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Techniques for Cutting Irradiated Fuel Ducts at FFTF/IEM Cell

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TECHNIQUES FOR CUTTING IRRADIATED FUEL DUCTS AT FFTF/IEM CELL

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ABSTRACT

Two remotely controlled mill-type cutters have been used in the Fast Flux Test Facility Interim Examination and Maintenance Cell to assist in the disassembly of 18 fuel assemblies. These cutters slit the outer duct of the fuel assemblies, which allows the ducts to be removed and provides access to the encased fuel pins. The cutters were developed by Westinghouse Hanford Company and thoroughly tested by cutting prototypic ducts. During actual use, however, occasional loss of cutting depth control occurred. A discussion of the control problems and the operation and design techniques developed for their resolution is presented.

INTRODUCTION

The Fast Flux Text Facility (FFTF) is a U.S. Government owned, 400 MWt, sodium-cooled fast reactor plant designed for irradiation testing of nuclear reactor fuels and materials, reactor safety, research and development, testing of advanced reactor concepts, and equipment demonstration for liquid-metal fast reactors. The FFTF is located on the U.S. Department of Energy's Hanford Site near Richland, Washington, and is operated by the Westinghouse Hanford Company, a subsidiary of the Westinghouse Electric Corporation.

The Interim Examination and Maintenance (IEM) Cell is a vertical hot cell located within the FFTF containment building and is used for processing reactor core assemblies and limited maintenance activities. The atmosphere within this hot cell is argon, which permits sodium-wetted assemblies to be handled. Selected irradiated fuel assemblies from the FFTF reactor core are processed in the IEM Cell to determine the performance of experimental fuels and materials. Typically, sodium is cleaned off of the irradiated fuel assemblies, which then are dimensionally measured and disassembled, and the fuel pins are sent elsewhere for further examination.

Disassembling a fuel assembly requires cutting the outer hexagonal duct horizontally above the inlet nozzle and lifting the duct off the encased fuel pins. If the duct has dilated significantly in the fuel region, the duct must first be cut vertically on three sides. This allows the duct to expand over the internal swollen fuel pins as it is removed. Specially designed vertical and horizontal cutters are used to perform the duct cutting.

During the last seven years, these duct cutters have been used for remote disassembly of 18 fuel assemblies. During the early years of operation, cutting problems were common, but their frequency diminished as experience was gained, equipment upgrades were incorporated, and techniques were developed. Duct cutting is now becoming routine.

EQUIPMENT

Both the horizontal and vertical duct cutters are controlled by a computer and operator console located in the operating gallery.[3] The cutting hardware is located on the disassembly station inside the IEM Cell. Figure 1 illustrates this disassembly station and mounting for the cutters. The fuel assembly is clamped vertically to the support column and the vertical or horizontal cutter is mounted on the X-Y table of the equipment column. The Z-drive assembly of the equipment column provides vertical movement for the cutter. The X-Y table movement directions are also illustrated in Figure 1. Manual controls on the operating console provides for station setup and initial cutter positioning.

Both cutters use 127-mm (5-in.) by 1.58-mm (1/16-in.) metal slitting saws driven by 1/4 hp variable-speed motors. Table motions are controlled by the computer, which receives feedback information on the relative position of the duct surface to cutting blade from a depth-sensing probe. A backup stop-disk is mounted on the vertical cutter arbor to physically limit the maximum depth of cut.

Accelerometers, one mounted on each cutter, function as acoustical sensors to provide the operator with an audio indication of the cutting process. A shroud covers the cutting blade, except for the immediate cutting area; the shroud is attached to a vacuum system which contains the activated cutting particles. Figure 2 shows the horizontal cutter in use at the disassembly station.

CUTTER OPERATION

Fuel assembly ducts are cut by performing multiple cutting passes, each .381 mm (.015 in.) deep, until the desired depth is reached. For significantly dilated ducts, as determined by previous dimensional measuring, vertical cuts are performed, typically on three sides. Horizontal cutting is then performed on all six sides. Figure 3 illustrates a fuel assembly with both horizontal and vertical cuts. Fuel assemblies with insignificant dilation need only horizontal cutting.

Because fuel pins contact the inner surface of the duct wall, vertical cutting requires precise control of depth to avoid cutting into the fuel pins. The computer control system achieves precision by using feedback information from the depth-sensing probe mounted adjacent to the cutter blade. For vertical cutting, the desired depth of cut is

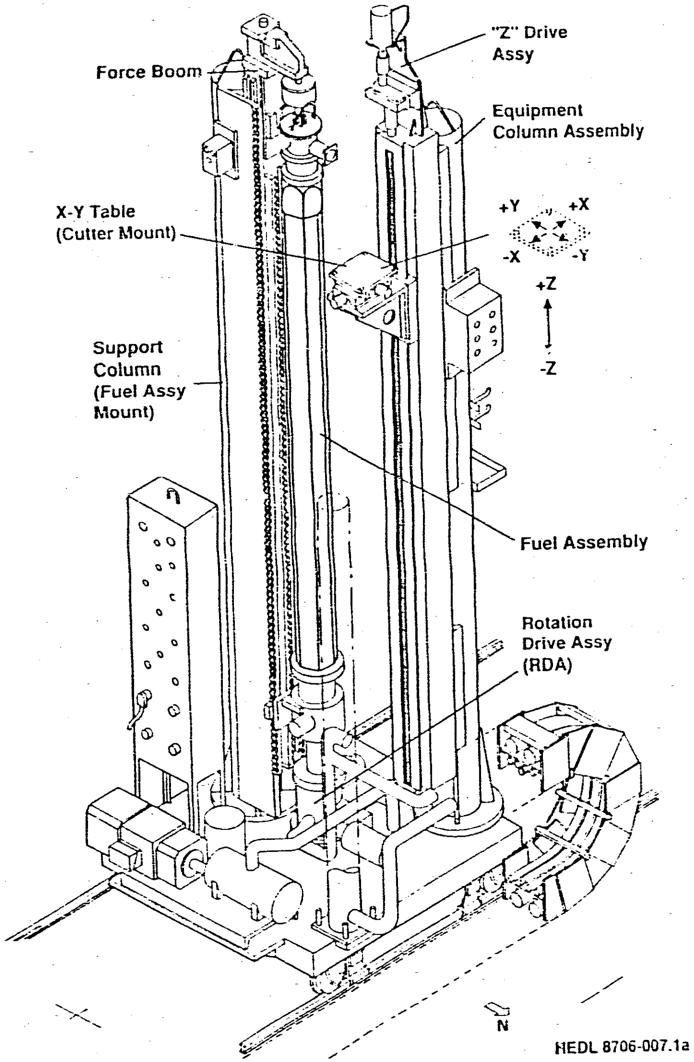

Figure 1. Fuel Disassembly Station.

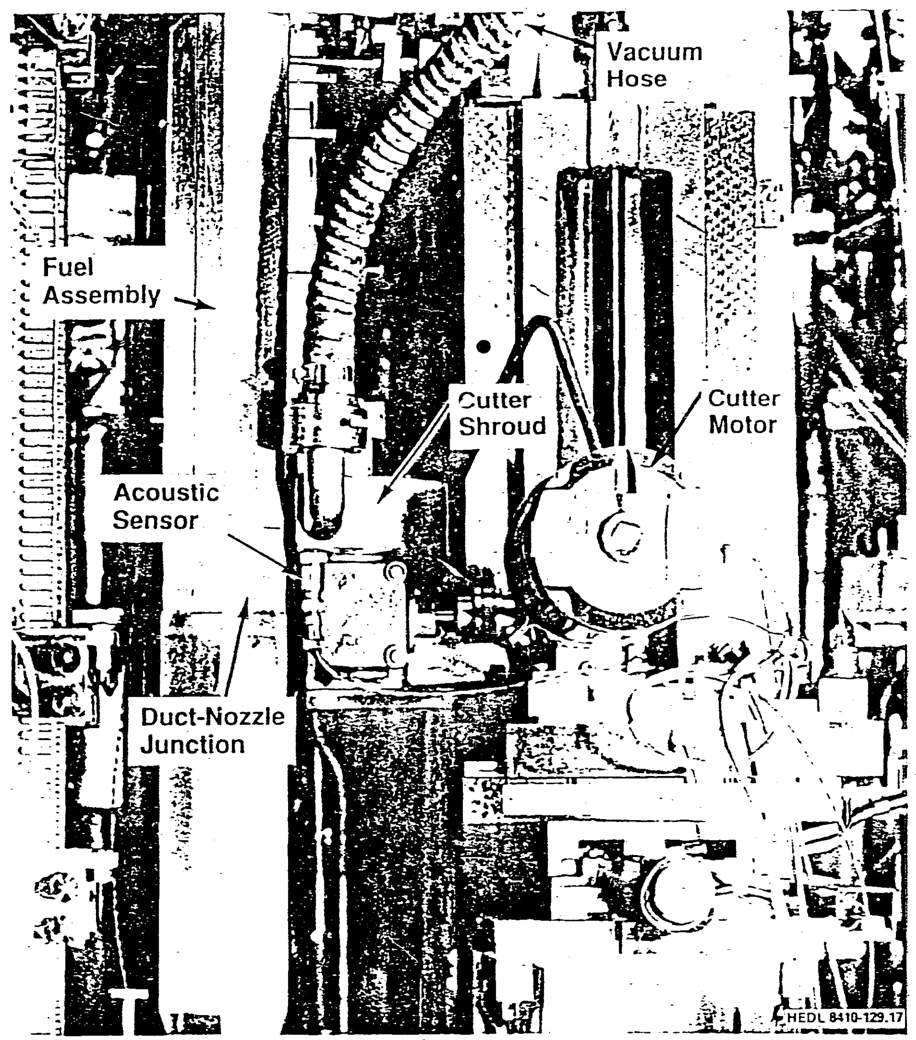

Figure 2. Horizontal Cutter Remotely Operated to Perform Cuts on Each Hexagonal Surface.

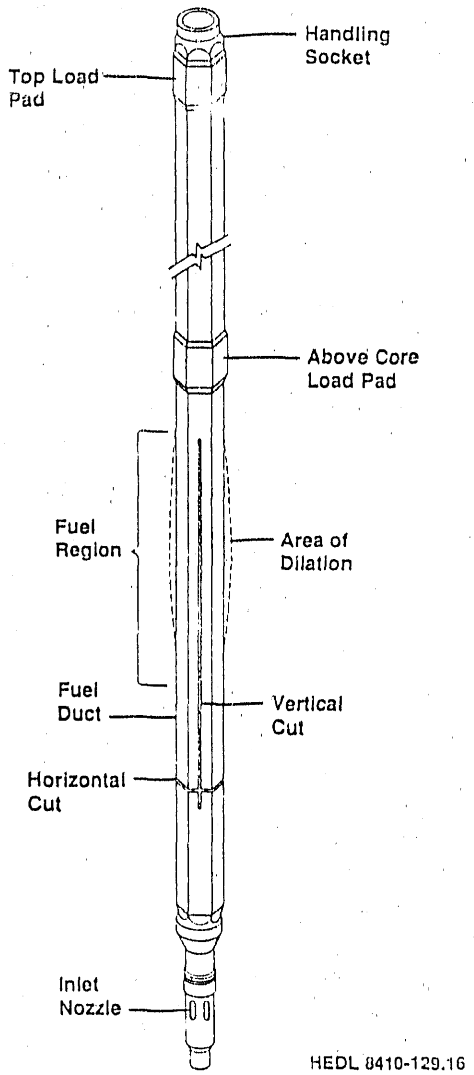

Figure 3. FFTF Fuel Assembly Illustrated With Horizontal and Vertical Cuts.

nominally .051 mm (.002 in.) less than the thickness of the duct wall, leaving a thin web. After all cutting is completed, but before pulling the duct off the pin bundle, this web is then mechanically broken with a pry bar. To guard against inadvertently cutting through the cladding of fuel pins inside the duct because of a possible system anomaly, the backup stop-disk, which is only slightly smaller than the cutting blade, physically contacts the duct and limits the blade's depth.

Precision depth control for horizontal duct cutting is not as crucial as for vertical cutting because this cut is located below the fuel pin region. Multiple cutting passes, done similarly to vertical cutting but without the backup stop-disk, are performed until full penetration of the duct is achieved.

The initial development of the duct cutters was performed in a mock-up facility and tested by cutting prototypic ducts. However, during actual use of this system in the FFTF/IEM Cell, occasional loss of depth control occurred.

The depth control problem was found to have three primary causes, categorized as geometric, electrical, and mechanical. The geometric cause was limited to the vertical cutter whereas the electrical and mechanical causes affected both the horizontal and vertical cutters.

SPECIAL TECHNIQUES

A. Geometric

The loss of depth control from geometric causes was found to result from the uneven topography of the duct surfaces. The duct surfaces become uneven in the reactor core when the swelling internal fuel pins, which are spiral-wire wrapped for pin spacing, push outward on the containing duct. This pressure results in a general dilation of the duct surface in the fuel region as well as localized dilation where the fuel pins exert the greatest pressure. Figure 4 shows a fuel assembly with its duct partially removed, revealing the spiral-wire wrapped fuel pins. As the cutter traverses these dilated duct surface areas, the geometric relationship of the duct surface to the cutter's depth sensing probe, blade, and backup stop-disk changes. Figure 5A illustrates how cutting depth errors occur with uneven duct surfaces. Neither the sensing probe nor the backup stop-disk provide the required depth control when the cut is located on the slope of dilated areas.

Correcting the loss of depth control from geometric causes requires making the geometry as consistent as possible throughout the full vertical cutting range. This range extends from below the fuel pins near the duct/nozzle junction to above the fuel region, typically about 1.27 m (50 in.). The geometry of the duct surface below the fuel region is essentially flat and can be readily adjusted parallel to the cutter's x-axis. In the fuel region, the only surface area parallel to the below-fuel region is at the peak of each of the dilation areas. Therefore, as illustrated by Figure 5B, cutting across the peaks of the dilation areas became a necessity. Also, straight-line vertical cutting needed to be retained because other methods would add considerable complexity.

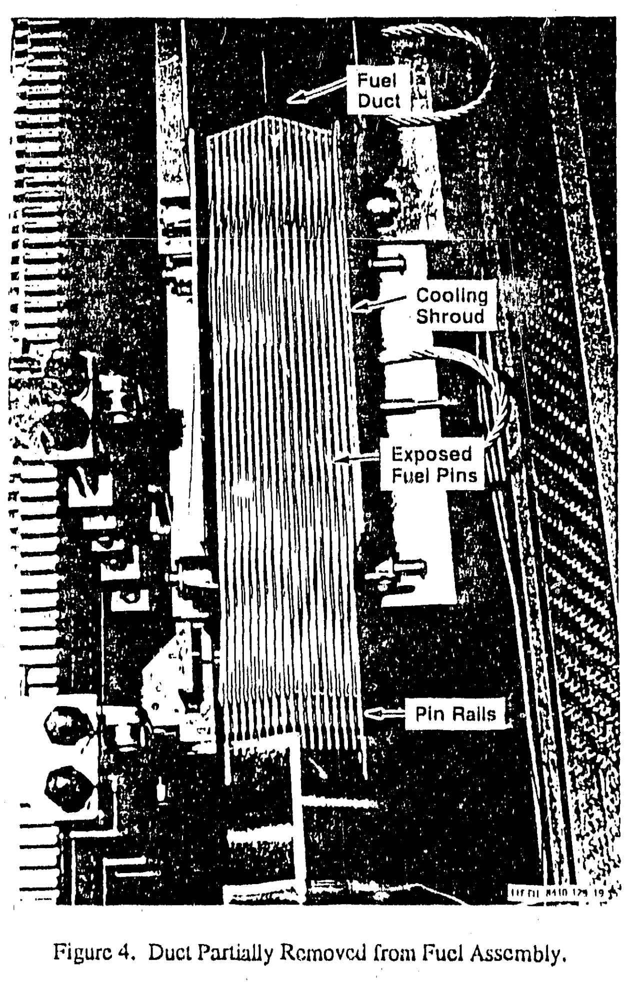

Figure 4. Duct Partially Removed from Fuel Assembly.

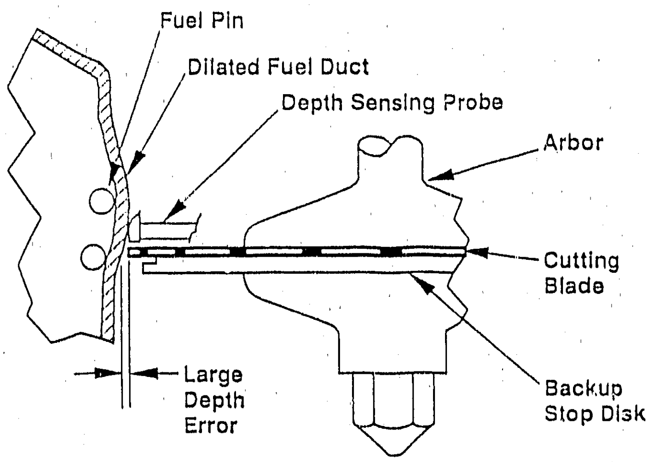

Figure 5A. Cutting on Slope of Dilation Causes Large Depth Control.

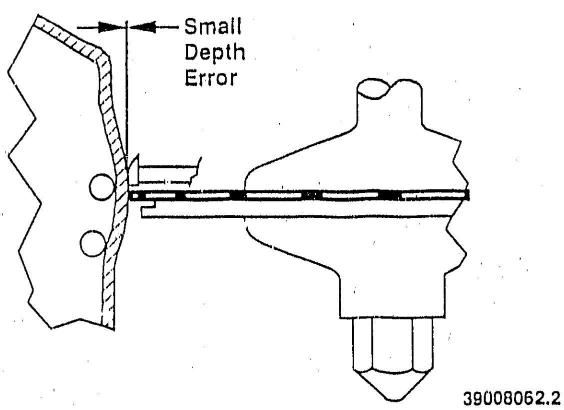

Figure 5B. Cutting at Center of Dilation Minimizes Depth Control Errors.

Implementing these requirements required characterizing the duct surface topography to locate the areas of greatest dilation. Then, at the disassembly station, setup would require the following:

- Assuring correct rotational alignment of the fuel assembly in the disassembly station, as referenced to the cutter's horizontal x-axis
- Locating the horizontal position of the dilation area peaks and assuring these peaks are aligned vertically in the disassembly station, as referenced to the cutter's vertical axis
- Positioning the cutter such that the vertical cut traverses the peaks of the dilation areas.

Characterizing the duct's surface topography was accomplished by using profilometry data acquired previously at the duct measuring station. An off-line computer program, BULGE, reports the areas of greatest dilation with a graph and numeric listing. The graph shows the position of greatest dilation for each measurement scan, while the numeric listing delineates its magnitude. The correlation between this BULGE-generated graphical map and the physical duct is shown in Figure 6A. One face of a fuel region duct segment is overlaid with a BULGE-generated graph; the three points having the greatest dilation for the entire duct face indicated by open square data points.

BULGE generates one program report for each duct face. If a BULGE program report indicates that the maximum duct face dilation is small [i.e., less than about .036 mm (.015 in.)], the x-axis position for vertical cutting is set to the center of the duct face. This magnitude of dilation will not cause significant depth errors, regardless of where the vertical cut is located. However, if the BULGE program report indicates greater duct face dilation, alignment of the duct dilation areas with the cutter's vertical axis and placing the cutter's x-axis at the apex of the dilation areas is necessary.

The horizontal position of the dilation peaks, as indicated by the BULGE report, is not directly transferrable to the disassembly station because of the following:

- Deformation of the fuel assembly by bowing and twisting along the vertical axis causes horizontal shifting of the dilation peaks in reference to the cutter's x-axis
- No mechanism exists for transferring given horizontal positions at the measuring station to corresponding positions at the disassembly station. The reference position at the measuring station is a mathematically derived centerpoint whereas the reference position for cutting is the cutter's x-axis east movement limit.

Profilometry data acquired at the measuring station is routinely used to generate face plots. These are point graphs of individual measuring passes across all the faces of the duct at all the measured vertical positions. Figure 6B shows an example of three face plots, corresponding to the three largest dilation peaks reported by BULGE, and showing the contour of the dilation areas. The greater the slope of the dilation contour at the position of cutting, the greater the depth control error will be. The BULGE program report is used in conjunction with the face plots and two of the three dilation peaks are selected based on their potential to cause the greatest depth control errors. In the case of the example shown by Figures 6A and 6B, the two dilation peaks selected would be at vertical positions 1.92 and 1.49 m (75 and 58 in., respectively). These two vertical positions are used with an on-line program, HIGH, at the disassembly station.

When a fuel assembly is transferred to the disassembly station, an on-line program, RALIGN, is first run to assist with rotational alignment. With the cutting blade removed, this program automatically moves the cutter's depth sensing probe across the face of the duct, just above the duct/nozzle junction, and reports the slope of the duct face in reference to the cutter's horizontal axis. When the slope is less than 0.007 (slope = $\Delta Y/\Delta X$), rotational alignment is satisfactory.

To locate the optimum position for the vertical cut along the cutter's horizontal x-axis, the program HIGH is run. With the cutting blade removed, HIGH automatically moves the cutter's depth sensing probe across the face of the duct at the two vertical positions previously selected using BULGE and reports the horizontal positions where the peaks occur. If the horizontal positions of the two peak dilation points do not agree within a specified tolerance, the assembly is adjusted vertically on the support column and the alignment rechecked.

To assist the operators in positioning the cutters at their initial starting locations, the on-line program PLACE is run. This program accepts position information, compensates for offsets such as the blade to depth sensing probe distance, and moves the cutter to the desired position. The duct/nozzle junction is used as the vertical reference position for the initial vertical starting location, whereas the horizontal reference point is the table's east movement limit.

Characterizing Duct Surface Topography

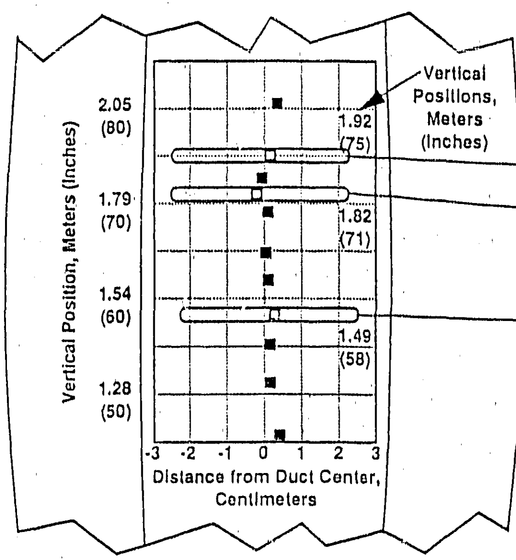

Figure 6A. Fuel Region Duct Segment with Overlay of Duct Surface Dilation Map.

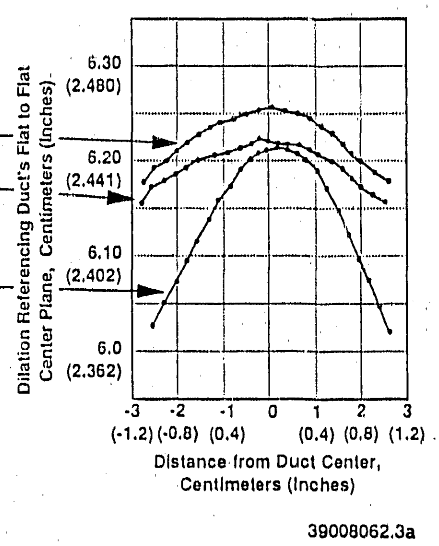

Figure 6B. Across Duct Face Plots of Three Largest Dilation Peaks.

B. Electrical

The loss of depth control from electrical causes was attributed to the harsh environment of the IEM Cell and the vulnerability of the instrumentation and electrical (I&E) cables and connectors to physical abuse. The original design of these components on the duct cutters, while similar to other long-lived hot cell components, did not hold up well. Factors identified as unique to the cutters and contributing to difficulties in the I&E components' performance were as follows:

- Frequent remote handling, including coupling and uncoupling of electrical connectors
- Snagging potential, since normal operation involved significant movement, during both cutting and handling
- Electrical connectors not sufficiently rugged for repeated handling by heavy duty remote manipulators.

Correcting the loss of depth control from electrical causes was implemented during a general system upgrade and involved a newly designed cutting system with a complete cable and connector replacement. Before the upgrade, the motor, depth sensor, and accelerometer each had its own cable, which were separately connected to a nearby junction box. The depth sensor and accelerometer each had a connector on their housing for connecting their cables, but the motor did not and was hard-wired. The cables were then harnessed together for ease of handling. As the individual depth sensor and accelerometer cables failed, they were remotely replaced, but the cables could not be remotely harnessed to the original cable. At the time of the general upgrade, the vertical and horizontal cutters had three and two separate cables, respectively. These extra cables were difficult to handle remotely and were additional obstacles to the cutting process. Figure ? shows the disarrayed horizontal cutter cabling, which was also typical of the vertical cutter cabling, before the general upgrade.

Figure 7 illustrates the upgraded vertical cutter; the horizontal cutter was similarly upgraded. The major electrical improvements were as follows:

- Installing a removable wiring harness with a local motor connector and a heavy-duty main connector designed for remote applications
- Consolidating the mating I&E cables into one of rugged design, and making them remotely detachable.

Special design features of the cable included the following:

- Remote connector plugs with stainless steel shells
- Double-jacketed polyimide insulated wires
- Woven stainless steel outer jacket
- Multiple layers of densely woven fiberglass sleeving between wires and the outer jacket.

With these electrical improvements, avoiding component damage and improving the ease of remote operation and maintenance have been significantly enhanced.

C. Mechanical

The loss of depth control from mechanical causes was attributed primarily to cutter parts loosening from vibration.[2] A contributing cause was the sensor probe linkages sticking because of mechanical binding.

Both cutters use mechanical linkages between the depth sensing probe's contact point and the position transducer. The position transducers are Linear Variable Differential Transformers (LVDT) with moveable center cores. Each cutter's linkage consists of a lever, pivoted at the center, with a hardened steel contact button at one end to follow the duct surface. The other end connects to the position transducer's core via an extension shaft. Return springs are used to hold the contact button against the duct and to remove backlash of the lever's pivot bearing and extension shaft joint.

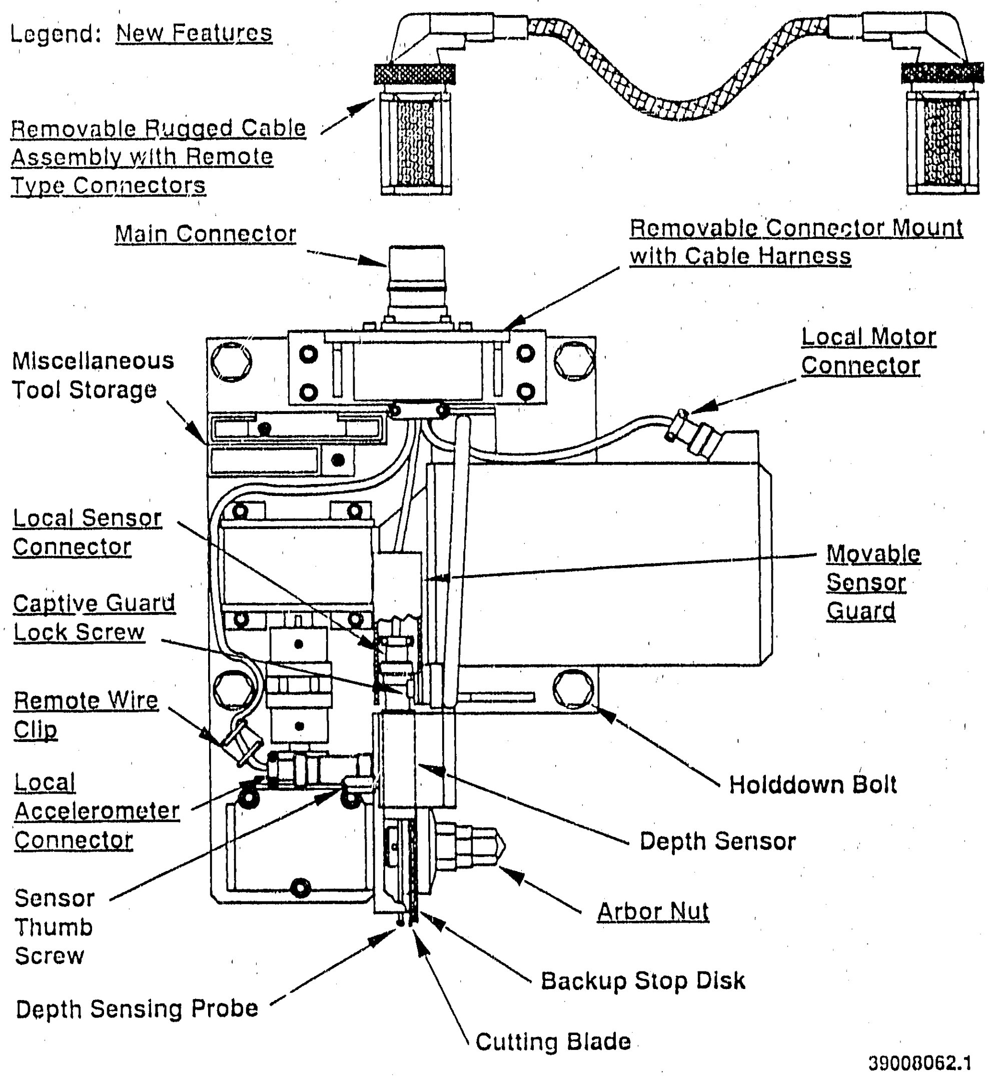

Figure 7. FFTF/IEM Cell Vertical Duct Cutter.

Correcting the loss of depth control from mechanical causes was implemented as follows:[1]

- Using a permanent aerobic thread adhesive on all fixed threaded fasteners, notably the LVDT core extension shafts
- Routinely checking tightness of the LVDT securing thumb screws
- Design refinement of the position transducer linkages
- Reversing the blade and stop-disk position. With the stop-disk next to the arbor nut and being thicker than the blade, it will not slip out of place as the blade has done. This also positions the blade closer to the depth sensing probe, reducing the depth control error when cutting through dilated areas of the duct.

CONCLUSION

Several years of operating experience has enabled us to refine the techniques for cutting fuel assembly ducts. Vertical cutting depth control improved markedly after implementing techniques to eliminate errors caused by the non-uniform geometry of dilated ducts. These techniques, which utilize existing profilometry data and computer-assist programs, significantly facilitate the duct cutting process. The electrical and mechanical cutter upgrades utilized techniques that assure reliable performance in the harsh environment of the IEM Cell. The methodology that has been developed has proven to be very successful in preparing ducts for removal from the irradiated fuel assemblies.

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