

SENSOR HEAD DRIVE SYSTEM FOR INSPECTION OF FUEL CHANNELS IN CANDU REACTORS

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ABSTRACT

The failure of a pressure tube in Pickering Nuclear Generating Station 'A' in August 1983 created an urgent requirement to inspect other pressure tubes as quickly as possible. Equipment consisting of a drive, drive rod conveyor system, and the associated control and instrumentation was designed, developed, manufactured, tested and delivered in less than 4 weeks by Atomic Energy of Canada Limited, CANDU Operations.

This paper describes this remote controlled and operated system which is used to drive an inspection head in a programmed sequence, and to provide sensor head axial and polar position information in conjunction with the inspection data.

INTRODUCTION

In August 1983 a failure of a pressure tube in the Pickering 'A' Unit 2 reactor and its subsequent failure analysis identified the need to nondestructively examine other fuel channels.

Ontario Hydro had, at the time, taken delivery of a highly automated system for nondestructive examination of fuel channels [1] for their CANDU nuclear reactors, which was called CIGAR, for "Channel Inspection and Gauging Apparatus for Reactors", to perform pressure tube gauging, full volumetric ultrasonic flaw inspection, pressure tube-calandria tube gap measurement and pressure tube sag measurement. The equipment consisted of an inspection head equipped with the necessary transducer modules, a special channel closure, a drive mechanism with a

control system, and a data acquisition system.

However, the complete CIGAR system, with a fully integrated drive mechanism, was still being commissioned by Ontario Hydro and as such, was not yet available when the sudden need arose to perform inspections at Pickering 'A'. A simplified version of CIGAR, dubbed "CIGAR-ette" was conceived to make use of CIGAR's inspection head, connector rods and special fuel channel closure. The CIGAR-ette drive mechanism and control system was designed and custom built at the CANDU Operations facilities of Atomic Energy of Canada Limited in Mississauga, Ontario, to perform the basic functions of positioning control and data acquisition to meet Ontario Hydro's immediate inspection requirements.

When the need to establish the condition of the pressure tubes was defined as an essential factor in determining the immediate plans for maintenance or operation of the reactors, work was immediately started and the first sensor drive and control unit compatible with CIGAR was designed, built, tested and delivered to the station within four (4) weeks of determining, with Ontario Hydro, the general design requirements. No time was available for prototype development. To meet the very tight schedule restraints, the approach taken in the design and development of the system was to use commercial components which were available off-the-shelf and to temper the design to suit component availability as the design proceeded in parallel with the initial manufacturing, assembly and development testing.

GENERAL

A fuel channel and the principal components of interest for the inspections are shown in Figure 1. The installed inspection equipment is also depicted.

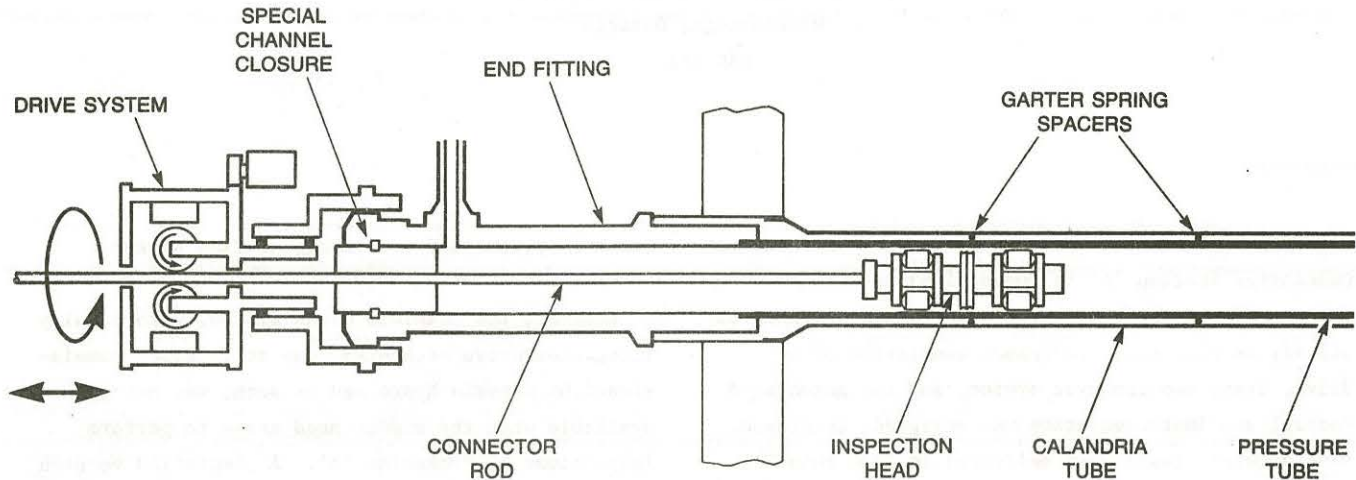


FIGURE 1 CHANNEL INSPECTION

The fuel channel inspections required were: the examination of the condition of the pressure tube, the detection of the location of garter spring spacers in the annulus gap between the pressure tube and the surrounding calandria tube and the determination of the spacing between the pressure tube and the bottom of the calandria tube. The CIGAR inspection head provided the capability to perform all of these measurements, including the detection of garter springs by a proven technique using the eddy current modules of CIGAR.

The inspections are performed with the reactor shut down. Prior to installing CIGAR-ette to inspect a fuel channel, the reactor fuelling machines first partially defuel or displace fuel to one end of the channel to be inspected and install a special fuel channel closure that houses the inspection head, into the opposite end fitting of the fuel channel. The fuel channel thus does not have to be drained.

The CIGAR-ette drive equipment is also mounted on the fuelling machine bridge. To bring the conveyor

and drive mechanism to the channel with the special closure installed, the fuelling machine bridge, fitted with working platforms on which the conveyor can move laterally is positioned at the desired elevation. The drive mechanism is manually attached to the out-

board end of the end fitting external to the fuel channel pressure boundary. The closure is penetrated by the head connector rod which passes through seals and a bushing and is mechanically and electrically connected to the inspection head. The drive system connected to the rod supports, conveys and drives the connector rod and in turn the inspection head. The connector rod and integral cable pass through the drive mechanism and the portion of the connector rod and cables outboard of the drive mechanism is supported and guided by a conveyor. All cables from the end of the conveyor pass through a containment wall penetration to the inspection instrumentation located outside of the reactor building where the drive system is remotely controlled from a console.

Following system set-up, the inspection of one channel is typically completed in three hours, during which the data obtained is viewed and recorded on strip chart hardcopy and on videotape for replay. The filtered and digitized signals are processed on a computer program to obtain statistical and profile information.

DRIVE SYSTEM

GENERAL

The drive mechanism (see Figure 2) comprises an assembly which is manually clamped to the fuel channel end fitting and provides and transmits both rotary and axial motion to the inspection head through the connector rod. Gearing and potentiometer linkages provide position indication of rotary and axial displacement. The assembly consists of a fixed structure attached to the end fitting and an outboard structure supported by the fixed structure which can rotate relative to it. The fixed structure houses the end fitting mechanical clamp, the rotary drive and the rotary position feedback sensor, while the outboard structure houses the axial drive assembly, connector rod clamp and the axial position readout assembly.

ROTARY DRIVE ASSEMBLY

The fixed structure consists of a sleeve which fits onto the end fitting and two circular aluminum plates all held together by 3 tubular posts. The end fitting sleeve contains a clamp mechanism to secure the drive assembly to the end fitting. Mounted in the intermediate and end circular plates are radial anti-friction bearings which support the shaft to which the axial drive assembly is bolted. The drive for rotational movement is mounted on a horizontal plate between the intermediate and end plates. The rotary drive uses an electrical stepping motor to drive a double-worm reduction gearbox. A pinion gear on the output shaft of this gearbox engages with a spur gear attached to the shaft which supports the axial drive assembly. A 10 turn potentiometer is driven through a gearing arrangement to provide rotational position information.

The rotational drive range is 406° controlled between fixed stops by two limit switches which stop the rotary drive 5° before solid mechanical stops at each extreme.

AXIAL DRIVE ASSEMBLY

The axial drive assembly is comprised of two circular aluminum discs connected together and

spaced apart by 2 tubes and one round bar and bolted to the shaft which is supported within and driven by the rotary drive assembly. The connector rod axial and rotary motions are transmitted to the rod by two radially grooved rollers which contact opposite sides of the rod 180° apart. The rollers are each mounted in yokes, one of which is fixed and one which is driven by an air cylinder to produce a friction contact force between the rollers and the connector rod. Rotational drive is applied to the grooved roller of the fixed yoke through the gears driven by an electrical stepping motor. This motor, identical to that used on the rotary drive, provides incremental motion to the roller for axial position of the inspection head.

EMERGENCY CLAMP

An emergency clamp is mounted on the axial drive assembly. Its function is to grip the connector rod to prevent it from being pushed out of the fuel channel by the primary system pressure in the event that the axial drive rollers inadvertently become disengaged in an event such as a loss of air supply pressure. The clamp force is produced by a preload on two stacks of Belleville springs which is applied when an air cylinder is not energized. A limit switch mounted on the clamp is interlocked with the control logic to prevent axial drive whenever the clamp is applied.

AXIAL POSITION READOUT ASSEMBLY

Linear position information for the inspection head is provided by a potentiometer assembly which is attached outboard of the outer frame disc. This assembly is held against the connector rod by a spring which holds a controlled diameter roller against the rod. This arrangement ensures that the true position of the rod and inspection head is given independent of the axial drive. A shaft through the roller drives a 10 turn potentiometer through a reduction gearbox and gives coarse position information, while fine position is provided from a continuous, single turn potentiometer driven through a pair of gears from the same roller shaft.

A roller actuated limit switch in contact with the connector rod, operated by a recessed flat on the

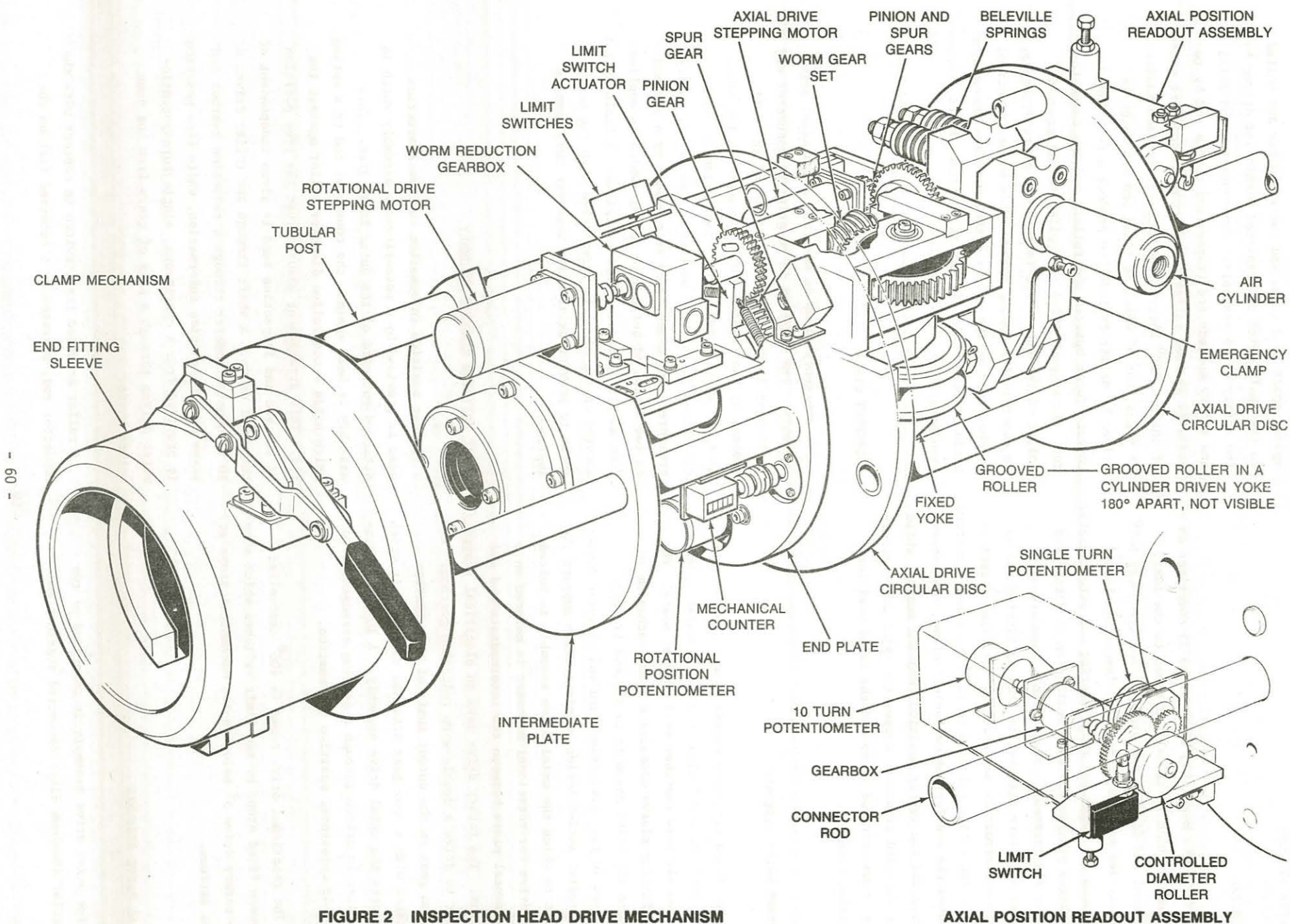


FIGURE 2 INSPECTION HEAD DRIVE MECHANISM

AXIAL POSITION READOUT ASSEMBLY

electrical connector attached to the end of the connector rod, is used to stop the drive before the electrical connector can pass between the drive rollers. The drive is actually stopped so that the end of the connector rod is in a position to facilitate the removal of the electrical connector for installing extensions to drive rods. The design provides that position information from the potentiometers is maintained and not lost during such operation.

ELECTRICAL CONTROL AND READOUT

Both the axial and rotational drives are powered by stepping motors controlled by preset indexers (see Figure 3). The number of steps corresponding to a certain range of axial travel and rotational angle and drive speeds are preset in accordance to the scan required of the particular inspection sequence. One step on the "axial" preset indexer corresponds to 0.007 mm of axial travel. Speed can also be selected between 100 mm per minute to 950 mm per minute. One step on the "rotational" preset indexer corresponds to 0.005° of rotation and the speed can be selected between 0.3 rpm to 3.0 rpm.

Three digital panel meters (DPM) are part of the Position Feedback System. Axial position is displayed on two DPM's - "COARSE" DPM giving axial position in metres over the full axial travel (approximately 9.00 m) and "FINE" DPM giving axial position in millimetres over a range of approximately 85.00 mm.

Rotational position is displayed in degrees over a normal 000.00 to 360.0 degree range. The maximum range which can be displayed (between CW and CCW limits) is approximately -18.0 to +378.0 degrees.

Three BNC connectors, located on the control cabinet side wall, are connected in parallel with 0-5V analog position signals for use with external equipment.

The drive system can be operated in manual mode, where all motions are under full control of an operator, or in an automatic mode, where sequence of axial and/or rotational movement is initiated in accordance to the preset parameters by the program in a Modicon Programmable Controller. Combinations of axial, rotational, or both axial and rotational movements can be selected for the program. The program can be stopped or modified during operation if required.

All function controls, indicating lights and digital panel meters are consolidated on the control panel, where the electrical components are housed. The control panel is located outside of containment and connected to the equipment by cables passing through the reactor building containment wall penetrations.

CONVEYOR SYSTEM

The conveyor (see Figure 4) is a structure which provides support, alignment and low friction guidance for the portion of the connector rod which is out-board of the drive and support for the inspection head electrical cables connected to the rod. The conveyor is aligned with the drive using a laser target system. A helium-neon laser tube attached to the drive frame is used to align targets located on the conveyor. The targets are positioned by operating the conveyor drives.

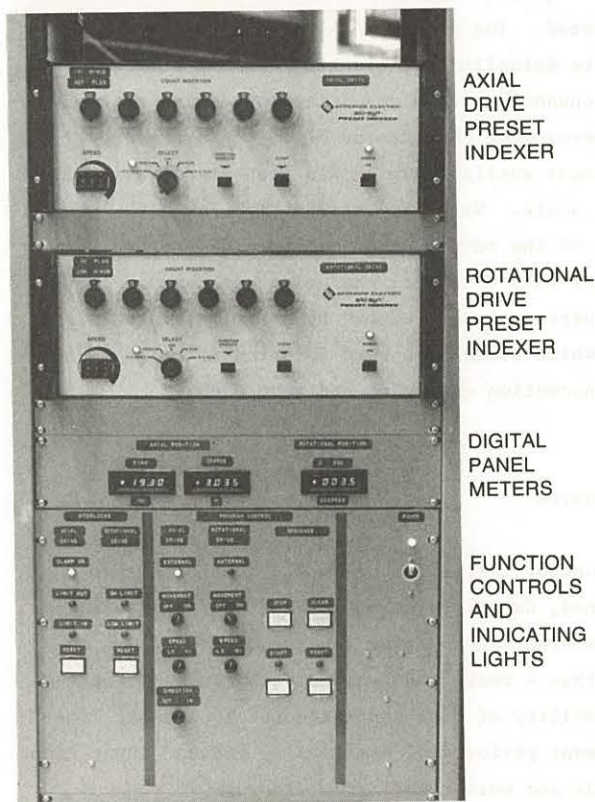


FIGURE CONTROL PANEL

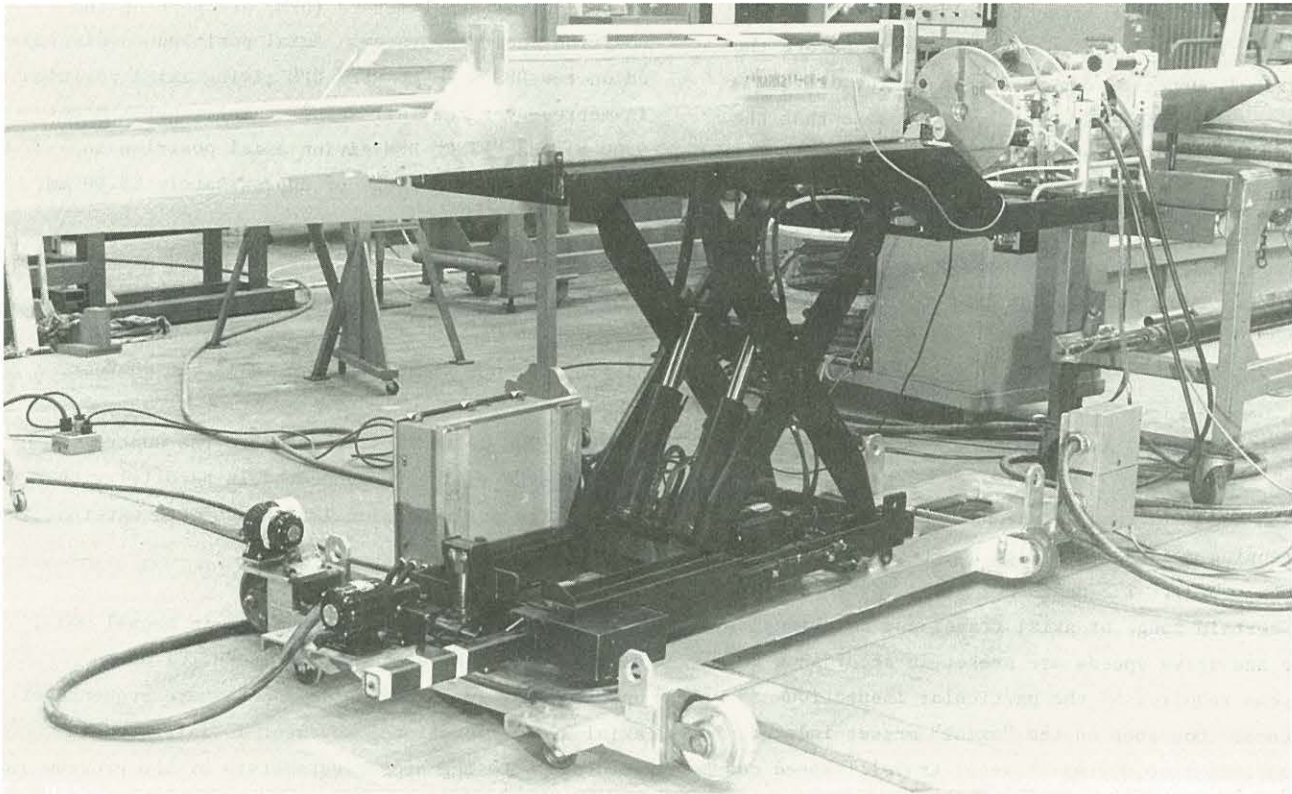


FIGURE 4 CONVEYOR ALIGNED WITH THE DRIVE SYSTEM CLAMPED TO THE END FITTING DURING TESTING

The conveyor also provides a storage location for one or both of the 14 foot connector rods and for the drive assembly when these components are not in use. The conveyor supports the electrical cables and junction boxes for the drive assembly and also the pneumatic valve panel which contains the drive pneumatic equipment.

The conveyor vertical positioning is achieved by a scissor mechanism located on a carriage which can move horizontally. The collapsible feature allows full utilization of the fuelling machine bridge to access fuel channels at any location on the core with the equipment still on the fuelling machine bridge. Tilt positioning achieved by a separate tilt mechanism is also provided. All movements for the conveyor positioning are motorized and controlled from a control panel located near the conveyor. The drives are monitored directly by limit switches, to limit travel or indicate position. Associated indicating lights are located on the control panel.

EQUIPMENT PERFORMANCE

In the four months immediately following delivery

of the equipment, over sixty fuel channels were inspected. The use of this equipment did not require defuelling or blanking-off and draining of fuel channels. The resulting inspection rate was an improvement by a factor of 10 to 15 times over the equipment available which had been used previously on small scale. With the reduced time for each inspection and the advantage of maintaining the fuel channel full of water, radiation exposure to operating personnel was reduced by a similar factor from that which would have been incurred if the dry-channel inspection equipment had been used.

CONCLUSION

A unique inspection drive and control system was designed, developed, manufactured and successfully implemented. The urgent requirements were met in less than 4 weeks and avoided delay in awaiting the availability of more sophisticated equipment. The equipment performance drastically reduced inspection periods and worker radiation exposure.

This success is attributed to the concerted effort of the design, laboratory and operations

staff of Ontario Hydro and Atomic Energy of Canada Limited. The innovativeness of OH and AECL staff in conceiving a new and compatible system, the speed with which AECL was able to respond and the nearly 'round-the-clock' effort all groups contributed to a demanding and complex challenge, all combined to successfully achieve the inspection objectives.

REFERENCES

- [1] J.A. BARON, et al., "Improved Pressure Tube Inspection in CANDU Reactors", Nuclear Engineering International, December 1981, pages 45-48.