THE AECL FUEL CHANNEL INSPECTION SYSTEM (AFCIS)

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ABSTRACT

Inspection of fuel channels is an important part of a CANDU maintenance program. AECL has an active program to provide support to utilities requiring inspection services. The AECL Fuel Channel Inspection System (AFCIS) has been used to perform the baseline fuel channel inspection of Cernavoda Unit 1, C6, in Romania and the periodic fuel channel inspection of Embalse, C6, in Argentina. AFCIS is comprised of three main components: an Advanced Delivery Machine, two inspection heads, and a data acquisition system. This paper describes the basics of the system.

1. BACKGROUND

AECL has developed a fuel channel inspection system. This system is being used to provide a service to CANDU 6 generating stations and AECL is duplicating the system for Korea. The NDE techniques and systems used have been successfully applied during inservice inspections of Embalse and KANUPP and in the pre-service inspections of Pickering, Bruce, Darlington, Embalse, Gentilly 2, Pt. Lepreau, and Wolsong 1. The gauging techniques have been applied for many years to the dimensional analysis of fuel channels. The delivery machine, the Advanced Delivery Machine, is based upon the Advanced SLARette Delivery Machine, of which AECL previously built two, and the SLARette Delivery Machine, of which AECL previously built three.

Development of the AECL Fuel Channel Inspection System (AFCIS) began in 1998. In the summer of 1999 a week-long performance demonstration was conducted in which AFCIS was evaluated by AECL and the Romanian customer. AFCIS was shown to meet or exceed the requirements of CAN/CSA N285.4 (94). The material surveillance requirement is performed by a different AECL system. AFCIS successfully performed the baseline inspection of Cernavoda Unit 1 in the Fall of 1999. This inspection took place with the operators and instrumentation inside the reactor building.

AFCIS as used at Cernavoda relied heavily upon technology and components developed or used by AECL over the last 20 years. Some improvements are underway to implement the "lessons learned" on that first inspection. These improvements will reduce operator effort and will provide better inspection control, analysis of results, and reporting. In addition, AFCIS has been enhanced to operate with longer cables and a reactor building penetration, to allow the operators and instrumentation to be outside the reactor building.

AFCIS inspected Argentina's CANDU 6, Embalse, in the Fall of 2000 using long cables and a reactor building penetration.

2. THE SYSTEM

2.1 General

AFCIS performs baseline, periodic, and in-service fuel channel inspections to meet and exceed the requirements of CAN/CSA N285.4 (94), except for material surveillance. The following measurements and inspections can be performed:

- flaw detection and detailed characterization,
- wall thickness measurement,
- inner diameter measurement,
- measurement of gap between the pressure tube and calandria tube,
- measurement of pressure tube sag,
- measurement of pressure tube length, although utility fuelling machine data are typically used to provide these results, and
- measurement of garter spring (spacer) location.

Figure 1 is a sketch of the system. The main sub-systems of AFCIS are:

- the Advanced Delivery Machine (ADM), described further in Section 2.2,
- two inspection heads, described further in Section 2.3, and the
- Data Acquisition System (DAS), described further in Section 2.4.

2.2 Advanced Delivery Machine

The system that delivers the inspection heads into the CANDU fuel channel consists of an Advanced Delivery Machine (ADM) with its remote control panel and D_2O Valve Stations. This system is based on AECL's Advanced SLARette delivery systems, which has have been in use at Gentilly 2 (Quebec) since 1995 and Point Lepreau Generating Station (New Brunswick) since 1999.

The ADM, which requires minimal manual operation, is placed on a work platform mounted under the fuelling machine bridge. The bridge and platform provide coarse positioning of the machine on the reactor face, with fine positioning being performed using the ADM axial and vertical adjustment drives remotely controlled by ADM operators.

The ADM (Figure 2) consists of the following subassemblies, including two supporting valve stations (carts):

- Primary Turret
- Secondary Turret
- Calibration Tube
- Telescoping Ram Tubes (3 tubes)
- Table Frame
- Front & Rear Supports (pedestals)
- Locking Tool
- Umbilical Cable
- Control Panel
- Tool D_2O Valve Station
- D_2O Valve Station (Vent and Fill Cart).

The manually operated Primary and Secondary Turrets are used for clamping onto the target end fitting, removing and storing the closure plug and allowing access for the tool and ram tubes into the fuel channel. Connecting the turrets is a Transition Tube which advances to the end fitting seal ring and provides a constant fuel channel nominal bore for equipment entering the channel. Machined features in the transition tube are also used to calibrate the diametrical measurement probes of the inspection head during the fuel channel periodic inspection process.

Mounted to the outboard end of the turrets is the Calibration Tube which contains a number of machined notches, features and fuel channel components that are used to calibrate the eddy current and ultrasonic transducers on the inspection heads. The on-line calibration is performed on the reactor face just before the tools are inserted into the fuel channel, and provides verification that all components are functioning properly.

A Ram Tube Assembly, consisting of three telescoping rams, extends axially and transports the inspection heads (SLAR tool possibly) back and forth through the fuel channel. The ram motion is controlled remotely from a panel in the control room and actuated by variable speed drive motors, ball screws, limit switches, etc., located on the Table Frame.

Located on the leading end of the Ram Tube Assembly is the Locking Tool. The tool, which is actuated by the Tool D_2O Valve Station, is used to facilitate the mechanical latching operations of the telescoping rams. The tool also has the capability of providing a restraint for future functions such as pressure tube sampling (axial and circumferential). Also, the leading face of the Locking Tool acts as a mount for the inspection head connector block which houses the inboard end of the umbilical cable.

The umbilical cable is a multi-purpose bundle of electrical, pneumatic, and hydraulic lines designed for use with all inspection heads. The umbilical connects the head and Locking Tool to a DAS junction box situated at the end of the ADM. The umbilical cable runs through the centre of the delivery machine rams, and provides all electrical, pneumatic, and hydraulic lines to actuate motors and pistons in the Locking Tool and in the heads. There are also many coaxial and twisted pair cables that are signal lines that communicate between the DAS and the heads. The same umbilical can be connected to either inspection head

During inspection operations, the target fuel channel must be de-fueled and the shield plugs removed. The ADM is then clamped to the target fuel channel, filled with D_2O and pressurized by the D_2O Valve Station and the closure plug is removed. The ADM then delivers the inspection head into the fuel channel while maintaining the primary heat transport pressure boundary.

The axial stroke of the ADM is sufficient to allow for full insertion of the working parts of the inspection heads beyond the far end rolled joint in an end of life (i.e., 210,000 EFPH) CANDU 6 fuel channel. Placement accuracy is within $\pm$ 5 mm of the specified location with a resolution of 0.2 mm. The ADM also has rotational placement capability and can position the inspection head in any rotational orientation to within $\pm 5°$. The axial velocity of the ADM ranges from 0.5 mm/sec to 55 mm/sec while the rotational velocity goes from 1 deg/sec to 30 deg/sec.

The ADM is registered as a Class 1 Temporary Fitting, and is designed for operation in fuel channels at pressures up to 345 kPa(g) (50 psig) with an upset condition of 1.38 Mpa(g) (200 psig) with the reactor in a guaranteed shutdown state.

To date the ADM and ASDM have successfully participated in outage campaigns at Gentilly 2 (SLARette 1995, 1996, 1997, 1998 – double ended, 1999), Pt. Lepreau (SLARette 1999, 2000), Cernavoda (PIP 1999) and Embalse (PIP 2000).

While the ADM has been designed for use in CANDU 6 reactors, with a few minimal adjustments it can also be used on the Pickering type reactors.

2.3 Inspection Heads

A head (tool) is inserted into the fuel channel by the ADM to perform measurements. Heads are mechanically interfaced to the delivery machine ram through a Locking Tool. There are two types of head:

- NDE Head, Figure 3, and
- Re-Inspection Head, Figure 4.

The NDE Head is used for general NDE and dimensional gauging of fuel channels. It meets all of the requirements listed in Section 2.1. Figure 3 depicts the NDE Head as used in the Cernavoda Unit 1 baseline inspection. The head has three main modules and five minor modules. The minor modules provide electrical connection, centering of the inspection head in the fuel channel, and flexible mechanical support.

The Rotating Inspection Module (RIM), at the top of Figure 3, houses the probes that require a helical scan pattern for full volume coverage. Rotational drive to the Rotating Inspection Module is provided by the Motor Module. Probes in the RIM are:

- five ultrasonic probes for flaw detection and characterization,
- two eddy current probes for flaw detection and characterization,
- a wall thickness probe, and
- an inner diameter probe.

The Sag Module contains probes that do not require constant rotational motion, but rather use the rotational motion provided by the ADM rams. These probes include:

- eddy current probes for pressure-to-calandria tube gap measurement,
- eddy current probe for spacer (garter spring) detection, and
- displacement probes used to measure pressure tube sag.

The Re-Inspection Head is used only when more detailed characterization of fuel channel flaws is required than was possible with the NDE Head. On near surface flaws, it performs video examination, replication (for tip radius measurement), and high frequency ultrasonics. An eddy current capability is also incorporated, to aid in locating the flaw. The head is comprised of 4 sections: the video module, the NDE module, the replicating module, and the connector extension.

2.4 Data Acquisition System

2.4.1 Introduction

The DAS includes the following:

- the junction box,
- the trunk lines,
- the instrumentation racks, containing instruments, cabling, and five, IBM-PC compatible, industrial computers, and
- the software installed in the five industrial computers.

The DAS junction box is located on the platform, which is suspended from the fuelling machine bridge on the reactor face. The DAS trunk lines travel from the instrumentation racks outside of containment, through a penetration, to:

- the DAS junction box, or,
- the ADM.

2.4.2 Instrumentation Racks

The DAS has several functions. It provides control of the ADM and two heads. It also provides data acquisition, display, and storage of data from probes on the heads. Data are displayed in a number of standard NDE and gauging formats, required for expert analysis and reporting. All data, except video, are written to a permanent archiving medium.

For the Cernavoda inspection, the DAS system components were mounted in the eight racks listed in Table 1.

Communication within the DAS is performed by the following:

- trunk lines dedicated to ADM operation, which are terminated at either of racks 5 or 6,
- trunk lines dedicated to operation of either of the two heads, which start at the junction box (Figure 1) and are terminated either at (1) rack 7 if the NDE Head is installed or (2) at rack 4 if the Re-Inspection Head is installed,
- signal lines from the NDE head (or the Re-Inspection Head if it is installed) required for racks 1, 2, 3, and 4 are distributed from rack 7
- the Position Bus (PB), which originates at rack 7 and is distributed to racks 1, 2, 3, and 4,
- the analog communications bus, which connects every rack except for rack 6, and contains interlocks, Emergency Stop signals, and other control signals, and
- a LAN for transfer of data, which connects racks 1, 2, 3, 4, and 7.

TABLE 1: DAS Racks

	Rack Name	Purpose
1	Ultrasonic (UT)	perform UT inspection, and UT flaw characterization
2	Eddy Current (ET)	perform ET inspection and ET flaw characterization, garter spring detection, and gap analysis
3	Dimensional Gauging	perform measurement of sag, wall thickness, and diameter
4	Re-Inspection	perform video inspection, and control of the replication module in the Re-Inspection Head
5	ADM Control	contains the computer and hardware to interface to the ADM
6	ADM components	contains gauges and pressure control devices for the ADM tool cart
7	SCADA	drives the Position Bus, controls RIM rotation, and controls retract and release of probes in the RIM
8	System Power	contains the transformers to interface between site power and (1) the instrumentation in the other racks on one circuit or (2) the uninterruptible power supplies and the computers on the other racks on another circuit.

The PB enables the Data Acquisition Computers (DACs) in racks 1, 2, and 3, to collect data on the same coordinate system, defined by the inspection requirements. There are three positions transmitted on the PB:

- RIM rotational position,
- Sag Module rotational position, and
- axial position of the inspection head.

The four inspection racks, 1, 2, 3, and 4, require only minimal connections with each other. Therefore, it is possible to remove one, or more, racks from the system and the other racks will work as designed.

Inspection racks 1, 2, and 3 all have a very similar layout. The inspection instrument is in the top of the rack. Below this is the monitor and keyboard for the inspection DAC. Below this is the analog adapter that interfaces the DAC to the instrument and the PB. Below this is the DAC and on the bottom is the printer, which outputs all of the information required for that rack.

3. OPERATION

AFCIS can be transported from its home base at Chalk River Laboratories to CANDU-6 stations to perform periodic or in-service fuel channel inspections. Installation and layout at reactor stations is temporary, and is expected to vary slightly from station to station.

Before a fuel channel inspection, the fuel channels are de-fueled, and both shield plugs removed with the station fueling machine. AFCIS is un-packed and mock-up testing performed to ensure damage did not occur during shipment. An inspection head and umbilical cable will then be installed in the delivery machine before transport into the reactor building. The delivery machine, with head loaded, is mounted on a platform that is under the fueling machine bridge. Typically, the platform is supplied by the site. Typically, the site also supplies staff to perform the manual, reactor face, operations required by the ADM.

During normal operation, the following sequence of events occurs for each channel inspected:

- the ADM clamps onto a fuel channel,
- the system performs a calibration verification scan,
- the entire fuel channel is scanned, using two or three passes,
- a final calibration verification scan is then performed, and
- the ADM un-clamps.

The delivery machine then moves to the next channel and repeats the process above, beginning with closure plug removal. During all scan passes, for both calibration verification and channel examination, data will be collected and stored by the computer-controlled data acquisition system.

Channels containing indications that cannot be characterized using the capabilities of the NDE Head are re-inspected with the Re-Inspection Head, which performs video or ultrasonic examination and obtains soft replicas if necessary.

An operator, with expertise in the relevant inspection technique, sits in front of each rack, and controls the instrumentation, and the collection, display, analysis, and archiving of data on that rack. For the Cernavoda inspection, there was a crew of five operators supplied by AECL, plus two more operators supplied by site for reactor face duties. The five AECL operators were:

- a gauging expert,
- an eddy current expert,
- an ultrasonics expert,
- an ADM expert, and
- a crew supervisor, responsible for the correct performance of the inspection on their shift.

Routine maintenance on the system is performed at Chalk River Laboratories, using a combination of decontamination and mock-up facilities.

4. SUMMARY

The AECL Fuel Channel Inspection System is based upon technology developed over the last 20 years at AECL. It can be used for periodic and inservice fuel channel inspection that meet or exceed CAN/CSA N285.4 (94). The system detects and characterizes flaws and makes measurements of pressure tube: sag, inner diameter, wall thickness, length, and the gap between the pressure tube and the calandria tube.

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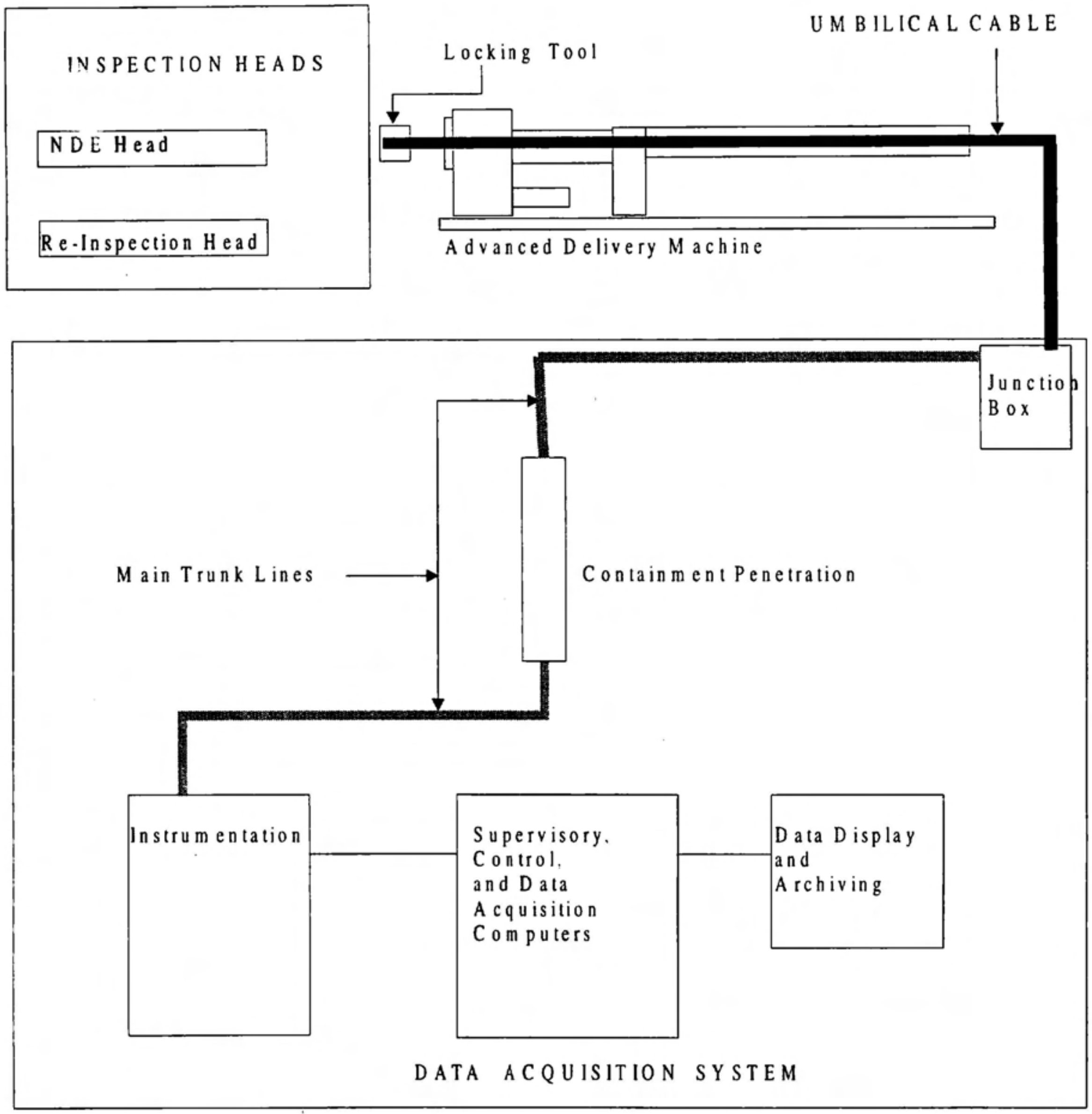

FIGURE 1: General System Layout

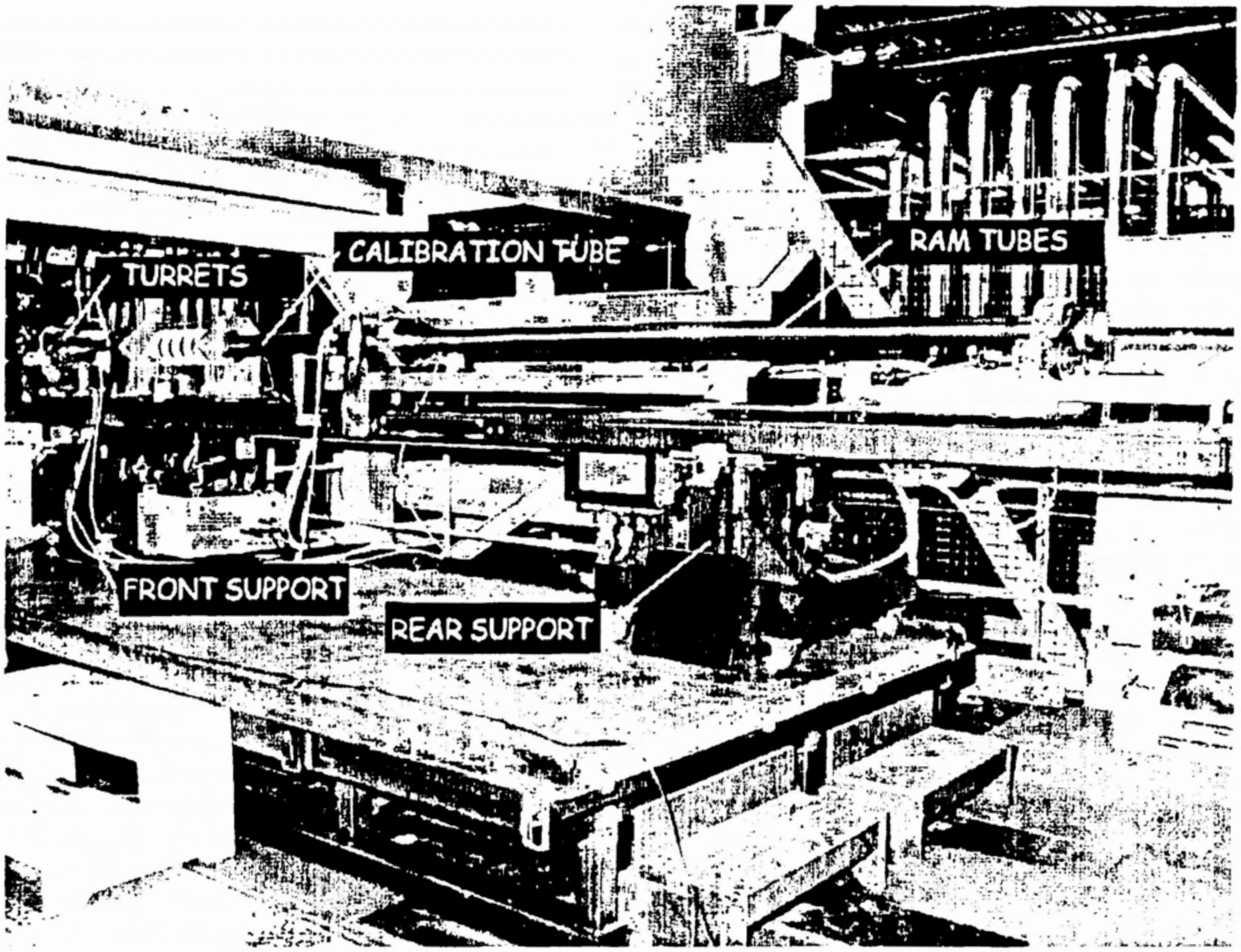

FIGURE 2: Advanced Delivery Machine

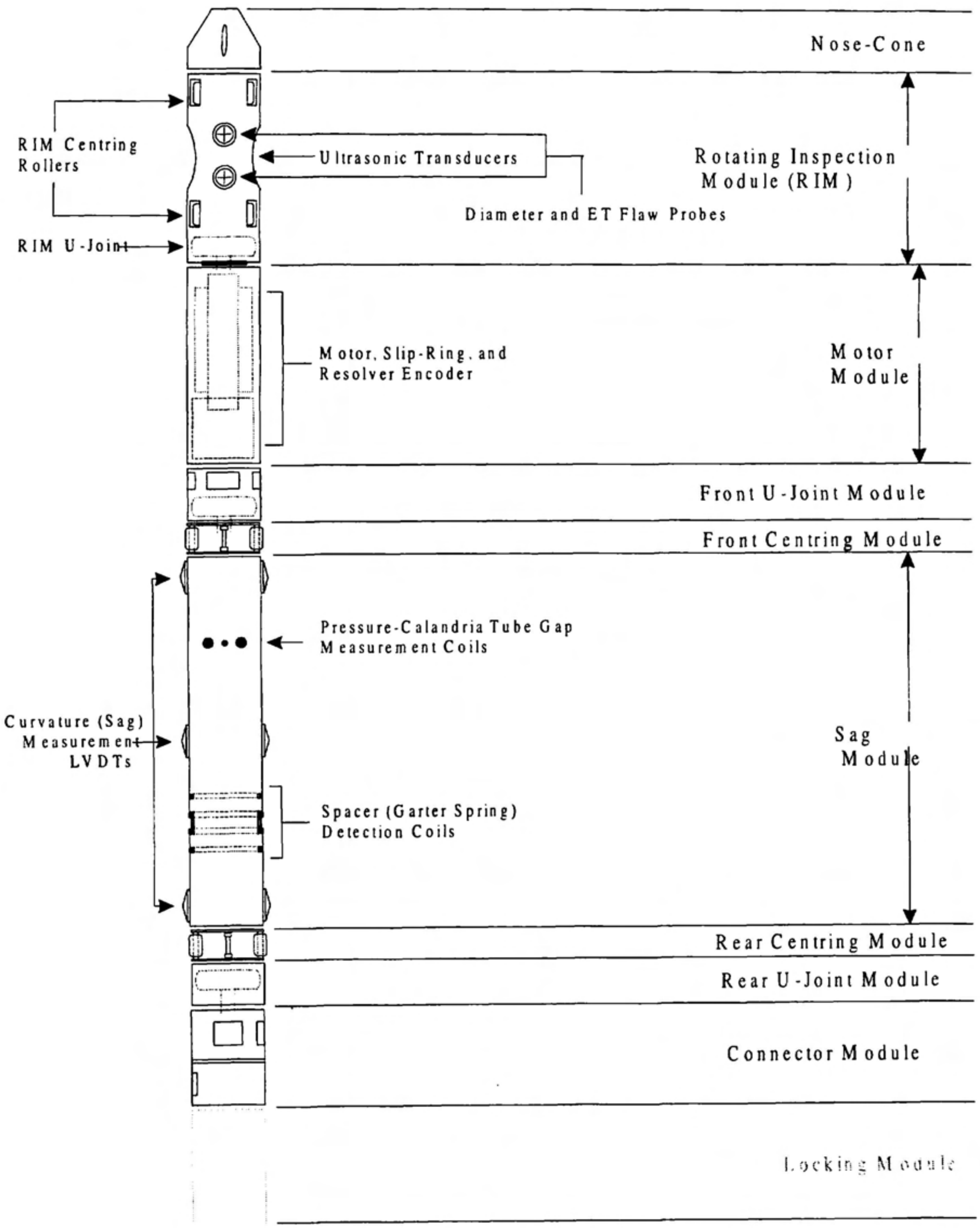

FIGURE 3: NDE Head

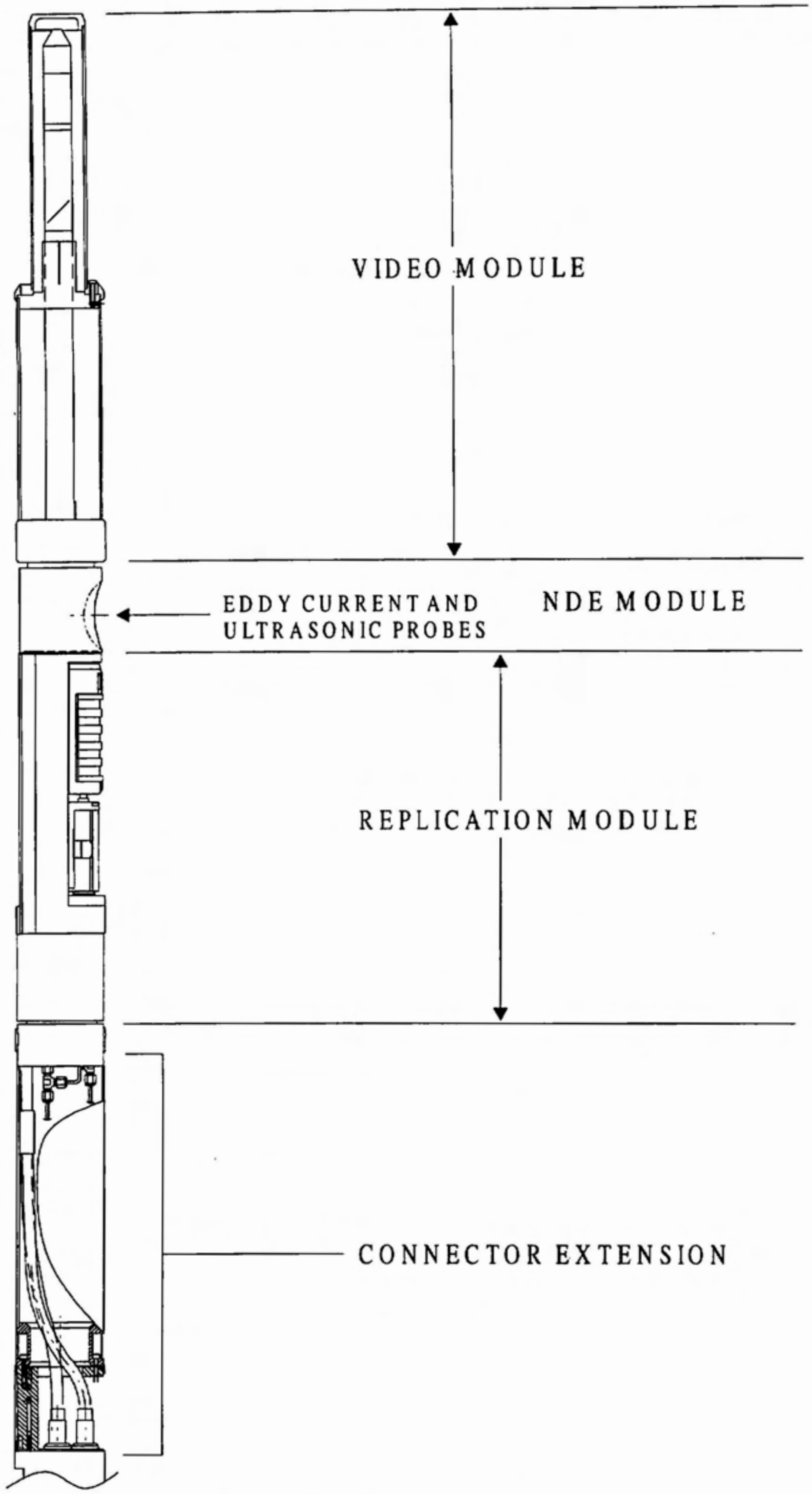

FIGURE 4: Re-Inspection Head