A TROLLEY MOUNTED MAGAZINE FOR REACTOR MAINTENANCE

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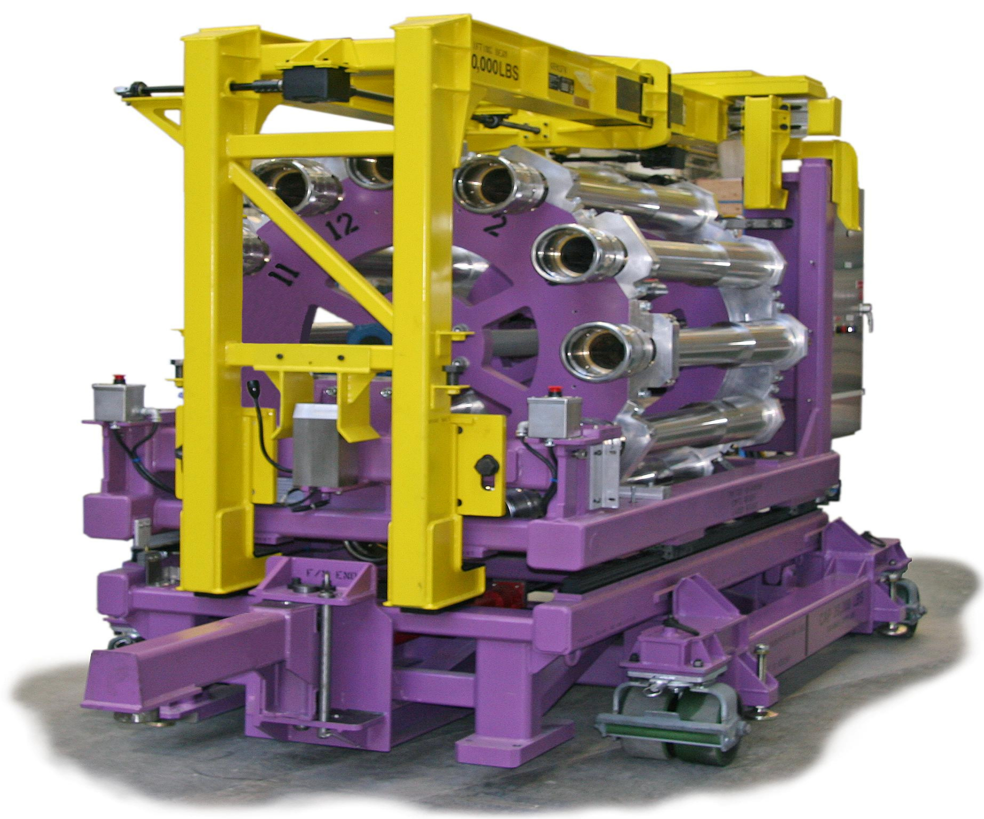
ABSTRACT

This paper describes the design of a mechanism incorporating a rotary magazine to be mounted on a fuelling machine transport trolley for use at a Darlington reactor during a feeder replacement or maintenance outage. The magazine stores reactor channel maintenance components, such as channel isolation plugs and vented closure plugs, in twelve available magazine channels. Use of the magazine rather than a fuelling machine reduces the time required to transfer such components between the Central Service Area and reactor channels. Component transfers are accomplished by locking the fuelling machine onto one of the magazine channels and using a local controller to execute commands received from the fuel handling control system.



1. Introduction

Reactor channel feeder pipes at Darlington N.G.S. have shown signs of local erosion over the life of the reactors. A feeder replacement program has been implemented by Ontario Power Generation (OPG) to cut and replace the affected sections of feeder pipes. To facilitate this, portions of the target feeders and respective channel end fittings must be temporarily isolated from the primary heat transport system. This is achieved by first defuelling the channel, then exchanging the reactor shield plug (SP) and channel closure (CP) with a channel isolation plug (CIP) and a modified (vented) closure (VCP), using the fuelling machine (FM). The target feeder pipe is then frozen off at a strategic location on the header side of the defect. During the freezing operation, the VCP will be manually operated to relieve pressure without the FM present. After the freezing operation, the VCP is used to manually drain the isolated portion between the CIP and the ice plug to allow the feeder cutting and welding operations to commence.

In early 2007, GE-Hitachi Nuclear Energy Canada (GEH) was commissioned by Inspection, Maintenance and Commercial Services (IM&CS) division of Ontario Power Generation to conceive and develop the means for manipulating these components using the FM on a transport trolley at the target reactor. In addition, a means of protecting the reactor shield plugs against oxidization was required.

To facilitate the manipulation of the SP's, CP's, CIP's and VCP's during feeder replacement campaigns, the Trolley Mounted Magazine (TMM), a twelve-channel rotary magazine apparatus, is installed on the trolley in front of the FM. As directed by commands from the fuel handling (FH) control system, the FM can travel between the TMM and a reactor channel to exchange components as required.

Once the component exchanges are complete, the SP's and CP's remain in the TMM channels, either on or off the trolley, until they are to be returned to the reactor in a typical manner.

The TMM's greater storage capacity over that of the FM means time saved in fewer trolley runs between a reactor and the Central Service Area. This arrangement also reduces radiation dose, as manual shield plug handling is not required.

2. System Description and Arrangement

As shown in Figure 1, the TMM is a twelve-channel rotary magazine apparatus that is installed on the trolley such that the top channel is laterally and vertically aligned with the centreline of the FM snout.

When the TMM upper frame is in the fully extended position (i.e., toward the FM) the TMM channel E-face is axially aligned with an uncrept "A" type reactor end fitting. To accommodate FM seal ring maintenance, the TMM upper frame assembly can be axially retracted to its transportation and storage position (Figure 1).

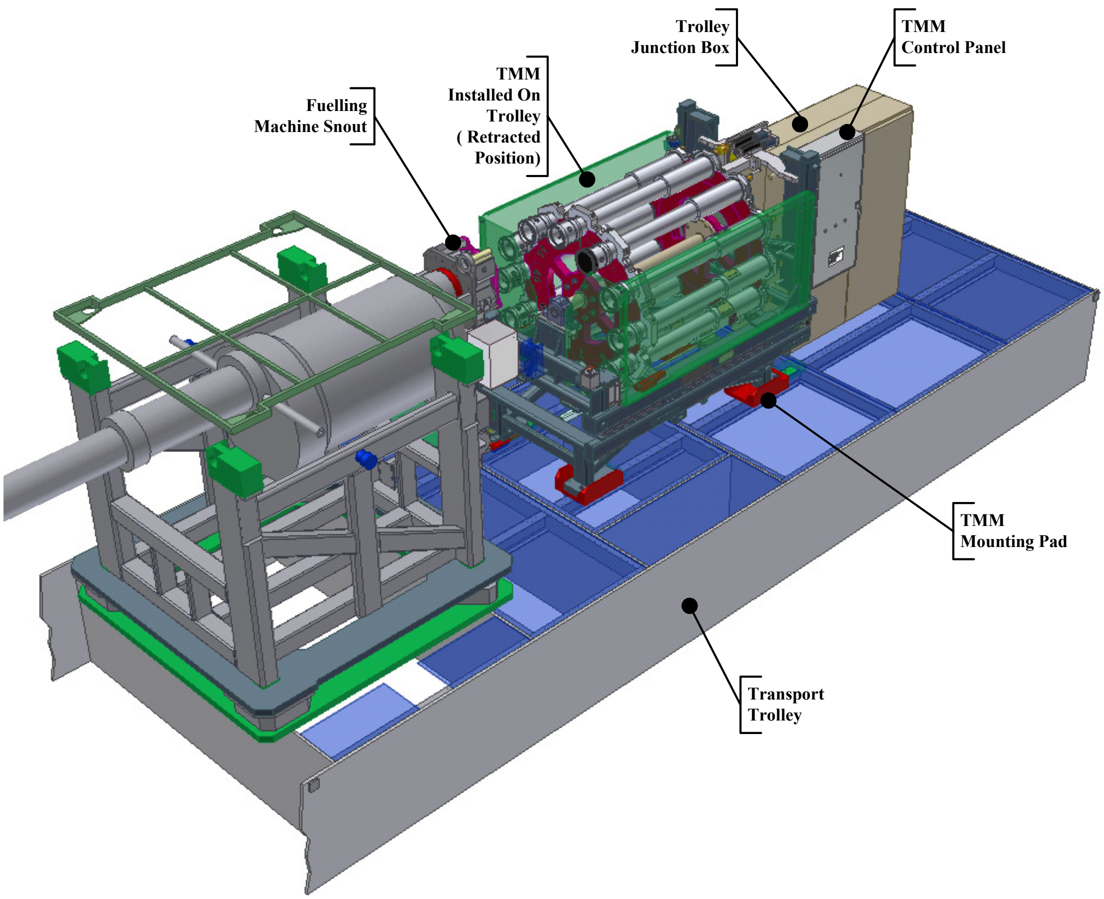


Figure 1: TMM Shown on Transport Trolley with FM

The TMM functions include:

- Transportation of up to twelve CIPs and VCPs from the Central Service Area to a reactor using the Transport Trolley.
- Interaction with the FM to exchange channel components. After homing and locking onto the active (top-dead-centre) TMM channel, the FM exchanges a VCP and CIP for a CP and SP. Once the feeder replacement operations are complete, the FM returns the CPs and SPs to the reactor channel and the VCPs and CIPs to the TMM.
- A Purge system that vacuum boils residual water off the SP, then floods the TMM channel with low-pressure nitrogen to prevent oxidation of the SP.

3. Mechanical Description

The TMM has an overall envelope of 63.5 inches wide by 125.25 inches long by 82.5 inches high. It has a tare weight of 11,000 lb and is capable of carrying a maximum payload of 2,500 lb (i.e., 12 SPs and 12 CPs).

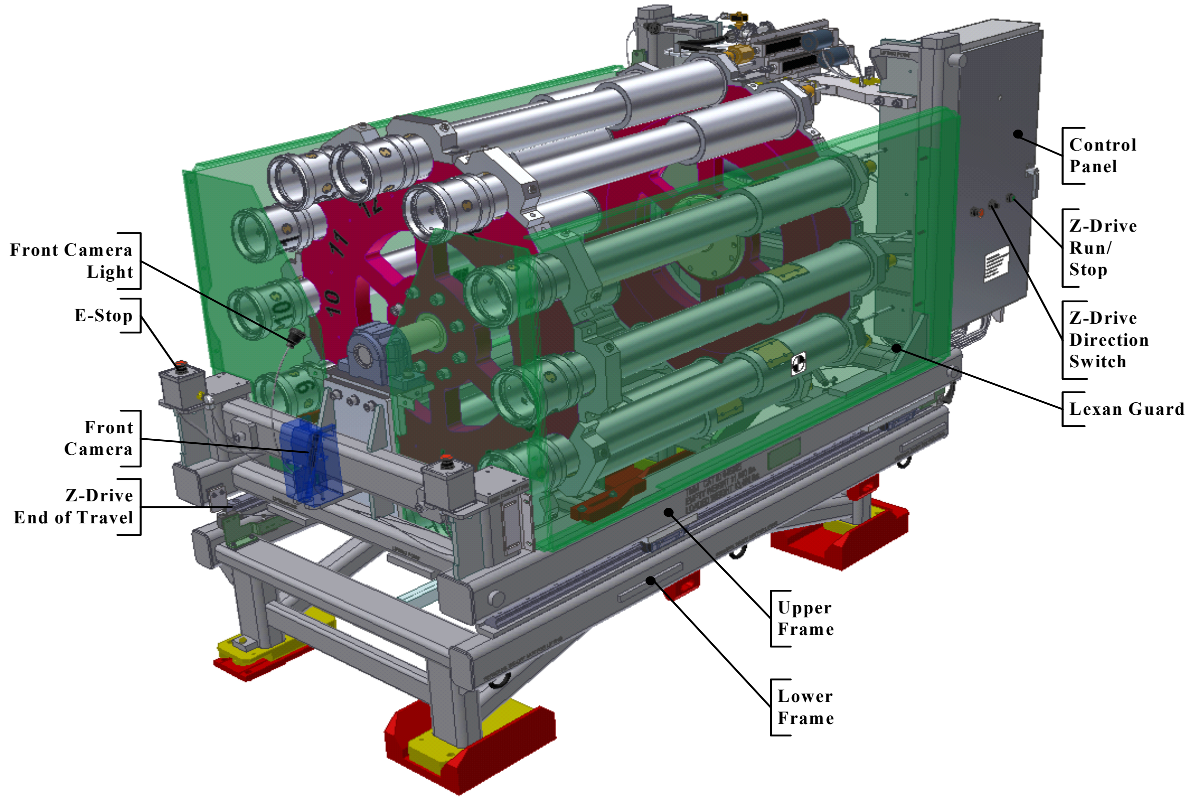


Figure 2: TMM General Assembly

The TMM consists of five main sub assemblies, as discussed below.

3.1 Lower Frame Assembly

The lower frame assembly, as shown in Figure 2, is a structural weldment that consists primarily of hollow structural steel members. Its function is to locate and support the TMM upper frame assembly on the trolley and provide the TMM axial motion.

A ¼ hp AC motor is attached to a ball screw mechanism at the TMM lower frame to retract the TMM upper frame on the rail system. This provides sufficient separation between the TMM and the FM for maintenance purposes. This mechanism is operated by local controls that are located on the control panel (as discussed in section 4).

The lower frame also provides locating/restraint hardware for interfacing with the TMM Transportation Cart as discussed in section 5.2.

3.2 Upper Frame Assembly

The upper frame assembly, as shown in Figures 2 and 3, is a structural weldment that consists primarily of hollow structural steel members. Its function is to support and align the magazine assembly and the Purge system.

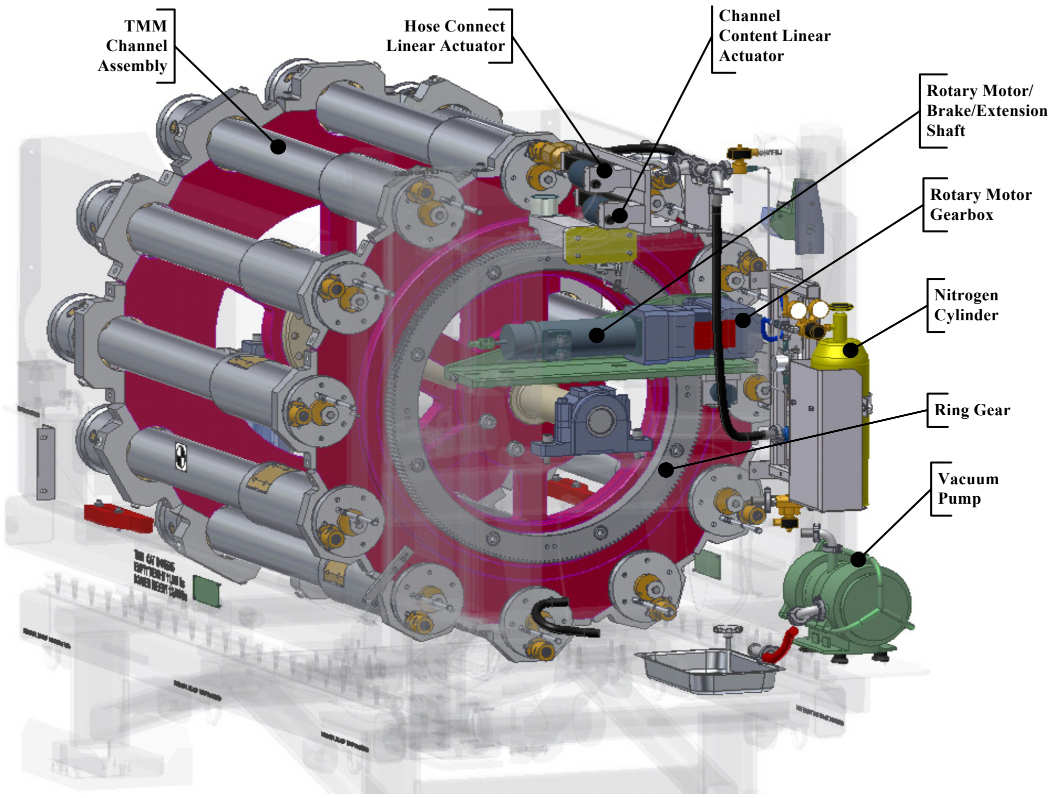


Figure 3: TMM Assembly – Rear View
(The TMM Upper and Lower frames are shown in phantom for clarity)

The upper frame is mounted on four linear bearings attached to the lower frame assembly, and supports the following components:

- Magazine assembly (discussed in section 3.3)
- Rotary drive motor (discussed in section 4)
- Hose Connect and Channel Contents linear actuators (discussed in section 4)
- Vacuum/nitrogen (Purge) system (discussed in section 3.5)
- Front and rear cameras (discussed in section 4.1)
- Control devices (discussed in section 4)
- Removable Lexan guard system (Figure 2)

The upper frame also provides locating/restraint hardware for interfacing with the TMM Lifting Beam and Transportation Cart.

3.3 Magazine Assembly

The magazine assembly is a circular array of twelve channel assemblies as shown in Figure 3. Each assembly is clamped into a front and rear (aluminum) magazine plate that positions and axially restrains each channel. The magazine plates are supported by a centre shaft, which is constrained by two commercially available roller bearing housing assemblies.

The twelve front channel clamps are spring loaded with disc springs that allow the channel to rotate and deflect up to .38 inches in the X-Y plane during FM clamp up. This compliance simulates the ability of a reactor end fitting to flex, due to its longer length and restraint geometry.

The rear channel clamp arrangements position and restrain each channel axially and radially.

3.4 Channel Assembly

The TMM channel assembly is typical of a reactor end fitting as it provides an interface for FM clamp up and accommodates the installation and removal of CPs, CIPs, SPs and VCPs.

All of the channel components are sealed with appropriate o-rings to ensure an airtight design (necessary for vacuum drying and nitrogen retention). As illustrated in Figure 4, the channel itself is a two-piece stainless steel assembly that consists of the channel end and channel body.

The channel end has a typical chrome-plated outer profile that accommodates FM homing and locking operations. The inner profile that interfaces with the FM seal ring is slightly relieved to reduce FM clamping loads, thereby reducing wear on the FM and seal ring. The inner profile that interfaces with the CP or VCP uses four aluminum bronze pins in place of the very complex and expensive 16-lug breech design. The removable pins are profiled to make tangential contact over a very short distance along the flanks of four of the sixteen closure lugs. This arrangement provides the same geometric function as the breech lugs in terms of radially and axially positioning the closure, however do not provide the same strength as the lugs.

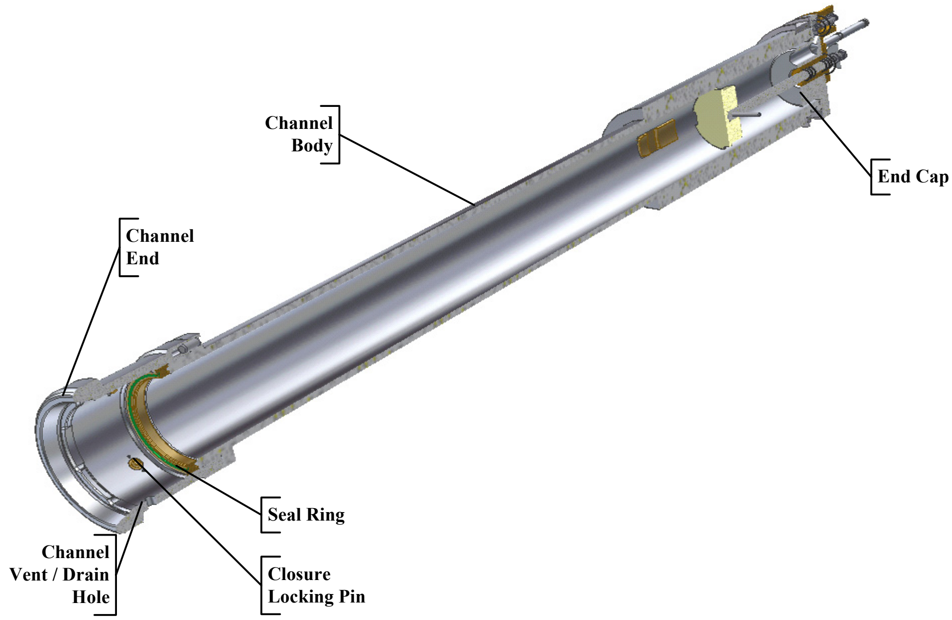


Figure 4: TMM Channel (Sectioned View)

At assembly, an aluminum bronze seal ring is clamped between the two channel sections. The seal ring has a specially molded polyurethane seal ring that simulates the end fitting seal face. When the CP or VCP is installed into the TMM channel at the reduced torque (from 250 lb-ft to 150 lb-ft), the seal disc (seal face) presses into the elastomeric ring, thereby isolating the main bore of the channel to accommodate the vacuum drying and nitrogen injection operations.

To ensure that the FM cannot accidentally pressurize the TMM channel, the channel end is vented to the atmosphere by a .5 inch diameter vent hole which is drilled through the wall of the channel end.

To accommodate locking SPs and CIPs into the TMM channel (typical of a reactor end fitting installation), the TMM channel uses the same inside diameter as an end fitting liner and has a similar locking lug arrangement.

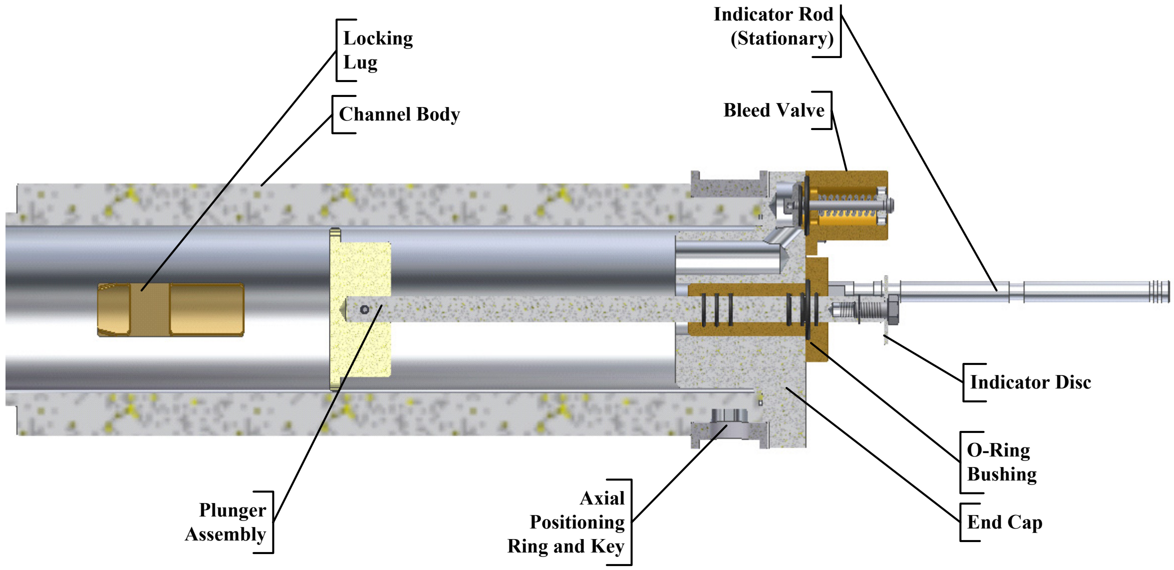


Figure 5: TMM Channel (Section View Close Up)

The end of the channel assembly opposite the FM is sealed with an end cap assembly as shown in Figures 4 and 5. The assembly consists of a plunger rod assembly that registers off the reactor end of the various length components to provide a visual indication of the channel contents. As illustrated in Figure 6, the indicator disc, which is attached to the outboard end of the plunger rod, will align with the appropriate groove in the indicator rod (i.e., an empty channel, an inlet SP, an outlet SP, an inlet CIP, or an outlet CIP). The position of the indicator disc against the indicator rod can be viewed remotely using the rear TMM camera, or locally from the left side of the TMM (as viewed from the FM).

Also attached to the channel end cap is a special purpose bleed valve assembly. The spring-loaded valve, which is normally closed, provides a means of accessing the sealed channel during TMM operation for the vacuum drying and nitrogen injection operation (further discussed in section 3.5).

One of the major design challenges encountered was a concern that the FM would encounter significantly higher loads during end fitting clamp up due to the stiffness of the TMM channel. In order to accommodate the spatial limitations of the trolley, the TMM channel was considerably shorter than that of a reactor end fitting, and therefore could not bend to provide the typical lateral (XY) compliance of approximately .4 inches. To solve this problem, the FM end of each channel was mounted in four preloaded spring packs to simulate the flexibility of a reactor end fitting.

3.5 Purge System

As discussed in section 1, during one exchange cycle a reactor SP and CP are exchanged with a CIP and VCP using the FM. The CP and wet SP are carried to, and installed into, the active TMM channel for short-term storage. Once the wet SP is installed, the channel is sealed with the CP and the FM disengages from the channel. To prevent rusting during storage, the SP is vacuum-dried within minutes of being installed. Once dried, the channel is filled with nitrogen at atmospheric pressure to ensure that the SP is protected from oxidization. The entire drying process, including nitrogen injection, requires approximately forty minutes for a channel.

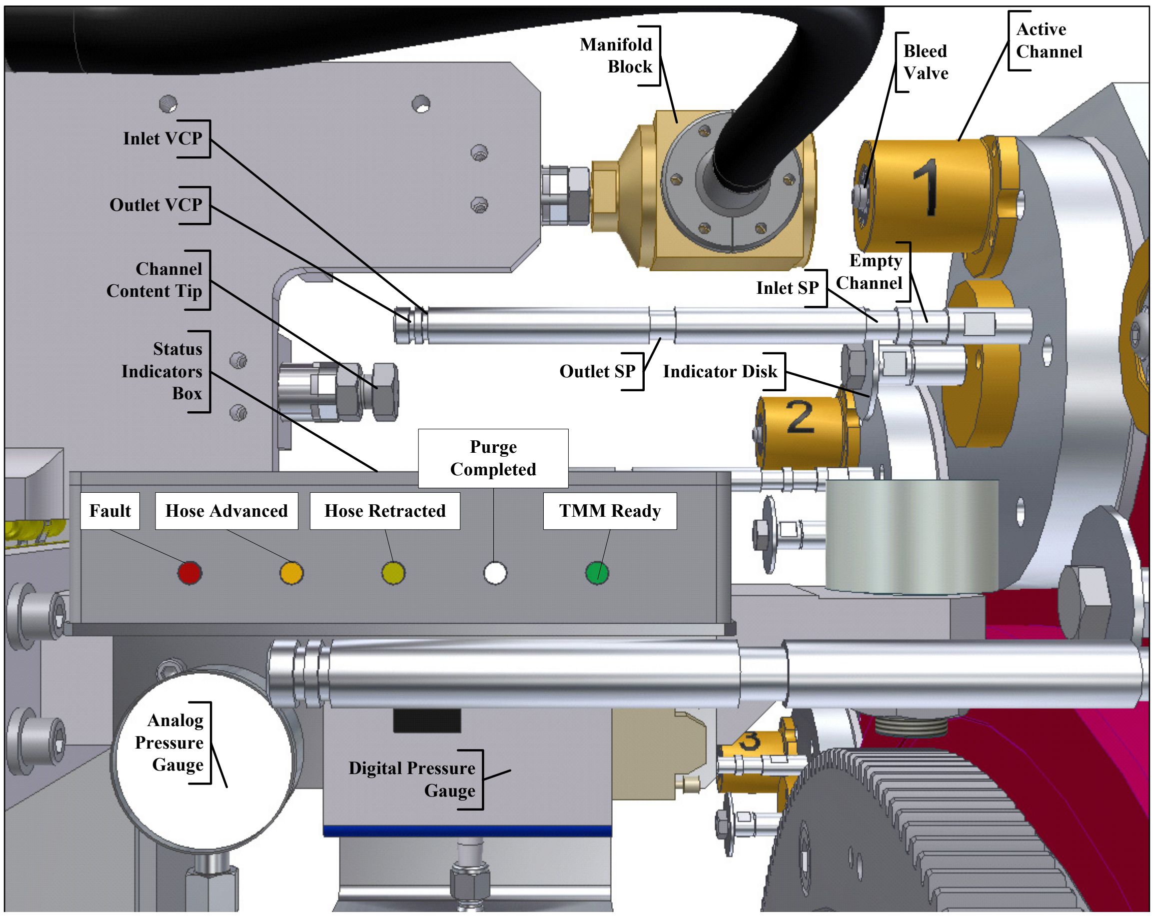


Figure 6: TMM Rear Camera View

4. Control Description

A Galil DMC-4040 4-axis motion controller, installed in the TMM electrical panel, is used to control the three drives, vacuum pump, and valves. The controller runs stand-alone, with no supervisory control from outside the reactor vault. The entire control application is stored on the device along with data arrays containing target magazine active channel positions and Channel Contents drive stall positions. Commands are sent to the controller from the FH control system over a parallel link. In this way the TMM is remotely commanded to index the rotary magazine by one channel (clockwise or counter-clockwise), run a Purge cycle on the active channel, or advance the Channel Contents linear actuator to stall the plunger rod against a component in the active channel.

The three drives managed by the controller are the magazine rotary drive and two linear actuators.

The magazine drive is capable of providing 30 percent more torque than required to accommodate a worst-case unbalanced magazine load and still meet or exceed positioning and speed requirements. A 16-bit multi-turn absolute encoder is used to perform end-point backlash compensation and to establish the state of an incremental encoder used for position feedback. The absolute encoder is driven by an anti-backlash gear mounted on the magazine ring gear.

The linear drives include the Hose Connect actuator, used to advance the vacuum/nitrogen manifold block to mate with the bleed valve and seal on the active channel (Figure 6), and the Channel Contents actuator, used to extend the plunger rod into the active channel to stall against either an installed component or to indicate an empty channel. Normal operation requires the rod to be pushed to the empty channel position and then back-driven as the FM installs a component in the channel. A spacer mounted on the outboard end of the plunger rod thereby aligns with markings on the fixed indicator rod to identify the component installed in the channel. The rear camera view shows this alignment to the FH operator (Figure 6).

A Z motor, not controlled by the Galil unit, is used to retract the upper frame to provide sufficient separation between the TMM and the FM for maintenance purposes. Control of this motor is by hand switches mounted on the TMM electrical panel door.

Two operating modes, Production and Maintenance, are available for controlling the TMM.

Production Mode is the normal at-reactor operating mode for the TMM. In this mode, the machine is controlled remotely, as described previously, from the FH control system under the supervision of the FH operator, or locally by an operator using a hand-held pendant. When connected to the FH system, this mode allows indexing the magazine clockwise or counter-clockwise to move the next channel to the active position, performing the Purge cycle on the active channel, or advancing the plunger rod with the Channel Contents actuator. When connected to the local pendant, Production Mode includes all the remote commands, but also the ability to independently advance or retract the Hose Connect actuator, which is used in the Purge cycle.

Maintenance Mode requires connection to the hand-held pendant and the installation of a wire jumper in the electrical panel. This mode allows a local operator to jog the magazine drive at high or low speed and store channel positions in the local controller's non-volatile memory to support calibration of the magazine encoder.

4.1 Interfaces

The primary FH operator interface consists of CCTV views provided by two cameras located at either end of the TMM. These views provide confirmation of controller process state (via status lamps), magazine position, active channel number, and channel contents. A coaxial switch located within the TMM electrical panel allows the FH operator to select the front or rear camera view. The status lamps viewed on the CCTV monitor indicate Fault, Hose Advanced, Hose Retracted, Purge Complete, and TMM Ready (Figure 6). A fault declared by the controller application remains in effect until the controller receives another command. The new command is executed unless the fault persists. Because this is a standalone controller on the transport trolley, the FH operator is generally given the opportunity to attempt to resolve a fault condition by issuing a new command. The Hose Advanced, Hose Retracted, and Purge Complete lamps, along with the pressure gauges, provide assurance that the Purge cycle is running properly. In Production Mode, the TMM Ready lamp indicates that the magazine drive is stopped (with brake engaged), a channel is in the active position, the active channel number is available to be read by the FH controller, and no other tasks are running. Without this signal, the FH controller cannot advance the FM or if advanced, the FM cannot install or remove channel components.

A parallel connection is used to transfer the active channel number to the FH controller. Aside from the CCTV views, the FH operator is presented with a graphical image of the magazine and channel contents as part of the FH control display system. The active channel number transmitted from the TMM controller is used to update the magazine image following completion of a magazine index command. The displayed channel contents are presently updated based on data entered by the FH operator. The TMM control design supports the future capability to transmit a component code, determined by the plunger rod stall position, to the FH controller to make this display update automatic.

A serial communication link connects the local TMM controller to a port located in the Common Equipment Room adjacent to the main control room. A technician can use this port to examine the logic in the TMM controller for troubleshooting purposes. This is the preferred method for interrogating the controller under a fault condition during operation at a reactor. The alternative is to use an Ethernet connection locally at the TMM controller. The controller maintains an array of the most recent fault codes, which can only be determined through such a direct link.

4.2 Safety Interlocks

The following interlocks are implemented in hardware:

- The magazine cannot be rotated unless both linear actuators are fully retracted.
- The linear actuators cannot operate if the magazine brake is not engaged.
- None of the motors (magazine, linear actuators, or Z), solenoid valves, or vacuum pump can be operated if the E-Stop circuit is activated.
- An E-Stop trips an electronic lock-out input on the controller, thereby shutting down the drive amplifiers at the hardware level, effectively disabling the magazine and two linear actuator motors.

In addition to the hardwired interlocks, logic in the TMM controller inhibits operation of a control function unless certain interlock conditions are satisfied. For example, the Hose Connect actuator is not permitted to advance unless the magazine rotary drive is stopped, a magazine channel is in the active position, TMM is in Production or Maintenance Mode, and no general fault exists.

5. Special Purpose Components

5.1 Lifting Beam

The TMM Lifting Beam (Figure 7) is a structural weldment that is designed to lift the fully loaded TMM with or without the TMM Transportation Cart. The assembly has a tare weight of 2,400 lb and a lifting capacity of 20,000 lb. When installed onto the TMM, it adds 14.5 inches of height for a total vertical envelope of 100 inches. The lifting beam has an adjustable lift point that provides ±8 inches of travel in the axial (FM Z) direction to accommodate various load conditions (i.e., variations between TMM empty or full, TMM with or without the Transportation Cart, and beam empty). The lift point adjustment can be easily performed by one operator from floor (or trolley) level.

Four feet on the lifting beam provide lifting points that interface with the TMM. Guide pads are provided at each end of the beam to safely locate the beam and ensure that TMM components are not damaged during installation or removal. When the lifting beam is being manoeuvred into its lift position, four stationary lifting arms are positioned under lift points within the TMM upper frame. Once positioned, two bolts (that are not within the load path) are installed to lock the beam in place. The time required to install or remove the lifting beam (including set up) is less than 5 minutes.

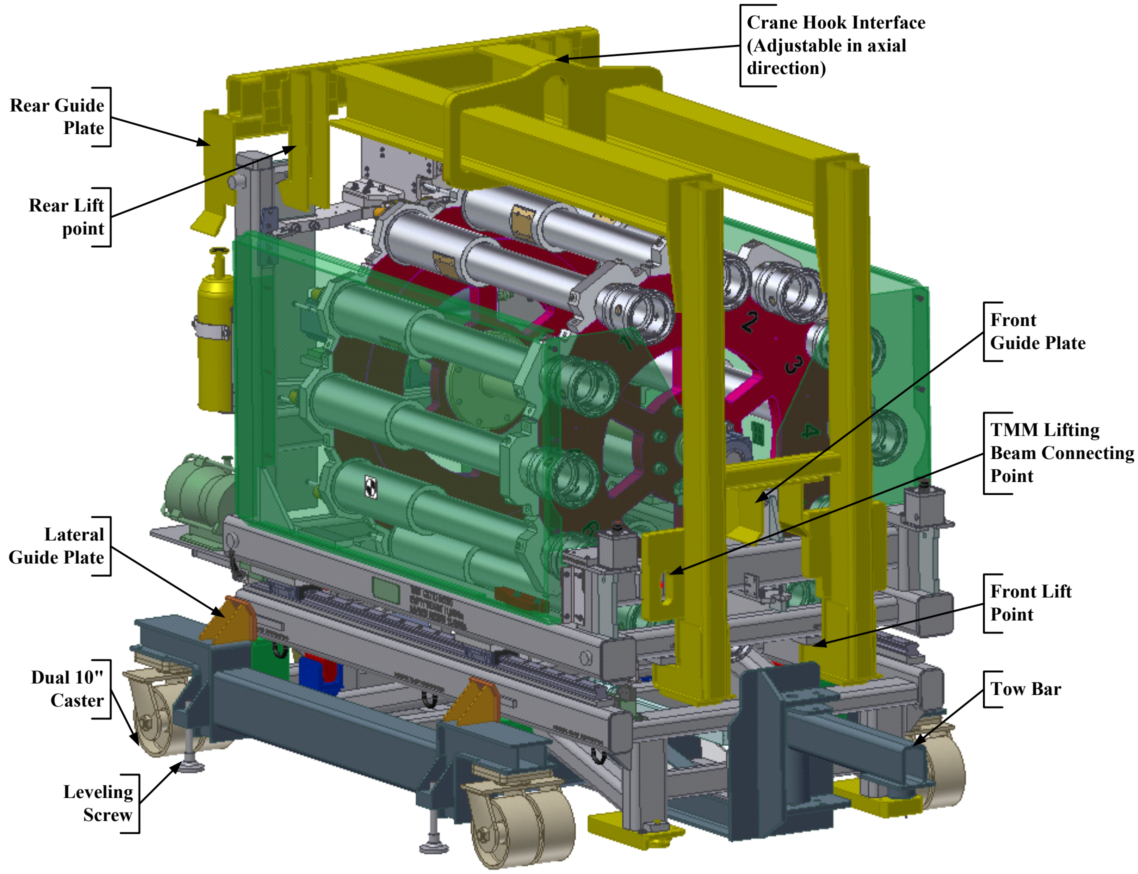


Figure 7: TMM with Lifting Beam and Transportation Cart

5.2 Transportation Cart

The TMM Transportation Cart (Figure 7) is a structural weldment that is designed to support a fully loaded TMM with the Lifting Beam installed. The assembly has a tare weight of 3,300 lb and a carrying capacity of 20,000 lb. The cart is 84 inches wide by 130 inches long, and adds 4 inches to the total TMM / TMM Lifting Beam height envelope (104 inches total).

The cart is supported by four polyurethane dual lockable swivel casters and has 4 inches of ground clearance. Both ends of the cart have a removable lockable tow bar that can be folded in to reduce the overall cart length. Side and end guide plates are strategically located to ensure that TMM components are not damaged during installation or removal. The cart also provides a four-point interface for lifting, either with or without the TMM installed. The time required to install or remove the TMM is less than five minutes.

6. Alternatives Considered

A number of design alternatives were considered in the initial design stages. The two primary alternatives were abandoned because of cost and schedule concerns. One concept used a continuous chain conveyor arrangement with 24 reactor end fittings arranged in a "D" shape. One of the positions would include a drive that would temporarily move the end fitting out of formation toward centre to provide FM alignment and snout clearance. Another concept involved a double circular array of 16 outer channels and 12 inner channels. This would have required the top-dead-centre channel be advanced toward the FM to provide snout clearances. A vertical drive would have also been required to elevate the inner channel pitch to the FM centreline.

Given the accelerated schedule and budget constraints, it was necessary to keep the design as basic as possible, have ongoing customer support and involvement, and leverage past experience and proven technology wherever practical.

7. Summary

The TMM represents a lean design that addresses the need for improved efficiency in transferring channel components between a reactor and the Central Service Area to support the feeder replacement project at Darlington N.G.S.

Several aspects of this paper focus on solutions for creating a minimal design that satisfies a number of sophisticated requirements. In that respect, lessons learned from previous projects and special simplifications were incorporated. In particular:

- The magazine drive was designed to use a large ring gear/servo drive arrangement similar to that used successfully for the Darlington Universal Delivery Machine magazine.
- Past success with the Pickering UDM transporter and the Darlington and Bruce UDMs and Fuelling Machine Tool Stations (FMTS) provided valuable lessons when addressing critical spatial clearances during transportation of the TMM through the station and during trolley installation.
- Off-the-shelf technology was used for the vacuum drying/nitrogen injection system while accommodating the added complication of channel indexing. As such, a commercially available linear actuator was used to advance a custom manifold block to seal against a special purpose bleed valve. To keep the design as basic as possible, the same piping and hardware were used to deliver the low-pressure nitrogen.
- A relatively low-cost, robust digital controller was installed local to the apparatus, i.e., within containment. The control application therefore had to be compact and fault tolerant. A simple serial connection to the Common Equipment Room was added to allow remote troubleshooting under fault conditions.
- A minimalist interface to the FH control room was provided, relying primarily on CCTV camera views, for monitoring TMM operations. The only graphical interface was provided with an addition to the existing FH control display system.

Although a number of modifications would be required, the design of the Darlington TMM is considered sufficiently flexible to lend itself readily to other stations' needs.

The total design and supply cycle for TMM was fourteen months. Two TMM assemblies, two TMM Transportation Carts, one TMM Lifting Beam, and one TMM Lifting Beam Transportation Cart were delivered to Darlington N.G.S. in early 2008.

The TMM is currently being commissioned for use in 2009.

8. Acknowledgements

We would like to thank Mike Gray (OPG), Patrick Henry (GEH), David Murray (GEH) and Dave Rayment (GEH) for their assistance during the design phase of this project.