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MANIPULATOR REQUIREMENTS FOR NDT

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One of the ROV markets which is seeing a high growth is NDT by ROV. Historically this topic has been limited to gross video inspection and C.P. survey. Recently a level of success has also been achieved in Flooded Member Detection and limited close visual inspection. With the advent of efficient grit blasting, the ROV has been used, with a high success level, to preclean structural welds for diver MPI inspection.

Pressures of economics are driving the ROV industry to develop NDT equipment which will allow the ROV to detect, and assess, the presence of fatigue induced surface breaking defects in nodal welds and their associated heat affected zones. Two main techniques of NDT are currently being developed by Comex to provide ROV services to meet client needs. One is an MPI system and the other an Eddy Current system. Both are derivatives of equipment currently being used successfully by divers in the North Sea. The two systems are compementary to each other rather than in competition and offer a high degree of defect evaluation.

To produce NDT equipment suitable for remote deployment and operation is a small part of the overall problem. It is the manipulation of these tools around a complex nodal weld geometry, and the identification of the tool position on the weld, that holds the key to success of NDT by ROV.

This paper will discuss the requirements placed on the tool deployment system by the task, the worksite, the ROV characteristics and the NDT tooling.

A number of problems and solutions encountered in the development of an ROV NDT system will be addressed including tool carriers, tooling motion and manipulator envelopes.

ROV NDT TOOLING

AND ITS DEPLOYMENT

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1. INTRODUCTION

This paper covers the development of equipment, suitable for deployment by ROV, designed to detect and assess surface breaking defects in steel structures. Primarily the equipment is used to detect and assess defects in nodal welds and their associated heat affected zone.

The equipment has been developed under a Comex U.K. Ltd. self funded initiative known as the MARI project.

The MARI project has addressed the following topics:

- work site access
- cleaning requirement and methods
- close visual inspection
- MPI testing
- Eddy Current testing
- Deployment of NDT tooling

The MARI project has developed Micro Video equipment, MPI equipment and Eddy Current equipment. In addition a platform attachment system has been developed to facilitate parking of the ROV during cleaning and NDT operations. This is designed as an interchangeable self contained module mounted on the front of the Comex General Purpose ROV Toolskid.

Having conducted an exhaustive study of NDT and ROV equipment, Comex believe that the elements of the system are in place and that what is required is the integration as an overall ROV package.

2. ACCESS TO WORK SITE

An extensive study of North Sea structures was conducted. This study was aimed at obtaining a range of member sizes and nodal configurations over which the NDT system would be required to operate. This survey also included the position of likely obstructions such as anodes.

From the survey it became apparent that the equipment would have to operate within the following constraints:

- Accommodate members through the range 18" to 72" diameter
- Fit and work within a 30^{o} cone
- Fit and work within a 24" length

The worst case is exhibited by a vertical diagonal member joining a leg.

Figure 1 shows the predicted worst case working envelope. It consists of a cone whose base is 24" back from the crutch of the weld, is centred on the centre line of the member and whose apex has an angle of 60°. The maximum reach of a tool to cover the whole length of the weld is 105" along the axis of the member.

3. NDT SYSTEMS SELECTION

A study was undertaken of a number of NDT systems to assess suitability for remote deployment and operation.

Based on the equipment study and Comex NDT experience the most suitable techniques were determined as:

- For detection of surface breaking defects the MPI technique was identified and in particular the single leg electro-magnetic yoke.
- For assessment of surface breaking defects the Comex/Thistle underwater Eddy Current System. (Note that this is also used for defect detection).

It was further established that the ROV would have to be securely attached to the structure during all cleaning and NDT operations. Figure 2 shows a general arrangement of the ROV, Tool skid and attachment/manipulation package.

The toolskid is general purpose and of Comex design. It may be fitted with a variety of work modules. The front and rear frames are designed to be interchangeable to accept task specific modules. For NDT use a platform attachment and manipulation module has been designed and built.

4. CLEANING

MPI requires a cleaning standard to SA2.5 whilst Eddy Current only requires the removal of marine growth.

Low pressure dry grit has been identified as the most effective form of cleaning to attain the SA2.5 standard. This technique has a successful ROV track record. Due to its high efficiency it is as effective to use this to clean for Eddy Current testing rather than remove the marine growth only. In areas where Eddy Current testing only is to be conducted and the paint coat is to remain intact then conventional manipulator deployed hydraulic wire brushing may be adopted.

5. MPI TESTING

Of the various methods of inducing a magnetic field the single leg yoke was adopted as the least complex to articulate. It is a technique adopted by divers in complex nodal geometry when only one pole piece of a conventional yoke can be fitted into the test area.

Figure 3 illustrates this technique.

5.1 Subsystem Description

The single leg yoke MPI system essentially provides all functions necessary for performing magnetic particle inspection to the majority of components and component geometries encountered on fixed offshore steel structures.

The system provides for the following:-

i) Magnetisation of the component parts to be inspected.

ii) Application of the magnetic ink used to detect discontinuities.

iii) Removal of excess magnetic particles to aid interpretation of any indications.

iv) Video viewing system to monitor all operations and record relevant results as necessary.

The Yoke (Figure 4)

A development single leg E-M yoke was manufactured based on a prototype model successfully demonstrated by Sea Test Services of Florida as a joint industry development of which Comex was a participant. A number of modifications in configuration were included by Comex to enhance performance. It measures 300mm long x 110mm wide x 50mm high and weighs about 11.5 kg. The yoke is cast moulded in a urethane compound and enclosed in a Nyloil housing. Nyloil was chosen for the housing as a conductive material would overheat due to Eddy Currents generated by the intense magnetic field. The yoke magnetising coil is rated for up to 110 V a.c. at 25 Amps. Successful results have, however, been obtained below 50 V at 5 Amps.

The yoke current is supplied from a variable transformer to give full control of the magnetising force. An articulated joint is included in the yoke to ensure compliance with the test area.

Ink and Ink Dispenser System

Mi Glow No. 1 white light fluorescent magnetic ink has been successfully used during prototype testing allowing the use of white light as the MPI and visual inspection light source.

The ink is held in a 10 litre container which is mounted on the toolskid. To avoid settling, the ink is constantly agitated by a pump circulating the ink within the container. Ink dispensing is achieved by utilising this pump and a selector valve. A hose runs from the valve, down the yoke and across the front of the yoke leg. Fan jet nozzles attached to this hose disperse the ink directly at the test area.

Excess ink is dispersed from the test site to eliminate the occurrence of false readings. This is achieved by use of a water pump and dispersal nozzle. The nozzle for the excess particle removal system is positioned just behind the leg of the yoke. The nozzle holes are at an angle so the water being pumped through it has a swirling effect which disturbs the ink on the test area which is not attracted by the field focusing effect of a defect.

Viewing

Viewing of the test area is achieved with an "Elmo EM102" micro colour camera which offers excellent resolution in excess of 400 horizontal TV lines and real time visual acuity better than 20/20. Lighting for the test area is provided by 2 x 150 watt miniature ROS tube lights.

The reasons for the choice of this particular camera are as follows:

1) Camera is unaffected by powerful magnetic fields.
2) Small package size, to allow geometrical closeness of approach, minimal footprint and ability to be mounted onto the magnetising device.
3) High degree of visual acuity, colour balance and depth of field to allow for pattern discrimination of magnetic particle indications.
4) Adequate field of view.

The field of view of the camera is approximately 85mm high x 175mm wide at the fixed stand-off distance. Resolving power is in excess of 800 lines per inch (about 30 lines per millimeter).

This camera is also ideally suited for close visual inspection and access into very restricted areas.

The camera and lights are mounted on a plate which lifts with the yoke articulation ensuring that the area under test remains in the field of view of the camera.

Monitoring in the control container is performed using a compatible high resolution colour TV monitor and video cassette recorder. Additionally, a video frame grabbing facility enables a high quality hard copying facility for permanent records.

5.2 MPI System Performance

BS 6072 states that a field strength of 0.72 Tesla is required and further that a field in excess of 1 Tesla results in saturation of the material under test. Additionally, a pull off force in excess of 10 lbs is required to be exhibited by the yoke.

Figure 5 shows a plot of field strength versus distance from the yoke tip on its centre line. This shows that testing may be undertaken at a distance of between 75 and 175 mm from the yoke with a current set between 3 and 9 amps.

Figure 6 gives a typical field distribution pattern. Pull off forces between 10 and 20 lbs are exhibited in the current range 3 to 10 Amps.

The above data shows that the single leg yoke is capable of meeting the magnetising requirements of BS 6072 as required by the Certifying Authorities.

6. EDDY CURRENT TESTING

Whereas MPI can be used to detect the presence and map the position of surface breaking defects, it cannot detect size defects.

Comex has a proven track record with a diver deployed eddy current system. This equipment has been developed jointly with Thistle Well Services and is based on the Hocking AV100 equipment.

The Comex/Thistle Eddy Current system can detect and depth size defects up to 30^{o} from the normal plane of the areas being tested and detect the presence of flaws outwith this range. The significance of the 30^{o} figure is that it represents the 3dB point of the sensor field pattern.

The EC technique requires that cleaning consists of removal of marine growth only, thus leaving any paint coat intact. This feature dramatically reduces site preparation time.

6.1 System Description

The eddy current system is based on a Hocking Phasec system modified by Comex for sub-sea use. The Phasec is an updated Hocking AV100. The Phasec sub sea unit is connected to a surface P.C. via an RS232 interface. This interface provides full control of the Phasec system from the P.C. and a data link to call up and log output data. Real time scan information is obtained from the Phasec's video output.

The search coil is manipulated by a tool carrier deployed from the ROV manipulator.

The Elmo EM102 video camera described in section 5 is mounted on the tool carrier and shows the picture of the probe running along the weld. This picture is combined with the Phasec video output and recorded. Figure 7 shows a block diagram of the system.

Phasec Control and Data Logging

The Phasec unit is mounted on the ROV tool skid. It is connected to a surface P.C. via an RS232 link for data logging and control. Real time scan information is obtained from the Phasec video output and displayed on a surface monitor which is combined with the supervisory video picture and recorded. When a scan "of interest" is observed the P.C. is used to record it on disc along with a unique comment file.

The MARI project has developed new reporting software which is utilised to record the scan along with its comment file. This automatically stores such information as time, date, location, weld identification, position etc. and gives the file a unique file name allowing easy sorting and recovery.

Probe

A standard weld scan coil is used and is deployed by a tool carrier. The tool carrier in turn is offered up to the work site by the ROV manipulator. It is the tool carrier, not the manipulator, which produces the fine controlled movements required to scan the coil along the weld. The manipulator is used to step the tool carrier between scans. Figure 8 illustrates the probe and tool carrier arrangement.

6.2 Use of the Eddy Current System

This section highlights the main considerations when using the system and is not exhaustive.

Eddy Current testing uses a magnetic field produced by a current carrying conductor. The principle is based upon the fact that a coil carrying an alternating current produces an alternating magnetic field. If the coil is placed in close proximity to a conductive metal surface, the changes in magnetic field will produce eddy currents in the surface of the metal, which in turn produce a magnetic field of their own. The interaction of these magnetic fields produce measurable changes in the impedance of the coil. These impedance changes remain constant unless changes in metallic composition or a discontinuity is encountered. When this occurs, it is manifested as a voltage change outside the expected range for the material under test. As the test coil is one arm of a phase balanced bridge this change in voltage causes an imbalance to occur which is detected and displayed. The technique is more properly referred to as Electro-Magnetic Detection (EMD) of surface breaking defects.

The display (figure 9) is a trace on a storage crt. A normal scan is a short diagonal line running from the bottom left quadrant to top right with the trace passing through the balance position. A detected flaw causes the trace to deflect vertically upwards. The amplitude of this deflection is proportional to the defect depth.

Before use, the probe has to be calibrated. This is done by use of a calibration block with .5mm, 1mm and 2mm deep slots cut in it. The block material is the same as the parent material of the structure (normally 50D steel). A trace is obtained at each slot proportional to depth. Phase correction is added to set this trace vertically. The sensitivity is then adjusted to set the 1 mm reading to full scale deflection.

The relative sensitivity levels are adjusted to compensate for the effects of coating and weld geometry.

The sensor head is now positioned on the member, clear of the effects of the weld geometry and the heat affected zone, and the bridge balanced to the material of the member.

Flaw Detection

The probe is slid up the member to the toe of the weld. The weld geometry decreases the impedance of the coil causing a negative going trace. The angle of the sensor head is changed to maximise this trace and the bridge rebalanced.

The sensor head is run along the toe of the weld. A positive change in the trace obtained indicates the presence of a surface breaking defect. The amplitude of such change is proportional to the depth of the defect.

The EC equipment is susceptible to change in lift off distance and care must be taken to ensure this remains constant.

7. NDT TOOLING DEPLOYMENT

Although the current project is based on MPI and Eddy Current NDT, a number of ultrasonic based systems could also be deployed.

For successful NDT inspection the sensor head deployment must be delicate and precise, both in its complex scanning pattern and in its positional resolution. There are two viable approaches to the problem. One is to produce a manipulator of a far higher standard than currently exists. This involves designing and manufacturing a manipulator, with high tolerance joints, anti backlash gearings and a complex control system, required by this task. It should be noted that available robotic arms, whilst precise in movement are heavy, large and have fixed references e.g. a base with which to relate to. For this reason a departure from the conventional ROV manipulator concept is advocated and this is to split the problem.

This resulted in the manipulator "hand" or tool carrier being designed.

When the human hand is being used for precise manipulation, for example when writing, the wrist is rested on the work surface and the fingers are used for fine control of the pen. As writing moves across the page the wrist is stepped in course movements to allow full coverage. In the same way the ROV manipulator "arm" steps the tool carrier "hand" around to weld. The two NDT tasks were defined as "heavy" and "light".

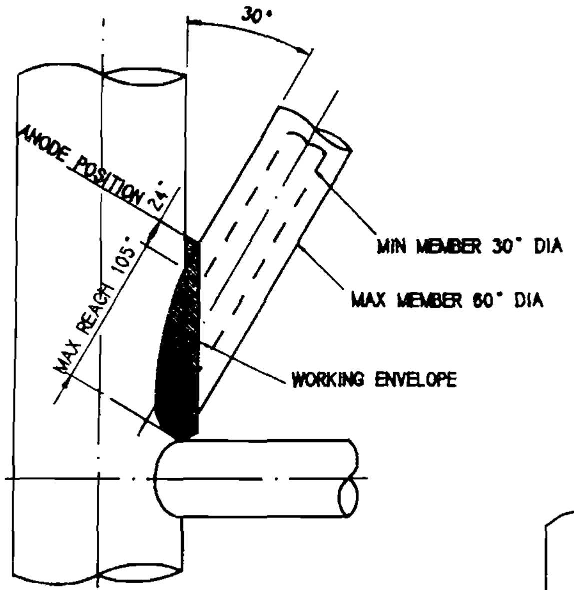
For "heavy" MPI work the tool carrier rotates the yoke in azimuth by $\pm$ 90^{o} from the axis of the member, setting the yoke normal to the path of the weld at any position along it. A slide allows the yoke to be stepped in or out form the weld to set the stand of distance, and a $\pm$ 20^{o} roll action, along with the compliant yoke tip, ensures the yoke is tangential to the surface under test.

One more function is included and that is elevation. This function is fitted with a strain gauge to measure lift off force. Reference to the field plot of the yoke indicates a manipulator step distance round the weld of 150mm $\pm$ 50mm to guarantee overlap and a stand off distance of 100m $\pm$ 25mm. In this way precise manipulation of the tool is achieved even when it is deployed by a fairly crude "position only" feedback ROV manipulator.

For "light" Eddy Current work a different tool carrier is utilised. This differs from the MPI carrier, in that the NDT sensor is smaller and more delicate, and that the sensor is required to conduct a mechanical scan. Similarly to the MPI, the tool carrier sits along the axis of the member. The main functions are the X and Y slides each with 150mm of travel. A combination of these motions controls movement of the probe along the path of the weld. Rotation of the probe about its Y and Z axis by compliance, allows the probe to remain normal to the surface under test. Rotations about the X axis by a set 30^{o} enables the first step of set up to be undertaken.

By using this concept the manipulator is only required to step the tool carrier around the weld in 125mm $\pm$ 25mm steps with a 125mm $\pm$ 25mm stand off to weld.

Although this has been designed for Eddy Current probe deployment, a number of sensors, such as ultrasonic can be deployed.



SECTION THRO' CONE
OF OPERATION

FIGURE 1

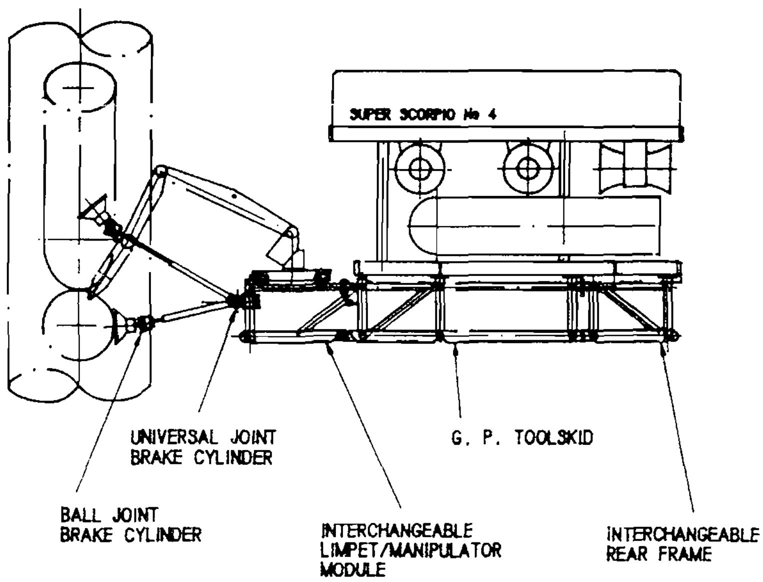
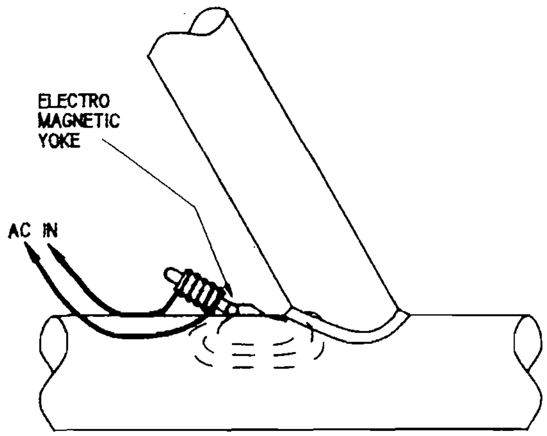


FIGURE 2



FLUX FLOW USING A SINGLE
LEG ELECTRO MAGNETIC YOKE

FIGURE 3

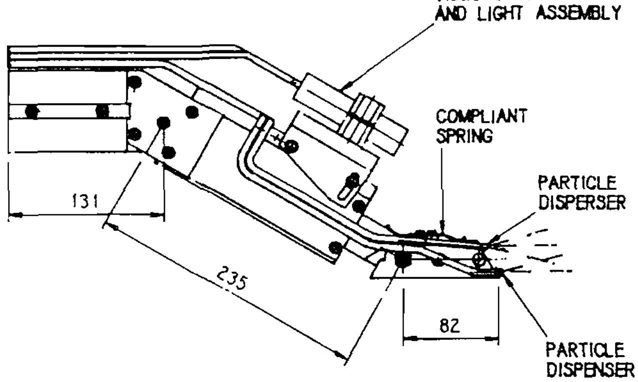


FIGURE 4

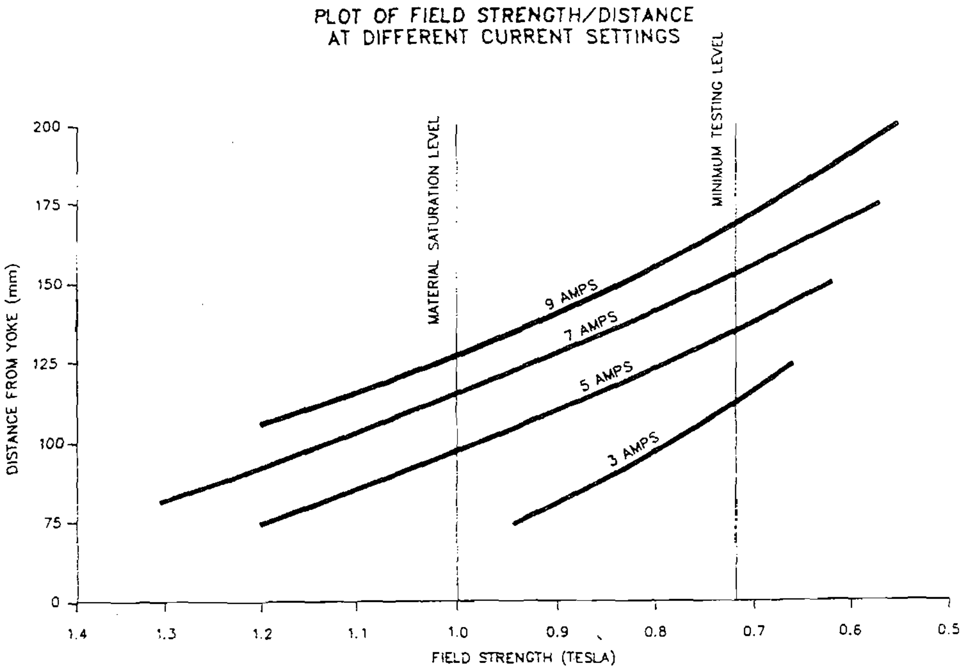
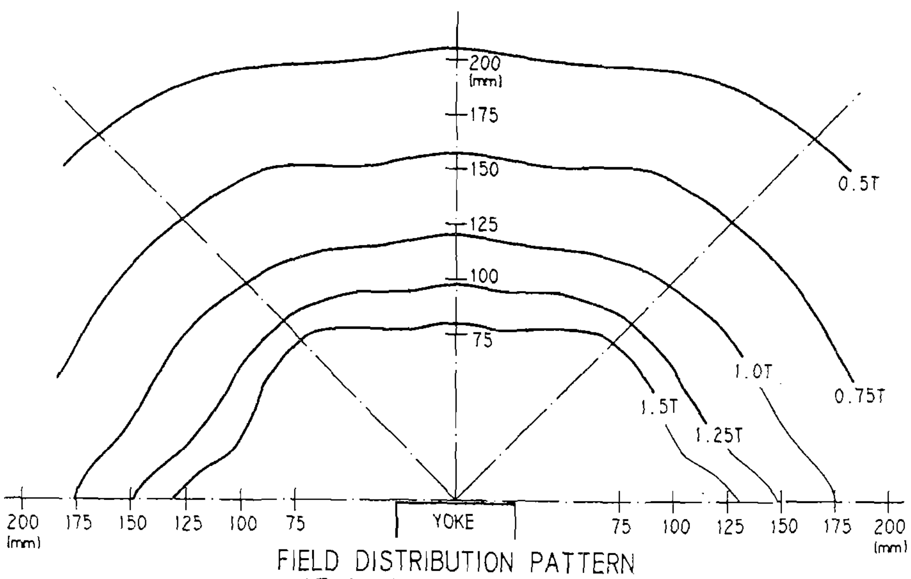


FIGURE 5



FIELD DISTRIBUTION PATTERN
AT 9 AMP COIL CURRENT

FIGURE 6

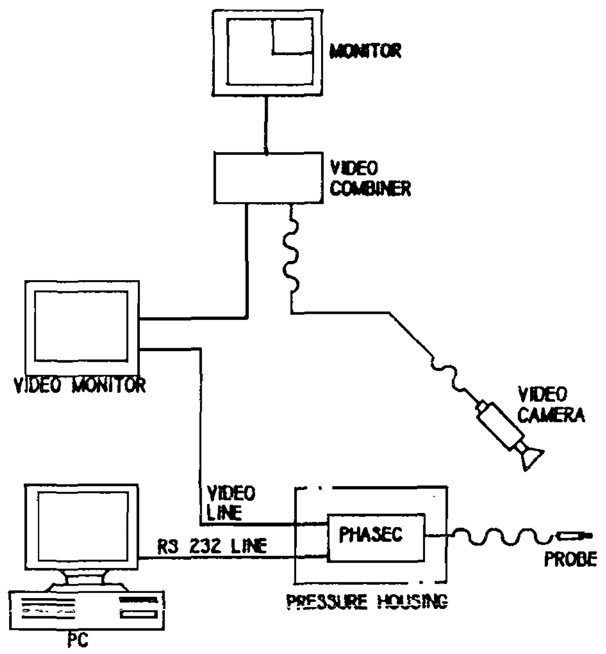


FIGURE 7

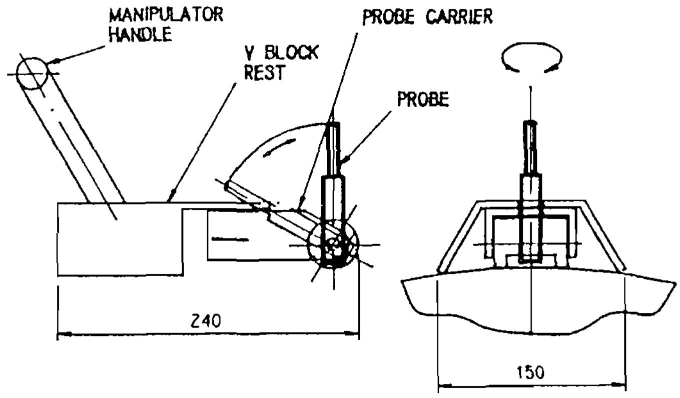
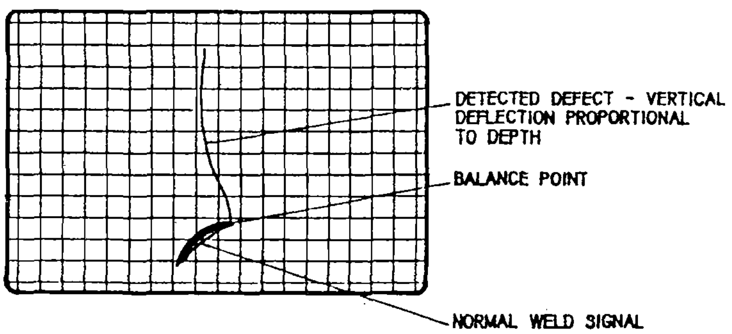


FIGURE 8



HOCKING AV-100L DISPLAY

FIGURE 9