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AUTOMATED FUEL ELEMENT CLOSURE WELDING SYSTEM

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ABSTRACT - The Automated Fuel Element Closure Welding System is a robotic device that will load and weld top end plugs onto nuclear fuel elements in a highly radioactive and inert gas environment. The system was developed at Argonne National Laboratory-West as part of the Fuel Cycle Demonstration. The welding system performs four main functions, it; (1) injects a small amount of a xenon/krypton gas mixture into specific fuel elements, and (2) loads tiny end plugs into the tops of fuel element jackets, and (3) welds the end plugs to the element jackets, and (4) performs a dimensional inspection of the pre- and post-welded fuel elements. The system components are modular to facilitate remote replacement of failed parts. The entire system can be operated remotely in manual, semi-automatic, or fully automatic modes using a computer control system. The welding system is currently undergoing software testing and functional checkout.

INTRODUCTION

The Automated Fuel Element Closure Welding System is a robotic device designed to operate in a highly radioactive and inert gas environment. Its functions include: (1) "tagging" specific fuel elements with a unique mixture of xenon/krypton gas, and (2) loading end plugs into the tops of fuel-element jackets, and (3) welding the end plugs to the element jackets, and (4) performing automated dimensional inspections of the welded fuel elements. The system will be located inside a "hot cell" in the Fuel Cycle Facility at Argonne National Laboratory-West in Idaho. The hot cell will be filled with argon gas and anticipated average radiation exposure rate to the welding system equipment will be approximately 10 Gy/hr (10^4 Rad/hr). The welding system will be placed in front of one of the hot cell viewing windows and will be accessible only through the use of a master-slave manipulator and remote crane handling system. The welding system will be operated from the computer control station located outside of the hot cell in the operating corridor. The Operator Control Station (OCS) allows an operator to change parameters, monitor system status, and issue control commands using a touch-screen monitor. Equipment interlocks and error checking are programmed into the operating software to ensure safe and consistent operation of the equipment.

OPERATION

An Element Fabrication Magazine (EFM) loaded with 36 fuel element jackets is loaded into the rotate drive mechanism of the welding system using the in-cell Electromechanical Manipulator (EM). Once the magazine is in place, the sequence to "tag", load, weld and inspect a fuel element commences. The sequence is as follows; first, a small amount (approximately 2 to 3 cc) of xenon/krypton gas is injected into the open fuel element jacket using the tag gas apparatus. In conjunction with the tagging operation, the X-Y-Z robot picks up an end plug from the vibratory parts feeder assembly and transfers it to the loading position. Second, the fuel element is rotated to the end plug loading position using the rotate drive mechanism. Third, the end plug is loaded into the top of the element jacket and inspected using the vision system to ensure proper seating. Fourth, the end plug is welded to the element jacket using a high-amperage burst from a Gas Tungsten Arc Welding (GTAW) power supply and controller. Fifth, the welded fuel element is dimensionally inspected for defects and anomalies in the weld. This process continues until all 36 fuel elements in the magazine have been welded and takes approximately 3-1/2 hours to complete. Figure 1 shows the sequence to load and weld the end plug to the element jacket.

DESCRIPTION OF COMPONENTS

The welding system, shown in Figure 2, is made of six main assemblies; (1) the support table and rotate drive mechanism, (2) the vibratory parts feeder assembly, (3) the

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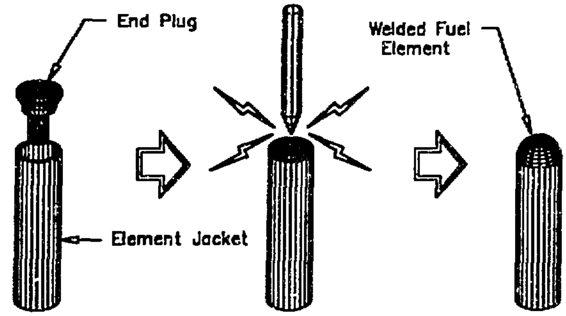

Figure 1 - Sequence Of An End Plug Being Loaded Into and Welded To An Element Jacket

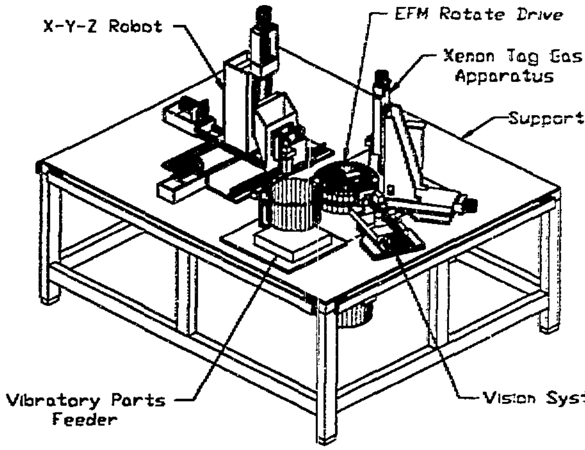

Figure 2 - 3-D View of the Automated Fuel Element Closure Welding System

Figure 3 - Photograph of the Argon Compressor/Accumulator Assembly

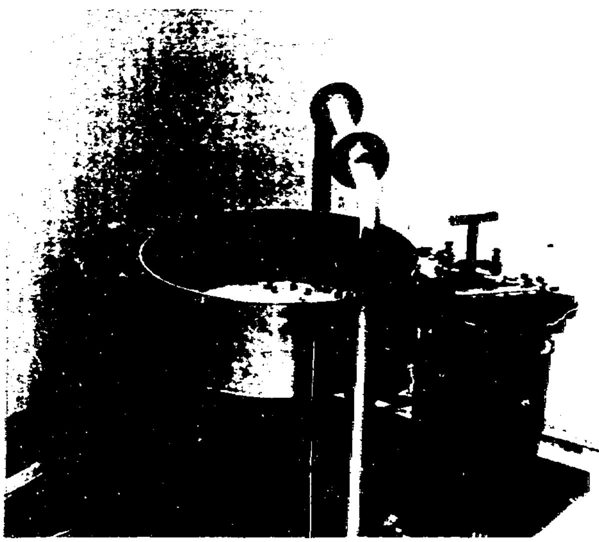

Figure 4 - Photograph of the Vibratory Parts Feeder Assembly

X-Y-Z robot, (4) the compressor assembly and pneumatics system, (5) the vision system, and (6) the xenon tag gas apparatus. Most of the equipment is stationed on top of the support table with the exception of the compressor assembly, shown in Figure 3, which sits on the floor to the side of the table. The majority of the electronics to operate the system have been placed outside of the hot cell to protect them from the radiation. All of the components that make up the in-cell portion of the welding system have been selected because of their gamma radiation tolerance and off-the-shelf availability. All in-cell electrical cables are made with radiation resistant insulation and have Amphenol connectors on both ends with their locking rings removed. Where possible, components which have a higher probability of failure such as motors, switches, solenoid valves, etc. have been designed so that they can be replaced remotely on location with minimal effort and down time. Assemblies with small or inaccessible parts have been designed to be removable as modules so that they can be taken to a glove box or similar repair station. Special lifting handles that interface with the EM's are built into the various modules to facilitate their removal. The modular design of the system allows it to operate in a high gamma radiation field for an extended period of time.

Support Table and Rotate Drive Mechanism - The support table is made of carbon steel structural tubing and houses the rotate drive mechanism. The table measures about 1.52 m by 1.83 m by 0.76 m high (5 ft by 6 ft by 2.5 ft high). The rotate drive mechanism holds a magazine which contains 36 fuel elements in the vertical attitude for end plug insertion and welding. A stepper motor rotates the magazine and a resolver provides angular position readouts to the computer. The resolver is made with radiation resistant wires and has Viton seals. The stepper motor is similar to other stepper motors that have been operated in high radiation fields at ANL-W for many years without failure. Both the resolver and stepper motor modules can be replaced on location.

Vibratory Parts Feeder Assembly - The vibratory parts feeder assembly, shown in Figure 4, consists of a stainless steel bowl, in-line feeder, and shuttle mechanism. The bowl is capable of holding several thousand end plugs and has a feed rate of approximately 30 end plugs per minute. Both the bowl and the in-line feeder are powered by electromagnets. All of the feeder bowl's components are made of metal except for the vibration isolation pads under the base of the unit. The shuttle mechanism, which isolates one end plug from the others for pickup, consists of an air cylinder with Viton seals, a mounting plate, and a T-handled screw for attaching it to the feeder bowl assembly. The shuttle mechanism is modular and can be replaced on location. If a part of the feeder bowl fails, such as an electromagnet, the entire feeder bowl assembly can be lifted from off the table and transferred to a repair station.

X-Y-Z Robot - The X-Y-Z robot, shown in Figure 5, is made of three linear slide mechanisms and provides 0.305 m, 0.610 m, and 0.152 m (12 in., 24 in., and 6 in.) of travel in the X, Y, and Z directions, respectively. The X-Y-Z robot is capable of travel speeds up to 1-inch per second on any axis and is repeatable to ± 0.003 inches. Stepper motors control the X, Y, and Z motions and resolvers provide absolute position readouts for each axis. The stepper motors and resolvers are similar to the ones used in the rotate drive mechanism. Both the resolver and stepper motor modules, shown in Figure 6, have been designed to be replaceable on location. Limit switches, mounted on one end of travel of each axis of the X-Y-Z robot, provide a "Home" position. The limit switches are held in place with a screw and dowel pins and are designed to be replaceable on location.

Mounted on the Z-drive of the X-Y-Z robot is the micro Z-drive which holds the end plug pickup and welding torch devices, see Figure 7. The end plug pickup device uses a small ejector jet vacuum to pickup the end plugs. The vacuum has Viton seals and uses a vacuum switch to indicate when an end plug has been picked up. The GTAW torch houses a 1.59 cm (0.0625) diameter lanthanum/tungsten electrode and is designed for easy electrode replacement. The micro Z-drive moves both devices up and down independent of the main Z-drive. Mounted on the main Z-drive just below each device is a pneumatic gripper. The grippers clamp onto the element jackets and keep them centered underneath the end plug pickup device or the welding torch electrode. The grippers are made of aluminum and also have Viton seals.

Because of the complexity, size, and inaccessibility of the many components attached to the micro Z-drive, the entire micro Z-drive assembly is designed as one module. Replacement of failed parts on the micro Z-drive module is accomplished by removing the module and transferring it to a glove box or repair station to facilitate individual component replacement.

Compressor Assembly and Pneumatics - The compressor assembly, shown in Figure 3, supplies all of the pneumatic requirements of the system. The compressor uses metal bellows to compress the gas and is specifically designed for radiation environments. The compressor takes the argon gas directly from the hot cell through a filter which limits the amount of internal contamination to the accumulator and compressor. The pneumatic hoses are made of reinforced PVC vinyl or Viton and have quick-

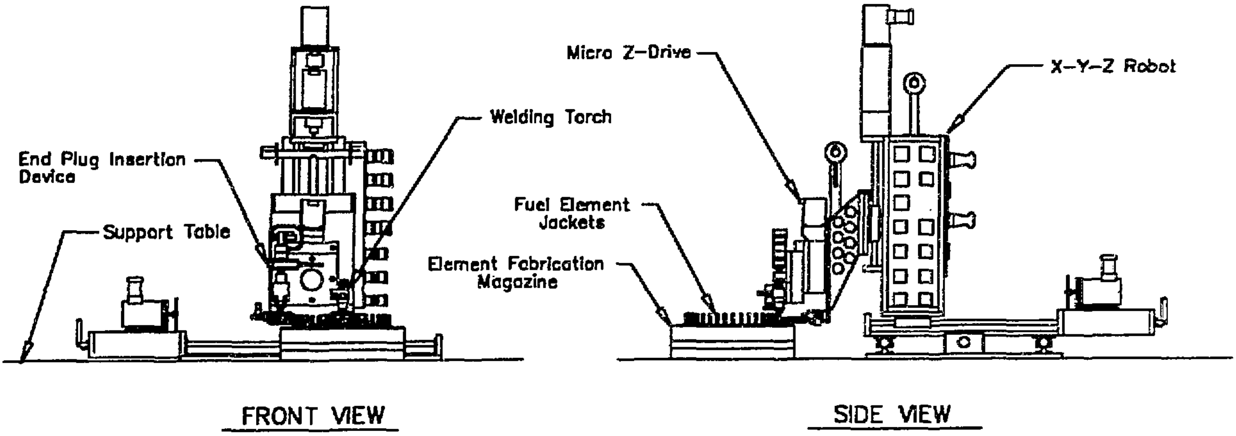

Figure - 5 - X-Y-Z Robot

Figure 6 - Photograph of theX-Y-Z Robot Stepper Motor Drive (bottom) and Resolver (top)

Figure 7 - Photograph of the Micro Z-drive showing End Plug Insertion Device (left side) the Welding Torch (right side)

connects on both ends for easy replacement of the hose assemblies. The solenoid valves are made of stainless steel with Viton seats and are modular so that they can be replaced individually on location.

The Vision System - The vision system, shown in Figure 8, consists of an in-cell radiation hardened camera connected to an out-of-cell computerized image recognition system. The camera is mounted on a horizontal linear slide device driven by a stepper motor. A pair of radiation hardened lights help to illuminate the fuel elements for inspection. The out-of-cell portion of the vision system performs the automated dimensional inspection of the fuel elements using pattern recognition techniques. Auto-focus and auto-iris control routines built into the vision system software allow complete automation of the inspection process.

Xenon Tag Gas Apparatus - The Xenon Tag Gas Apparatus, shown in Figure 8, is used to "tag" batches of fuel elements with a unique mixture of xenon/krypton gas. Each batch of 61 fuel elements in a subassembly will have a specific isotope of Krypton mixed with Xenon. This "tagging method has been used in the Experimental Breeder Reactor II (EBR-II) for many years to locate failed fuel elements in the reactor. The tag gas apparatus has a horizontal and a vertical linear slide, both of which are driven by stepper motors. The vertical slide drives a small probe down into the open fuel element jackets and a series of solenoid valves are opened and closed in a sequence to inject the gas into the element jackets. Since the tag gas is heavier than argon, it will remain inside the element jacket. The entire tag gas apparatus is designed as one module because of the small size and complexity of the individual components.

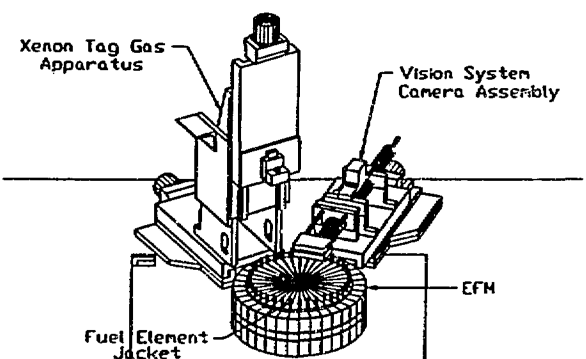

Figure 8 - Xenon Tag Gas Apparatus and Vision System

CONCLUSION

In summary, the modular design of the automated fuel element closure welding system will allow it to operate for many years in a high radiation and inert gas environment. Much of Argonne's past experience in designing for and operating equipment in hot cells has been incorporated into the design and choice of components for the element welder. Once the qualification process for the welding system is completed, it will be placed in the argon hot cell of the Fuel Cycle Facility at ANL-W and be expected to operate for the life of the fuel cycle demonstration project.

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