Automation Design of Spent Fuel Rod Consolidation

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ABSTRACT

Rod consolidation is a method of increasing spent nuclear fuel storage capacity by disassembling fuel assemblies thus storing the fuel rods in a tighter array. It involves some basic operations which closely resemble to the material handling of a manufacturing process. But all the operations must be controlled remotely in shielded environment from outside due to the highly radioactive nature of the workpiece. In this study the status of the rod consolidation technology in other countries has been surveyed and a feasibility study for the conceptual design of this process have been made.

1. INTRODUCTION

Today the nuclear industry is faced with critical spent fuel pool overcrowding and eventual plant shutdown due to limited spent fuel storage capability. Rod consolidation is a leading candidate for more efficient utilzation of existing space in storage pools. It also has a possible application for dry storage of spent fuel and can increase the existing storage capacity by a factor approaching 2(see Fig.1).

Rod consolidation has been examined and accomplished both at-reactor(AR) and at-away-from-reactor(AFR) facilities. The process can take place in both wet(storage pool) and dry (hot cell) environments. The process can also be performed in either a vertical or horizontal position. Hot demonstrations have occured with vertical rod consolidation[1] using irradiated fuel in water pools as shown in Fig.2. Remote horizontal demonstrations[2] have taken place in a dry environment using "dummy" fuel assemblies as shown in Fig.3. Design differences between these two require adjusted disassembly techniques. There are, however, some basic operations common to all of the consolidation tasks.

- Transfer/position of intact assembly to the consolidation equipment
- Sawing off top end fitting
- Fuel rod extraction from structural material
- Dense packing of fuel rods in canister
- Appropriate disposal of remaining structural wastes.

Fig.4 illustrates these mechanical operational

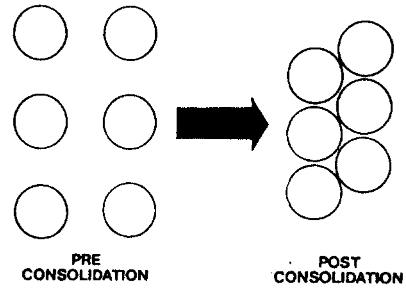

Fig.1 Rod Consolidation

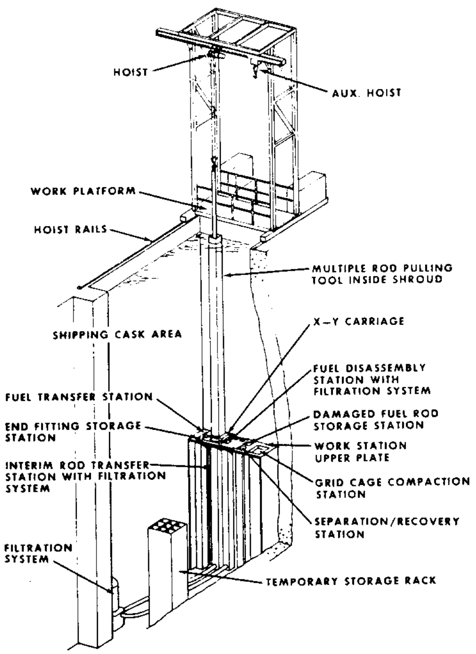

Fig.2 Vertical Rod Consolidation Process(C.E.Inc)

procedure. In this paper the status of both wet and dry type rod consolidation techniques in other countries has been surveyed and comparison study between these two has been made. From these studies the dry type rod consolidation seems to be have more benifits compared with the wet type one and seems to be available in Korean Nuclear Industry. Therefore, the primary concern of this paper is focused on the conceptual design of the dry type rod consolidation with special emphasis on automation of this mechanical facility.

2. COMPARISON between WET and DRY type ROD CONSOLIDATION

The wet type rod consoldation is generally used in the other countries due to the self radiation shielding and cooling characteristics of the water. Analysis of wet and dry cooling characteristics, respectively, revealed that wet consolidation can be performed a few months after discharge (independent of bundle size); dry one requires a number of years of decay (depending

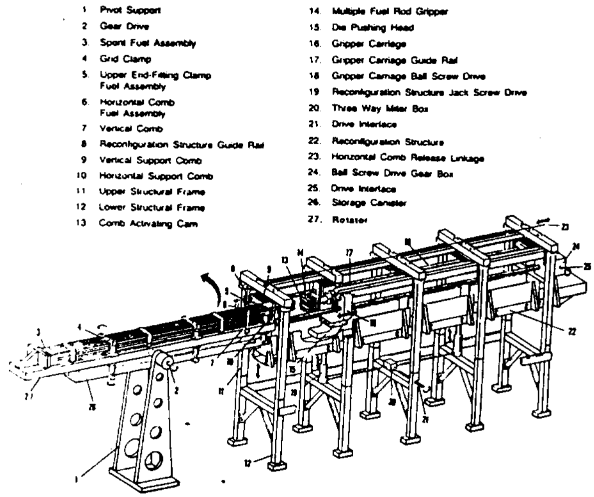

Fig.3 Horizontal Rod Consolidation Machine (Westinghouse Inc.)

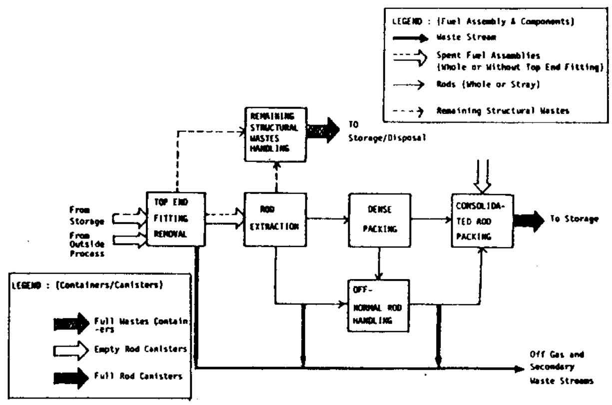

Fig.4 Flow Diagram of Rod Consolidation Process

upon bundle size, burn-up, and heat removal from the canister surface)[3,4]. However, the dry type rod consoliation in the hot cell has considerable benifit such as production rate, capital cost, operatability and convenience. Based upon the experience accumulated in the fuel reconstitution and inspection performed in the hot cell, this process now shapes up. In this paper the representative rod consolidation both wet and dry type processes are briefly surveyed.

(1) Wet Type Rod Consolidation

Fig.2 shows the wet type rod consolidation process proposed by Combustion Engineering Inc. [1]. This process consists of the respective work station, hoist equipment and various handling tools. The consolidation takes place in the work station frame, which supports seven individual work stations. The fuel is disassembled in the first station by cutting off the top end fitting and then removing the fuel rods singly or up to one row at a time by means of a mutiple rod pulling tool. Damaged fuel rods are deposited in the damaged fuel rod storage station after being seperated from the row in the seperation/recovery station. Fuel assembly top end fitting are placed in storage boxes at its storage station, for storage in the pool since they have high activity. Remaining structural wastes such as bottom end fitting, grid spacers and control guide tubes have much lower activity and are compacted by the hydraulic cylinders in the compaction station.

(2) Dry Type Rod Consolidation

Although few productions of dry type rod consolidation currently exist, many types have been proposed. Westinghouse Inc. proposed one of these types as shown in Fig.3. This system consists of four components; a rotator with fuel assembly and canister clamp, a mutiple gripper and its carrage, horizontal and vertical combs, and a rod pushing system. After the fuel rod bundle whose top end fitting is removed is placed into this system, the horizontal and vertical combs latch each fuel rods. Then, the fuel rods are grasped and extracted from the fuel assembly grid spacers. The withdrawn rods are then pushed by the die pushing head and placed into the canster. Once the fuel rods are in the canister, the residual structural wastes (the fuel assembly skeleton) can be collected, transfered to a secondary waste volume reduction system, and placed in an appropriate container.

In 1979, Allied General Nuclear Services(AGNS) performed feasibility study to develop a new methods of increasing storage at the hot cell of the spent fuel assemblies[5]. This studies indicated that there was considerable benifit in utilizing the hot cells for large quantities of fuel. The following advantages were noted:

i) Improved Production Rate : 12-15 assemblies in a day(hot cell), 2-3 assemblies in a day(pool).

ii) Improved Visibility : Using the shielding windows the operator visibility is considerably increased. Water clarity is frequently poor in a pool where fuel has been stored.

iii) Reduced Operator Exposure : The potential for radiological exposure is considerably lower than for fuel pool operation because the operator is stationed behind shielded walls. Pool water temperature, typically in excess of 100 °F, contribute to operator fatigue an discomfort.

iv) Operational Control and Flexibility : The hot cell technique readily accomodate peripheral operation such as handling of badly failed rods, or rods jammed in the grid spacers. Additional operations such as rod inspection, cleaning, and segregation can be performed "on-line" as a portion of the disassembly process.

AGNS also performed economic evaluation study about the option of either adding pool space or disassembling spent fuel. They assumed that up to two times the installed capacity could be made available (i.e., for study purposes, capacity increases would be doubled from 1000 to 2000 MTU, 2000 to 4000 MTU, etc). Fig.5 presents the results of this study. When the hot cell capital cost is included, the disassembly break-even point is approximately 1500 MTU. If only 20-30 % increase is desired, the added capital cost of the hot cells and equipment will probably exceed the cost of the new pool. In this instance, wet type rod consolidation would be some practical value.

3. CONCEPTUAL DESIGN of HORIZONTAL ROD CONSOLIDATION MACHINE

The scope of disassembly work to be performed at the hot cell is highly dependent upon the fuel bundle design. In our case the PWR (Pressurized Water Reacter) fuel bundle(Fig.6) is to be disassembled. This bundle 0.2 m wide, 0.2 m deep, 4.2 m high and 1.3 ton consists of 14 by 14 fuel rods and control guide tubes, top and bottom end fittings, and seven grid spacers. This bundle design will permit fuel disassembly without undue difficulty. Only top end fitting removal and subsequent rod pulling operations are necessary. The preliminarily designed horizontal rod consolidation machine is shown schematically in Fig.7. The operational principle and the basic design bases of the individual steps are as follows;

i) Transfer/position of Intact Assembly

A fuel assembly and an empty canister are conveyed by the in-cell crane to and placed horizontally upon the tilting table which is operated by the hydraulic cylinder. On this table the fuel assembly is mechanically restrained by the bottom end fitting holder and grid spacer clamp opreated by the pneumatic cylinder. This table also involves the horizontal combs that prevent grid spacer displacement during fuel rod pulling.

ii) Top End Fitting Removal

The top end fitting is served from the assembly by cutting the control guide tubes. The cut is performed by the mill saw in the gap between the top end fitting and the fuel rods end. The mill saw is mounted on a horizontally movable base (not shown in the figure) that advances for sawing and retacts to permit pin pulling. In order to ensure cut accuracy it seems to be necessary to mount a fuel indexer on this base. Published information

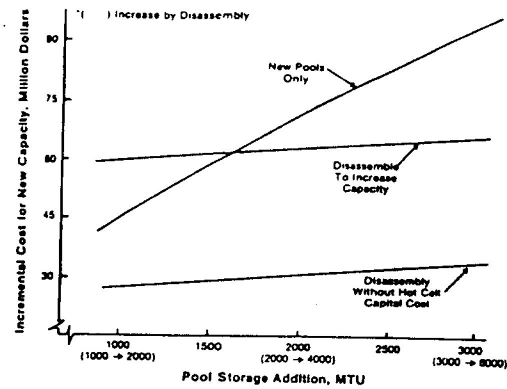

Fig.5 Incremental Cost of Additional Storage

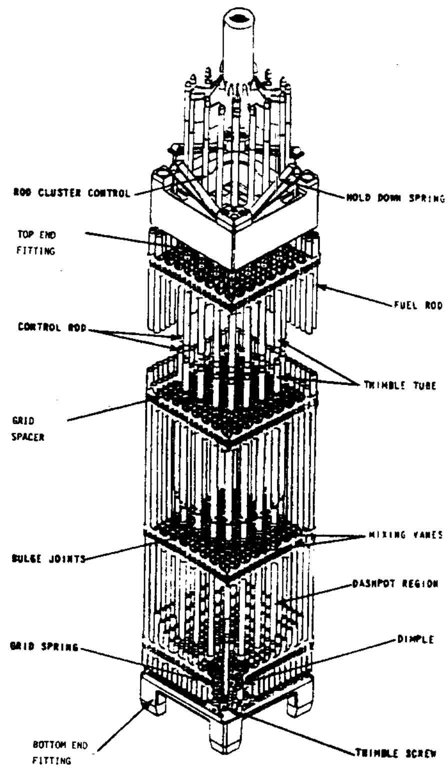

Fig.6 Schematic Diagram of PWR Fuel Bundle

[6] indicates that the cutting tool must be positioned with an accuracy of ± 1/8 inch to prevent the undesirable cut of the fuel rod cladding. It is also required to develop a cutting operation which has minimal zirconium fines generation. Since zirconium fines employed in the control guide tube are pyrophoric, there is a remote possibility that some of the fines could ignite during cutting operation. A near term method is a friction sawing using an abrasive saw or a mill

saw which generates approximately 0.25 inch kerf and future possibility is given to the arc saw(.07 -0.15 inch) or laser cutting (0.05-0.1 inch)[7].

iii) Fuel Rod Extraction

A fuel rod gripper mounted on a X-Y positioning table engages the individual fuel rod being pulled and pulls this rod from the fuel assembly structural hardware. This gripper is shown schematically in Fig.8. The gripping operation is controlled by the pneumatic cylinder and preloaded leaf spring. The gripper jaw is closed when the piston retacts. As the piston advances the preloaded leaf spring opens the gripper jaw. The position detection is performed by the LVDT and provides information to control logic regarding fuel rod penetration into the gripper and fuel rod slip. The gripper pulling force must be monitored so that disengagement controls can safeguard the fuel rod in abnormal conditions where any rods experience excessive pulling forces. The maximum pulling force is approximately 250 pounds[5] to assume a complete release rate for typical fuel rod and to simultaneously preclude damage to failed fuel rod. The fuel and the gripper must be vertically and horizontally aligned within ± 0.005 inch[6].

iv) Dense Packing of Fuel Rods in Canister

After pulling, the individual fuel rods roll by gravity into a trough with a triangular cross section and the shaped rod pusher forces all the fuel rods from one assembly into the a half section of a squared canister. Vibration is used during the collection and pushing operation to facilitate fuel rod-to-canister loading. At this time the pushing force must be limited within 1500 pounds[5] to prevent buckling. After a half section of canister is fulled the canister must be rotated for the next fuel loading.

v) Disposal of Remaining Structural Wastes

The fuel skeleton, consisting of the bottom end fitting, grid spacers, and control guide tubes, remains after disassembly. This skeleton are conveyed by the in-cell crane to the compaction area (not shown in the figure). This material is non-TRU waste and can be compacted up to 0.5 ft^3 /assembly for the volume reduction.

4. CONTROL SYSTEM for AUTOMATION

A main feature for the instrumentation and control system of the conceptually designed rod consolidation machine is the use of the computer in the servo control loop for all the operating modes: automatic, semi-automatic and manual. Fig.9 shows a schematic block diagram of the control architecture. The horizontal rod consolidation machine is controlled through a local computer

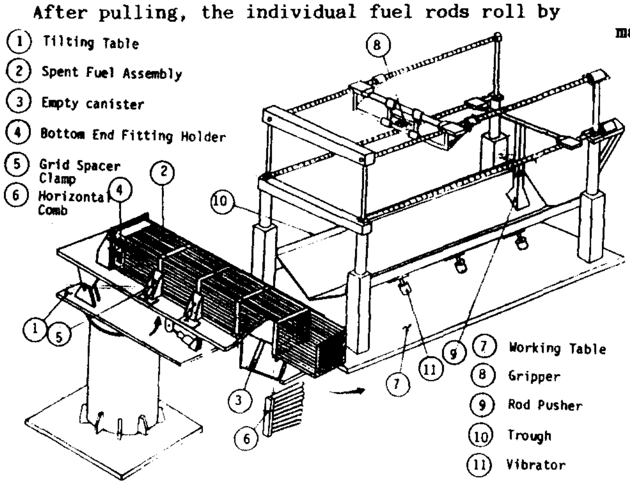

Fig.7 Schematic Diagram of Preliminarily Designed Horizontal Rod Consolidation Machine

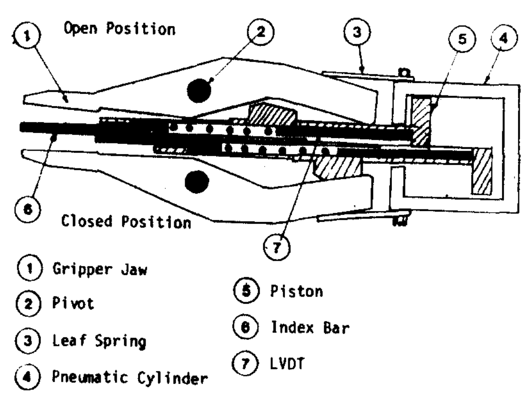

Fig.8 Schematic Diagram of Fuel Rod Gripper

which handles ON/OFF signals to the relay box, analog signals to the servo control rack, and various sensory feedback signals. These signals can be specified from the preliminarily determined drive parameters of the rod consolidation machine as shown in Table 1. There are approximatedly 10 ON/OFF solenoid valve signals, 3 analog DC-servo motor and one hydraulic-servo control signals, 3 discrete stepper control signals and various sensor signals. The auxiliary equipments in the hot cell such as power manipulator, master/slave manipulator, in-cell crane and TV monitor are controlled by the another local computers. These local computers are interfaced with a supervisory computer through the RS-232 interface. In addition the supervisory computer will have several RS-232/422 links to program development and recording system. The operator console contains all of the controls for operating rod consolidation machine and the auxiliary equipments in the hot cell and includes a local area front-operating panel with monitoring system, operating mode selection switch, and emergency stop switch.

5. CONCLUDING REMARKS

The horizontal rod consolidation machine has been conceptually designed in a dry environment with the hierarchical control concepts. In this design the traditional control concepts and the standard commercially available components similar

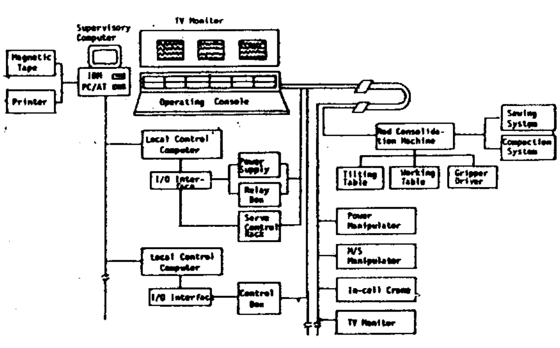

Fig.9 Block Diagram of Control Architecture

to those used elsewhere in manufacturing plants were employd. However, future efforts must be made on the development of the new control concepts and the development/replacement of commercial components with a general radiation resistive components.

Table.1 Horizontal Rod Consolidation Drive Parameters

Components	Drive Parameters				
	Actuator	Operational speed	Travel	Position / Operational Verification	Sensor Resolution
Tilting Table Tilting Actuator	Hydraulic 40,000 N	On/Off	240cm	Limit Switch	.
Bottom End Fitting Holder	Pneumatic 1,000 N	On/Off	5cm	Limit Switch	.
Grid spacer Clamp	Pneumatic 500 N	On/Off	7cm	Limit Switch	.
Horizontal Comb Holder Driver	Stepper 0.05 N.m	2 - 4 cm/sec	25cm	Encorder Limit Switch	0.01mm/count
Horizontal Comb Driver	D.C Servo 0.05 N.m	1 - 2 cm/sec	25cm	Encorder	0.01mm/count
Tilting table Rotator	Stepper 2 N.m	3 deg/sec	90deg.	Encorder Limit Switch	0.005mm/count
Work Table Gripper Guide Puller	D.C Servo 0.7 N.m	50 cm/sec	400m	Encorder Limit Switch	0.01mm/count
X - slide	Stepper 0.1Nm	1 cm/sec	60 cm	Encorder	0.001mm/count
Y - slide	"	1 cm/sec	25 cm	"	"
Gripper	Pneumatic Cylinder 1 N	On/Off	4cm	Limit Switch	.
Rod Pusher	D.C Servo 40N.m	20 cm/sec	400cm	Encorder	0.01mm/count
Trought Vibrator	Hydraulic Servo	.	.	Potentiometer	.

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