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Development of a Remotely Operated Band Saw for the Tritium Extraction Facility

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DEVELOPMENT OF A REMOTELY OPERATED BAND SAW FOR THE TRITIUM EXTRACTION FACILITY

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ABSTRACT

Future tritium production will be accomplished by irradiation of Tritium Producing Burnable Absorber Rods (TPBARs) in a pressurized water reactor (PWR). The highly radioactive TPBARs will be shipped from the PWR to the Savannah River Site for processing. All processing operations will be accomplished remotely including preparation of the TPBARs for extraction by providing a vent path for the tritium. The Tritium Extraction Facility (TEF) will accomplish this breaching operation by using a remotely operated band saw. The development of the system necessary to breach the TPBARs is the focus of this paper.

TPBARs will be received at TEF in groups of 300, packaged in an open-topped container referred to as the consolidation container. The TPBARs are packaged loosely inside the consolidation container; therefore, it is advantageous to breach them as a group rather than individually. Numerous breaching methods were considered and four were selected for further investigation: shearing, cold sawing, abrasive sawing, and band sawing. Each of the four methods was compared in tests using stainless steel tubing to simulate the TPBARs. All four methods are discussed, including the selection of band sawing as the preferred method for TPBAR breaching.

Testing with the band saw revealed that proper clamping of the tubing bundle is critical to successful cutting. Adequate clamping pressure must be maintained throughout the bundle in order to ensure that the saw blade removes metal rather than simply spinning the individual tubes. The identification of successful clamping techniques is discussed, as well as remote clamp application.

The current development effort with the band saw is discussed and focuses on integrating the band saw with a feed control system. Precise feed control is required to ensure that the pressurized TPBARs are not breached at a faster rate than can be accommodated by the module pressure control system. Also addressed are the design details necessary to allow remote maintenance of all breaching system components via existing in-cell tooling and a pair of in-cell master-slave manipulators (MSMs).

1. INTRODUCTION

The Department of Energy has selected the Commercial Light Water Reactor (CLWR) program as the preferred method for producing tritium. The CLWR program will produce tritium for the United States nuclear weapons stockpile by irradiation of Tritium Producing Burnable Absorber Rods (TPBARs) in the pressurized water reactors (PWRs) of the Tennessee Valley Authority (TVA). Tritium will be extracted from the TPBARs in the Tritium Extraction Facility (TEF) at the Savannah River Site (SRS). The TEF will be a new facility at SRS dedicated to the removal of tritium from TPBARs irradiated by TVA. The TEF will receive TPBARs from TVA, prepare the TPBARs for extraction, and then extract the tritium from the TPBARs.

The highly radioactive nature of the irradiated TPBARs requires the use of remote handling to ensure worker safety. TPBARs are highly radioactive due to induced radiation in their stainless steel cladding. Therefore, the TEF is a heavily shielded, remotely operated facility.

The TEF will receive TPBARs from the reactor as loose groupings of up to 300 rods in a single group or bundle. The groups of TPBARs will be received in TEF from the reactor packaged in an open-topped container referred to as the consolidation container. Once in the TEF the consolidation container will be placed in another container called the furnace basket, initially used for storage and eventually processing. Furnace baskets selected for processing will be moved from storage to the TPBAR Preparation Module. This module is similar to an inert atmosphere hot cell and contains the equipment necessary to prepare the furnace basket and the TPBARs for processing. One of the steps in the extraction preparation process is to provide a vent path from the TPBAR for the tritium gas. This process is referred to as "breaching." The current rod design suggests that cutting the tops off of the rods may be the most efficient way of achieving this breach.

A variety of factors impact how the TPBARs should be prepared to ensure a successful extraction. These include the design of the TPBAR itself, the configuration of the TPBAR group received by TEF, limitations imposed by the TPBAR Preparation Module, and compatibility with the extraction process. These factors are discussed in more detail below.

1.1 Design of the TPBARs

The TPBARs must fit into existing positions within the core of the host reactor. The TPBARs are intended to replace existing burnable absorber rods in the core. Both Watts Bar and Sequoyah are Westinghouse Pressurized Water Reactors (PWRs) and will accept TPBARs of similar dimensions. TPBARs will be approximately 3/8" in diameter and about 12 feet in length. Each TPBAR will have a threaded stud at the upper end that will pass through the baseplate and be secured by a nut.

1.2 TPBAR Preparation Module

The TPBAR Preparation Module will be the designated area within TEF where the breaching operation will be performed. The module atmosphere and the available support equipment within the module will impact the selection of the breaching technology. An inert atmosphere within the module will assure that any tritium released to the module atmosphere is readily recoverable. In order to assure that module atmosphere is maintained as desired, there will be a module stripper and make-up system. Pressure control limits on these systems constrain how many TPBARs may be breached within a given time period, since breaching of TPBARs will release the internal gas pressure. A pair of master-slave manipulators (MSMs) will be available to service equipment within the TPBAR Preparation Module. The MSMs are commercially available; however, they are constrained by two features – reach and payload. Auxiliary devices will be provided in the TPBAR Preparation Module, such as a hoist system, to move items that would otherwise be beyond the operating envelope of the MSMs.

1.3 TPBAR Extraction Process

High-temperature vacuum extraction will be used to extract tritium from the TPBARs. This imposes certain limitations on the breaching process to ensure that extraction will be successful. The vacuum pumps used in the process are delicate, and can be damaged by uncontrolled pressure transients. To protect these pumps the breaching process must be verifiable, so that unbreached rods are not introduced into the furnace. The vacuum process also demands cleanliness, as cutting oils or similar substances would be vaporized and plate out inside vacuum piping.

2. BREACHING METHODS

A large number of potential breaching methods were considered and compared against the factors identified as impacting the breaching operation. From this review shearing and saw cutting evolved as the most versatile options and were evaluated in further detail by breaching a limited number of simulated TPBARs.

Four methods of cutting simulated TPBARs were observed. The four methods included the following: shearing, band saw cutting, abrasive wheel cutting and cold sawing. The simulated TPBARs consisted of 3/8 inch by 0.035 wall, type 304L stainless steel tubing, initially four feet in length. These simulated rods were then bundled into groups of 24 and clamped together using two hose clamps. The bundle as a whole was then clamped to the working surface.

2.1 Shearing

The bundle of 24 rods was sheared using a Hurst® model ML-50 hydraulic cutter operating at 4000 psi pressure. This cutter is capable of 38,000 pounds of force and employs curved blades in a scissors type action. However, it was not capable of cutting an entire bundle of 24 rods with the results of this effort shown in Figure One. Twelve- and eight-rod bundles were also tested and in each case the result was similar to the 24-rod case. The eight-rod bundle was sheared after three cycles of the shear and repositioning of the bundle; these results are shown in Figure Two. A single rod was also sheared. In all of the shearing cases it was noted that the rods tended to be crimped closed as can be seen in Figure Two.

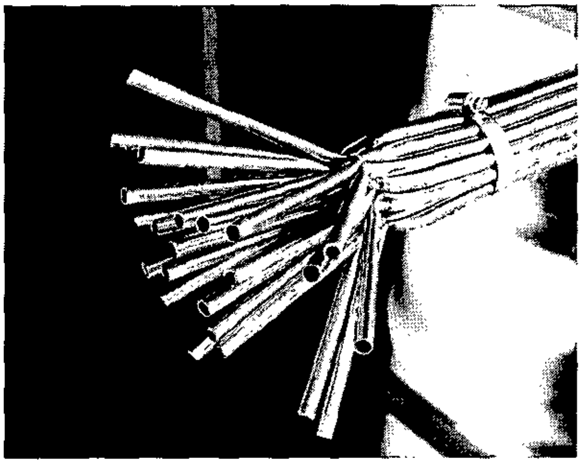

Figure One
Attempted Shear of 24-Rod Bundle

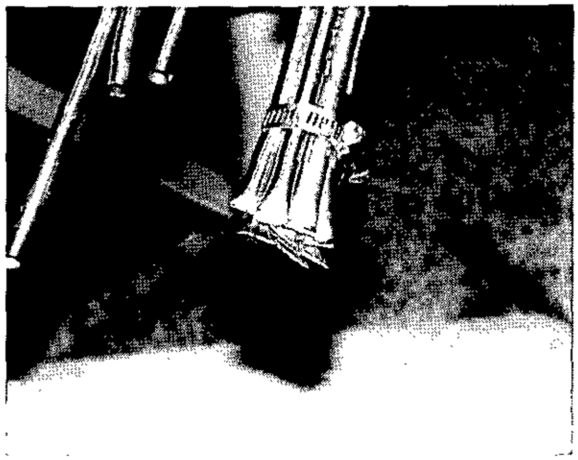

Figure Two
Shear of Eight-Rod Bundle

A more powerful shear may actually be able to cut through the rods; however, crimping of the rods would still be a concern. Another potential problem with shearing is the introduction of hydraulic equipment to the TPBAR Preparation Module.

2.2 Band Sawing

A Porter Cable® model 7724, Porta Band was used to manually cut the 24-rod bundle. The saw was operated at a speed of 100 surface feet per minute using an 11-tooth-per-inch blade. The band sawing operation is shown in Figure Three. This technique was highly successful and additional tests were conducted to refine and examine band sawing further.

A square clamping arrangement was used to completely replace the hose clamps previously used. The square clamp consisted of two sections of angle brought together from two directions at the same time shaping the bundle into a square. The square clamping arrangement is shown in Figure Four. Tests were conducted in a horizontal and then a vertical configuration using the square clamp along with the band saw.

Expanding on the success of these tests a bundle of 72 rods was clamped in a vertical position and saw cut. A single 3-inch floor riser pipe clamp was used to clamp the bundle into a circular shape and then the clamp was held in a vice. This test was generally successful; however, some "spinning" of rods was noted. Two of the rods were not held tight enough and were spun by the saw blade which, due to the angle of the blade, caused the rod to "walk" up out of the bundle. The "spinning" appears to be due to the shape of the clamp since the rods involved were located on the exterior of the bundle near where the two halves of the clamp met.

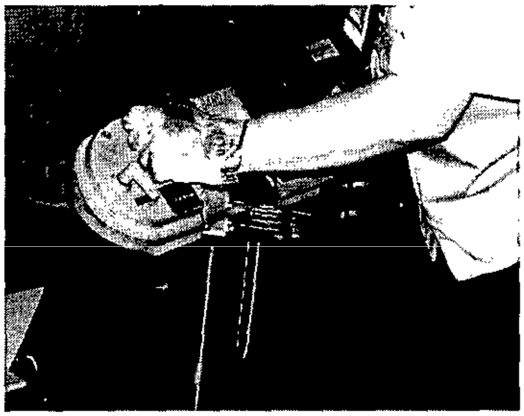

Figure Three
Band saw Cutting

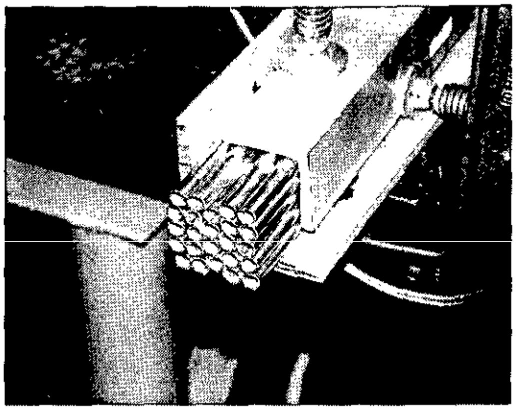

Figure Four
Square Clamping

2.3 Cold Sawing

A Torret® model T 315 circular cutoff saw with metal cutting blade was used to cut the 24-rod bundle. The saw was not capable of cutting the entire bundle of rods. The saw began to cut into the bundle, but, as the cut progressed, it began to bind and the cut was aborted. The increased friction or contact with multiple tubes may have caused the binding with the sides of the saw blade as it passed deeper into the bundle. Also, some loosening of the clamped bundle may have occurred which contributed to the binding problem that was observed. The loosening may have been due to an awkward clamping arrangement that employed the hose clamps on the bundle in conjunction with the built-in clamp on the saw.

2.4 Abrasive Sawing

The bundle of 24 rods was cut using a Makita® model 2414B, abrasive-wheel cutoff saw operating at 3800 rpm. This device quickly and easily cut through the entire bundle producing a nice surface with only minor smearing of metal over the ends of the rods. However, this saw produced a large spray of sparks and an increased amount of debris due to the wheel material wearing away during the cut. It also tended to throw the debris in a plume that extended over three feet from the saw.

2.5 Initial Test Results

Based on these tests the band saw was found to be the best technique for cutting a bundle of TPBARs in the TEF rod preparation module. These initial tests also demonstrated the importance of clamping to the success of the breaching operation. The circumferential clamping method appeared to be the most usable with all sizes of rod bundles and was the most adaptable technique demonstrated in these initial tests for use with a full 300-rod bundle.

3. CLAMP DEVELOPMENT

Further development of circumferential clamps began by first fabricating a set of clamps to be used in conjunction with band saw breaching tests with a full size 300-rod bundle. For these tests two sets of C shaped clamps were employed to clamp the tubes around their circumference. The clamps were positioned at 90° to each other and then torqued to produce the clamping force on the rods. Torque values were recorded so that clamping forces could be determined. The clamps mimic a standard pipe support clamp as was used successfully in the initial tests but were custom fabricated to match the 7-inch bundle diameter. The clamped vertical bundle is shown in Figure Five.

The circular clamping design used in the 300-rod band saw tests was then adapted to remote operation. A review of commercially available clamps as well as discussions with clamp vendors led to the selection of a clamp style that should overcome the need to use two clamps to secure the TPBARs. TEF design requirements allow the receipt of loads of TPBARs that may vary in number. It was therefore necessary to determine the relationship between number of rods and clamp diameter. Measurements were made of the clamped diameter of various numbers of 3/8 inch rods and the relationship between number of rods and clamp diameter was determined. Based on this data and the physical constraints of the clamp design, two different size clamps will be required in the TEF. The clamp style selected and the diameter data led to the remote clamp design shown in Figure Six.

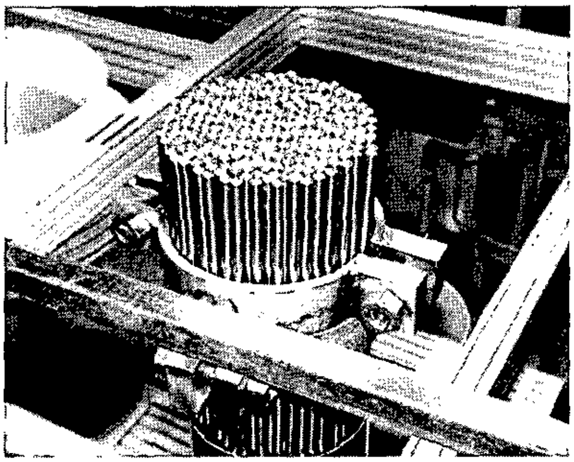

Figure Five
Clamped Bundle Detail

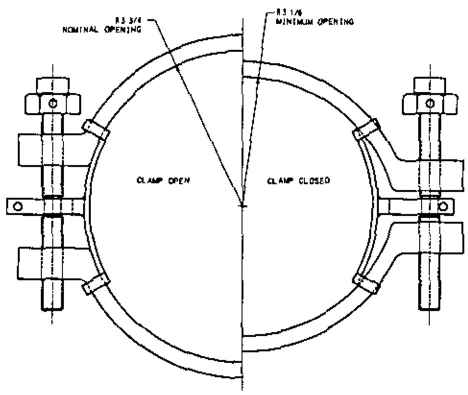

Figure Six
Remote Clamp Design

The remote clamp was tested in conjunction with furnace testing. Figure Seven shows the remote clamp with a partially loaded consolidation container loaded in a furnace basket. During these tests, the clamp proved capable of holding the bundle during cutting operations; however, it was also found to be difficult to operate and not robust enough for the intended service. Therefore, the remote clamp design was modified as shown in Figure Eight. The majority of the changes were in the bolt design as the custom dual thread bolts were replaced with a modified commercial fastener. A snap ring was also employed to limit the movement of one clamp half so that the clamp would remain in the open position for installation on the rod bundle. A nut was tack welded to each end of one clamp half to increase clamp range and avoid threading the clamp half itself. Bolt clearance could now be provided in the other clamp half thus making the clamp much easier to operate.

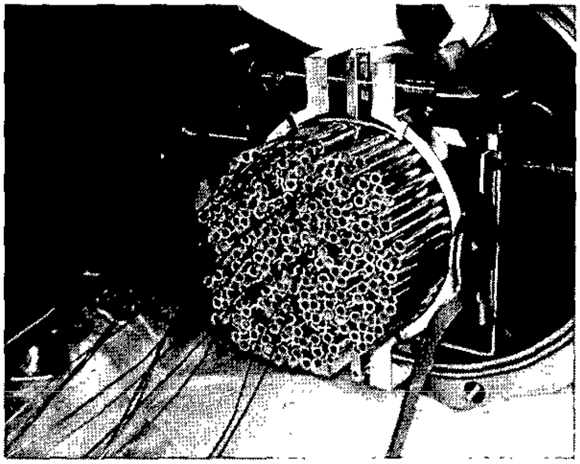

Figure Seven
Remote Clamp in Basket

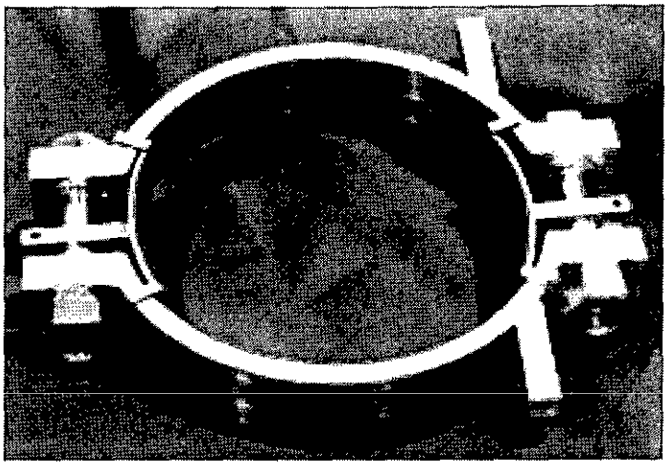

Figure Eight
Modified Remote Clamp Design

4. SAW DEVELOPMENT

Saw development continued from the initial test by conducting a test with a full 300-rod bundle. The 300-rod tests led to a saw maintenance demonstration with an MSM and finally to the development of the automated remotely operated saw.

4.1 Testing With 300 Rods

The 300-rod tests were conducted using a CS Unitech®, deep throat, air-powered, portable band saw. This saw has a capacity of 7.25 inches. The saw was positioned so that between 1 and 2 inches would be removed from each tube in the bundle. The saw was operated at an air pressure of 40 to 50 psi, which produced a tool speed of approximately 110 surface feet per minute. A 10 to 14 tooth-per-inch (TPI) variable-pitch M42 steel blade was used in the saw. The sawing operation and saw are shown in Figure Nine.

The 300-tube bundle was successfully cut two times with similar results. The bundle of tubes after the second cut is shown in Figure Ten. During the first cut the clamps were torqued to between 40 and 50 foot-pounds, which corresponded to a clamping force of 5250 pounds. In the second case the clamp torque was reduced to 25 foot-pounds or a force of 2550 pounds. In both of these cases all 300 tubes were severed with no spinning of the tubes noted. The time to cut through the full 300-tube bundle was slightly less than 10 minutes. Severe blade wear was noted during each cut and, for all practical purposes, a single cut rendered the band saw blade useless. Blade wear was expected to be a problem since the cut was made dry as would be required in the TEF; however, it was more severe than expected given the results of the initial band saw tests (also a dry cutting operation).

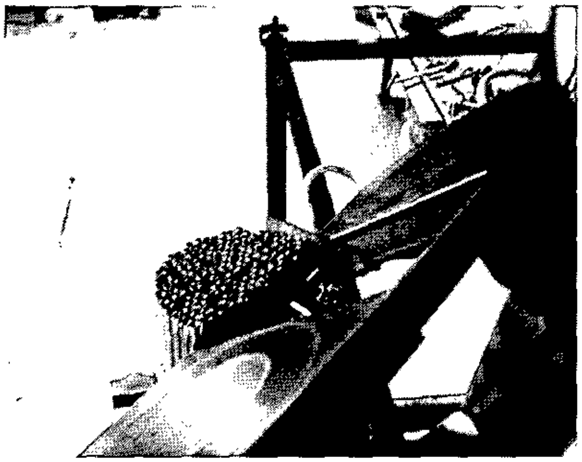

Figure Nine
Cutting Operation Top View

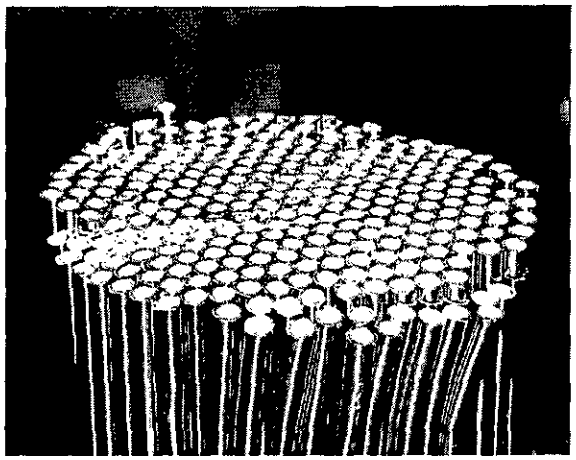

Figure Ten
View of Completed Cut

The direction of blade travel with respect to Figure Ten was from the front of the picture toward the rear. Note in Figure Ten the bent tubes located along the front of the bundle. This bending has been typical in all band saw cuts made to date and is caused during the initial entry of the blade into the bundle as the toothed blade catches on the first row of tubes it encounters. While not apparent in Figure Ten some bending also occurs as the blade exits the bundle of tubes. Other items to note in Figure Ten are how well the circular clamps formed the bundle into a close packed array and the relatively clean/clear openings left in the ends of the tubes.

4.2 Remote Maintenance Demonstration

Due to the limited blade life experienced during cutting of 300-rod bundles, a remote maintenance demonstration, specifically, blade replacement was considered necessary. The air-powered bandsaw was used to demonstrate blade replacement. The saw uses a 5/8-inch wide, 66-inch long band.

The saw received two modifications for the maintenance test. The wheel tension release handle was lengthened by 8 inches because the manipulator could not reach the existing handle. The blade guides were modified to remove the 45-degree blade twist at the saw throat. This twist enables the saw to cut items that are too long to fit in the space between the cutting zone and the structural brace, such as long pipe runs or posts. Since the TPBARs will not extend above the structural brace, the twist is not necessary to the TPBAR Breaching Saw. Following the modification, some lessening of blade tension was observed, but the blade still tracked well and did not give indications of jumping off the wheels.

The MSMs used for this test were a Model 8 and a System 50, both of which are manufactured by Central Research Laboratories®. The Model 8 is a light duty, fully mechanical unsealed manipulator that uses low friction metal tapes to drive the slave arm. The System 50 is a heavy-duty manipulator with a power-assisted gripper capable of applying an 80-lb. compressive force.

After several successful manual blade changes, the modified bandsaw was placed on a table in front of the MSMs for remote blade replacement. Through trial and error it was determined that the best method for blade replacement was to seat the blade in the blade guides first. However, this proved impossible with the Model 8 MSM because it lacked sufficient grip to force the blade into the space between the guides. Eventually the Model 8 was used to hold the blade in front of the guides while the more powerful System 50 pressed the blade into position. After the blade was anchored by the blade guides, the manipulators were used in combination to route the blade around the take up wheels and finally through the guide slot in the structural brace. The total time to complete this operation was 40 minutes, and it required two operators. Note: The MSM "operators" in this test were engineers who are not experienced MSM users.

4.3 Automated Saw Development

Testing demonstrated saw cutting and maintenance with a portable bandsaw. While these tests were successful, the saw was not easily adapted to automated operation. A commercial saw head designed for automated operation was selected and procured for incorporation into the automated breaching system. The saw chosen is a Wellsaw® model 58BD with a maximum capacity of 9.5 inches. The saw blade is 1/2 inch wide and 93 inches long. It is hoped that this longer blade length will increase blade life due to the increased blade material available as well as the increased time outside the cut zone to allow better blade cooling. It is still not expected that more than a single cut can be made with an individual blade; however, additional testing with this new saw may lead to a correlation between blade length and life for this dry cutting operation. Additional items required for automated operation include a drive system to move the saw through the cut and a force control system to protect the saw from becoming overloaded. The automated saw assembly is shown in Figure Eleven.

The drive system includes a set of linear bearings to carry the load of the saw and is driven by an electric linear actuator. The standard actuator was modified so that the speed of travel could be reduced into a range useful for testing and control. A maximum saw feed of 1 inch per minute is required by the current module pressure control system. A range of speed to either side of the 1 inch per minute requirement is necessary both for control of the saw and for testing purposes. A pneumatic drive system was considered since this type system would also provide some level of force control. However, the pneumatic system was not pursued since speed control would be a concern in the TEF and better speed control is required for testing purposes.

The force control system uses both mechanical and electronic means to maintain an acceptable force on the saw blade. The primary element of this system is a spring component located in the drive system. The spring can be easily changed during testing to allow optimization of this element for the final TEF breaching system design. Since the saw is driven through this spring element, the load on the blade will increase if the saw does not maintain adequate speed through the cut. In parallel with this mechanical system is a sensor which measures the deflection of the spring element and reduces the speed of the drive system in proportion to this deflection after an initial preload is achieved. In combination these two components allow the blade to remain under load if the feed rate momentarily exceeds the material removal rate of the saw and effectively allows the saw to catch up with the drive system.

The main components of the force control system as well as the drive system can be seen in the saw detail shown in Figure Twelve.

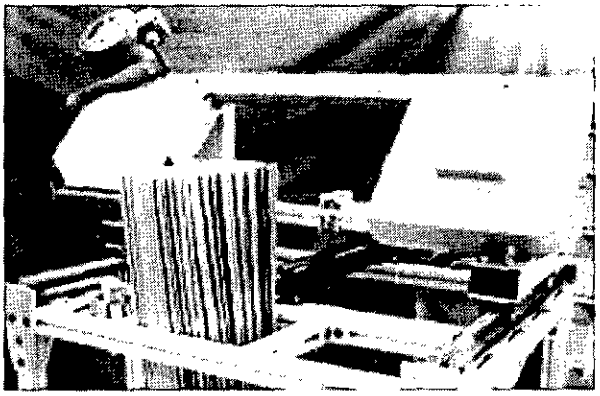

Figure Eleven
Automated Saw Assembly

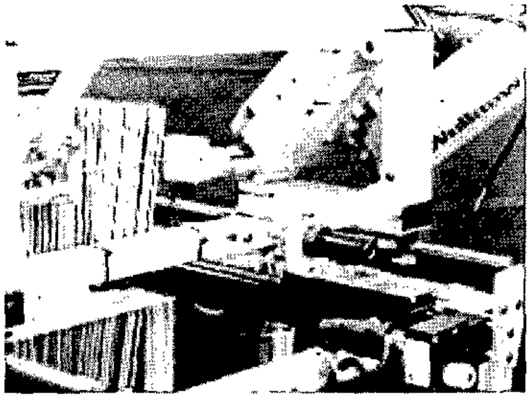

Figure Twelve
Saw Detail

4.4 Future Work

The 300-rod saw test identified the need for a system to control the cut ends of the TPBARs as well as the need for a means of controlling or cleaning up the fines produced by the saw. Contamination control in the TPBAR Preparation Module is a key area of concern and the automated saw system will be used to develop the necessary systems to control the spread of contamination. The current design concept calls for the addition of a funnel to direct the cut ends down into the furnace basket and from there out of the process with the rods. The funnel method of collecting cut ends appears feasible since 300-rod tests demonstrated that the cut ends do not leave the bundle top energetically but rather are swept away by the saw. Control of the fines generated by the saw is a similar problem in that the low blade speed of the saw does not produce a plume of debris but rather a concentrated area of debris near the cut line. It is expected then that the funnel system will also capture the bulk of the fines. A blade cleaner is currently part of the saw design to aid in this process. A vacuum cleaner system is also planned for installation in the TPBAR Preparation Module. A shroud will be designed for attachment the vacuum system to provide for dust collection during the cutting operation. The vacuum will also be used after the cut is completed to manually clean the area with the MSM of any debris not previously contained.

5. CONCLUSIONS

Given the requirements imposed by the TEF operating environment testing has shown that an automated band saw will provide the best means for breaching TPBARs. The development of the band saw system has progressed in parallel with development of a remote clamping system since testing indicated that clamping is a vital part of the sawing operation. An automated saw with remotely operable clamp has been designed based on the testing program to date and will be used in future tests to finalize the design requirements for the TEF breaching system.

The testing program has identified many important elements of the TEF breaching operation. These include the selection of band sawing as the preferred breaching method along with the detailed cutting parameters listed in Table One. Note that blade tooth pitch will be examined in more detail in future tests and Table One provides only the current recommendation for this parameter. Blade life was identified as a concern; however, a blade replacement demonstration proved that this concern would not adversely impact the use of the band saw. It is recommended that the blade length be maximized in TEF to reduce further the impact of limited blade life.

Table 1
Band Saw Cutting Parameters

Blade Material	Starrett®, Powerband M-42
Tooth Shape	Regular with straight rake
Tooth Pitch	Variable pitch (10-14 TPI)
Blade Speed	110 feet per minute

A circular clamping system was identified as best meeting the needs of the TEF breaching system. The clamp design has evolved over several testing phases and is yet to be tested in final form. The clamp is a fairly bulky and heavy apparatus and may not be able to be positioned by the module MSMs. Further testing will be required to verify that the MSMs or the in-cell crane can position the clamp. Additional design may be required if the in-cell crane is required for clamp positioning.

ACKNOWLEDGEMENTS

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