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Development of Pressure Tube Inspection Equipment for ATR

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DEVELOPMENT OF PRESSURE TUBE INSPECTION EQUIPMENT FOR ATR

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Abstract

A remote-controlled in-service inspection device has been developed for inspecting pressure tubes of the Fugen, which is a heavy water moderated and boiling light water cooled pressure-tube type reactor. The equipment is capable of performing three kinds of inspection: ultrasonic flaw detection; measurement of inside diameter; and visual inspection of the internal surface. To reduce the radiation exposure of inspectors, the three kinds of detectors, with their associated electronics and drive mechanisms for vertical and rotating movements, are housed in the inspection tool assembly, which can be mounted on or removed from the pressure tubes by a refueling machine through remote control operation. The ultrasonic technique has been adopted for measurement of the internal diameter in order to shorten the inspection time. Detectors, TV camera, and electronic components used in the inspection tool assembly were selected on the basis of irradiation test results.

Before inspection of the Fugen reactor, the total system was tested on a mock-up pressure tube to confirm its functions, performance, durability and reliability. Test results are: (1) The ultrasonic flaw detector can detect an artificial flaw of 2.0mm in length, 0.1mm in width and 0.1mm in depth with S/N=7dB; (2) The inside diameter measurement system can measure the inside diameter, ranging from 117.5mm to 119.5mm, to an accuracy of $\pm 20\ \mu m$; (3) An artificial flaw of 2.0mm in length, 0.1mm in width and 0.1mm in depth can be observed by the internal surface observation system.

The equipment was used for the inspection of ten pressure tubes of the Fugen reactor during the May 1984 annual inspection. No degradation of the performance of the equipment was observed even after 55 hours of inspection under a maximum dose rate of 2.5×10^5R/h. Based on these results, the functions and performance of the equipment in practical use were fully confirmed.

1. INTRODUCTION

ATR is a heavy water moderated and boiling light water cooled pressure-tube type reactor having the special feature of using mainly plutonium-uranium mixed oxide (MOX) fuels. The prototype reactor, Fugen (165 MWe), has operated satisfactorily since the start of commercial operation in March 1979. It achieved total electrical generation of 5.3×10^9 kwh in March 1985.

The pressure components of the primary system of the Fugen reactor are inspected during annual inspection. The inspection of the pressure tube assemblies is essential in order to confirm their in-service integrity for the safety of the pressure-tube reactor.

In-service inspection of the pressure components of the Fugen reactor is carried out with a 10-year ISI program, prepared according to the Japan Electric Association Code JEAC-4205 "in-service inspection of light water cooled nuclear power plant components" (almost the same as ASME Boiler and Pressure Vessel Code Section XI). The 10-year program includes a schedule of ISI and monitoring of the pressure tube assemblies.

Each pressure tube assembly consists of a pressure tube made of zirconium niobium alloy, and upper and lower extension tubes made of stainless steel. It is about 9m in total length. The pressure tube is approximately 5m long, with 117.8mm inside diameter and 4.3mm wall thickness. The reactor core of the Fugen consists of 224 pressure tube assemblies each of the same shape, size and material. Therefore ISI of the pressure tube assemblies is made by "sampling inspection" criteria.

The structural material of the pressure tubes, Zr-2.5%Nb alloy is the first experience to be used for in-reactor pressure components in Japan. Accordingly, several selected pressure tubes (follow-up pressure tubes) are monitored in follow-up inspection to measure a history of the inside diameter change due to fast neutron irradiation creep. This aspect of inspection is called a monitoring.

For the above purposes of ISI and monitoring, development of a trial pressure tube inspection equipment was initiated in 1970. After a mock-up test of the equipment for one year, pre-service inspection (PSI) was conducted for 23 pressure tube assemblies of the Fugen in 1977.

The trial pressure tube inspection equipment, however, has to be assembled or disassembled manually underneath the reactor core. And besides, the equipment itself is fairly massive. Its handling thus requires much manpower and time. The inspection as above cannot be conducted in water, so after operation of the reactor the primary cooling water must be drawn out from the pressure tubes. This involves the work of an ice plug to serve as a valve. Considerable radiation exposure of the personnel was thus expected in the inspection with this trial pressure tube inspection equipment.

To reduce largely the radiation exposure at the time of pressure tube inspection and to shorten the time of inspection, a remote-controlled in-service inspection device has been developed. The equipment consists of two types of inspection tool assemblies; a control panel; a signal transmission system; and auxiliary equipment, and is capable of performing three kinds of inspection: ultrasonic flaw detection; measurement of inside diameter; and visual inspection of the internal surface.

Extensive trial tests and evaluation of the test data were performed before developing the final equipment for in-reactor use. In development of the equipment, much attention has been paid to the following points.

(1) To reduce the radiation exposure of inspectors, three kinds of detectors, with their associated electronics and drive mechanisms for vertical and rotating movements, are housed in the inspection tool assembly. This can be mounted on or removed from the pressure tubes by a refueling machine through remote control operation.

(2) The ultrasonic technique has been adopted for measurement of the internal diameter in order to shorten the inspection time. The detector has a compensation mechanism to allow for water temperature change.

(3) Detectors, TV camera, and electronic components used in the inspection tool assembly were selected on the basis of irradiation test results.

(4) Each of the three kinds of inspection systems has a built-in test piece, and can be calibrated even during inspection.

Before inspection of the pressure tube assemblies of the Fugen reactor, the total system of the equipment was tested on a mock-up pressure tube to confirm its functions, performance, durability and reliability. The course taken in its development, configuration of the equipment and its performance are described, and also the results of inspection with this equipment in the fourth periodical inspection of the Fugen.

2. DESIGN AND CONSTRUCTION OF PRESSURE TUBE INSPECTION EQUIPMENT

2.1 Summary of design

Development of the remote-controlled inspection equipment was started in 1977. The method of inspection was first studied in the design. Extensive trial tests and evaluation of the test data were repeated until the final design was determined. The structure of the remote-controlled inspection equipment was completely changed from that of the trial inspection equipment which had been used in PSI. In the present equipment, the detectors, electronic components and drive mechanisms are integrated in the inspection tool assembly, which can be inserted into the pressure tube using the refueling machine. As a result, there is no need to assemble or disassemble the inspection equipment underneath the reactor core. The radiation exposure can thus be largely reduced and the time of inspection is shortened.

The present remote-controlled inspection equipment for the Fugen is capable of ultrasonic flaw detection and inside diameter measurement of the pressure tube, and internal surface visual inspection of the pressure tube, the welds in the extension tube and the upper and the lower rolled joints. The regions of inspection are shown in detail in Fig. 1.

The pressure tube inspection equipment has features as follows.

(1) The equipment is mounted on and removed from the pressure tube by remote manipulation, using a refueling machine.

(2) For the inspection, there is no need to draw out reactor water from the pressure tubes; an ice plug is not required.

(3) High-precision inspection is possible under high radiation field, about $2x10^5$ R/h (gamma rays).

(4) Ultrasonic flaw detection and inside diameter measurement are made at the same time, so the inspection period is shortened.

(5) In each detector, there is a buit-in calibration mechanism. So, with the equipment inserted in the pressure tube, the confirmation of its function and the calibration are made readily.

Specifications of the pressure tube inspection equipment are shown in Table I.

The pressure tube inspection equipment consists of inspection devices, control board, signal transmission system, etc. The inspection devices are an ultrasonic flaw detection - inside diameter measuring device and an internal surface visual inspection device. The ultrasonic flaw detection - inside diameter measuring device (shown in Fig. 2 (a)) is composed of an ultrasonic reflectroscope, an inside diameter measuring device, drive mechanisms, a seal plug, etc.. It is then set up in a cylindrical form of outside diameter 114mm x height 3.4 m. The internal surface visual inspection device (shown in Fig. 2 (b)) is composed of television cameras and optical system arranged in detection sections. The equipment is in double-walled structure; the inner tube containing detectors moves vertically within the outer tube.

In the signal transmission system, time-division multiplexing transmission scheme is employed to facilitate cable laying, which is capable of transmitting multiple signals and power current in a limited number of cores.

The pressure tube inspection equipment is almost all in automatic, remote operation. Works done manually are thus only the attachment of the equipment to a refueling machine and its detachement from it, the connection and disconnection of a connector, and cleaning of the equipment after inspection.

Signals detected at the respective detectors are transmitted to the control board through signal transmission cables. Ultrasonic flaw detection signals are displayed on a Braun tube and inside diameter measurement signals on a Braun tube and a digital device. The respective data are then fed to a minicomputer and graphic processed off-line. Internal surface visual inspection signals are displayed as image in a monitoring television, which are recorded with a video tape recorder.

2.2 Ultrasonic flaw detection inspection device

The ultrasonic flaw detection device detects flaws on the inner and the outer surface of the pressure tubes using the ultrasonic wave. The ultrasonic flaw detection device is illustrated in Fig. 3. To detect flaws in axial direction and flaws in circumferential direction, there are provided two probes; one for flaws in axial direction and one for flaws in circumferential direction, as shown in Fig. 3 (b).

The ultrasonic wave emitted from a probe passes through the reactor water and then propagates into the material of the pressure tube. Part of the ultrasonic wave is reflected at the outer and the inner surface, thereby passing in zigzag course in the pressure tube wall. If then there exists a flaw in the path of propagation of the ultrasonic wave, the ultrasonic wave is reflected back and so returns to the probe along the same course through which the ultrasonic wave propagated from the probe to the flaw. In this manner, it is confirmed whether there exists a flaw or not.

Frequency and incidence angle of the ultrasonic wave have large influence on flaw detection performance of the ultrasonic flaw detection device. Therefore, ultrasonic characteristic of the pressure tube material (Zr-2.5%Nb), the resolution, the SN ratio and the relation between the size of a flaw and the level of a signal were studied. Consequently, the frequency and the angle of incidence were chosen to be 5 MHz and 25 degrees, respectively.

The flaw detection performance was planned, as follows. The results of a study on strength of the pressure tube material showed that with a flaw of length up to 5mm x depth up to 0.4mm, integrity of the pressure tube was retained during life of the tube. The specification for flaw detection was thus determined that an artificial defect of length 5mm x depth 0.4mm x width 0.1mm should be detected easily.

As shown in Fig. 3 (a), inspection is made over the whole region by revolving the detector section at a high speed of 1 rps in spiral upward move with a 3mm pitch.

In the ultrasonic flaw detection device, there is a built-in Zr-2.5%Nb test piece with a standard flaw to enable easy calibration of the detector even during inspection. Function and performance of the device can thus be confirmed appropriately.

2.3 Inside diameter measuring device

It is predicted that the inside diameter of the pressure tubes increases about 100 μm per year, in the middle of the reactor core, due to irradiation (fast neutron) creep phenomenor. In order to measure such a small change in dimension accurately, the accuracy in the inside diameter measuring device is designed to be ± 20 μm. In the trial pressure tube inspection equipment, the method by differential transformer was adopted. In the present pressure tube inspection equipment, however, to reduce its size and to increase the inspection speed, the method by ultrasonic wave is employed. The method of inside diameter measurement is illustrated in Fig. 3 (c).

In the inside diameter measuring device, separately from the probes for ultrasonic flaw detection, there are provided two probes in symmetrical arrangement at 180 degrees. By measuring the time from the instant when the ultrasonic is emitted from the probe to the instant when it returns back to this probe after its reflection at the inner surface of the pressure tube, the distance the ultrasonic wave covers in this travel is obtained (the distance = sound velocity x propagation time). With d_1 as the distance from the probe 1 to the inner surface of the pressure tube, d_2 as the distance from the probe 2 to the inner surface and d_0 as the distance between the probe 1 and the probe 2, the inside diameter ID of the pressure tube is given by the formula

$$ID = d_1 + d_2 + d_0$$

As shown in Fig. 3 (c), inside diameter measurement is made over the whole region along with the ultrasonic flaw defection inspection in upward spiral move with a pitch of 3 mm.

Similarly to the case of ultrasonic flaw detection inspection, the inside diameter measuring device has a built-in easy calibration mechanism.

2.4 Internal surface visual inspection device

In the internal surface visual inspection device, the technology of industrial television system is applied. As shown in Fig. 4, it consists of a television camera, a lens, a mirror, illumination lamps (Fig. 2 (b)), etc.. The television camera etc. are also provided in the lower part of the inner tube, in addition to the set in the upper part, to observe the lower extension tube to the pressure tube. In each set there is a built-in easy calibration mechanism, with which function and performance of the device can be confirmed appropriately.

In the internal surface visual inspection device, its specification is such as to enable the differentiation of an artificial defect of length 2mm x width 0.1mm x depth 0.2mm in order to observe the internal surface with precision similar to that in direct observation.

Flaw detection performance depends significantly on the manner of illumination. Therefore, four illumination lamps are set, above and below the observation window and left and right to it, as shown in Fig. 2 (b). Each lamp can be switched on and off independently and their brightness is also adjustable.

As indicated in Fig. 4, internal surface visual inspection is made by moving in axial direction of the pressure tube.

2.5 Drive mechanisms

2.5.1 Vertical drive mechanism

In the vertical drive mechanism, which is operated in water, the rack-and-pinion type is employed to enable the precision position detection and the containment in a narrow space in the inner tube. In order to have the inner tube balanced in weight, two racks are attached on the internal surface of the outer tube in symmetrical arrangement at 180 degrees. By rotating the pinions in the inner tube, the inner tube moves up and down.

The vertical position of the inspection device is detected by measuring the number of revolutions made by the pinion. For this purpose, the optical pulse encorder is better in the respect of its small size and high resolution but it is not resistant to the radiation. Therefore, the magnetic pulse generator is employed.

As a countermeasure for failures of the vertical drive mechanism there is incorporated a contraction mechanism to let the inner tube fall gravitationally in minimizing the overall length, to facilitate removal of the inspection equipment by a refueling machine.

As the stroke of the vertical driving system is about half the inspection length for the pressure tube (i.e. 2.5 m). It is therefore necessary to inspect the pressure tube in the upper and the lower half. To inspect the upper half, an extension tube is connected between the outer tube and the seal plug.

2.5.2 Rotary drive mechanism

The rotary drive mechanism is gear type. In the ultrasonic flaw detection - inside diameter measurement device, the detector section in the inner tube is rotated continuously at high speed, so the connection of the probes to the signal transmission line is made through a slip ring (a sliding contact). In this manner, the automatic inspection on half of the pressure tube takes about 20 minutes.

In the internal surface visual inspection device, television cameras are set in the upper and the lower part of the inner tube, respectively. To revolve both these two cameras, a common drive mechanism is provided in the lower part of the outer tube. The range of revolution is 540 degrees, including the overlapping. Automatic inspection on half of the pressure tube takes about 40 minutes.

2.6 Control board

The control board is composed of an operation panel to operate the pressure tube inspection equipment, a display panel for inspection signals and a data processor. In data processing, the data of ultrasonic flaw detection inspection and of inside diameter measurement are recorded by magnetic tape, in each degree of the rotation and in each pitch (3 mm) of the spiral upward move. The data are then graphic processed off-line by a plotter.

2.7 Signal transmission system

To reduce the size of a transformer in the pressure tube inspection equipment, the commercial power of AC 450 V, 60 Hz is converted to the power of AC 200 V, 400 Hz in the control board. This power is then transmitted to the inspection equipment from the control board.

Time-division multiplexing transmission is used in sending and receiving the control signals to reduce the number of cores in the cable between the control board and the inspection equipment. The signals of ultrasonic flaw detection inspection and of inside diameter measurement are sent to the control board through a coaxial cable in time-division multiplexing transmission. The video signals of internal surface visual inspection are sent to the control board through a coaxial cable.

3. SIGNIFICANT POINTS IN DEVELOPMENT OF THE PRESSURE TUBE INSPECTION EQUIPMENT

Following are significant points introduced in development of the pressure tube inspection equipment.

3.1 Improvement of performance of detection systems

In ultrasonic flaw detection, the operating conditions suitable for the purpose differ with such as the kind of material for inspection and the shape. Therefore, ultrasonic flaw detection tests were made with artificial defects of several sizes made in test pieces of the same material and shape as the pressure tube. On the basis of the test results, the optimal frequency, angle of incidence, probe size, etc. were determined, as shown in Table I.

The accuracy required in measurement of the inside diameter is $\pm 20\ \mu$m. So, it is necessary to study on the design of the measuring system having high accuracy and high stability. The ultrasonic inside diameter measurement system has a compensation mechanism to allow for sound velocity change due to water temperature change.

In the internal surface visual inspection device, the flaw detection performance is influenced not only by the performance of a television camera but also by the mode of illumination. Therefore, illumination lamps are set above and below the observation window and left and right to it, and the brightness of each lamp can be adjustable independently.

3.2 Radiation resistance

As the interior of the pressure tubes is high in radiation level, 2×10^5 R/h (gamma rays) at the center of the core, it is expected that in the electronic parts the deterioration and damage due to cumulative exposure dose will be considerable. Irradiation tests of various electronic parts, including the polymer material and the glass, were conducted to grasp quantitatively their radiation resistances, and those resisting to radiation were selected for the present devices.

3.3 Electric noise

The ultrasonic flaw detection signal is a feeble electric signal. So, it is affected by electric noises from various parts of the equipment. The SN ratio was thus originally a few dB. Therefore, to suppress the electric noises from varions parts of the equipment, measures were taken, including the stabilization in a sinchronizing signal and the selection of an optimal filter, shield and earth location. Consequently, the SN ratio could be raised up to 20 dB.

3.4 Drive mechanism

Because of the underwater specifications, the vertical drive mechanism cannot use a lubricating oil and in addition must be accomodated in a narrow space. It was initially made in wire type, but its durability and the precision in its location were found to be insufficient.

It was thus changed to the rack-and-pinion type. As described in chapter 2.5, the stroke became half as large but the durability was increased to more than 500 reciprocations from tens of reciprocations for the wire type.

Following on the above efforts for improvement, modifications were continued in the pressure tube inspection equipment from 1981 to 1982. To acquire the data and experiences necessary in design and construction of the practical, pressure tube inspection equipment for the Fugen, tests were conducted to confirm the functions and performance.

4. PERFORMANCE IN OUT-OF-PILE TESTS

Before inspection of the Fugen reactor, the total system was tested on a mock-up pressure tube to confirm its functions, performance, durability and reliability. Test results are as follows:

(1) The ultrasonic flaw detector can detect an artificial flaw of 2.0mm in length, 0.1mm in width and 0.1mm in depth with S/N=7dB. Figure 5 shows an example of the echo amplitude as a function of the artificial defect depth.

(2) The inside diameter measurement system can measure the inside diameter, ranging from 117.5mm to 119.5mm, to an accuracy of $\pm 20\ \mu$m.

(3) An artificial flaw of 2.0mm in length, 0.1mm in width and 0.1mm in depth can be observed by the internal surface observation system. The typical visual observation of an artificial defect is shown in Fig. 6.

(4) The driving system has a stroke of 2.5m and can inspect the pressure tube of 5m in total length by being connected with a 2.5m long extension tube. The positioning precision is ±2.6mm. The durability of the driving mechanism was confirmed up to 500 reciprocations.

Performance confirmed in the out-of pile tests is summarized in Table II.

5. PRESSURE TUBE INSPECTION CARRIED OUT IN THE FUGEN REACTOR

The equipment was used for the inspection of ten pressure tubes of the Fugen reactor during the May 1984 annual inspection. It was found that:

(1) No flaw with more than 2mm in length, 0.1mm in width and 0.1mm in depth was detected, except scars due to the passage of the pressure tube inspection equipment and the fuel assemblies.

(2) At the center of the core, the maximum increase of the inside diameter due to creep was 360 μm which is within the design value.

(3) No degradation of the performance of the equipment was observed even after 55 hours of inspection under a maximum dose rate of 2.5×10^5 R/h.

(4) The inspector's total exposure during the inspection of 10 pressure tubes was 5 man-rem. This was due to associated activities performed before and after the inspection.

Based on these results, the functions and performance of the equipment in practical use were fully confirmed.

6. Acknowledgements

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TABLE I. SPECIFICATIONS OF THE PRESSURE TUBE INSPECTION EQUIPMENT

ULTRASONIC INSPECTION DEVICE (UT)	FLAW DETECTION TYPE	PULSE-ECHO TYPE
	FREQUENCY, ANGLE OF INCIDENCE	5 MHz, 25 DEGREES
	NUMBER OF PROBES	1 CHANNEL FOR LONGITUDINAL 1 CHANNEL FOR CIRCUMFERENTIAL
	DETECTION PERFORMANCE	5.0mm(L)X0.4mm(D)X0.1mm(W) WITH S/N=10dB
INSIDE DIAMETER MEASURING DEVICE (ID)	MEASUREMENT TYPE	ULTRASONIC TYPE (5MHz)
	MEASURING ACCURACY	±20μm
	MEASURING RANGE	117.5mm~119.5mm
INTERNAL SURFACE VISUAL INSPECTION DEVICE (VT)	TYPE	BLACK-AND-WHITE ITV
	DIFFERENTIATION PERFORMANCE	2.0mm(L)X0.2mm(D)X0.1mm(W)
	VISUAL FIELD	HEIGHT 30mmX WIDTH-40mm
VERTICAL DRIVE MECHANISM	TYPE	RACK-AND-PINION TYPE
	SPEED	UT・ID：30mm/min～300mm/min VT：200mm/min～800mm/min
	POSITION DETECTION ACCURACY	±4mm
ROTARY DRIVE MECHANISM	TYPE	GEAR TYPE
	SPEED	UT・ID：0.1～1 rpm VT ：1 rpm
	ANGLE DETECTION ACCURACY	±2 DEGREES
EQUIPMENT OPERATING CONDITIONS	ENVIRONMENT	REACTOR PRIMARY COOLING WATER
	TEMPERATURE	10℃～40℃
	PRESSURE	MAXIMUM 4kg/cm²
	RADIATION	GAMMA RAYS $2X10^{4}$R/h

TABLE II. PERFORMANCE OF PRESSURE TUBE INSPECTION EQUIPMENT

	SPECIFICATIONS	OUT-OF-PILE TEST	PERFORMANCE IN-CORE EXAMINATION IN FUGEN
ULTRASONIC TEST	DETECTABLE DEFECTS: 5.0mm(L)X0.4(D)X0.1mm(W) WITH S/N=10dB	MINIMUM DEFECTS DETECTED: 5.0mm(L)X0.1mm(D)X0.1mm(W):S/N=11dB 2.0 X0.1 X0.1 :S/N= 7dB 1.0 X0.2 X0.1 :S/N=12dB	THE PRESENT OXIDE LAYER DID NOT CAUSE ANY SIGNIFICANT ATTENTION OR DISTORTION OF ULTRASONIC
INSIDE DIAMETER MEASUREMENT	INSIDE DIAMETER RANGES: 117.5mm~119.5mm ACCURACY: ±20μm	ACCURACY CONFIRMED: ±18mm	————
INTERNAL SURFACE VISUAL TEST	OBSERVABLE DEFECTS: 2.0mm(L)X0.2mm(D)X0.1mm(W) UNDER $2X10^5$R/h FOR 30 HOURS	MINIMUM DEFECT DETECTED: 2.0mm(L)X0.1mm(D)X0.1mm(W)	USABLE WITH THE SPECIFIED PERFORMANCE, UNDER $2.5X10^6$R/h FOR 55 HOUR OPERATION
VERTICAL POSITIONING	TOTAL STOROKE : 2.5m ACCURACY : ±4mm	ACCURACY CONFIRMED: ±2.6mm	————

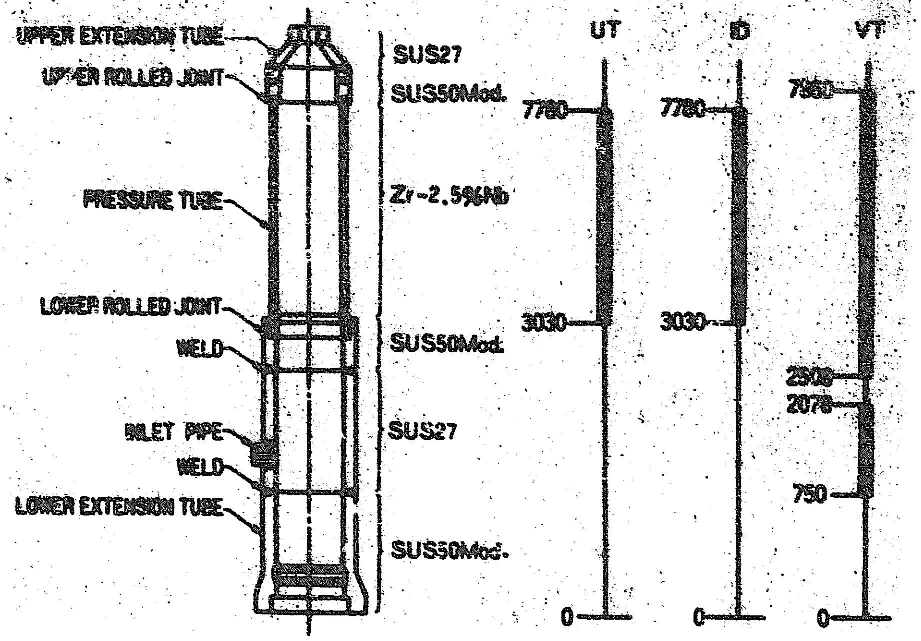
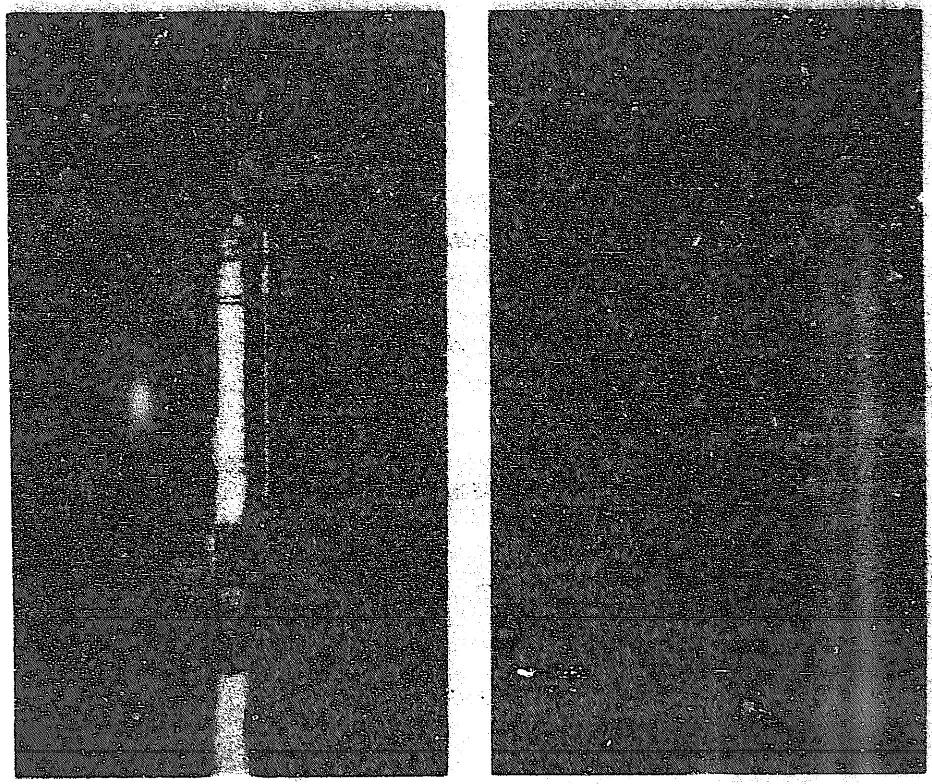


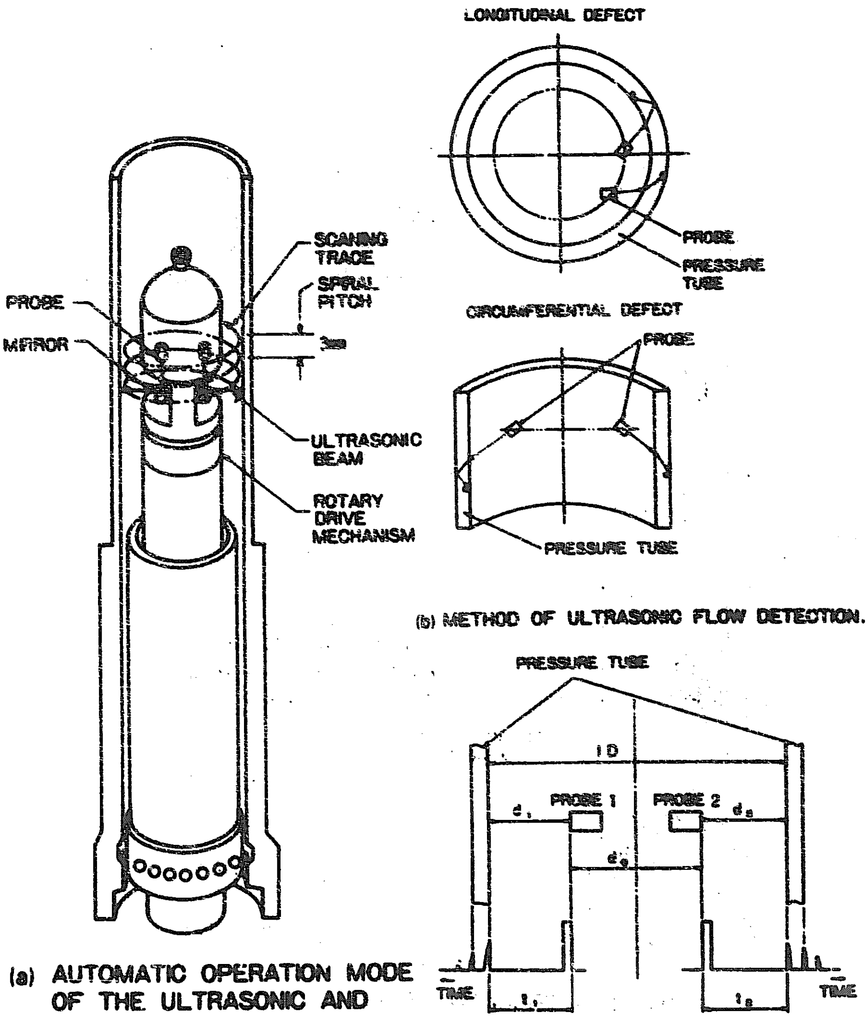
FIG. I. REGIONS OF THE INSPECTION.



(a) ULTRASONIC FLOW DETECTION-INSIDE DIAMETER MEASURING DEVICE.

(b) INTERNAL SURFACE VISUAL INSPECTION DEVICE.

FIG. 2. PRESSURE TUBE INSPECTION EQUIPMENT.



(a) AUTOMATIC OPERATION MODE OF THE ULTRASONIC AND INSIDE DIAMETER MEASUREMENT.

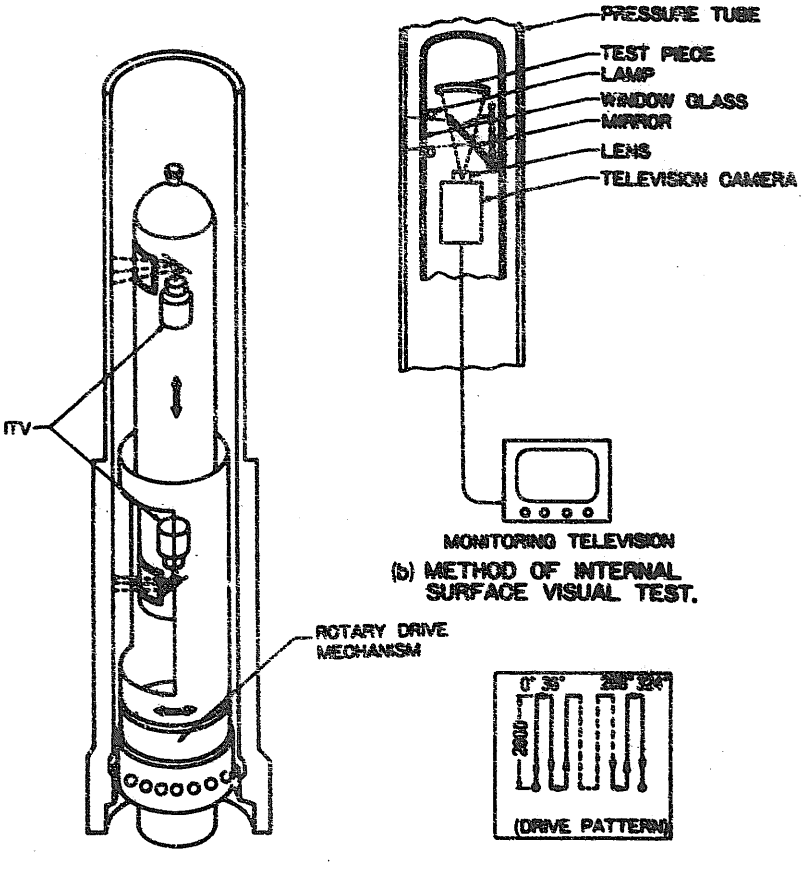
(b) METHOD OF ULTRASONIC FLOW DETECTION.

$$ID = d_1 + d_2 + d_0 = \frac{1}{2}(t_1 + t_2) \times V + d_0$$

V : SOUND VELOCITY IN WATER

(c) METHOD OF INSIDE DIAMETER MEASUREMENT.

FIG. 3. ULTRASONIC FLOW DETECTION - INSIDE DIAMETER MEASURING DIVICE.



(b) METHOD OF INTERNAL SURFACE VISUAL TEST.

(a) AUTOMATIC OPERATION MODE OF THE INTERNAL SURFACE VISUAL TEST.

FIG. 4. INTERNAL SURFACE VISUAL INSPECTION DIVICE.

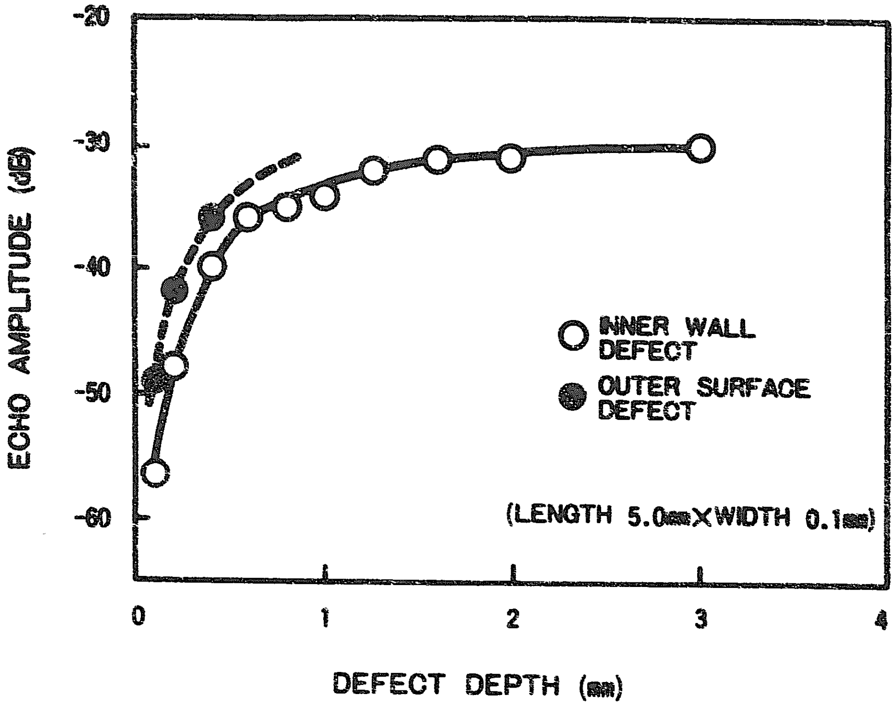


FIG. 5. ECHO AMPLITUDE VS. ARTIFICAL DEFECT DEPTH.

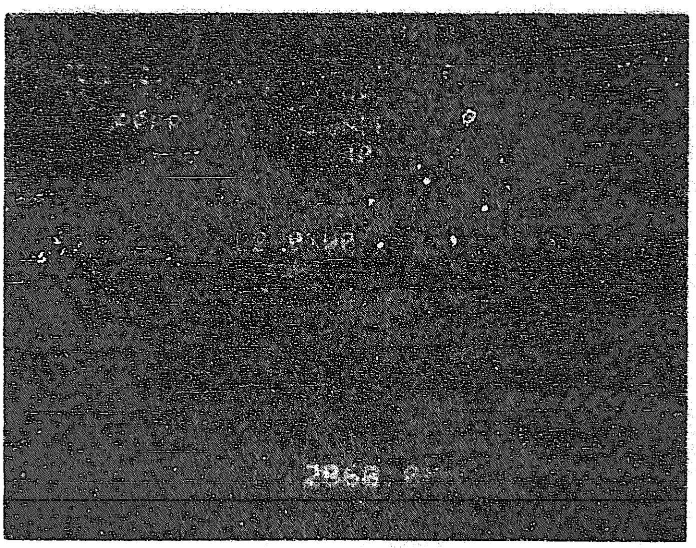


FIG. 6. PERFORMANCE OF INTERNAL SURFACE VISUAL INSPECTION (OUT-REACTOR).