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A Robotic Pinch-Off System for the Sealing of Neutron Tube Assemblies

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A ROBOTIC PINCH-OFF SYSTEM FOR THE SEALING OF NEUTRON TUBE ASSEMBLIES

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Abstract:

The process of manufacturing the MC4277 Neutron Tube requires the evacuation of the device through a 4.76 mm (.1875 in.) OD copper tube. Eight tubes are simultaneously evacuated and then baked out. When the process is completed, the tubes must be separated from the system without compromising the ultra-high vacuum in the tube and the system. Previously, a manual pinch-off tool was used. This procedure required up to 3 operators with a high probability of creating defective seals or destroyed tubes. Two new identical robotic systems were built to allow a single operator to consistently produce good tubes with perfect seals. These systems have the added capability of partially pinching off tubes at jaw displacements repeatable to ± 0.05 mm (± 0.002 in.). Both systems have operated flawlessly since their installation in January and March, 1998. A detailed description of these systems is given in this report.

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Figure 1. The ultra high vacuum system with the ceramic heaters mounted around the tubes. A water cooled aluminum bell jar (upper left) is lowered into position, evacuated to roughing vacuum, and the heaters are energized.

Introduction:

The process of manufacturing the MC4277 Neutron Tube requires the evacuation of the device through a 4.76 mm (.1875 in.) OD copper tube. A system was built which eight tubes are simultaneously evacuated and then simultaneously baked out. The tubes are attached via a flared connection to the high vacuum system in a radial pattern (**Figure 1**). Ceramic heaters are installed around the tubes and a "bell" type water cooled aluminum chamber is lowered into position and evacuated. The tubes are then heated in this chamber. When the process is completed, the "bell" is raised, the heaters removed, and the tubes must be separated from the system without compromising the ultra-high vacuum in the tubes and the system. Previously, a manual pinch-off tool was used (**Figure 2**).

Figure 2. Manual pinch-off tool. A hand-held hydraulic tool was used before the robotic system was installed.

This procedure required up to 3 operators, and the pinch-off operation required a skilled operator to prevent defective seals or destroyed parts. The new system was designed and built to allow a single operator to consistently produce good parts with perfect seals.

Pinch-off Tool and Anti-Rotation Tool:

A commercial hydraulic pinch-off tool, manufactured by Team Inc., was modified and mounted on counterweighted positioning slides. The hydraulic tool, shown in **Figure 3**, incorporates 2 jaws, one fixed and one coupled to a hydraulic piston.

Figure 3. Photograph of the pinch-off tool. This tool has not been modified with limit switches or the hydraulic fittings that allow it to be freely moved on the system.

Each stainless steel jaw (**Figure 4**) has a precisely ground tungsten carbide insert. The slide system rotates 350° with the circle concentric to the circle of the tubes mounted on the vacuum system. This allows the tool to be precisely positioned at each tubulation (the copper tube that extends from the Neutron Tube header) and precludes the use of circular contacts for the wiring of the limit switches mounted on the housing and the pinch-off tool. The rotating slide housing is mounted on a crosshead that can be raised and lowered into position on vertical posts, allowing clearance for the roughing bell jar to be lowered and raised into/out of position for the bakeout operation. The slides and counterweight allow further precise but fully adjustable manual positioning of the tool at each tubulation. A hand-held switchbox (**Figure 12**) allows the operator to control the pinch-off process with one hand and catch the tube with the other when the jaws are released. Indicator LED's on the control notify the operator of the tool's correct placement. Limit switches on the tool allow the system to operate in full or partial pinch-off modes.

Figure 4. Close-up of a pinch-off tool jaw. The precisely ground tungsten carbide insert is held in a slot machined into the end of the jaw.

The tubes, when first attached to the system, must be rotated on the tube axis into a position that allows holes in the pinch-off tool to clear electrical feedthrough pins protruding from the tube header. A separate clamping device, **Figure 5**, is mounted on the counterweight in such a way as to be able to rotate out of the way when not being used. The clutch-type torque limiting thumbwheel is tightened to prevent the tubulation from rotating while the vacuum flare nut is tightened.

Figure 5. The tubulation clamping device in the vertical position with a piece of copper tubing inserted into the clamp. The device is mounted on the end of the counterweight that rides on the track on the right side of the photo. Two clutch type thumbwheels are used—one to locate the clamp and one to tighten the spring loaded jaws on the tube.

Lift System:

The lift system (**Figure 6**) mounts atop the Bosch framework supporting the vacuum system. The center housing holds the counterweight system. The vertical housing rotates on 2 ball bearings preloaded and mounted in the crosshead. A DelTron Inc. track ball slide is mounted on each of two opposing sides of the housing.

Figure 6. A schematic drawing of the system. The cover guides were designed to more easily locate the aluminum "bell." The clamps secure it flatly in place to more quickly seal the system upon pump-down. The lift cable statically and dynamically supports the right end of the crosshead.

One slide holds the hydraulic tool (**Figure 7**). The other slide holds a counterweight and the antirotation clamp used (**Figure 5**) when mounting the tubulations to the vacuum system. The slide tracks are hardened stainless steel. The precision manufactured recirculating ball slides are rated statically for a 690 Kg f (1520lb) basic load and an axial moment of 5.7 kgf.m (191 in-lb). The moving slides are connected (balanced) with two nylon coated cables that loop over ball bearing mounted nylon idler pulleys. Aluminum brackets above the pulleys prevent the cable from slipping out of the pulley grooves.

Figure 7. The center rotating housing with a slide on either side. A cable connects the counterweight to the pinch-off support arm.

The hydraulic pinch-off tool is mounted in a holder which swivels to allow adjustment of the angle of the jaws $\pm 10^\circ$ from the horizontal. The holder is attached to a horizontally mounted crossed roller slide supplied by DelTron Precision, Inc. The slide allows about 40 mm. (1.6 in.) of travel along the radial direction, that is, in and out along the length of the tubulation. The jaws are placed directly against the headers, minimizing the length of the tubing extending from the header after the tubing has been pinched off. The slide is spring loaded to apply a slight outward pressure on the header. This assembly is mounted to an arm which is attached to the vertical track ball slide. The track ball slide allows the tool 12 cm. (4.7 in.) of vertical motion while the crosshead remains stationary.

The crosshead lift system is driven by a Dayton satellite dish antenna actuator selected for use in this application due to its suitability and availability. The screw drive DC actuator quietly travels up to 3 cm/sec (1.2 in/sec) and applies up to 2700 N (600 lb.) force. An eyebolt/swivel on of the actuator is bolted directly to the left end of the crosshead (**Figure 6**). The crosshead slides on teflon sleeve bearings on 2 vertical aluminum upright tubular posts 50 mm. (2 in.) OD with 12.5 mm. (0.5 in.) wall thickness. The posts are clamped into upright housings which are bolted to the Bosch framework.

The right end of the crosshead is driven with a cable that threads upward and over a pulley mounted in the right upright post, across and over a pulley in the left upright post, down through the center of the left post and around a pulley

below the crosshead in the left post. The cable then attaches to a point on the crosshead directly below the eyebolt/swivel actuator attachment point. Additional mass (~15 Kg, 33 lb.) attached to the crosshead at the cable end ensures stiction free operation.

With a teflon bearing/upright post clearance of less than 0.1 mm. (.004 in.), the system is extremely sensitive to alignment. The cable/pulley action tends to pull the posts together. To prevent this, the top of the tubular posts is connected with a 12.7 mm. (0.5 in.) diameter stainless steel stabilizing crossmember that is threaded at both ends for adjustability.

LIFT CONTROL/LIMIT CIRCUIT

Figure 8. Schematic drawing of the lift electrical system. The 5VDC relay, limit switches and the 3PDT switch control the 120VAC power to the 90VDC actuator motor power supply.

The crosshead lift system is fitted with limit switches and interlocks to prevent damage in the event of an obstruction or should the lift cable break. **Figure 8** is a schematic of the electrical system. The logic circuitry is powered by 5 VDC. A triple pole double throw switch and a 5 VDC electromechanical relay supply AC power to the adjustable 90VDC power supply for the DC actuator when the limit switches are all closed. **Figure 9** is a schematic diagram of the level limit switch assembly. A teflon button mounted on a spring rides against the upright post. If the assembly moves away from the upright post, the spring moves relative to the assembly and a limit switch in the lower limit switch circuit opens, stopping downward travel.

DTS151 SHT 14 LEVEL SWITCH ASSEMBLY

Figure 9. Schematic drawing of the level and lower limit switch housing assembly. The teflon slide, mounted on a spring, rides on the upright. The spring actuates one of 2 limit switches, depending on the position of the housing relative to the upright.

If the assembly moves toward the upright post, a switch in the upper limit switch circuit opens, stopping upward travel. The level limit switch assembly stops the crosshead if it tilts in excess of 1.5° in either direction. Upper and lower travel limits stop the crosshead at the nylon collar clamps on the upright post. Limit switches in the centerhousing at the lower end of the ball slides stop upward crosshead travel if either the anti-rotation clamp or the pinch-off tool slide assemblies reach the lower end of travel (in the event the crosshead is moved upward with the clamp or the tool still engaged with the tubulation). When a limit switch has been tripped, whether for tilt or end of travel, the opposite circuit will allow the operator to move the crosshead in the opposite direction.

Pinch-off Control System:

The Team, Inc. pinch-off tool is hydraulically actuated with a sealed piston and return spring. The piston area is 6.45 cm^2 (1 in^2). Hydraulic pressure is applied from a small ratcheting pump with the pressure limit set to 12.4 MPa

(1800 psi) which yields 820 Kgf (1800 lb.) jaw force, enough to pinch off the softened copper tubulation. The manual Team, Inc. hydraulic supply was automated as shown in **Figures 10 and 11**. The hydraulic fluid, Lubriplate HO-1, is fed through two hoses and a swivel to the pinch-off tool.

Figure 10. The compressed-gas-actuated Power Team, Inc. hydraulic power supply was automated by mounting it in a steel box with a 24VDC power supply, a latching relay, Festo, Inc. solenoid valves, a terminal strip, a solid state relay (SSR) and an air actuator attached to the hydraulic pressure release. The compressed gas enters the system in the lower left.

From the pump to the crosshead, the oil travels through Aeroquip FC373 "Polyon/Thermoplastic" 11 mm (.438 in.) OD tubing rated at 21 MPa (3000 psi) working, 83 MPa (12000 psi) burst pressure. At the crosshead, the oil passes through an Aeroquip swivel into the center housing. From the housing to the tool the oil is fed through Aeroquip 2807 stainless steel reinforced teflon 6.35 mm (.25 in.) OD tubing rated at 21 MPa working, 83 MPa burst. This tubing is sufficiently flexible to allow the positioning of the pinch-off tool.

The latching relay must be in the "reset" position to allow pressure to be applied to the tool. The latching relay releases in automatic or manual mode depending on the position of the "auto" switch. When the switch is in "auto," the latching relay is switched from reset to latch (or "release") when the jaw travel limit switch closes, allowing a partial pinch-off, depending on the position of the adjusting screw on the pin mounted in the movable jaw. The "seated" green LED is energized when the header, properly seated against the tool, closes the "go-no-go" switch on the tool. The operator control switches and indicators are mounted in a small plastic box (**Figure 12**) connected to the system with an 8 conductor cable and designed to be conveniently held where the operation is taking place. The "reset" switch is a 4PDT, thus if all buttons are pressed simultaneously the system will be placed back into the "reset" mode.

GRADUATED PINCHOFF TOOL CONTROL and LIMITING CIRCUIT

9/25/97 D. T. Salami

Figure 11. Pinch-off control electrical schematic. The solenoid compressed gas control valves are energized with 120 VAC; the hand-held control box and limit switches are energized with 24 VDC.

Figure 12. Photograph of the hand-held pinch-off control. When the tube header is correctly positioned against the pinch-off tool, the green "seated" (upper left) LED is illuminated. With the switch in the "man" position the jaws will completely close and pinch off the tubulation and will not separate until the "release" button is pushed, illuminating the "release" (lower left) LED. In the "auto" position the jaws are released when the jaw travel limit switch closes.

Procedure:

This process description begins with the rough vacuum manifold at atmospheric pressure, the tube/header assemblies not installed, and the cross-head/robot pinch-off anti-rotation tool (C/RPAT) in its uppermost position.

The rubber insert/stop that fits into the counterweight tool track must be installed in one of the holes. The stop locks the counterbalance system. If this stop is not installed and the pinch-off tool is not in its lowermost position the anti-rotation tool may contact, bend and harm an installed neutron tube. With the clutch/type thumbscrew, the anti-rotation clamping system should be secured in the horizontal position, (entirely out of the vertical clamping groove). The aluminum bell jar is rotated clockwise to provide clearance for the descending cross-head.

After turning on the power, the C/RPAT is lowered by moving the up/down switch to the down position. The yellow "drive" pilot lamp is illuminated and the beeper activated as the crosshead moves down. The motor speed is set between 50 and 100%. The cross-head stops when it gets to the preset lower limit switch position. If downward motion is blocked, the crosshead jams and the level switch mechanism will stop the motor. Freeing the crosshead requires that it be moved upward. Once free, downward motion can be continued. If the cable should break, the crosshead will tilt and the level switch will prevent the "up" circuit from operating. The system should not be operated with a broken cable.

The anti-rotation clamp system is now utilized to aid the installation of the tube/tubulation assemblies. The eight tube assemblies are installed by finger tightening the flare nut on the vacuum system with the header in the correct position. With the counterweight against the upper rubber stop, the clutch type thumbscrew is loosened and the anti-rotation clamp is slipped into the groove on the end of the counterweight assembly and the tool slid to the lowermost position with the thumbscrew at the upper end of the slot. The thumbscrew is tightened until the clutch begins to slip.

The anti-rotation clamp is rotated into position directly over one of the tubulations with the jaws of the clamp in the open position. When opening the jaws, the thumb-wheel/clutch is turned counterclockwise just until resistance is felt to attain the jaw open condition. Any further than the initial resistance and

the most efficient preset conditions are changed. The open clamp is lowered onto the tubulation. The thumb-wheel is rotated clockwise until the clutch can be felt slipping, securely clamping the tubulation. The flare nut is tightened. The installation is repeated for 8 tube/tubulation assemblies. The anti-rotation clamp is then placed back in the horizontal position and the system is leak tested.

The C/RPAT is raised to the upper limit switch. If the cable should break, the crosshead will tilt and the level switch will prevent the "up" circuit from operating. The system should not be operated with a broken cable. To ensure clearance of the bell jar/pinch-off tool, the pinch-off tool is rotated to a position diametrically opposite the direction from which the aluminum bell jar approaches when it is rotated into position. The rubber stop is removed from the counterweight up/down slide, heaters installed, and the aluminum bell jar is lowered and evacuated for the bake-out procedure. After the bake-out process, the bell is raised and rotated out of the way and the heaters removed. The C/RPAT is once again moved down to the lower limit.

Nitrogen at 0.550 MPa (80 psi) is applied to the energized pinch-off hydraulic power supply control system. The pinch-off tool is lowered and rotated into position on one of the tubulations. The tube header must be located inside the 2 locating pins and against the outer side of the pinch-off tool. Outward spring pressure from the hydraulic line and the slide spring forces the go/no-go microswitch into "go" position with the header making contact with the outer surface of the pinch-off tool. The green "seated" LED on the remote control should light. If the header does not seat properly, the tubulation is slightly bent to align the header plane with the surface of the tool. When the header is properly seated, the pinch-off nipple length will be within spec.

A partial pinch-off is performed by moving the auto/manual switch on the pinch-off remote control to the "auto" position. This releases the hydraulic pressure when the tool jaws get to a preset distance apart. If the "release" LED is lit, the "reset" button must be pushed. The "pressure" button is pushed and held until the "release" LED comes on and the partial pinch-off is complete. This is repeated for 8 tubes on the manifold. A full pinch-off is performed by pushing the pressure button until the ratcheting power supply begins to labor and the pressure has maximized. The "release" button is pressed to reopen the jaws and the tube falls into the dedicated hand. The process is then repeated for 8 tubes on the manifold.

The C/RPAT may remain in the lower position while the ultra high vacuum manifold is brought up to atmospheric pressure and another set of tube/tubulations is installed. The entire process can then be repeated.

Summary:

A system to aid in the pinching off of evacuated neutron tubes has been designed and built. Previously, a manual pinch-off tool was used. This procedure required up to 3 operators with a high probability of creating defective seals or destroyed tubes. Two new identical robotic systems were built to allow a single operator to consistently produce good tubes with perfect seals. Both systems have operated flawlessly since their installation in January and March, 1998. A commercial hydraulic pinch-off tool was modified and mounted on counterweighted positioning slides. The slide system rotates 350° with the circle concentric to the circle of the tubes mounted on the vacuum system, allowing the tool to be precisely positioned at each tubulation. A clamping device, attached to the counterweight, holds the tube secure when the flared joint is tightened while mounting the tube to the system before evacuation/bakeout. A remote control allows the operator to start and end the pinch-off process with one hand and catch the tube with the other when the jaws are released. Indicator LED's on the control notify the operator of the tool's correct placement. Limit switches on the pinch-off tool allow full or partial pinch-off of the tubulation. Limit switches on the crosshead provide end stops for the crosshead assembly. Other safety limit switches on the level limit switch assembly and the center slide housing stop the crosshead should it tilt more than 1.5° or should the operator attempt to move the crosshead while the pinch-off tool is located on a tubulation.

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