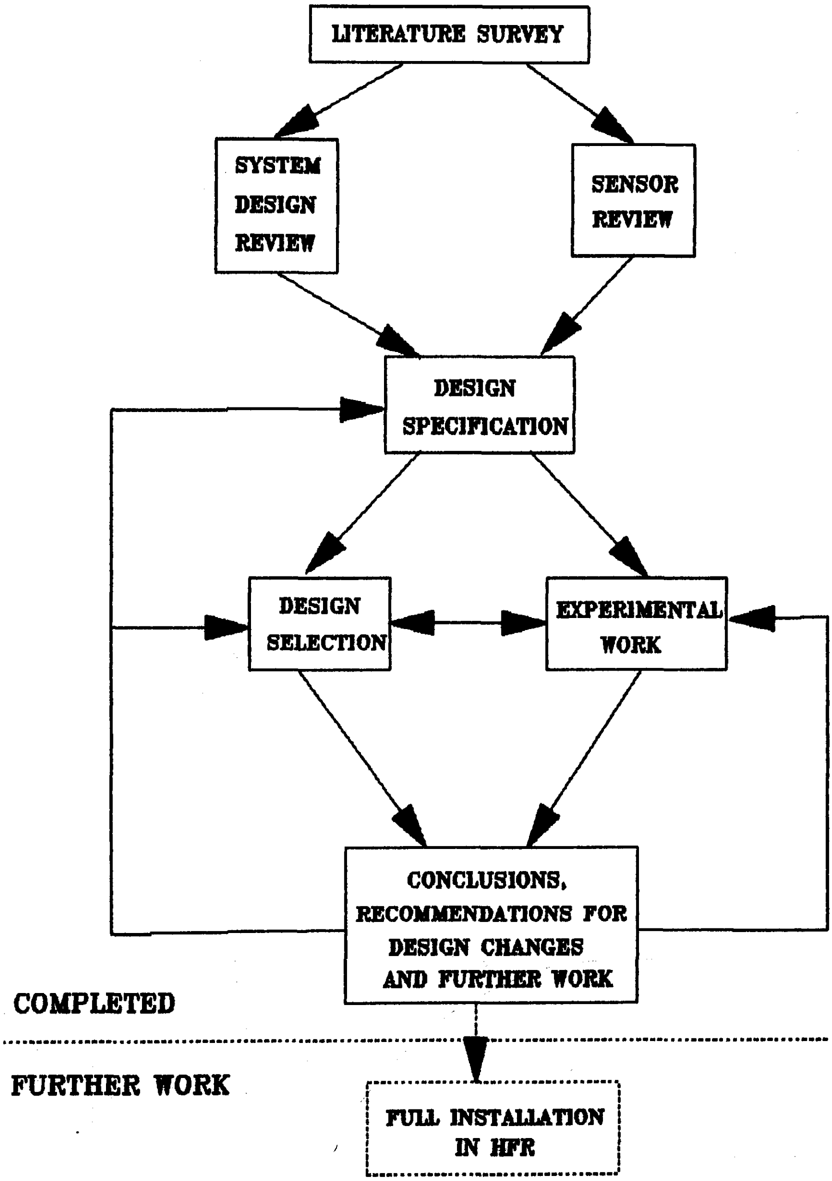

Figure 1.3 – Overall Design Process

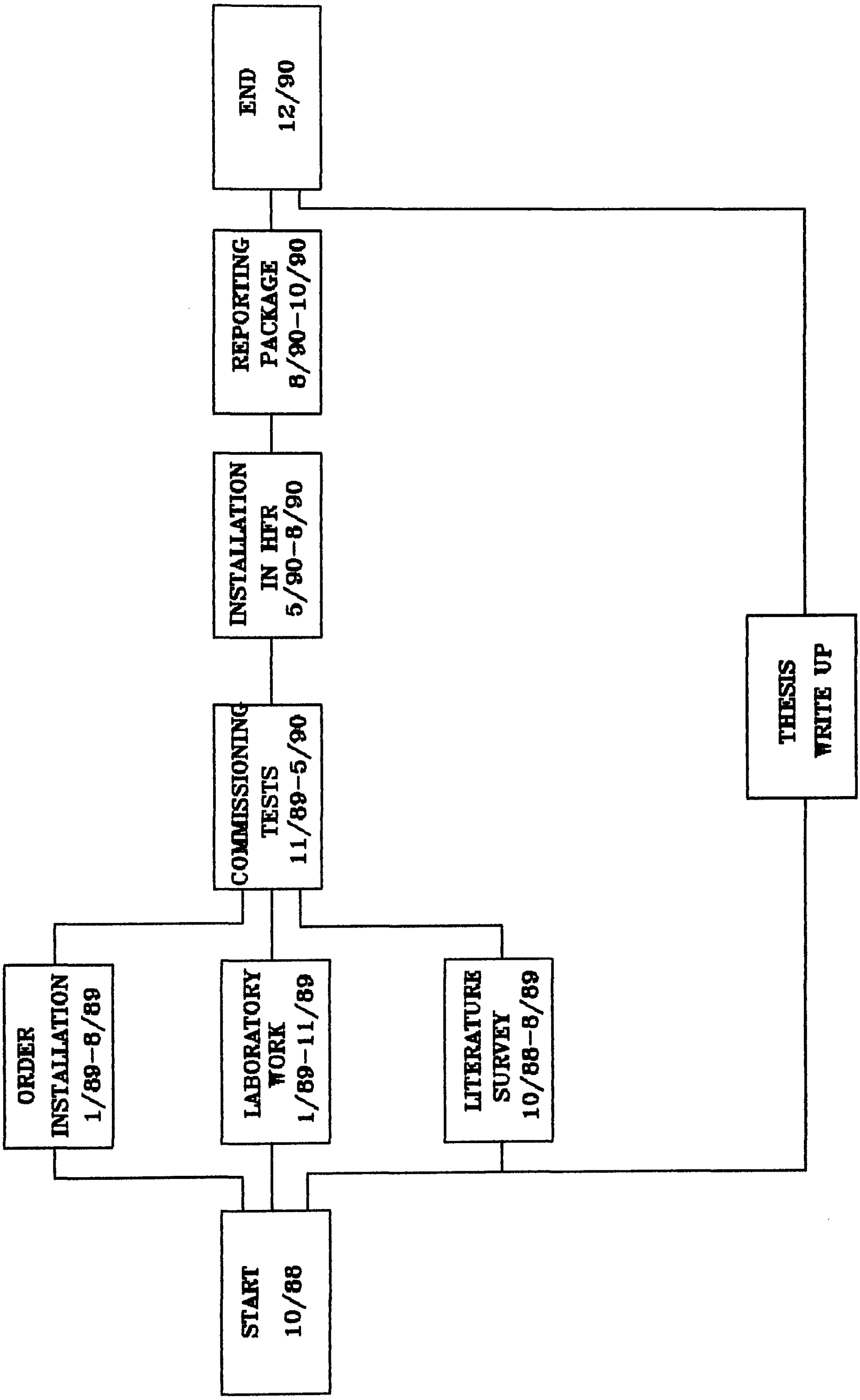

Figure 1.4 - Original Project Work Plan

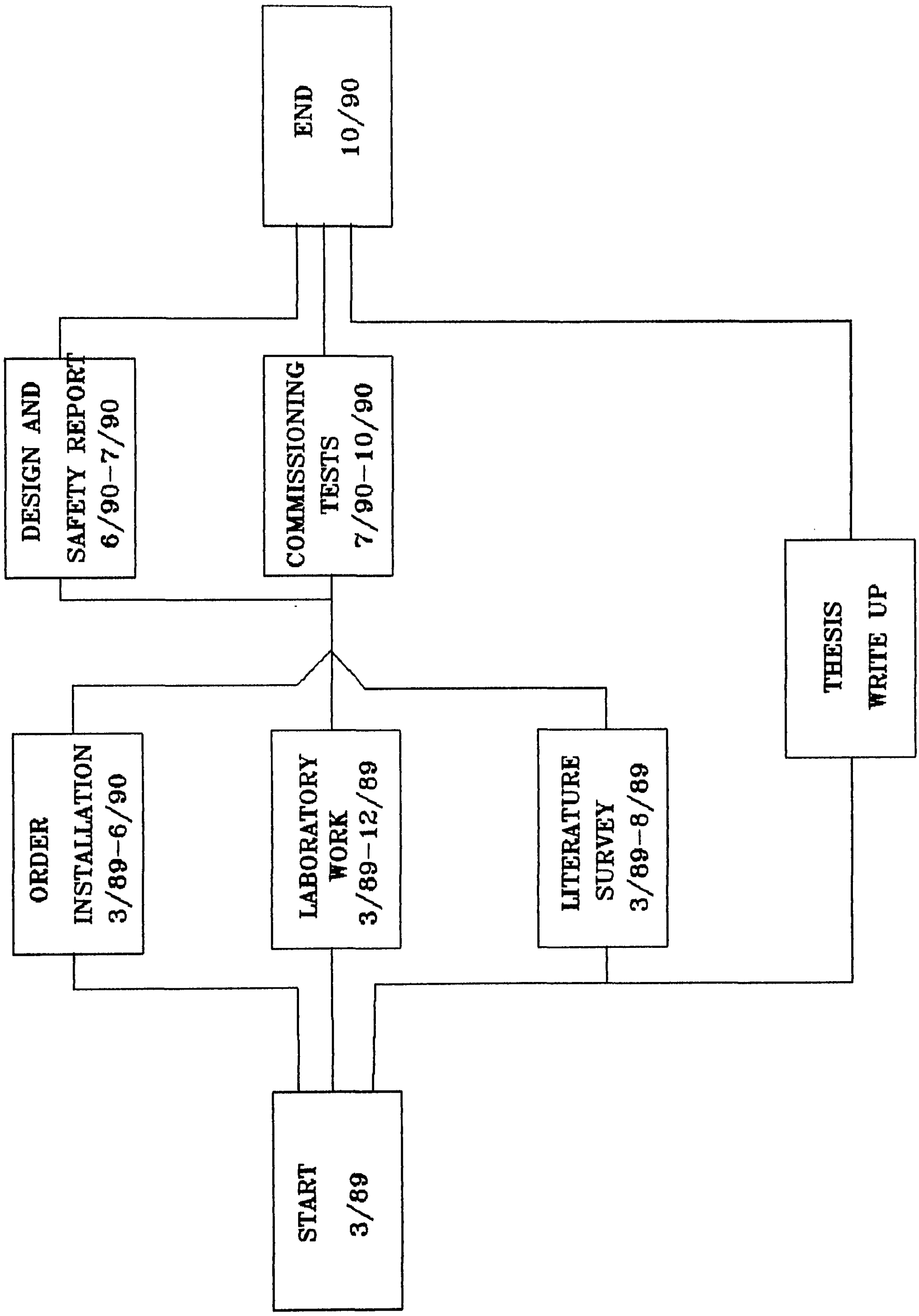

Figure 1.5 – Actual Project Work Plan

CHAPTER TWO - LITERATURE SURVEY & DESIGN REVIEW

2.0 LITERATURE REVIEW

2.1 EDDY CURRENT NON DESTRUCTIVE TESTING TECHNIQUES

2.1.0 Introduction

Eddy Current Testing (ECT) is one of the most widely used techniques for the Non Destructive Examination (NDE) of irradiated nuclear fuel rods. One of the reasons for this, is the large amount of information that can be extracted from a workpiece during an eddy current test. Depending on the individual test parameters, eddy currents can be used for defect detection, diameter measurement, oxide thickness measurement or material characterisation. However, this versatility can cause problems in the interpretation of eddy current data.

2.1.1 Basic Theory

When an alternating current flows in a coil, it causes a magnetic field to be established around it (figure 2.1.1). If a conductor is placed near this coil, as in figure 2.1.2, the (primary) magnetic field will cause eddy currents to be induced in the conductor. These eddy currents are closed loops of induced current flowing in planes perpendicular to the magnetic flux. They assume a direction opposite to that of the current in the coil and generate their own secondary magnetic field which is in opposition to the original primary field created by the coil. The primary field will then be modified to an extent which depends on the phase and magnitude of the eddy currents flowing in the specimen.

When a defect is present, as in figure 2.1.3, the eddy currents must redistribute themselves in order to flow around it. This causes the eddy current density around the defect to be reduced. This results in a reduction in the magnitude of the secondary magnetic field which in turn alters the impedance of the inspection coil. The change in coil impedance, Z, is not only affected by the distribution of the eddy currents, but also by their magnitude and phase. By suitable analysis the change in coil impedance can be used to give information relating to the chemical, physical and metallurgical properties of a specimen.

Impedance can be considered to consist of a real and an imaginary term. The real term is the resistance R, and the imaginary term is the reactance jwL i.e.

$$Z=R+jwL$$

In general, coil resistance can be considered negligible compared to the coil reactance. A common method of graphically representing the impedance of a coil is to consider it as a vector with real(R) and imaginary(wL) parts. This type of presentation is called an Impedance Plane Diagram (IPD) and was first used by Dr Forster in the early 50's /1/.

2.1.2 Test Equipment

There are two alternative techniques used in eddy current testing. The first is termed the impedance method. This works by monitoring the voltage drop across the primary coil as the coil impedance changes. The second, send-recieve method, however, measures the voltage developed across a sensing coil (or in some cases a Hall Effect detector) which is placed in close proximity to the excitation coil. The latter method is most commonly used in through transmission examinations and therefore is not suitable for the examination of sealed irradiated nuclear fuel rods.

Most Eddy Current impedance measuring instruments require two external coils to incorporate into an internal AC bridge network. The bridge circuit consists of two test coils connected in parallel with potentiometers for adjusting amplitude and phase (figure 2.1.4). The purpose of the bridge circuit is 'balance' the two test coils i.e. to keep the current amplitude and phase in each coil equal. With the probe in a defect free region the circuit is balanced when the impedance ratios of Z1/Z2 and Z3/Z4 are equal. The phase control is altered until Z3/Z4 has a zero phase angle, after which the amplitude control is adjusted until the ratio Z1/Z2 equals Z3/Z4. When this is achieved the output voltage, Vo, will be zero. The output voltage will then be shifted away from zero only when there is a difference between the signals from the two test coils caused by a change in their relative impedances.

The output voltage from the probe is then fed to a signal processing system which usually consists of an amplifier, rectifier, phase detector and phase rotator. A block diagram of typical inspection apparatus can be seen in figure 2.1.5. The AC signal is then analysed by resolving it into quadrature components. If, as in figure 2.1.6, the driving signal is a sinusoidal voltage, then the output voltage can be expressed as -

$$Vo = A \sin (wt + \phi)$$

where - A = amplitude

$wt = 2\pi ft$

f = frequency

The signal can be considered to consist of a resistive component Vx and a reactive component Vy. i.e.

$$\begin{aligned} Vo &= A \sin (wt + \phi) \\ &= A(\sin wt \cos\phi + \cos wt \sin\phi) \\ &= B \sin wt + C \cos \phi \\ &= Vx + Vy \end{aligned}$$

The amplitude coefficients are called the Fourier resistive Coefficients of Vo. The resistive component is also called the phase component and the reactive component the quadrature component of Vo. Because of the linear relationship between Vo and it's components it is possible to express it uniquely in terms of a vector. This vector has an in-phase and an out of phase (quadrature) component. Most eddy current instruments are able to display this vector on a storage oscilloscope. As Vo changes, a loci of points will be traced out on the screen. The exact shape of the display depends on the test parameters and the defect encountered by the probe.

By measuring the phase and amplitude of the signal it is possible to gain information about the defect size, position and type. The exact relationships depend on individual test conditions, but figure 2.1.7 shows a relationship between phase angle and defect type established by one worker /2/. Other attempts have been made to establish the defect type from the shape and orientation of the figure /3,14/.

2.1.3 Types of Probes

As stated above most Eddy Current instruments require two external coils to incorporate into their internal AC bridge network. Either one or both of these coils can be used to examine the test surface.

2.1.3.1 Absolute Probes

In an Absolute probe one coil is used to examine the specimen whilst the other is located far enough away from the specimen so that is not influenced by it. When the probe is balanced in air the coils have the same impedances, but there will be a slight relative change when the test coil is influenced by the specimen. Absolute probes have the advantage of being sensitive to both sudden and gradual variations in properties and dimensions.

2.1.3.2 Differential Probes

A differential probe contains two coils usually wound in opposition located side by side within the probe tip. The two coils sense adjacent areas of the specimen surface. In a defect free region these areas are assumed to have identical properties and therefore give identical signals to both coils. As the coils are wound in opposition this results in a net zero output. When a flaw is present, one coil will sense it before the other resulting in the net output being moved away from zero. As both coils are located together, differential probes are much more sensitive to sharp defects than gradual ones and are less prone to temperature variation and probe wobble than absolute probes.

2.1.3.3 Encircling Coils

In order to conduct an examination it is first necessary to induce eddy currents in the specimen surface by using a probe. When examining fuel rods the most common way of doing this is to pass the rod through the centre of an encircling coil (figure 2.1.8a). The wire diameter, number of turns and coil dimensions are all factors which affect the suitability of a probe for a particular test. Within the probe the wire is wound circumferentially into a coil around a hollow insulating core. The eddy currents are therefore induced to flow in a circumferential direction in the fuel rod cladding. The sensitivity of a particular coil is dependant on coil length, with a narrow coil being more sensitive to surface cracks and diameter variations and less sensitive to sub-surface defects. Since the coil is affected by all the metal within its length it is possible that a long shallow defect will give a similar signal to a short deep defect. An advantage of this type of coil is that it is possible to make fast volumetric examinations, however it has the disadvantage of only being suitable for axial location of defects. In order to establish a defects circumferential position it is necessary to use a point or button probe with a small localised magnetic field.

2.1.3.4 Point Probes

Small point probes are used to examine smaller areas of the cladding. These probes consist of coils wound on an axis parallel to the specimen surface (figure 2.1.8b). Eddy Currents are induced to flow in a circular path beneath the probe. Maximum probe response is obtained when the defect is perpendicular to the eddy current flow. If the defect is parallel to the eddy currents, any disruption to their flow, and hence test coil impedance changes, are kept to a minimum. These types of probes are therefore relatively insensitive to flaws that are parallel to the specimen surface or those between layers such as between an oxide layer and parent metal.

2.1.3.5 Bobbin Probes

The third type of probe is the bobbin probe which fits inside tubular specimens (figure 2.1.8c) and although cannot be applied to examine irradiated fuel rods is widely used for other purposes such as the examination of heat exchanger tubing.

2.1.4 Depth Of Penetration

In most cases, induced eddy currents tend to be concentrated at or near the surface of a conductor. This phenomena is known as the Skin Effect as is well documented in /4/. This effect causes the density of eddy currents to be reduced exponentially in relation to the distance from the surface of the conductor. The reasons for this are as follows. Firstly, as stated earlier, all induced eddy currents create a magnetic field in opposition to the primary field. Thus the further away from the surface the weaker the primary field will become due to combined magnetic field created by all the eddy currents between any one point and the surface. If at a test frequency f, the conductivity and permeability of a specimen are assumed constant then the depth of penetration may be expressed as-

$$=1/\sqrt{\pi \mu f \sigma}$$

The standard depth of penetration (SDOP) is that where the magnitude of the eddy currents has been reduced to that of 37% (1/e) of the value at the surface. In Zircaloy σ, μ are assumed to be constant so the depth of penetration is inversely proportional to the test frequency i.e. low frequencies are more suitable for deep penetration and high frequencies for near surface examination /13/. Figure 2.1.9 shows the relationship between frequency and SDOP for four different materials /16/. A more commonly used parameter is the Effective Depth Of Penetration (EDOP) which is where the eddy current density is only 5% of the value at the surface, in most practical cases this is slightly less than 3δ .

2.1.5 Phase Lag

The signal produced by a defect is dependant on both the magnitude and phase of the eddy currents. Although a small surface and a large sub-surface defect can have a similar effect on the magnitude of the test coil impedance, the phase of the eddy currents from the sub-surface defect will lag those from the surface defect /15/. The effect of phase lag increases linearly with depth and the phase lag B (in radians) at any depth x is related to the standard depth of penetration as follows -

$$B = x/\delta$$

When x is equal to the SDOP the phase lag is equal to one radian or 57° . This means that any eddy currents flowing at the SDOP will lag the surface currents by 57°. This is an important fact in signal analysis as it allows the depth and type of a defect to be established in addition to allowing discrimination between defects and false signals. As phase lag is a function of the standard depth of penetration it also varies with test frequency, conductivity and permeability.

2.1.6 Multi-Frequency Eddy Current Testing

As mentioned in the introduction, eddy current testing can be used to measure many different test parameters. In many cases this can be a hinderance as unwanted signals can mask the signal that is of interest. However, the response of different test parameters varies with test frequency. This makes it possible, by examining with more than one frequency, to discriminate against unwanted signals /10,11/. In multi-frequency eddy current testing two or more sinusoidal signals of different frequencies are used to drive a single probe. By making one or more of the frequencies sensitive to unwanted parameters, the resultant output signals can be combined algrebraicaly in such a way to intensify the desired signal and reduce unwanted ones.

Multi-Frequency Eddy Current (MFEC) testing has only been used as a research tool for examining irradiated fuel rods. One series of experiments at Battelle Colombus Laboratory /5/, using frequencies of 100KHz and 700KHz, found MFEC was able to detect wide cracks but had difficulty in detecting sharp incipent defects (also a problem with single frequency testing). It also found that a strong eddy current signal was more likely to indicate the presence of Pellet Cladding Interaction than that of a defect.

2.1.7 Pulsed Eddy Current (PEC) Examination

In this method the excitation signal is sent to the test coil in a series of pulses. The induced eddy currents produce a corresponding pulsed magnetic field which in turn induces a voltage pulse in the inspection probe. The initial part of the pulse only contains information on the outer surface, but the final section contains information on the wall thickness and both the inner and outer surfaces. By gating the signal both parts can be displayed on separate channels. If a defect signal appears on both channels, its position can be estimated from the relative strength on each channel. One drawback with PEC is that it is very sensitive to variations in lift-off making it difficult to get accurate results from a moving probe.

Again this method has been successfully applied to examine irradiated fuel in Hot Cells on an experimental basis. Research at General Electric Vallecitos Nuclear Centre,USA /6/ has shown it is very sensitive to external defects but only after the rods had been chemically cleaned. If the rods were examined beforehand a large amount of spurious signals were generated from various deposits. Further work conducted at the Aerojet Nuclear Laboratory,USA /7,8/ and at the Idaho National Engineering Laboratory,USA /9/ concluded that PEC was capable of detecting internal defects as small as 0.10mm or external defects as small as 0.05mm. The same studies also showed that PEC was more sensitive to internal longitudinal defects than internal transverse ones.

2.1.8 Speed Of Examination

In order that signals can be recorded without undue distortion it is necesary that the speed of examination does not exceed the speed of response of the system. This is due to the finite response time needed to respond to any input signal. Figure 2.1.5 shows a common recording equipment arrangement. Typical response speeds of the various components are -display instrument 100-300Hz, chart recorder 100Hz, XY recorder 8Hz /12/. It is for this reason that any XY plots are best obtained offline so as to obtain an undistorted output. An examination speed of 250mm/s is the maximum tolerable with most presently available commercial equipment /15/.

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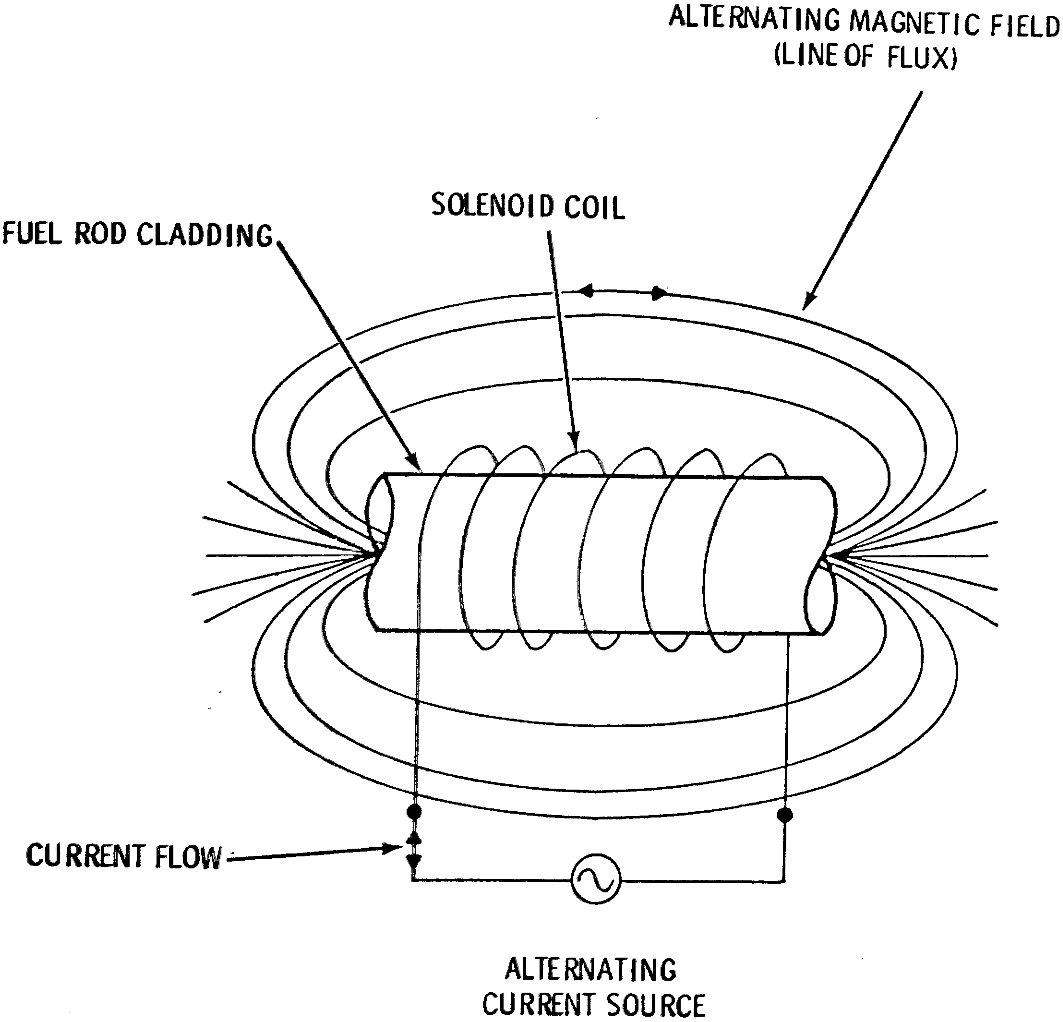


Figure 2.1.1 - Alternating Magnetic Field Around A Cylindrical Conductor Generated By An Alternating Current In An Encircling Coil.

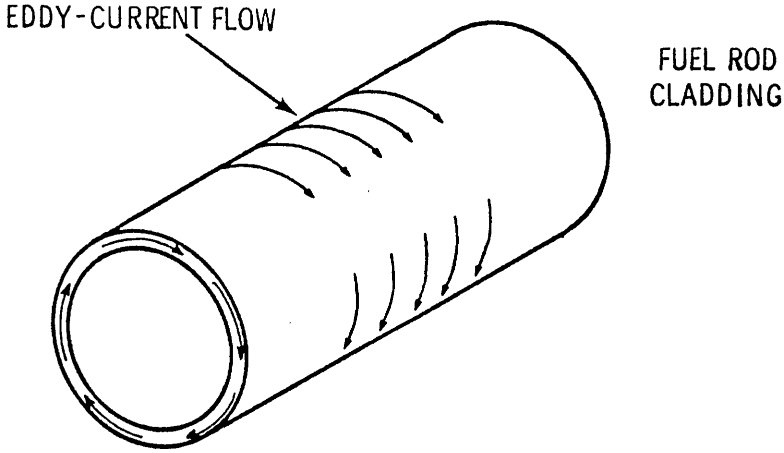


Figure 2.1.2 - Eddy Current Flow In A Circular Conductor Induced By An Encircling Coil.

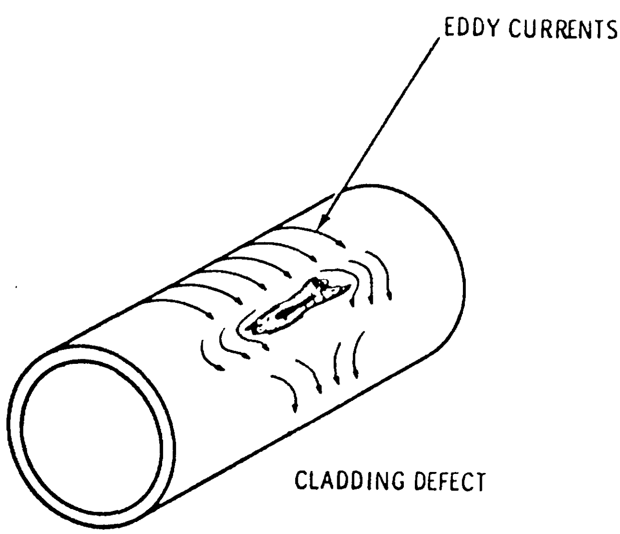


Figure 2.1.3 - Eddy Current Flow In Presence Of A Defect.

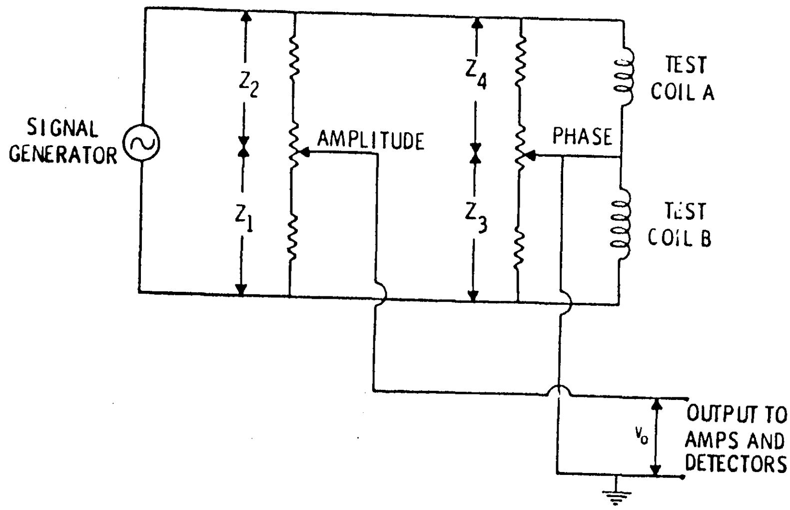


Figure 2.1.4 - Wheatstone Bridge Type Measuring Circuit.

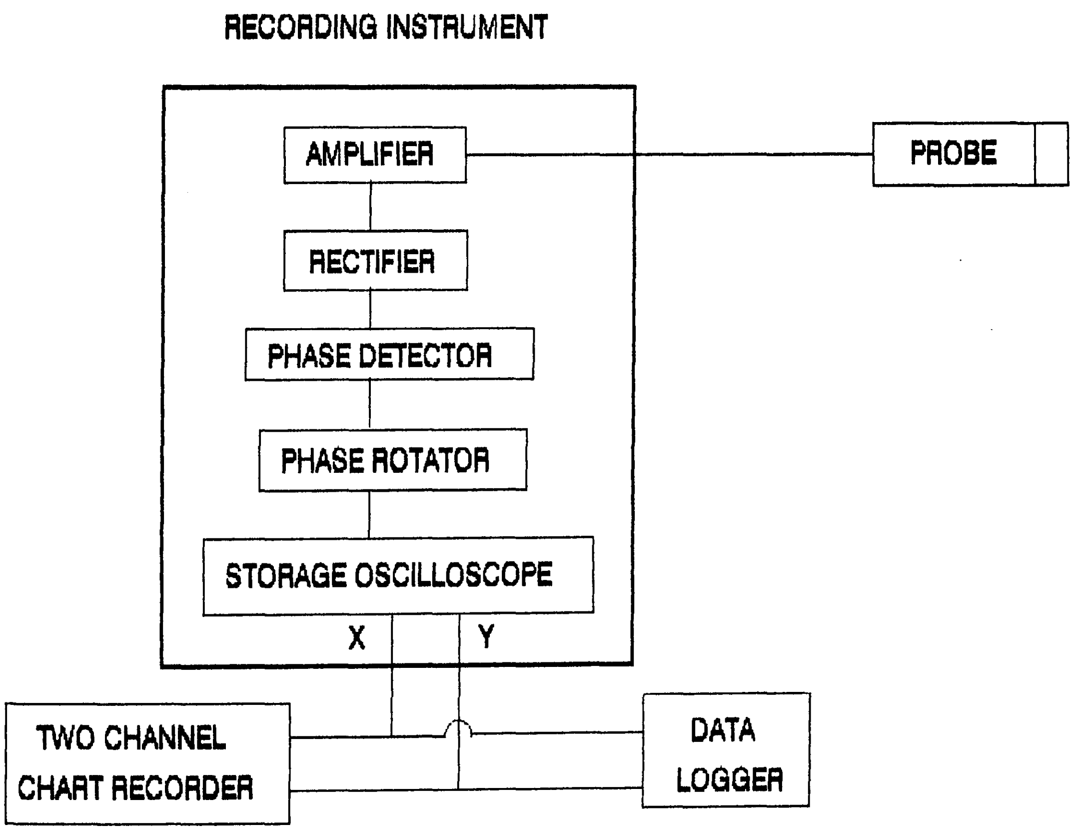


Figure 2.1.5 - Block Diagram Of TYpical Equipment Used
In Eddy Current Inspection.

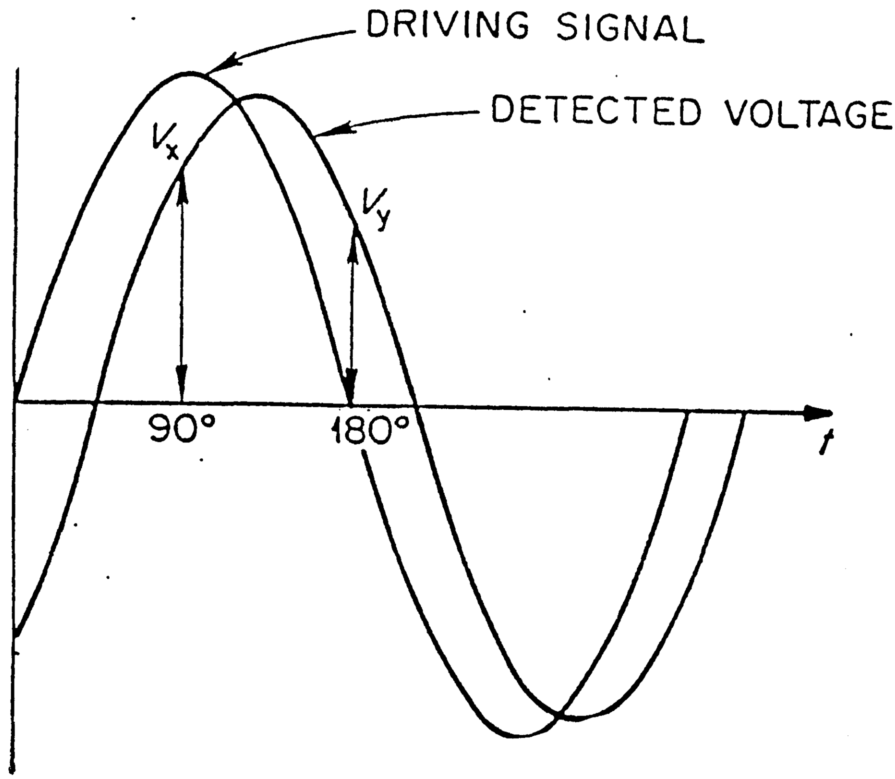


Figure 2.1.6a - Phase Relationship Between Driving And Measured Signals.

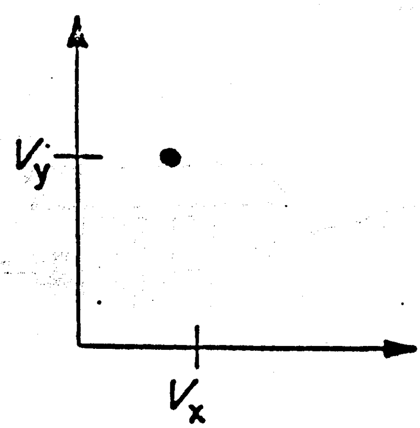
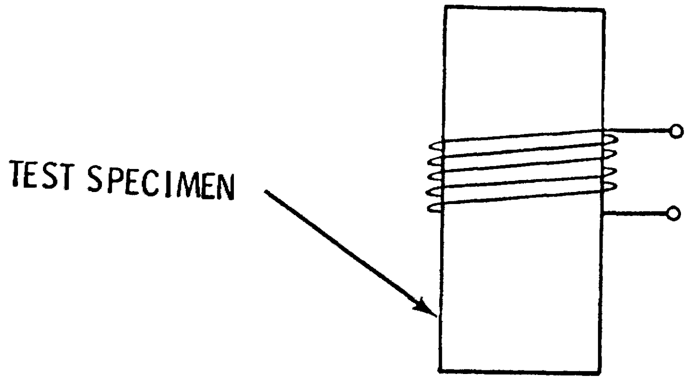
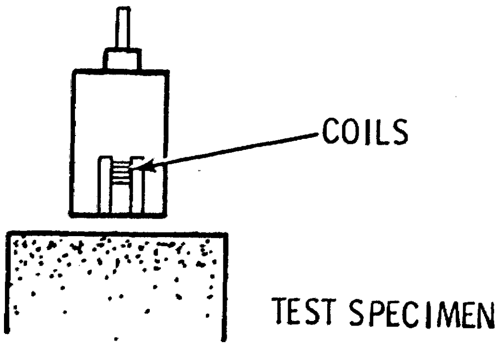


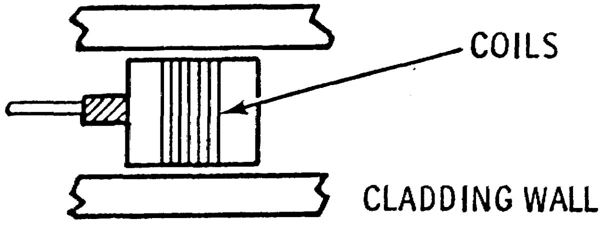
Figure 2.1.6b - Display Of Above On Oscilloscope.



(a) Encircling Coil.



(b) Point Probe.



(c) Bobbin Probe.

Figure 2.1.8 - Different Types of Eddy Current Probes.

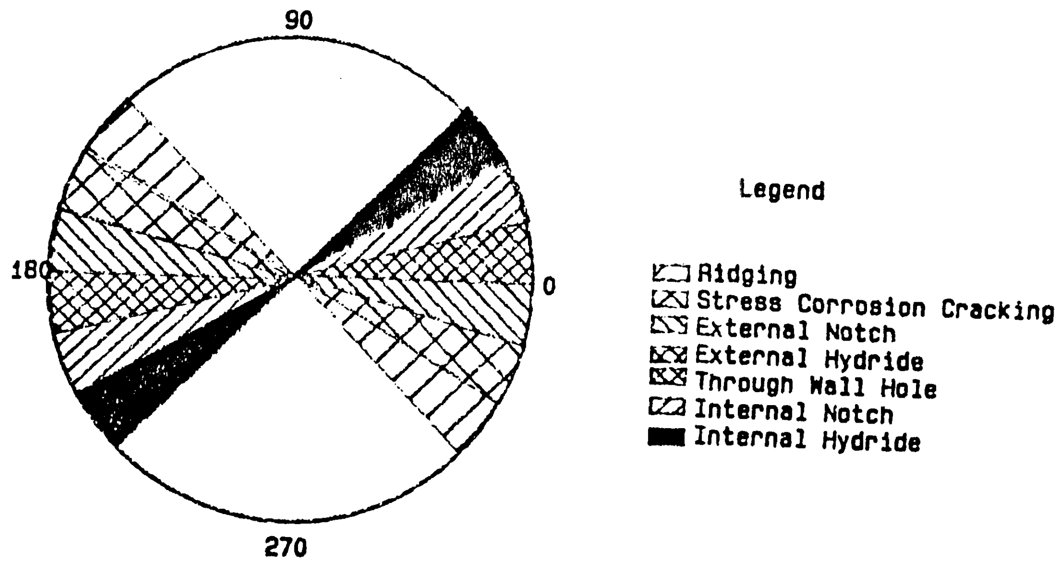


Figure 2.1.7 - Characteristic Phase Angle For Various Defects

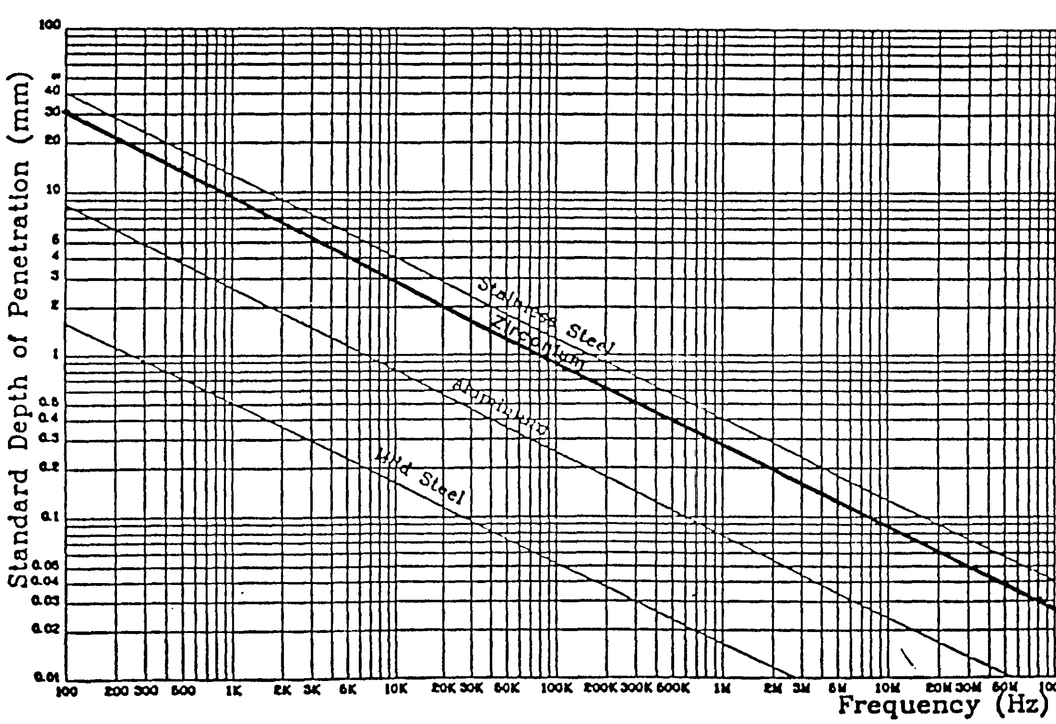


Figure 2.1.9 - Relationship Between Frequency And SDOP For Various Materials.

2.2 ULTRASONIC NON DESTRUCTIVE TESTING

2.2.0 Basic Theory

2.2.1 Ultrasonic Waves

Ultrasonic waves are mechanical oscillations above the human audible range caused by the elastic vibration of particles within a material. As these are mechanical and not electromagnetic waves they assume different wavelengths in different materials. Assuming a sinusoidal vibration it is possible to describe the relationship between the frequency(f), wavelength(λ) and velocity(v) in the well known equation -

$$f = v / \lambda$$

A single pulse of ultrasonic energy may consist of a spectrum of sinusoidal vibrations each having different frequencies and amplitudes. The different wave types are differentiated between depending on their exact method of propagation.

2.2.1 Types of Ultrasonic Waves

Two of the most common wave types applied in ultrasonic NDE are the Longitudinal and the Shear wave.

Longitudinal Waves : able to travel in solids, liquids or gases, with particle motion in the same direction as the wave. Also termed compression waves.

Shear Waves : Only occurs in solids and have particle motion normal to that of the wave. Wave velocity is around half that of longitudinal waves (table 2.2.1).

There are many other types of waves which can be used for specific applications such as Lamb Waves, Rayleigh Waves, Love Waves, Head Waves and Creeping Waves. A more detailed description of each wave and specific applications can be found in /2/.

2.2.2 Transmission Of Waves

When an ultrasonic wave of energy Ei, encounters an interface of two different materials, part of the energy Er is reflected, and part Et is transmitted across the interface (figure 2.2.1). The ratio of reflected to incident energy is termed the reflection coefficient, ar. These coefficients can be related to the acoustic impedences (Z1,2) of each media as follows /15/ -

$$ar = \frac{Er}{Ei} = \frac{(Z1-Z2)^2}{(Z1+Z2)^2}$$

Also,

$$Er/Ei + Et/Ei = 1$$

$$ar + at = 1$$

The ratio of transmitted to incident energy is called the transmission coefficient, at. It can be seen that as the difference between the two acoustic impedences is reduced, less energy is reflected and hence more transmitted across an interface. It is for this reason that, when examining with ultrasonics, all media (i.e. probe, couplant, workpiece) should have similar acoustic impedences.

The angle at which a wave is reflected from an interface is dependant upon the angle of the incident wave. In all cases the transmitted wave undergoes to some degree mode conversion, that is an incident shear wave may lead to the transmission of a compressive wave and vice-versa. The relationship between the incident angle and the refractive angle is defined by Snells Law -

$$\frac{\sin A}{\sin B} = \frac{Va}{Vb}$$ (see figure 2.2.2)

In cases where Vb>Va there exists an incident angle which will give a reflective angle of 90°. This is the critical angle and is related to the two materials forming the interface. Any incident angles greater than this value will result in total reflection of the wave. As compressive and shear waves travel at different velocities in the same medium, an interface will have a critical angle for each, e.g. a perspex/aluminium interface has critical angles at 26° for compressive waves and 58° for shear waves (figure 2.2.3). It can be seen that no compressive or shear waves are transmitted after the respective critical angles.

2.2.3 Generation of Ultrasonic Waves

2.2.3.1 Piezoelectric Effect

Most ultrasonic probes operate by making use of the piezoelectric effect or its reverse. This is a phenomenon which causes the surfaces of certain materials to become charged when they are subjected to an external pressure.

Materials which behave in such a way are termed piezoelectric. These can either be natural occurring crystals such as quartz or synthetic polycrystalline ceramics such as barium titanate /12/. The exact mode of vibration of a particular crystal is dependant upon its cleavage plane, as different planes generate different wave modes. The frequency of the generated ultrasoundis dependant on the size and shape of the crystal. Oscillations can be induced either by an alternating voltage or by a short electric discharge pulse.

2.2.3.2 Magnetostriction Effect

The Magnetostriction Effect is where materials exhibit a change in form when they are exposed to a magnetic field. A typical arrangement for utilising this effect to produce ultrasound can be seen in figure 2.2.4 where a current carrying coil passes through a series of plates. The frequency of the ultrasonic beam that is produced depends on the thickness of the plates but is usually very low i.e. <200 KHz and therefore finds little applications in metal testing but has been used in other field i.e. concrete examination.

2.2.3.3 Electromagnetic Acoustic Effects

One of the advantages of this technique is that it is non-contacting and does not require any coupling to the workpiece /1/. A typical Electro Magnetic Acoustic

Transducer (EMAT) consists of a flat coil and a strong magnet. A high frequency current flows in the coil which induces eddy currents in the specimen surface. These then interact with the magnetic field and the resultant Lorentz forces cause the surface of the specimen to vibrate which in turn sends ultrasonic waves in to the body of the material. The receiving transducer is able to measure the ultrasonic energy indirectly by the reverse process of that for transmission.

Alternative arrangements of the magnet and coil enable different types of ultrasonic waves to be produced. Figure 2.2.5a & 2.2.5b show EMATs for shear and compressive waves respectfully. Shear waves are generated in a vertical, and compression waves in a horizontal magnetic field. A special case of the compression wave EMAT in fig 2.2.5b where the coils are spaced at intervals of half a wavelength will cause surface or Lamb waves to be induced.

One drawback with EMATs is that it is not possible to transmit angled beams into a workpiece. The efficiency of transmission is also highly dependant on probe lift off, although at most working frequencies a distance of up to 1mm can be tolerated /2/.

2.2.3.4 Laser Generation Of Ultrasonic Waves

When a laser beam is incident upon the surface of a solid or a liquid it causes a highly localised energy absorption. This in turn leads to very rapid thermal expansion which causes the generation of ultrasonic pulses of energy which transmit into the body of the workpiece. Compressive, Shear and Rayleigh waves can be generated by this technique. Interferometric techniques can then be used to observe ultrasonic waves by monitoring the motion of the specimen surface /13,14/.

2.2.4 Coupling Materials

In order to enable waves to be efficiently transmitted across a solid/solid interface a liquid couplant is used. As solids have much higher acoustic impedances than liquids it is important that the couplant should have a high value of acoustic impedance such as silicon oil, petroleum jelly, thick oil etc. Depending on the thickness of the couplant layer signal interference can occur. In practice, however, the variation in layer thickness over the probe width will cause random variations in the signal.

2.2.5 Inspection Techniques

2.2.5.1 Pulse Echo System

Most ultrasonic probes work using the Pulse Echo (PE) method where a short pulse is transmitted many times a second into the workpiece either directly or through a couplant layer. Any inhomogenities in the material cause some of the wave to be reflected back to the transducer. The resulting signals are usually displayed on an oscilloscope although the exact method of presentation depends on the type of scan that has been performed. Figure 2.2.6 shows a typical A-scan from a specimen containing two defects. A description of the other main methods of displaying ultrasonic signals is given in Table 2.2.2 and in figure 2.2.7. A more detailed explanation of each scan can be found in /3/.

Scan	Description
A-scan	Plot of time against signal amplitude.
B-scan	2-D Cross section showing defect size and depth.
C-scan	2-D Plan view with no information on defect depth.
D-scan	2-D Cross section normal to B-scan.
P-scan	Simultaneous 3-D display of B and C-scans.

Table 2.2.2 - Various Methods of Presentation of Ultrasonic Signals.

2.2.5.2 Time Of Flight Diffraction Methods

This alternative technique of Time Of Flight Diffraction (TOFD) has recently been developed at AERE, Harwell by Silk et al /2/. It differs from other ultrasonic methods in that it does not rely on measuring signal amplitudes and is unaffected by defect orientation, but instead measures the time difference between ultrasonic pulses.

In this method, separate probes and transducers are scanned across the specimen surface at a fixed distance apart. Compressive waves are transmitted into the workpiece which can then either be transmitted past a defect, reflected, mode converted or diffracted at the crack tip. By measuring the time difference between the initial pulse and these diffracted signals it is possible to establish the exact position of a defect. The main drawback with this method is in examining defects with jagged edges due to the multiple diffractions.

2.2.5.3 Synthetic Aperture Focusing Technique

There are a number of methods for recording and processing data from a scanning transducer which gives the impression of using a much larger transducer with superior resolution and signal to noise ratio. One such method is the Synthetic Aperture Focusing Technique (SAFT). This technique records wave amplitude and phase of pulsed ultrasound from a number of probe positions. Signal noise is reduced by averaging a series of pulses from each position /4/. A flight time correction is applied to each signal and the resulting signals are then mixed to give an improved defect signal.

2.2.6 Applications

2.2.6.1 Thickness Testing

One of the most important applications of ultrasonics is the measurement of material thicknesses. The material thickness is determined by measuring the time of flight of the backwall echo. The precision of the measurement relies on the velocity of ultrasound in the material being accurately known. Most commercial systems are capable of measuring thicknesses from 1mm to 300mm to an accuracy of 0.01mm /2/, whilst some workers /5/ have shown an accuracy of 0.0075mm on the wall thickness measurement of Zirconium tubing.

2.2.6.2 Tube Testing

Ultrasonics have also been successfully applied to measuring wall thicknesses and defect detection in metal tubes. By using a piezoelectric probe some workers have claimed a resolution of 0.01mm over tube diameters from 2-25mm. EMATs suitable for the generation of surface waves (Section 2.2.3.3) have been used successfully for defect detection in tube walls. This arrangement is susceptible to lift-off, so probe/surface separation should be less than 1mm with the operating frequency between 300kHz and 500kHz /2/.

2.2.6.3 Automated Inspection Systems

When examining specimens of a known geometry it is possible to automate the scanning procedure to provide a satisfactory coverage of the area required. It is also possible to gate the A-scan so that the display only shows the portion of the pulse where relevant flaws might occur. By relating the movement of the probe to the timebase, positional information on defects can be obtained. There are many different automated systems available such as 'Zipscan' developed by Harwell /6,7/ a multipurpose system using either TOFD or PE, 'ALOK' developed in Germany by KWU /8/ or 'CUSS' a dual probe system developed in the USA by Garret Engineering for inspection of gas turbine components. /9,10/. A comparative assessment of these and other systems can be found in /11/.

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MATERIAL	LONGITUDINAL WAVES Velocity (x1000)	Wavelength (um) 15MHz	Wavelength (um) 30MHz	SHEAR WAVES Velocity (x1000)	Wavelength (um) 15MHz	Wavelength (um) 30MHz
Zirconium (Annealed)	4.6	310	155	2.25	150	75
Zircaloy-2 (Cold Drawn)	4.62	308	154	2.34	156	78
Zircaloy-4 (Cold Drawn)	4.53	302	151	2.44	162	81

Table 2.2.1 - Comparison Of Properties Of Ultrasonic Waves In Zirconium And Zircaloy.

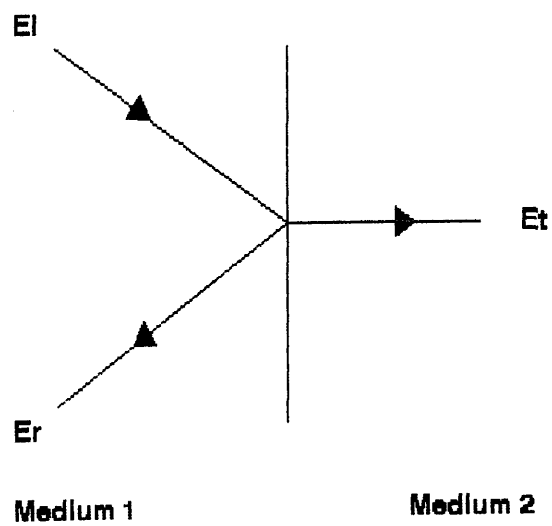


Figure 2.2.1 - Sound Energy Transmission Between Two Media.

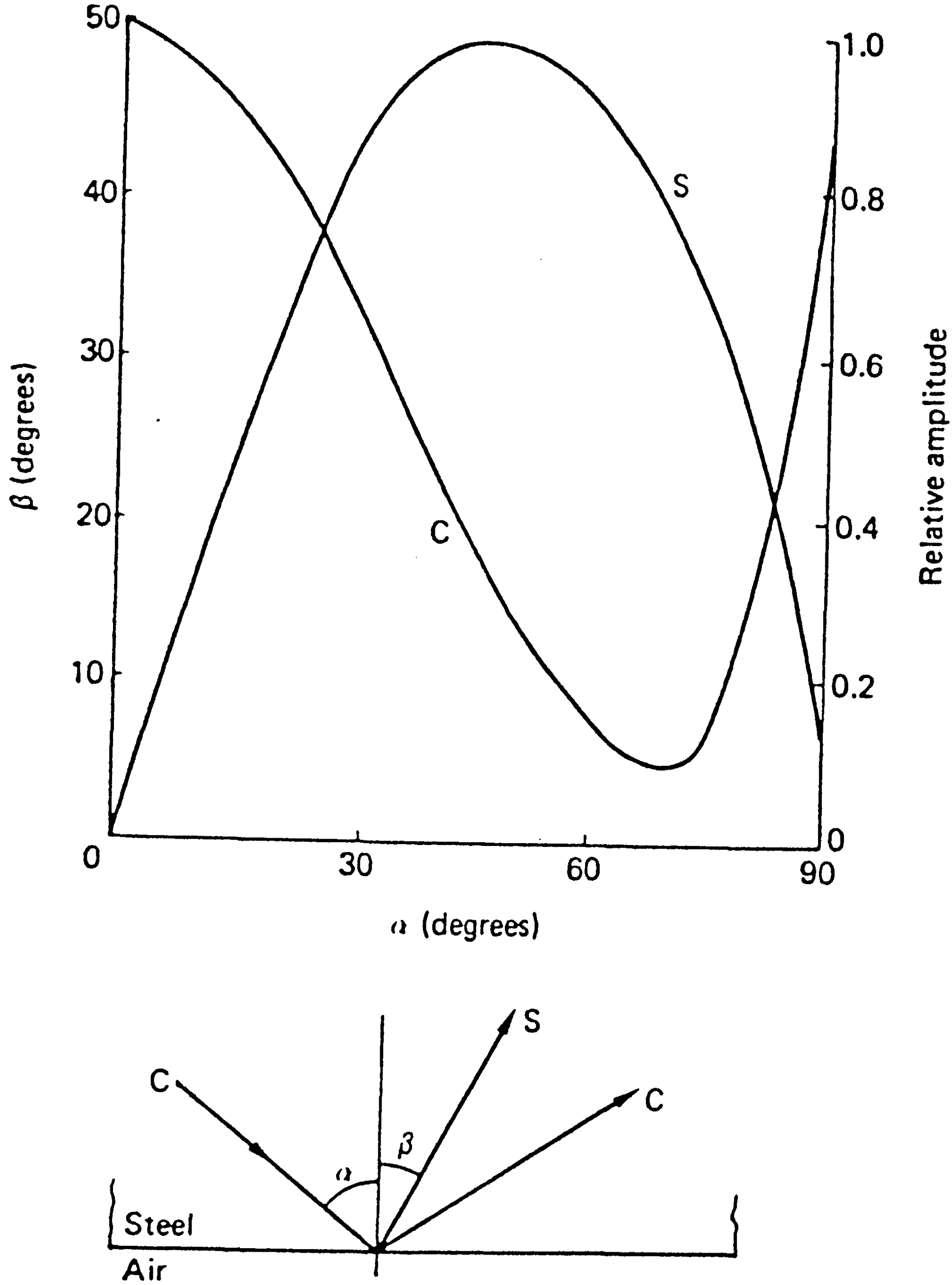


Figure 2.2.2 - Relative Amplitude Of Reflected Waves At Steel/Air Interface From Incident Compresive Waves.

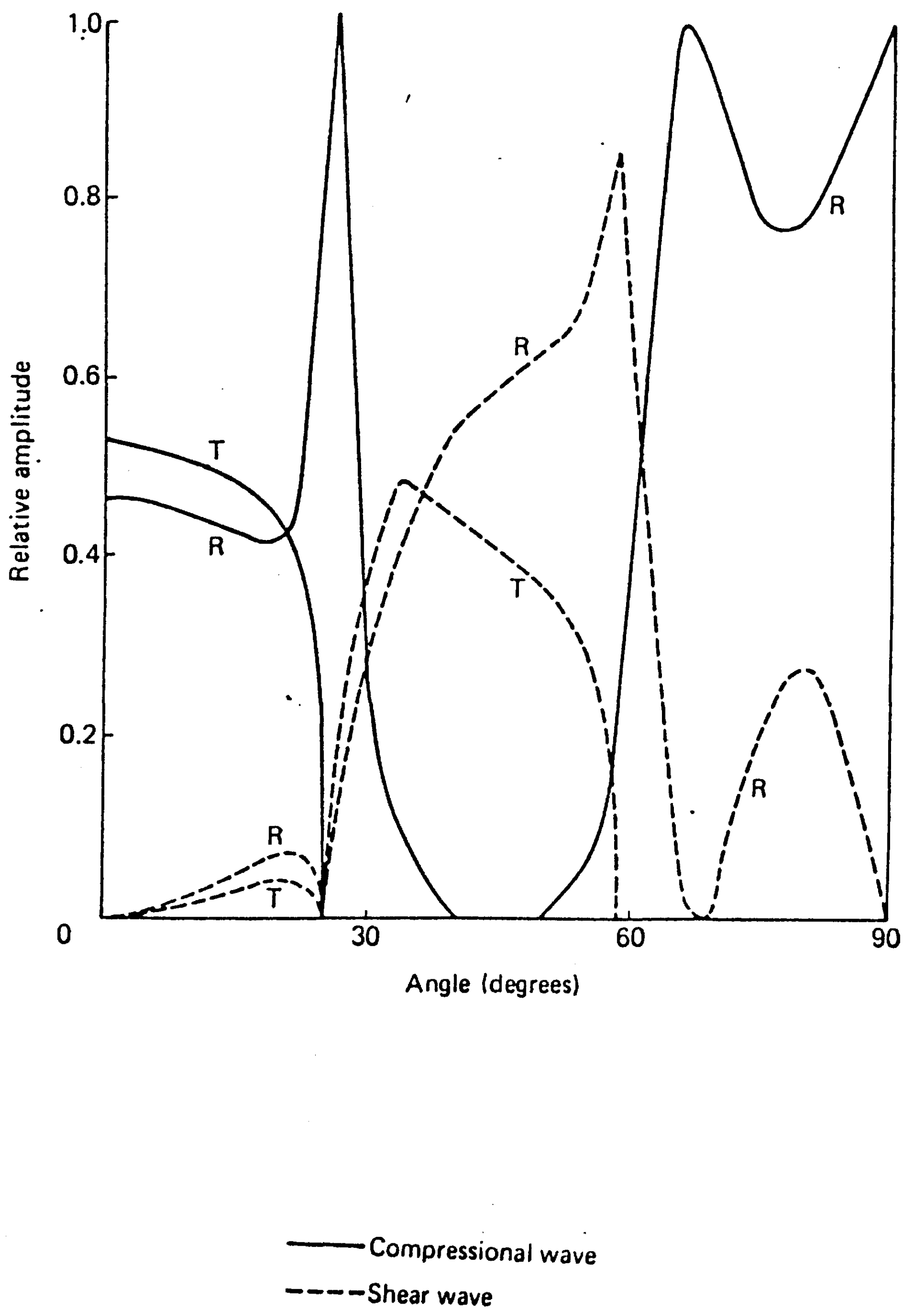


Figure 2.2.3 - Relative Amplitude Of Reflected Waves At Perspex/aluminium Interface.

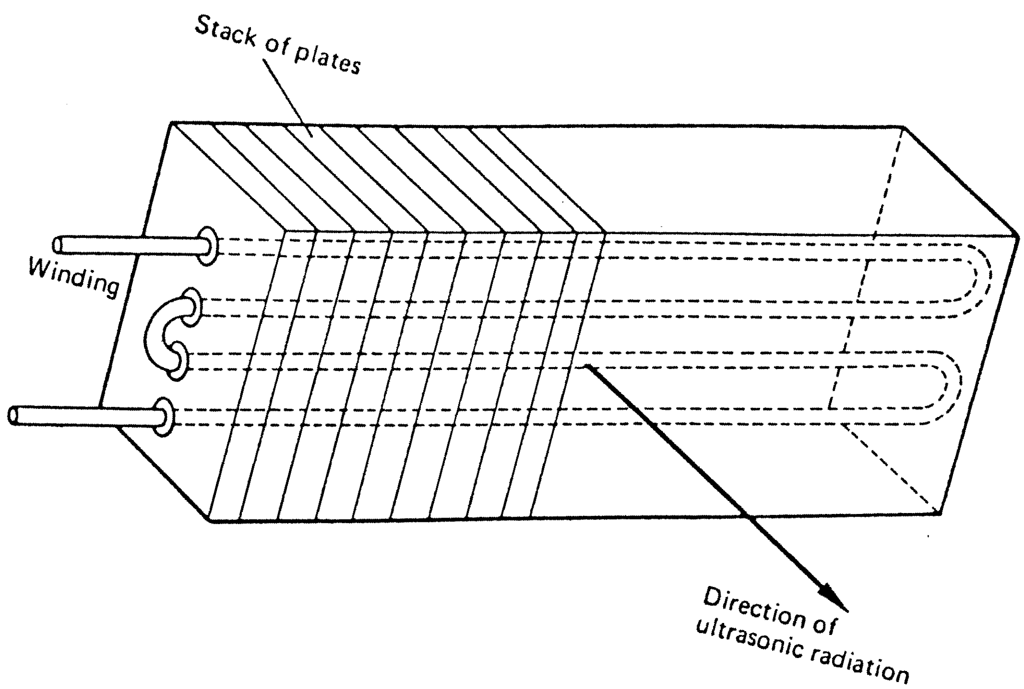


Figure 2.2.4 - Magnetrostrictive Transducer.

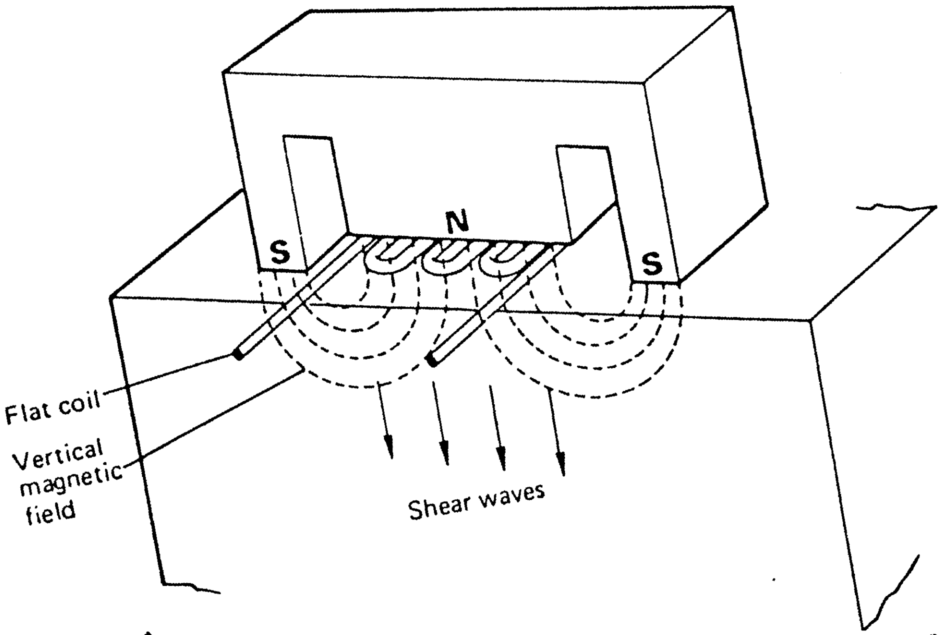


Figure 2.2.5a - EMAT For Production Of Shear Waves.

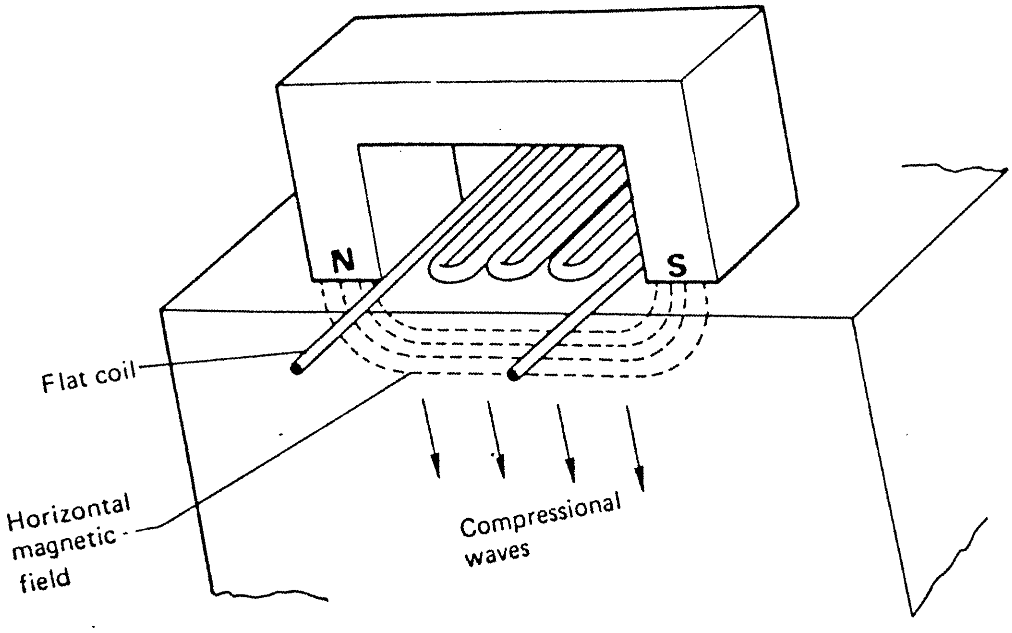


Figure 2.2.5b - EMAT For Production Of Compresive Waves.

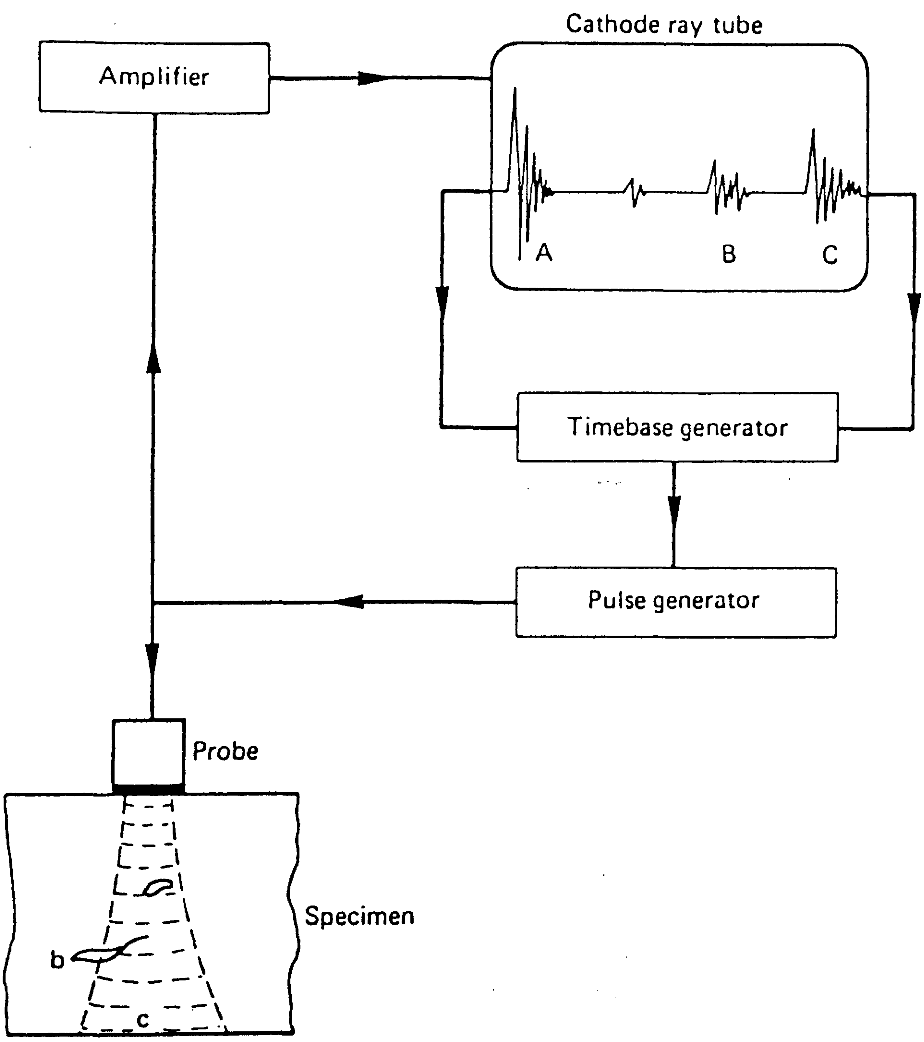
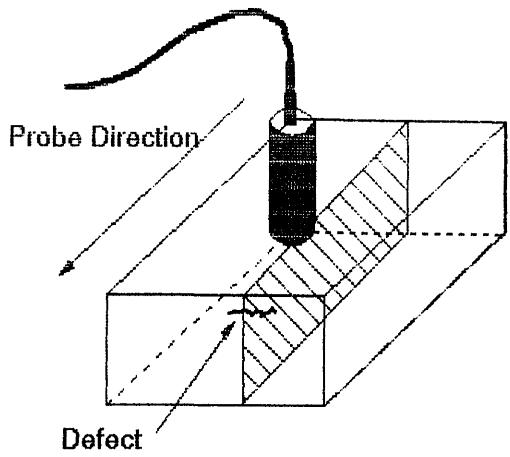
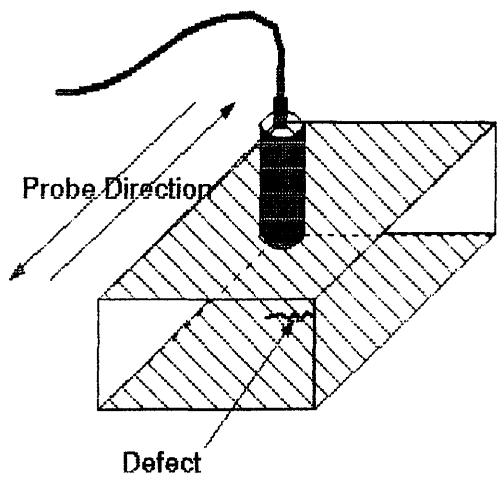


Figure 2.2.6 - A-scan Of Specimen Containing Defect.



B-SCAN

Scan along section of workpiece parallel to probe direction.

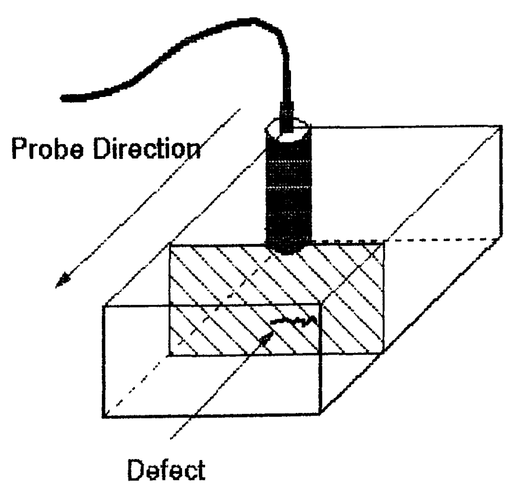


C-SCAN

Combination of B & D scans.

Plan view of workpiece.

Gives no information on defect depth.



D-SCAN

Scan along section of workpiece perpendicular to probe direction.

Figure 2.2.8 - Various Types Of Ultrasonic Scanning Techniques.

2.3 NON DESTRUCTIVE EXAMINATION OF NUCLEAR FUEL RODS

2.3.0 Introduction

There are a number of non destructive techniques which have been developed to monitor the condition of LWR fuel rods. All commercial power reactors operate some form of fuel surveillance program. This is necessary to the ensure safe, reliable operation of the reactor and will involve a number of NDE techniques to give periodic inspections of both fuel assemblies and individual rods. In research reactors, more sophisticated tests are carried out on new fuel designs or on fuel rods subjected to new operating conditions. Several of the techniques can be applied in the measurement of more than one test parameter i.e. eddy currents are used in defect detection as well as in rod diameter and oxide thickness measurement.

Fuel examinations can be conducted either in a Hot Cell or an In-Pool environment. Hot Cell examination enables more precise measurements to be taken, but in general is only performed on a small number of rods which have previously been subjected to in-pool examination. The main disadvantage with Hot Cell examination is that it requires the rod to be transported from the pool after a long cooling off period. This is not only expensive but also introduces the possibility of damage to the rod by mechanical shock. Another problem associated with Hot Cell examination is the disposal of any active waste. In-pool examination on the other hand, requires less handling, produces less waste and can be performed a relatively short time after removal from the core. Whilst the main emphasis of this section shall be placed on three in-pool examination techniques, (eddy current, profilometery and ultrasonics) occasional reference shall be made to other applications where it is deemed appropriate.

2.3.1 In-Pool NDE Systems

The methods and techniques used in-pool have generally been derived from similar applications in the hot cells. There are a large number of methods employed for the examination of both fuel rods and assemblies. Most In-pool systems consist of a number of different sensors located together in a multiple examination facility.

2.3.2 Eddy CurrentSystems

2.3.2.1 Defect Detection

Almost all of the systems used for the in-pool examination of fuel rods have as their basic element an eddy current encircling coil /1-4/. Although an encircling coil can only provide information on the axial, and not the circumferential, position of a defect, it does enable a more rapid examination than would be possible by using point probes which can give a precise location. To overcome this some systems, such as that described in /2/, use an encircling coil for a fast volumetric scan and then later re-examine areas which have given suspect signals using a point probe if required. The systems encountered during the Design Review (see section 2.4) used test frequencies of between 64-256 MHz depending on the nature of defect to be detected.

2.3.2.2 Oxide Thickness Measurement

Another important application of eddy currents is in the measurement of oxide layer thicknesses on the external surfaces of fuel rods. In this application a small point probe is used to measure the 'lift-off' due to the non-conducting oxide between the cladding and the probe. The probe is held in constant contact with the surface by means of a small spring force. Care must be taken to ensure that the contact pressure is not great enough to damage the fuel rod surface /6,10-13/.

It is important to be able to monitor the oxide layer thickness as it possesses different mechanical and heat transfer properties from the parent metal. Any significant build up of oxide deposits could lead to a reduction in fuel rod performance and also increase the likelihood of failure due to burn out /16/. It is generally accepted that an oxide thickness of 0.07mm (approximately 10% of wall thickness) is the maximum tolerable for PWR rods /14/. Eddy currents, therefore, do not have to penetrate deep beneath the surface of the cladding so the required depth of penetration is low and the corresponding test frequency high. During the Design Review test frequencies used to measure oxide thicknesses were in the region of 2-3 MHz, although the Nippon Fuel Laboratory, Japan has successfully used frequencies as low as 0.5MHz /11/.

In some cases oxide thickness measurements are done in conjunction with crud sampling. Crud is the name given to the various deposits that form on the outer surface of the fuel rod after long periods of immersion in water. There are systems which can perform the two operations simultaneously /3,12,13/,

2.3.2.3 Diameter Measurement

Eddy current probes may also be used for the in-pool non-contact diameter measurement of PWR rods. Such a system generally consists of a pair of diametrically opposed point probes at a known distance apart. The distance between each probe and the rod surface is established by examining the 'lift-off' component of each signal. Rod diameter can then be determined by subtracting the two probe/surface readings from the known probe/probe separation. Again this system is usually incorporated into a multiple examination facility /5,17/. Such diameter measuring systems can resolve the fuel rod diameter to 0.005mm.

2.3.2.4 Tube Wall Thickness Measurement

A more recent application of eddy currents has been in the non-contact determination of cladding wall thickness. Measurement of the cladding thickness is important since the service life of a fuel rod is predicted by the minimum cladding thickness. This is achieved by using a dual frequency probe with the lower frequency having sufficient penetration to measure the lift off plus cladding thickness and the higher frequency only being able to measure the lift off. Subtraction of the two signals will then give the cladding thickness. Battelle Laboratories, USA have developed such a system using frequencies of 50KHz and 5MHz measuring Zircaloy cladding to an accuracy of 0.025mm /28/.

A system operating on a similar principle has been developed in Japan by Kobe Steel to measure the thickness of Zirconium lined Zircaloy cladding. This system uses frequencies of 2MHz and 4MHz and is able to measure the liner thickness to an accuracy of less than 0.003mm /29/.

2.3.2.5 Limitations to Eddy Current Testing

The main drawback with ECT is that as well as being sensitive to defects it is also sensitive to other test parameters i.e. changes in diameter, variations in permeability & temperature, etc. Unless data is interpreted correctly erroneous conclusions can be drawn about the significance of a signal /6,32/. It is for this reason that a supplemental technique (ultrasonic, visual or profilometery) is usually employed in conjunction with ECT to confirm any signals which indicate the presence of a defect. A survey by Bailey et al /7/ found there was a high probability of visually confirming large amplitude eddy current signals, but a much smaller probability (<10%) with smaller amplitude signals. The survey also found that some operators had experienced difficulty in detecting small pinhole defects when using ECT. In addition ECT cannot be used to examine fuel rod end cap weld areas due to the large signals resulting from the end of the rod. These areas can normally only be examined by visual inspection. Whilst ECT is sensitive to axially orientated defects, the ability of ECT to detect circumferential defects is less than that of other methods such as Ultrasonics /26,31/. Limitations have also been found in the reliability of eddy currents to detect incipient defects /8,9/.

2.3.3 Capacitive Transducers

A more recent development in the area of fuel rod profilometery has been the use of capacitive transducers to measure rod diameters. This method operates by passing a fuel rod through a metal ring whose capacitance is continually monitored. Any variation in the diameter of the rod will increase the fuel rod/ring gap and hence alter the capacitance. Although, not in widespread use, this method has been successfully applied in hot cells /18,19/ where rod diameters have been resolved to 0.0025mm.

2.3.4 Contact Diameter Measurement

The most commonly encountered fuel rod diameter measurement technique uses a direct contact method in conjunction with a Linear Variable Differential Transformer (LVDT). In this technique the LVDT is displaced by the fuel rod to give an output voltage in proportion to the magnitude of the displacement. The system has a number of drawbacks. Firstly, it is a contacting system which may damage or alter the surface of the rod which is being examined. In addition it contains moving parts which are liable to seize up if left unused for long periods of time. LVDT's are capable of accuracies of 0.005mm, although they are also subject to temperature variations /7/. Examples of this system can be found in most inspection facilities /2,5/.

2.3.5 Ultrasonic Techniques

The final technique to be discussed is that of the application of ultrasonics to in-pool NDE. Although not in as widespread or frequent use as other testing techniques for the examination of individual rods, ultrasonics do have a number of important applications related to the NDE of nuclear fuel.

2.3.5.1 Ultrasonic Leak Detection

The most common application of ultrasonics in in-pool NDE is for the detection of water ingress between fuel and cladding. These systems rely on the fact that there is very little energy transmission across a wet interface. A defect free rod will therefore give a large return signal compared to that from a rod with a defect which allows water ingress /4,8,20/. The technique is commonly used on fuel pins and/or assemblies as an alternative to sipping. This is a technique where fuel assemblies which contain defective rods are identified by measuring the activity of the primary coolant water around the assembly /6/. There are many such commercial Ultrasonic Leak Detection systems available /21,22/ such as the Failed Fuel Rod Detection System (FFRDS) from BBR Gmbh of Germany. The operation of this system is specifically well documented in /23,24/. Another similar tried and tested system is the ECHO 330 from B&W of the US /25/.

2.3.5.2 Ultrasonic Defect Detection

Ultrasonics have also been applied to the examination of fuel rod cladding integrity. By transmitting shear waves circumferential around the cladding wall it is possible to establish a defects axial position. This method is more effective at detecting external surface defects as reflections from inner surface defects require a more complex interpretation /8/. It is commonly used as a supplemental technique to verify any defect signals encountered during an eddy current scan. Ultrasonics are more suitable for locating circumferential defects and are also considered to have a greater sizing accuracy than ECT /26/. However, Q.A. tests on finished stainless steel cladding tubes have shown that ultrasonics can fail to detect short defects which would otherwise have been detected by ECT and that the two techniques should be seen as being complementary /27,30/.

2.3.5.3 Ultrasonic Test Of Pellet/Cladding Bonding

This is a relatively new technique. It works by transmitting ultrasonic waves radially through the cladding wall and measuring the amplitude of the reflected signal. When there is no bonding between the fuel and cladding the magnitude of the reflected signal is high. However, if there is bonding between the two, some energy crosses the interface and there is only partial reflection resulting in a lower signal received by the instrument.

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2.4 DESIGN REVIEW

Before embarking on the design selection and evaluation a market survey was conducted in order to establish the capabilities of other systems in use in other institutions. The results of this survey can be seen in table 2.4.1. The information it contains is the most

institutions. The results of this survey can be seen in

of these systems which were considered to be the most relevant to our design will now be described in more detail below. The four systems are -

System A - currently in use at the HFR, JRC Petten, The Netherlands

System B - in use at the OSIRIS Reactor, Saclay, France.

System C - mobile inspection frame used by KWU Germany.

System D - mobile inspection frame used by TVO Finland.

2.4.1 System A

The first system to be considered is that which is currently operational at the HFR, Petten /1/. This system has been in operation now for some thirteen years and has successfully been used to obtain information on fuel rods from eddy current and LVDT scans. A scan is performed by rotating and translating the fuel rod through stationary sensors (see figure 2.4.1.).

To perform a scan the fuel rod is held by a handling tool which is then attached to a drive unit through which linear and rotary motion can be transferred to the fuel rod. The drive unit consists of a DC motor and gearbox and is designed to give the rod a linear displacement of 500mm at linear speeds of up to 650mm/min. A potentiometer connected to the drive is used to establish linear displacement with a tacho generator employed for linear speed control. A system of gears between the drive unit and the handling tool enable fixed pitch helical scans to be conducted but in practice this is no longer used.

The drive unit is located 150mm above the water level on a platform at the top of a support frame. This hangs over the poolside wall and also supports a sensor table 3.5m beneath the water level. Two sets of sensors are provided in order to examine both BWR (12.5mm dia) and PWR (10.75mm dia) fuel rods. The sensors are located 270mm apart 460mm out from the pool wall. Each set consists of an LVDT for rod profilometery and an eddy current encircling coil for defect detection. Before passing through the sensors, the fuel rod must first pass a guide funnel and centralising rollers. Depending on the diameter of the fuel rod to be examined, the drive unit must be moved manually above each sensor set.

Tests are performed at a linear speed of 120mm/min with the data from the eddy current coil and the LVDT being recorded on two separate chart recorders. In practice, three scans are performed on a rod at intervals of 120°with the rod being turned manually after each scan.

2.4.2 System B

The next system to be considered is in use at the Saclay Research, France /2/. This can be seen in figure 2.4.2. Although fundamentally similar to that in use at JRC Petten by having a fuel rod moving through stationary sensors, it utilises a different method for holding and moving the tool.

The facility was designed to examine a high residual power rod without generating excessive mechanical stresses or disturbing its cooling pattern. It was designed to perform a variety of NDE tasks which would be used to complement results obtained from neutron radiography and gamma scanning. Inspection of fuel rods is possible using eddy currents, ultrasonics, profilometery or visual methods. Measurement of cladding oxide thicknesses may also be made.

A drawing of the complete assembly can be seen in figure 2.4.2. The main components of the assembly are a support frame, rotating plate, elevator and measuring heads.

At the start of a scan, the rod to be examined is held by a pair of hydraulic tongs which are attached to the elevator bar. This bar can be raised or lowered by means of a chain driven winch. The winch is driven by a stepping motor located on the upper part of the assembly. Rotary motion is achieved by means of a 'rotary plate' which turns a hollow shaft through which the elevator bar slides. At the end of this shaft is a fluid bearing to guide the vertical movements of the elevator and cause it to rotate. This arrangement also has the effect of reducing the transmission of vibrations induced by the mechanisims located in the upper part of the assembly.

The control package which has been developed for the system has three main functions -

- provide manual and/or automatic scan definition and execution.
- provide the operator with the necessary operating information and an overall view of operation.
- monitor safety aspects e.g. limit switches, load transducers, power loss etc.

The system is capable of 2m vertical travel with a positional resolution of 0.1mm at speeds of up to 2400 mm/min. Rotation through 360 is possible in steps of 0.5. Test data is recorded on 4 channel magnetic tape at a maximum sampling rate of 400Hz. Attempts have been made to establish a library of characteristic defects in order to be able to use simple algorithms to help to identify defects.

Future development of this system may enable more rods to be examined and may also incorporate several eddy current coils in order to reduce scanning time or to undertake multi frequency scans. It is also anticipated that further development of the system will incorporate on-line data processing.

2.4.3 System C

A conceptually different approach is taken by that of KWU, Germany for the design of their mobile in-pool NDE facility (see figure 2.4.3) /3/.

In this arrangement the fuel rod is held stationary whilst the sensors are moved along it's length on a mobile trolley. The trolley is moved along the fuel rod by a system of chains driven from a motor on the top part of the frame assembly. The rod is held in position by a handling tool and which is supported at the top of the frame and also midway along it's length. Rotary motion is achieved by a stepping motor which rotates the handling tool enabling linear, circumferencial of helical scans to be conducted.

Four different sensors are located on the instrument trolley - a TV camera (connected to a VCR) for visual inspection, an eddy current point probe for oxide thickness measurement, an eddy current encircling coil for defect detection and an LVDT for fuel rod profilometery.

2.4.4 System D

The final system to be considered is that employed by TVO of Finland /4/. Although this system is less flexible than those already considered, it has been included as it is powered pneumatically.

Unlike the systems previously mentioned, this system is purely dedicated to the measurement of cladding oxide thickness. It is mainly used to examine the periphery rods in a complete fuel assembly. As can be seen from figure 2.4.4. the eddy current probe is located on a table which is able to rotate around a fuel assembly. The probe is pneumatically moved between fuel rods and is traversed along each rod by a trolley. The trolley is raised or lowered pneumatically on a support frame which hangs over the poolside wall.

2.4.5 Discussions And Conclusions

As a result of the survey, it was apparent that there were two conceptually different systems in use for the in-pool examination of irradiated fuel rods. The first, as with systems A and B, has the fuel rod rotating and translating through stationary sensors, whilst the alternative approach in systems C and D has underwater sensors translating along a stationary rod.

The latter approach is more commonly found in systems used in power reactors for the examination of complete fuel assemblies and has a number of salient features -

- can examine individual rods in complete assemblies.
- able to examine longer rods.
- rod can be supported midway along its length.
- cannot perform helical scans.
- requires secondary power source to move underwater sensors.

However, it was decided to adopt the alternative approach having the rod rotating and translating through stationary sensors because -

- only individual rods and not complete assemblies are to be examined.
- the length of rods to be examined was such that they could be raised full length and still maintain a safe depth of water between the active rod and the surface.
- experience has been gained using the existing system operating on a similar approach /1/.
- it allowed the use of existing equipment which would reduce time spent on design and manufacture.

As the overall system concept has now been established, it is now possible to begin to define the detailed specifications for the design of the complete system.

2.4.6 References For Chapter 2.4

1. Perry D.J.
A Versatile, Remotely Operated, Non-Destructive Testing And Inspection Facility For Light Water Reactor Fuel Examination Within The Pool At The High Flux Reactor (HFR) Petten.
JRC Petten Internal Report, December 1984.

2. Marchand L. & Faure M.
Non Destructive Test Bench For Fuel Rods In The OSIRIS Reactor Pool.
Sixth International Conference On NDE In The Nuclear Industry, December 1983.

3. Franke K.P. et al.
Eddy Current Testing As A Tool For Post-Irradiation Examination.
British Nuclear Engineering Society Conference On Post-Irradiation Examination, 1981.

4. Moisio J. & Patrakka E.
Fuel Examination Techniques & Experience At Finnish Nuclear Power Plants.
IAEA Specialists Meeting On Post-Irradiation Examination And Experience, Tokyo, November 1984.

Ref	System Type	Method of Power	Eddy Current Probe	Eddy Current Coil	Test Frequency	Linear Resolution	Angular Resolution	Scan Length	Additional Features & Comments
1	In–pool		Y	Y	3MHz				LVDT, Oxide Thickness Measurement.
2	Hot Cell	Stepping Motor	Y	Y	128 kHz	0.1mm	1°	4200mm	LVDT, Gamma Scanning.
5	In–pool	Stepping Motor	Y	Y	Variable	0.1mm	0.5°	2000mm	LVDT, TV camera.
10	In–pool		Y	N				3200mm	LVDT, Oxide Thickness Measurement.
13	In–pool	Pneumatic	Y	N					
16	In–pool		Y	Y					LVDT, TV Camera.
18	Hot Cell	Stepping Motor	Y	Y	Variable 50–500kHz			4000mm	LVDT, TV Camera, Gamma Scanning, Dual Frequency Eddy Current Testing.
27	Q.A.		Y	N	450 kHz				
28	Q.A.		Y	N	50k & 5MHz				Dual Frequency Eddy Current Testing.
29	Q.A.		N	N	2&4MHz				Dual Frequency Eddy Current Testing. Bobbin Probe For Internal Examination.
30	Q.A.		Y	N	Variable 100–700kHz				Dual Frequency Eddy Current Testing.
32	Hot Cell	Stepping Motor	Y	Y	Variable 200k–1MHz			1000mm	Dual Frequency Eddy Current Testing.

(Reference Numbers Refer To Chapter 2.3.6)

Table 2.4.1 – Operational Capabilities Of Systems Encountered In Market Survey.

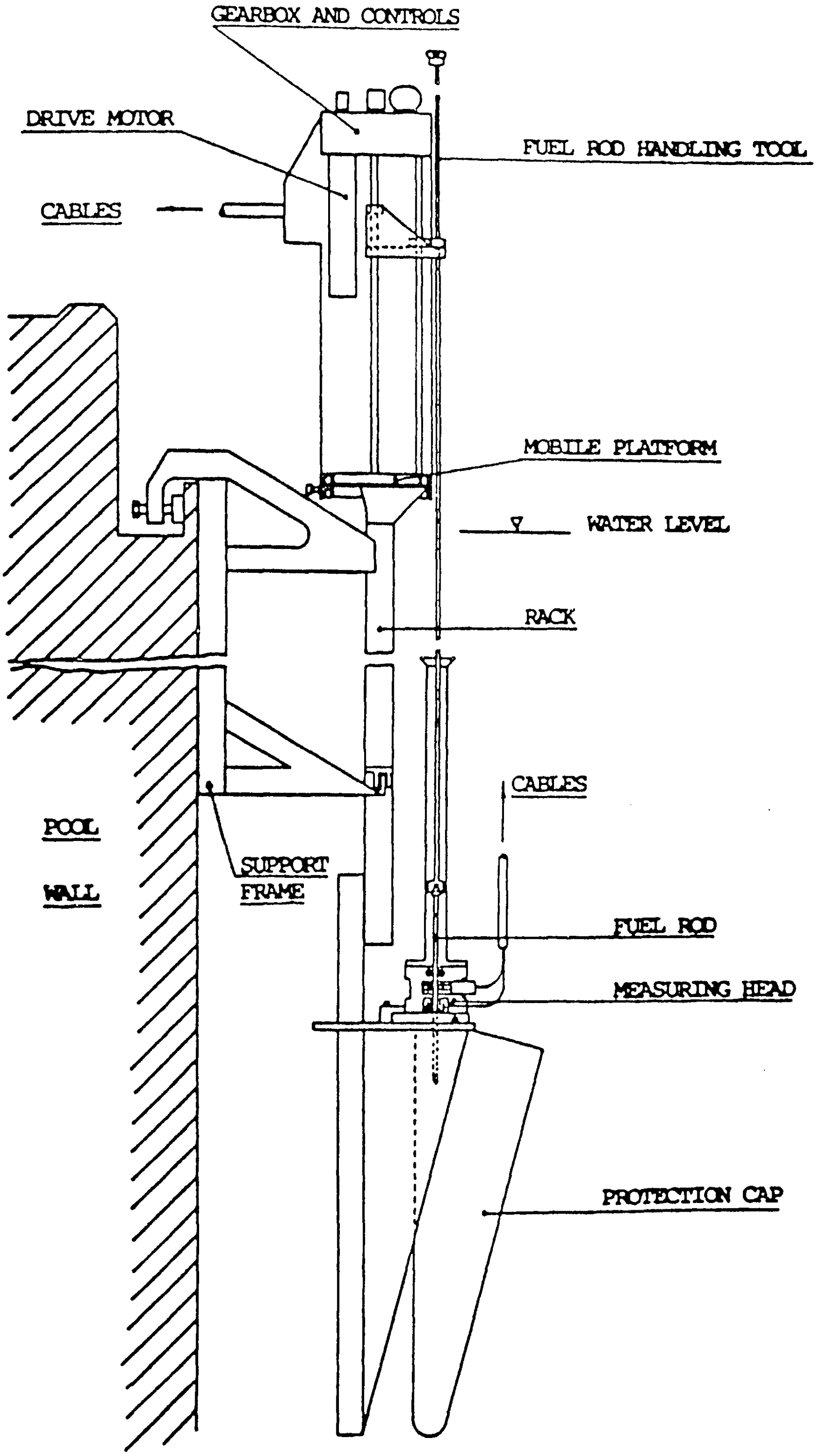


Figure 2.4.1 - Poolside Inspection Facility In Use At JRC Petten

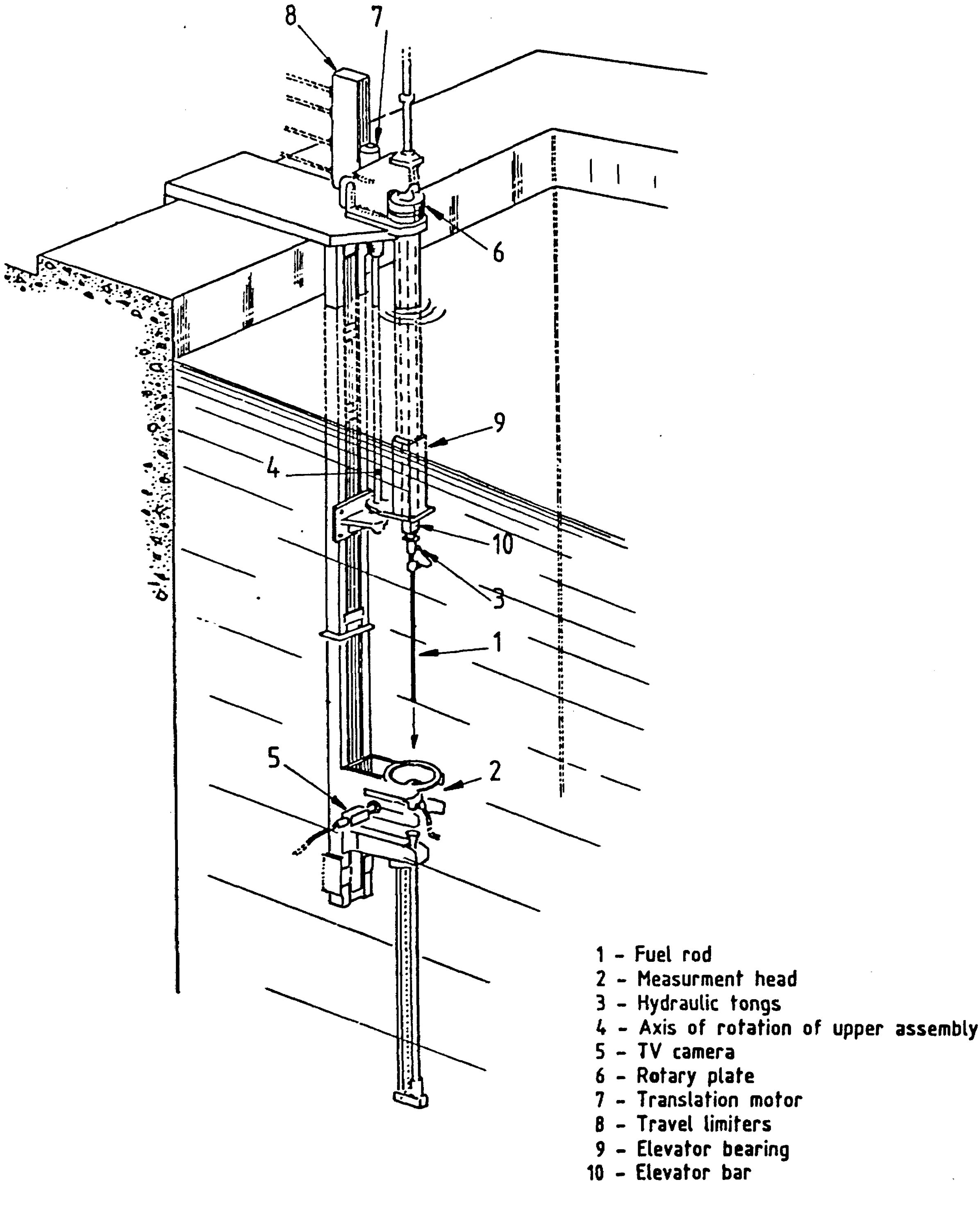


Figure 2.4.2 - Poolside Inspection Facility In Use At Saclay.

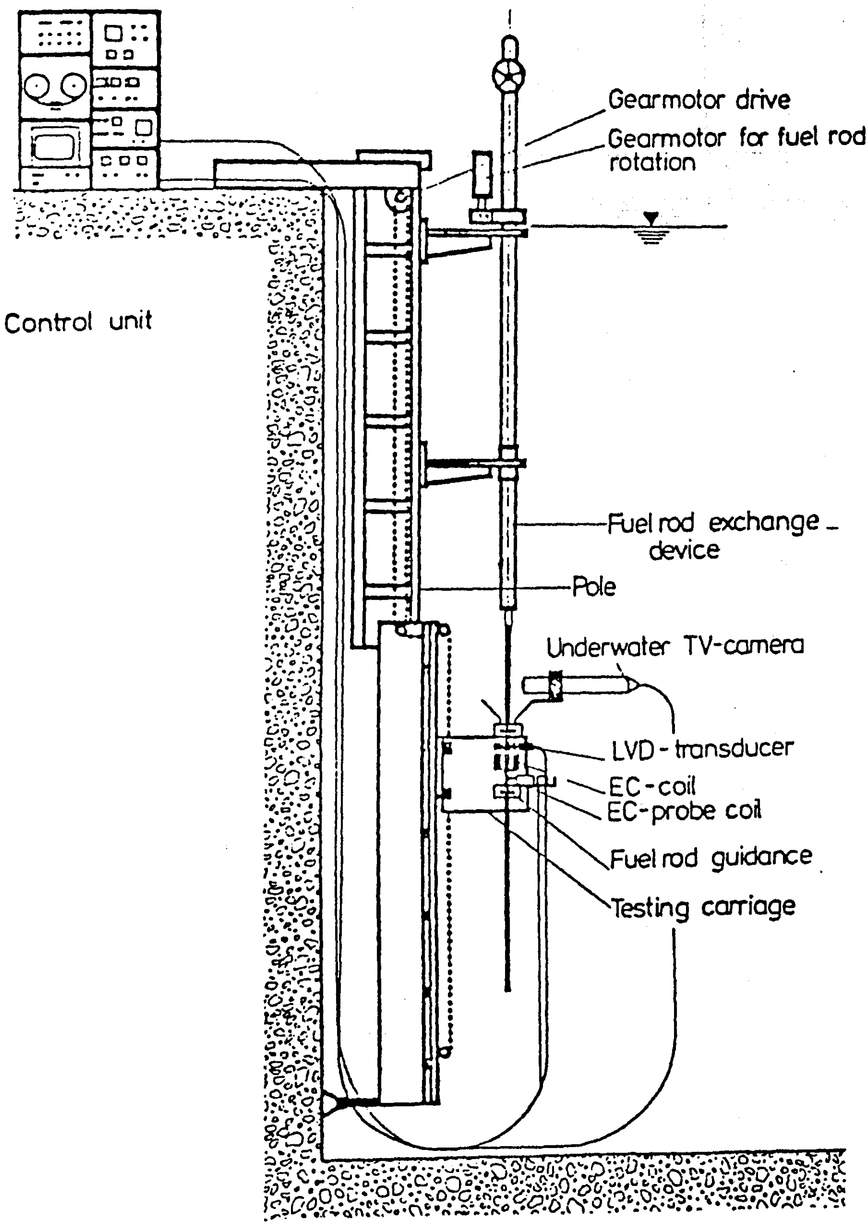
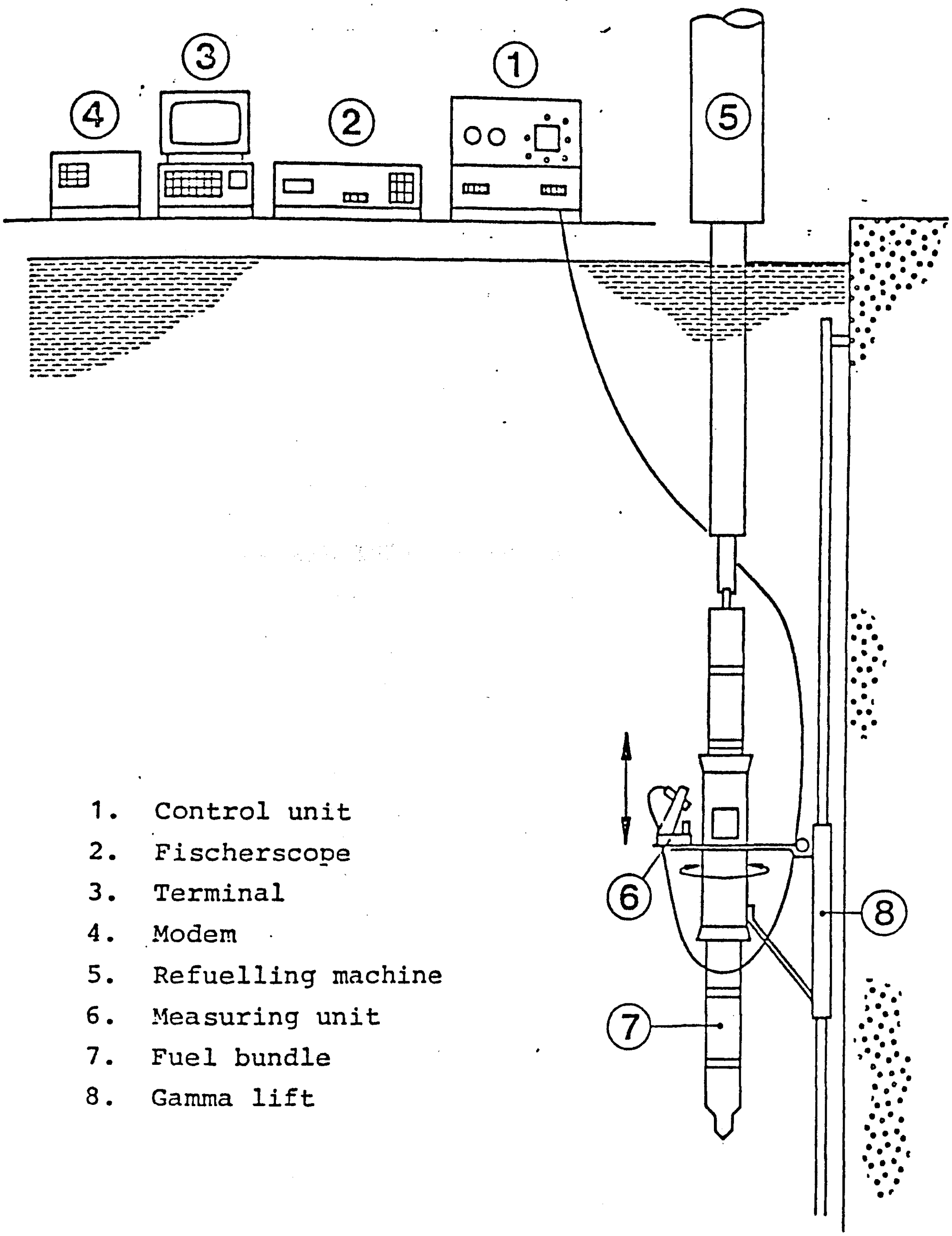


Figure 2.4.3 - Poolside Inspection Facility In Used By KWU Germany.



1. Control unit
2. Fischerscope
3. Terminal
4. Modem
5. Refuelling machine
6. Measuring unit
7. Fuel bundle
8. Gamma lift

Figure 2.4.4 - Poolside Inspection Facility In Used By TVO Finland.

CHAPTER THREE - DESIGN SPECIFICATION

3.0 Design Specification

As a consequence of the Design Review (section 2.4), it was decided to develop a system using a similar concept as the existing facility having the fuel rod rotating and translating through stationary sensors.

Working with this as an overall system concept, the new design must be such that it includes the following features -

(i) progress of examination to be controlled via an IBM PC.

(ii) data logging of examinations at a high enough resolution to prevent need to re-examine areas of rod suspected of containing a defect.

(iii) repeatable linear and angular datum points.

(iv) digital displays showing linear and angular position of fuel rod with respect to datums.

(v) capability to perform helical and vertical fuel rod scans using an eddy current point probe.

(vi) ability to perform helical and vertical scans either individually or combined together in a sequential string.

In addition to incorporating all of the above points, there are a number of important restrictions in relation to the overall system design -

(vii) design, installation and commissioning to be completed within two years.

(viii) ability to examine all of the rods listed in table 3.0.1

(ix) capability to conduct identical fuel rod scans as the existing system in order to be able to compare previous results (i.e. three vertical scans offset by 120^{o}).

(x) all design and safety considerations to be documented in a separate report.

For the purpose of simplification, the overall system design was split into four separate subsections -

(1) system hardware : drive unit, support frame and sensors.

(2) scan definition and control software.

(3) data recording package.

(4) automatic results analysis and reporting package.

The specifications for the individual areas will now be considered separately.

3.1 System Hardware

3.1.1 Drive Unit

In addition to meeting all of the above specifications, the design of the drive unit must also take into account the following-

(i) Drive unit must rotate and translate the fuel rod smoothly through the sensors.

(ii) in the event of a power loss, the drive unit must fail safe and hold the same vertical position. In addition, upon power restoration, the drive unit must remain stationary.

(iii) drive unit must have a linear resolution of 0.025mm and an angular resolution of 0.25 degree.

(iv) due to constraints at the poolside, the top of the drive unit must not exceed 1010mm above the normal water level of the pool.

(v) the drive unit must be able to run manually or automatically, with the possibility of manual interruption during an automatic scan.

(vi) all external electrical connections must be watertight and easily removed.

3.1.2 Support Frame

The support frame must be designed for the following functions-

(i) to accommodate the drive unit on a platform above the pool surface.

(ii) to include an underwater table to allow quick and easy fitting of the sensors from the poolside whilst in-situ.

3.1.3 Sensors

The new facility must incorporate a range of sensors which are able to provide the following -

(i) production of identical reports as that generated by the existing system.

(ii) production of contour maps of a fuel pin surface using an eddy current probe selected from laboratory tests.

(iii) all sensors selected must be able to operate together without any mutual interference.

All of the sensors included in the new system must be able to be accommodated in the sensor cassette system (figure 3.1.3a). This is a recently developed system where different sensors are fitted to cassettes which have identical outer dimensions. A cassette for the eddy current encircling coil is shown in figure 3.1.3b whilst a cassette for an LVDT can be seen in figure 3.1.3c. These cassettes are then located in a common housing between two centralising cassettes (figure 3.1.3d) to ensure the centralisation of the fuel rod within the sensors.

3.2 Scan Definition And Control Software

As previously stated, it is a main requirement of the specification that the progress of a fuel rod scan is controlled via an IBM PC. Consequently, it is necessary that a number of software packages are written to perform the following-

(i) input, via the operator, the necessary test parameters and after completion of test, create a data file which can later be accessed by the Automatic Reporting Package.

(ii) calibrate each sensor to be used during an examination .

(iii) carry out a calibration scan.

(iv) conduct a fuel examination using either a vertical, helical or custom scan.

3.3 Data Logging System

The data logging system must provide the following -

(i) a sufficiently high data acquisition frequency to resolve the internal defect on the calibration pin during one full length scan. This data acquisition frequency will need to be determined from experimental work.

(ii) a minimum of two digital and eight analogue channels.

(iii) data files containing test information which can be handled by an IBM PC.

3.4 Automatic Reporting Package

The specifications for the Automatic Reporting Package are that it must be able to -

(i) produce identical reports as present .

(ii) run on an IBM compatible PC.

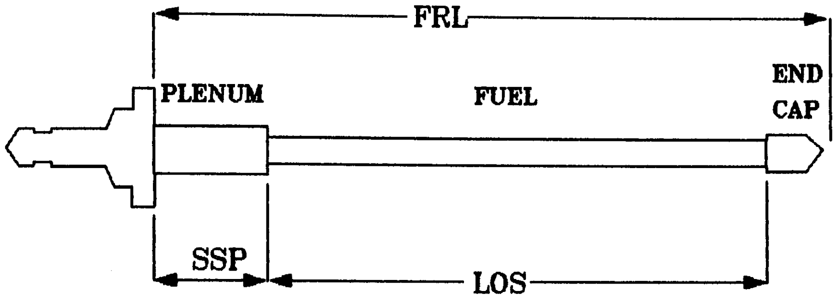
(iii) handle the data generated by the data logger.

(iv) take into account sensor offset to produce in phase plots from several sensors.

(v) use data from eddy current point probe and/or LVDT to produce contour plots of the pin surface.

(vi) perform ridging analysis on data from a diameter scan.

(vii) include data from a gamma scan and/or previous test results if required.



FRL = Fuel Rod Length

LOS = Length Of Scan

SSP = Scan Start Position

Drawing Number	Diameter	Fuel Rod Length (FRL)	Scan Start Position (SSP)	Length Of Scan (LOS)
33845	10.75	458	55	390
33886	10.75	534	100	390
33950	10.75	534	108	382
53881	10.75	534	90	390
36378	12.5	458	55	390
35343	12.5	534	100	390
40868	12.5	534	100	390

(All dimensions in mm.)

Table 3.0.1 - External Dimensions Of Fuel Rods To Be Examined

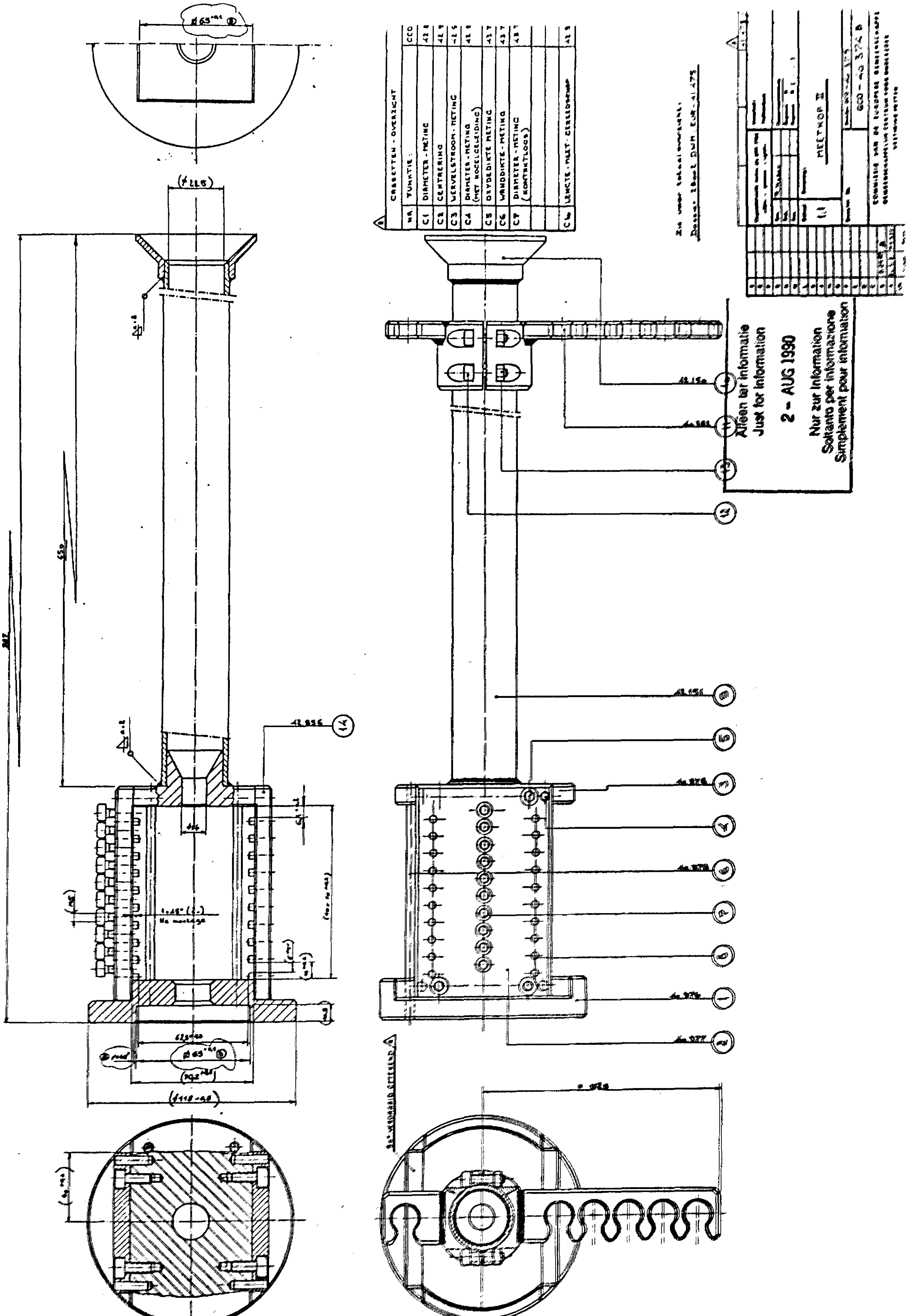


Figure 3.1.3 a - Assembly Drawing Of Cassette Housing

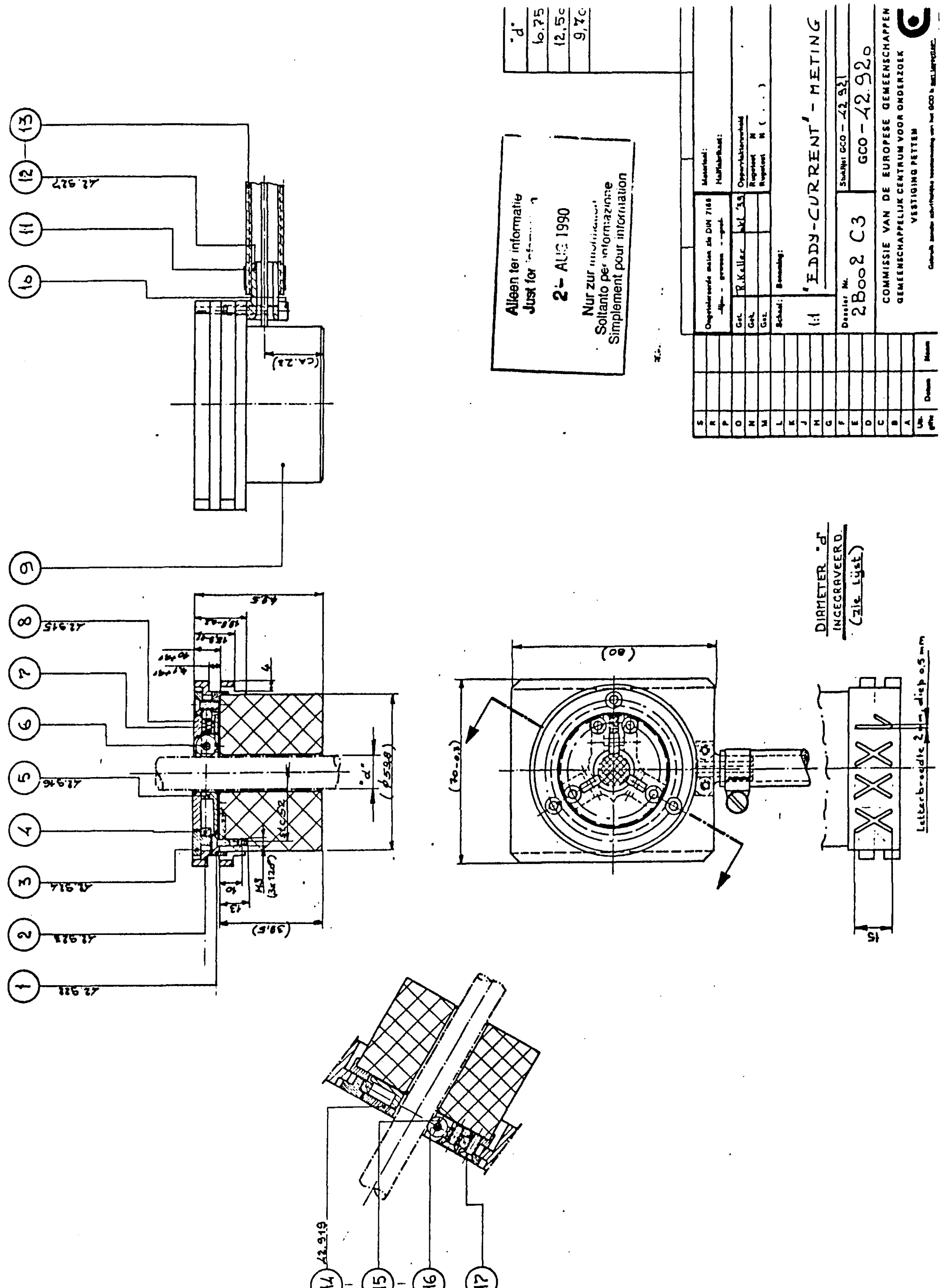


Figure 3.1.3b - Assembly Drawing Of Eddy Current Cassette.

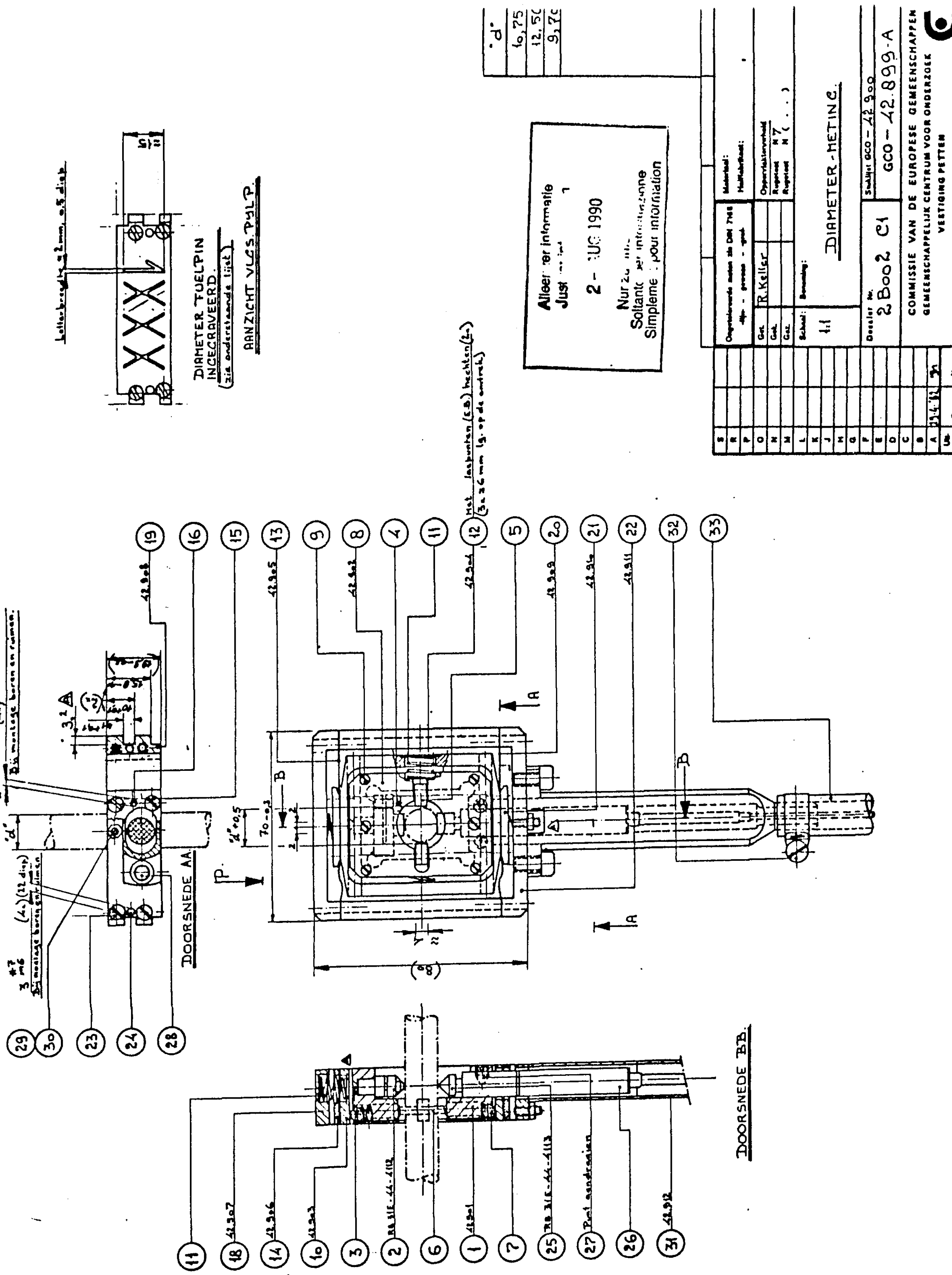


Figure 3.1.3 c - Assembly Drawing Of LVDT Diameter Measuring Cassette.

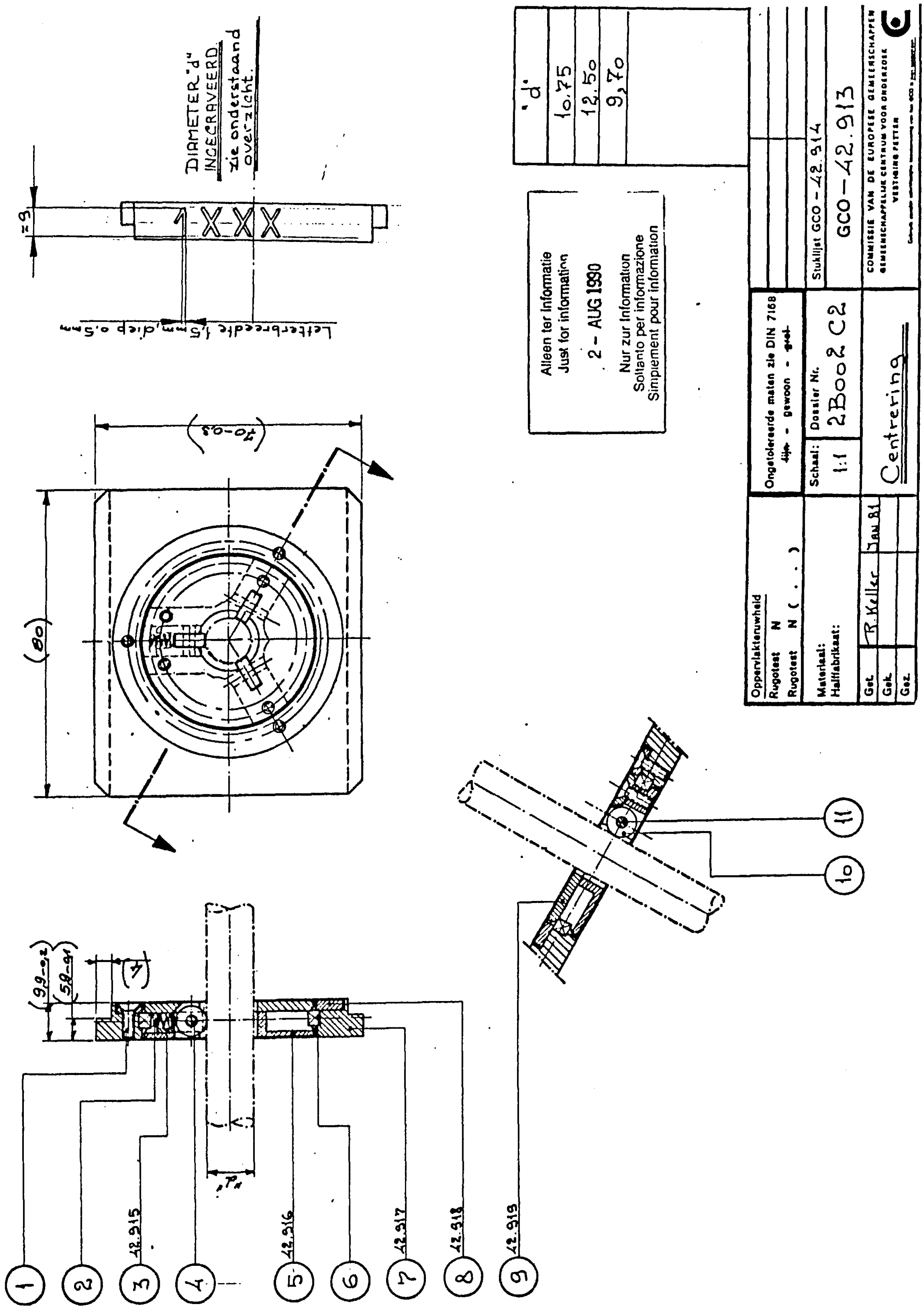


Figure 3.1.3d - Assembly Drawing Of Centralising Cassette.

CHAPTER FOUR - DESIGN SELECTION

4.0 DESIGN SELECTION

In order to best satisfy the Design Specifications, the Design Selection and evaluation was split into a number of distinct phases or subsections. These phases were concurrent with the breakdown of the overall system design within the Design Specification (section 3.0). For each phase, alternative concepts were generated as solutions to the specifications and a critical selection and evaluation carried out.

4.1 System Hardware

4.1.1 Drive Unit

4.1.1.1 Method of Powering Drive Unit

As a result of the Literature Survey (Section 2.3) and Design Review (Section 2.4) it was evident that there were a number of options available for powering the drive unit e.g.-

(i) DC stepping motors

(ii) DC server motors

(iii) pneumatic motors

It was decided to adapt an existing two axis programmable stepping motor drive system using one motor for rotating and one for translating the tool. The utilisation of an existing system would eliminate any possible delays in procurement and additionally a number favourable attributes make stepping motors ideal for this particular type of application.

(i) they can be used in an open loop control system without the need for any additional feedback components as is necessary with DC servo motors.

(ii) they offer excellent point to point positioning capabilities as the speed and distance travelled are controlled by counting the stepping rate and the number of steps performed.

The drive system consists of two Stebon FDL 602-250-45 DC stepping motor drives and a Digiplan IF-2 Motor Controller. The two motors supply a maximum output torque of 0.2Nm and are able to operate in a half step mode giving 400 steps/revolution. An RS-232 interface on the Motor Controller by a PC and it also contains a clock datum card enabling both motors to be sent to repeatable datums points thus satisfying parts 3.0i&iii of the Specification.

A schematic diagram showing the layout of the drive unit at this stage in the design phase can be seen in figure 4.1.1. The main points to note are the toolholder located on an arm which moves up and down the backplate of the drive unit along a pair of linear slides.

4.1.1.2 Positioning of Stepping Motors

The motor to rotate the tool was placed on the moving arm immediately adjacent to the toolholder and rotates the handling tool by means of two nylon spur gears (see figure

4.1.1). The gears were chosen to have a 1:1 ratio and a module of 1 mm. This gearing system was chosen as:

(i) it offered the shortest drive path between the handling tool and the motor and

(ii) it allowed the handling tool to be easily removed from the tool holder.

Initially it was intended to hold the tool in the toolholder using a combined set of roller and thrust bearings. Unfortunately, due to the adverse nature of the proposed working environment, it was later considered that this arrangement was liable to corrode and lubricant loss and was therefore deemed unsuitable. It was replaced with a dry bearing of aluminium bronze running on stainless steel. Consequently due to the increased friction in system, the available stepping motor did not have sufficient power to rotate the tool. To overcome this problem a gearbox of ratio 40:1 was added to the output shaft of the stepping motor. with this arrangement the angular resolution of the system is 0.02 degree which is within the specification of 0.1 degree.

As established from the Design review, the toolholder will be contained on an arm which moves vertically up and down the backplate of the drive unit along two linear slides. With this arrangement there are a number of possibilities for transferring drive from the motor to the arm-

(i) Place motor on backplate and connect to a screw shaft with the arm running along the screw by means of a ball screw bearing.

(ii) Place motor on arm and move arm along the backplate by means of a rack and pinion system.

(iii) place motor on backplate and couple directly to the arm by a chain or belt drive.

The first arrangement is the most widespread and was chosen for our design because:

(i) it allowed the stepping motor to be mounted adjacent to the shaft thereby enabling the drive path to be kept to a minimum.

(ii) the screw shaft/ball screw bearing combination has a very low friction coefficient.

The motor was connected to the screw shaft by a belt drive as this offered a number of operational benefits -

(i) any vibrations from the motor is reduced due to the damping action of the belt.

(ii) positioning of the motor relative to the screw shaft is more flexible as the separation is only dependant on length of belt and not gear size.

The belt drive has a reduction ratio of 2.5:1 which gives a linear resolution of 0.014mm thus meeting Specification 3.1.1iii.

4.1.1.3 Orientation Of Drive Unit

The basic design outline for the new system has now been established, therefore the next phase was to decide how to integrate this chosen design into the proposed working environment. Three different options were considered -

(i) slides and bearings are aligned parallel to the poolside wall on the front of the drive unit with the toolholder located on the middle of the arm. The drive unit is moved into different positions along the frame baseplate and secured, by a locating bolt, above the required sensor location (see figure 4.1.1.3a).

(ii) slides and bearings are aligned as in (i) but with separate toolholders at opposite ends of the arm positioned above each sensor set (Figure4.1.1.3b)

(iii) slides and bearings are located perpendicular to the pool wall and the toolholder is attached to the end of the arm with the unit being moved as in (i) (Figure 4.1.1.3c).

It was decided to use (iii) as this permitted the drive unit to be fitted to a baseplate of the similar dimensions as the existing system. This would allow a much greater use of the existing equipment with only minimal redesign work concentrated on a few critical components. Consequently, this would reduce the workload and shorten the timescale of this part of the project.

4.1.2 Support Frame

4.1.2.1 Support Frame / Drive Unit Interface

In order to accommodate the drive unit on the existing support frame, it was necessary to modify both the drive unit baseplate and the frame support plate.

The only alterations made to the drive unit base plate were to move the holes for the locating bolts which attach the drive unit to the baseplate. The holes were relocated so that they would be easily accessible when the unit was fully assembled.

Unlike the existing system, the toolholder was located off the centreline of the drive unit as a result it was necessary to increase the overall length of the support plate to 460mm.

4.1.2.2 Support Frame / Sensor Interface

In order to incorporate the cassette box system in to the design and to facilitate ease replacement of faulty sensors, the bottom of the cassette box has been modified to include a square recess. This recess fits loosely over a square plate on the sensor table and is then secured to the table by two locking D-nuts.

A schematic of the fully assembled support frame containing the drive unit, fuel rod handling tool and sensor housing is shown in figure 4.1.2.

4.1.3 Sensors

To enable the new system to carry out identical examinations as the existing system (Specification 3.1.3i), it is necessary to include an LVDT and an Eddy Current encircling coil identical to those presently in use. However, to fulfill specification 3.1.3ii it will be necessary to provide an Eddy Current point probe in the new sensor set. In order to ascertain the most suitable probe for our needs, a number of different probes will be evaluated in a series of laboratory tests (see Chapter 5.3). It will also be necessary to conduct a number of commissioning tests to establish the suitability and interaction (if any) of the sensors selected as required in specification 3.1.3iii.

4.2 Scan Definition And Control Software

In order to best satisfy the specification for the scan definition and control software (specification 3.2), it was decided to write the software using GWBASIC. A flowchart of the program structure can be seen in figures 4,2,1a-c. The software is run on a Corona IBM compatible PC and controls the stepping motors via the programmable interface. Due to memory restrictions the software had to be written in four separate programs and then chained together. The names and functions of the four programs are-

(i) CALSCAN.BAS - input test information, calibrate sensors and carry out a calibration scan.

(ii) VERT.BAS - execute either three vertical scans separated by 120^{o} or one helical scan at a predetermined pitch.

(iii) CUST.BAS - allow operator to create custom scan from selected elements and then carry it out.

(iv) SPLINE.BAS - carry out a series of 37 vertical scans separated by 10^{o}.

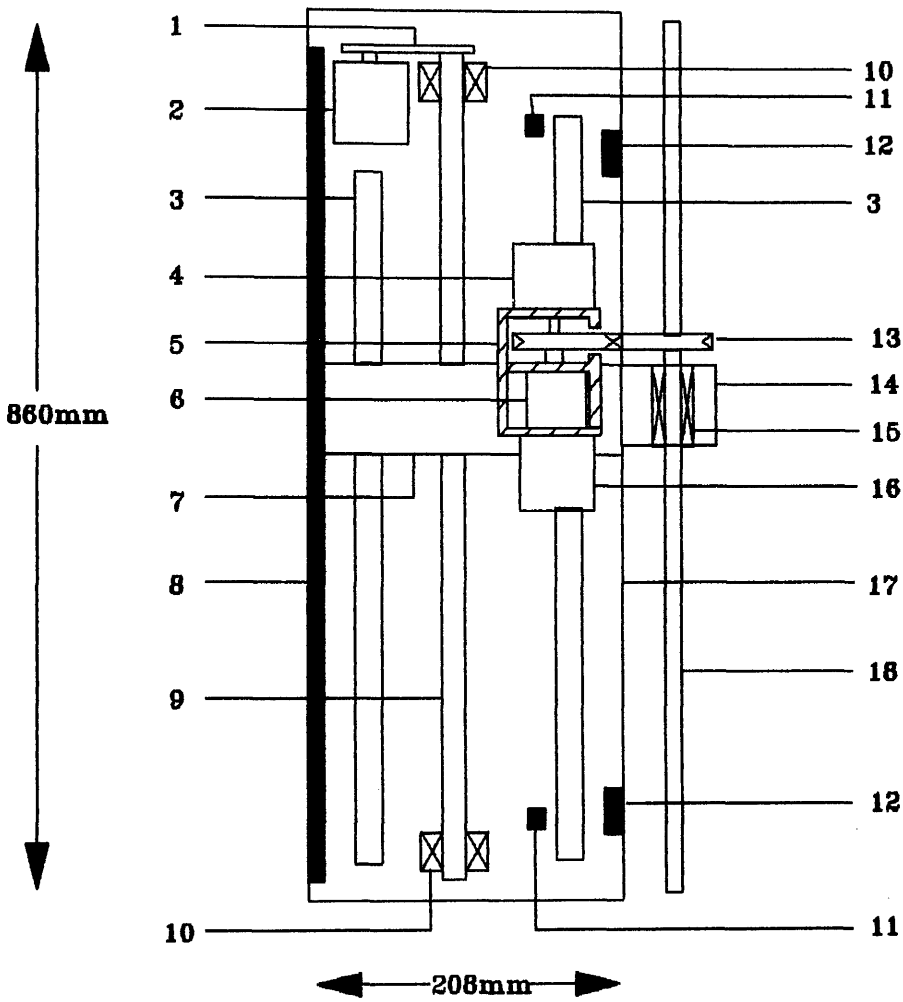
In addition, all four programs contain a sub-routine to continually monitor the interface for the presence of faults in the drive unit. If a fault is detected, the drive unit is immediately stopped and the operator is informed as to the cause of the problem and how best to correct it. Once the fault has been removed, the test restarts from the stage immediately before the fault occurred.

4.3 Data Logging

A NEFF System 470 Data Acquisition System was selected to be used for the data logging of the fuel rod examinations. The system consists of a NEFF 470 data logger controlled by the NDAS-PC software package. This is an IBM PC run, menu driven package to control the operation of the data logger. The data is initially recorded in a compressed binary format and is later converted off-line to a standard ASCII file. The data logger accepts both digital and analogue inputs and is capable of recording data at frequencies greater than 100 Hz. The data is recorded using a 'ping-pong' buffer method so that whilst one buffer is recording data the other is writing data to disc. Thus preventing non-registration of data due to disc operations.

4.4 Summary

The main operating characteristics of the facility are shown in table 4.4. The maximum force on a fuel rod was determined experimentally, whilst the maximum torque was derived by calculation. A schematic of the proposed layout of the complete facility in the Reactor Hall can be seen in figure 4.4a along with the corresponding cabling layout in figure 4.4b. A photograph of the drive unit in the test pool at JRC Petten can be seen in Figure 4.4c.



1. Drive Belt (Reduction Ratio 2.5:1)
2. Stepping Motor (Output Torque 0.2Nm)
3. Linear Slide
4. Angular Absolute Encoder
5. Gearbox Housing
6. Gearbox (ratio 40:1)
7. Moving Arm
8. Linear Encoder
9. Screw Shaft
10. Bearings
11. Mechanical End Stop
12. Electrical Limit Switch
13. Meshing Spur Gears (Module 1, Ratio 1:1)
14. Toolholder
15. Dry Bearing
16. Stepping Motor (Output Torque 0.2Nm)
17. Drive Unit Backplate
18. Fuel Rod Handling Tool

Figure 4.1.1 - Schematic Drawing of Drive Unit

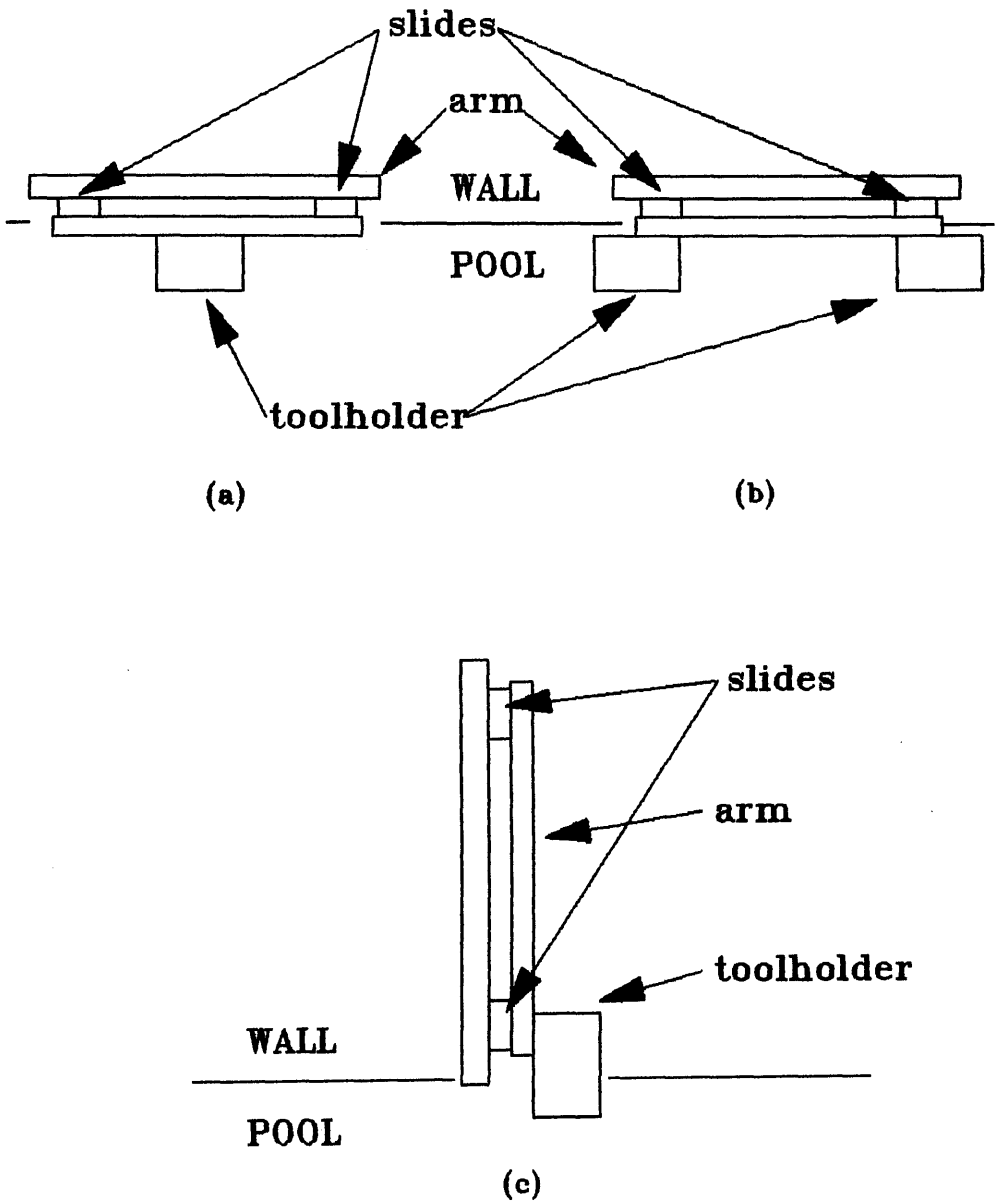


Figure 4.1.1.3 - Alternative Arrangements Of Drive Unit.

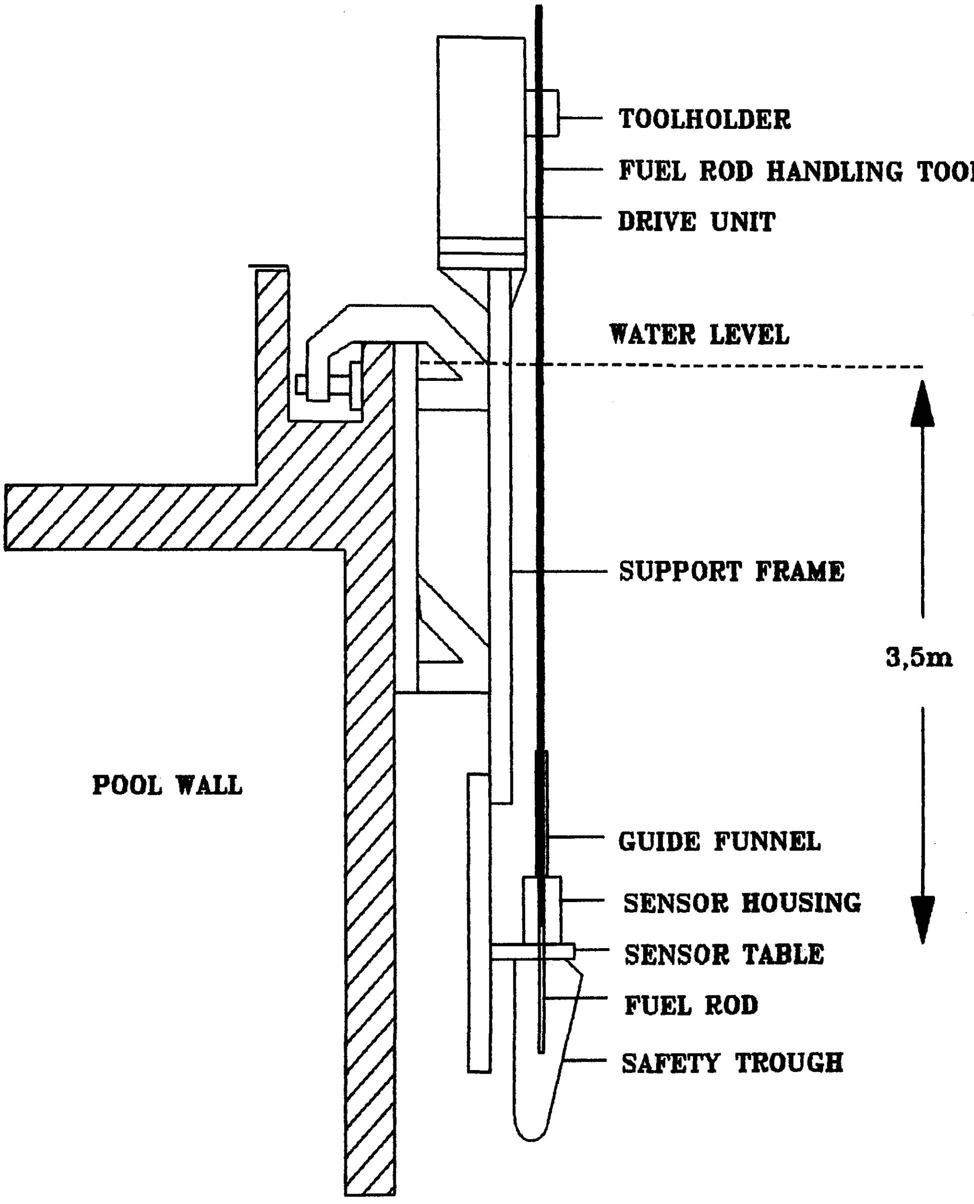


Figure 4.1.2 - Schematic Drawing of Fully Assembled Facility.

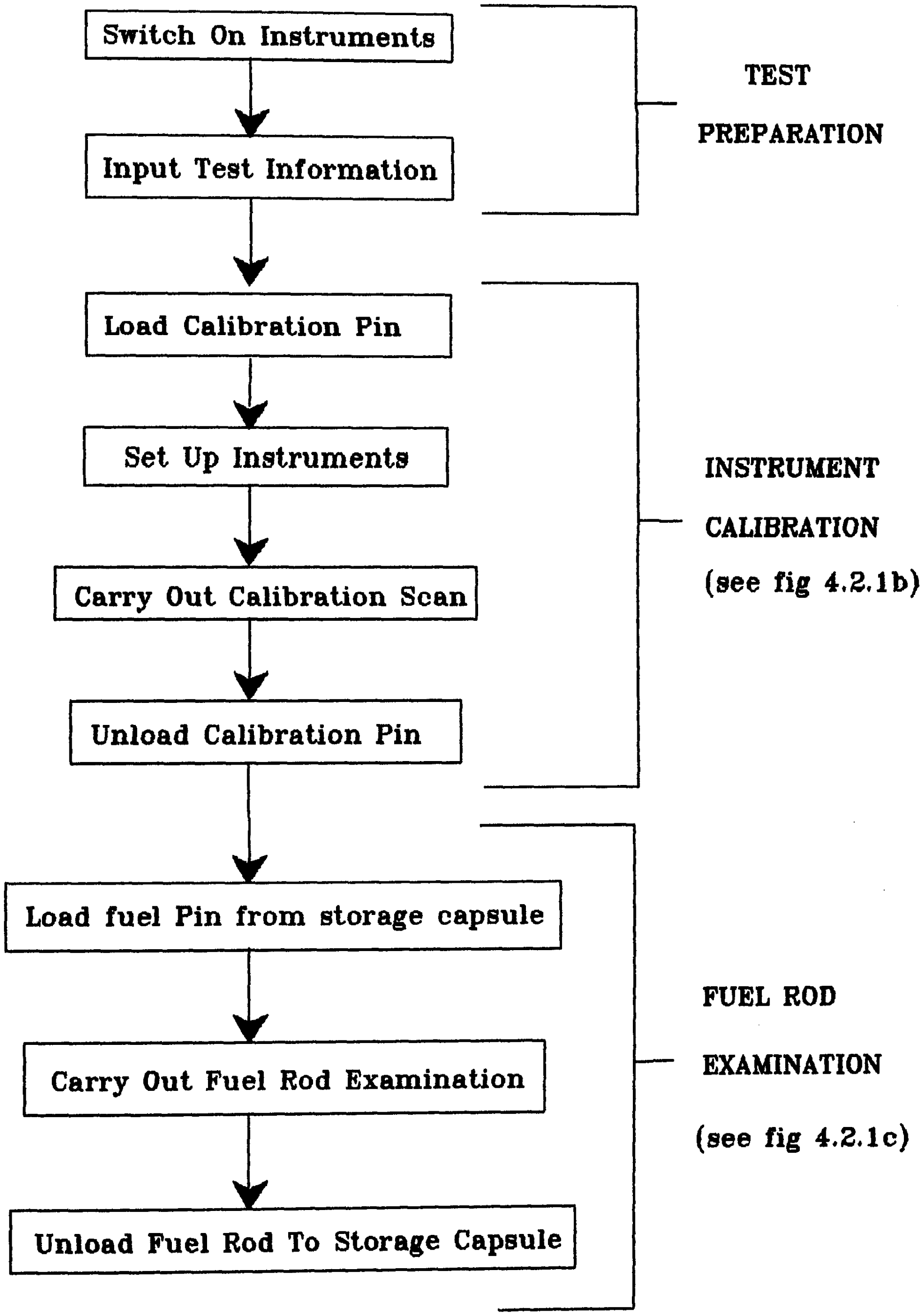


Figure 4.2.1a - Breakdown Of A Complete Test Sequence

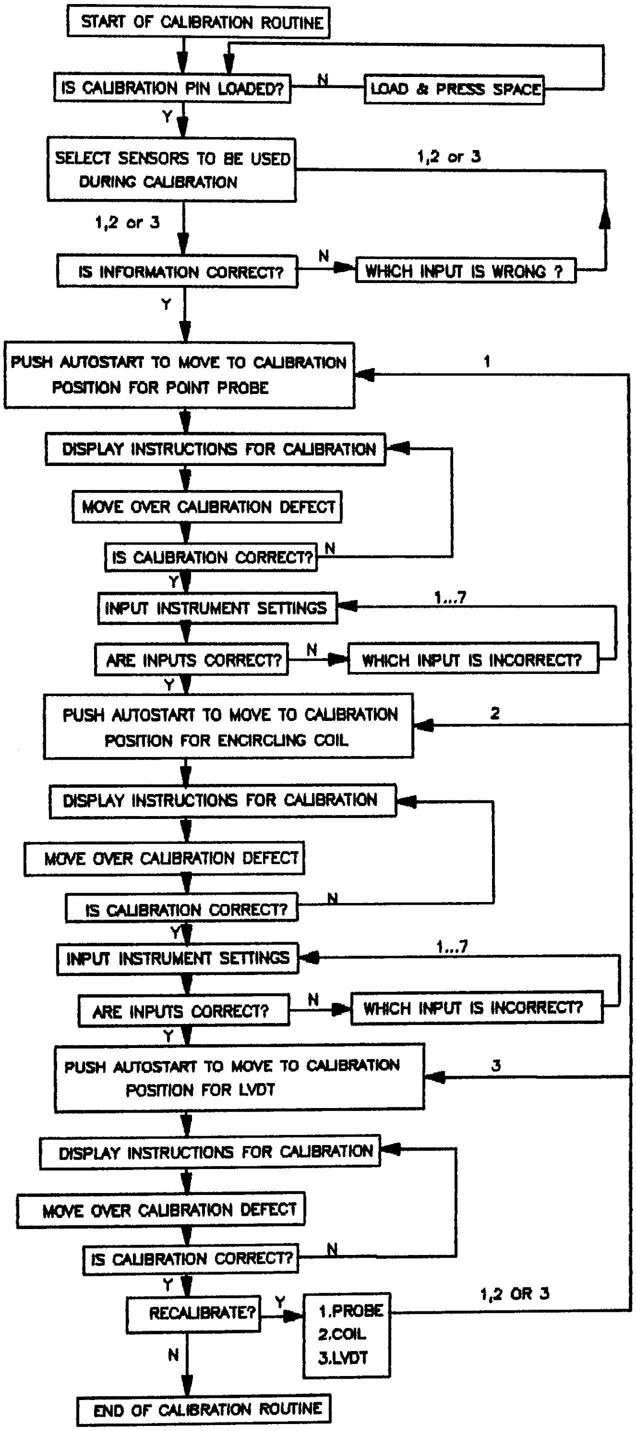


Figure 4.2.1b - Breakdown Of Calibration Routine.

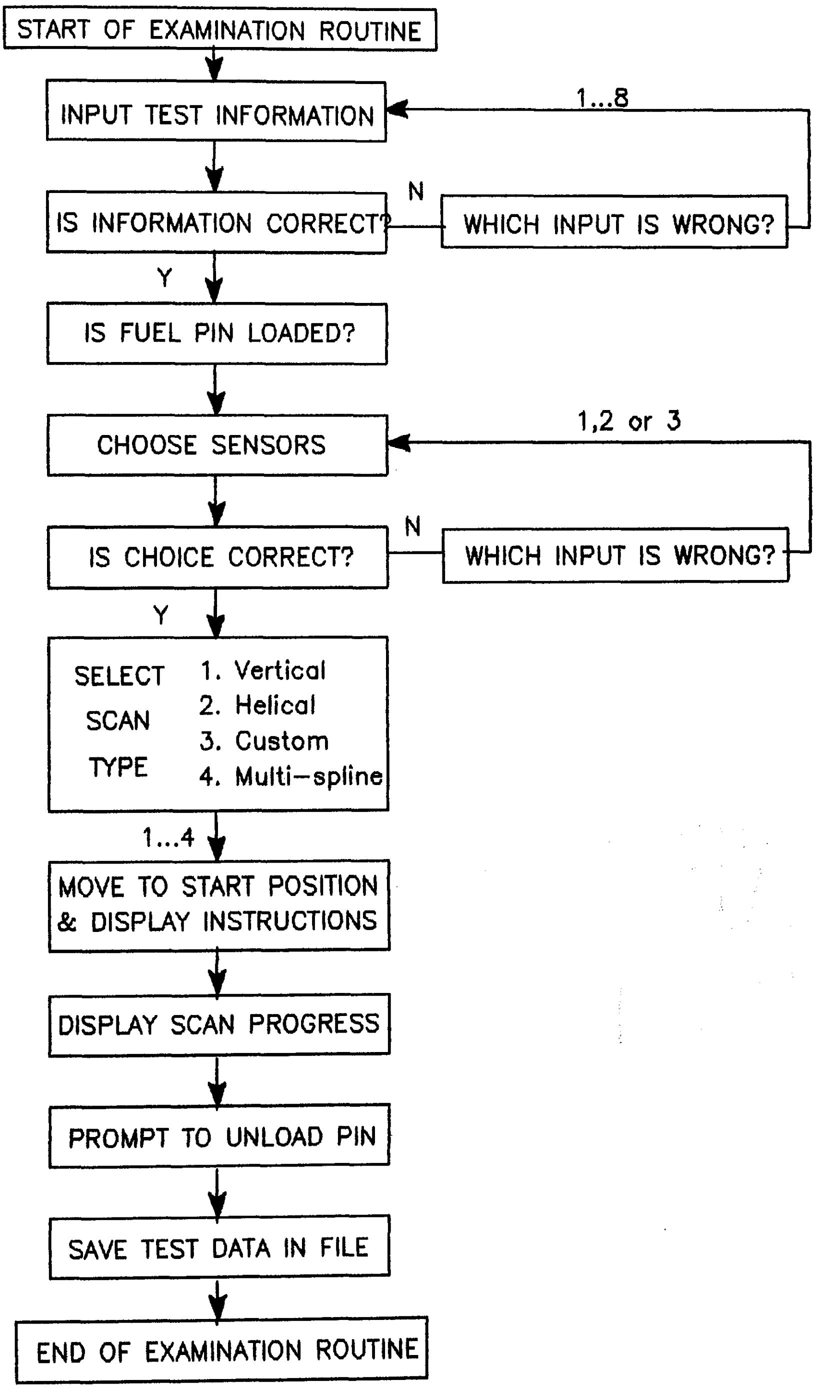
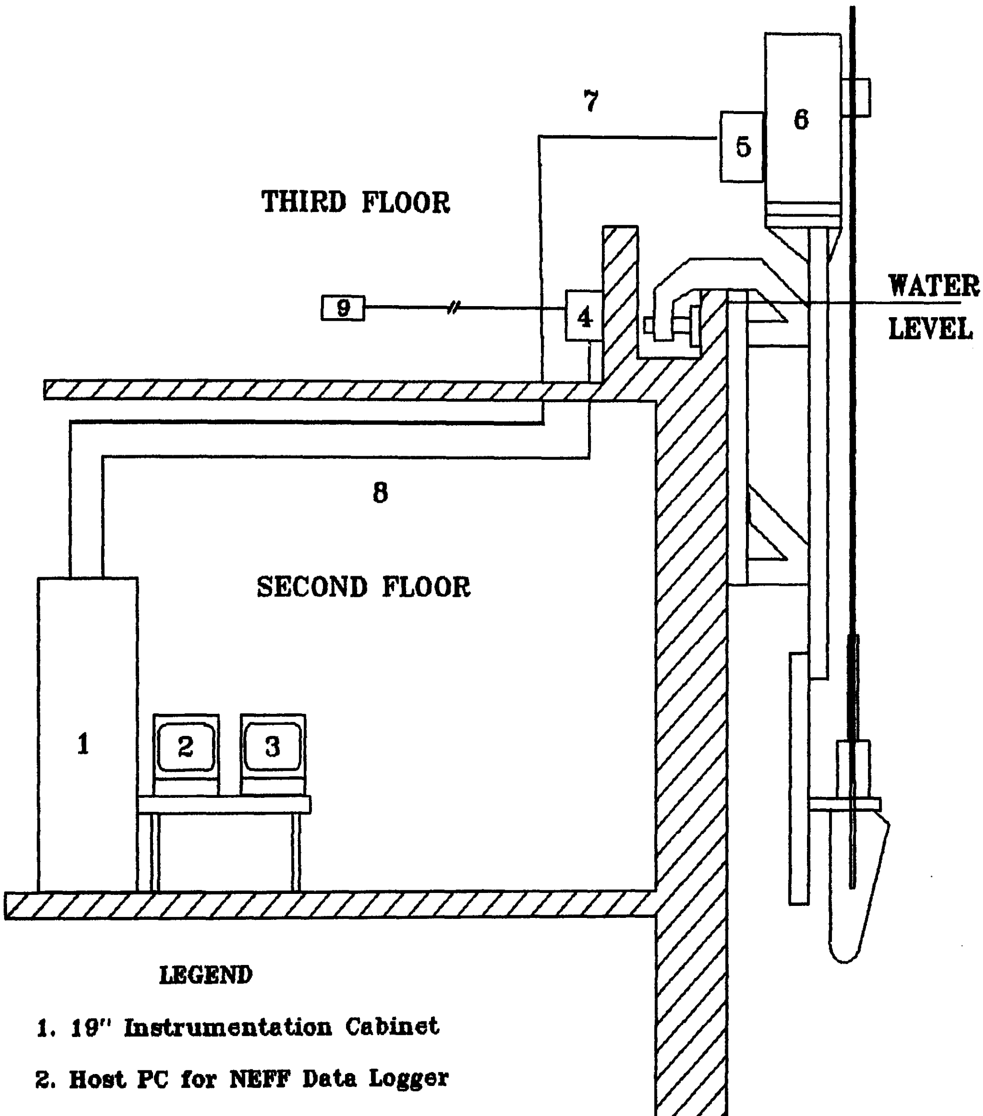


Figure 4.2.1c – Breakdown Of Examination Routine



LEGEND

1. 19" Instrumentation Cabinet
2. Host PC for NEFF Data Logger
3. PC to control Motor Interface
4. Sensor Poolside Connection Box
5. Drive Unit Connection Box
6. Drive Unit
7. Drive Unit Cabling
8. Sensor Cabling
9. Drive Unit Remote Control Box

Figure 4.4a – Schematic of Proposed Facility and Instrumentation Layout in Reactor Hall.

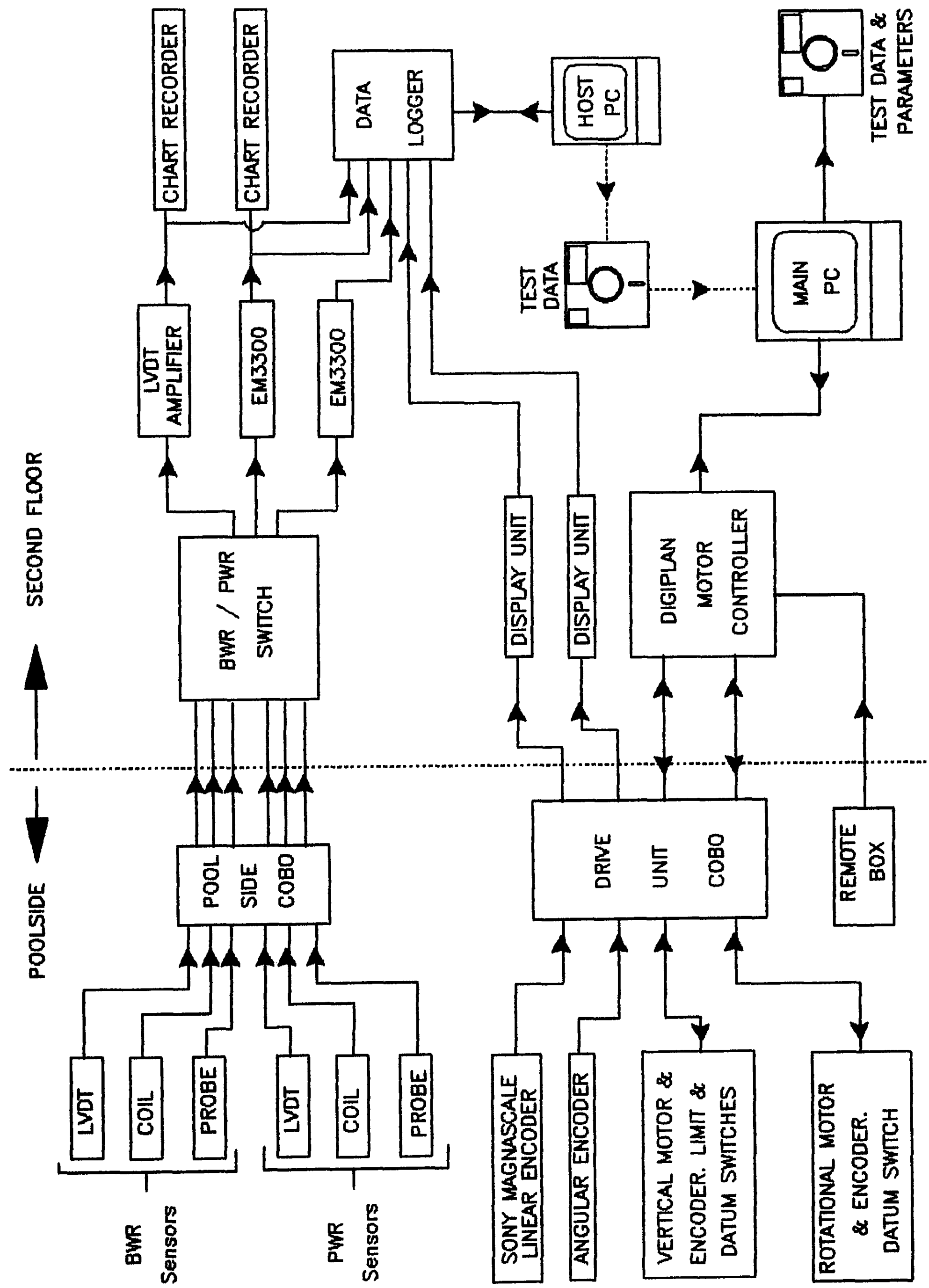


Figure 4.4b –Schematic Diagram of Proposed Signal Cabling

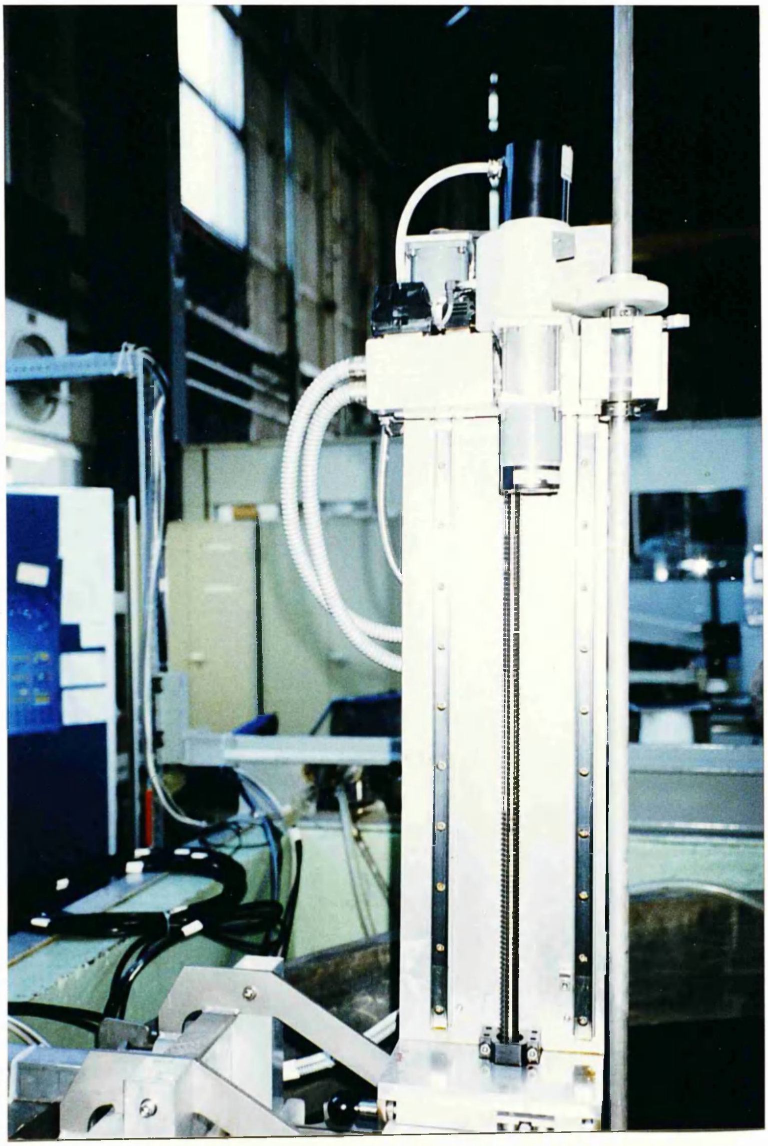


Figure 4.4c - Photograph Showing Drive Unit At Test Pool

Scan Length	540 mm
Vertical Speed (manual control)	200 mm/min
Vertical Speed (computer control)	120 or 250 mm/min
Rotational Speed (manual control)	0.06 rev/sec
Rotational Speed (computer control)	0.06 rev/sec
Maximum Force Exerted on Fuel Rod	441 N (measured)
Maximum Torque Exerted on Fuel Rod	1100 Nmm
Maximum Data Logging Frequency	100Hz

Table 4.4.1 - Operational Characteristics of New System

CHAPTER FIVE - EXPERIMENTAL WORK

5.0 Experimental Work

The experimental work undertaken during the project was conducted for two separate purposes.

Firstly, in order to help with the selection of a suitable eddy current point probe, it was necessary to conduct a number of tests using different probe types (Section 5.3). Secondly, once the entire facility had been assembled, a series of commissioning tests were conducted in order to prove the functionality of the system (Section 5.5).

5.1 Equipment Used During Experimental Work

5.1.1 Sensors

The following sensors were used during part or all of the experimental work -

1. Hocking 5P409 Differential Eddy Current Point Probe (1MHz)
2. Hocking 5P411 Differential Eddy Current Point Probe (2MHz)
3. Hocking 100P1 Absolute Eddy Current Point Probe (200kHz)
4. Hocking 100P2 Absolute Eddy Current Point Probe (2MHz)
5. KWU 11mm internal diameter Differential Eddy Current Encircling Coil (200kHz)
6. RDP 110/A5 Linear Variable Differential Transformer (LVDT)

(figures in brackets indicate design frequencies).

5.1.2 Instrumentation

All the eddy current sensors were used in conjunction with an Automation Industries EM3300 whilst the LVDT was operated with an amplifier constructed from an in-house design.

5.1.3 Calibration Pin

All the tests were conducted on a standard calibration pin identical to that used by the existing system. The pin is constructed from two sections of Zircaloy tubing of nominal diameter 10.75mm and wall thickness of 0.7mm. The upper section of the pin is used to calibrate the LVDT and has five stepped changes in diameter. The lower section of the pin is used for calibrating the eddy current instruments and contains the following defects -

- D1 : 4 x 0.75mm diameter through wall defects
- D2 : 1 x 1.5mm diameter through wall defect
- D3 : 0.15mm deep external saw cut
- D4 : 0.35mm deep external saw cut
- D5 : 0.35mm deep internal circumferential groove

5.2 Experimental Method

The experimental method used during the laboratory work for the testing of the eddy current point probes is similar to that used by Barat et al /1/. In this method, the magnitude of probe impedance is recorded whilst a defect is scanned by a probe operating at a known frequency. This process is repeated over a range of test frequencies. The optimum test frequency for a specific probe/defect combination is then defined as that which gives the highest value of probe impedance. By comparing the results from the range of defects on the calibration pin, it is then possible to establish a general optimum test frequency for each probe.

To enable an accurate comparison of results between tests, it was necessary to establish a set up procedure for each sensor which allowed consistent set up conditions to be maintained between tests. The following routines were established for each sensor.

5.2.1 Setting Up of Differential Eddy Current Encircling Coil

The procedure followed for setting up the encircling coil is identical to that carried out by Siemens/KWU before a fuel rod examination. This involves calibrating the coil against a 1.5mm through wall defect. The resulting Impedance Plane Diagram on the EM3300 is a 'figure 8', and the object of the calibration is to rotate the phase angle of the display so that the main diagonal lies at 45^{o} to the axes. With this procedure, it is possible to maintain consistent set up conditions between different tests.

5.2.2 Setting Up of Differential Eddy Current Point Probes

Initially it was intended to adopt a similar set up procedure as to that used for the encircling coil. Unfortunately, due to the irregular shapes of the Impedance Plane Diagrams, it was not possible to establish a set up procedure which was repeatable between tests.

5.2.3 Setting Up of Absolute Eddy Current Point Probes

During an examination, the eddy current point probes were to be used purely for defect detection with no interest being taken in other factors such as lift-off etc. The set up procedure for the probes involved making the X channel on the EM3300 predominantly sensitive to lift-off and then using the Y channel to give an indication to the presence of a defect. This was achieved by scanning the probe over four stepped diameter changes in the calibration rod and then adjusting the EM3300 until the display was horizontal. It was then assumed that any horizontal signal was primarily lift-off and any vertical signal could indicate the presence of a defect.

5.2.4 Setting Up of LVDT

The set up procedure for the LVDT is similar to that used by the existing system where the LVDT is reset on a part of the calibration rod of known diameter. The output signal from the LVDT is calibrated by comparing values from different sections of the rod of known diameters.

5.3 Objectives Of Laboratory Work

The work carried out in the laboratory was conducted in three separate test series with the results of each series being used to establish the optimum parameters for an examination. The objectives of each series were as follows -

Series 1 : to determine the most suitable probe for examining a range of defects.

Series 2 : to investigate the effect of probe speed on signal magnitude.

Series 3 : to find the optimum combination of probe speed and data logging frequency.

5.4 Experimental Description

5,4,1 Series 1

The four eddy current point probes were used to examine the calibration pin at a scan speed of 250mm/min with the test frequency being varied between 100kHz and 700kHz. It was not possible to balance all of the probes at the higher test frequencies and in general, the higher the frequency the more difficult it was to balance the probes accurately.

The best overall results were obtained using probe 1 operating at a frequency of 700kHz. However, it can be seen from figure 5.4.1a that the probe appears to be sensitive to other test parameters and relatively insensitive to the internal defect. In addition, due to the irregular shaped

Impedance plane Diagrams, it was not possible to establish a set up procedure which was consistently repeatable between tests. Consequently, it was considered that the differential probes were unsuitable for further use.

The best overall results obtained from an absolute point probe were obtained with probe 3 operating at a frequency of 600kHz (figure 5.4.1b). Figure 5.4.1c shows the variation in signal amplitude with increasing frequency for all of the defects. An optimum test frequency of 500kHz was selected as this gave an acceptable performance and enabled the probes to be set up accurately.

5.4.2 Series 2

This series of tests involved using the probe which was selected after series 1 and investigating the effect of scan speed on signal amplitude. The scan speed was varied from 100mm/min to 1000mm/min in steps of 100mm/min. The effect on signal magnitude for each of the defects can be seen in figure 5.4.2. It appears from the graph that there is a general, though not significant, reduction in signal amplitude with increasing scan speed for the range tested.

5.4.3 Series 3

The aim of this series of tests was to determine the maximum Data Point Separation (DPS) on the fuel pin surface which could adequately resolve the internal circumferential groove on the calibration pin. This defect was chosen as it is considered to be the most likely to occur and the hardest to detect of the defects on the calibration pin. The results of a number of DPS can be seen in figure 5.4.3. It was considered that the DPS of 1.4mm was sufficient and a maximum allowable DPS of 1.5mm was adopted.

5.5 Commissioning Tests

Once the complete facility had been assembled, a series of commissioning tests using the test parameters established in the Laboratory were undertaken to ensure that the sensors were capable of operating to the specification. The tests were conducted in the Test Pool of the Technology Hall at JRC Petten and used the same calibration pin as the laboratory experiments.

5.5.1 LVDT

The results of an underwater scan with the LVDT can be seen in figure 5.5.1a along with the measured values in figure 5.5.1b. The scan clearly show the stepped diameters as well as variations in slope along each step. This is most clearly seen in step 3 which is higher at the ends than in the middle on the scan and also in the measured values.

5.5.2 Eddy Current Encircling Coil

The results of a scan with the encircling coil can be seen in figure 5.2.2. The scan clearly shows the five defects on the lower section of the pin and the stepped diameter changes on the upper section. A comparison of signal magnitudes between tests conducted in the laboratory and tests conducted in the test pool are shown in table 5.5.2.

5.5.3 Eddy Current Point Probe

During initial testing, it was found that the probe was unable to balance over the same range of frequencies that were possible in the laboratory. This is thought to have been caused by the additional cabling necessary for operation in the Technology Hall. As the probe would only balance between 160kHz and 210kHz, a test frequency of 210kHz was chosen as this gave the greatest signal magnitude. A comparison of the signal magnitudes obtained for each of the defects in the calibration pin is given in table 5.5.3.

The point probe was tested on the lower section of the calibration pin containing the defects by conducting 36 scans separated by 10^{o} degrees. An example of a scan of the complete circumference can be seen in figure 5.5.3a whilst an alternative presentation of the section containing the defects only can be seen in figure 5.5.3b.

From figure 5.3.3b, it can be seen that there is an unexpected signal on either side of defect noD3. In order to investigate this further, the defect was re-examined with a number of vertical scans separated by 1 degree. The result of this can be seen in figure 5.5.3c. Initial visual inspection of the surface surrounding the defect did not reveal any indications of a defect and further examination by destructive or non destructive means is necessary to determine the nature of the signal. One possible cause could be areas of metal which have been work hardened during the machining of the defect.

5.6 References For Chapter 5

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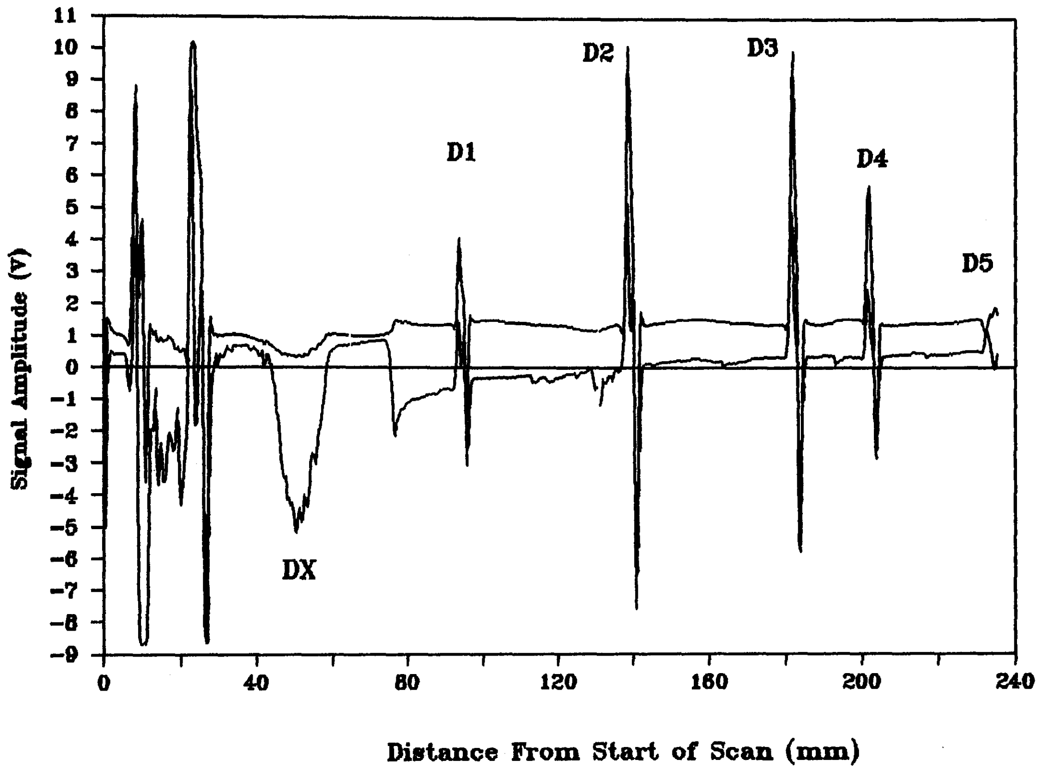
Eddy Current Testing In The Q.A. Of The Cladding Tubes Of The Fast Breeder Test Reactor.
Symposium On Q.A. For Safety And Reliability Of Nuclear Power Plants, Bombay, India, 1987.

Defect	Signal Magnitude (V)		
	Laboratory		Commissioning
	(500kHz)	(200kHz)	(200kHz)
D1	1.6	0.6	0.5
D2	4.3	2.1	1.4
D3	2.1	1.5	0.5
D4	1.0	0.8	0.3
D5	2.5	1.0	N/A

Table 5.5.3 - Comparision Of Signal Magnitudes Obtained From Defects In Calibration Pin During Laboratory And Commissioning Tests.



LEGEND

D1 : 1 x 0.75mm diameter through wall defect.

D2 : 1 x 1.5mm diameter through wall defect.

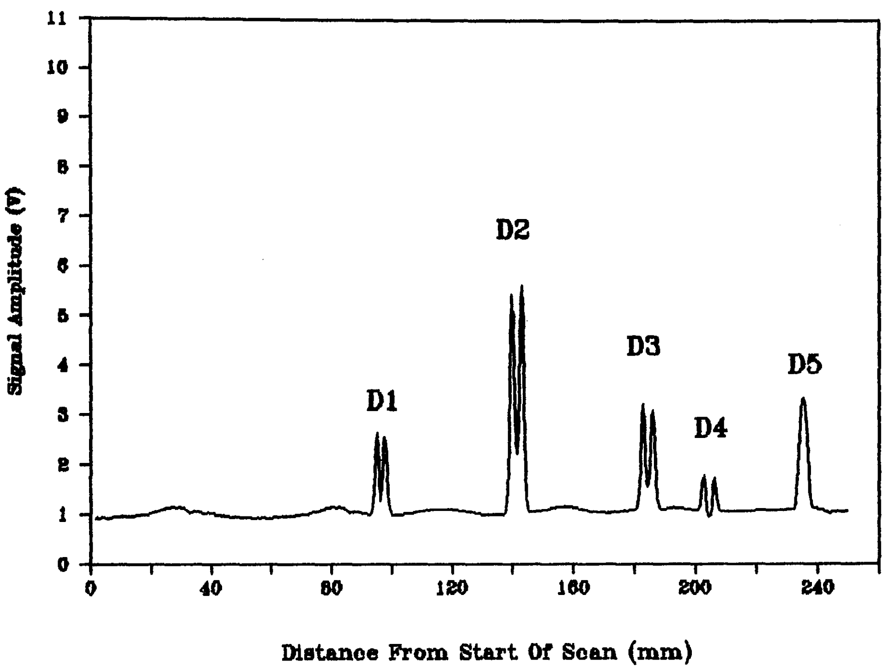
D3 : 1 x 0.35mm external saw cut.

D4 : 1 x 0.15mm external saw cut.

D5 : 1 x 0.35mm internal circumferencial defect.

DX : Unknown Signal.

Figure 5.4.1a - Scan ofCalibration Pin Using Probe #1 at 700kHz.



LEGEND

D1 : 1 x 0.75mm diameter through wall defect.

D2 : 1 x 1.5mm diameter through wall defect.

D3 : 1 x 0.35mm external saw cut.

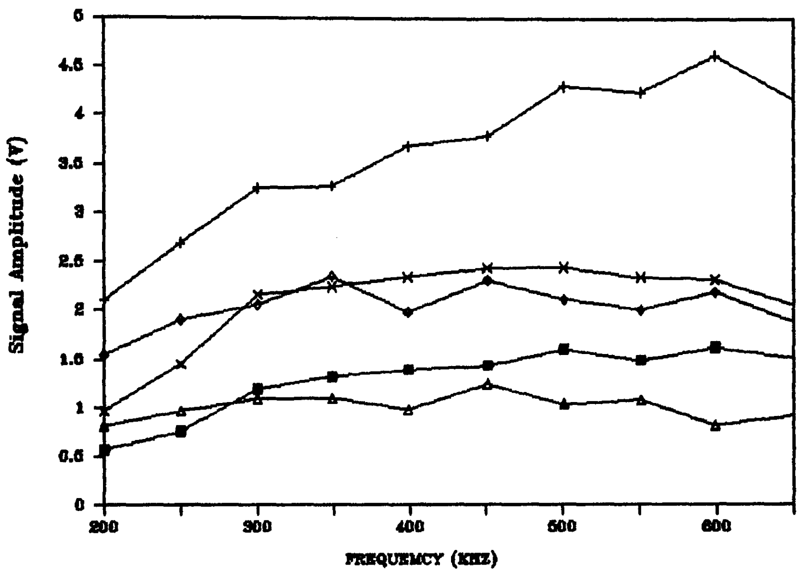
D4 : 1 x 0.15mm external saw cut.

D5 : 1 x 0.35mm internal circumferencial defect.

Test Frequency = 600kHz

Scan Speed = 250 mm/min

Figure 5.4.1b - Best Results Obtained With Probe 3



LEGEND

■ D1 : 1 x 0.75mm diameter through wall defect.

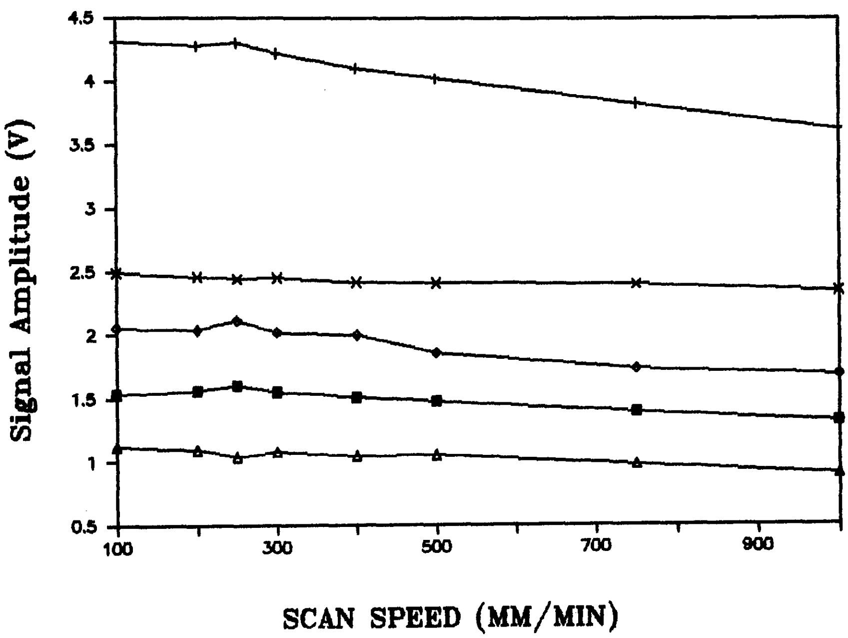
+ D2 : 1 x 1.5mm diameter through wall defect.

◇ D3 : 1 x 0.35mm external saw cut.

△ D4 : 1 x 0.15mm external saw cut.

× D5 : 1 x 0.35mm internal circumferencial defect.

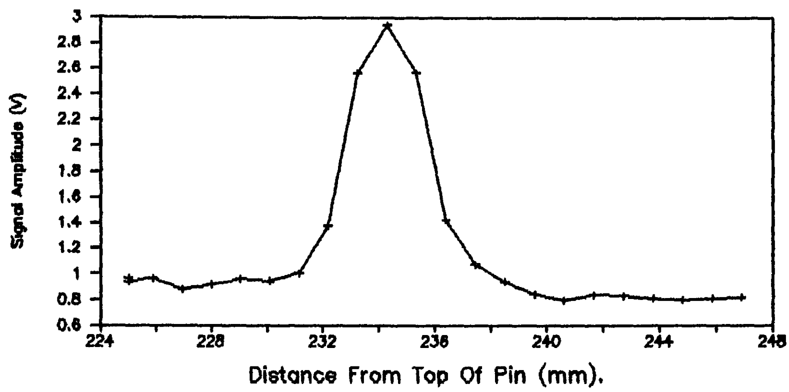
Figure 5.4.1c - Variation In Signal Amplitude With Frequency For Probe #3.



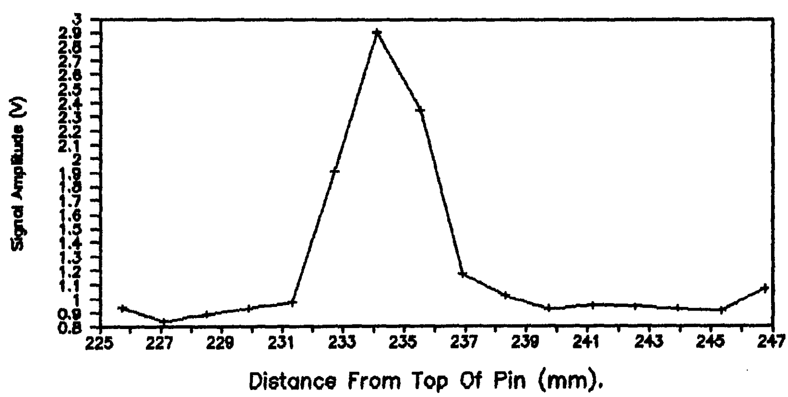
LEGEND

- ▪ D1 – 1 x 0.75mm Diameter Through Wall Defect
- ⊥ D2 – 1 x 1.5mm Diameter Through Wall Defect
- ◇ D3 – 1 x 0.15mm Deep External Saw Cut.
- △ D4 – 1 x 0.35mm Deep External Saw Cut.
- × D5 – 1 x 0.35mm Deep Internal Circumferencial Groove.

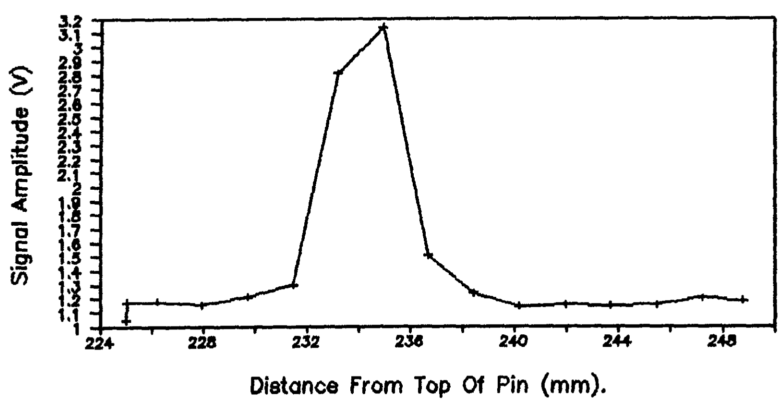
Figure 5.4.2 – Variation In Signal Amplitude With Scan Speed For Probe 3.



(a) Data Point Separation of 1.0mm



(b) Data Point Separation of 1.4mm



(c) Data Point Separation of 1.75mm

Figure 5.4.3 - Effect Of Data Point Seperation On Signal Resolution For Internal Defect.

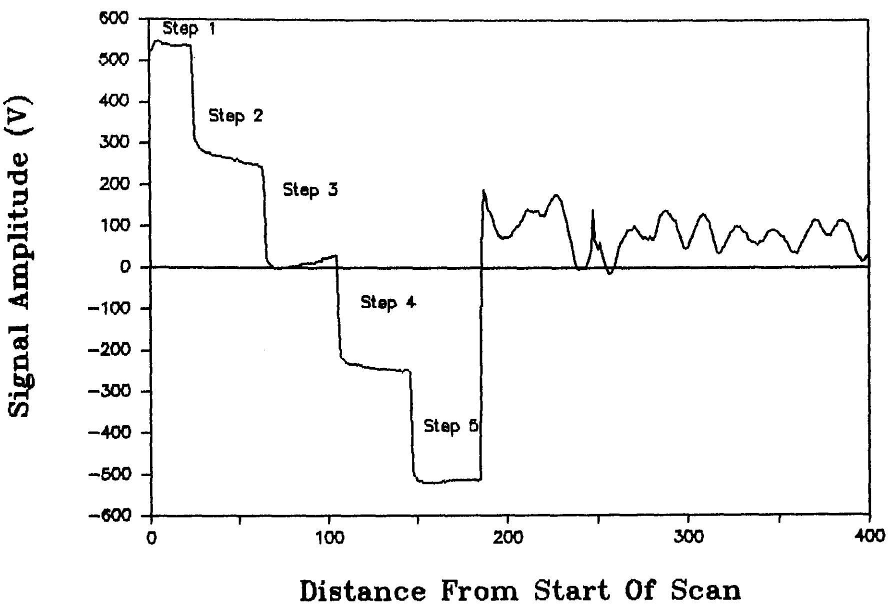
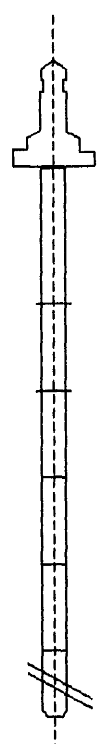


Figure 5.5.1a - Result of Underwater Scan on Calibration Pin



	Machined Values	Measured Values 0°	Measured Values 90°
Step 1	10.800	10.805	10.805
		10.805	10.807
		10.806	10.808
Step 2	10.775	10.782	10.781
		10.779	10.777
		10.778	10.776
Step 3	10.750	10.756	10.753
		10.753	10.754
		10.754	10.756
Step 4	10.725	10.731	10.733
		10.728	10.731
		10.727	10.730
Step 5	10.700	10.700	10.704
		10.699	10.702
		10.700	10.701

Figure 5.5.1b - Measured Diameters of Calibration Pin

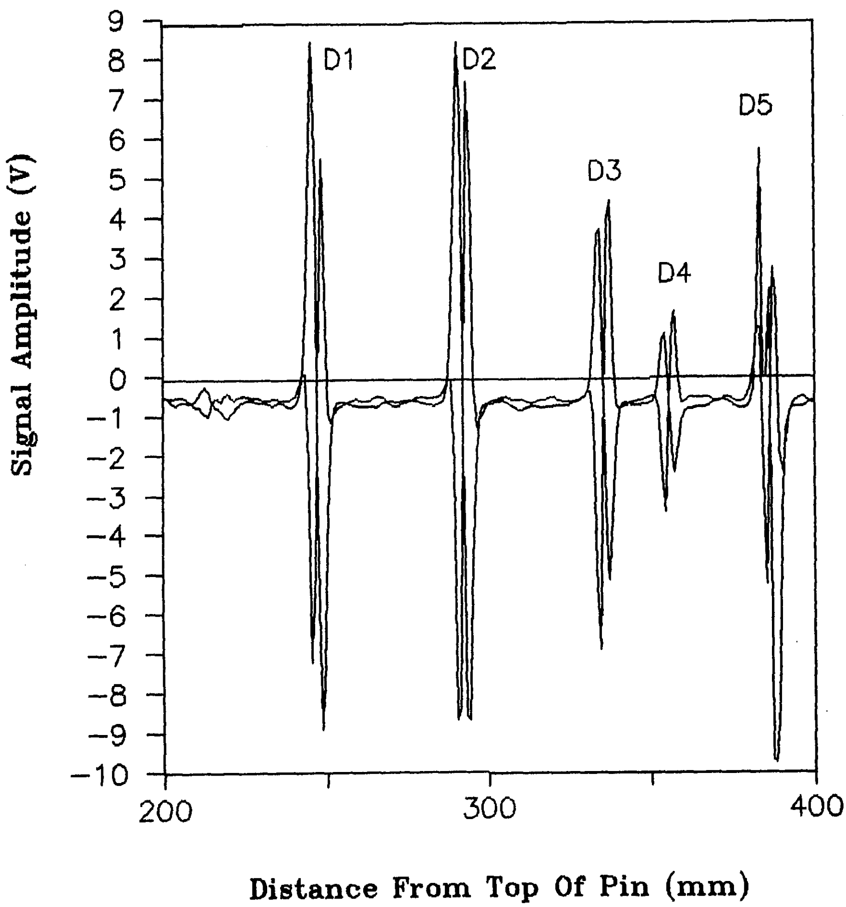


Figure 5.5.2 – Scan Of Calibration Pin Using Eddy Current Encircling Coil.

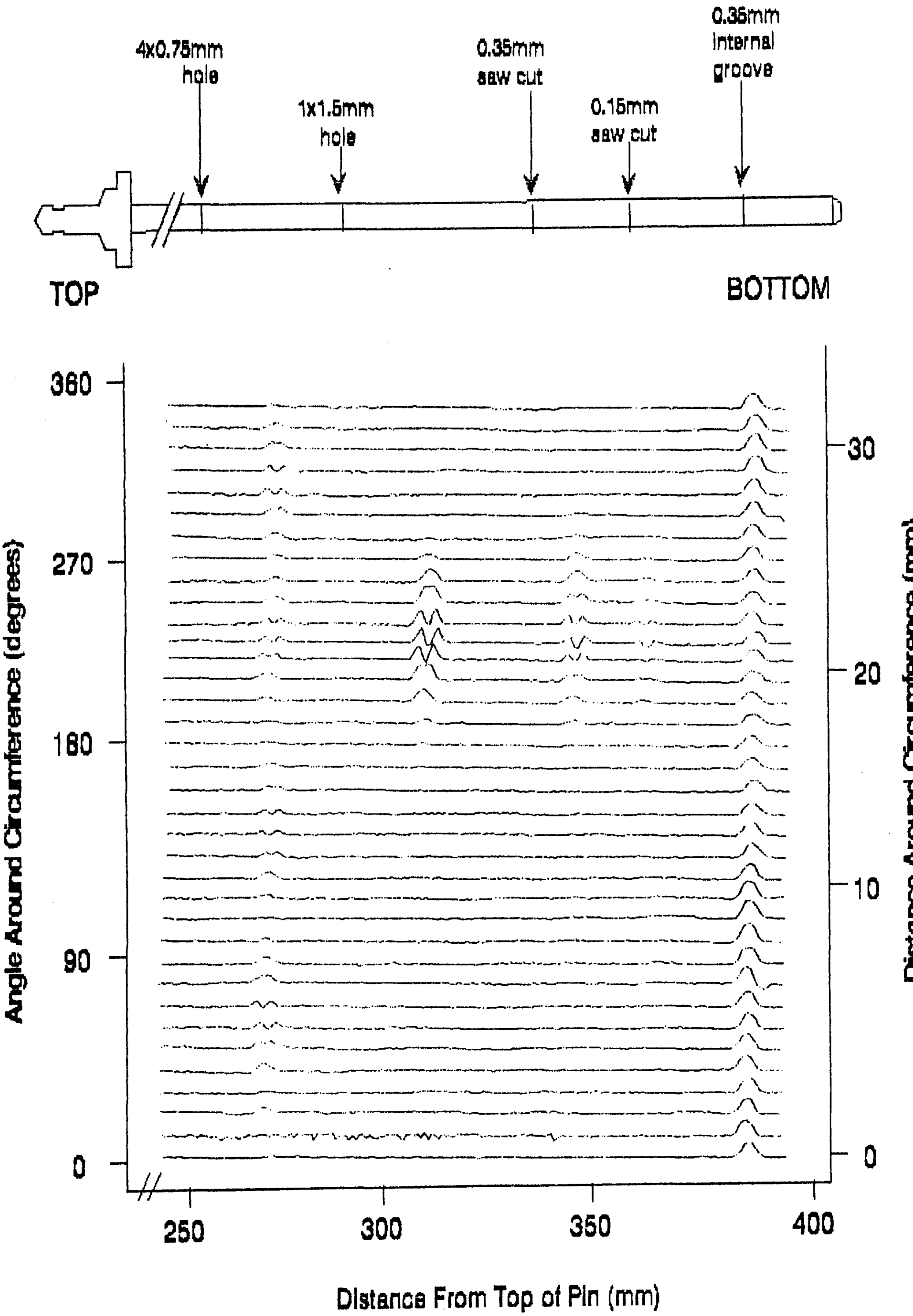


Figure 5.5.3a - Example Presentation Of Eddy Current Data.

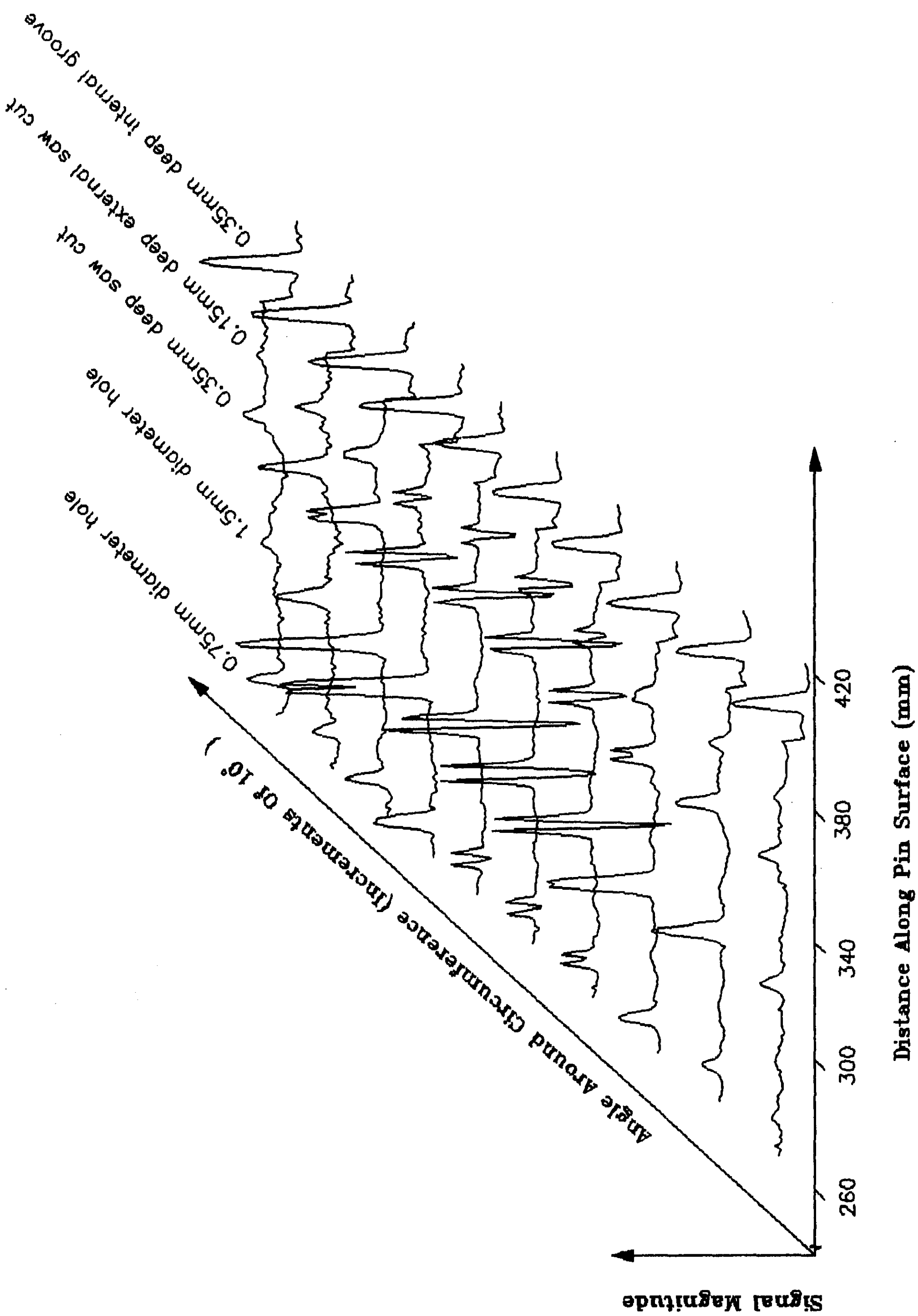
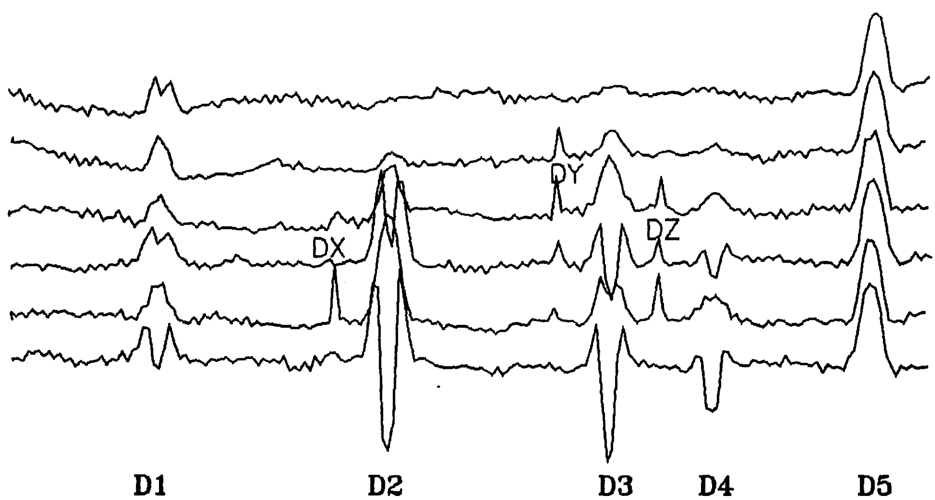


Figure 5.5.3b - Example Presentation of Point Probe Data



LEGEND

D1 : 1 x 0.75mm diameter through wall defect.

D2 : 1 x 1.5mm diameter through wall defect.

D3 : 1 x 0.35mm external saw cut.

D4 : 1 x 0.15mm external saw cut.

D5 : 1 x 0.35mm internal circumferencial defect.

DX, DY & DZ : Unidentified Signals.

Figure 5.5.3c – Six Vertical Scans Of Calibration Pin Seperated By 1° Showing Unexpected Signals.

CHAPTER SIX - CONCLUSIONS & RECOMMENDATIONS FOR FURTHER WORK

6.0 CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

6.1 Conclusions

1. The functionality of the fully assembled system has been proven in the commissioning trials in the Technology Hall at JRC Petten.

During these trials, it was found that the vertical stepping motor was prone to rotor resonance and was unable to operate at speeds of between 72 and 110 steps/sec. After consultations with the manufacturer, it was considered that the normal operating speed of 144 steps/sec was too close to the resonance range and in order to avoid resonance, a minimum speed of 400 steps/sec should be used. This could be achieved by replacing the motor and drive with a combination which is capable of microstepping. The associated higher operating speed would also enable a higher linear resolution and smoother drive transmission to be achieved.

The commissioning trials have also proved the capability of the data logging system in being able to resolve the internal defect of the calibration pin during one full length scan as per specification 3.0ii.

The reduction in operator workload due to the increased level of automation in both the calibration and examination routines has been demonstrated during the commissioning trials.

The operation of the system was described in a presentation given by the author at the ASM's 10th International Conference on NDE in the Nuclear and Pressure Vessel Industries held at Erskine, Scotland in June of 1990. A comparison between the main operational characteristics of the new and the existing system is given in table 6.1.

2. The point probe has successfully been used to produce contour plots showing all the artificial defects in the calibration pin as required in specification 3.1.3i.

Significantly however, the same plots have also revealed unexpected signals which could indicate the presence of an unidentified defect. In order to establish complete confidence in the probes ability to detect real defects, these signals must be investigated further.

The suitability of using the point probe with the EM3300 Eddy Current test unit must be questioned. Due to the insensitive rotary controls on the unit and the fact that the frequency could drift by 5-6Hz during a test, it was very difficult to maintain consistent set-up conditions between tests. A more modern test instrument with digital controls, such as the Hocking AV-10 or the PAC Smart Eddy, would overcome this problem and establish consistency between tests.

With hindsight, it was a mistake not to conduct the laboratory tests with the point probes using full length cables. The increased length of cabling used in the commissioning trials caused an unforeseen reduction in signal magnitude which led to the probe performance being less than was expected.

3. Sensor interaction has been shown not to be a concern during normal operation as required in specification 3.1.3iii.

During the commissioning trials, all the sensors were able to operate at their normal settings without any interference. The only time that any interference was observed was when the two EM3300s were operating at exactly the same test frequency. As this is not likely to occur in normal operation, it was not considered significant.

4. The modular approach adopted towards the thesis write up can be considered a partial success.

By writing up each section of work as it was completed the final write up of the thesis was considerably simplified. However, during the course of the project, the tendency was to continually re-edit sections as often as the available time would permit. A more sensible approach would have been to freeze each section after an initial edit, and then to apply the time more effectively in other areas of the project.

5. The initial project plan did not accurately asses the time required for manufacture and delivery of parts and the level of available technical and administrative support.

As a result of overruns in manufacturing and delivery times, it was not possible to complete the Automatic Reporting Package as required in the initial Specification.

These delays also caused a longer than anticipated time to be spent on the Literature Survey whilst the delivery of drive system components was awaited. Although this was of benefit to the scope and extent of the Literature Survey, it is considered that the time could have been more constructively used with regard to the other aims of the project.

The limited availability of technical support compelled a larger than expected proportion of time to be taken up with technical tasks. Additionally, the degree of help given in administering and monitoring the progress of the project was less than had been anticipated.

6.2 Further Work

1. An investigation into the source of the unexpected signals shown in the point probe contour plots of the calibration pin. This is necessary in order to determine whether they are caused by a defect or by a variation in some other test parameter.

2. Replacement of the existing vertical stepping motor and drive with a motor and driver which are capable of microstepping.

3. Completion of the Automatic Reporting Package as per Specification 3.4.

4. Full installation of the system in the HFR storage pool.

5. Addition to system sensor set of cassettes which have already been manufactured to accommodate the following sensors -

   - fibre optic visual inspection probe
   - ultrasonic probe
   - eddy current oxide thickness measuring probe
   - eddy current non contact diameter measuring probe

PARAMETER	NEW	EXISTING
Vertical Scan	$3x120^{\circ}$ or $36x10^{\circ}$	$3x120^{\circ}$
Helical Scan	Yes	No
Scan Length (mm)	540	390
Scan Speed (mm/min)	120 or 250	120
Datum Points	Yes	No
Data Logging	Yes	No
No Of Sensors	3	2

Figure 6.1 - Operational Capabilities Of New And Existing Systems.

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THE DESIGN AND COMMISSIONING OF A NON DESTRUCTIVE EXAMINATION (NDE) FACILITY FOR THE IN-POOL TESTING OF LIGHT WATER REACTOR (LWR) FUEL RODS.

VOLUME TWO

By ALISTAIR J. CAREY

A Thesis Submitted To The Faculty Of Engineering of
The University Of Glasgow For The Degree Of
Master Of Science (Engineering).

CHAPTER SEVEN - APPENDIX

NOTE - This volume consists of a number of individual reports.
In this chapter only, page numbers appearing at the bottom of a page refer to volume pagination, whilst numbers at the top of a page refer to the individual report.

COMMISSION OF THE EUROPEAN COMMUNITIES

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PETTEN ESTABLISHMENT

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HFR DIVISION

Petten,24/8/90

AC/84.082

Technical Memorandum

HFR/90/4868

Eddy Current LWR Fuel Rod Examination Facility

Design and Safety Report

by

A. Carey, S. McAllister & J. Markgraf.

	Author	Group Leader	Division Head
Name	A. Carey	J. Markgraf	J. Ahlf
Date			
Signature			

(i)

Page

List Of Tables Contained In Report

List Of Figures Contained In Report

1.0 INTRODUCTION

The facility described in this report is designed to conduct Non Destructive Examination (NDE) of Light Water Reactor (LWR) fuel rods. The facility will be used to examine fuel rods prior to and immediately after irradiation in the HFR. It will be located in the HFR storage pool, replacing the present system which has been in use since 1977 and has performed approximately 600 examinations. The introduction of the new facility will realise the twin objectives of increased operational flexibility and reduced operator workload.

2.0 EXPERIMENTAL CONDITIONS

2.1 Experiment Location

The facility will be located in the HFR storage pool in an identical position to that occupied by the present system (see fig 14).

2.2 Experiment Description

The installation will be used to non destructively examine LWR fuel rods before and after irradiation at the HFR. A Linear Variable Differential Transformer (LVDT) based extensometer is used for rod profilometery with an Eddy Current Encircling Coil and Eddy Current Point Probe being used for defect detection.

The installation is mounted on a support frame which hangs over the pool wall. At the top of the frame, there is a drive unit which is used to rotate and translate the fuel rod through stationary sensors located in a common housing 3.5 m beneath the water level. The drive system consists of a two axis programmable stepping motor drive which acts on instructions it receives from an IBM compatible PC. Software has been written which enables the operator to control the progression of the test via a series of menu screens on the PC. All data from the sensors and from vertical and angular positional registration devices are recorded on a NEFF System 470 Data Logger.

3.0 FUEL RODS

The facility will be used to examine both fresh and pre-irradiated PWR (10.75mm dia) and BWR (12.5mm dia) fuel rods. The external dimensions of a number of standard LWR rods can be seen in table 1. A drawing of a typical fuel rod can be seen in figure 2.

4.0 FACILITY

4.1 HFR Poolside Installation

The general assembly drawing for the poolside installation can be seen in figure 11. Figure 3 shows a schematic diagram of the facility installed in the HFR pool. It can be considered to consist of four separate components -

- support frame
- drive unit
- sensor housing
- fuel rod handling tool

4.1.1 Support Frame

The general assembly drawings of the support frame are shown in figures 12 & 13. The frame is hung over the wall of the HFR storage pool (see figure

14) and is secured to the overflow channel by means of two clamps. It is approximately 4m in length and constructed primarily from aluminium with some components being manufactured from stainless steel.

At the top of the frame, the drive unit is positioned in one of two locations, above different sensor sets for BWR and PWR fuel rods, on an aluminium baseplate approximately 150mm above the water level. The unit can be manually moved between each position and is secured by a spring loaded locating bolt.

The frame also supports the sensor housing on a table 3.5m beneath the water level. The sensor housing locates onto a square mounting on the sensor table and is secured by means of two locking D-nuts.

The support frame has been mechanically overdesigned and is identical to that of the present installation, except for minor modifications which have been necessary to accommodate the new drive unit and sensor housing.

4.1.2 Drive Unit

The drive unit rotates and translates the fuel rod through the stationary sensors by means of two Stebon FDL 602-250-45 stepping motors. The rod is attached to the fuel rod handling tool (see section 4.1.4) which is fitted to the toolholder on the moving arm of the drive unit (see figure 4). The tool is secured in the toolholder by means of a spring loaded locating bolt.

The tool is rotated in the toolholder by a stepping motor located on the moving arm of the drive unit. The motor drives the tool via a gearbox (of ratio 40:1) and two meshing spur gears. The motor operates at 400steps/revolution with one step corresponding to 0.0225^{o} rotation of the fuel rod. An absolute encoder is mounted on the output shaft of the gearbox to indicate the angular orientation of the fuel rod. The output of this encoder is shown on a display unit in the 19" instrumentation cabinet.

The moving arm (fig4,#7) is displaced vertically along two linear slides (fig4,#3) on the backplate of the drive unit by the second stepping motor. The motor operates at 400 steps/revolution with one step corresponding to 0.014mm vertical displacement of the arm. The drive is transferred to a screwed shaft (fig4,#9) on the drive unit backplate via a belt drive with a reduction ratio of 2:1. The vertical position of the fuel rod is established by a Sony MagnesĉaIe GF-60E system attached to the side of the moving arm and the backplate. This system has an effective measuring length of 600mm and a resolution of 1um. Approximately 50mm from the end of each slide there are two 3 wire limit switches to prevent the unit being moved out of its operational range. As a further safety feature, mechanical stops are provided before the end of each slide.

4.1.3 Sensor Housing

In order to facilitate the easy replacement of defective sensors, a system has been developed where each sensor is contained within a 'cassette'. These cassettes have identical outer dimensions and are assembled within a common housing (see figure 6). The cassettes are secured in the housing by a screw.

In order to improve measurement quality, two centralising cassettes (fig 15) are located at the entry/exit to the housing to offer some alignment of the fuel rod through the sensors. Further, each sensor cassette has a self centering mechanism built in. Since each sensor is specifically tailored to examine a fuel rod of a given nominal diameter, two sensor sets have been installed on the sensor table to permit the examination of PWR rods (10.75 mm did) and BWR rods (12.5 mm dia). Each may be accessed by moving the drive unit to a position above the relevant sensor set.

The following sensors have been equipped for underwater use and will be located in each housing-

- **KWU Eddy Current Encircling Coil** : This is a differential coil and has been developed and manufactured by KWU to operate at a frequency of 200kHz. It is used in conjunction with an EM3300 eddy current test unit and enables integral axial detection of cladding defects (e.g. porosity, wall thinning and diameter variations).
- **Hocking 100P1 Absolute Eddy Current Point Probe** : This probe has an impedance of 120uH and operates at 500kHz. The test frequency was experimentally derived for optimal signal sensitivity from the range of defects in the standard calibration pin (figure 21). It is used in conjunction with an EM3300 and provides axial and circumferential location of defects as well as the possibility to differentiate between inner surface and outer surface/through wall defects.
- **RDP Type D5/100 AW Linear Variable Differential Transformer** : This AC LVDT is used for rod profilometery. It operates at 5V rms and 5kHz, has a measuring range of +/-2.5mm and an output sensitivity of 70mV/V/mm.

The two eddy current sensors are mounted in a combination cassette. This is based on the cassette for the eddy current encircling coil (fig 16) but has a nylon holder for the point probe on the lower face of the cassette (fig 17). The LVDT is mounted in a dedicated cassette (fig 18).

4.1.4 Fuel Rod Handling Tool

The fuel rod handling tool has two separate functions. Firstly it is used as a handling tool to move the fuel rod to and from the facility and then, once secured in the toolholder, it is used to rotate and translate the fuel rod through the stationary sensors. The assembly drawing for the handling tool is shown in figure 5.

The tool locates on to a standard 'Dilo' connector on the top of the fuel rod. This is a specially shaped upper fuel rod support and capsule sealing component. In order to attach the handling tool to the Dilo it is necessary to perform the following tasks -

1. place bottom of tool over Dilo on the top of the fuel pin.
2. rotate tool until square hole on the bottom of tool locates over square mounting on Dilo.
3. Dilo should now be locked on to tool.

To release the fuel rod from the tool -

1. hold tool shaft stationary and turn handle through 90^{o}
2. push handle down
3. the fuel rod should now be released.

During normal operation, the toolholder locates in a toolholder on the moving arm of the drive unit. The tool rotates in the toolholder on a dry bearing of aluminium bronze running on stainless steel. This is located in a housing approximately 1m from the top of the tool. Rotation is transferred from the adjacent stepping motor via a gearbox and two meshing nylon spur gears. The tool is secured in the holder by means of a spring loaded pin.

4.2 Instrumentation and Cabling

4.2.1 Instrumentation

The instrumentation necessary for the operation of the installation will be located on the second floor of the reactor hall in an identical position to that used by the present system. A schematic of the overall cabling layout can be seen in figure 10. The recording and display instrumentation will be located in a 19" cabinet (see figure 7) with two PCs located on an adjacent table.

4.2.1.1 General

The 19" cabinet contains a common power supply for all of the instrumentation except the two computers (fig 7 #2). The power supply contains a main on/off switch for all components within the 19" cabinet and additional on/off switches for the motor controller and the LVDT. A seven day timer is also provided to switch on and warm up the EM3300s before the start of a test.

The input to the EM3300s and the LVDT amplifier can be changed between the output from either the BWR or PWR sensors by means of the BWR/PWR switch (fig 7 #3).

4.2.1 2 Motor Control System

The two stepping motors in the drive unit are controlled by the Digiplan IF-2 motor controller (figure 7 #10). This unit contains a Digiplan CD20 driver for each stepping motor, an IF-2 programmable controller card, a clock datum card to enable the motors to move to repeatable datums and a common power supply. The unit is able to operate in either Manual or Programmable mode.

In Manual mode, the operator is able to raise or rotate the fuel rod at predetermined speeds of 200 mm/min and 0.06 revs/sec. In order to move the rod, it is necessary to depress one of the labelled buttons on the front panel of the motor controller or on the remote box (see figure 22). As a safety feature, the rod only moves when pressure is applied to the button. The drive unit can only be controlled from either the remote box or the main control panel. An illuminated switch is provided on the main control panel indicating which is being used.

In Programmable mode, the controller acts on instructions it receives from the Corona PC (fig 7#12) which controls the progress of the test. These instructions are sent in the form of a command string via an RS-232 interface. The operator can only choose from a number of default commands and is not able to instruct the controller directly. As a precaution against transmission errors, a parity bit is included in the command instruction which is sent with echo back.

4.2.1 3 Positional Registration

The linear and angular position of the fuel rod are determined by two absolute encoders and displayed on separate units in the 19" cabinet (fig 7 #4&5). The angular encoder (TWK WA/VW 100) has a resolution of 0.1^{o}, whilst the linear encoder (Sony LH20-1G5R Magnescale) has a resolution of 1um. The Sony display is capable of working in both Absolute and Incremental mode.

4.2.1.4 EM3300 For Eddy Current Point Probe

The eddy current point probe is operated in conjunction with an Automation Industries EM3300 Eddy Current Test Instrument (fig 7,#6). The instrument operates either the BWR or PWR point probe (selected by the BWR/PWR switch section 4.2.1.2) at a frequency of 500kHz and displays the resulting coil impedance on a storage oscilloscope.

4.2.1.5 EM3300 For Eddy Current Encircling Coil

The eddy current encircling coil is operated at a frequency of 200kHz on an identical instrument to that for the point probe (fig 7 #7).

4.2.1.6 LVDT Amplifier

The output signal from each LVDT is fed to a separate amplifier within the 19" cabinet. The amplifiers have an output range of +/-1V which corresponds to a displacement of +/-100um. The output signal is fed to a chart recorder where 1mm on the chart corresponds to a displacement of 8um.

4.2.1.7 Data Recording

The data from the sensors and the positional registration devices are recorded on a NEFF System 470 data logger (fig 7,#11) which is controlled via an IEEE-488 interface by a host computer (fig 7,#13). The data logger is controlled by the data acquisition software package, NDAS-PC. This software is initiated from the start up menu on the host PC and is a menu driven package written in compiled BASIC. It is capable of recording both analogue and digital inputs at frequencies in excess of 100Hz. The data is initially recorded in a compressed binary format and is later processed off-line into a standard ASCII file.

In addition, the outputs from the Eddy Current Encircling Coil and the LVDT are recorded on Philips PM8272 xyt Recorders (fig 7, #8&9).

4.2.2 Reactor Hall Cabling

4.2.2.1 Cabling Between Second Floor And Poolside

In total it will be necessary to run thirteen cables from the poolside installation to the instrumentation on the second floor. The cables will be 20m long and will be laid in the same trunking as that used by the present system.

The cables can be divided into two groups. The first set corresponds to the operation of the drive unit and run from the back of the IF-2 motor controller to a connection box on the side of the drive unit. The cables are fitted with bayonet type connectors and are easily removed if the drive unit needs to be moved from the pool side.

The second set of cables carry the signals from the sensors and run from the BWR/PWR switch to a connection box on the pool wall.

A functional description of each cable is given in table 3. All of the cables are low tension, the highest voltage being 24V DC in the motor power cables.

4.2.2.2 Underwater Cabling

The cables used between the sensors and the poolside connection box are approximately 5m long and are suitable for underwater use. The eddy current probe and coil are connected to six BNC sockets and the LVDTs are connected to two 5-pin sockets on the side of the connection box. All the cables are individually contained within protective plastic hosing and run along a protective duct on the side of the support frame to the sensors.

5.0 CHARACTERISTICS

5.1 Operational Characteristics

Scan length	540mm
Vertical Speed (manual control)	200mm/min
" " (computer control)	120 or 250 mm/min
Rotational Speed (manual control)	0.06 rev/sec
" " (computer control)	0.06 rev/sec
Maximum Force Exerted on Fuel Rod	441 N
Maximum Torque Exerted on Fuel Rod	1100 Nmm (See Appendix)

5.2 Fuel Rod Handling Characteristics

5.2.1 Activity and Decay Heat Characteristics of Fuel Rod

Figures for the decay heat and activity for typical segmented PWR fuel rods with a fuel stack of 320mm have been evaluated using a procedure described in /1/. The results of these calculations can be seen in figures 19 & 20 and in table 4. It has been conservatively estimated that the rods were subjected to a linear heat rate of 300 W/cm for pre-irradiation periods of 1, 2 or 3 years then cooled for 1 year and subsequently irradiated at the HFR for 18 days at 600 W/cm.

	pre-irradiation period					
days after end of irradiation	1year		2years		3years	
	Decay Heat (W)	Activity x10000 (GBq)	Decay Heat (W)	Activity x10000 (GBq)	Decay Heat (W)	Activity x10000 (GBq)
1	54	2368	88	3700	91	3885
3	32	1406	64	2738	66	2849
5	25	1073	54	2368	57	2479
10	16.5	693.8	44	1850	46	1998
50	6.9	255.3	23.5	999	26	1110
100	3.8	166.5	17	721.5	21	814

Table 4 - Decay Heat and Activity Characteristics of a Typical PWR Fuel Rod

In normal operation, an examination will only be conducted on a fuel rod at the earliest three days after termination of the irradiation period. After a three day cooling period, the rods which have been pre-irradiated for one year have a decay heat of 32 W whilst the rods pre-irradiated for 2 or 3 years have a decay heat of 65 W. These levels are not high enough to raise the local temperature of the water and affect the sensor measurement.

The corresponding activities of the rods are 1.4x10**7 GBq for rods with a 1 year pre-irradiation period and 2.8x10**7 GBq for the rods with 2 or 3 year pre-irradiation periods. From the present system, it is known that, during normal operation under a depth of 3.5m of water, these levels will not result in a measurable increase in activity at the pool surface. Only if the depth of water is reduced to less than 1m will an increase in activity be detected.

5.2.2 Loading Characteristics Due To a Stuck Fuel Rod And A Stalled Motor

A stress analysis has been carried out on the fuel rod to determine the maximum stresses in the event of one of the motors stalling. The vertical motor will exert a force of 441N and the rotary motor a torque of 1100Nmm before stall. At each of these conditions, the stresses generated in five components of the fuel rod were considered (see figure 25 & table 5).

1. 2mm diameter pin in the bottom of the handling tool which locks the dilo to the tool during operation.
2. M4 pin which screws into the bottom of the dilo and to the top of the fuel rod support piece. The pin is tack welded to the dilo.

3. 2mm diameter pin securing /2/ to the top of the fuel rod support piece.

4. 4mm diameter pin attaching fuel rod support piece to section containing fuel.

5. restraining pin between fuel rod support piece and section containing fuel.

The resulting maximum stresses and resulting torques were determined and these can be seen in table 5 and in Section 12.

5.3 Failsafe Characteristics

The facility includes a number of fail safe features.

The length of travel of the moving arm on the drive unit is limited by two limit switches. These are 3 wire witches will be activated in the event of a broken or loose wire.

If during operation the drive unit should be subjected to a power failure, upon restoration of power, the unit will hold the same position and will only move when it receives instructions from the PC or from the manual control panel via the motor controller.

Each of the stepping motors are equipped with an incremental encoder which counts the number of steps performed by each motor. The motor controller continually compares this with the number of pulses sent to each motor. If there is a discrepancy between the two values, as would happen if one motor stalled, the motor controller immediately registers a fault which is detected by the scan control software running on the PC. The software immediately stops both stepping motors and informs the operator as to the cause of the fault. It is not possible to move the drive unit until the fault has been removed or corrected.

6.0 Fabrication And Inspection

The support frame, fuel rod handling tool and sensor housing have been designed, fabricated and assembled by JRC Petten. The drive unit and associated equipment has been supplied by Van Gelder BV, Rotterdam.

Final testing of the complete installation has been carried out in the test pool at the Technology Hall, JRC Petten.

6.1 Testing Prior To Assembly

6.1.1 Instrumentation

Once all the instrumentation had been fitted to the 19" cabinet, the operation of the following instruments were checked -

- power supply
- timer
- BWR/PWR switch
- LVDT amplifier
- EM3300 (for eddy current encircling coil)
- EM3300 (for eddy current point probe)
- chart recorder (eddy current encircling coil)
- chart recorder (LVDT)
- NEFF data logger and host PC
- motor controller and Main PC

6.1.2 Sensors

In the technology hall, the sensors were assembled in their cassettes and connected to the appropriate instrumentation via the BWR/PWR switch. The following tests were performed on a standard calibration pin -

- operation of both eddy current encircling coils at 200kHz using an EM3300.
- operation of both eddy current point probes at 500kHz using an EM3300.
- operation of both LVDT amplifiers over the correct range.

6.1.3 Mechanical Equipment

The relevant dimensions on the support frame, sensor housing and fuel rod handling tool were checked to ensure that they conformed to the design dimensions. In addition, the following functionality checks were performed-

- fuel rod handling tool was able to lock/unlock onto a standard calibration pin.
- sensor housing could be locked/unlocked to sensor table
- sensor cassettes could be securely fitted to senor housing
- drive unit could be securely located above both sensor positions

6.2 Testing After Assembly

6.2.1 Motor Control System

The motor control system was checked to ensure that the drive unit was able to perform the following functions -

- move fuel rod handling tool up
- move fuel rod handling tool down
- rotate fuel rod handling tool clockwise
- rotate fuel rod handling tool anti-clockwise
- move to vertical datum
- move to angular datum
- stalling characteristics determined

6.2.2 Safety Functions

The ability and speed of response of the scan control software to halt the test sequence in the event of an error in the motor control system was determined for the following faults -

- upper limit switch activated
- lower limit switch activated
- encoder error due to stalled motor
- emergency stop

In all of the above cases, the drive unit stopped less than 1mm after occurrence of the fault.

6.2.3 Data Recording

Checks were made during a simulated test that -

- output from LVDT amplifier was able to be recorded on the chart recorder
- output from EM3300 connected to the encircling coil was able to be recorded on the chart recorder.
- NEFF data logger recorded correct data on the correct channels

6.3 Preparation Prior To Transfer To HFR

Before transfer to the HFR, it will be necessary for the Fuel Rod Handling Tool and the Support Frame to be cleaned and degreased with alcohol.

7.0 Operation

7.1 Preparation Before Test

Before starting a test, it is necessary for the operator to ensure the following -

(i) the timer has been set to switch on the two EM3300s at least 30 minutes before the start of the test.

(ii) the bridge on the HFR pool has been securely locked and is not able to travel over the installation.

(iii) the correct fuel rod handling tool is present.

(iv) he has a copy of the relevant instruction sheet (Bijlage).

(v) a member of the Health Physics Department (GBA) is present.

(vi) the drive unit is positioned over the correct sensor set.

(vii) he has paper for the chart recorders, a floppy disc formatted to 360k for the main PC and a floppy disc formatted to 1.2M for the NEFF PC.

Only when all of the above requirements have been met should the operator proceed with the test.

7.2 Instrument Calibration

All the instrumentation in the 19" cabinet can be switched on via the main switch on the power supply within the cabinet. The two PCs must be switched on individually.

In order to reduce both the examination time and the operator workload, the test procedure has been semi-automated. This now being controlled by a computer program resident on a portable Corona PC, permanently located on a table adjacent to the 19" cabinet (see fig 8). The program guides the operator, via a series of menu screens, through the complete test sequence.

The test is initiated from the start up menu on the PC by selecting option 'E - Start Eddy Current Test.'. A block diagram of the contents of a test sequence can be seen in figure 1. After initiating the software, the operator is required to input various test parameters such as fuel rod number, experiment number etc. This information is later used to produce a standard test report. The operator is then prompted to load a calibration pin to the handling tool which is then placed and secured in the toolholder. After the calibration pin has been loaded the software moves the drive unit to the linear and angular datum points.

7.2.1 Calibration of Eddy Current Encircling Coil

The eddy current encircling coil is calibrated against a 1.5mm diameter through wall defect which is locate approximately 300mm from the top of the calibration pin. The program automatically moves the pin to the correct position and will then display an instruction screen advising the operator on how best to calibrate the encircling coil. The operator may then scan over the defect by pressing the Autostart button on the main panel of the motor controller. The object being to obtain a 'figure 8' orientated at 45^{0} to the X & Y axes of the display as shown in figure 23. The operator must adjust the phase control on the EM3300 in order to give the correct orientation of the display. When he is satisfied he can proceed to the next instrument calibration by pressing the space bar on the PC.

7.2.2 Calibration of Eddy Current Point Probe

The eddy current point probe is calibrated against a stepped diameter change in the calibration pin approximately 120mm from the top of the pin. The software automatically moves the pin to the correct position and will then display an instruction screen advising the operator on how best to calibrate the point probe. The operator may scan the stepped diameter change by pressing the Autostart button on the main panel of the motor controller. The objective in this case is to obtain a near horizontal display on the oscilloscope as shown in fig24. The operator must adjust the phase control on the EM3300 to give the correct orientation of the display. When he is satisfied he can proceed to the next instrument calibration by pressing the space bar on the PC.

7.2.3 Calibration of LVDT

The LVDT is calibrated against five diameters on the calibration pin, with the difference between each being 25um. There are two outputs from the amplifier (fig 7,#3) one is fed to the data logger, whilst the other is sent to one of the chart recorders. The chart recorder should be set with a chart speed of 120 mm/min and a sensitivity of 0.1 V/cm. The operator starts the set up procedure by pressing the space bar on the PC. The calibration pin will then be moved so that the LVDT measures the third stepped diameter. At this point, the LVDT should be switched from Absolute to Relative which should cause the display to change to 0.00. The pen on the chart recorder should then be zeroed in the centre of the scale. When he is satisfied that the LVDT has been set up correctly, he can proceed with the calibration routine by pressing the space bar on the PC.

7.2.4 Calibration Scan

After all the instruments have been set up correctly, the software will move the calibration pin to the correct position for the start of the calibration scan. The operator is then prompted to start the data logger recording and can start the scan by pressing the space bar on the PC. Whilst the scan is in progress, there is a continuous on-screen display of the progress of the scan. When the scan has been completed, the operator is prompted to stop the data logger and to return the calibration pin to the storage position on the sensor table. Typical outputs obtained from each of the three sensors during a calibration scan can be seen in figure 21.

7.3 Fuel Rod Examination

The operator must first locate the fuel rod in the handling tool and load the tool and fuel rod to the drive unit. The examination commences by pressing the space bar on the PC. The operator will then be invited to chose the type of examination that he wishes to conduct from a menu screen consisting of four scan types -

- 3 x vertical scans separated by 120^{o} at 120mm/min
- 37 x vertical scans separated by 10^{o} at 120mm/min
- Helical scan at a pitch of 3mm and speed of 250mm/min
- custom combination of helical and vertical scans built up from the following selections-
    1. Slow Helical Scan (120mm/min)
    2. Fast Helical Scan (250mm/min)
    3. Slow Vertical Scan (120mm/min)
    4. Fast Vertical Scan (250mm/min)
    5. Rotate Rod 120^{o}
    6. Pause (until Autostart button is pressed).

When the operator has selected the required scan, the software will first move the fuel rod to the datum points and then to the scan start position. The operator is prompted to switch on the chart recorders and to start the data logger. The test is started by pressing the space bar on the PC. Whilst the test is in progress, the operator is given an indication of the extent of progression by an on-screen display. The operator is informed by an on-screen display when the test has been completed and is prompted to switch off the data logger and to note the file name that the test data has been saved in. He is then required to insert a floppy disc, formatted to 360kBytes, into drive 'A' of the main PC which is used to create a file in which the test parameters will be saved. After this, he must remove the disc, insert it into drive 'B' of the Tatung, insert a 1.2M Byte disc into drive 'A' and select option 'C - Combine test data' from the main menu. The files containing the test data and set up parameters will then be saved on a single disc (see Figure 9). Finally, the operator will be given the choice of conducting another examination or of terminating the test sequence.

7.4. Termination of Test

In order to terminate the test sequence, the operator must carry out the following tasks -

(i) remove the fuel rod from the installation and store handling tool.

(ii) return the drive unit to the vertical datum (storage position)

(iii) switch off the mains switch on the 19" cabinet

(iv) switch off both PCs

(v) unlock bridge.

8.0 HANDLING

8.1 Loading of Rods To Installation

Before a test, the fuel rod to be examined will be loaded to the installation using the fuel rod handling tool described in section 4.1.4. The fuel rod will be available in one of two locations on the BWFC loading and discharge station (fig 14, #8). If the rod has not yet been irradiated at the HFR it will be located in a transport container. Otherwise it will be located in a BWFC irradiation capsule.

8.2 Unloading of Rods From Installation

After completion of a test, the fuel rod will be removed with the fuel rod handling tool. The rod must be replaced in either the transport container, if it is not to be subsequently irradiated, or in a BWFC capsule in preparation for irradiation. The loaded transport container will then be stored on the fuel rod storage rig (fig 14, #10).

10 SAFETY ANALYSIS

10.1 Safety Features

There are a number of features which have been built into the installation to prevent incidents occurring which may lead to damage to the fuel rod. These features are included in both the scan control software and in the poolside installation.

10.1.1 Emergency Stop of Drive Unit

At all times during the test, the operator has the opportunity to stop the drive unit immediately by means of an emergency stop button. There are two buttons provided, one on the main control panel in the 19" cabinet and one on the remote manual control box by the pool wall.

10.1.2 Drive Unit Safety Features

10.1.2.1 Stepping Motor Encoders

Both of the stepping motors are equipped with incremental encoders which enable the motor controller to monitor the number of steps performed by each motor. If there is a discrepancy between this value and the number of pulses issued by the controller, the controller will register a fault and illuminate an LED on the main control panel. The presence of this fault can be detected, via the controller, by the scan control software running on the main PC which will immediately stop the drive unit.

10.1.2.2 Stalling of Stepping Motors

If during a test, the fuel rod should become stuck in the sensors or the sensor housing, the stepping motors will stall before any damage can be done to the fuel rod. This has been ensured by limiting the maximum torque of each stepping motor should the motors stall. This will then be detected as a motor encoder error by the scan control software which will immediately stop the test and inform the operator.

10.1.2.3 Limit Switches

Approximately 50mm from the end of each linear slide on the drive unit an electrical limit switch has been positioned. These are 3 wire switches which become activated in the event of a loose or broken wire. If, during operation, one of these switches is tripped, the drive unit is immediately stopped and manual movement is only possible in a direction away from the switch. As an additional safety feature, mechanical end stops are included before the end of each slide. These stops will only be needed in the event of the failure of an electrical limit switch, but if encountered will cause the stepping motor to stall and stop before it can damage the drive unit.

10.1.2.4 Manual and Programmed Motion of Drive Unit

When under manual control, the operator is only able to move the drive unit by means of the push button switches on the main control panel or on the remote box at the following speeds-

- vertical speed = 200 mm/min
- angular speed = 0.06 revs/sec

If the drive unit is moving under instruction from the main PC, it can only move at the following pre-set speeds -

- vertical speed = 120 or 250 mm/min
- angular speed = 0.06 rev/sec

It is not possible for the drive unit to be moved at speeds other than those listed above.

10.1.3 Software Safety Features

To guard against errors in transmission between the PC and the motor controller the instructions are sent with a parity bit and echoback. Other safety features in the scan control software include a routine which continually monitors the motor controller for the presence of faults in the drive unit. The software is able to detect the following faults in the drive unit -

- encoder error due to motor stalling
- limit switch activated
- emergency stop

If any of these faults should occur, the software immediately stops the drive unit. An on-screen display informs the operator as to the cause of the problem and offers advice on how to correct the fault. Once the operator removes the fault, the software will allow the operator to restart the test from a position immediately before the section where the fault occurred.

10.1.4 Support Frame and Fuel Rod Handling Tool Safety Features

When the tool is placed in the toolholder, it is secured by means of a positive locking device. This ensures that the tool is secured to the toolholder during a test and prevents its accidental removal.

Beneath each of the sensor housings on the underwater table there is a catchment trough. This trough is provided in order to contain any debris which may result from an accident within the sensor housing. It will also contain the fuel rod in the event that it becomes detached from the dilo nut and falls through the sensor housing.

10.2 Effect of Power Loss and Restoration

If during operation, the installation suffers a power loss, the drive unit will hold the same vertical position. Upon restoration of power it will remain stationary and will only move when instructed to do so by the operator or the scan control software.

10.3 Maximum Credible Accident

The maximum credible accident is considered to occur when the fuel rod becomes jammed in the sensor housing. The rod can then not be damaged by being forced through the sensors by the drive unit, as the torque of the motors is limited so that they will stall before any damage could be done (see section 5.2.2). If this should occur, the motor interface will register an encoder error which is detected by the scan control software which immediately stops the test and informs the operator.

11.0 References

1. Nuclear Reactor Engineering, Third Edition
   Glasstone & Sesonske
   Van Nostrand Reinhold Company. New York 1987.

12.0 APPENDIX

12.1 Calculations For Stress Analysis

All the components used in the stress analysis were deemed to be subjected to a maximum axial load 441N (measured) and a torque which was to be established from calculations. This maximum allowable torque was determined by calculating the maximum permissible shear stresses as follows -

Assume - P1, P2 = Principal Stresses

T_{xy} = Maximum Shear Stress

S_x = Maximum Tensile Stress

S_e = Equivalent Stress = 250 MPa

From Von Mises Yield Criteria,

$$S_e^2 = P1^2 - P1P2 + P2^2 \qquad (1)$$

But : $P1 = S_x/2 + ((S_x^2/4) + T_{xy}^2)^{0.5}$

$P2 = S_x/2 - ((S_x^2/4) + T_{xy}^2)^{0.5}$

Let $a = (S_x/2)$

$b = ((S_x^2/4) + T_{xy}^2))^{0.5}$

Then $P1 = a + b$

$P2 = a - b$

Substitute for P1,P2 in equation (1)

$$S_e^2 = (a+b)^2 - (a+b)(a-b) + (a-b)^2$$

$$= (a^2 + 2ab + b^2) - (a^2 - b^2) + (a^2 - 2ab + b^2)$$

$$= a^2 + 3b^2$$

Substitute for a, b

$$S_e^2 = (S_x^2/4) + 3((S_x^2/4) + T_{xy}^2)$$

Rearrange for T_{xy}

$$T_{xy}^2 = (S_e^2 - S_x^2)/3 \qquad (2)$$

A diagram of the components used in the stress analysis can be seen in figure 25. Table 5 shows the Maximum Tensile Stress and the Maximum Allowable Torques which were determined for each component as follows -

(1) AISI 301 cylindrical pin dia 1.5 x 12mm long

Assume - $S_x = 0$

Yield Stress = 750 MPa

Axial load = 441N

dia=1.5mm, A=1.77mm^2

two shearing planes (see fig 25), total shearing area = 3.54mm^2

T_{xy} = shearing force / shear area

=441 / 3.54

= <u>124.58 MPa</u>

From equation 2 and rearranging for S_e,

$$S_e^2 = (S_x^2 + 3 \times T_{xy}^2)$$

S_e = <u>215.77 MPa</u>

Factor of Safety = Yield Stress / Maximum Tensile Stress

= 750 / 215.77

= <u>3.48</u>

(2) AISI 304 Threaded Pin dia 6, M4

(a) In Tension

Assume - Yield Stress = 250 MPa

M4 therefore dia=2.9mm. area= 6.607 mm^2

Max tensile stress = 441/6.607

= <u>66.75 MPa</u>

Factor of Safety = Yield Stress / Maximum Tensile Stress

= 250 / 66.75

= <u>3.75</u>

(b) Under Combined Tension And Torsion

Assume : S_e = Yield Stress = 250 MPa

S_x = 66.75 MPa

T_{xy} to be determined

From equation (2)

$T_{xy}^2 = (S_e^2 - S_x^2)/3$

= (250 x 250 - 66.75 x 66.75) / 3

T_{xy} = <u>139.10 MPa</u>

Maximum Allowable Torque= Maximum Shear Stress x Shear Area x Moment Arm

= 139.1 x 6.607 x (2.9/2)

= <u>1.333 Nm</u>

(3) AISI 316 Cylindrical Pin

dia 2mm, area = 3.14mm^2

Yield Stress = YS = 250 MPa

(a) In pure tension

T_{xy}= shear force / shear area

= 441/ (2 x 3.14)

= <u>70.17 MPa</u>

Factor of Safety = Yield Stress / Maximum Tensile Stress

= 250 / 70.17

= <u>3.56</u>

(b) Combined Tension And Torsion

Assume pin will fail along interface of component 2 and fuel rod support piece as a result of perpendicular shear stresses caused by the torque and axial loadings.

Yield Stress = YS = 250 MPa

Shear stress due to axial loading = T_{xy} = 70 MPa

Shear Stress due to torque = T_{zx} = to be determined

The Principal Stresses P_1, P_2, P_3 are given by the following equation-

$$P^3-(S_x+S_y+S_z)P^2+(S_xS_y+S_yS_z+S_zS_x-T_{xy}{}^2-T_{yz}{}^2-T_{zx}{}^2)P-(S_xS_yS_z+2T_{xy}T_{yz}T_{zx}-S_xT_{yz}{}^2-S_yT_{zx}{}^2-S_zT_{xy}{}^2)P^0 = 0$$

In our case, $S_x = 0$

$S_y = 0$

$S_z = 0$

$T_{xy} = 70.17$ MPa

$T_{yz} = 0$

T_{zx} = to be determined

Substitute these values into the above equation and reduce it to -

$$P^3 + (-T_{xy}{}^2 - T_{zx}{}^2)P = 0$$

$$P^2 = T_{zx}{}^2 + T_{xy}{}^2$$

$$P^2 = T_{zx}{}^2 + 70.17^2$$

This equation has the following roots,

$$P_1 = (T_{zx}^{\;2} + 4924)^{0.5}$$

$$P_2 = -(T_{zx}^{\;2} + 4924)^{0.5}$$

$$P_3 = 0$$

From Von Mises Yield Criteria,

$$S_e^{\;2} = P1^2 - P1P2 + P2^2$$

$$= 3 \times (T_{zx}^{\;2} + 4924)^2$$

Assume maximum value of S_e = Yield Stress = 250 MPa

$$250^2 = 3 \times (T_{zx}^{\;2} + 4924)$$

$$T_{zx}^{\;2} = \underline{126.13 \text{ MPa}}$$

This shear stress will be generated from a torque of

Maximum Allowable Torque= Maximum Shear Stress x Shear Area x Moment Arm

$$= 126.13 \times 3.14 \times (6.0/2)$$

$$= \underline{1.188 \text{ Nm}}$$

(4) AISI 304 cylindrical pin dia 1.7mm, area= 2.27 mm^2

Assume - C/L of pin is 3.9mm from C/L of tool

YS= 250 MPa

S_x=0

From equation (2), let S_e=YS

$$T_{xy}^{\;2} = (YS^2 - S_x^{\;2})/3$$

$$= (250 \times 250 - 0) / 3$$

$$T_{xy} = \underline{144.34 \text{ MPa}}$$

This shear stress will be generated from a torque of

Maximum Allowable Torque= Maximum Shear Stress x Shear Area x Moment Arm

= 144.34 x 2.27 x 3.9

= 1.278 Nm

(5) AISI 304 M5 Thread

Assume : pin will only fail in pure tension

dia = 4mm, area = $12.56mm^2$,

Axial Load = 441N

S_x = 441/12.56

= 35.08 MPa

Factor of Safety = Yield Stress / Maximum Tensile Stress

= 250 / 35.08

= 7.13

12.2 Stepping Motor Current Limitations

12.2.1 Vertical Stepping Motor

The minimum factor of safety for tensile loading of the components examined during the stress analysis was found to be 3.48. Consequently, it was not considered necessary to reduce the output of the vertical stepping motor by limiting the supply current.

12.2.2 Rotational Vertical Stepping Motor

The theoretical maximum output torque of the rotational stepping motor was calculated as follows -

Motor torque = 200 Nmm

Gearbox Ratio = 40:1

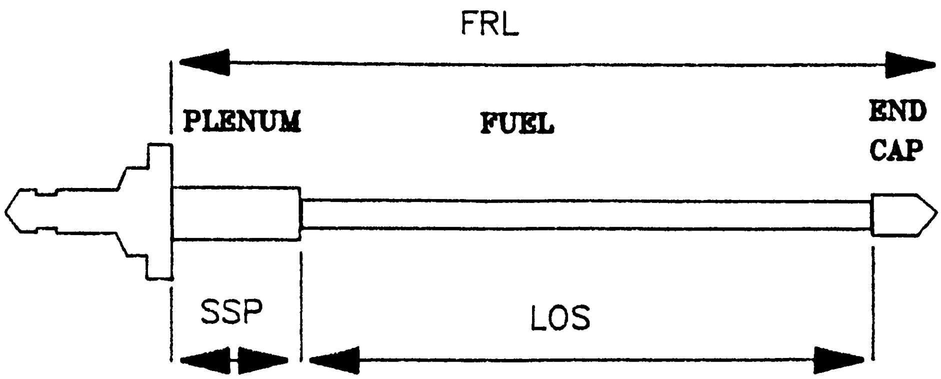
Gearbox Efficiency = 75 %

Output Torque = 200 x 40 x 0.75

= 6.00 Nm

The (measured) frictional torque in the toolholder bearing was found to be 800 Nmm, thus giving a nett torque on the tool of 5.20 Nmm.

From the stress analysis. the maximum allowable torque on the tool was found to be 1188 Nmm. As a result, the maximum supply current to the rotational stepping motor has been limited to give a maximum torque on the tool of 1.1 Nm.



FRL = Fuel Rod Length

LOS = Length Of Scan

SSP = Scan Start Position

Drawing Number	Diameter	Fuel Rod Length (FRL)	Scan Start Position (SSP)	Length Of Scan (LOS)
38467	9.7	534	160	317
33845	10.75	458	55	390
33886	10.75	534	100	390
33950	10.75	534	108	382
53881	10.75	534	90	390
36378	12.5	458	55	390
35343	12.5	534	100	390
40868	12.5	534	100	390

(All dimensions in mm.)

Table 1 – External Dimensions Of Fuel Rods To Be Examined

Cable No	Function
1	Sony Magnescale signal cable
2	Stepping Motor power cable
3	Stepping Motor encoders and Datum switches
4	Angular Position Indicator signal cable
5BL	LVDT (BWR)
5BP	Point Probe (BWR)
5BX	X channel eddy current encircling coil (BWR)
5BY	Y channel eddy current encircling coil (BWR)
5PL	LVDT (PWR)
5PP	Point Probe (PWR)
5PX	X channel eddy current encircling coil (PWR)
5PY	Y channel eddy current encircling coil (PWR)
6	Remote operation of drive unit

Table 3 - Functional Description of Reactor Hall Cabling.

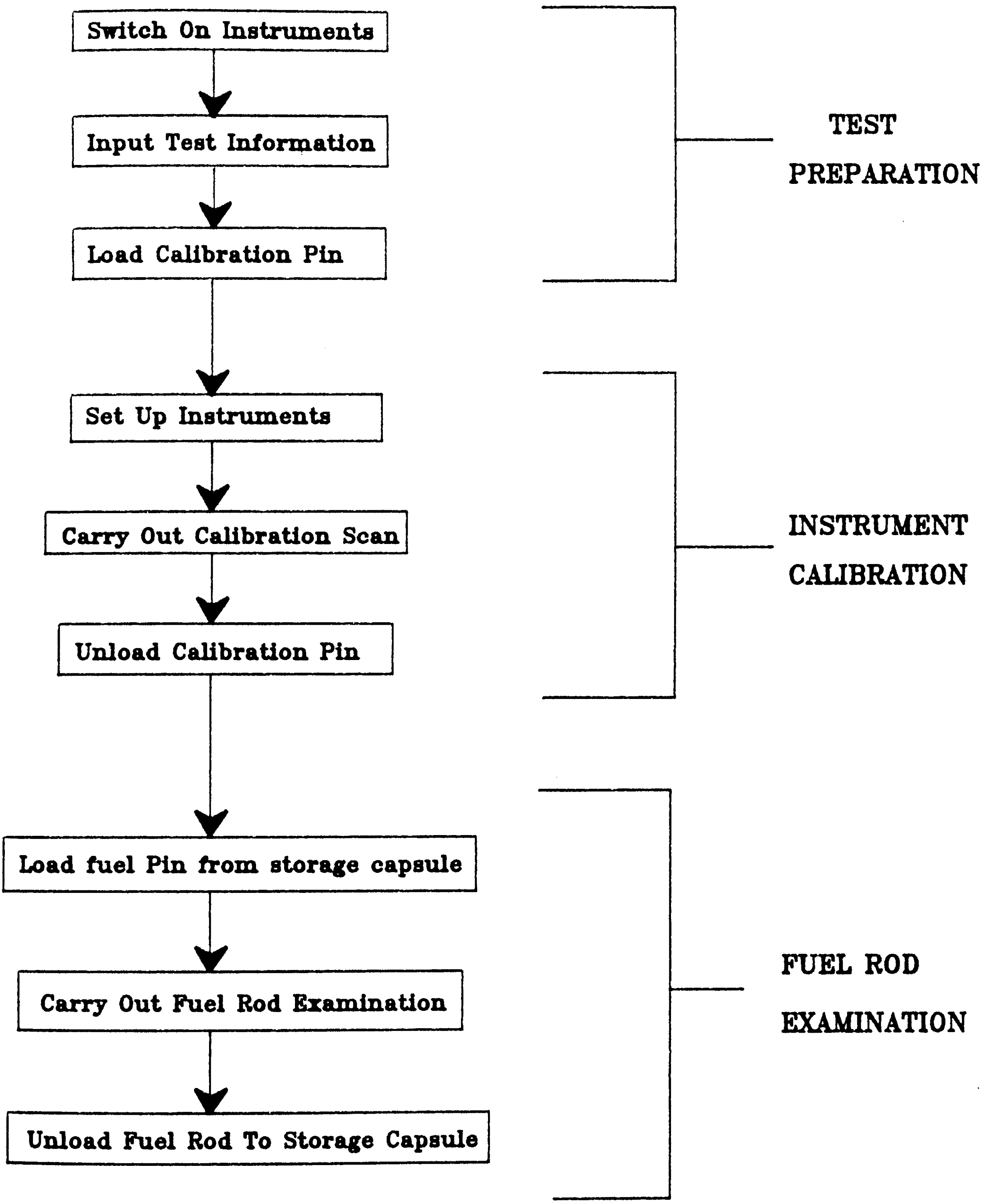


Figure 1 – Breakdown Of A Complete Test Sequence

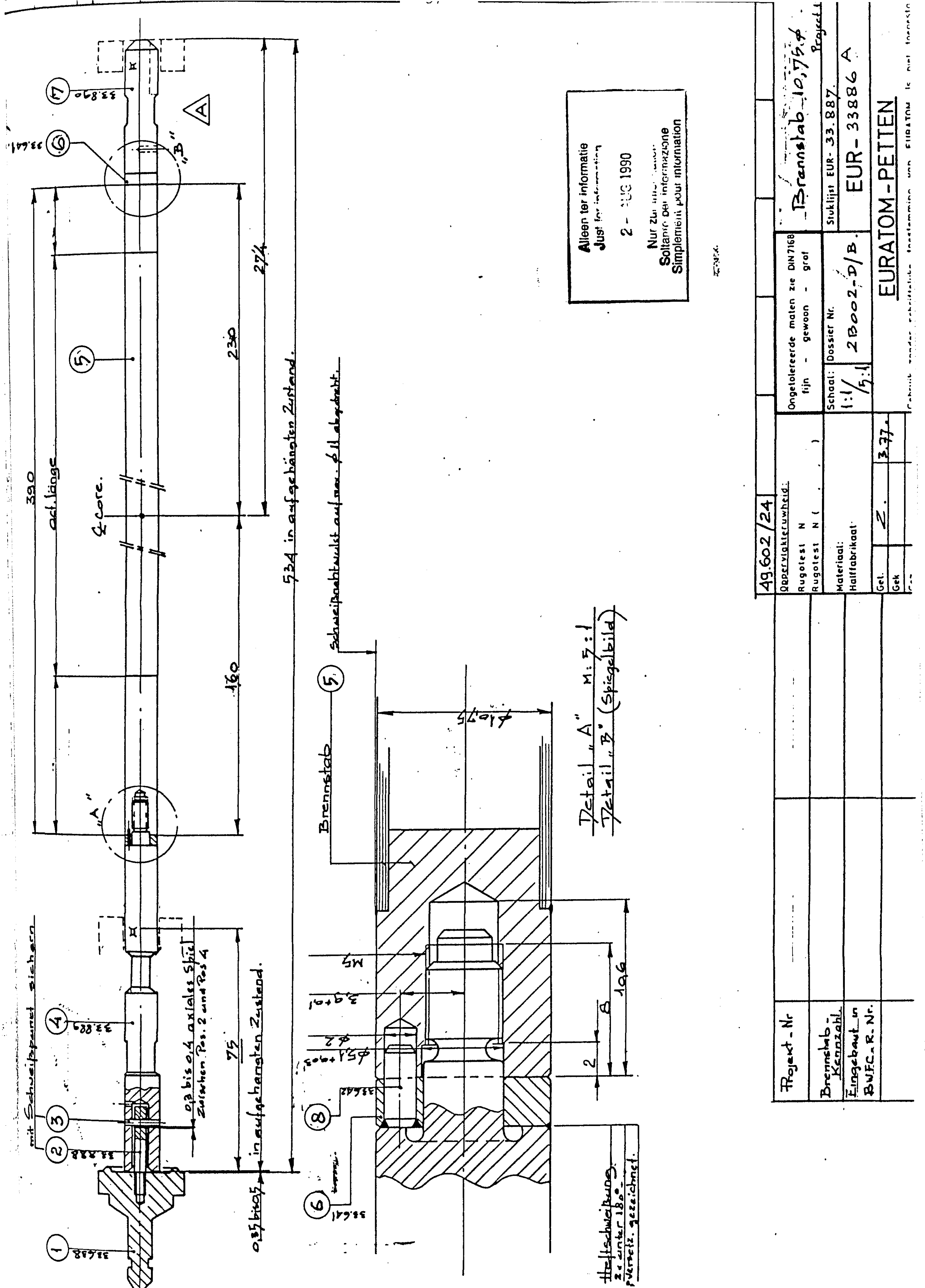


Figure 2 – Assembly Drawing of Typical LWR Fuel Rod

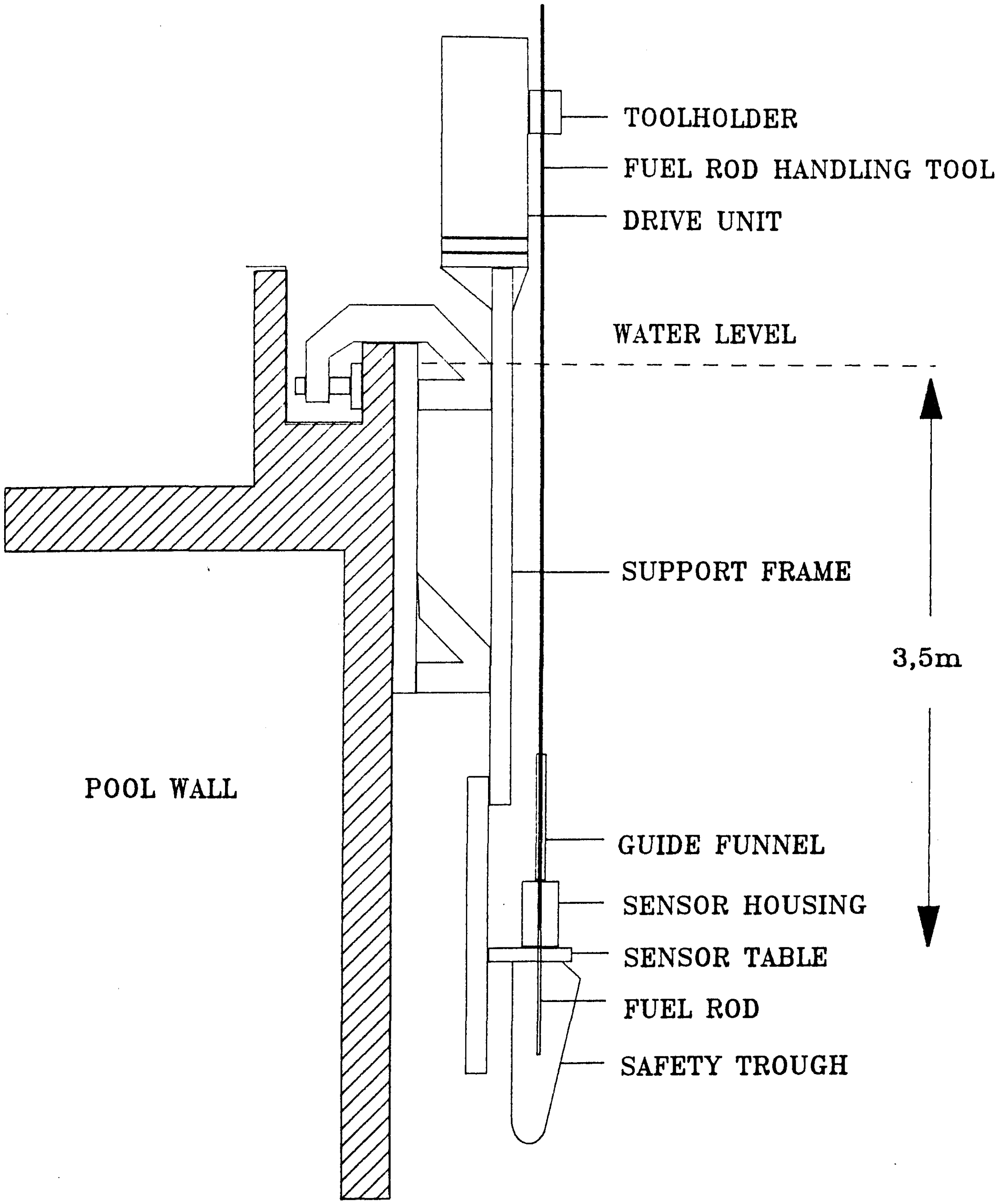
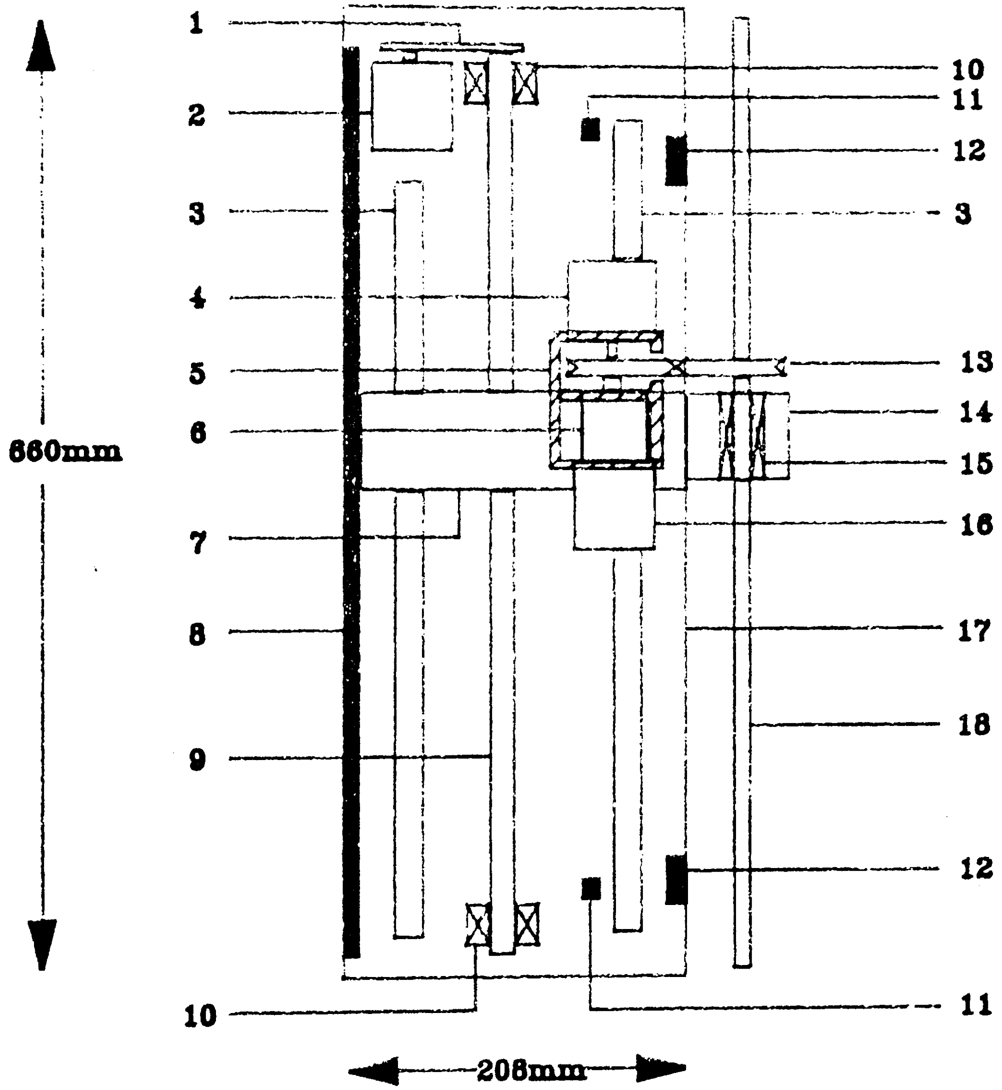


Figure 3 – Schematic Drawing of Poolside Installation.



1. Drive Belt
2. Stepping Motor
3. Linear Slide
4. Angular Absolute Encoder
5. Gearbox Housing
6. Gearbox
7. Moving Arm
8. Linear Encoder
9. Screw Shaft
10. Bearings
11. Mechanical End Stop
12. Electrical Limit Switch
13. Meshing Spur Gears
14. Toolholder
15. Dry Bearing
16. Stepping Motor
17. Drive Unit Backplate
18. Fuel Rod Handling Tool

Figure 4N – Schematic Drawing of Drive Unit

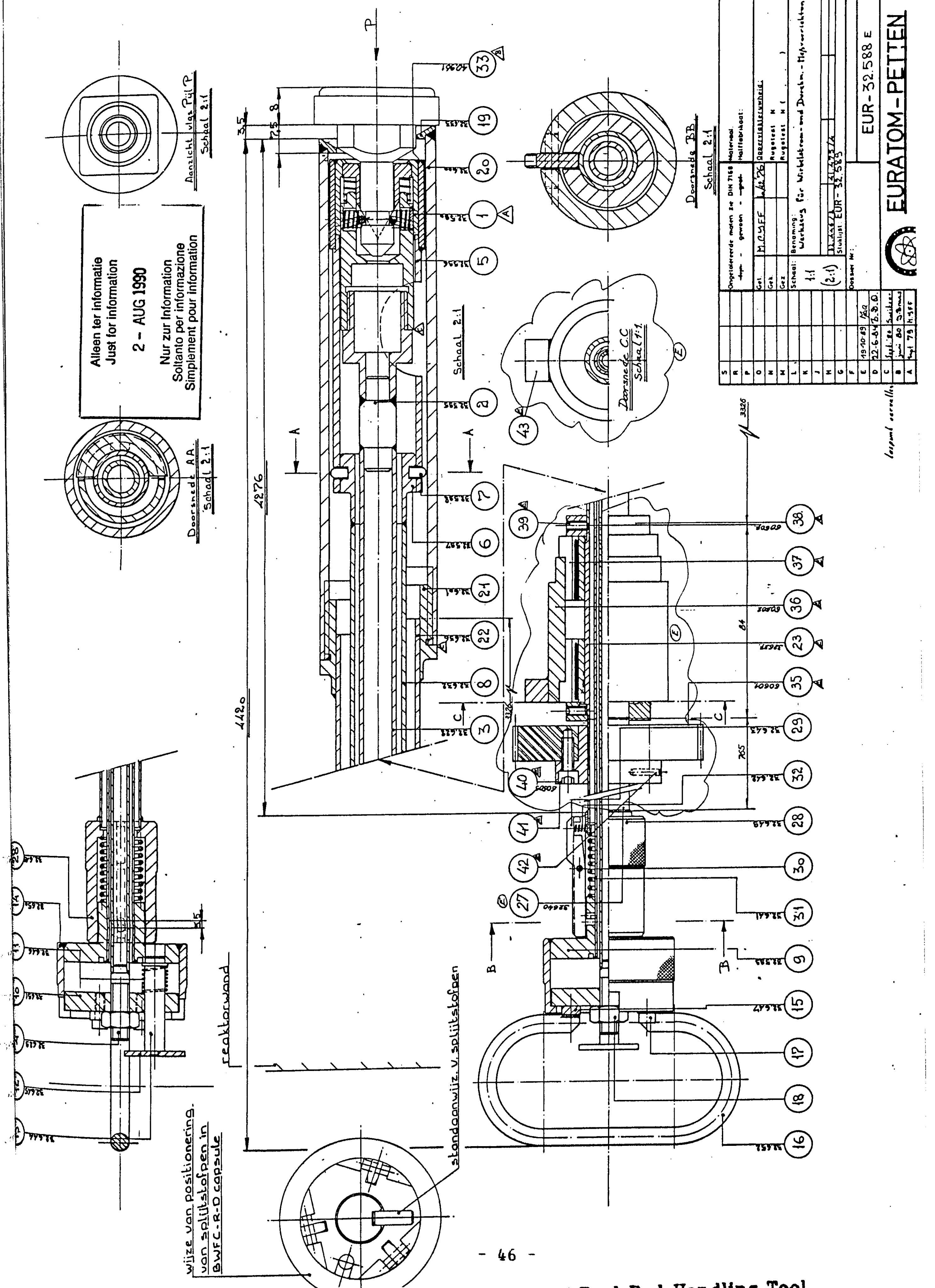


Figure 5 – Assembly Drawing of Fuel Rod Handling Tool

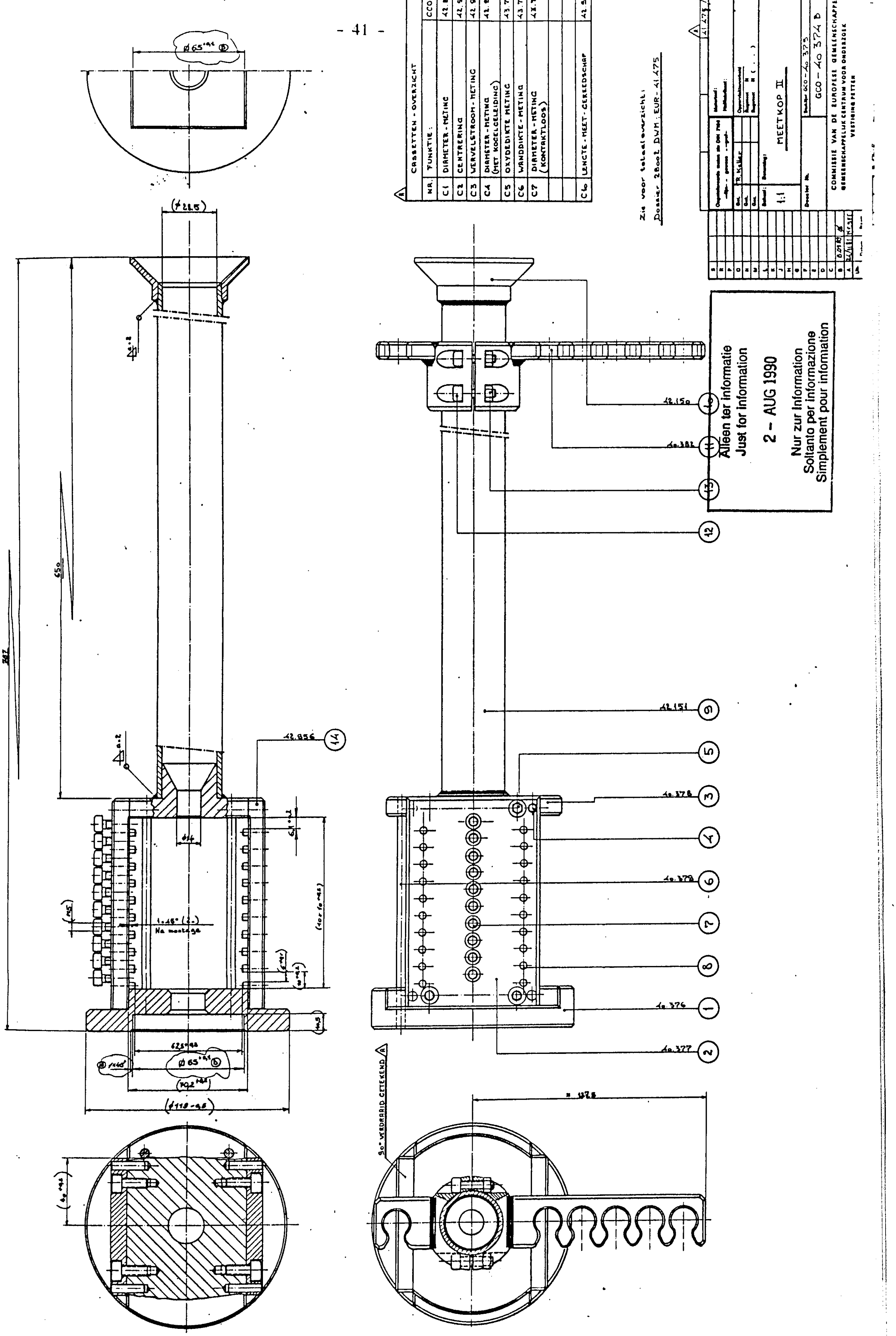
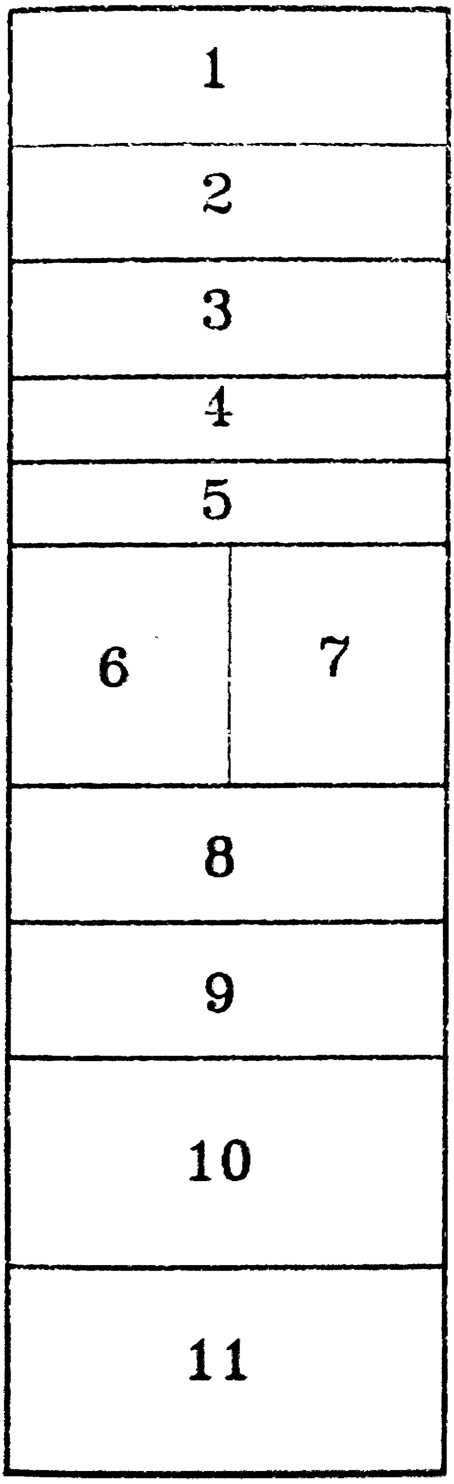


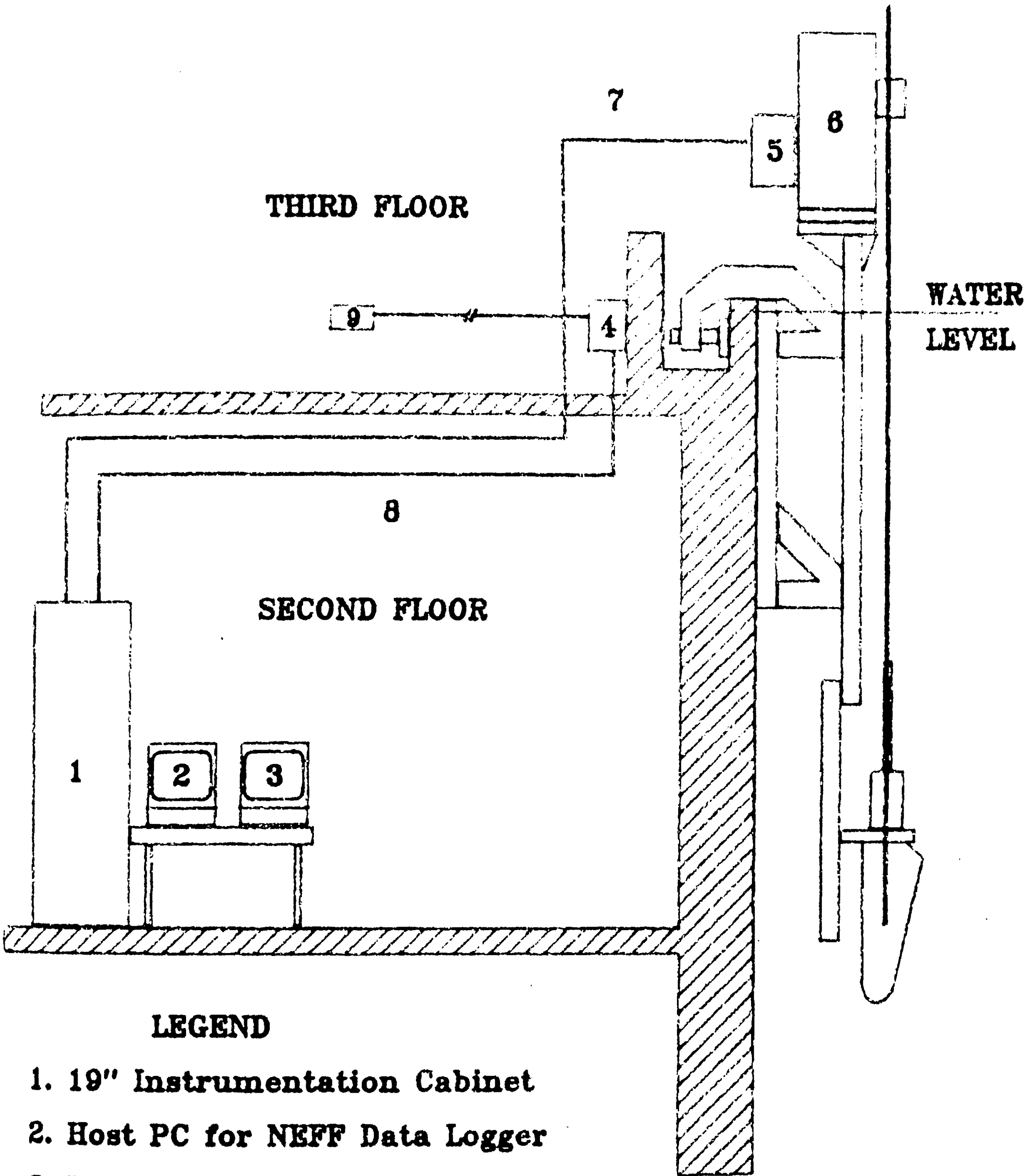
Figure 6 – Assembly Drawing of Sensor Housing



LEGEND

1. Unoccupied
2. Power Supply with main ON/OFF Switch and Timer
3. LVDT Amplifier
4. Linear Displacent Indicator
5. Angular Displacement Indicator
6. EM3300 (Point Probe)
7. EM3300 (Encircling Coil)
8. Chart Recorder (Encircling Coil)
9. Chart Recorder (LVDT)
10. Motor Controller Main Control Panel (See Figure 22)
11. NEFF Data Logger

Figure 7 – Layout of 19" Cabinet



LEGEND

1. 19" Instrumentation Cabinet
2. Host PC for NEFF Data Logger
3. PC to control Motor Interface
4. Sensor Poolside Connection Box
5. Drive Unit Connection Box
6. Drive Unit
7. Drive Unit Cabling (Cable No 1,2,3,4 & 6)
8. Sensor Cabling (Cable No 5BL,5BP,5BX,5BY,5PL,5PP,5PX & 5PY)
9. Drive Unit Remote Control Box

Figure 8 – Schematic Layout of Facility and Instrumentation in Reactor Hall.

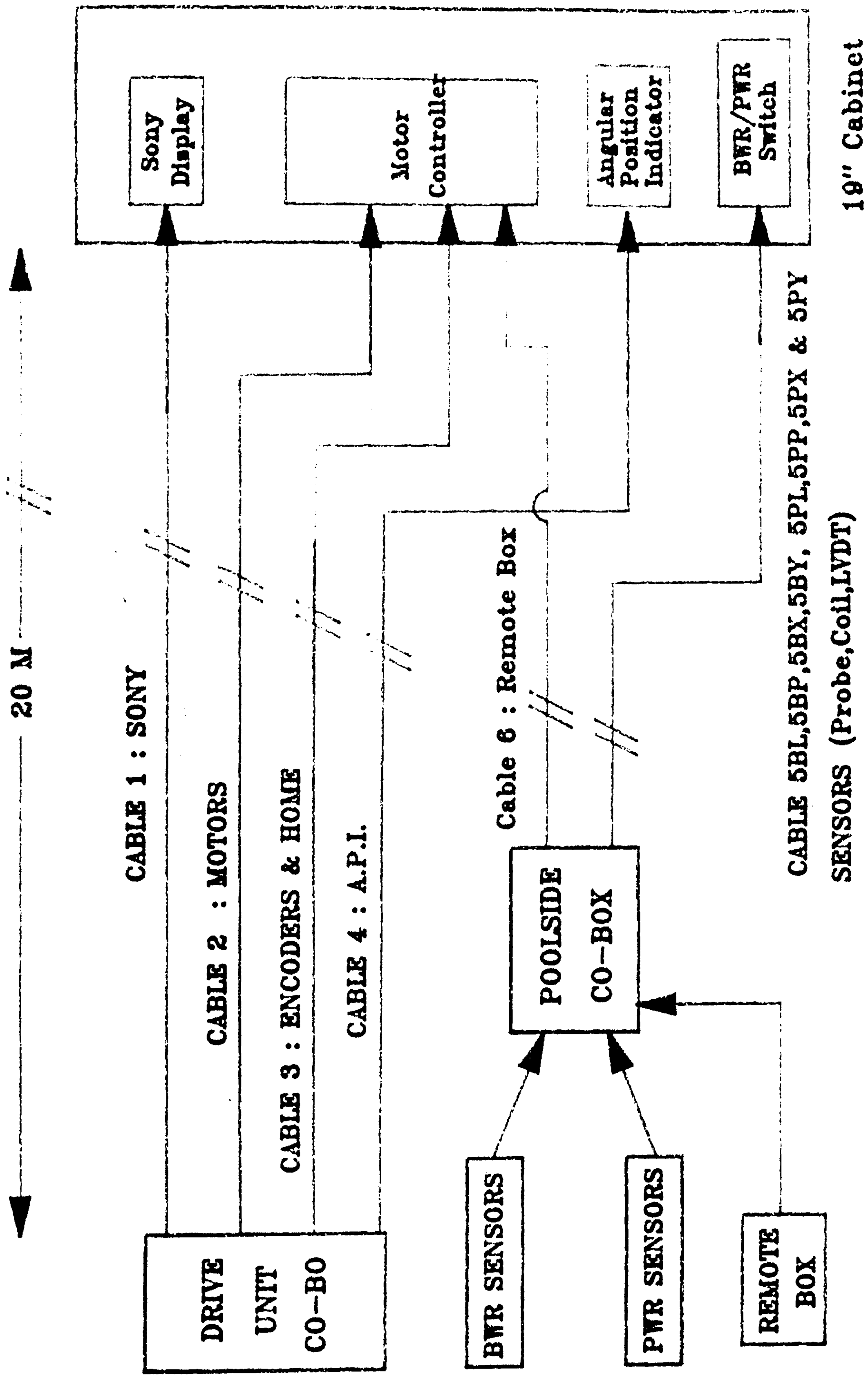


Figure 9 – Layout of Cabling In Reactor Hall

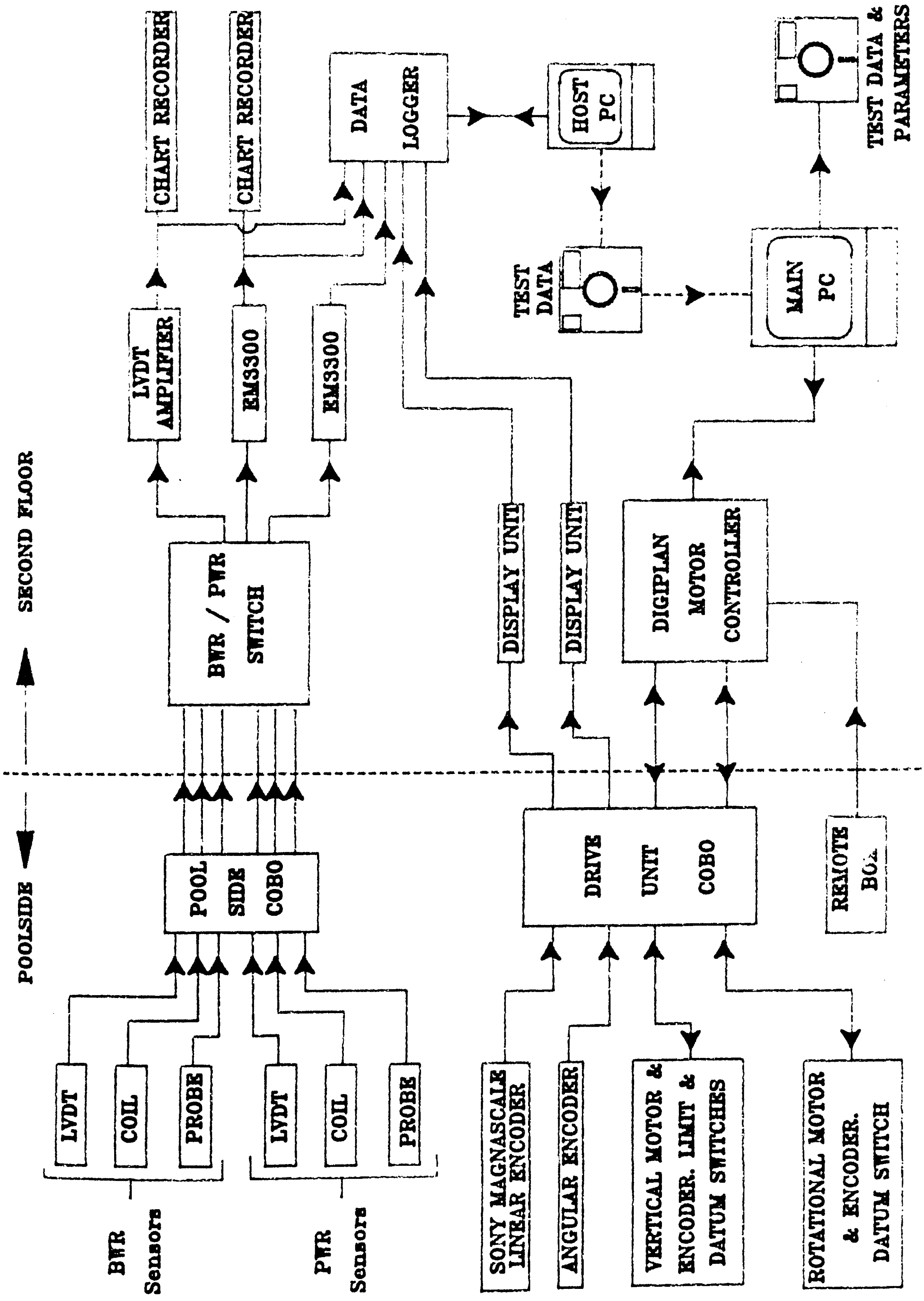


Figure 10 –Schematic Diagram of Installation Signal Cabling

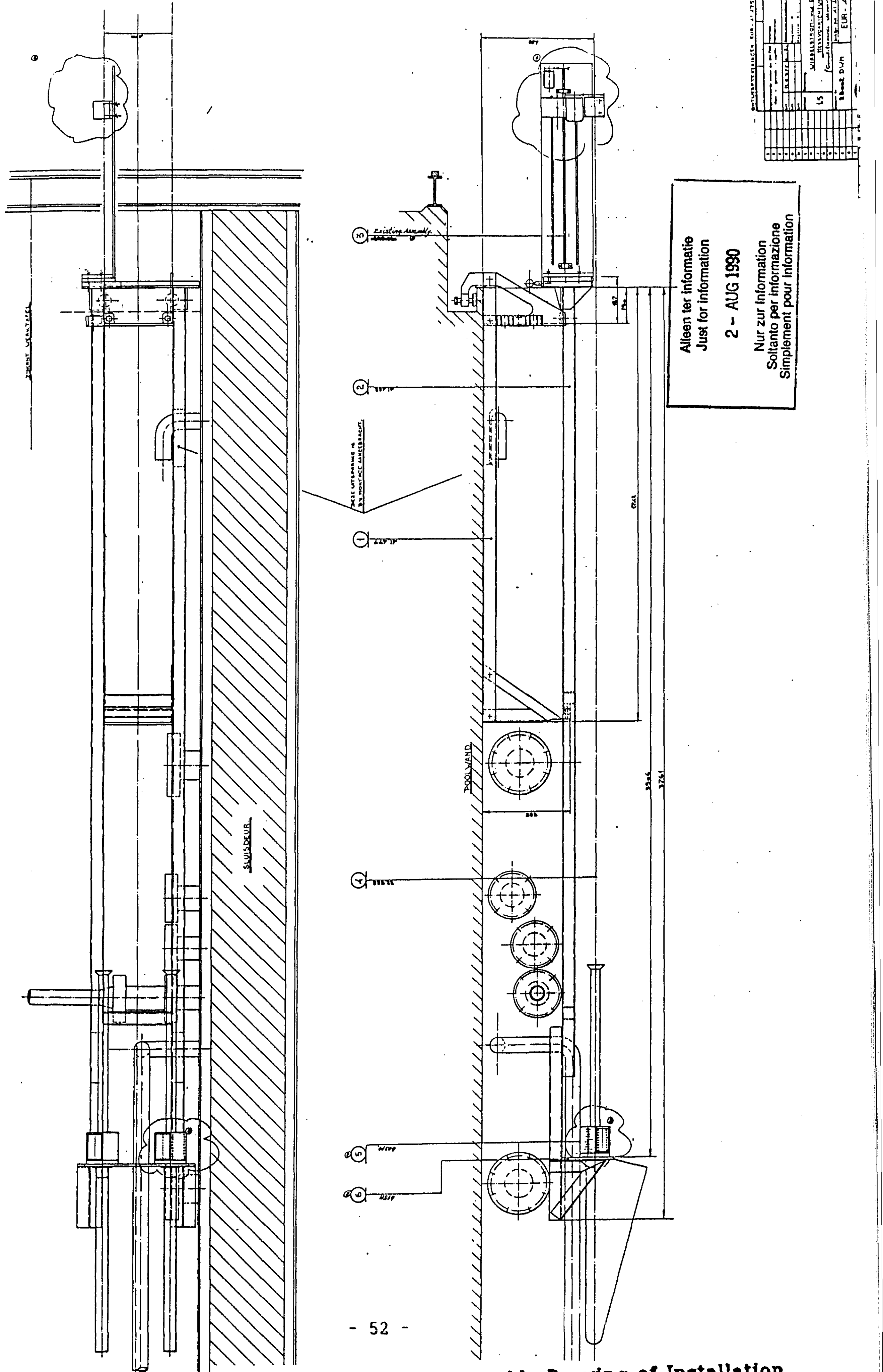


Figure 11 – General Assembly Drawing of Installation

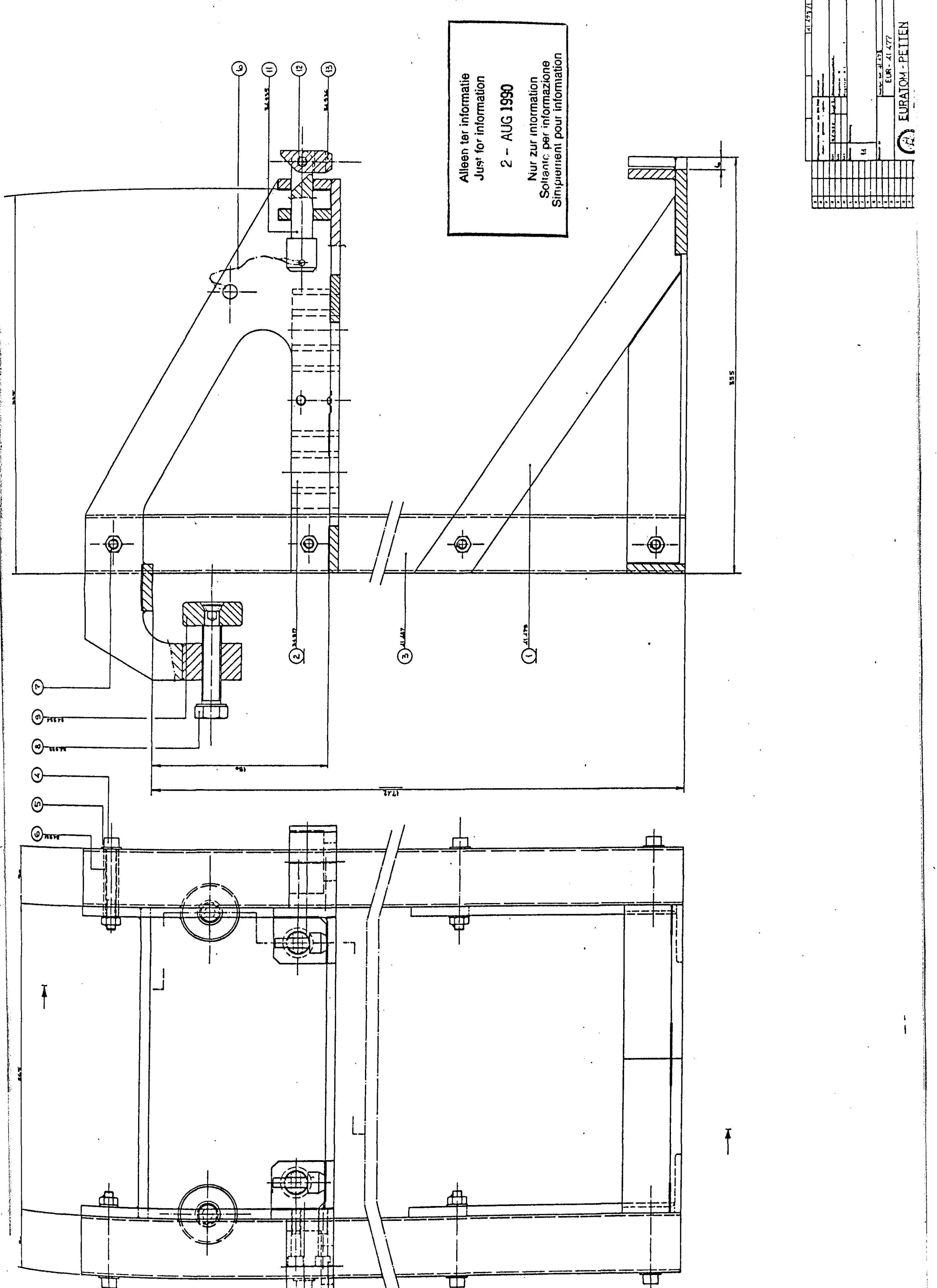


Figure 12 – Assembly Drawing of Support Frame

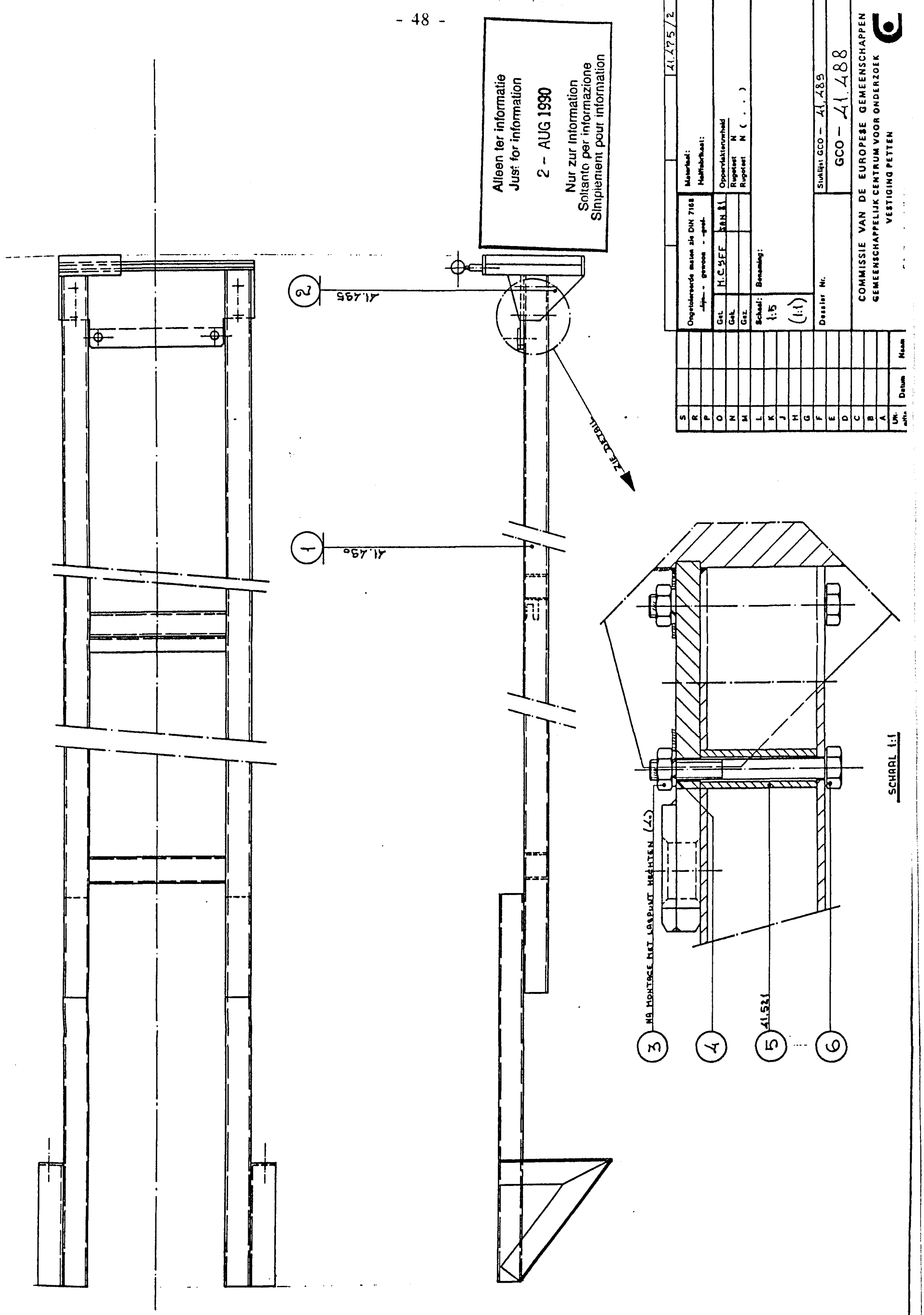
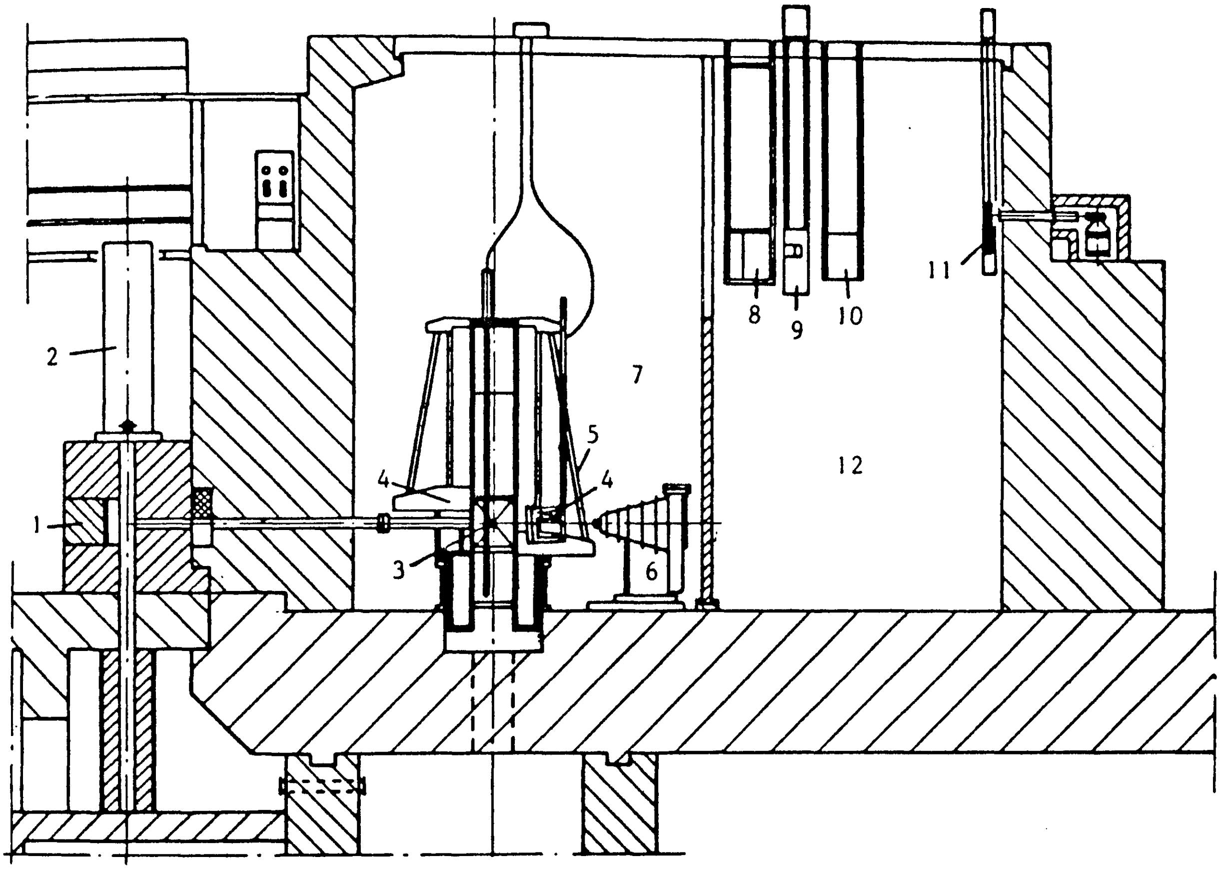


Figure 13 – Assembly Drawing of Support Frame



1. Dry Neutron Radiography (DNR)
2. Transport Container for DNR
3. HFR core
4. Pool Side Facility (PSF)
5. PSF irradiation device
6. Neitron radiography camera
7. HFR reactor pool
8. Loading & discharing station for fuel rod irradiation devices.
9. HFR INPOOL NDE INSTALLATION
10. Fuel rod storage rig.
11. Gamma Scan installation
12. HFR storage pool.

Figure 14 – Overall Arrangement of LWR Fuel Rod Test Equipment In The HFR Pools.

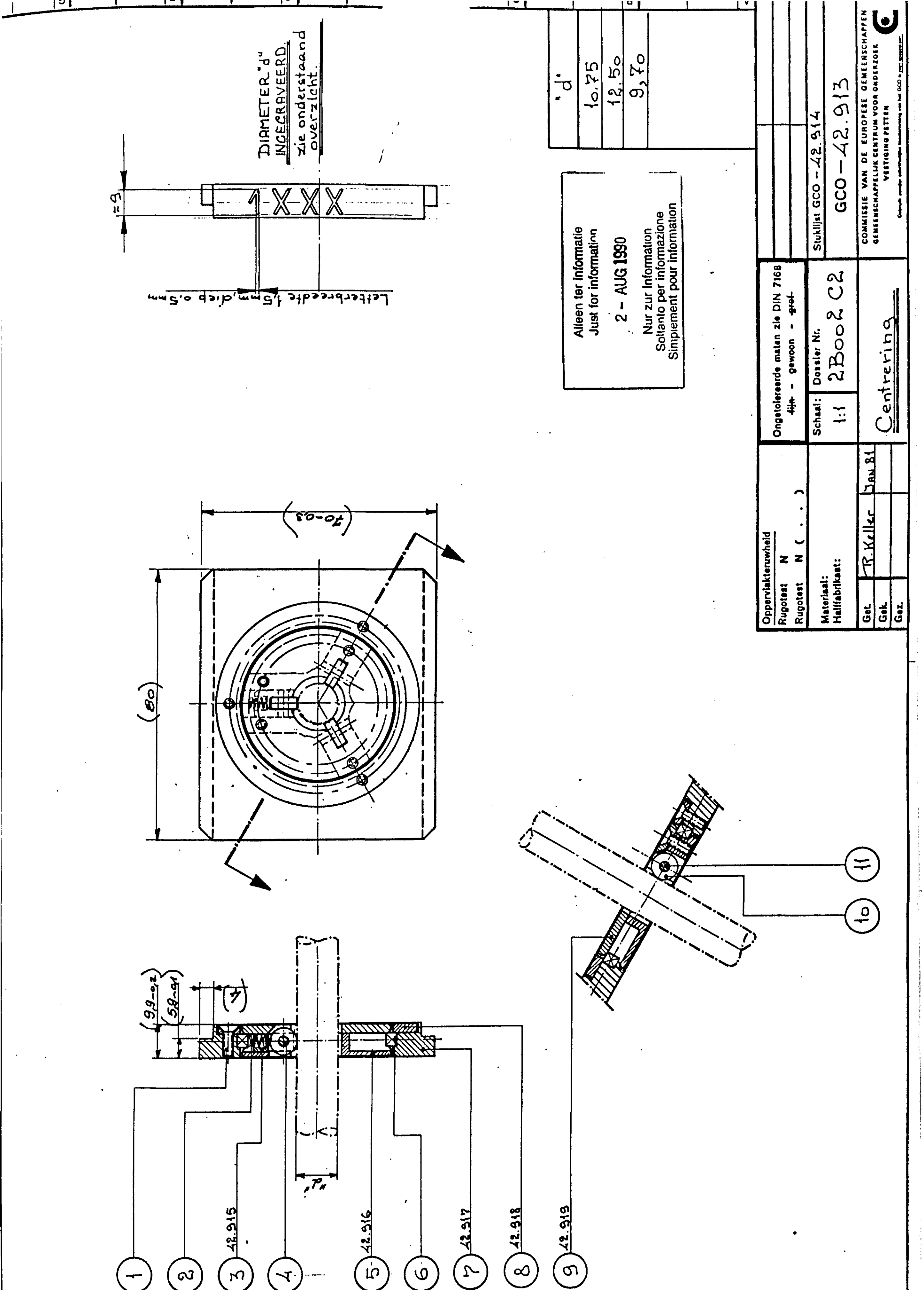


Figure 15 – Assembly Drawing of Centering Cassette

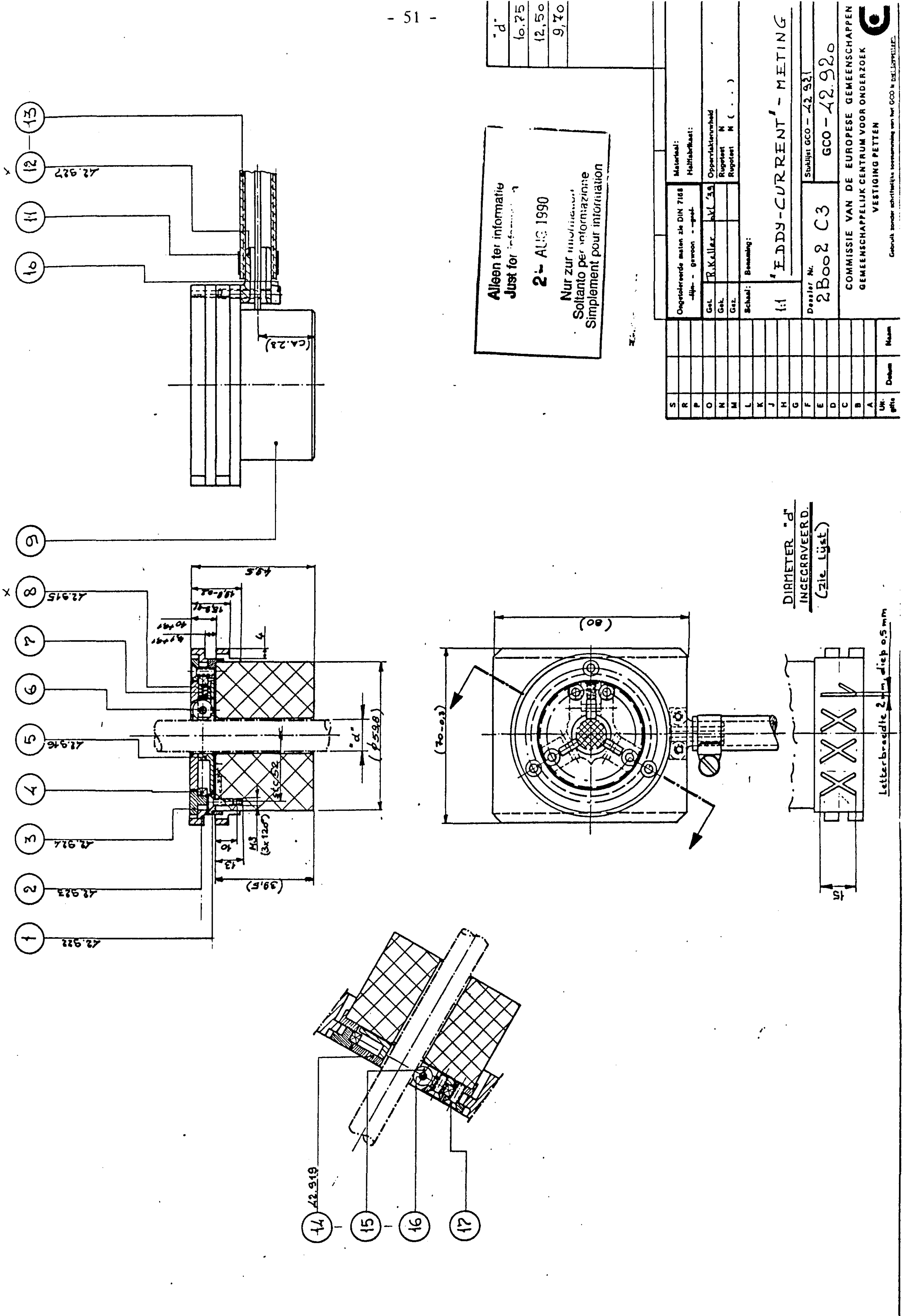


Figure 16 – Assembly Drawing of Eddy Current Cassette

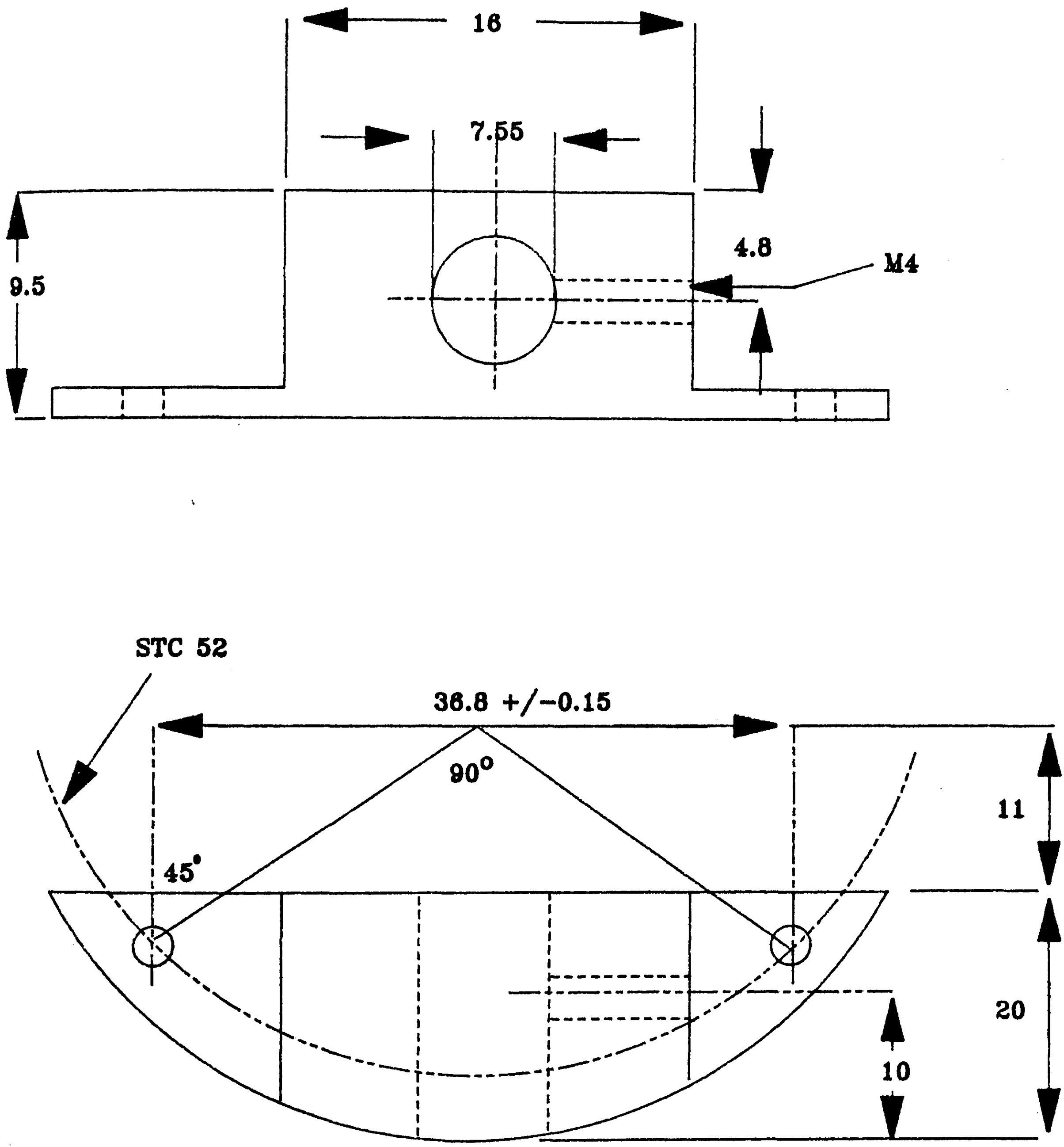


Figure 17 - Nylon Toolholder For Eddy Current Point Probe Attached To Underside of Eddy Current Cassette (Fig 16).

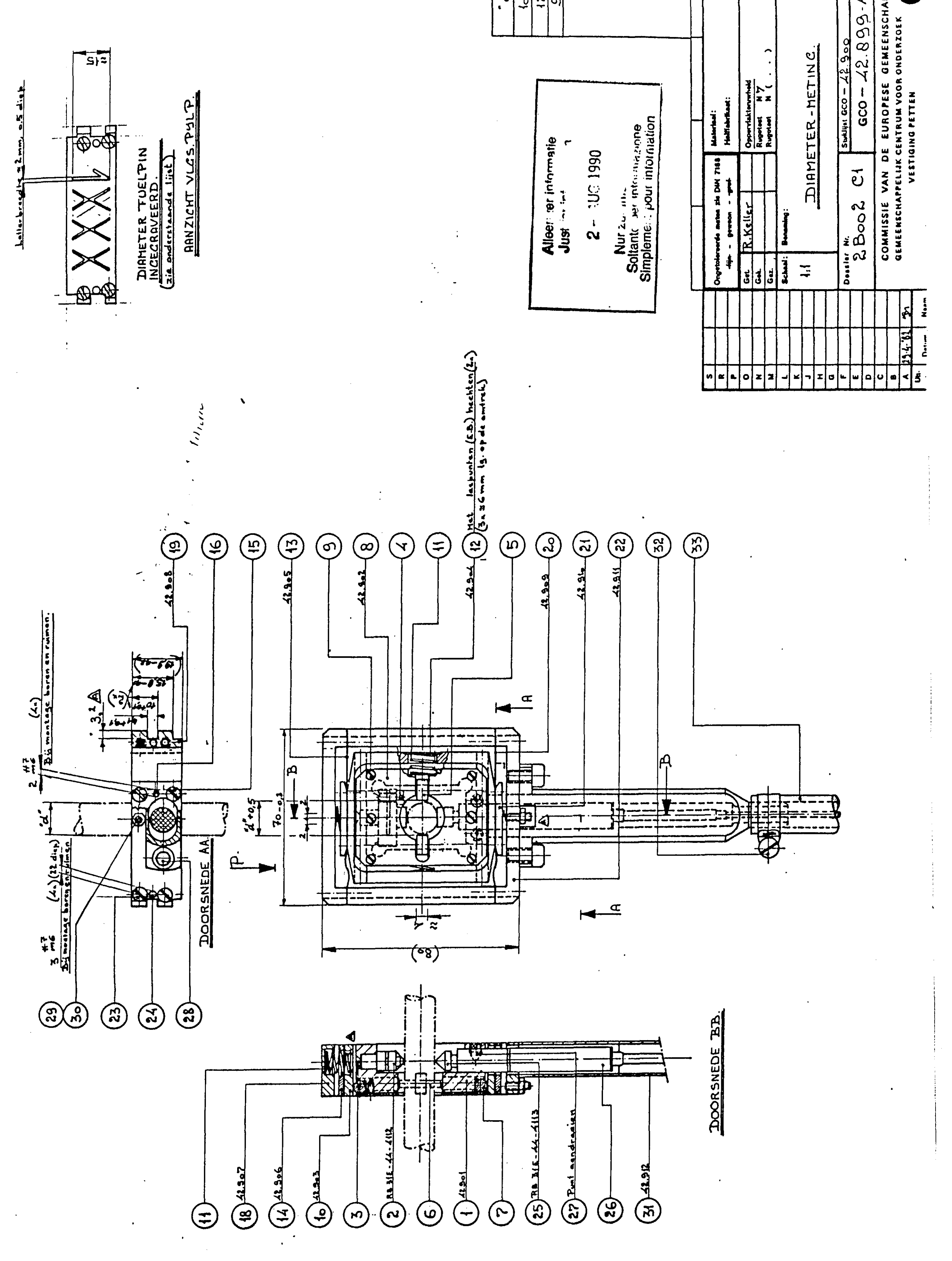


Figure 18 - Assembly Drawing of LVDT Diameter Measuring Cassette

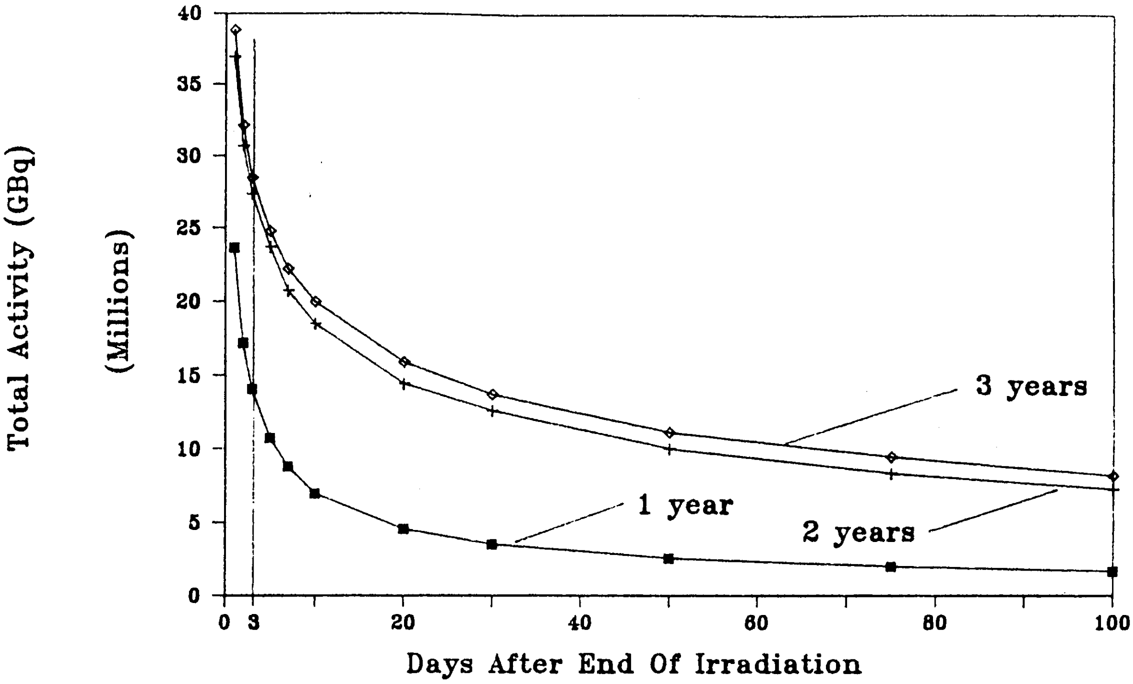


Figure 19 – Activity Characteristis of Fuel Rods With Different Pre–Irradiation Periods.

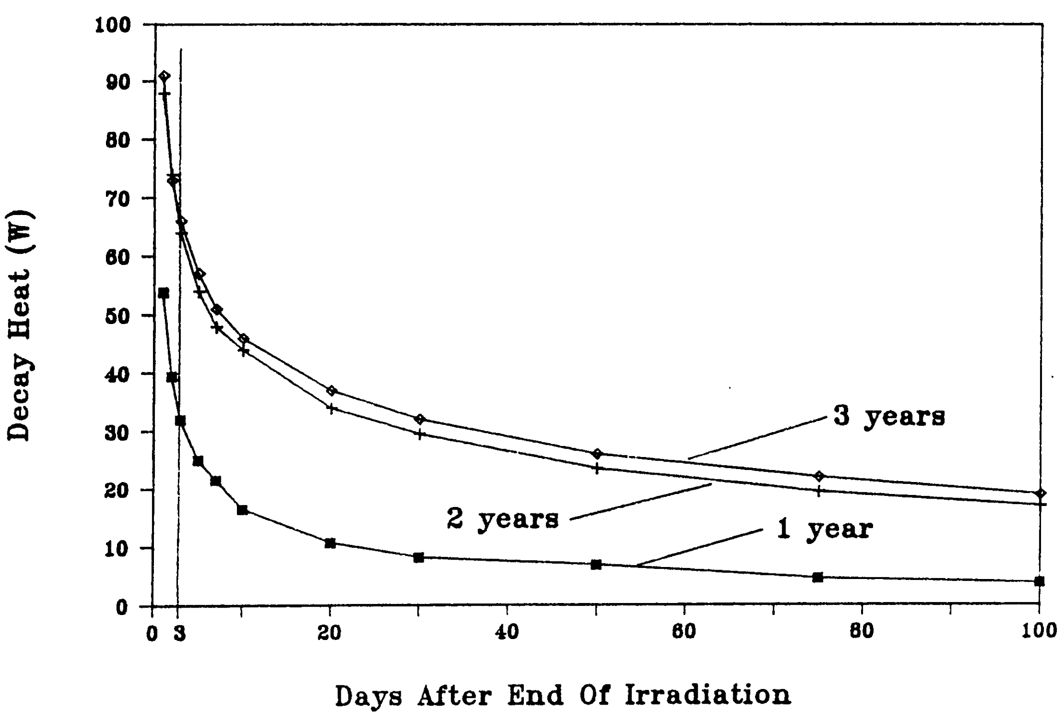


Figure 20 – Decay Heat Characteristis of Fuel Rods With Different Pre–Irradiation Periods.

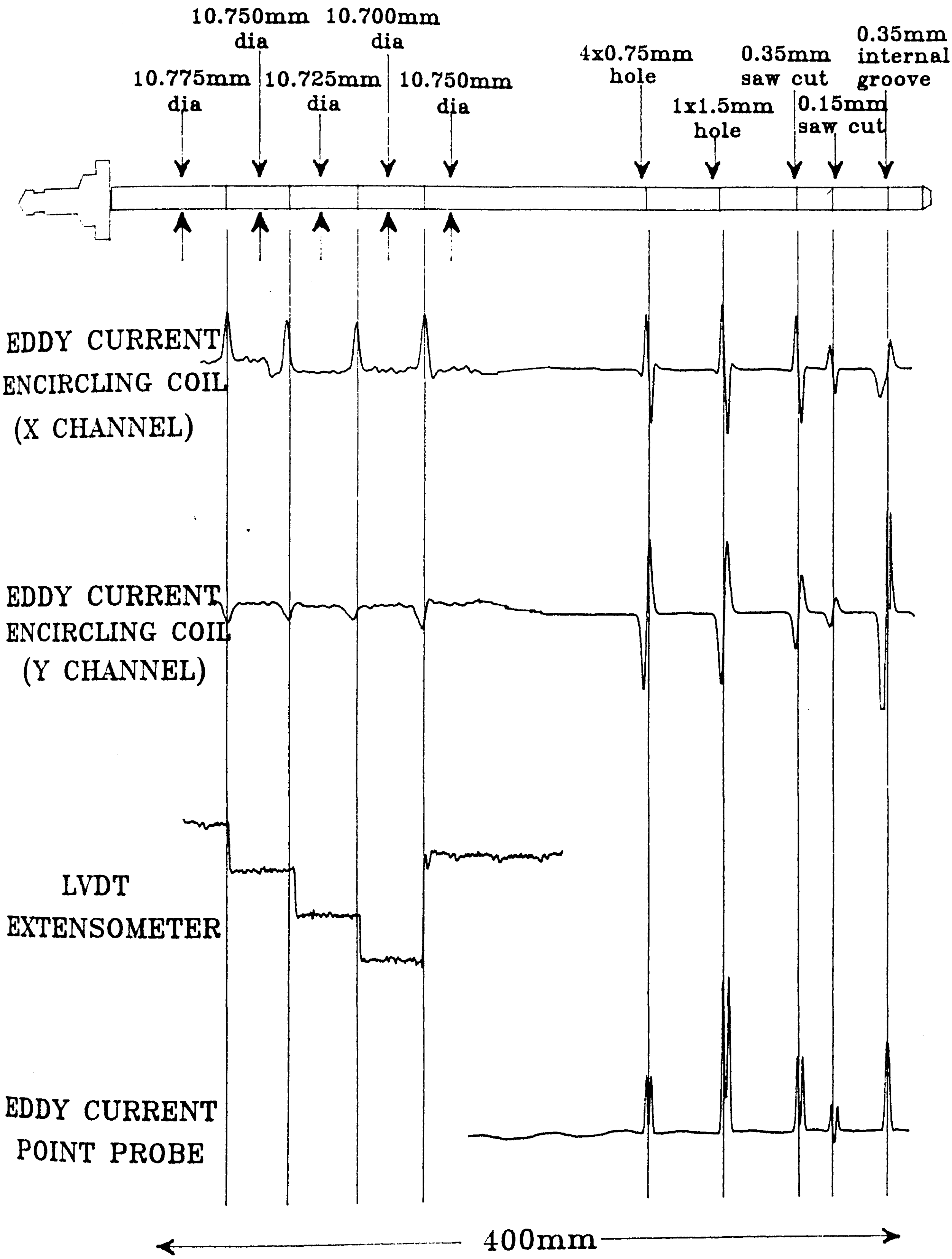
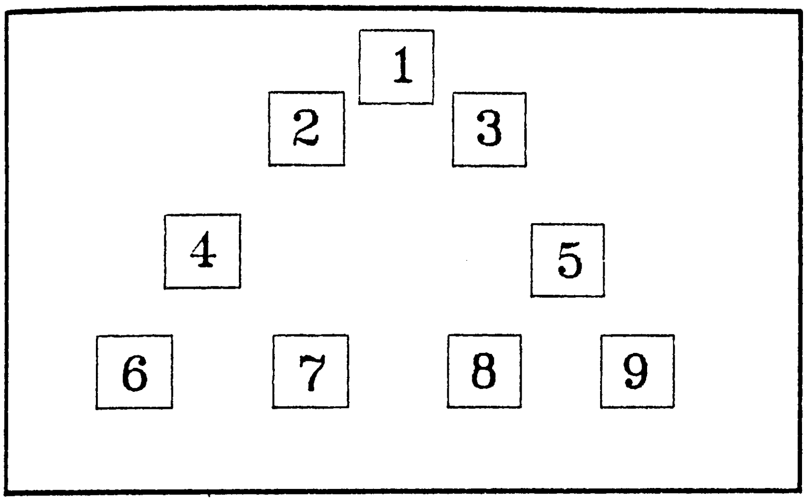
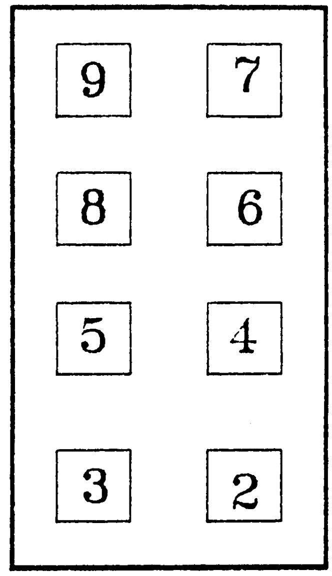


Figure 21 – Sensor Output From Standard Calibration Pin



Main Control Panel on Motor Controller



Remote Box

1. Local / Remote Control
2. Autostart
3. Emergency Stop
4. Move To Vertical Datum
5. Move To Angular Datum
6. Up
7. Down
8. Anticlockwise
9. Clockwise

Figure 22 – Functions of Push Buttons on Motor Controller Control Panel And Remote Box.

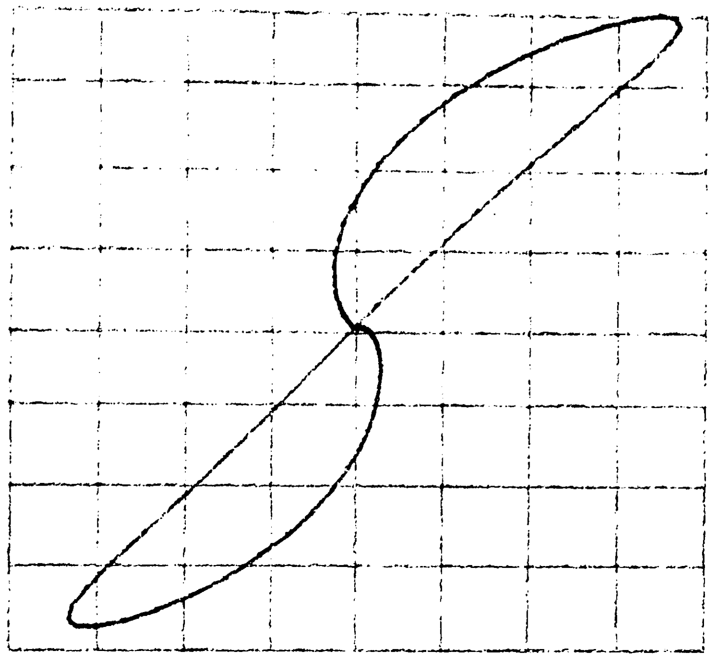


Figure 23 – EM3300 Display of Eddy Current Encircling Coil Examining a 1.5mm Through Wall Defect.

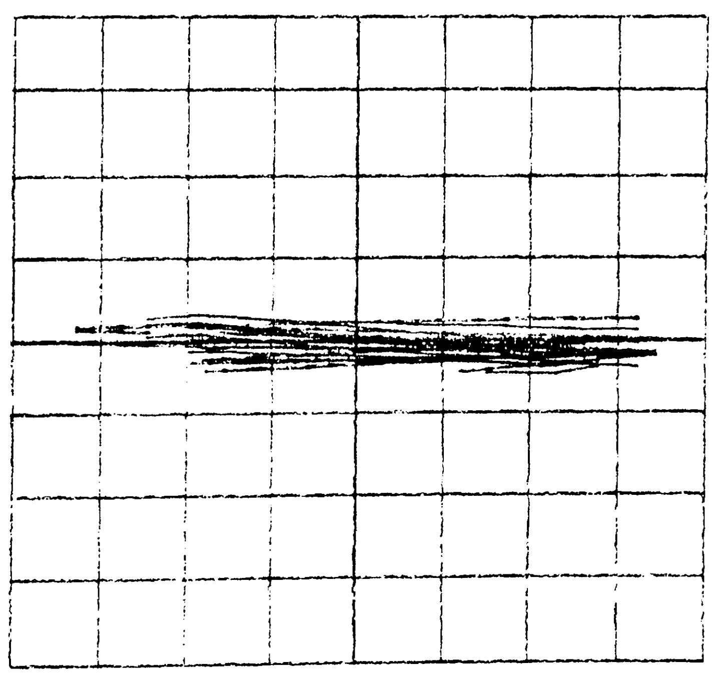


Figure 24 – EM3300 Display of Eddy Current Point Probe Examining A Series of Stepped Diameter Changes

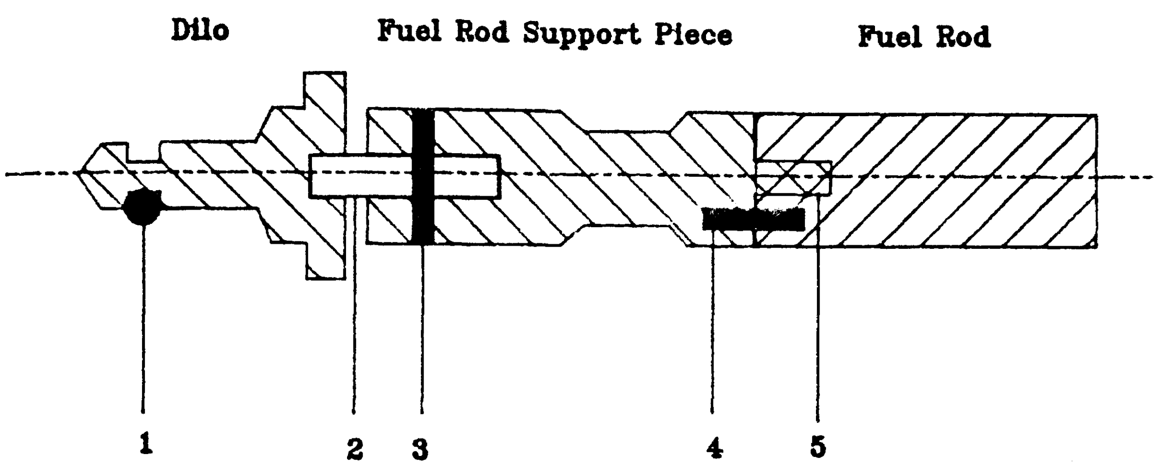


Figure 25 – Components Of Fuel Rod Used In Stress Analysis

Component	Maximum Tensile Stress (MPa)	Factor of Safety For Tensile Loading	Maximum Allowable Torque (Nm)
1	124.58	3.48	N/A
2	66.75	3.74	1.333
3	70.17	3.56	1.188
4	N/A	N/A	1.278
5	35.08	7.13	N/A

Table 5 – Maximum Tensile Stresses And Maximum Allowable Torques For Components Used In Stress Analysis

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HFR - DIVISION

17/12/89

Progress Report Of Experimental Work Conducted In Lab 16.

A. Carey

Contents

1.0 Introduction

This report is a summary of the work which has been conducted in Lab 16 during the first part of the test program. It contains a description of each series of tests along with initial comments on the results. Detailed analysis of the results will be done once the experimental work has been completed.

Some of the original objectives have already been achieved, whilst others have had to be removed or redefined. Additional objectives have also been set. These alterations have come about due to the experience gained from the tests so far conducted.

2.0 Equipment To Be Used In Test Program

2.1 Probes To Be Used In Test Program

(1) KWU Encircling Coil 11mm internal dia (200kHz)
(2) KWU Encircling Coil 13mm internal dia (200kHz)
(3) Hocking Absolute Probe 100P1 (200kHz)
(4) Hocking Absolute Probe 102P1 (2MHz)
(5) Hocking Differential Probe 5P409 (1MHz)
(6) Hocking Differential Probe 5P411 (2MHz)

Figures in brackets indicate normal operating frequencies.

2.2 Pins To Be Used In Test Program

(1) Standard PWR Calibration Pin
consisting of
- D1 - 4x 0.75mm dia holes
- D2 - 1x 1.5mm dia hole
- D3 - 0.35mm deep saw cut
- D4 - 0.15mm deep saw cut
- D5 - 0.35mm deep internal circumferential groove.

(2) Combination Pin made up of various segments.
Consisting of -
- D1 - 1x 1.5mm dia hole
- D2 - 0.25mm deep external circumferential groove.
- D3 - 0.25mm deep internal circumferential groove.
- D4 - 0.25mm deep external longitudinal groove.
- D5 - 0.25mm deep internal longitudinal groove.

3.0 Description Of Tests Carried Out

Series 1

Purpose : to find optimum scan speed for probe 1 at 200KHz.

Remarks : scan speed was varied from 100-2000 mm/min to test pin 1. General trend was for signal amplitude to decrease with increasing scan speed. For eddy-x best results at 100-200mm/min and for eddy-y 200-300/min. Note high sensitivity to internal defect.

Conclusions : Eddy-y was considered to be of more interest than eddy-x so a scan speed of 250 mm/min was chosen. (this assumption was later shown to be incorrect).

Series 2

Purpose : to investigate the effect of altering the sensitivity on the EM3300 on the output signal.

Remarks : output of both x & y signals appear to vary linearly with sensitivity settings between 0.5-3.0

Conclusion : sensitivity can be varied between0.5 & 3.0 and the output can be scaled accordingly.

Series 3

Purpose : to investigate the effect of frequency on signal amplitude using probe no 1 at a scan speed of 2000mm/min.

Remarks : test frequency varied from 50-800KHz after which it was no longer possible to balance instrument. Pin 1 was used.

Conclusions : largest amplitude occurs at frequency of 300KHz, but due to difficulties in balancing the instrument a test frequency of 250 KHz was considered most suitable (see figure 1).

Series 4

Purpose : to find optimum scan speed for a variety of defects using a test frequency of 250KHz.

Remarks : essentially a repeat of series 1, but in smaller increments and using pin 2.

Conclusion : for internal defects there is a larger difference between X & Y signals, as X is the larger of the two this implies that X must be more diameter sensitive and therefore less affected by internal defects. This would also explain why the X signal from the external circumferential defect is lower than the Y.

Best overall scan speed is between 200-300 mm/min, so a optimum speed was set at 250mm/min

<u>Series 5</u>

Purpose : to investigate the effect of frequency on signal amplitude at a scan speed of 250 mm/min.

Remarks : probe 1 was used to examine pin 2. Scan speed chosen as per results from previous series. Test frequency was varied from 50 to 325 KHz after which the instrument would no longer balance. As before external circumferential defect gave a stronger X than Y signal. This would imply that the Y signal is more influenced by 'lift-off'. This is shown again as both the internal defects have a larger relative difference between the X & Y, with Y being the greater signal.

Figures 2 & 3 show the best results obtained by probe 1 on pin 1 & 2 respectfully. (The out of range readings on fig 3 are caused by the joints between the tube segments.)

<u>Series 6</u>

Purpose : to examine the effect of coil fill factor on signal amplitude.

Remarks : 11mm & 13mm dia encircling coils were used to examine pin 2 at a scan speed of 250mm/min. Larger probe would only balance at 100 & 150KHz. In general signal from larger coil was about 25-50% of the signal from the narrower coil, except for the internal defects at 150KHz when the larger coil gave the strongest signal.

Conclusion : due to only being able to conduct two test at relatively low frequencies, no firm conclusions can be gained from the results other than the fact that in general decreasing fill factor leads to a decrease in signal amplitude.

Series 7

Purpose : to try to define an operating procedure for the absolute point probes.

Remarks : results not accurate as probe was only held in a makeshift holder.

Conclusions : by making X signal predominately lift-off, Y can be used to give a good indication of presence of a defect.

Series 8

Purpose : various test to try to reduce noise from differential point probes.

Remarks : problem cured by earthing probe cable and EM3300 and by insulating probe from probe holder. Tests were conducted to find optimum frequency at a scan speed of 250mm/min. In all cases largest amplitudes were obtained at a test frequency of 700KHz. Tests were repeated and totally different results were obtained. Problem is due to irregular shaped IPD's making a consistent set-up procedure difficult.

Conclusions : try to find a scan speed where a consistent set-up procedure is possible.

Series 9

Purpose : to find optimum scan speed for probe 5 at a test frequency of 700KHz.

Remarks : results showed a decrease in signal amplitude with increasing scan speed. However when tests were repeated they showed the same overall trend but at much lower amplitudes.

Conclusion : signal amplitude decreases with increasing scan speed. Although the amplitude of the signal are about 2-3 times as great as that from the absolute point probes the irregular shapes of the IPD's makes it very difficult to have a consistent set-up procedure. Figure 4 shows the best results obtained from this probe i.e. a test frequency of 700KHz at a scan speed of 250mm/min.

Due to difficulties in setting up the differential probes consistently they seem unsuitable and work should therefore concentrate on the absolute point probes.

Series 10

Purpose : to investigate the effect of frequency on signal amplitude for probe 4.

Remarks : pin no 1 was used at a scan speed of 250mm/min. Frequency varied from 250-600 KHz , unable to balance above or below this range. Plots show a superimposed sine wave (see fig 5), possibly due to rollers pushing rod. Max amplitude achieved at : large through wall defect & saw cuts = 550KHz, small through wall & internal defect = 600KHz. (See figure 6).

Conclusions : due to problems balancing the instrument, 500KHz should be taken as the best frequency.

Series 11

Purpose : to find optimum test frequency for probe 3 using a scan speed of 250mm/min on pin 1.

Remarks : frequency varied from 200-650 KHz. Overall trend is for amplitude to increase up to 600KHz then decrease to 650KHz. Apart from 1.5mm dia hole there are no sudden changes in sensitivity (see figure 7). Plots give a very clear indication of a defect against a constant background level(fig 8), although they are only 25-50% of the signals received from probe 1 (encircling coil).

Conclusions : as we are more interested in internal defects 500 KHz should be chosen as the optimum frequency.

Signal amplitudes are significantly higher than those from probe 4 therefore discontinue using 4 and concentrate on 3. Although the amplitudes are not as great as that from probe 1 they are high enough to give an excellent indication of the presence of a defect.

Series 12

Purpose : to investigate to investigate the effect of scan speed on signal amplitude using probe 3 at 500KHz.

Remarks : results show a general reduction in amplitude with increasing scan speed (figure 9). In going from 100 to 1000mm/min amplitude is reduced by about 10%. When test were repeated the results differed by about +/-10%.

Conclusions : scan speed does not seem to have a significant effect on signal amplitude, although increasing speed does result in a gradual reduction in amplitude. The difference in results is caused by difficulties in setting up the EM3300 exactly to the same conditions each time and is not considered significant.

4.0 Problems Encountered During Testing

(1) EM3300 will only balance over a limited frequency range with most probes.

(2) EM3300 is difficult to balance accurately near limiting frequencies.

(3) Point probes have been found to operate best at frequencies away from their design frequencies. This may affect to operation of the probes.

(4) It has not been possible to use the combination pin consisting of different tube segments with the point probes. This is because the segments are not exactly concentric with each other, so when one passes through the centralizing rollers at the entry/exit of the cassette box it deflects the segment which is being examined by the point probe. As the probe/specimen separation is only 0.01mm even a slight deflection of 0.005mm is significant. This is not a problem with the encircling coil as it operates with probe/specimen spacing of approx 8mm.

5.0 Progress Against Original Objectives

(I) Accomplished.

Probe 1 gave best overall results at a test frequency of 250KHz and a scan speed of 250mm/min.
Probe 3 was the best point probe operating at 500KHz and not significantly dependant on scan speed (from 100-1000mm/min).

(II)(a) Redefined.

Due to the unsuitability of the differential probes this will only be possible for coil 1.

(b) Deleted.
Due to same reason as (II)(a).

(c) (i) No Progress.
Waiting for manufacture of test pin.

(ii) Accomplished.
Only partly accomplished as larger coil would only balance at two relatively low frequencies. Results show general trend of a reduction in amplitude with decreasing fill-factor, but unable to draw any firm conclusions.

(d) In Progress.
Next part of program to be conducted, but in a revised format.

(III) (a) In Progress.
To be conducted in parallel with (II)(d)

(b) No Progress.
Dependant on results from (III)(a).

6.0 Additional Objectives

(1) Try out point probes on Zetec MIZ-12 to see if point probes will balance over a wider frequency band or operate nearer their design frequencies.

(2) Try out MIZ-12 to see if it is easier to balance probes accurately.

(3) Try to find a way of using the tube segments so that they can be examined with the point probes.

7.0 Appendix A.

Original Objectives Of Test Program.

19/10/89

Objectives Of Test Program

(i) to indentify an optimal frequency for each probe for the detection of the following types of defects -

(a) long inner surface
(b) sharp inner surface
(c) long outer surface
(d) sharp outer surface
(e) through wall.

This is to be done by selecting one defect from each of the above types and examining with each probe in turn at a number of different frequencies, (say in range 200kHz-1MHz in steps of 100KHz).

In the case of the point probes, the immediate area around the defects should be scanned in a non-interpolated manner with a series of circumferential scans.

From the resulting plot of frequency against amplitude it should be possible to establish an optimal test frequency for each probe/defect combination. This frequency can then be compared with that expected from theory.

(5probes x5defects x9freqs = 225readings).

This optimal test frequency should then be used to test all the defects and to compare the results in order to find the most suitable probe for each defect type.

(5probes x5defects = 25 tests).

(ii) (a) Each defect type should then be examined at the optimum parameters. By taking one of the defects as standard, an attempt should be made to size the remaining defects by comparing the test signals.

(2probes x5defects = 10 tests)

(b) Variation in phase lag of signals from inner surface defects to be examined in order to try to determine defect depth.

(2probes x3freqs = 6tests)

(c) With coil probes -

(i) using 10.75mm dia coil only compare signals from sets of 1,2,3 &4 holes all with same total volume of metal removed.

(5freqs = 5tests)

(ii) using both coils examine one set of defects in order to investigate the effect of 'fill-factor'.

(2probes = 2tests)

(d) for point probes - examine smallest inner & outer surface defects in a series of stepwise circumferential scans. Test frequency should be varied in order to alter the effective probe diameter (EPD). From contour plots of the data it should be possible to establish an optimum pitch for the helical scan.

(2probes x2defects x5freqs = 20 tests)

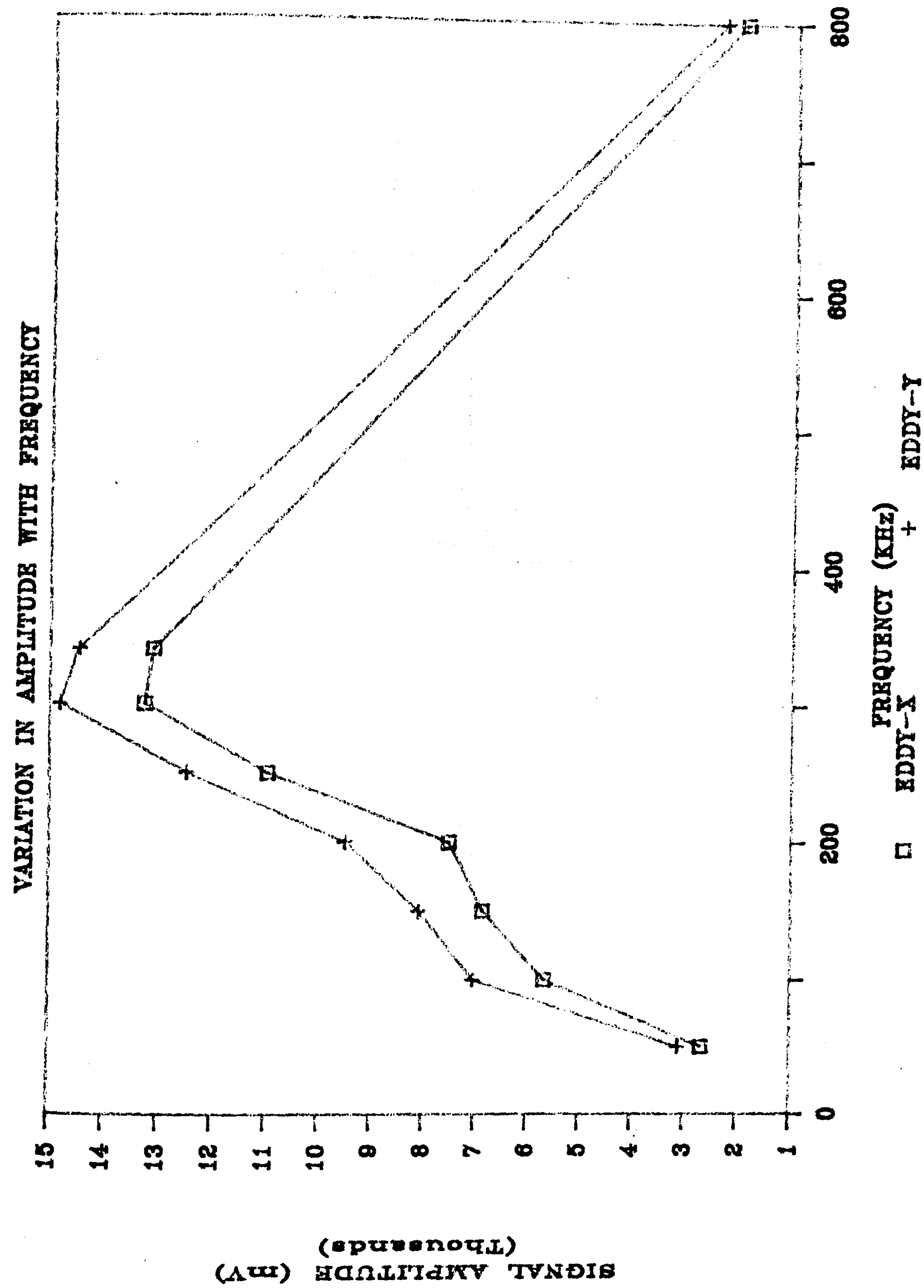

Figure 1 - Variation in Signal Amplitude With Frequency For Probe 1.

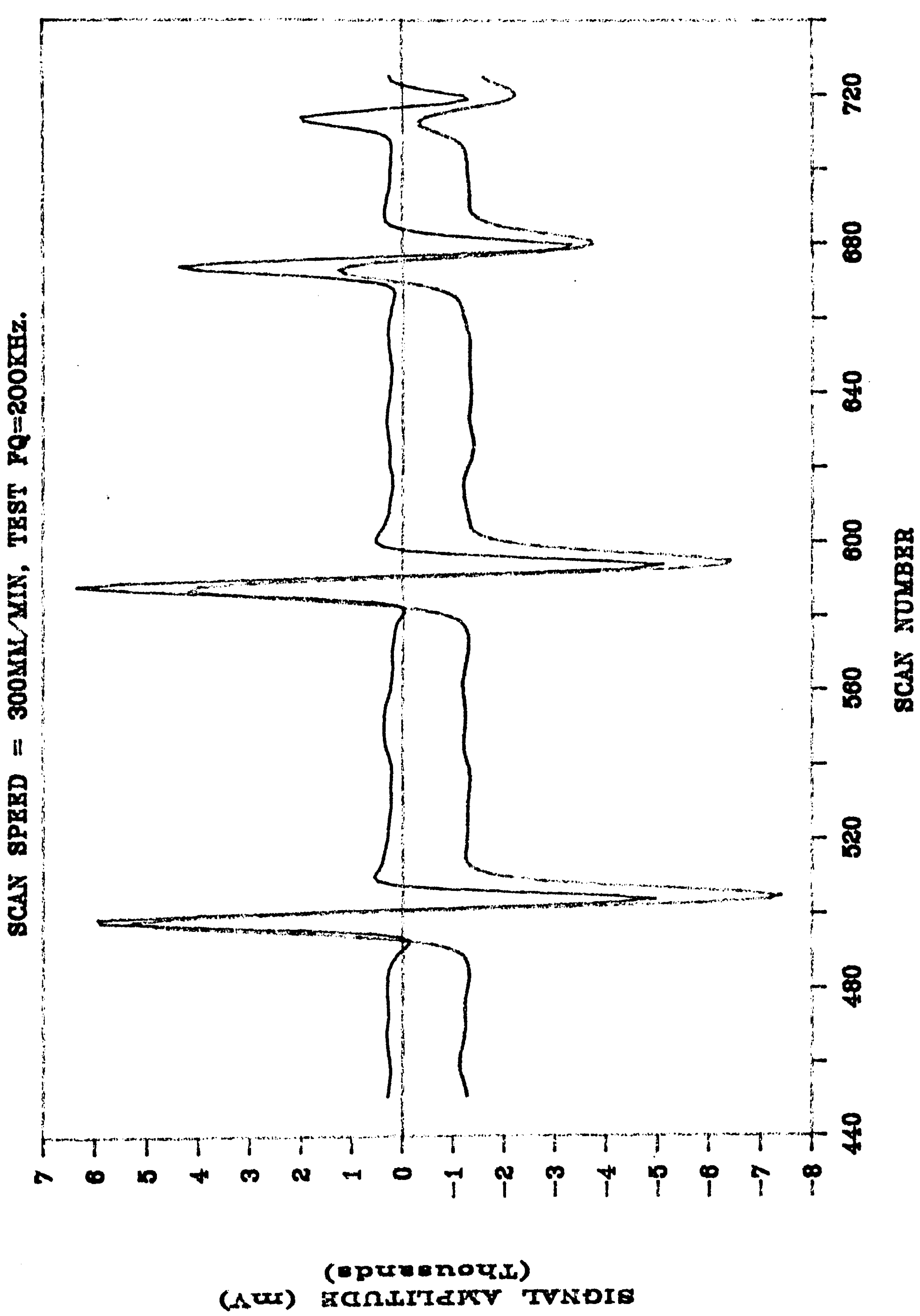

Figure 2 - Scan Of Pin 1 By Probe 1

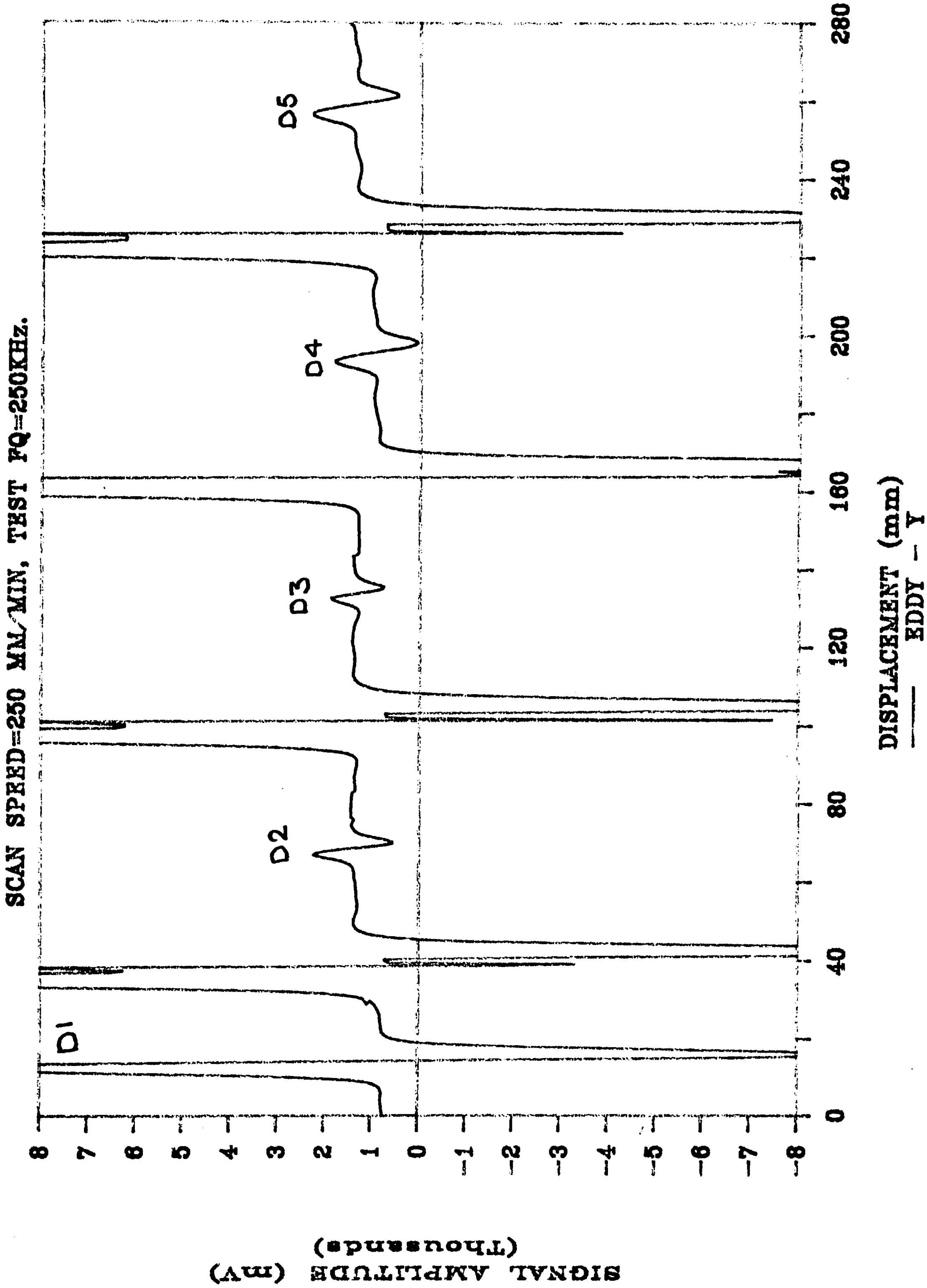

Figure 3 - Scan Of Pin 2 By Probe 1

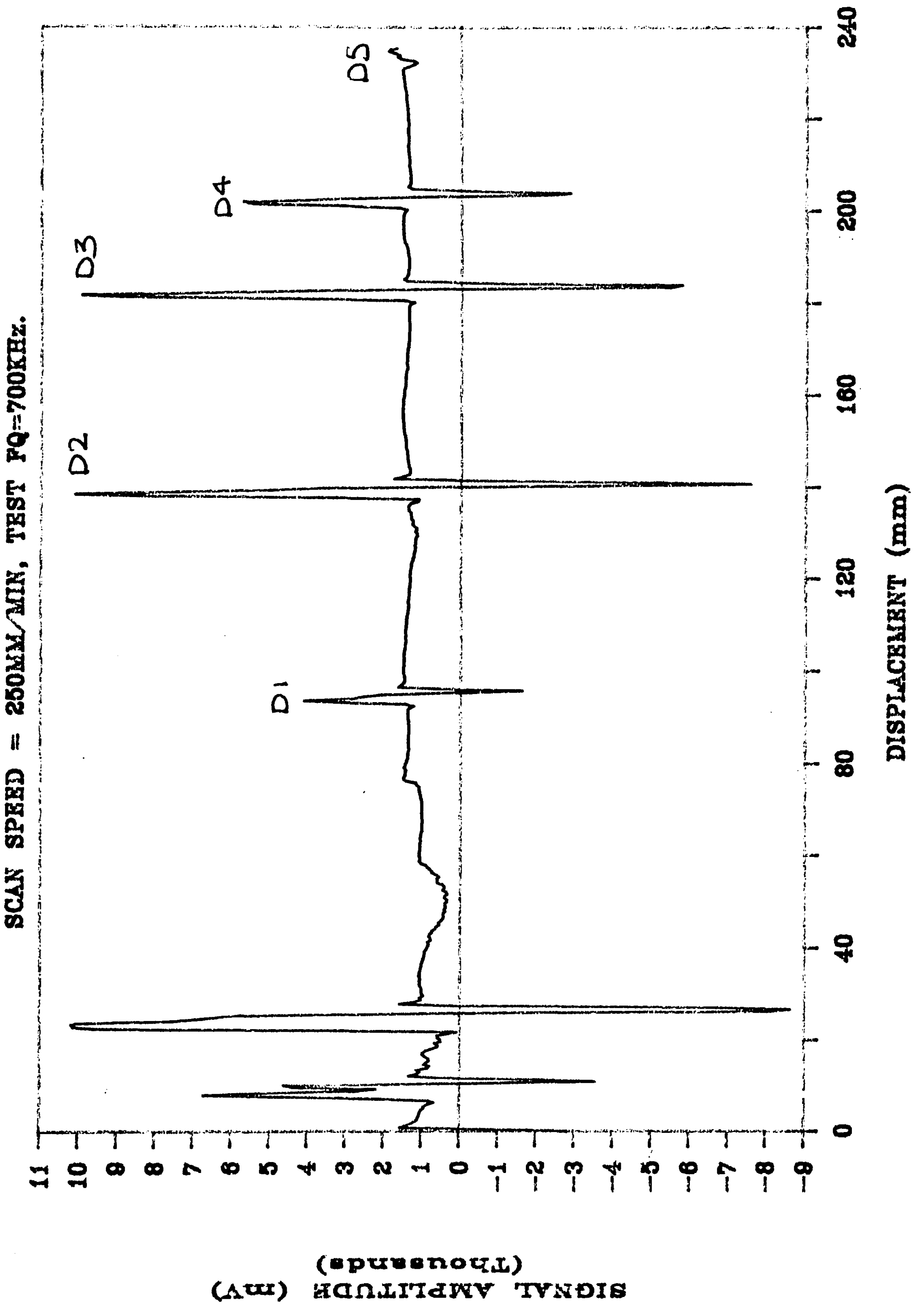

Figure 4 - Scan Of Pin 1 By Probe 5

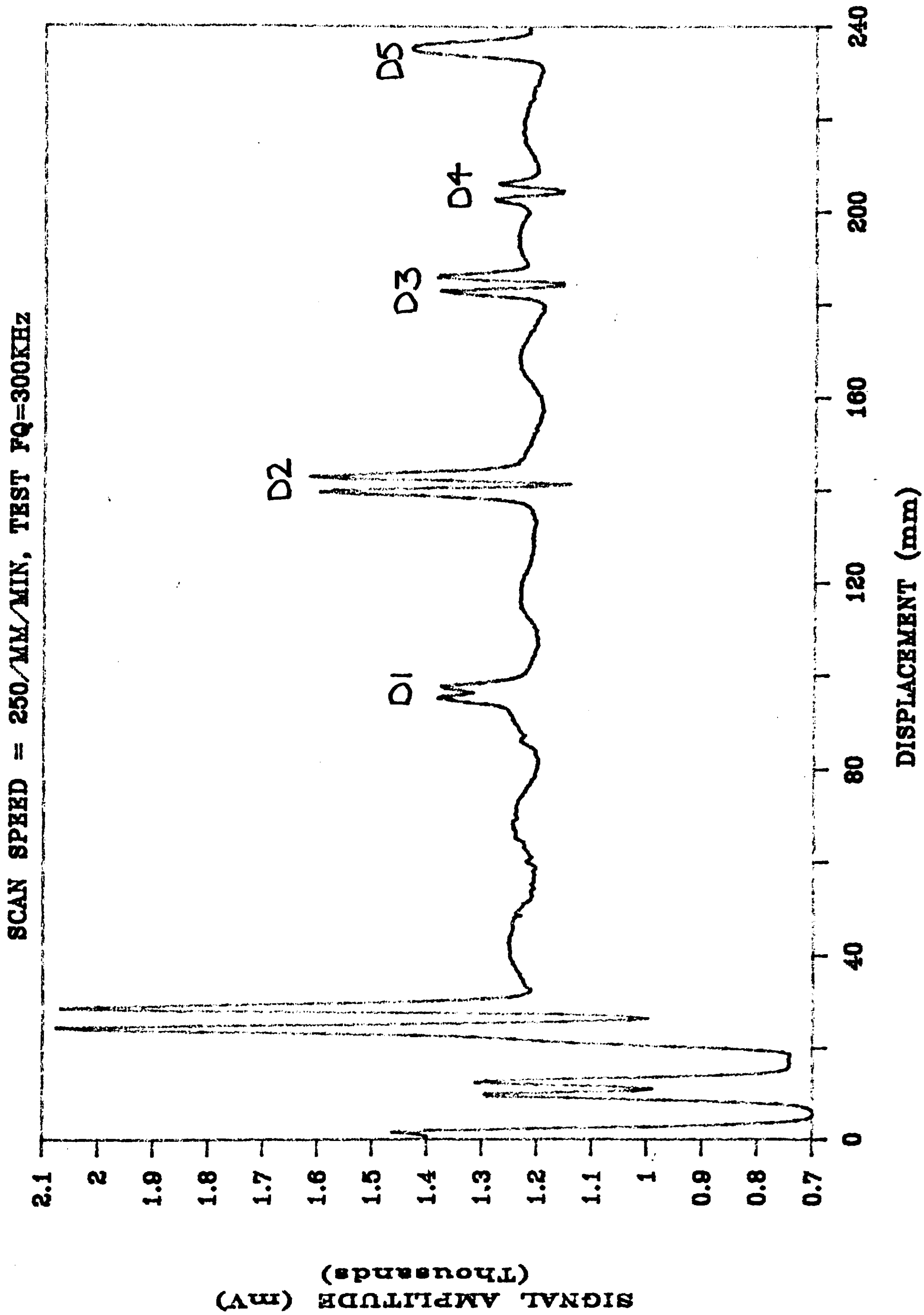

Figure 5 - Scan Of Pin 1 By Probe 4

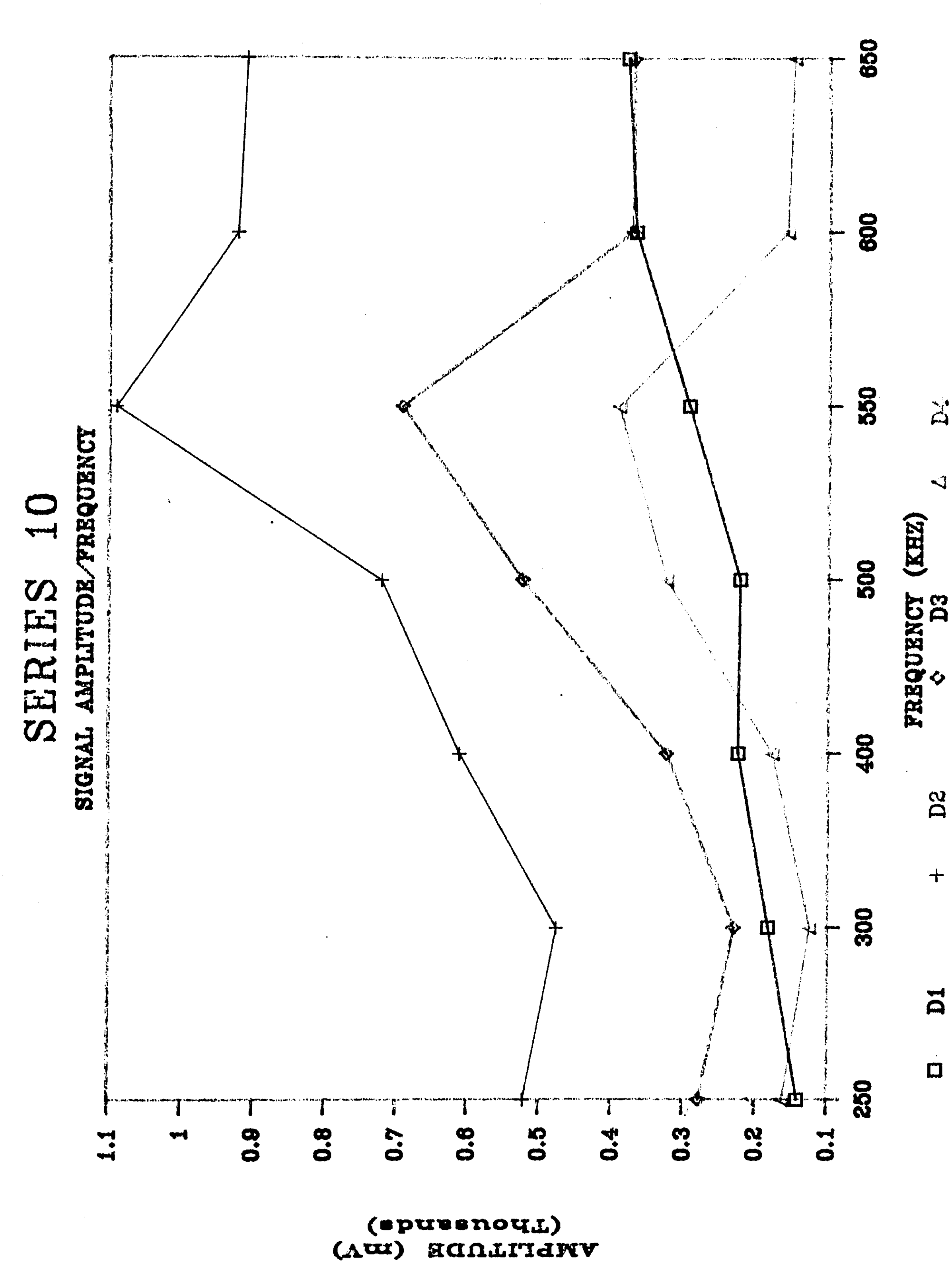

Figure 6 - Variation in Signal Amplitude With Frequency For Probe 4.

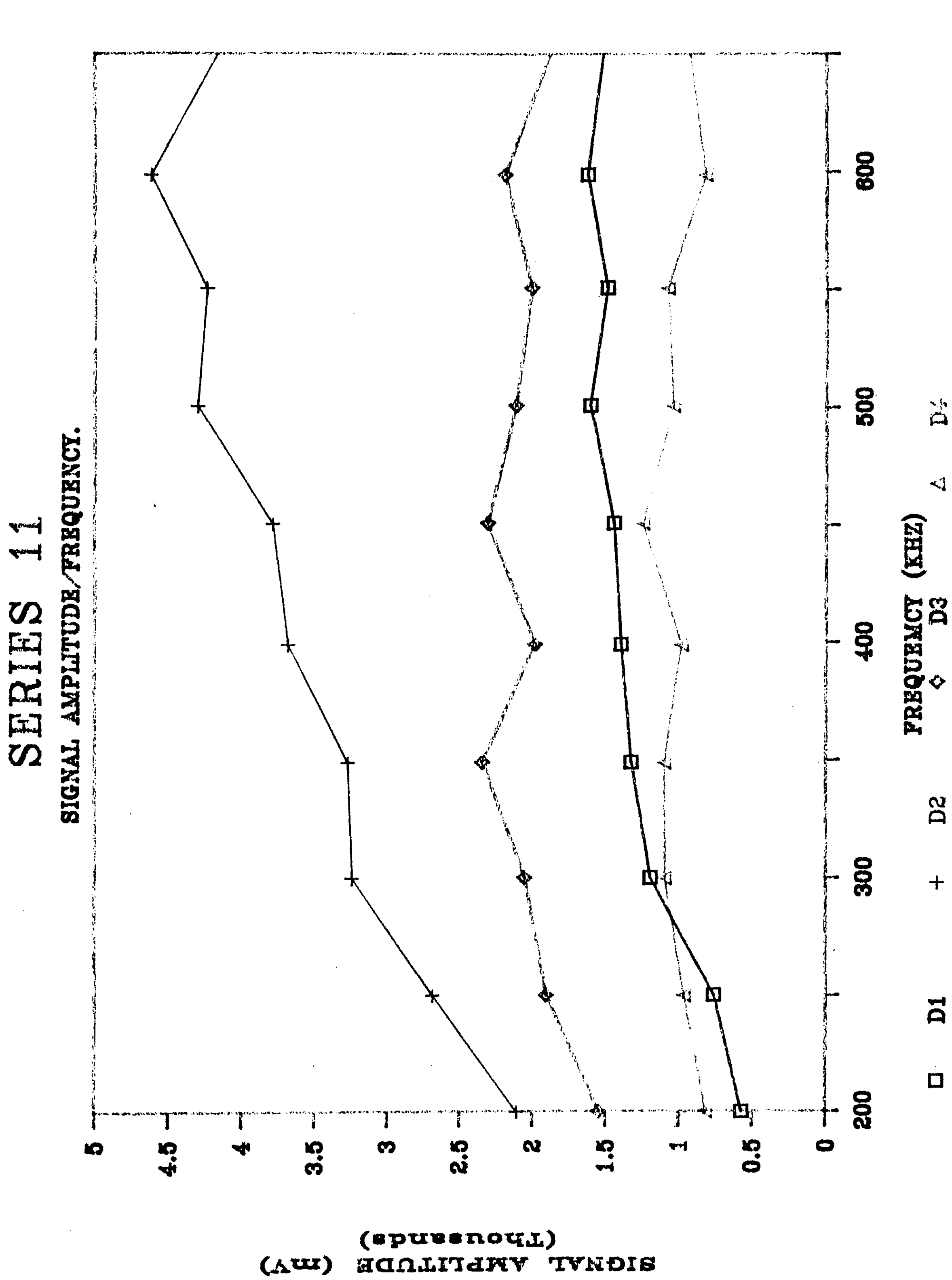

Figure 7 - Variation in Signal Amplitude With Frequency For Probe 3.

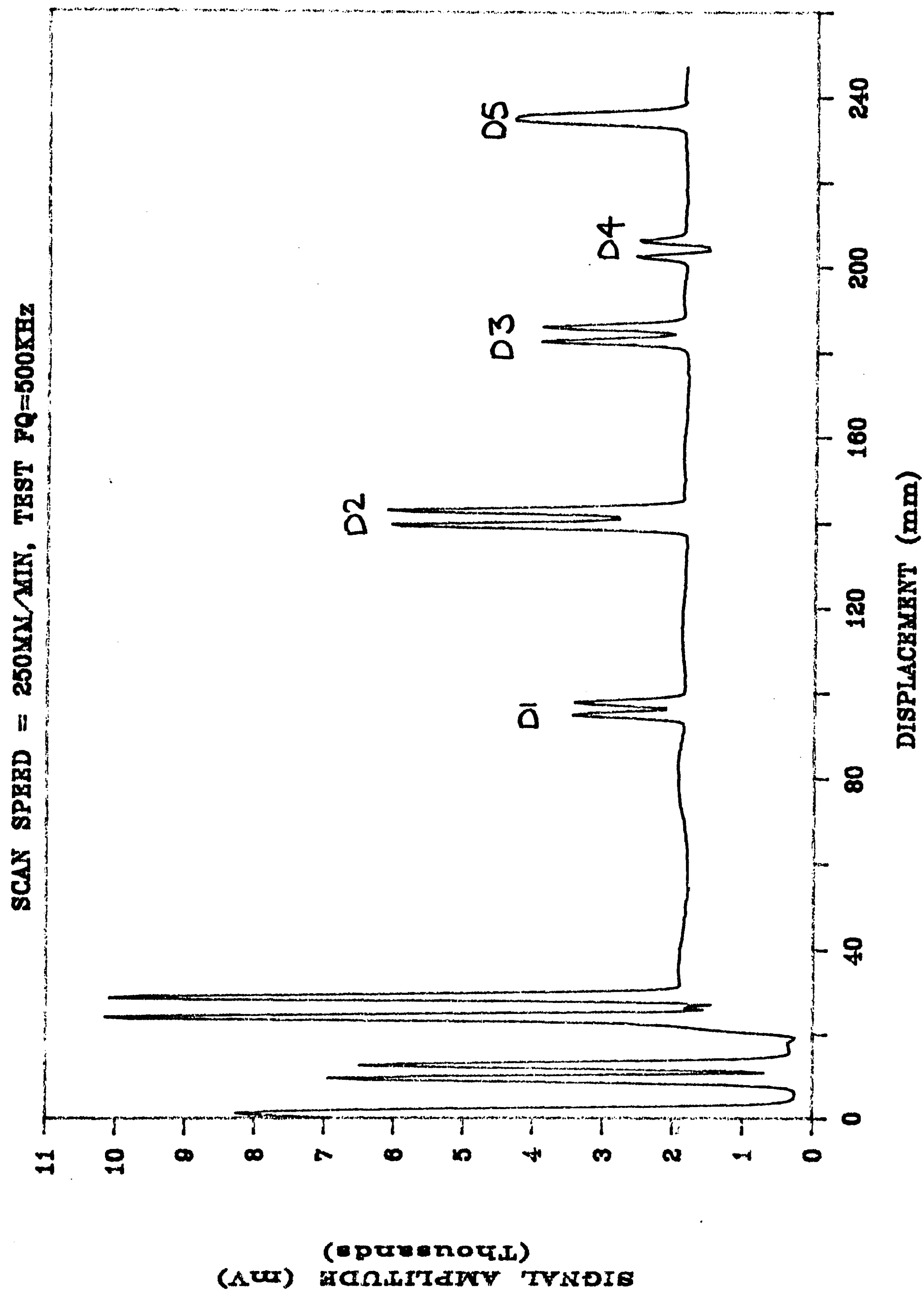

Figure 8 - Scan Of Pin 1 By Probe 3

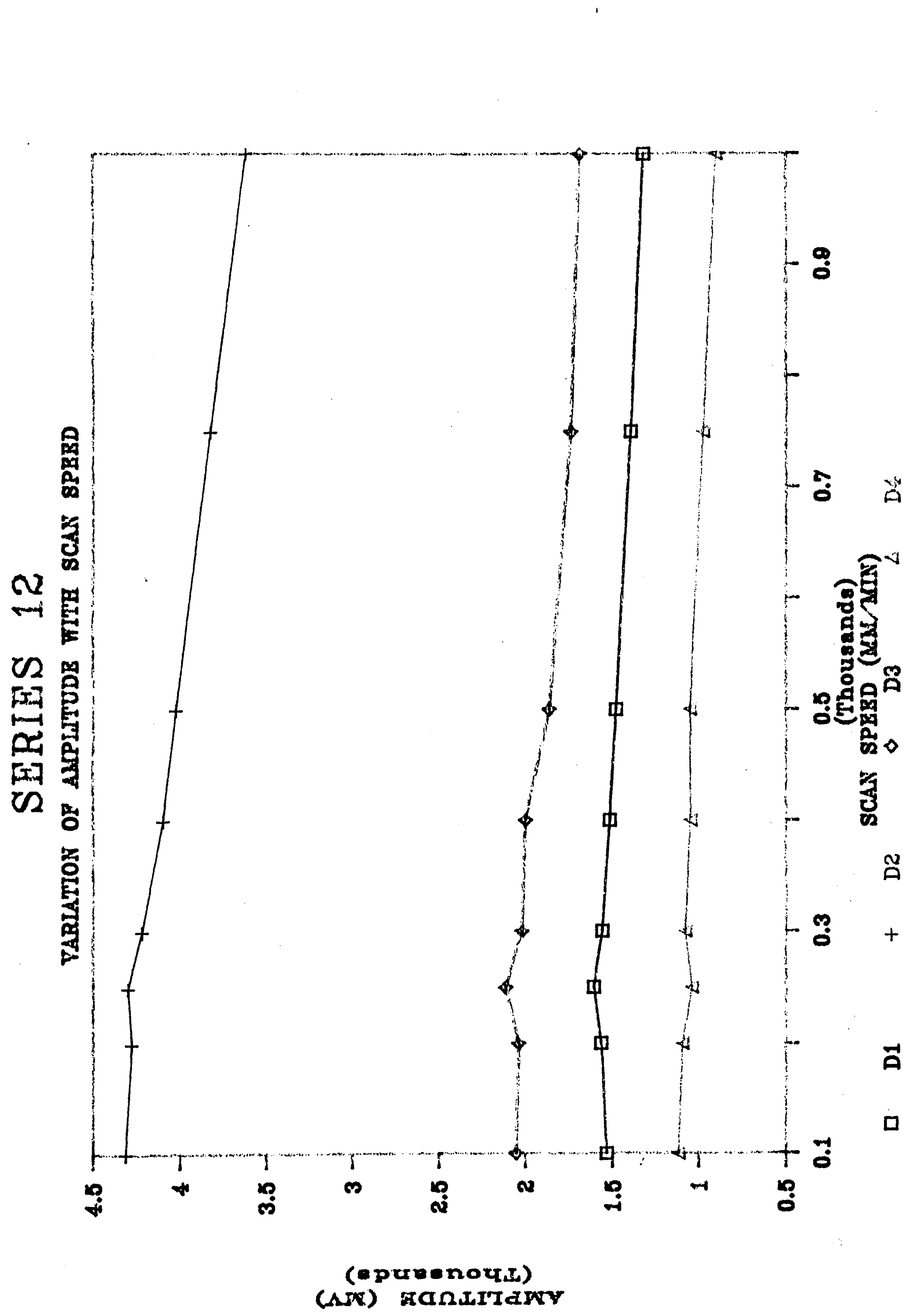

Figure 9 - Variation in Signal Amplitude With Scan Speed For Probe 3.

CHAPTER 7.3.1 - LISTING OF CALSCAN.BAS

```
10 FOR K=1 TO 15 : KEY (K) ON : NEXT K
15 UP=1 : UC=1 : UT=1
20 ON ERROR GOTO 24000
30 SENS1$="E/C POINT PROBE" : SENS2$="ENCIRCLING COIL" :
   SENS3$="LVDT" : SENS4$="NONE"
40 SENS1A$ = SENS1$ : SENS2A$ = SENS2$ : SENS3A$ = SENS3$ :
   SENS4A$ = SENS4$
50 '
55 '
60 ' The purpose of this program is to calibrate the
instruments
62 ' which are going to be used during the examination and
to
64 ' record the instrument settings. The program then
carries
66 ' out a calibration run.
90 '
100 '**************  CALSCAN.BAS  5/4/90  *****************
110 '
120 '-----------------------------------------------------
122 '
124 '                     Initialise Interface
126 '
128 GOTO 9000
130 '
140 '-----------------------------------------------------
142 '
150 '                 Procedure to load calibration pin.
152 '
160 CLS : LOCATE 9,24 : PRINT"Before starting ensure that
    you have -"
162 LOCATE 12, 2 : PRINT"1. a DS/DD floppy disc formatted
    to 360K in drive 'A' of this computer."
164 LOCATE 14, 2 : PRINT"2. a DS/HD floppy disc formatted
    to 1.2M in drive 'A' of the TATUNG computer."
166 LOCATE 16, 2 : PRINT"3. switched the NEFF data logger
    and TATUNG computer on."
168 PD$="" : PD$=INKEY$ : LOCATE 19,29 : PRINT"Press SPACE
    to continue." : IF PD$=" " THEN GOTO 169 ELSE GOTO 168
169 CLS
170 CPL$=INKEY$ : LOCATE 13,20 : IF COE$="1" THEN PRINT "Is
    the Calibration Pin loaded (Y/N)  ?        " ELSE IF
    COE$="2" THEN PRINT "    Is the Fuel Pin Loaded  (Y/N)
    ?     "
175 IF CPL$="Y" OR CPL$="y" THEN BEEP : GOTO 191
180 IF CPL$="N" OR CPL$="n" THEN BEEP : GOTO 190
185 GOTO 170
189 CLS
190 LOCATE 13,15 :PRINT"      Once the pin has been loaded
    press SPACE BAR.  " : PD$="": PD$=INKEY$ : IF PD$=" "
    THEN GOTO 169 ELSE GOTO 190
191 '
192 '
193 '-----------------------------------------------------
```

```
194 '
195 '          Procedure to determine sensor locations.
196 GOSUB 7440
198 '
200 '------------------------------------------------------
205 '
210 '          list variables to be saved for next program.
215 IF COE$="1" THEN 350
220 COMMON CSDF$,SENS1$,SENS2$,SENS3$,PSSV$,PSSH$,PTFQ$,
    PSENS$,PPAS$,PSBR$,PSBX$,CSSH$,CSSV$,CTFQ$,CSENS$,
    CPAS$,CSBR$,CSBX$,JRC$,TEST$,FRN$,MAN$,BOP$,FRD$,SSP$,
    LOS$  : CHAIN "VERT",ALL
230 '
300 '-------------------------------------------------------
310 '
320 ' Invoke routine to calibrate eddy current point probe.
330 '
350 GOSUB 1200
360 '
400 '-------------------------------------------------------
410 '
420 '    Invoke routine to calibrate e/c encircling coil.
430 '
440 IF RC=1 THEN 465
450 GOSUB 3200
460 '
462 '-------------------------------------------------------
465 '
470 '                  Invoke routine to calibrate LVDT.
475 '
480 IF RC=1 THEN 500
485 GOSUB 5000
495 '
500 '-------------------------------------------------------
510 '
515 CLS
520 LOCATE 12,12 : PRINT"Have instruments been calibrated
    correctly ?  (Y or N)   "
530 Q$=INKEY$ : IF Q$="N" OR Q$="n" THEN GOTO 550
540 IF Q$="y" OR Q$="Y" THEN GOTO 600
545 GOTO 520
550 CLS
555 LOCATE 6,18 : PRINT "Which instrument do you want to
    recalibrate ?   "
558 LOCATE 10,24 :PRINT"0. None - continue with test."
560 LOCATE 12,24 :PRINT"1. Eddy Current Point Probe."
565 LOCATE 14,24 :PRINT"2. Eddy Current Encircling Coil."
570 LOCATE 16,24 :PRINT"3. LVDT."
575 LOCATE 20,25 : INPUT "Please enter 0, 1, 2 or 3.   ",Q$
578 IF Q$= "0" THEN 600
580 IF Q$= "1" THEN RC=1 : GOTO 350
585 IF Q$= "2" THEN RC=1 : GOTO 450
590 IF Q$= "3" THEN RC=1 : GOTO 480
595 BEEP : GOTO 555
```

```
600 '
605 '--------------- Start Calibration Scan -------------
608 FLTNUM=3 : CLS
610 LOCATE 12,20: PRINT"Press space bar to move to start of
    scan."
620 Q$="" : Q$=INKEY$ : IF Q$=" " THEN GOTO 630 ELSE GOTO
    610
630 PRINT#1,":X2000@500:R1:S1:H3:X36800@1600:$"
    '----------------   Move to start of calibration scan.
638 CLS
640 PRINT#1,"K" : INPUT #1,K :PRINT#1,"E" : INPUT #1, IB$ :
    IF IB$="F" OR K=64 THEN 6000 ELSE IF K AND 1 THEN 650
    ELSE IF IB$ ="C" THEN 658 ELSE IF IB$="F" THEN 6000
    ELSE GOTO 640
650 LOCATE 12,15 : PRINT"   Moving to Start position for
    calibration scan. ": GOTO 640
658 CLS
660 COLOR 2,1 : LOCATE 8,25 : PRINT"        Pin At Start
    Position.        " : COLOR 2,0
665 LOCATE 12,15 : PRINT"        Switch SONY display to
    INCremental and RESET.  "
668 LOCATE 14,26:PRINT" (Push joystick UP and then LEFT)."
670 LOCATE 17,28 : PRINT"Press SPACE Bar To Continue." :
    PD$="" : PD$=INKEY$ : IF PD$=" " THEN GOTO 705 ELSE
    GOTO 670
705 CLS
710 LOCATE  6,8 : PRINT"Before starting calibration scan
    ensure that data logger is recording."
712 LOCATE  8,8 : PRINT"From the start up menu on the
    TATUNG select 'A - START NEFF DATA LOGGER.'"
714 LOCATE 10,8 : PRINT"From the main menu select option 'E
    - ACQUIRE LIVE DATA,RECORD & PROCESS'"
716 LOCATE 12,8 : PRINT"Enter scan list file name 'QED' and
    set scan period = 100ms."
718 LOCATE 14,8 : PRINT"Press F2 (on the TATUNG) to start
    data acquisition."
719 LOCATE 16,8 : PRINT"To record continueously press Alt-
    F2 (on the TATUNG)."
720 LOCATE 22,12 : PRINT"Once data logger is recording
    press space bar to start scan. "  : PD$="" : PD$=INKEY$
    : IF PD$ =" " THEN GOTO 750 ELSE GOTO 710
750 CLS : PRINT#1,":X-28000@300:$"
    '-------- CALIBRATION SCAN  --
755 LOCATE 20,5 : PRINT STRING$(50,176)
760 PRINT#1,"K" : INPUT #1,K :PRINT#1,"E" : INPUT #1, IB$ :
    IF IB$="F" OR K=64 THEN 6000 ELSE IF K AND 1 THEN 770
    ELSE IF IB$ ="C" THEN 780 ELSE GOTO 760
770 COLOR 2,1 : LOCATE 12,15 : PRINT"
    Calibration Scan in Progress.         " : COLOR 2,0
772 PRINT#1,"N" : INPUT #1,N : ST=N/280 : ST=INT(ST)
774 LOCATE 20,5 : PRINT STRING$(ST/2,219)
776 LOCATE 20,62: PRINT"% Completed"
778 LOCATE 20,56: PRINT,ST   : GOTO 760
780 CLS : COLOR 2,1 : LOCATE 5,29 : PRINT"  Calibration
```

```
    Scan Completed.  ":COLOR 2,0
782 LOCATE 8,18 : PRINT"To stop data logger recording press
    F2 on the TATUNG.       "
785 COLOR 2,1 : LOCATE 12,10 : PRINT"    !!! WARNING !!! -
    WHEN F2  IS  PRESSED  PC  WILL  SAVE  DATA  IN  A  FILE.
    ":COLOR 2,0
786 COLOR 2,1 : LOCATE 13,10 : PRINT"        FILE NAME WILL
    BE OF FORM TESTxx.DAT (WHERE xx IS A NUMBER)":COLOR 2,0
787 COLOR 2,1 : LOCATE 14,10 : PRINT"   THE FILE NAME WILL
    BRIEFLY BE DISPLAYED ON THE MIDDLE LEFT OF THE" : COLOR
    2,0
788 COLOR 2,1 : LOCATE 15,10 : PRINT"         SCREEN - NOTE
    THE FILE NUMBER AND ENTER IT BELOW.":COLOR 2,0
790 LOCATE 18,18 : PRINT"Enter name of file data has been
    saved in - TEST   .DAT" : LOCATE 18,66 : INPUT"",CSDF$
795 CLS
797 CSDF$="TEST"+CSDF$+".DAT"
800 LOCATE 10,10 : PRINT "Data from the calibration scan
    has been saved in file -  ";CSDF$
808 PD$="": PD$=INKEY$
810 LOCATE 13,29 : PRINT "Is this correct (Y/N) ?      "
830 IF PD$="Y" OR PD$="y" THEN GOTO 860
840 IF PD$="n" OR PD$="N" THEN GOTO 850
845 GOTO 808
850 CLS : LOCATE 12,18 : PRINT"Enter name of file data has
    been saved in - TEST   .DAT" : LOCATE 12,66 : INPUT""
    ,CSDF$ : CLS : GOTO 797
860 CLS
865 LOCATE 10,20 : PRINT"The calibration scan has now been
    completed."
870 LOCATE 12,20 : PRINT"The next stage is to unload the
    calibration pin "
875 '
876 '
877 LOCATE 16,20  :  PRINT"Once  calibration  pin  has  been
    unloaded press SPACE. "
878 PD$="" : PD$=INKEY$
880 '
883 IF PD$=" " THEN CLS :GOTO 915
885 '
890 '
892 GOTO 878
900 '*************  run examination sub-routine ***********
905 CLS
910 '
915 LOCATE  8,25 : PRINT"You now have the following options
    -   "
920 LOCATE 11,25 : PRINT"1. To go back and perform an
    examination."
922 LOCATE  13,25  :  PRINT"2.  To  carry  out  another
    calibration."
924 LOCATE 15,25 : PRINT"3. End session.    "
926 LOCATE 17,25 : INPUT"Please enter 1,2 or 3.   ",Q$
930 IF Q$="1" THEN COE$="2" : GOTO 11110
```

```
932 IF Q$="2" THEN COE$="1" : GOTO 169
934 IF Q$="3" THEN GOTO 940
936 LOCATE 18,40 : PRINT SPACE$(38) : GOTO 926
940 LOCATE 17,15 : PRINT "Are you sure that you want to end
    session (Y/N)  ?   "
942 PD$="" :PD$=INKEY$
944 IF PD$="Y" OR PD$="y" THEN SYSTEM
946 IF PD$="n" OR PD$="N" THEN GOTO 905
948 GOTO 940
1000 '--------------------------------------------------------
1005 '
1010 '      list variables to be saved for next program.
1020 COMMON CSDF$,SENS1$,SENS2$,SENS3$,PSSV$,PSSH$,PTFQ$,
     PSENS$,PPAS$,PSBR$,PSBX$,CSSH$,CSSV$,CTFQ$,CSENS$,
     CPAS$,CSBR$,CSBX$,JRC$,TEST$,FRN$,MAN$,BOP$,FRD$,
     SSP$,LOS$  : CHAIN "VERT",ALL
1200 '-------------------------------------------------------

1201 IF UP = 0 THEN RETURN
1210 '
1220 '        Calibration Procedure For EM330 (Point Probe)
1230 '
1240 IF SENS1$=SENS1A$ OR SENS2$=SENS1A$ OR SENS3$=SENS1A$
     THEN GOTO 1250 ELSE RETURN
1250 CLS : LOCATE 12,5 : PRINT"Push AUTOSTART to move to
     Calibration Position for POINT PROBE."
1255 PRINT#1,":#:$"
1260 PRINT#1,":L1:X2000@500:R1:S1:H3:X30286@1500:$"
1263 PRINT#1,  "E"  :  INPUT  #1,  IB$  :  IF  IB$="F"  THEN
     FLTNUM=1 : GOTO 6000
1265 PRINT#1, "I" : INPUT #1, IS : IF IS AND 1 OR IS AND 16
     OR IS AND 32 OR IS AND 64 THEN FLTNUM=1 : GOTO 6000
1268 PRINT#1,"K" : INPUT #1, K : IF K AND 1 THEN 1275
1270 PRINT#1,"E"  :  INPUT  #1,  IB$  :  IF  IB$="C"  THEN  1279
     ELSE 1265
1275 LOCATE 12,3 : PRINT"                        Moving to
     Calibration position for POINT PROBE.         " : GOTO
     1265
1279 CLS
1280 COLOR 0,1 : LOCATE 3,28 : PRINT"   Pin At Calibration
     position.   " : COLOR 2,0
1282 LOCATE 6,5 : PRINT"Unless otherwise instructed set the
     EM3300 for the POINT PROBE to - "
1284 LOCATE 10,14 : PRINT"Test Frequency = 500 KHz. "
1286 LOCATE 12,14 : PRINT"Signal strength (vertical) = 2
     Volts/div."
1288 LOCATE 14,14 : PRINT"Signal strength (horizantal) = 2
     Volts/div.
1289 LOCATE 16,14 : PRINT"Sensitivity Setting = 2.0 "
1290 LOCATE 20,22 : PRINT"Press Space Bar To Continue." :
     PD$="" : PD$=INKEY$ : IF PD$=" " THEN GOTO 1300 ELSE
     GOTO 1280
1300 '--------------------------------------------------------
```

```
1310 '                  Calibration Procedure For EM3300's
1320 '
1330 CLS:LOCATE 2,25:PRINT"CALIBRATION PROCEDURE FOR EM330"
1340 LOCATE 4,10 : PRINT"Before conducting a test it is
     first necessary to balance the EM3300."
1350 LOCATE 6,10 :PRINT"This can be done in one of two ways
     -"
1360 LOCATE 8,10 :PRINT"1. Press the RED 'autobalance'
     button."
1370 LOCATE 9,13 :PRINT"When button is depressed the 'R'
     and 'X' knobs will rotate.
1380 LOCATE 10,13 :PRINT"Keep button depressed until the
     knobs stop rotating."
1390 LOCATE 11,13 :PRINT"Rotate 'PHASE' knob to give a
     circle on the screen."
1400 LOCATE 12,13 :PRINT"Manually adjust R & X until spot
     appears in centre of circle."
1410 LOCATE 13,13 :PRINT"When spot is in centre rotating
     PHASE should have little effect."
1420 LOCATE 16,10 :PRINT"2. In some cases 'autobalance'
     button may be ineffective."
1430 LOCATE 17,13 :PRINT"If this happens the instrument
     must be balanced manually"
1440 LOCATE 18,13 :PRINT"Rotate PHASE knob to give a circle
     (or part of) on the screen."
1450 LOCATE 19,13 :PRINT"Adjust R & X to move the spot
     towards the centre of the circle."
1460 LOCATE 20,13 :PRINT"Repeat last two steps until spot
     lies in centre."
1470 LOCATE 21,13 :PRINT"When spot is in centre rotating
     PHASE should have little effect."
1480 LOCATE 23,54 : PRINT SPACE$(22) : LOCATE 23,25 :
     PRINT" Press Space Bar To Continue ": PD$=INKEY$ : IF
     PD$=" " THEN 1610 ELSE GOTO 1480
1610 CLS : LOCATE 5,10: PRINT"The pin is now at the
     calibration position. The calibration"
1620 LOCATE 6,7: PRINT"procedure for the eddy current POINT
     PROBE is as follows -"
1630 LOCATE 9,7 :PRINT"Firstly the probe examines a step
     change in diameter on the rod."
1640 LOCATE 11,7 :PRINT"The objective is to obtain a near
     horizantal display on the EM3300."
1650 LOCATE 13,7 :PRINT"1. The rod is moved by pressing the
     AUTOSTART button on the drive unit."
1660 LOCATE 15,7 :PRINT"2. After each movement rotate the
     EM3300 display by using the PHASE knob."
1670 LOCATE 17,7 :PRINT"3. Repeat 1 & 2 until the display
     is horizantal."
1680 LOCATE 19,7 :PRINT"4. When display is OK press space
     bar to continue.    "
1690 PRINT#1,":L1:X 5600@300:X-:=0,1:$"
     '--  SEND CALIB COMMAND -
1700 PD$=INKEY$ : IF PD$<>" " THEN GOTO 1700
1705 BEEP
```

```
1710 LOCATE 19,7 : PRINT"Are you sure that the display is
     correct ?  (Y or N)    "
1720 PD$=INKEY$ : IF PD$ ="n" OR PD$="N" THEN BEEP : GOTO
     1680
1730 IF PD$ ="y" OR PD$="Y" THEN GOTO 1800
1740 GOTO 1710
1800 PRINT#1,":#:$"  '-------  cancel calibration commands
2000 '------------------------------------------------------
2002 '
2005 '                 Prompt for instrument settings.
2007 '
2010 CLS : LOCATE 3,15: PRINT"PLEASE ENTER THE FOLLOWING
     INSTRUMENT SETTIMGS."
2020 LOCATE 5,22 : PRINT"EM3300 - EDDY CURRENT UNIT (POINT
     PROBE)"
2025 GOTO 2400
2030 LOCATE 8,38 :PRINT SPACE$(38)
2032 LOCATE 8,44 : PRINT"V/div" : LOCATE 8,10 :INPUT"1.
     Signal Strength (vert) - ",PSSV$ : GOSUB 25050 : IF
     Q1=1 THEN Q1=0 : RETURN
2040 LOCATE 10,38 : PRINT SPACE$(38)
2042 LOCATE 10,44 : PRINT"V/div ": LOCATE 10,10 :INPUT"2.
     Signal Strength (horz) - ",PSSH$ : GOSUB 25060 : IF
     Q1=1 THEN Q1=0 : RETURN
2050 LOCATE 12,30 : PRINT SPACE$(41)
2052 LOCATE 12,35 : PRINT"KHz  " : LOCATE 12,10 :INPUT"3.
     Test Frequency - ",PTFQ$ : IF Q1=1 THEN Q1=0 : RETURN
2060 LOCATE 14,35 : PRINT SPACE$(41)
2062 LOCATE 14,10 :INPUT"4. Sensitivity Setting - ",PSEN$ :
     IF Q1=1 THEN Q1=0 : RETURN
2070 LOCATE 16,35 : PRINT SPACE$(41)
2072 LOCATE 16,10 :INPUT"5. Phase Angle Setting - ",CPAS$ :
     IF Q1=1 THEN Q1=0 : RETURN
2080 LOCATE 18,41 : PRINT SPACE$(37)
2082 LOCATE 18,10 :INPUT"6. Signal Balance Setting - R -
     ",PSBR$ : IF Q1=1 THEN Q1=0 : RETURN
2090 LOCATE 20,41 : PRINT SPACE$(37)
2092 LOCATE 20,10 :INPUT"7. Signal Balance Setting - X -
     ",PSBX$ : IF Q1=1 THEN Q1=0 : RETURN
2200 '---------------- Routine to check data  -----------
2210 LOCATE 23,5 : PRINT SPACE$(70)
2212 LOCATE 23,15 : INPUT " Has data been entered correctly
     ?  (Y or N)    ",DEC$
2220 IF DEC$="y" OR DEC$="Y" THEN 360
2230 IF DEC$="N" OR DEC$="n" THEN GOSUB 2250
2240 GOTO 2210
2250 LOCATE 23,5 : PRINT SPACE$(70)
2252 LOCATE 23,15 : INPUT " Which number do you wish to
     change ? (1..7)    ",Q$
2260 IF Q$="1" THEN Q1=1 : GOSUB 2030 : RETURN
2270 IF Q$="2" THEN Q1=1 : GOSUB 2040 : RETURN
2280 IF Q$="3" THEN Q1=1 : GOSUB 2050 : RETURN
2290 IF Q$="4" THEN Q1=1 : GOSUB 2060 : RETURN
2300 IF Q$="5" THEN Q1=1 : GOSUB 2070 : RETURN
```

```
2310 IF Q$="6" THEN Q1=1 : GOSUB 2080 : RETURN
2320 IF Q$="7" THEN Q1=1 : GOSUB 2090 : RETURN
2330 GOTO 2250
2350 '-----------------------------------------------------
2360 LOCATE 12,25 :PRINT"Press Space Bar to continue."
2370 PD$="" : PD$=INKEY$ : IF PD$=" " THEN RETURN ELSE GOTO
2360
2400 '-----------------------------------------------------
2410 '
2420 LOCATE 8,10 :PRINT"1. Signal Strength (vert) - 2
     V/div" : PSSV$="2"
2430 LOCATE 10,10 :PRINT"2. Signal Strength (horz) - 2
     V/div" : PSSH$="2"
2440 LOCATE 12,10 :PRINT"3. Test Frequency - 500 KHz" :
     PTFQ$="500"
2445 LOCATE 14,10 :PRINT"4. Sensitivity - 2.0" :
     PSENS$="2.0"
2450 GOTO 2070
2460 '
2470 '-----------------------------------------------------
3200 '-----------------------------------------------------
3201 IF UC = 0 THEN RETURN
3210 '
3220 '    Calibration Procedure For EM330 (Encircling Coil)
3230 '
3240 IF SENS1$=SENS2A$ OR SENS2$=SENS2A$ OR SENS3$=SENS2A$
     THEN GOTO 3250 ELSE RETURN
3250 CLS : LOCATE 12,5 : PRINT"Push AUTOSTART to move to
     Calibration Position for ENCIRCLING COIL."
3255 PRINT#1,":#:$"
3260 PRINT#1,":L1:X2000@500:R1:S1:H3:X16006@1500:$"
3263 PRINT#1, "E" : INPUT #1, IB$ : IF IB$="F" THEN
     FLTNUM=1 : GOTO 6000
3265 PRINT#1, "I" : INPUT #1, IS : IF IS AND 1 OR IS AND 16
     OR IS AND 32 OR IS AND 64 THEN FLTNUM=2 : GOTO 6000
3268 PRINT#1,"K" : INPUT #1, K : IF K AND 1 THEN 3275
3270 PRINT#1,"E" : INPUT #1, IB$ : IF IB$ ="C" THEN 3279
     ELSE GOTO 3265
3275 LOCATE 12,5 : PRINT"          Moving to Calibration
     position for ENCIRCLING COIL.      " : GOTO 3270
3279 CLS
3280 COLOR 0,1 : LOCATE 3,28 : PRINT"   Pin At Calibration
     position.   " : COLOR 2,0
3282 LOCATE 8,5 : PRINT"Unless otherwise instructed set the
     EM3300 for the ENCIRCLING COIL to - "
3284 LOCATE 10,14 : PRINT"Test Frequency = 200 KHz. "
3286 LOCATE 12,14 : PRINT"Signal strength (vertical) = 2
     Volts/div."
3288 LOCATE 14,14 : PRINT"Signal strength (horizantal) = 2
     Volts/div.
3289 LOCATE 16,14 : PRINT"Sensitivity Setting = 2.0 "
3290 LOCATE 20,22 : PRINT"Press Space Bar To Continue." :
     PD$=INKEY$ : IF PD$=" " THEN GOTO 3300 ELSE GOTO 3280
3300 '-----------------------------------------------------
```

```
3310 '              Calibration Procedure For EM3300's
3320 '
3330 CLS:LOCATE 2,25:PRINT"CALIBRATION PROCEDURE FOR EM330"
3340 LOCATE 4,10 : PRINT"Before conducting a test it is
     first necessary to balance the EM3300."
3350 LOCATE 6,10 :PRINT"This can be done in one of two ways
     -"
3360 LOCATE 8,10 :PRINT"1. Press the RED 'autobalance'
     button."
3370 LOCATE 9,13 :PRINT"When button is depressed the 'R'
     and 'X' knobs will rotate.
3380 LOCATE 10,13 :PRINT"Keep button depressed until the
     knobs stop rotating."
3390 LOCATE 11,13 :PRINT"Rotate 'PHASE' knob to give a
     circle on the screen."
3400 LOCATE 12,13 :PRINT"Manually adjust R & X until spot
     appears in centre of circle."
3410 LOCATE 13,13 :PRINT"When spot is in centre rotating
     PHASE should have little effect."
3420 LOCATE 16,10 :PRINT"2. In some cases 'autobalance'
     button may be ineffective."
3430 LOCATE 17,13 :PRINT"If this happens the instrument
     must be balanced manually"
3440 LOCATE 18,13 :PRINT"Rotate PHASE knob to give a circle
     (or part of) on the screen."
3450 LOCATE 19,13 :PRINT"Adjust R & X to move the spot
     towards the centre of the circle."
3460 LOCATE 20,13 :PRINT"Repeat last two steps until spot
     lies in centre."
3470 LOCATE 21,13 :PRINT"When spot is in centre rotating
     PHASE should have little effect."
3480 LOCATE 23,54 : PRINT SPACE$(22) : LOCATE 23,25 :
     PRINT" Press Space Bar To Continue ": PD$=INKEY$ : IF
     PD$=" " THEN 3610 ELSE GOTO 3480
3610 CLS : LOCATE 5,10: PRINT"The pin is now at the
     calibration position. The calibration"
3620 LOCATE 6,7: PRINT"procedure for the eddy current
     ENCIRCLING COIL is as follows -"
3630 LOCATE 8,7 :PRINT"The coil has to examine a 1.5mm
     through wall defect. "
3635 LOCATE 9,7 :PRINT"This will give a 'figure 8' on the
     EM3300."
3640 LOCATE 10,7 :PRINT"The figure must be rotated until it
     lies at 45 degrees to the axes."
3645 LOCATE 11,7 :PRINT"The spot must move first to the 2nd
     and then to the 4th quadrant."
3648 LOCATE 12,7 :PRINT"(i.e. move from centre to top left
     to bottom right to centre.)"
3650 LOCATE 14,7 :PRINT"1. The rod is moved by pressing the
     AUTOSTART button on the drive unit."
3660 LOCATE 16,7 :PRINT"2. After each movement rotate the
     EM3300 display by using the PHASE knob."
3670 LOCATE 18,7 :PRINT"3. Repeat 1 & 2 until the display
     is satisfactory."
```

```
3680 LOCATE 20,7 :PRINT"4. When display is OK press space
     bar to continue.    "
3690 PRINT#1,":L1:X-1500@300:X:=0,1:$"
     '--  SEND CALIB COMMAND --
3700 PD$=INKEY$ : IF PD$<>" " THEN GOTO 3700
3705 BEEP
3710 LOCATE 20,7 : PRINT"Are you sure that the display is
     correct ?  (Y or N)    "
3720 PD$=INKEY$ : IF PD$ ="n" OR PD$="N" THEN BEEP : GOTO
     3680
3730 IF PD$ ="y" OR PD$="Y" THEN GOTO 3800
3740 GOTO 3710
3800 PRINT#1,":#:$"
     '----------- cancel calibration commands  ---
4000 '--------------------------------------------------------
4002 '
4005 '                  Prompt for instrument settings.
4007 '
4010 CLS : LOCATE 3,15: PRINT"PLEASE ENTER THE FOLLOWING
     INSTRUMENT SETTIMGS."
4020 LOCATE  5,20  :  PRINT"EM3300  -  EDDY  CURRENT  UNIT
     (ENCIRCLING COIL)"
4025 GOTO 4400
4030 LOCATE 8,38 :PRINT SPACE$(38)
4032 LOCATE  8,44  :  PRINT"V/div"  :  LOCATE  8,10  :INPUT"1.
     Signal Strength (vert) - ",CSSV$ : GOSUB 25070 : IF
     Q1=1 THEN Q1=0 : RETURN
4040 LOCATE 10,38 : PRINT SPACE$(38)
4042 LOCATE  10,44  :  PRINT"V/div ": LOCATE 10,10  :INPUT"2.
     Signal Strength (horz) - ",CSSH$ : GOSUB 25080 : IF
     Q1=1 THEN Q1=0 : RETURN
4050 LOCATE 12,30 : PRINT SPACE$(41)
4052 LOCATE 12,35 : PRINT"KHz   " : LOCATE 12,10 :INPUT"3.
     Test Frequency - ",CTFQ$ : IF Q1=1 THEN Q1=0 : RETURN
4060 LOCATE 14,35 : PRINT SPACE$(41)
4062 LOCATE 14,10 :INPUT"4. Sensitivity Setting - ",CSEN$ :
     IF Q1=1 THEN Q1=0 : RETURN
4070 LOCATE 16,35 : PRINT SPACE$(41)
4072 LOCATE 16,10 :INPUT"5. Phase Angle Setting - ",CPAS$ :
     IF Q1=1 THEN Q1=0 : RETURN
4080 LOCATE 18,41 : PRINT SPACE$(37)
4082 LOCATE  18,10  :INPUT"6.  Signal  Balance  Setting  - R -
     ",CSBR$ : IF Q1=1 THEN Q1=0 : RETURN
4090 LOCATE 20,41 : PRINT SPACE$(37)
4092 LOCATE  20,10  :INPUT"7.  Signal  Balance  Setting  - X -
     ",CSBX$ : IF Q1=1 THEN Q1=0 : RETURN
4200 '------------------ Routine to check data  ----------
4210 LOCATE 23,5 : PRINT SPACE$(70)
4212 LOCATE 23,15 : INPUT " Has data been entered correctly
     ?  (Y or N)    ",DEC$
4220 IF DEC$="y" OR DEC$="Y" THEN 460
4230 IF DEC$="N" OR DEC$="n" THEN GOSUB 4250
4240 GOTO 4210
4250 LOCATE 23,5 : PRINT SPACE$(70)
```

```
4252 LOCATE 23,15 : INPUT " Which number do you wish to
     change ? (1..7)   ",Q$
4260 IF Q$="1" THEN Q1=1 : GOSUB 4030 : RETURN
4270 IF Q$="2" THEN Q1=1 : GOSUB 4040 : RETURN
4280 IF Q$="3" THEN Q1=1 : GOSUB 4050 : RETURN
4290 IF Q$="4" THEN Q1=1 : GOSUB 4060 : RETURN
4300 IF Q$="5" THEN Q1=1 : GOSUB 4070 : RETURN
4310 IF Q$="6" THEN Q1=1 : GOSUB 4080 : RETURN
4320 IF Q$="7" THEN Q1=1 : GOSUB 4090 : RETURN
4330 GOTO 4250
4350 '-----------------------------------------------------
4360 LOCATE 12,25 :PRINT"Press Space Bar to continue."
4370 PD$="" : PD$=INKEY$ : IF PD$=" " THEN RETURN ELSE GOTO
4360
4400 '-----------------------------------------------------
4410 '
4420 LOCATE 8,10 :PRINT"1. Signal Strength (vert) - 2
     V/div" : CSSV$="2"
4430 LOCATE 10,10 :PRINT"2. Signal Strength (horz) - 2
     V/div" : CSSH$="2"
4440 LOCATE 12,10 :PRINT"3. Test Frequency -  200 KHz" :
     CTFQ$="500"
4445 LOCATE 14,10 :PRINT"4. Sensitivity Setting -  2.0" :
     CSENS$="2.0"
4450 GOTO 4070
4460 '
5000 '-----------------------------------------------------
5010 '
5020 '              Calibration procedure for LVDT.
5030 '
5040 IF UT=0 THEN RETURN
5050 RETURN
6000 '-----------------------------------------------------
6010 '*****************  fault.bas  12/3/90   *************
6020 'The purpose of this program is to determine which
6030 'fault has occurred and then advise how to correct it.
6040 '
6050 CLS
6060  '----------------------------------------------------
6070  '
6080  '                      FAULT FINDING ROUTINE
6085 PRINT#1,"#"
6090 LOCATE 2,15 :PRINT"The interface has detected a fault
     in the DRIVE UNIT"
6100 LOCATE 3,19 : PRINT"and switched the drive unit to
     MANUAL control."
6110 LOCATE 4,12 :PRINT"The test can only be restarted when
     the fault has been corrected."
6120 LOCATE 6,3 : PRINT"The following faults have occured "
6130 OLDN=N : N=5 :LN=4 : PRINT#1,"I" : INPUT #1,IS
6140 IF IS =128 THEN FLT$(N)="       NONE            ":N=N+1
6150 IF IS AND 1 THEN FLT$(N)="EMERGENCY STOP      ": N=N+1
     :ES=1
6160 IF IS AND 2 THEN FLT$(N)="X FAULT" : N= N+1
```

```
6170 IF IS AND 4 THEN FLT$(N)="Y FAULT" : N= N+1
6180 IF IS AND 8 THEN FLT$(N)="START SWITCH DEPRESSED" :
     N= N+1 : SS=1
6190 IF IS AND 16 THEN FLT$(N)="LOWER LIMIT REACHED   " :
     N= N+1 : LL=1
6200 IF IS AND 32 THEN FLT$(N)="UPPER LIMIT REACHED   " :
     N= N+1 : UL=1
6210 IF IS AND 64 THEN FLT$(N)="ENCODER FAULT         " :
     N= N+1
6220 FOR N=1 TO N-1
6230 LOCATE LN, 7 : PRINT FLT$(N) :LN=LN+1 : NEXT N
6240 LOCATE 6,43 : PRINT"These faults are still active - "
6250 OLDN=N : N=5 :LN=4 : PRINT#1,"I" : INPUT #1,IS:LOCATE
     21,58:PRINT"INPUT STATUS -"IS
6255 PRINT#1,"K" : INPUT #1,KS:LOCATE 21,38:PRINT"MOTION
     STATUS -"KS
6260 IF IS = 128 THEN FLT$(N)="        NONE           ":
     N=N+1
6270 IF IS AND 64 THEN FLT$(N)="ENCODER FAULT         " :
     N= N+1
     : MES$="Visually check drive unit then press AUTOSTOP"

6280 IF IS AND 2 THEN FLT$(N)="X FAULT" : N= N+1
6290 IF IS AND 4 THEN FLT$(N)="Y FAULT" : N= N+1
6300 IF IS AND 8 THEN FLT$(N)="START SWITCH DEPRESSED" :
     N= N+1 : MES$="Check START switch on drive unit and
     remote box"

6310 IF IS AND 16 THEN FLT$(N)="LOWER LIMIT REACHED   " :
     N= N+1 : MES$="Manually move drive unit UP.          "
6320 IF IS AND 32 THEN FLT$(N)="UPPER LIMIT REACHED   " :
     N= N+1 : MES$="Manually move drive unit DOWN.        "
6330 IF IS AND 1 THEN FLT$(N)="EMERGENCY STOP        ":
     N= N+1
6340 FOR N=1 TO N-1
6350 LOCATE LN, 47 : PRINT FLT$(N) :LN=LN+1 : NEXT N
6360 FOR Q= N TO OLDN
6370 LOCATE LN, 47 : PRINT SPACE$(24) :LN=LN+1 : NEXT Q
6380 LOCATE 18,5 : PRINT"CORRECTIVE ACTION - "+MES$
6390 IF IS = 128 THEN 6400 ELSE 6250
6400 BEEP : LOCATE 18,5 : PRINT SPACE$(72)
6410 LOCATE 18,20 : PRINT"    Push SPACE BAR to start a new
     scan."
6420 PD$=INKEY$ : IF PD$<>" " THEN 6410
6425 PRINT#1,"K" : INPUT#1,K : IF K=128 THEN PRINT#1,"F" :
     PRINT#1,"K"
6430 IF FLTNUM=1 THEN 1250     'point probe calib position
6440 IF FLTNUM=2 THEN 3250  'encircling coil calib position
6450 IF FLTNUM=3 THEN 600                       'calib scan
7000 '
7001 CLS
7010 '
7020 ' The purpose of this routine is to define the sensor
7030 ' positions inside the cassette box and then to choose
```

```
7040 ' which sensors are to be used during the examination.
7050 '
7060 '--------------------------------------------------------
7070 '    Set default sensors.
7080 '
7090 SENS1$="E/C POINT PROBE" : SENS2$="ENCIRCLING COIL" :
     SENS3$="LVDT" : SENS4$="NONE"
7100 SENS1A$ = SENS1$ : SENS2A$ = SENS2$ : SENS3A$ = SENS3$
     : SENS4A$ = SENS4$
7105 IF COE$="1" THEN 7440
7110 '-------------------------------------------------------
7120 '
7130 '     Draw outline of cassette box on screen.
7140 '
7150 LOCATE 8,30 : PRINT STRING$ (20,223)
7160 LOCATE 11,30 : PRINT STRING$ (20,205)
7170 LOCATE 14,30 : PRINT STRING$ (20,205)
7180 LOCATE 17,30 : PRINT STRING$ (20,220)
7190 FOR T=8 TO 17 : LOCATE T,29 : PRINT CHR$ (222) :
     LOCATE T,50 : PRINT CHR$ (221): NEXT T
7200 FOR T= 3 TO 7:LOCATE T,36 : PRINT CHR$(222) : LOCATE
     T,43:PRINT CHR$(221):NEXT T
7210 '
7220 '-------------------------------------------------------
7230 '
7240 '     Show default sensors
7250 '
7260 LOCATE 9,31 :PRINT"1. "+SENS1$
7270 LOCATE 12,31 :PRINT"2. "+SENS2$
7280 LOCATE 15,31 :PRINT"3. "+SENS3$
7290 '
7300 '--------------------------------------------------------
7310 '
7320 '     Option to change default sensors
7330 '
7340 LOCATE 21,1 :PRINT SPACE$(77):LOCATE 21,17: BEEP :
     INPUT"Is this arrangement of sensors correct (Y or N)
     ? ",SA$
7350 IF SA$="y" OR SA$="Y" THEN 160
7360 IF SA$="N" OR SA$="n" THEN 7380
7370 GOTO 7340
7380 BEEP : LOCATE 21, 1 : PRINT SPACE$(77) : LOCATE 21,17
     : INPUT "Which number do you want to change (1,2 or 3)
     ? ",NS$
7390 IF NS$="1" THEN LOCATE 9,34 : PRINT SPACE$(16) : GOSUB
     7890 : SENS1$ =SENS$ : GOTO 7260
7400 IF NS$="2" THEN LOCATE 12,34 : PRINT SPACE$(16) :
     GOSUB 7890 : SENS2$ =SENS$ : GOTO 7260
7410 IF NS$="3" THEN LOCATE 15,34 : PRINT SPACE$(16) :
     GOSUB 7890 : SENS3$ =SENS$ : GOTO 7260
7420 GOTO 7380
7430 '
7440 '-------------------------------------------------------
7450 '
```

```
7460 '    Select which sensors are to be used during the
                          examionation.
7470 '
7480 CLS :BEEP : LOCATE 5,15 : PRINT"Which sensors are to
     be used during the examination ?"
7490 '
7500 '     Option to change sensor 1.
7510 '
7520 LOCATE  9,15 :PRINT "1. ";SENS1$;"    (Y or N)" : IF
     SENS1$=SENS4$ THEN US1$="N"  : GOTO 7540 ELSE LOCATE
     9,59 :INPUT"",US1$
7530 IF LEFT$(US1$,1)="y" OR LEFT$(US1$,1)="Y" THEN US1$="
     Yes     ": LOCATE 9,54 :PRINT US1$ : GOSUB 7560 : IF
     SC=1 THEN RETURN ELSE GOTO 7580
7540 IF LEFT$(US1$,1)="n" OR LEFT$(US1$,1)="N" THEN US1$="
     No      ": LOCATE 9,54 :PRINT US1$ : GOSUB 7570 : IF
     SC=1 THEN RETURN ELSE GOTO 7580
7550 PRINT SPACE$(20) : GOTO 7520
7560 '
7562 IF LEFT$(SENS1$,2)="E/" THEN UP=1
7564 IF RIGHT$(SENS1$,1)="L" THEN UC=1
7566 IF RIGHT$(SENS1$,1)="T" THEN UT=1
7568 RETURN
7570 '
7572 IF LEFT$(SENS1$,2)="E/" AND UP=1 THEN UP=0
7574 IF RIGHT$(SENS1$,1)="L" AND UC=1 THEN UC=0
7576 IF RIGHT$(SENS1$,1)="T" AND UT=1 THEN UT=0
7578 RETURN
7580 '     Option to change sensor 2.
7590 '
7600 LOCATE 11,15 :PRINT "2. ";SENS2$;"    (Y or N)" : IF
     SENS2$=SENS4$ THEN US2$="n"  : GOTO 7620 ELSE LOCATE
     11,59 :INPUT"",US2$
7610 IF LEFT$(US2$,1)="y" OR LEFT$(US2$,1)="Y" THEN US2$="
     Yes     ": LOCATE 11,54 :PRINT US2$ : GOSUB 7640 : IF
     SC=1 THEN RETURN ELSE GOTO 7660
7620 IF LEFT$(US2$,1)="n" OR LEFT$(US2$,1)="N" THEN US2$="
     No      ": LOCATE 11,54 :PRINT US2$ : GOSUB 7650 : IF
     SC=1 THEN RETURN ELSE GOTO 7660
7630 LOCATE 11,54 : PRINT SPACE$(20) : GOTO 7600
7640 '
7642 IF LEFT$(SENS2$,2)="E/" THEN UP=1
7644 IF RIGHT$(SENS2$,1)="L" THEN UC=1
7646 IF RIGHT$(SENS2$,1)="T" THEN UT=1
7648 RETURN
7650 '
7652 IF LEFT$(SENS2$,2)="E/" AND UP=1 THEN UP=0
7654 IF RIGHT$(SENS2$,1)="L" AND UC=1 THEN UC=0
7656 IF RIGHT$(SENS2$,1)="T" AND UT=1 THEN UT=0
7658 RETURN
7660 '     Option to change sensor 3.
7670 '
7680 LOCATE 13,15 :PRINT "3. ";SENS3$;"    (Y or N)" : IF
     SENS3$=SENS4$ THEN US3$="n"  : GOTO 7700 ELSE LOCATE
```

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     13,59 :INPUT"",US3$
7690 IF LEFT$(US3$,1)="y" OR LEFT$(US3$,1)="Y" THEN US3$="
     Yes     ": LOCATE 13,54 :PRINT US3$ : GOSUB 7720 : IF
     SC=1 THEN RETURN ELSE GOTO 7800
7700 IF LEFT$(US3$,1)="n" OR LEFT$(US3$,1)="N" THEN US3$="
     No      ": LOCATE 13,54 :PRINT US3$ : GOSUB 7760 : IF
     SC=1 THEN RETURN ELSE GOTO 7800
7710 LOCATE 13,54 : PRINT SPACE$(20) : GOTO 7680
7720 '
7722 IF LEFT$(SENS3$,2)="E/" THEN UP=1
7724 IF RIGHT$(SENS3$,1)="L" THEN UC=1
7726 IF RIGHT$(SENS3$,1)="T" THEN UT=1
7750 RETURN
7760 '
7762 IF LEFT$(SENS3$,2)="E/" AND UP=1 THEN UP=0
7764 IF RIGHT$(SENS3$,1)="L" AND UC=1 THEN UC=0
7766 IF RIGHT$(SENS3$,1)="T" AND UT=1 THEN UT=0
7768 RETURN
7790 '        Option to alter incorrect inputs.
7800 '
7810 BEEP : LOCATE 15,15 :PRINT SPACE$(60):LOCATE 19,15 :
     INPUT "Is the information correct  (Y or N) ? ",YN1$
7820 IF YN1$="n" OR YN1$="N" THEN LOCATE 19,15 :PRINT
     SPACE$(60):LOCATE 19,15 : INPUT " Which number do you
     wish to change  (1,2 or 3) ? ",NSC$ :SC=1: GOTO 7850
7830 IF YN1$="y" OR YN1$="Y" THEN RETURN
7840 GOTO 7810
7850 IF NSC$="3" THEN LOCATE 13,54 : PRINT SPACE$(15) :
     LOCATE 19,15 : PRINT SPACE$(60) : GOSUB 7660 : GOTO
     7810
7860 IF NSC$="2" THEN LOCATE 11,54 : PRINT SPACE$(15) :
     LOCATE 19,15 : PRINT SPACE$(60) : GOSUB 7580 : GOTO
     7810
7870 IF NSC$="1" THEN LOCATE 9,54 : PRINT SPACE$(15) :
     LOCATE 19,15 : PRINT SPACE$(60) : GOSUB 7500 : GOTO
     7810
7880 BEEP : GOTO 7820
7890 '
7900 '-----------------------------------------------------
7910 '
7920 '        Show available sensors.
7930 '
7940 LOCATE 8,55 :PRINT"SENSORS AVALIABLE"
7950 LOCATE 10,55 :PRINT"1. ";SENS1A$
7960 LOCATE 12,55 :PRINT"2. ";SENS2A$
7970 LOCATE 14,55 :PRINT"3. ";SENS3A$
7980 LOCATE 16,55 :PRINT"4. ";SENS4A$
7990 '
8000 '-------------------------------------------------------
8010 '
8020 '        Choose new sensor.
8030 '
8040 BEEP : LOCATE 21,1 :PRINT SPACE$(77) : LOCATE 21,17:
     INPUT "Which new sensor do you wish to add (1,2,3 or
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     4) ?  ",NA$
8050 IF NA$="1" THEN SENS$=SENS1A$ : RETURN
8060 IF NA$="2" THEN SENS$=SENS2A$ : RETURN
8070 IF NA$="3" THEN SENS$=SENS3A$ : RETURN
8080 IF NA$="4" THEN SENS$=SENS4A$ : RETURN
8090 IF NA$><"1" OR NA$<>"2" OR NA$<>"3" OR NA$ <>"4" THEN
     GOTO 8040
8100 '
8110 '----------------------------------------------------
9000 '**********************  INIT.BAS  *****************
9030 CLS:KEY OFF
9050 ON KEY (5)   GOSUB 9760
9060 ON KEY (7)   GOSUB 9740
9070 KEY (8) ON : ON KEY (8)   GOSUB 9750
9080 KEY (5) ON
9100 GOSUB 9320
9130 COM(1) ON
9140 CLOSE
9150 OPEN"COM1:2400,N,8,2,CS350,DS" AS #1
9160 GOTO 1200
9170 GOSUB 9320
9190 FOR KN = 1 TO 15 : KEY(KN) OFF : NEXT : GOTO 11000
9270 LOCATE 2,31:PRINT"PROGRAM TERMINATED":CLOSE : END
9320 CLS:BEEP
9330 LOCATE  9,15:PRINT"The Interface must be re-set before
     a test can be started"
9340 LOCATE 13,24:PRINT"Press F8 to re-set the Interface.":
     GOTO 9330
9350 CLS :BEEP
9360 LOCATE 13,25:PRINT"Once power has been switched back
     ON  "
9370 LOCATE 15,32:PRINT"Press F7 to continue. ":GOTO 9360
9410 PRINT#1,"]" : CLS
9440 PRINT#1,"*"
9450 CLS : LOCATE 12,29:PRINT"Interface has been re-set"
9460 LOCATE 14,14:PRINT"Switch the interface power OFF and
     then back ON again."
9470 FOR T= 1 TO 2000 : NEXT T: GOTO 9350
9530 CLS:BEEP:LOCATE  11,25:PRINT"Initiailsing Interface -
     Please wait."
9540 COM(1) ON : CLOSE
9560 OPEN"COM1:2400,N,8,2,CS350,DS" AS #1
9570 RETURN
9590 PRINT #1,"(" : INPUT #1,A$
9610 IF A$="U" THEN 9680
9620 LOCATE 15,20:PRINT "COMMUNICATION FAULT" :GOTO 6000
9630 RETURN
9680 PRINT#1,"U61"
9720 RETURN
9740 GOSUB 9530: KEY (5) ON : GOSUB 9590 : GOTO 9190
9750 GOSUB 9530: KEY (7) ON : GOTO 9410
9760 GOSUB 3040 : GOTO 9230
11000 FOR T= 1 TO 15 : KEY (T) ON : NEXT
11010 CLS
```

```
11015 '--------------------   INFO.BAS 15/3/90   ---------
11020 '*************  Prompt for test information. ********
11030 LOCATE  7,25 :PRINT"Do you want to conduct either - "
11040 LOCATE 10,30 :PRINT"1. Calibration Scan . "
11050 LOCATE 12,30 :PRINT"2. Examination Scan."
11060 COLOR 0,1 : LOCATE 15,28 :PRINT"  Select either 1 or
      2.  " : COLOR 2,0
11070 COE$="" : COE$=INKEY$
11080 IF COE$="1" THEN 169
11090 IF COE$="2" THEN GOTO 11110
11100 GOTO 11070
11110 CLS:LOCATE  1,5:PRINT"BEFORE  STATRING  EXAMINATION
      PLEASE ENTER THE FOLLOWING DATA"
11120 LOCATE 4,29 : PRINT SPACE$(44)
11130 LOCATE 4,5 : INPUT "1. JRC Project Number - ",JRC$ :
      IF Q1=1 THEN Q1=0 : RETURN
11140 LOCATE 6,22 : PRINT SPACE$(44)
11150 LOCATE 6,5 : INPUT "2. Test Number - ",TEST$ : IF
      Q1=1 THEN Q1=0 : RETURN
11160 LOCATE 8,25 : PRINT SPACE$(30)
11170 LOCATE 8,5 : INPUT "3. Fuel Rod Number - ", FRN$ : IF
      Q1=1 THEN Q1=0 : RETURN
11180 LOCATE 10,30: PRINT SPACE$(47)
11190 LOCATE 10,5 : INPUT "4. Operator - ",MAN$ : IF Q1=1
      THEN Q1=0 : RETURN
11200 LOCATE 12,39: PRINT SPACE$(38)
11210 LOCATE 12,5 : INPUT "5. Bwr or Pwr (B or P) - ",BOP$
      : GOSUB 11490 : IF Q1=1 THEN Q1=0 : RETURN
11220 LOCATE 14,39: PRINT SPACE$(38)
11230 GOSUB 11540 : LOCATE 14,45 : PRINT".DAT" : LOCATE
      14,5 : INPUT "6. Fuel Assembly Drawimg Number -
      ",FRD$ : GOSUB 11580 : IF Q1=1 THEN Q1=0 : RETURN
11240 LOCATE 16,30: PRINT SPACE$(48)
11250 LOCATE 16,5 : INPUT "7. Scan Start Position - ";SSP$
      : IF Q1=1 THEN Q1=0 : RETURN
11260 LOCATE 18,25: PRINT SPACE$(50)
11270 LOCATE 18,5 : INPUT "8. Length Of Scan - ";LOS$ : IF
      Q1=1 THEN Q1=0 : RETURN
11280 LOCATE 23,5 : PRINT SPACE$(60) : LOCATE 23,15 : INPUT
      "Has data been entered correctly ? (Y or N)   ",DEC$
11290 IF DEC$="y" OR DEC$="Y" THEN GOTO 7000
11300 IF DEC$="n" OR DEC$="N" THEN GOSUB 11330 : GOTO 11280
11310 GOTO 11280
11320 LOCATE 23,5 : PRINT SPACE$(60)
11330 '------------------------------------------------------
11340 '
11350 '           SUB ROUTINE TO ALTER DATA ON SET UP MENU
11360 '
11370 LOCATE 23,5 : PRINT SPACE$(60)
11380 LOCATE 23,5 : BEEP : INPUT "Which number do you want
      to change ?   ",Q$
11390 IF Q$="1" THEN Q1=1 : GOSUB 11130
11400 IF Q$="2" THEN Q1=1 : GOSUB 11140
11410 IF Q$="3" THEN Q1=1 : GOSUB 11160
```

```
11420 IF Q$="4" THEN Q1=1 : GOSUB 11180
11430 IF Q$="5" THEN Q1=1 : GOSUB 11200
11440 IF Q$="6" THEN Q1=1 : GOSUB 11220
11450 IF Q$="7" THEN Q1=1 : GOSUB 11240
11460 IF Q$="8" THEN Q1=1 : GOSUB 11260
11470 RETURN
11480 '--------------------------------------------------
11490 '
11500 IF BOP$="b" OR BOP$="B" THEN RETURN
11510 IF BOP$="p" OR BOP$="P" THEN RETURN
11520 LOCATE 12,30 : PRINT SPACE$(22) : BEEP : GOTO 11200
11530 END
11540 '
11550 COLOR 2,1 : LOCATE 17,1 : PRINT SPACE$(240) : LOCATE
      19,1 :PRINT SPACE$(240)
11560 LOCATE 17,25 :PRINT"Drawings available are -"
11570 FILES "PINS\D*.DAT" : LOCATE 18,1 : PRINT SPACE$(20)
      : COLOR 2,0 : RETURN
11580 IF LEFT$(FRD$,1)= "d" OR LEFT$(FRD$,1)= "D" THEN GOTO
      11600
11590 IF LEFT$(FRD$,1)<>"d" OR LEFT$(FRD$,1)<>"D" THEN BEEP
      : GOTO 11220
11600 COLOR 2,0 : LOCATE 17,1 : PRINT SPACE$(240) : LOCATE
      19,1 : PRINT SPACE$(240)
11610 '
11620 FRDD$="PINS\"+FRD$+".DAT"
11625 CLOSE #2
11630 OPEN "I",#2,FRDD$
11640 IF EOF (2) THEN 11680
11650 INPUT #2,SSP$,LOS$,DFR$ : CLOSE #2
11660 LOCATE 16,5 : PRINT "7. Scan Start Position - ";SSP$
11670 LOCATE 18,5 : PRINT "8. Length Of Scan - ";LOS$
11680 GOTO 11280
11690 RETURN
24000 '
24100 IF ERL=11630 THEN BEEP : LOCATE 23,13 : PRINT"Sorry
      file does not exist - choose one of the above." :
      LOCATE 14,40 : PRINT SPACE$(15) : RESUME 11230
24110 IF ERN=53 THEN LOCATE 23,13 : PRINT"Sorry file does
      not exist - choose one of the above." : BEEP : GOTO
      11230
24999 RESUME
25000'***************************************************
25010 '
25020 '----------------- Error trapping routines. -------
25030 '
25040 '************ Check on signal strength inputs ******
25050 IF PSSV$ ="0.2" OR PSSV$ ="0.5" OR PSSV$ ="1" OR
      PSSV$ ="2" OR PSSV$ ="5" THEN 2200 ELSE BEEP : LOCATE
      23,5 : PRINT SPACE$(10) : LOCATE 23,15 : PRINT
      "Incorrect entry - valid values are 0.2, 0.5, 1, 2 or
      5." : LOCATE 8,38 : PRINT"" : GOTO 2032
25060 IF PSSH$ ="0.2" OR PSSH$ ="0.5" OR PSSH$ ="1" OR
      PSSH$ ="2" OR PSSH$ ="5" THEN 2200 ELSE BEEP : LOCATE
```

```
      23,5 : PRINT SPACE$(10) : LOCATE 23,15 : PRINT
      "Incorrect entry - valid values are 0.2, 0.5, 1, 2 or
      5." : LOCATE 10,38 : PRINT"" : GOTO 2042
25070 IF CSSV$ ="0.2" OR CSSV$ ="0.5" OR CSSV$ ="1" OR
      CSSV$ ="2" OR CSSV$ ="5" THEN 4200 ELSE BEEP : LOCATE
      23,5 : PRINT SPACE$(10) : LOCATE 23,15 : PRINT
      "Incorrect entry - valid values are 0.2, 0.5, 1, 2 or
      5." : LOCATE 8,38 : PRINT"" : GOTO 4032
25080 IF CSSH$ ="0.2" OR CSSH$ ="0.5" OR CSSH$ ="1" OR
      CSSH$ ="2"
      OR CSSH$ ="5" THEN 4200 ELSE BEEP : LOCATE 23,5 :
      PRINT SPACE$(10) : LOCATE 23,15 : PRINT"Incorrect
      entry - valid values are 0.2, 0.5, 1, 2 or 5." :
      LOCATE 10,38 : PRINT"" : GOTO 4042
25090 '
25100 IF ERL=11630 THEN LOCATE 23,5 : PRINT"Sorry file does
      not exist - choose one of the above." : GOTO 11230
25110 IF ERN=53 THEN LOCATE 23,5 : PRINT"Sorry file does
      not exist - choose one of the above." : GOTO 11230
29999 RESUME
99999 END
```

CHAPTER 7.3.2 - LISTING OF CUST.BAS

```
5 ON ERROR GOTO 25500
8 CLS:KEY OFF
9 '
10 '--------------------   cust.bas  15/3/90  -----------
20 '                  The purpose of this program is to build
30 '                   up a custom scan and then perform it.
40 '
111 '--------------------------------------------------------
1200 DIR$="-"
1245 SGAP=INT(VAL(SSP$)*72.225):SGAP=36800!-SGAP :
     SGAP$=STR$(SGAP)
1246 SFLEN=INT(VAL(LOS$)*72.225):SFLEN$=STR$(SFLEN)
1250 '-------------------------------------------------------
1251 '
1252 '           CREATION OF CUSTOM SCAN
1253 RN=8 : GOTO 4100
1255 LOCATE 22,25:PRINT STRING$(30,205):LOCATE 20,25:PRINT
     STRING$(30,205):LOCATE 20,41:PRINT CHR$(202)
1256 LOCATE  2,9:PRINT"SELECT  ANY  NUMBER  OF  DIFFERENT
     ELEMENTS TO BUILD A COMPLETE SCAN"
1258 LOCATE 5,5:PRINT"SELECTION       DESCRIPTION"
1260 LOCATE 7,9 :PRINT"1       FAST VERTICAL SCAN"
1262 LOCATE 9,9 :PRINT"2       SLOW VERTICAL SCAN"
1264 LOCATE 11,9 :PRINT"3       FAST HELICAL SCAN"
1266 LOCATE 13,9 :PRINT"4       SLOW HELICAL SCAN"
1268 LOCATE 15,9 :PRINT"5       TURN ROD 120 DEGREES"
1269 LOCATE 17,9 :PRINT"6       PAUSE TEST        "
1270 LOCATE 19,9 :PRINT"0       NO MORE SELECTIONS"
1271 LOCATE   5,46:PRINT  "ELEMENTS  ALREADY  ADDED  TO
     SCAN":LOCATE 7,51:PRINT"RETURN TO DATUM"
1272 BEEP:LOCATE 21,5:PRINT SPACE$(70):LOCATE 21,24 : INPUT
     "CHOOSE ELEMENT TO BE ADDED TO SCAN     ",CS$
1273 CS=VAL(CS$): IF CS<7 AND CS>0 OR  CS$="0" THEN GOTO
     1276
1275 BEEP  : LOCATE 21,60 : PRINT SPACE$(15) : LOCATE
     23,23 : PRINT"INCORRECT SELECTION - PLEASE RE-ENTER" :
     GOTO 1256
1276 GOSUB 2110
1277 IF  DIR$="-"  THEN  QDIR$="+"  ELSE  IF  DIR$="+"  THEN
     QDIR$="-"
1278 IF CS= 1 THEN ST$="FAST VERTICAL SCAN " : NS$=
     ":X"+QDIR$+FLEN$+"@1500": K1=1
1280 IF CS= 2 THEN ST$="SLOW VERTICAL SCAN " : NS$=
     ":X"+QDIR$+FLEN$+"@300": K1=1
1282 IF CS= 3 THEN ST$="FAST HELICAL SCAN ": NS$
     =":X"+QDIR$+FLEN$+"/"+YFLEN$+"@1500" : K1=1
1284 IF CS= 4 THEN ST$="SLOW HELICAL SCAN ": NS$
     =":X"+QDIR$+FLEN$+"/"+YFLEN$+"@300" : K1=1
1286 IF  CS=  5  THEN  ST$="TURN  ROD  120  DEGREES  ":  NS$
     =":Y133@60" : K1=1
1288 IF CS= 6 THEN ST$="PAUSE TEST  ": NS$ =":L1" : K1=1
1289 IF CS= 0 THEN ST$="START SCAN ":GOTO 1342
1290 IF K1=1 THEN LOCATE 23,5 : PRINT SPACE$(60) : LOCATE
     21,5:PRINT SPACE$(70):LOCATE 21,15: IF CS=5 OR CS=6
```

```
     THEN PRINT;ST$;"SELECTED - IS THIS CORRECT " ELSE
     PRINT;DIR$;ST$"SELECETED IS    THIS    CORRECT    "
     :ST$=DIR$+ST$
1291 LOCATE 21,64:INPUT QT$
1293 IF  QT$="Y"OR  QT$="y"  THEN  LOCATE  23,5  :  PRINT
     SPACE$(60 ) : GOTO 1330
1296 IF QT$="N"OR QT$="n" THEN DIR$=LD$ : GOTO 1255
1298 LOCATE 21,64 : PRINT"     " : GOTO 1291
1330 CS$(NC)=ST$:NC=NC+1
1334 LOCATE 5,46:PRINT"ELEMENTS ALREADY ADDED TO SCAN"
1336 LOCATE 23,25:PRINT SPACE$(50)
1338 LOCATE  RN,51:IF  CS=5  OR  CS=6  THEN  PRINT;ST$:  ELSE
     PRINT;ST$
1339 RN=RN+1:GOTO 1500
1340 '
1342 LOCATE  23,5:PRINT  SPACE$(70):LOCATE  23,23:INPUT"NO
     MORE SELECTIONS - ARE YOU SURE ?",Q$
1346 IF Q$ = "y" OR Q$= "Y" THEN GOTO 1600
1348 IF Q$ = "N" OR Q$ ="n" THEN GOTO 1254
1350 GOTO 1342
1387 '
1388 '-----------------------------------------------------
1389 '
1390 IF K1=1 THEN LOCATE 23,5 : PRINT,ST$;"SELECTED - IS
     THIS CORRECT?" : K1=0
1391 LOCATE 23,68:INPUT "",QT$
1392 IF QT$ ="N" OR QT$="n" THEN CS =9:GOTO 1254
1394 IF QT$ ="Y" OR QT$="y"THEN GOTO 1500
1396 IF QT$<>"Y" OR QT$<>"y" OR QT$<>"n" OR QT$<>"N" THEN
     GOTO 1291
1398 '
1400 '-------------------------------------------------------
1500 '
1502 '             ASSEMBLY OF WHOLE SCAN
1504 SCAN$=SCAN$+NS$
1506 NS$="":'SCAN$=CS$
1509 FOR T=1 TO 300:NEXT T :GOTO 1255
1510 '-------------------------------------------------------
1600 '             TRANSMIT SCAN STRING TO IF1
1602 '
1610 PRINT#1,":X2000@500:R1:S1:H3:X"+SGAP$+"@5000:$":CLS
1612 PRINT#1,"E": INPUT #1,IB$ : IF IB$="F" THEN 6010
1613 IF IB$="C" THEN 1618       'at start*
1614 PRINT#1,"O": INPUT #1,O : IF O<7 THEN LOCATE 12,20 :
     PRINT"   Moving To Start Position.          " : GOTO
     1612
1618 CLS
1620 LOCATE 5,30 : PRINT"Pin At Start Position."
1622 LOCATE    8,15   :   PRINT"Switch   SONY   display   to
     incremental and RESET."
1624 LOCATE 10,15 : PRINT"Before starting test ensure that
     the data logger is recording."
1626 LOCATE 12,15 : PRINT"Do this by selecting option 'E'
     from the options menu."
```

```
1628 LOCATE 14,15 : PRINT"Enter filename 'QED' and set scan
     period = 100ms."
1630 LOCATE 16,15 : PRINT"Press F2 to initialise.
1631 '---------------------------------------------------
1632 LOCATE 18,15 : PRINT"To record data continuously press
     Alt-F2."
1634 LOCATE 20,15 : PRINT"Once data logger is recording
     press Space Bar to start scan."
1635 PD$=""
1636 PD$=INKEY$ : IF PD$<>" "THEN 1636
1637 O=0 : PRINT#1,"#" : PRINT#1,SCAN$+":$"
1640 CLS : GOSUB 4100
1641 '---------------------------------------------------
1642 '         FIND INPUT STATUS
1643 PRINT#1,"I":  INPUT  #1,IS:LOCATE  21,58:PRINT"INPUT
     STATUS -"IS
1644 '
1645 '         FIND INTERFACE STATUS
1647 PRINT#1,"E": INPUT #1,IB$:LOCATE 21,5:PRINT"INTERFACE
     STATUS -"IB$
1650 '
1652 '         FIND MOTION STATUS
1654 PRINT#1,"K":  INPUT  #1,MS:LOCATE  21,32:PRINT"MOTION
     STATUS -"MS
1655 '
1656 '         FIND STAGE IN SEQUENCE
1657 PRINT#1,"O": INPUT #1,O
1658 '
1659 '
1675 GOTO 4208
1679 IF MS AND 3 THEN LOCATE 2,2:PRINT SPACE$(70):LOCATE
     2,31:PRINT"DRIVE UNIT IN MOTION"
1680 IF IB$="F" THEN 6010 : FLTNUM=1 : '           FAULT
1682 IF IB$="C" THEN 1800  '                CLEAR
1684 IF IB$="E" THEN 1641 '                            BUSY
1689 GOTO 1641
1800 '---------------------------------------------------
1802 '
1810 COLOR 0,1 : LOCATE 2,15 :PRINT"     TEST COMPLETED -
     Press Space Bar to contine.           " : COLOR 2,0
1812 PD$=INKEY$ : IF PD$<>" " THEN 1800
1815 CLS
1820 LOCATE 12,25 : PRINT"Stop Data logger recording."
1830 LOCATE 14,25 : INPUT"Enter name of file data has been
     saved in - ",TSDF$
1835 CLS : PD$=INKEY$
1840 LOCATE 10,25 : PRINT"Data has been saved in file -
     ";TSDF$
1845 LOCATE 12,25 : PRINT"Is this correct (Y/N)   ? "
1849 PD$=INKEY$
1850 IF PD$="n" OR PD$="N" THEN CLS  : GOTO 1830
1855 IF PD$="y" OR PD$="Y" THEN 1900
1860 GOTO 1845
1900 CLS : LOCATE 12,10 : PRINT"Once fuel pin has been
```

```
     unloaded insert a DS/DD disc into drive A."
1910 LOCATE 17,25 : PRINT"Press Space to continue."
1915 LOCATE 14,12 : PRINT"Test data will be saved in file -
     ";TSDF$
1920 PD$="" : PD$=INKEY$ : IF PD$ <>" " THEN 1910
1930 OPEN "O",#2,"a:"+TSDF$
1932 TTIME$=TIME$ : TDATE$=DATE$
1935 WRITE#2,TTIME$,TDATE$,CSDF$,SENS1$,SENS2$,SENS3$,
     PSSV$,PSSH$,PTFQ$,PSENS$,PPAS$,PSBR$,PSBX$,CSSH$,
     CSSV$,CTFQ$,CSENS$,CPAS$,CSBR$,CSBX$,JRC$,TEST$,FRN$,
     MAN$,BOP$,FRD$
1940 CLOSE #2
1990 CLS
1999 END
2110 IF CS>4 OR CS<1 THEN GOTO 2130 ELSE LD$=DIR$
2111 LOCATE 21,57 :PRINT SPACE$(20):LOCATE 21,24 : INPUT
     "WHICH DIRECTION UP OR DOWN ?       ",DIR$
2112 IF DIR$="U"OR DIR$="u" THEN DIR$="+" :DM=1:GOTO 2120
2113 IF DIR$="d"OR DIR$="D" THEN DIR$="-" : NS$="-"+NS$ :
     GOTO 2120
2114 BEEP : DIR$=LD$ : LOCATE 21,57 : PRINT SPACE$(9) :
     GOTO 2110
2120 IF DIR$="-"AND DM=0 THEN LOCATE 23,19 : BEEP :
     PRINT"!!!!        MUST MOVE UP FROM DATUM       !!!!!"
     : LOCATE 21,57 : PRINT SPACE$(9) : GOTO 2111
2125 LOCATE 23,5 : PRINT SPACE$(72) : IF LD$<>DIR$ THEN
     2130 ELSE LOCATE 23,9:BEEP: PRINT"!!!!        ERROR
     DIRECTION IS THE SAME AS PREVIOUS MOVEMENT   !!!!" :
     LOCATE 21,57 : PRINT SPACE$(9) :
     GOTO 2111
2130 RETURN
3100 '
3999 END
4100 '-----------------------------------------------------
4101 '
4102 '        ROUTINE TO DRAW BOXES FOR MAIN DISPLAY
4104 '
4105 CLS
4110 LOCATE 22,80:PRINT CHR$(188)
4111 LOCATE 20,80:PRINT CHR$(185)
4112 LOCATE 20,1:PRINT CHR$(204)
4113 LOCATE 22,1:PRINT CHR$(200)
4114 LOCATE 21,1:PRINT CHR$(186)
4115 LOCATE 21,80:PRINT CHR$(186)
4116 LOCATE 22,2 : PRINT STRING$(78,205)
4117 LOCATE 20,2 : PRINT STRING$(39,205)
4118 LOCATE 20,42: PRINT STRING$(38,205)
4119 LOCATE 20,41: PRINT CHR$(202)
4124 '
4125 '                 TOP BOXES
4126 '
4130 LOCATE 1,80:PRINT CHR$(187)
4131 LOCATE 1,41:PRINT CHR$(203)
4132 LOCATE 1,2:PRINT STRING$(78,205)
```

```
4133 LOCATE 1,1:PRINT CHR$(201)
4134 LOCATE 3,42:PRINT STRING$(38,205)
4135 LOCATE 3,2:PRINT STRING$(39,205)
4142 FOR T=4 TO 19:LOCATE T,41:PRINT CHR$(186)
4143 LOCATE T,80:PRINT CHR$(186)
4144 LOCATE T,1 :PRINT CHR$(186):NEXT T
4146 '
4148 '-------------------------------------------------------
4149 '
4150 LOCATE 2,1 :PRINT CHR$(186)
4151 LOCATE 2,80 :PRINT CHR$(186)
4153 LOCATE 3,80 :PRINT CHR$(185)
4154 LOCATE 3,1 :PRINT CHR$(204)
4155 LOCATE 3,41 :PRINT CHR$(203)
4161 LOCATE 20,28:PRINT CHR$(203)
4162 LOCATE 21,28:PRINT CHR$(186)
4163 LOCATE 22,28:PRINT CHR$(202)
4164 LOCATE 21,54:PRINT CHR$(186)
4165 LOCATE 20,54:PRINT CHR$(203)
4166 LOCATE 22,54:PRINT CHR$(202)
4169 '
4170 '-------------------------------------------------------
4171 '
4172 IF Q7=0 THEN Q7=1 : GOTO 1255
4173 LOCATE 5,14:PRINT"STAGES OF SCAN"
4174 LOCATE 5,48:PRINT"DRIVE UNIT FAULT CONDITIONS"
4175 LOCATE 7,59:PRINT"NONE"
4199 GOTO 1641
4208 IP$="IN PROGRESS":CP$="COMPLETED  "
4620 LOCATE  7,5:PRINT;CS$(0)
4623 IF O= 1 THEN VSM$=IP$ ELSE IF O>1 THEN VSM$=CP$
4628 LOCATE  7,25 : PRINT" - " ;VSM$:VSM$=""
4630 LOCATE  8,5:PRINT;CS$(1)
4633 IF O= 2 THEN VSM$=IP$ ELSE IF O>2 THEN VSM$=CP$ ELSE
     IF O<2 THEN 4640
4638 LOCATE  8,25:PRINT" - ";VSM$:VSM$=""
4640 LOCATE  9,5:PRINT;CS$(2)
4643 IF O= 3 THEN VSM$=IP$ ELSE IF O>3 THEN VSM$=CP$ ELSE
     IF O<3 THEN 4650
4648 LOCATE  9,25:PRINT" - ";VSM$:VSM$=""
4650 LOCATE 10,5:PRINT;CS$(3)
4653 IF O= 4 THEN VSM$=IP$ ELSE IF O>4 THEN VSM$=CP$ ELSE
     IF O<4 THEN 4660
4658 LOCATE 10,25:PRINT" - ";VSM$:VSM$=""
4660 LOCATE 11,5:PRINT;CS$(4)
4663 IF O= 5 THEN VSM$=IP$ ELSE IF O>5 THEN VSM$=CP$ ELSE
     IF O<5 THEN 4670
4668 LOCATE 11,25:PRINT" - ";VSM$:VSM$=""
4670 LOCATE 12,5:PRINT;CS$(5)
4673 IF O= 6 THEN VSM$=IP$ ELSE IF O>6 THEN VSM$=CP$ ELSE
     IF O<6 THEN 4680
4678 LOCATE 12,25:PRINT" - ";VSM$:VSM$=""
4680 LOCATE 13,5:PRINT;CS$(6)
4683 IF O= 7 THEN VSM$=IP$ ELSE IF O>7 THEN VSM$=CP$ ELSE
```

```
     IF O<7 THEN 4690
4688 LOCATE 13,25:PRINT" - ";VSM$:VSM$=""
4690 LOCATE 14,5:PRINT;CS$(7)
4693 IF O= 8 THEN VSM$=IP$ ELSE IF O>8 THEN VSM$=CP$ ELSE
     IF O<8 THEN 1679
4698 LOCATE 14,25:PRINT" - ";VSM$:VSM$=""
4699 GOTO  1679
6000 '-------------------------------------------------------
6010 '*************** fault.bas  12/3/90 ***************
6020 ' The purpose of this program is to determine which
6030 'fault has occurred and then advise how to correct it.
6040 '
6050 CLS
6060  '----------------------------------------------------
6070  '
6080  '                       FAULT FINDING ROUTINE
6085 PRINT#1,"#"
6090 LOCATE 2,15 :PRINT"The interface has detected a fault
     in the DRIVE UNIT"
6100 LOCATE 3,19 : PRINT"and switched the drive unit to
     MANUAL control."
6110 LOCATE 4,12 :PRINT"The test can only be restarted when
     the fault has been corrected."
6120 LOCATE 6,3 : PRINT"The following faults have occured "
6130 OLDN=N : N=5 :LN=4 : PRINT#1,"I" : INPUT #1,IS
6140 IF IS =128 THEN FLT$(N)="        NONE              ":N=
     N+1
6150 IF IS AND 1 THEN FLT$(N)="EMERGENCY STOP          ": N=
     N+1 : ES=1
6160 IF IS AND 2 THEN FLT$(N)="X FAULT" : N= N+1
6170 IF IS AND 4 THEN FLT$(N)="Y FAULT" : N= N+1
6180 IF IS AND 8 THEN FLT$(N)="START SWITCH DEPRESSED" :
     N= N+1 : SS=1
6190 IF IS AND 16 THEN FLT$(N)="LOWER LIMIT REACHED    " :
     N= N+1 : LL=1
6200 IF IS AND 32 THEN FLT$(N)="UPPER LIMIT REACHED    " :
     N= N+1 : UL=1
6210 IF IS AND 64 THEN FLT$(N)="ENCODER FAULT          " :
     N= N+1
6220 FOR N=1 TO N-1
6230 LOCATE LN, 7 : PRINT FLT$(N) :LN=LN+1 : NEXT N
6240 LOCATE 6,43 : PRINT"These faults are still active - "
6250 OLDN=N : N=5 :LN=4 : PRINT#1,"I" : INPUT #1,IS:LOCATE
     21,58:PRINT"INPUT STATUS -"IS
6255 PRINT#1,"K" : INPUT #1,KS:LOCATE 21,38:PRINT"MOTION
     STATUS -"KS
6260 IF IS = 128 THEN FLT$(N)="        NONE             ":
     N=N+1
6270 IF IS AND 64 THEN FLT$(N)="ENCODER FAULT          " :
     N= N+1 : MES$="Visually check drive unit then press
     AUTOSTOP.  "
6280 IF IS AND 2 THEN FLT$(N)="X FAULT" : N= N+1
6290 IF IS AND 4 THEN FLT$(N)="Y FAULT" : N= N+1
6300 IF IS AND 8 THEN FLT$(N)="START SWITCH DEPRESSED" :
```

```
     N= N+1  : MES$="Check START switch on drive unit and
     remote box.  "
6310 IF IS AND 16 THEN FLT$(N)="LOWER LIMIT REACHED    " :
     N= N+1 : MES$="Manually move drive unit UP.  "
6320 IF IS AND 32 THEN FLT$(N)="UPPER LIMIT REACHED    " :
     N= N+1 : MES$="Manually move drive unit DOWN.  "
6330 IF IS AND 1 THEN FLT$(N)="EMERGENCY STOP         ": N=
     N+1
6340 FOR N=1 TO N-1
6350 LOCATE LN, 47 : PRINT FLT$(N) :LN=LN+1 : NEXT N
6360 FOR Q= N TO OLDN
6370 LOCATE LN, 47 : PRINT SPACE$(24) :LN=LN+1 : NEXT Q
6380 LOCATE 18,5 : PRINT"CORRECTIVE ACTION - "+MES$
6390 IF IS = 128 THEN 6400 ELSE 6250
6400 BEEP : LOCATE 18,5 : PRINT SPACE$(72)
6410 LOCATE 18,20 : PRINT"   Push SPACE BAR to start a new
     scan."
6420 PD$=INKEY$ : IF PD$<>" " THEN 6410
6425 PRINT#1,"K" : INPUT#1,K : IF K=128 THEN PRINT#1,"F" :
     PRINT#1,"K"
6430 IF FLTNUM=1 THEN 1250      'point probe calib position
6440 IF FLTNUM=2 THEN 3250
     'encircling coil calib position
6450 IF FLTNUM=3 THEN 600                    'calib scan
25500 IF ERR=71 THEN BEEP : COLOR 0,1 : LOCATE 20,25 :
      PRINT"Disc drive is not closed." : COLOR 2,0 : RESUME
99999 END
```

CHAPTER 7.3.3 - LISTING OF VERT.BAS

```
2 '**********************   vert.bas  14/3/90    ********
4 '
6 '              This program determines which scan is to
8 '              be used and then performs the chosen scan.
9 '
10 ON ERROR GOTO 25500
100 '
1200 '-----------------------------------------------------
1202 '                SUB-ROUTINE FOR SELECTION OF SCAN
1204 CLS
1206 LOCATE 5,10:PRINT"      SCAN NUMBER      DESCRIPTION"
1208 LOCATE 7,22: PRINT"1"TAB(32)"VERTICAL SCAN"
1210 LOCATE 9,22: PRINT"2"TAB(32)"HELICAL SCAN"
1212 LOCATE 11,22: PRINT"3"TAB(32)"CUSTOM SCAN"
1213 Q6=0:SCAN$="" : SN$="" : STOLD=0
1214 LOCATE 19,9 :PRINT"ENTER SCAN NUMBER REQUIRED (1,2
     or 3) "
1216 SN$=INKEY$ : IF SN$="1" THEN 1230
1218 IF SN$="2" THEN 1240
1220 IF SN$="3" THEN CHAIN "CUST",ALL
1222 GOTO 1216
1228 '
1230 '-----------------------------------------------------
1231 '           CREATION OF VERTICAL SCAN
1232 '
1233 SGAP=INT(VAL(SSP$)*72.225):SGAP=36800! - SGAP : SGAP$
     = STR$(SGAP)
1234 SFLEN=INT(VAL(LOS$)*72.225):SFLEN$=STR$(SFLEN)
1236 SCAN$ = ":X-"+SFLEN$+"@300:X"+SFLEN$+"@3000:Y133@60:X-
     " +           SFLEN$+"@300:X"+SFLEN$+"@3000:Y134@60:X-
     "+SFLEN$+"@300::$": GOTO 1600
1238 '
1240 '-----------------------------------------------------
1242 '            CREATION OF HELICAL SCAN
1244 YLEN=VAL(LOS$)/1.5*400 : YFLEN$=STR$(YFLEN)
1245 SGAP=INT(VAL(SSP$)*72.225):SGAP=36800!-SGAP : SGAP$ =
     STR$(SGAP)
1246 SFLEN=INT(VAL(LOS$)*72.225):SFLEN$=STR$(SFLEN)
1247 SCAN$ = ":X-"+SFLEN$+"/Y"+YFLEN$+"300:$": GOTO 1600
1248 '
1600 '             TRANSMIT SCAN STRING TO IF1
1602 '
1606 '
1608 '-----------------------------------------------------
1609 CLS : PD$=""
1610 LOCATE 12,20 :PRINT"Push Space Bar To Move To Start
     Position." : PD$=INKEY$ : IF PD$<>" " THEN GOTO 1610
     ELSE PRINT#1,":X2000:R1:S1:H3:X"+SGAP$+"@2000:$"
1612 PRINT#1,"E": INPUT #1,IB$ : IF IB$="F" THEN 6010 ELSE
     IF IB$="C" THEN 1620
1614 PRINT#1,"O": INPUT #1,O : IF O<7 THEN LOCATE 12,20 :
     PRINT"     Moving To Start Position.             " :
     GOTO 1612
1618 CLS
```

```
1620 LOCATE 3,30 : PRINT"Pin At Start Position."
1622 LOCATE   6,15   :   PRINT"Switch   SONY   display   to
     INCremental and RESET."
1623 LOCATE   7,22   :   PRINT"(Push   joystick   UP   and   then
     LEFT)."
1624 LOCATE 10,15 : PRINT"Before starting test ensure that
     the data logger is recording."
1626 LOCATE 12,15 : PRINT"Do this by selecting option 'E'
     from the options menu."
1628 LOCATE 14,15 : PRINT"Enter filename 'QED' and set scan
     period = 100ms."
1630 LOCATE 16,15 : PRINT"Press F2 to initialise.
1632 LOCATE 18,15 : PRINT"To record data continuously press
     Alt-F2."
1634 LOCATE  20,15  :  PRINT"Once  data  logger  is  recording
     press Space Bar to start scan."
1635 PD$=""
1636 PD$=INKEY$ : IF PD$<>" "THEN 1636
1637 O=0 : PRINT#1,"#" : PRINT#1,SCAN$
1638 '---------------------------------------------------
1639 IF Q6=0 THEN GOTO 4100   'DRAW BOXES
1640 '
1641 '---------------------------------------------------
1642 '        FIND INPUT STATUS
1643 PRINT#1,"I":  INPUT  #1,IS:LOCATE  21,58:PRINT"INPUT
     STATUS -"IS
1644 '
1645 '        FIND INTERFACE STATUS
1647 PRINT#1,"E": INPUT #1,IB$:LOCATE 21,5:PRINT"INTERFACE
     STATUS - "IB$
1650 '
1652 '        FIND MOTION STATUS
1654 PRINT#1,"K":  INPUT  #1,MS:LOCATE  21,32:PRINT"MOTION
     STATUS -"MS
1655 '
1656 '        FIND STAGE IN SEQUENCE
1657 PRINT#1,"O": INPUT #1,O
1658 '
1675 'IF O>1 THEN GOSUB 4209  '**********update display
1679 IF MS AND 3 THEN LOCATE 2,2 : PRINT SPACE$(70):LOCATE
     2,31:PRINT"DRIVE UNIT IN MOTION"
1680 IF IB$="F" THEN 6010      '          FAULT
1682 IF IB$="C" THEN GOTO 1800         '  CLEAR
1684 IF IB$="E" THEN GOTO 1700 '       BUSY
1700 '--------------------------------------------------
1705 '                progress display
1708 '
1709 IP$= "IN PROGRESS" : CP$=" COMPLETED "
1710 IF SN$="1" THEN 1730
1712 LOCATE 19,62 : PRINT"% Completed"
1714 PRINT#1,"N" : INPUT #1,N
1716 ST=100*N/SFLEN : ST=INT(ST)
1722 IF ST<STOLD THEN ST=STOLD
1724 LOCATE 19,5 : PRINT STRING$(ST/2,219)
```

```
1726 LOCATE 19,56: PRINT,ST : STOLD=ST
1727 IF O=1 THEN VSM$=IP$ ELSE IF O>1 THEN VSM$=CP$
1728 LOCATE 9,5:PRINT"     HELICAL SCAN  -  ";VSM$ : GOTO
     1641
1730 LOCATE 19,62 : PRINT"% Completed"
1735 PRINT#1,"N" : INPUT #1,N
1740 ST=100*N/(3*SFLEN): ST=INT(ST)
1741 IF O>2 THEN ST=ST+33
1742 IF O>5 THEN ST=ST+34
1744 IF ST<STOLD THEN ST=STOLD
1745 LOCATE 19,5 : PRINT STRING$(ST/2,219)
1750 LOCATE 19,56: PRINT,ST : STOLD=ST
1766 LOCATE 8,5:PRINT" FIRST VERTICAL SCAN -"
1768 IF O=1 THEN VSM$=IP$ ELSE IF O>1 THEN VSM$=CP$
1770 LOCATE 8,28 :PRINT;VSM$:VSM$=""
1772 LOCATE 9,5:PRINT"   TURNING ROD 120"CHR$(248)"  -"
1774 IF O=3 THEN VSM$=IP$ ELSE IF O>3 THEN VSM$=CP$
1776 LOCATE 9,28 :PRINT;VSM$:VSM$=""
1778 LOCATE 10,5:PRINT"SECOND VERTICAL SCAN -"
1780 IF O=4 THEN VSM$=IP$ ELSE IF O>4 THEN VSM$=CP$
1782 LOCATE 10,28 :PRINT;VSM$:VSM$=""
1784 LOCATE 11,5:PRINT"   TURNING ROD 120"CHR$(248)"  -"
1786 IF O=6 THEN VSM$=IP$ ELSE IF O>6 THEN VSM$=CP$
1788 LOCATE 11,28 :PRINT;VSM$:VSM$=""
1790 LOCATE 12,5:PRINT" THIRD VERTICAL SCAN -"
1792 IF O=7 THEN VSM$=IP$ ELSE IF O>7 THEN VSM$=CP$
1794 LOCATE 12,28 :PRINT VSM$:VSM$=""
1796 GOTO 1641
1800 '-----------------------------------------------
1802 '
1810 COLOR 0,1 : LOCATE 2,15 :PRINT"      TEST COMPLETED -
     Press Space Bar to contine.       " : COLOR 2,0
1812 PD$="" : PD$=INKEY$ : IF PD$<>" " THEN 1800
1815 CLS
1820 LOCATE 12,25 : PRINT"Stop Data logger recording."
1830 LOCATE 14,25 : INPUT"Enter name of file data has been
     saved in - ",TSDF$
1835 CLS : PD$=INKEY$
1840 LOCATE 10,25 : PRINT"Data has been saved in file -
     ";TSDF$
1845 LOCATE 12,25 : PRINT"Is this correct (Y/N)   ? "
1849 PD$=INKEY$
1850 IF PD$="n" OR PD$="N" THEN CLS  : GOTO 1830
1855 IF PD$="y" OR PD$="Y" THEN 1900
1860 GOTO 1845
1900 CLS : LOCATE 12,10 : PRINT"Once fuel pin has been
     unloaded insert a DS/DD disc into drive A."
1910 LOCATE 17,25 : PRINT"Press Space to continue."
1915 LOCATE 14,12 : PRINT"Test data will be saved in file -
     ";TSDF$
1920 PD$="" : PD$=INKEY$ : IF PD$ <>" " THEN 1910
1930 OPEN "O",#2,"a:"+TSDF$
1935 WRITE#2,CSDF$,SENS1$,SENS2$,SENS3$,PSSV$,PSSH$,PTFQ$
     ,PSENS$,PPAS$,PSBR$,PSBX$,CSSH$,CSSV$,CTFQ$,CSENS$,
```

```
     CPAS$, CSBR$,CSB X$,JRC$,TEST$,FRN$,MAN$,BOP$,FRD$
1940 CLOSE #2
1990 '
1999 END
3999 END
4003 '
4100 '
4101 '
4102 '        ROUTINE TO DRAW BOXES FOR MAIN DISPLAY
4104 '
4105 CLS
4107 FOR T=4 TO 19:LOCATE T,41:PRINT CHR$(186)
4108 LOCATE T,80:PRINT CHR$(186)
4109 LOCATE T,1 :PRINT CHR$(186):NEXT T
4110 LOCATE 22,80:PRINT CHR$(188)
4111 LOCATE 20,80:PRINT CHR$(185)
4112 LOCATE 20,1:PRINT CHR$(204)
4113 LOCATE 22,1:PRINT CHR$(200)
4114 LOCATE 21,1:PRINT CHR$(186)
4115 LOCATE 21,80: PRINT CHR$(186)
4116 LOCATE 22,2 : PRINT STRING$(78,205)
4117 LOCATE 18,2 : PRINT STRING$(78,205)
4119 LOCATE 18,41: PRINT CHR$(206)
4120 LOCATE 18,1 : PRINT CHR$(204)
4121 LOCATE 18,80: PRINT CHR$(185)
4122 LOCATE 20,2 : PRINT STRING$(78,205)
4123 LOCATE 18,41: PRINT CHR$(202) : LOCATE 19,41 : PRINT
     CHR$(32)
4124 '
4125 '                    TOP BOXES
4126 '
4130 LOCATE 1,80:PRINT CHR$(187)
4131 LOCATE 1,41:PRINT CHR$(203)
4132 LOCATE 1,2:PRINT STRING$(78,205)
4133 LOCATE 1,1:PRINT CHR$(201)
4134 LOCATE 3,42:PRINT STRING$(38,205)
4135 LOCATE 3,2:PRINT STRING$(39,205)
4146 '
4148 '-----------------------------------------------------
4149 '
4150 LOCATE 2,1 :PRINT CHR$(186)
4151 LOCATE 2,80 :PRINT CHR$(186)
4153 LOCATE 3,80 :PRINT CHR$(185)
4154 LOCATE 3,1 :PRINT CHR$(204)
4155 LOCATE 3,41 :PRINT CHR$(203)
4161 LOCATE 20,28:PRINT CHR$(203)
4162 LOCATE 21,28:PRINT CHR$(186)
4163 LOCATE 22,28:PRINT CHR$(202)
4164 LOCATE 21,54:PRINT CHR$(186)
4165 LOCATE 20,54:PRINT CHR$(203)
4166 LOCATE 22,54:PRINT CHR$(202)
4169 '
4170 '------------------------------------------------------
4171 '
```

```
4172 LOCATE 5,14:PRINT"STAGES OF SCAN"
4174 LOCATE 5,53:PRINT"FAULT CONDITIONS"
4175 LOCATE 7,59:PRINT"NONE"
4190 LOCATE 19,5 : PRINT STRING$(50,176)
4199 Q6=1:GOTO 1641
4208 GOSUB 1657
4650 '---------------------------------------------------
6010 '******************** fault.bas 12/3/90 **********
6020 '  The purpose of this program is to determine which
6030 'fault has occurred and then advise how to correct it.
6040 '
6050 CLS
6060  '--------------------------------------------------
6070  '
6080  '                        FAULT FINDING ROUTINE
6090 LOCATE 2,25 :PRINT"The interface has detected a fault"
6100 LOCATE 3,19 : PRINT"and switched the drive unit to
     MANUAL control."
6110 LOCATE 4,12 :PRINT"The test can only be restarted when
     the fault has been corrected."
6120 LOCATE 6,3 : PRINT"The following faults have occured -
     "
6130 OLDN=N : N=5 :LN=4 : PRINT#1,"I" : INPUT #1,IS
6140 IF IS =128 THEN FLT$(N)="       NONE            ":N=
     N+1
6150 IF IS AND 1 THEN FLT$(N)="EMERGENCY STOP         ": N=
     N+1 :ES=1
6160 IF IS AND 2 THEN FLT$(N)="X FAULT" : N= N+1
6170 IF IS AND 4 THEN FLT$(N)="Y FAULT" : N= N+1
6180 IF IS AND 8 THEN FLT$(N)="START SWITCH DEPRESSED" : N=
      N+1 : SS=1
6190 IF IS AND 16 THEN FLT$(N)="LOWER LIMIT REACHED    " :
     N= N+1 : LL=1
6200 IF IS AND 32 THEN FLT$(N)="UPPER LIMIT REACHED    " :
     N= N+1 : UL=1
6210 IF IS AND 64 THEN FLT$(N)="ENCODER FAULT          " :
     N= N+1
6220 FOR N=1 TO N-1
6230 LOCATE LN, 7 : PRINT FLT$(N) :LN=LN+1 : NEXT N
6240 LOCATE 6,43 : PRINT"These faults are still active - "
6250 OLDN=N : N=5 :LN=4 : PRINT#1,"I" : INPUT #1,IS:LOCATE
     21,58:PRINT"INPUT STATUS -"IS
6260 IF IS = 128 THEN FLT$(N)="      NONE             ":
     N=N+1
6270 IF IS AND 64 THEN FLT$(N)="ENCODER FAULT          " :
     N= N+1 : MES$="Visually check drive unit then press
     AUTOSTOP.   "
6280 IF IS AND 2 THEN FLT$(N)="X FAULT" : N= N+1
6290 IF IS AND 4 THEN FLT$(N)="Y FAULT" : N= N+1
6300 IF IS AND 8 THEN FLT$(N)="START SWITCH DEPRESSED" : N=
     N+1 : MES$="Check START switch on drive unit and
     remote box.        "
6310 IF IS AND 16 THEN FLT$(N)="LOWER LIMIT REACHED    " :
     N= N+1 : MES$="Manually move drive unit UP.  "
```

```
6320 IF IS AND 32 THEN FLT$(N)="UPPER LIMIT REACHED    " :
     N= N+1 : MES$="Manually move drive unit DOWN.       "
6330 IF IS AND 1 THEN FLT$(N)="EMERGENCY STOP        ": N=
     N+1
6340 FOR N=1 TO N-1
6350 LOCATE LN, 47 : PRINT FLT$(N) :LN=LN+1 : NEXT N
6360 FOR Q= N TO OLDN
6370 LOCATE LN, 47 : PRINT SPACE$(24) :LN=LN+1 : NEXT Q
6380 LOCATE 18,5 : PRINT"CORRECTIVE ACTION - "+MES$
6390 IF IS = 128 THEN 6400 ELSE 6250
6400 BEEP : LOCATE 18,5 : PRINT SPACE$(72)
6410 LOCATE 18,20 : PRINT"   Push SPACE BAR to start a new
     scan."
6420 PD$=INKEY$ : IF PD$<>" " THEN 6410
6430 PRINT#1,"K"  : INPUT #1,K : IF K=128 THEN PRINT#1,"F"
6450 GOTO 1200
9000 '********************* INIT.BAS ******************
9030 CLS:KEY OFF
9050 ON KEY (5)   GOSUB 9760
9060 ON KEY (7)   GOSUB 9740
9070 KEY (8) ON : ON KEY (8)   GOSUB 9750
9080 KEY (5) ON
9100 GOSUB 9320
9130 COM(1) ON
9140 CLOSE
9150 OPEN"COM1:2400,N,8,2,CS350,DS" AS #1
9160 GOTO 1200
9170 GOSUB 9320
9190 GOTO 1200
9270 LOCATE 2,31:PRINT"PROGRAM TERMINATED":CLOSE : END
9320 CLS:BEEP
9330 LOCATE  9,15:PRINT"INTERFACE MUST BE RE-SET BEFORE A
     TEST CAN BE STARTED"
9340 LOCATE 13,24:PRINT"PRESS F8 TO RESET THE INTERFACE":
     LOCATE 17,24:PRINT"TO STOP TEST AT ANY TIME PRESS
     F10":GOTO 9330
9350 CLS :BEEP
9360 LOCATE 13,25:PRINT"ONCE POWER HAS BEEN SWITCHED BACK
     ON  "
9370 LOCATE 15,28:PRINT"PRESS F7 TO START TEST
     ":GOTO 9360
9410 PRINT#1,"]"
9420 CLS: LOCATE 14,25:PRINT"RE-SETTING INTERFACE - PLEASE
     WAIT"
9430 FOR T= 1 TO 1000: NEXT T
9440 PRINT#1,"*"
9450 CLS : LOCATE 12,29:PRINT"INTERFACE HAS BEEN RE-SET"
9460 LOCATE 14,14:PRINT"SWITCH THE INTERFACE POWER OFF AND
     THEN BACK ON AGAIN."
9470 FOR T= 1 TO 1000 : NEXT T: GOTO 9350
9530 CLS:BEEP:LOCATE 11,25:PRINT"INITIALISING INTERFACE -
     PLEASE WAIT"
9540 COM(1) ON
9550 CLOSE
```

```
9560 OPEN"COM1:2400,N,8,2,CS350,DS" AS #1
9570 RETURN
9590 PRINT #1,"(";
9600 INPUT #1,A$
9610 IF A$="U" THEN 9680
9620 LOCATE 15,20:PRINT "COMMUNICATION FAULT" :GOTO 6000
9630 RETURN
9680 PRINT#1,"U61"
9690 CLS:BEEP:LOCATE 13,31:PRINT"INITIALISATION OK"
9700 FOR T=1 TO 1000 : NEXT T
9710 '
9720 RETURN
9740 GOSUB 9530: KEY (5) ON : GOSUB 9590 : GOTO 9190
9750 GOSUB 9530: KEY (7) ON : GOTO 9410
9760 GOSUB 3040 : GOTO 9230
25500 IF ERR=71 THEN BEEP : COLOR 0,1 : LOCATE 20,25 :
      PRINT"Disc drive is not closed." : COLOR 2,0 : RESUME
```

Appendix 7.4 - Eddy Current Scan Control Software Manual

2/4/90

Instruction Manual For Eddy Current Scan Control Software

CONTENTS

1.0 Re-setting And Initialisation Of Interface

From the main start up menu on the PC select the option to run the Eddy Current Test. On starting the program the following message will be displayed -

```
The Interface must be re-set before a test can be started.

        Press F8 to re-set the interface.
```

Screen 1.1

Only valid input is F8 which re-sets the interface and changes the display to -

```
Initialising Interface - Please wait.
```

Screen 1.2

followed by -

```
          Interface has been re-set.

Switch the interface power OFF and then back ON again.
```

Screen 1.3

At this stage the interface power supply should be switched off and then back on again. After a short delay the screen shows the instruction -

```
Once power has been switched back ON

     Press F7 to continue.
```

Screen 1.4

Only valid input is F7.
Under NO circumstances should F7 be pressed before the power supply has been switched back on. If this happens communication between the PC and the interface will be broken and the program will have to be re-started from screen 1.1.

When F7 has been pressed the program will then ask whether a calibration scan or a rod examination is to be performed.

Do you want to conduct either - 1. Calibration Scan 2. Examination Scan Select either 1 or 2.

Screen 1.5

By selecting "1" the routine for the calibration scan will begin (section 2.1). Selecting option "2" will initiate the routine for a fuel rod examination (section 2.2).

2.0 Set up Conditions for Calibration Scan

The first stage of the calibration scan is the prompt to check that the calibration pin is loaded -

Is the Calibration Pin loaded (Y/N) ?

Screen 2.0.1

If the pin is loaded , enter "Y" and the screen will change to screen 2.0.3.

If the pin is not yet loaded select "N". This will cause the following message to be displayed -

Once calibration pin has been loaded press SPACE BAR

Screen 2.0.2

Pressing SPACE will cause the previous message to be displayed and "Y" should then be entered.

The operator is then required to input which sensors are to be used during the calibration scan.

Which sensors are to be used during the calibration ? 1. E/C POINT PROBE (Y or N) 2. ENCIRCLING COIL (Y or N) 3. LVDT (Y or N)

Screen 2.0.3

Only the sensors which are to be calibrated should be selected, this is done by entering "Y" next to each sensor. If a sensor is not to be used "N" should be selected. Before carrying on, the option to change one or more selections is offered-

```
Is the information correct  (Y or N)  ?
```

Screen 2.0.4

If "Y" is entered the calibration procedure will start from section 2.1. If "N" is entered the following prompt will be displayed -

```
Which number do you wish to change (1,2,3) ?
```

Screen 2.0.5

Select either 1,2 or 3 and change the input to the correct value. The previous 'Is information correct ' prompt will then be displayed. This procedure will continue until all the inputs are correct and "Y" is selected from screen 2.0.4.

The operator is then required to input which sensors are to be used during the calibration scan.

```
Which sensors are to be used during the calibration ?

1. E/C POINT PROBE  (Y or N)

2. ENCIRCLING COIL  (Y or N)

3. LVDT  (Y or N)
```

Screen 2.0.3

Only the sensors which are to be calibrated should be selected, this is done by entering "Y" next to each sensor. If a sensor is not to be used "N" should be selected. Before carrying on, the option to change one or more selections is offered-

```
Is the information correct  (Y or N)  ?
```

Screen 2.0.4

If "Y" is entered the calibration procedure will start from section 2.1. If "N" is enered the following prompt will be displayed -

```
Which number do you wish to change (1,2,3) ?
```

Screen 2.0.5

Select either 1,2 or 3 and change the input to the correct value. The previous 'Is information correct ' prompt will then be displayed. This procedure will continue until all the inputs are correct and "Y" is selected from screen 2.0.4.

2.1 Calibration of Eddy Current Point Probe

This calibration is only carried out if the eddy current point probe was selected to be included in the calibration scan from screen 2.0.3. If it was not selected the program proceeds to the next sensor calibration. Assuming that it has been selected the screen displays the instruction -

```
Push AUTOSTART to move to calibration position for POINT PROBE.
```

Screen 2.1.1

The AUTOSTART button on either the drive unit or the remote box should be depressed. WARNING - ensure that the button remains in the OUT position. When the button is depressed the drive unit will begin to move to the calibration position and the screen will display -

```
Moving to calibration position for POINT PROBE.
```

Screen 2.1.2

When the pin has arrived at the calibration position the following instructions will be displayed -

```
Pin at Calibration position.

Unless otherwise instructed set the EM3300 for the POINT PROBE to

Test Frequency = 210 KHz.

Signal Strength (vertical) = 1 Volts/div

Signal Strength (horizontal) = 1 Volts/div
```

- 5 -

Sensitivity Setting = 2.0

Press Space Bar to continue.

Screen 2.1.3

Once the instrument has been set to these (or other instructed) settings and the Space Bar has been pressed the instructions for the calibration procedure are displayed -

CALIBRATION PROCEDURE FOR EM330
Before conducting a test it is necessary to balance the EM3300.

This can be done in one of two ways -"

1. Press the RED 'autobalance' button.
   When button is depressed the 'R' and 'X' knobs will rotate.
   Keep button depressed until the knobs stop rotating.
   Rotate 'PHASE' knob to give a circle on the screen.
   Manually adjust R & X until spot appears circle centre.
   When spot is in centre rotating PHASE has little effect.

2. In some cases 'autobalance' button may be ineffective.
   If this happens the instrument must be balanced manually
   Rotate PHASE knob to give circle on the screen.
   Adjust R & X to move the spot towards centre of circle.
   Repeat last two steps until spot lies in centre.
   When spot is in centre rotating PHASE has little effect.

Press Space Bar To Continue

Screen 2.1.4

This is followed by -

The pin is now at the calibration position. The calibration procedure for the eddy current POINT PROBE is as follows -"

Firstly the probe examines step change in diameter on the rod.

The objective to obtain a horizontal display on the EM3300

1. The rod is moved by pressing AUTOSTART on the drive unit.

2. After each movement rotate the display by the PHASE knob

3. Repeat 1 & 2 until the display is horizontal.

4. When display is OK press space bar to continue.

Screen 2.1.5

- 6 -

Follow the instructions until the display is satisfactory then press space. This will cause the last line to change to -

```
Are you sure that the display is correct ?  (Y or N)
```

Screen 2.1.6

If the display is satisfactory select "Y" to proceed to the next stage, screen 2.1.7.

If the display is not satisfactory select "N" to continue with the calibration from screen 2.1.5.

Once the instrument has been calibrated correctly it is necessary to input the settings. This is done with the following prompts-

```
PLEASE ENTER THE FOLLOWING INSTRUMENT SETTINGS
   EM3300 - EDDY CURRENT UNIT (POINT PROBE)

1. Signal Strength (vert) -  1 V/div

2. Signal Strength (horz) -  1 V/div

3. Test Frequency  - 210 KHz

4. Sensitivity - 2.0

5. Phase Angle Setting -

6. Signal Balance Setting - R -

7. Signal Balance Setting - X -

  Has data been entered correctly  ?  (Y or N)
```

Screen 2.1.7

By selecting "Y" the calibration procedure for the point probe is complete and the calibration procedure for the next sensor is initiated.

If "N" is entered the following is displayed -

```
Which number do you wish to change (1...7) ?
```

Screen 2.1.8

The number of the incorrect input should then be entered. The cursor will then move to the appropriate input and erase the old entry. After a new entry has been made the display reverts to screen 2.1.7. This process is repeated until all the entries are correct and "Y" has been entered to complete the calibration routine for the eddy current point probe.

2.2 Calibration Of Eddy Current Encircling Coil

This calibration is only carried out if the eddy current encircling coil was selected to be included in the calibration scan from screen 1.5.

If it was not selected the program proceeds to the next sensor calibration. Assuming that it has been selected the screen displays the instruction -

```
Push AUTOSTART to move to calibration position for ENCIRCLING COIL
```

Screen 2.2.1

The AUTOSTART button on either the drive unit or the remote box should be depressed. WARNING - ensure that the button remains in the OUT position. When the button is depressed the drive unit will begin to move to the calibration position and the screen will display -

```
Moving to calibration position for ENCIRCLING COIL.
```

Screen 2.2.2

When the pin has arrived at the calibration position the following instructions will be displayed -

```
Pin at Calibration position.

Unless otherwise instructed set the EM3300 for the COIL.

Test Frequency = 200 KHz.

Signal Strength (vertical) = 2 Volts/div

Signal Strength (horizontal) = 2 Volts/div

Sensitivity Setting = 2.0

Press Space Bar to continue.
```

Screen 2.2.3

Once the instrument has been set to these (or other instructed) settings and the Space Bar has been pressed the instructions for the calibration procedure are displayed -

```
               CALIBRATION PROCEDURE FOR EM3300
Before conducting a test it is necessary to balance the EM3300.

   This can be done in one of two ways -"

   1. Press the RED 'autobalance' button.
      When button is depressed the 'R' and 'X' knobs will rotate.
      Keep button depressed until the knobs stop rotating.
      Rotate 'PHASE' knob to give a circle on the screen.
      Manually adjust R & X until spot appears circle centre.
      When spot is in centre rotating PHASE has little effect.

   2. In some cases 'autobalance' button may be ineffective.
      If this happens the instrument must be balanced manually
      Rotate PHASE knob to give circle on the screen.
      Adjust R & X to move the spot towards centre of circle.
      Repeat last two steps until spot lies in centre.
      When spot is in centre rotating PHASE has little effect.

                  Press Space Bar To Continue
```

Screen 2.2.4

This is followed by -

```
    The pin is now at the calibration position. The calibration
procedure for the eddy current ENCIRCLING COIL is as follows -


  The coil has to examine a 1.5mm through wall defect.
  This will give a 'figure 8' on the EM3300.
  The figure must be rotated to 45 degrees to the axes.
  The spot must move to the 2nd and then to the 4th quadrant.
 (i.e. move from centre to top left to bottom right to centre.)

 1. The rod is moved by pressing AUTOSTART on the drive unit.

 2. After each movement rotate the display by the PHASE knob

 3. Repeat 1 & 2 until the display is horizontal.

 4. When display is OK press space bar to continue.
```

Screen 2.2.5

Follow the instructions until the display is satisfactory then press space. This will cause the last line to change to -

```
Are you sure that the display is correct ?  (Y or N)
```

Screen 2.2.6

If the display is satisfactory select "Y" to proceed to the next stage, screen 2.2.7.

If the display is not satisfactory select "N" to continue with the calibration from screen 2.2.5.

Once the instrument has been calibrated correctly it is necessary to input the settings. This is done with the following prompts-

```
PLEASE ENTER THE FOLLOWING INSTRUMENT SETTINGS

  EM3300 - EDDY CURRENT UNIT (ENCIRCLING COIL)

1. Signal Strength (vert) -  2 V/div

2. Signal Strength (horz) -  2 V/div

3. Test Frequency  - 200 KHz

4. Sensitivity - 2.0

5. Phase Angle Setting -

6. Signal Balance Setting - R -

7. Signal Balance Setting - X -

  Has data been entered correctly  ?  (Y or N)
```

Screen 2.2.7

By selecting "Y" the calibration procedure for the point probe is complete and the calibration procedure for the next sensor is initiated.

If "N" is entered the following is displayed -

```
Which number do you wish to change (1...7) ?
```

Screen 2.2.8

The number of the incorrect input should then be entered. The cursor will then move to the appropriate input and erase the old entry. After a new entry has been made the display reverts to screen 2.2.7. This process is repeated until all the entries are correct and "Y" entered to complete the calibration.

2.3 Calibration Procedure For LVDT

This calibration is only carried out if the LVDT was selected to be included in the calibration scan from screen 1.5.

If it was not selected the program proceeds to the next sensor calibration. Assuming that it has been selected the screen displays the instruction -

```
Push AUTOSTART to move to calibration position for LVDT
```

Screen 2.3.1

The AUTOSTART button on either the drive unit or the remote box should be depressed. WARNING - ensure that the button remains in the OUT position. When the button is depressed the drive unit will begin to move to the calibration position and the screen will display -

```
Moving to calibration position for LVDT
```

Screen 2.3.2

When the pin has arrived at the calibration position the following instructions will be displayed -

```
Pin at Calibration position.

Set the Chart Recorder for the LVDT to the following -

chart speed = 120 mm/min

channel 1 span = 0.1 V/mm

channel 2 span = 0.1 V/mm

Press Space Bar to continue.
```

Screen 2.3.3

Once the chart recorder has been set to these settings and the Space Bar has been pressed the instructions for the calibration procedure are displayed -

CALIBRATION PROCEDURE FOR LVDT

1. check that the amplifier is switched to 'rel'
2. depress reset button
3. display should then change to '0.00'
4. zero channel 1 on the chart recorder in the centre of the paper.

Press Space Bar To Continue

Screen 2.3.4

This is followed by -

Are you sure that the settings are correct ? (Y or N)

Screen 2.3.5

If the settings are satisfactory select "Y" to proceed to the next stage, screen 2.4.1.

If the settings are not satisfactory select "N" to continue with the calibration from screen 2.3.4.

2.4 End of Instrument Calibration

If all the sensors have been calibrated correctly "Y" should be entered at the following prompt. This will start the calibration scan and display screen 2.4.1.

Have instruments been calibrated correctly ? (Y or N)

Screen 2.4.1

If "N" is entered a choice is given of which sensor is to be re-calibrated (see below). NOTE - it is only possible to re-calibrate a sensor which has been chosen to be included in the calibration scan from screen 1.5. If a sensor is chosen which was not originally selected from screen 1.5 the program will return to screen 2.4.1

Which instrument do you wish to re-calibrate ?

0. None - continue with test

1. Eddy Current Point Probe

2. Eddy Current Encircling Coil

3. LVDT

Please select either 0,1,2 or 3.

Screen 2.4.2

Selecting "0" has same effect as if "Y" had been entered at the previous prompt and will continue the test sequence without any re-calibrations. See screen 2.4.1.

Selecting "1" will re-run the procedure for calibrating the point probe only from screen 2.1.1. before returning to screen 2.4.2

Selecting "2" will re-run the procedure for calibrating the encircling coil only from screen 2.2.1. before returning to screen 2.4.2

Selecting "3" will re-run the procedure for calibrating the LVDT only from 2.3.1 before returning to screen 2.4.2.

2.5 Start of Calibration Scan

After all the instruments have been satisfactorily calibrated the following prompt is displayed.

Press space bar to move to start of scan.

Screen 2.5.1

Pressing space bar will cause the drive unit to move to the start of the scan and will display on the screen of the PC -

Moving to Start position for calibration scan.

Screen 2.5.2

When the start position has been reached the following instructions are displayed-

Pin At Start Position.

Switch SONY display to incremental and RESET.
(Push joystick UP and then LEFT).

Press SPACE bar to continue.

Screen 2.5.3

Press space to get -

```
Before starting calibration scan ensure data logger is recording

  Switch PC on, select option to start NEFF data logger

  From the main menu select 'E-Acquire Live Data Record & Process'

  Enter file name 'PWR' and set scan period to 100ms.

  Press F2 (on the SIEMENS) to initialise.

  To record continuously press Alt-F2 (on the SIEMENS)


  Once data logger is recording press space bar to start scan.
```

Screen 2.5.4

Pressing space bar will start the scan. When the scan is in progress the on-screen display gives an approximate indication of the rate of progress of the scan -

```
              Calibration Scan in Progress.


    XXXXXXXXXOOOOOOOOOOOOOOOOOOOOO   31 % Completed
```

Screen 2.5.5

When the scan has been completed successfully the screen display will automatically change to -

```
                    Calibration Scan Completed

                    Stop data logger recording

  !!! WARNING !!! - WHEN F2 IS PRESSED PC WILL SAVE DATA IN A FILE
      FILE NAME WILL BE OF THE FORM TESTxx.DAT (WHERE xx IS A NUMBER)
    THE FILE NAME WILL BE BRIEFLY DISPLAYED ON THE MIDDLE LEFT OF THE
            SCREEN - NOTE THE FILE NUMBER AND ENTER IT BELOW.

          Enter name of file data has been saved in - XXXX
```

Screen 2.5.6

It is now necessary to stop the data logger recording and to enter the file name that the NEFF saves the test data in. Once this has been entered the program will display the file name and ask for confirmation.

```
Data from calibration scan has been saved in file - TESTxx.DAT

                Is this correct (Y or N)  ?
```

Screen 2.5.7

If the file name is correct enter "Y" and the display will change to 2.5.9.
If the file name is incorrect enter "N". The correct file name can then be entered after the following prompt.

```
Enter name of file data has been saved in -TEST   .DAT
```

Screen 2.5.8

The correct file name should then be entered this will return to the previous prompt for confirmation.
When the file name is correct enter "Y". This will end the calibration scan and display the following screen -

```
The calibration scan has now been completed.

The next stage is to unload the calibration pin


Once calibration pin has been unloaded press SPACE bar.
```

Screen 2.5.10

Once the calibration pin has been unloaded the operator should press the space bar and he will then be given the following choices.

```
You now have the following options -

1. To go back and perform an examination.

2. To carry out another calibration.

3. End session.

Please enter 1,2 or 3.
```

Screen 2.5.9

Selecting "1" will carry out a fuel rod examination (i.e proceed to section 3.0).
Selecting "2" will carry out another calibration run (i.e. return to section 2.0).
Selecting "3" will exit the program and return to the start up menu.

If 'calibration & examination' had been selected from screen 2.0.1 the following screen will be displayed -

By selecting 'E' the system will return to the start up menu.
Alternatively, pressing space will start the examination scan routine.

3.0 Fuel Rod Examination

Before starting an examination sequence, it is necessary to input the following information -

```
BEFORE STARTING TEST PLEASE ENTER THE FOLLOWING INFORMATION

1. JRC Project Number -

2. Test Number -

3. Fuel Rod Number -

4. Operator -

5. Bwr or Pwr (B or P) -

6. Fuel Assembly Drawing Number -      .DAT

          Drawings available are -

D33845.DAT      D38467.DAT      D33886.DAT      D33950.DAT
D53881.DAT      D36378.DAT      D35343.DAT      D40868.DAT
```

Screen 3.0.1

The information should be entered as instructed. When the Fuel Assembly Drawing Number has been selected, this will determine the start and end points of the examination, and these will be displayed on the screen overwriting the available files.

```
7. Scan Start Position - 55

8. Length of Scan - 390

     Has data been entered correctly  ? (Y/N)
```

Screen 3.0.2

At this point it is possible to alter any of the above inputs. The start and end points of the scan should only be altered when a full length examination of a rod is not required. If "Y" is selected screen 3.0.4 will be displayed. Alternatively, if "N" is entered to the prompt, it will be overwritten by -

```
Which number do you wish to change (1...7) ?
```

Screen 3.0.3

Valid inputs are 1....7. The number selected will enable the corresponding input to be altered after which the previous prompt will be displayed -

```
Has data been entered correctly  ? (Y/N)
```

Screen 3.0.2

When all the data has been entered correctly enter "Y".

The next stage is to determine the order in which the sensors are located in the cassette box -

```
1. E/C POINT PROBE
2. ENCIRCLING COIL
3. LVDT

Is this arrangement of sensors correct (Y or N) ?
```

Screen 3.0.4

Unless otherwise instructed (in the bijlage) "Y" should be entered and screen 3.0.7 will be shown.
If the sensor arrangement has been changed, select "N". This will be followed by a prompt to determine which sensor is to be changed -

```
Which number do you wish to change (1,2 or 3) ?
```

Screen 3.0.5

After selecting the number to be changed, the possible replacements will be shown -

```
        SENSORS AVAILABLE

        1. E/C POINT PROBE

        2. ENCIRCLING COIL

        3. LVDT

        4. NONE

Which new sensor do you want to add (1,2,3 or 4)
```

Screen 3.0.6

The replacement sensor should then be chosen by entering 1,2,3 or 4. This will return to the previous screen, screen 3.0.4. Once the sensor arrangement is satisfactory "Y" should be entered. This will then display a reminder to have a floppy disc formatted to 360K for the Corona PC, a 1.2M floppy for the Siemens and to switch the NEFF data logger and computer on.

```
Before starting test ensure that you have -

1. a DS/DD floppy disc formatted to 360K

2. a DS/HD floppy disc formatted to 1.2M

3. switched the NEFF data logger and computer on

Press SPACE to continue.
```

Screen 3.0.7

After pressing SPACE the following reminder is displayed -

```
Is The Fuel Pin Loaded (Y/N) ?
```

Screen 3.0.8

Entering "Y" will proceed to screen
Entering "N" will change the display to -

```
Once the pin has been loaded press SPACE BAR
```

Screen 3.0.9

Pressing the SPACE BAR will return to screen 3.0.8., after which "Y" should be entered.

The next stage is to determine which sensors are to be used during the examination.

```
Which sensors are to be used during the examination ?

1. E/C POINT PROBE  (Y or N)

2. ENCIRCLING COIL  (Y or N)

3. LVDT  (Y or N)
```

Screen 3.0.10

Only the sensors which are to be used during the examination should be selected, this is done by entering "Y" next to each sensor. If a sensor is not to be used "N" should be selected. Before carrying on, the option to change one or more selections is offered-

```
Is the information correct  (Y or N)  ?
```

Screen 3.0.11

If "Y" is entered the examination procedure will start from section 3.1.
If "N" is entered the following prompt will be displayed -

```
Which number do you wish to change (1,2,3) ?
```

Screen 3.0.12

Select either 1,2 or 3 and change the input to the correct value. The previous 'Is information correct ' prompt will then be displayed. This procedure will continue until all the inputs are correct and "Y" is selected from screen 3.0.11.

3.1 Scan Selection

The type of examination to be performed is selected from the menu below -

SCAN NUMBER	DESCRIPTION
1	VERTICAL SCAN
2	HELICAL SCAN
3	CUSTOM SCAN
4	MULTI SPLINE SCAN

ENTER SCAN NUMBER REQUIRED (1,2 3 or 4)

Screen 3.1.1

Selecting "1" will examine the rod in three vertical scans, separated by 120 degrees (section 3.2).
Selecting "2" will examine the rod in one helical scan (section 3.3).
Selecting "3" will create a combination scan of individual helical and vertical scans (section 3.4).
Selecting "4" will examine the rod in 37 vertical scans, separated by 10 degrees (section 3.5).

3.2 Vertical Scan

After 'Vertical Scan' has been selected from screen 3.1.1 the following message is displayed

Push Space Bar to Move to Start Position

Screen 3.2.1

When the space bar is pressed the drive unit will begin to move to the start position and the display will change to -

Moving to Start Position

Screen 3.2.2

At the start position this will be replaced by -

```
                 Pin At Start Position.

            Switch SONY display to incremental and RESET.

Before starting test ensure data logger is recording

  Do this by selecting option 'E' from the options menu.

  Enter file name 'PWR' and set scan period to 100 ms.

  Press F2 (on the SIEMENS) to initialise.

  To record continuously press Alt-F2 (on the SIEMENS)

Once data logger is recording press space to start scan
```

Screen 3.2.3

Pressing space bar will cause the test to start. During the duration of the test the following display will be shown -

DRIVE UNIT IN MOTION		
STAGES OF SCAN		FAULT CONDITIONS
1st VERTICAL SCAN - COMPLETED TURNING ROD 120° - IN PROGRESS 2nd VERTICAL SCAN - TURNING ROD 120° - 3rd VERTICAL SCAN - TURNING ROD 120° -		NONE
XXXXXXOOOOOOOOOOOOOOOOOOOO 23 % COMPLETED		
INTERFACE STATUS - E	MOTION STATUS - 3	INPUT STATUS - 128

Screen 3.2.4

As each stage of the scan is carried out, the display will change from 'In Progress' to 'Completed'. An indication of the overall rate of progress is shown on the bar near the bottom of the screen. The Interface, Motion and Input Status boxes give information on the state of the Interface and the drive unit. In normal operation they should show E,3 and 128 respectfully.

The right hand side of the screen is used to give a list of any faults which occur. In normal operation there should be no faults present. For a detailed description of the fault diagnosis routine see section 4.0.

When the test has been completed, the top line of the display will change to -

Test Completed - Press Space Bar to Continue.

Screen 3.2.5

At the end of a successful test the Motion & Interface statuses should be 0 and C respectfully. Once space bar has been pressed the program will prompt for the file name that the NEFF has saved the test data in (see section 3.5.).

3.3 Helical Scan

After 'Helical Scan' has been selected from screen 3.1.1 the following message is displayed -

```
Push Space Bar to Move to Start Position
```

Screen 3.3.1

When the space bar is pressed the drive unit will begin to move to the start position and the display will change to -

```
Moving to Start Position
```

Screen 3.3.2

At the start position this will be replaced by -

```
            Pin At Start Position.

      Switch SONY display to incremental and RESET.

Before starting test ensure data logger is recording

  Do this by selecting option'E' from the options menu.

  Enter file name 'QED' and set scan period to 100 ms.

  Press F2 (on the SIEMENS) to initialise.

  To record continuously press Alt-F2 (on the SIEMENS).

Once data logger is recording press space to start scan
```

Screen 3.3.3

Pressing space bar will cause the test to start. During the duration of the test the following display will be shown -

DRIVE UNIT IN MOTION		
STAGES OF SCAN		FAULT CONDITIONS
HELICIAL SCAN - IN PROGRESS		NONE
XXXXXXOOOOOOOOOOOOOOOOOOO	23 % COMPLETED	
INTERFACE STATUS - E	MOTION STATUS - 3	INPUT STATUS - 128

Screen 3.3.4

An indication of the rate of progress of the scan is shown on the bar near the bottom of the screen. The Interface, Motion and Input Status boxes give information on the state of the Interface and the drive unit. In normal operation they should show E,3 and 128 respectfully.

The right hand side of the screen is used to give a list of any faults which occur. In normal operation there should be no faults present. For a more detailed description of the fault diagnosis routine see section 4.0.

When the test has been completed, the top line of the display will change to -

Test Completed - Press Space Bar to Continue.

Screen 3.3.5

At the end of a successful test the Motion & Interface statuses should be 0 and C respectfully. Once space bar has been pressed the program will prompt for the file name that the NEFF has saved the test data in (see section 3.6.)

3.4 Custom Scan

After selecting the Custom Scan option from screen 3.0.12, the scan is created by selecting the different elements from the following menu -

SELECT ELEMENTS TO BUILD A COMPLETE SCAN		
SELECT	DESCRIPTION	ELEMENTS ALREADY IN SCAN
1	FAST VERTICAL SCAN	RETURN TO DATUM
2	SLOW VERTICAL SCAN	
3	FAST HELICAL SCAN	
4	SLOW HELICAL SCAN	
5	TURN ROD 120°	
6	PAUSE TEST	
0	END	
CHOOSE ELEMENT TO BE ADDED TO SCAN (0....6)		

Screen 3.4.1

Individual elements are selected by entering the corresponding number, 0...6. NOTE - the first move in any scan is always to move to the datum, as shown on the right hand side of the screen. After an element is selected there is a prompt for the direction. To move the rod up '+' should be entered where as to move the rod down a '-' should be used. Before adding it to the scan the element and direction combination is displayed for confirmation i.e. for an upward fast vertical scan -

+FAST VERTICAL SCAN SELECTED - IS THIS CORRECT (Y/N) ?

Screen 3.4.2

If the selection is incorrect, enter "N" and the element will be discarded. The program will then display screen 3.4.1.

If the selection is correct, enter "Y" and it will be added to the scan and displayed on the right hand side of the screen. The next element to be added to the scan can now be chosen and the screen will change to screen 3.3.1 with the previous element added to the scan -

SELECT ELEMENTS TO BUILD A COMPLETE SCAN		
SELECT	DESCRIPTION	ELEMENTS ALREADY IN SCAN
1	FAST VERTICAL SCAN	RETURN TO DATUM +FAST VERTICAL SCAN
2	SLOW VERTICAL SCAN	
3	FAST HELICAL SCAN	
4	SLOW HELICAL SCAN	
5	TURN ROD 120°	
6	PAUSE TEST	
0	END	
CHOOSE ELEMENT TO BE ADDED TO SCAN (0....6)		

Screen 3.4.1a

Before selecting different elements the following points should be noted -
1. the length of each scan is that input at screen 3.0.1.
2. consecutive scans must be in opposite directions.
3. first direction must be up i.e.'+'
4. 'pause test' will pause until 'AUTOSTART' is depressed.

When the scan is complete '0' should be selected. This should be confirmed by entering "Y" at the following -

NO MORE SELECTIONS - ARE YOU SURE (Y/N) ?

Screen 3.4.3

This will transmit the completed scan to the interface and display -

Push Space Bar to Move to Start Position

Screen 3.4.4

When the space bar is pressed the drive unit will begin to move to the start position and the display will change to -

Moving to Start Position

Screen 3.4.5

At the start position this will be replaced by -

Pin At Start Position.

Switch SONY display to incremental and RESET.

Before starting test ensure data logger is recording

Do this by selecting option 'E' from the options menu.

Enter file name 'QED' and set scan period to 100 ms.

Press F2 (on the SIEMENS) to initialise.

To record continuously press Alt-F2 (on the SIEMENS)

Once data logger is recording press space to start scan

Screen 3.4.6

Pressing space bar will cause the test to start. During the duration of the test the following display will be shown -

DRIVE UNIT IN MOTION		
STAGES OF SCAN		FAULT CONDITIONS
RETURN TO DATUM - COMPLETED TURNING ROD 120° - IN PROGRESS +SLOW VERTICAL SCAN TURNING ROD 120° -FAST VERTICAL SCAN +SLOW VERTICAL SCAN		NONE
XOOOOOOOOOOOOOOOOOOOOOOOO	3 % COMPLETED	
INTERFACE STATUS - E	MOTION STATUS - 3	INPUT STATUS - 128

Screen 3.4.7

As each element is completed the display will change from 'In Progress' to 'Completed'. The Interface, Motion and Input Status boxes give information on the state of the Interface and the drive unit. In normal operation they should show E,3 and 128 respectfully.

The right hand side of the screen is used to give a list of any faults which occur. In normal operation there should be no faults present. For a more detailed description of the fault diagnosis routine see section 4.0.

When the test has been completed, the top line of the display will change to -

```
Test Completed - Press Space Bar to Continue.
```

Screen 3.4.8

At the end of a successful test the Motion & Interface statuses should be 0 and C respectfully. Once space bar has been pressed the program will prompt for the file name that the NEFF has saved the test data in (see section 3.6.)

3.5 Multi Spline Scan

After 'Multi Spline Scan' has been selected from screen 3.1.1 the following message is displayed

```
Push Space Bar to Move to Start Position
```

Screen 3.5.1

When the space bar is pressed the drive unit will begin to move to the start position and the display will change to -

```
Moving to Start Position
```

Screen 3.5.2

At the start position this will be replaced by -

```
            Pin At Start Position.

       Switch SONY display to incremental and RESET.

Before starting test ensure data logger is recording

  Do this by selecting option 'E' from the options menu.

  Enter file name 'PWR' and set scan period to 100 ms.

  Press F2 (on the SIEMENS) to initialise.

  To record continuously press Alt-F2 (on the SIEMENS)

Once data logger is recording press space to start scan
```

Screen 3.5.3

Pressing space bar will cause the test to start. During the duration of the test the following display will be shown -

DRIVE UNIT IN MOTION		
STAGES OF SCAN		FAULT CONDITIONS
MULTI SPLINE SCAN - IN PROGRESS		NONE
XXXXXX0000000000000000000	23 % COMPLETED	
INTERFACE STATUS - E	MOTION STATUS - 3	INPUT STATUS - 128

Screen 3.5.4

The display on the left screen shows how many scans have been performed and is updated after a scan has been completed. The Interface, Motion and Input Status boxes give information on the state of the Interface and the drive unit. In normal operation they should show E,3 and 128 respectfully.

The right hand side of the screen is used to give a list of any faults which occur. In normal operation there should be no faults present. For a detailed description of the fault diagnosis routine see section 4.0.

When the test has been completed, the top line of the display will change to -

Test Completed - Press Space Bar to Continue.

Screen 3.5.5

At the end of a successful test the Motion & Interface statuses should be 0 and C respectfully. Once space bar has been pressed the program will prompt for the file name that the NEFF has saved the test data in (see section 3.5.).

3.6 End of Examination Scan

After an examination has been completed it is necessary to enter the file name that the test data has been saved in -

```
Stop Data Logger recording and note name of data file

Enter name of file data has been saved in - XXXX
```

Screen 3.6.1

If the file name is correct it should be confirmed be confirmed by typing "Y" at the following prompt -

```
Data has been saved in file - XXXX

Is this correct (Y/N)  ?
```

Screen 3.6.2

If the file name is incorrect "N" should be entered which will allow the name to be re-entered at screen -

```
Enter name of file test data has been saved in - YYYY
```

Screen 3.6.3

After the file name has been re-entered it must be confirmed by typing "Y" at the previous prompt, screen 3.6.2.

Once the file name has been correctly entered the following message is displayed -

```
Unload fuel pin and insert a formatted DS/DD disc to drive A

            Test Data will be saved in file -

                 Press Space to Continue
```

Screen 3.6.4

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It is now necessary to insert a pre-formatted DS/DD disc into drive A and to close the drive. The name of the file in which the test data is to be saved will be the same as the test number which was entered at the beginning.

Once the data has been successfully saved the program is terminated and the system returns to the start up menu.

4.0 Fault Diagnosis Routine

If during any time that the drive unit is in motion, a fault is encountered, it will cause the fault diagnosis routine to be invoked. The purpose of this routine is to determine which faults have occurred, return the drive unit to manual control and advise the operator on how to correct the fault. The left hand side of the screen shows the faults that caused the test to be stopped, whilst the right hand side shows the faults that are still present. As the operator corrects the faults, they will be removed from the right hand side. When all the faults have been removed, the operator will be prompted to press space bar which will restart the scan at the section immediately before the fault occurred.

5.0 Manual Programming Of Drive Unit

If required, the facility exists for the manual programming of the drive unit interface. This option can be run from the start-menu by selecting the option to 'Initialise IF-2'. This will then initialise the interface in the same manner as described in section 1.0. Once the interface has been successfully initialised the screen will clear and commands can be sent to the drive unit (the commands are described in the IF-2 manual).
