Technological Innovations in spent fuel handling and their implementation for fuel reprocessing plants

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Mr. Kailash Agarwal is the recipient of the DAE Scientific & Technical Excellence Award for the year 2009

Introduction

Spent fuel reprocessing involves a good amount of nuclear material handling in very harsh environment of high radiation, coupled with corrosive nitric acid. For long, it has been felt that there is a strong need to provide automation in the field of head-end operations; i.e. spent fuel storage, under-water handling, charging and feed clarification, which will lead to higher plant throughput and shorter plant shut down periods. All the reprocessing plants in NRG/NRB have manually intensive operations, especially in the field of spent fuel handling. There was a strong need felt to put efforts for improvements in these areas. The feedback from KARP, PREFRE and PP were utilized in conceptualizing the ideas and converting them into full scale systems, before implementation in the plants.

The various innovative ideas which were developed in-house and implemented, are as follows,

Spent Fuel Storage Facilities (SFSF)

Design of safety features such as Infiltration system for keeping the ground water table below the raft of the pool, Leak detection system for pool liners, pool bridge design with automation features for positioning, locators for seismic qualification of stack of trays and single failure-proof cask handling crane, qualified for seismic event, for Spent Fuel Storage Facilities (SFSF) at Tarapur and Kalpakkam.

The pool walls are lined with 3 mm thick SS plate and the floor is lined with 6 mm thick SS plate, to avoid ingress/egress of pool water. The fuel pool is provided with an elaborate leak collection/detection system. The leak

Fig.1: Infiltration Trench
collection channels on the backside of the pool liners play the dual role of supporting the liners, and collecting of any water leakage through the welding. These channels are connected to pipe headers terminating at a deep leak detection and collection pit. In addition to the above, there are infiltration bore wells/infiltration galleries provided around the SFSF building, to maintain the ground water below the pool raft. In the infiltration system, four deep wells are connected to HDPE slotted pipes, covered by layers of gravel and soil around the pool. Ground water from the surrounding area travels into these pipes and gets collected in these four wells, where submersible pumps take care of pumping the water to storm water drains automatically. This system is quite useful in keeping the ground water table, below the raft of the pool in all the seasons.

Fuel bundles are handled underwater in the fuel pool in the following ways:

a) Handling of trays from shipping cask to storage locations.

b) Handling of tray from one location to another designated location.

c) Loading of fuel bundles from tray loading platform into the charging cask.

All the storage locations of the trays in the fuel pool and loading platform are at fixed co-ordinates, due to locators provided on the floor for the trays. This is useful for automation of the Pool Bridge for all these operations. The pool bridge has been provided with rack and pinion type positive drive arrangement, for long travel and cross travel motions. The PLC controls all x, y and z co-ordinates of the tray handling tool, with reference to the corner of the pool. The trays and casks are located at designated positions with the help of guiding locators. (Fig. 2).

**Direct Fuel Transfer System**

This innovative concept of direct fuel transfer, from pool to spent fuel chopper, eliminates the use of heavy charging casks. This gives an added approach towards total automation in fuel handling, at the reprocessing plants. Direct fuel transfer system is required, for remote transfer of the spent fuel bundles, from fuel pool of Fuel Handling Area (FHA) to the dissolver cell in an automated way, eliminating manual operation, saving man hours, eliminating dependency on skilled manpower and minimizing man-rem consumption. This will be achieved by connecting the fuel pool to the dissolver cell, through an underground tunnel and a tray transfer trolley running into it, from fuel pool to dissolver cell and vice versa. The system utilizes electro-mechanical wire rope driven trolley, for transferring of fuel bundles, from storage pool to the Cell; motorized X-table for movement of bundles from trolley position to the chopper position; pushing arrangement for transfer of bundles (from trolley to the X-table and later from X-table to the chopper) and various in-built interlocks/safety features. A small cycle time is required, in order to achieve high plant throughput capacity of 1INRP-1; the handling of 220 Mwe spent fuel bundles & system adaptable to 540 Mwe fuel bundles, low radiation exposure during the operation, less
maintenance, remote maintainability, ruggedness and safe handling of fuel. These critical factors were taken into account during the design of the system. Fig. 3 shows an elevational view of the Automation System Layout.

This automation system has been proposed for the first time, for nuclear reprocessing plants. The system is designed with built-in safety margin giving high service life, redundancy giving high reliability and modular construction with ease of maintenance. System design is aimed at simplicity in system assembly, operation & maintenance.

**Feed Clarification Filter**

Design and development of a vacuum-based filtration system for feed clarification is required, for filtration of zircalloy fines from the dissolved solution, before further processing. It also has features for remote handling and replacement. The new filter envisages zero by-passing of liquid solution through the gaskets, as it is compressed by a spring-loaded top cover. The development was systematically carried out and tested with simulated plant conditions, before implementation. This system has been recently implemented at KARP, PREFRE-2, PR-3A and the future recycle plant, INRP-1. The plant choking problems in metering pumps and valves seats have been solved to a large extent. The performance of the system at KARP for the last two years has been excellent.

**Development of an Automated Charging System for Reprocessing Plants**

This system is required to integrate and automate all the operations of transfer port, charging dolly, charging cask door, automatic coupling and de-coupling of pusher rods, pushing of fuel bundles and retracement of all pushers. This system is the first of its kind in a reprocessing plant and required a multi-disciplinary approach, for successful completion. The introduction of this system at KARP has improved the performance of the plant, it has reduced dependence on skilled operators required for spent fuel charging and reduced man-rem exposure. Spent fuel charging has been completely automated with these stupendous efforts for the last 5 years. The first unit is already operational at KARP and has successfully carried out two years of operations. This machine has been functioning well and has optimized the requirement of operators from six to just one and reduced man-rem exposure, being a non-contact automatic operation. A similar system has been provided for PREFRE-2, Tarapur and PR-3A Kalpakkam. The ACF for Power Plant operations is also being implemented. This development has been a major break-through for head-end operations of a reprocessing plant.
The system essentially has a trolley-mounted indexing pushing device, placed behind the charging cask dolley and run on a common set of rack and guide rails (Fig. 5). The system operates on a PLC controlled environment, which has a servo pusher, mechanical couplers for push rods and indexing system for alignment of push rods. The linear indexing device holds 4 liner and fuel pusher actuator rods on an X-table, mounted on LM guides and moves the actuators from home position to pushing position. The actuation is done by a pneumatic cylinder with reed switches at end positions. A locking cylinder confirms the alignment after each indexing.

A servo drive (servomotor with two pole resolver) with rack and pinion transmission and Linear Motion (LM) guides has been used, for pushing the liner and fuel bundles. Two types of grippers have been mounted on servo drive, one for pushing of liner actuator and the other for fuel pusher actuator. To place these grippers in position, a rotary indexer and vertical slide have been used. Rotary indexer has a pneumatic rotary actuator and the vertical slide is operated on LM guides, with the help of a pneumatic cylinder.

The control console system configuration uses a suitable CPU for PLC and a suitable station for Modbus. A MMI is mounted on this console, for setting the parameters. The PLC gives actuation signals depending on pre-conditions to be met, for each subsequent operation as per the ladder diagram. The PLC has been programmed according to ladder diagrams with defined inputs and outputs. There are about 160 sequences of operations during a single cycle of charging and these are repeated for subsequent charging. In the event of breakdown of any of these systems, fuel charging can be continued manually, either using the ACF unit or without the ACF as was practiced earlier.

This has very high benefits for reducing the number of cask visits to pool, thereby increasing efficiency in head-end operations. A 40 (10X4) bundle charging cask has been developed, to replace the 10 bundle charging cask at KARP and PR-3A. The system is under field trials before implementation at PR-3A. Similar casks are being provided for ROP, which will allow simultaneous head-end operations in PREFRE and ROP and will help in achieving plant throughput.

Charging cask is a lead shielded container, which serves the purpose of transferring the spent fuel bundles from fuel pool to SFC, without any radiation exposure to the
personnel. Existing Charging Cask has a capacity of 10 fuel bundles and is required to be handled underwater eight times per batch. In order to reduce the underwater handling of Charging Cask considerably, an Indexing charging cask has been developed. It accommodates 40 fuel bundles at a time, in place of existing 10 fuel bundles. It reduces the number of handling times of Charging Cask from 8 to 2, for one batch. The challenges in the design of the indexing mechanism were: keeping the half-cut open portion of cavity pipe (4 sets) always on the top to load the fuel bundles from top into the liner and to avoid falling of bundles in the cask cavity and rotation of indexing mechanism in a controlled manner, to load and charge the fuel bundles in all the 4 sets of cask liners.

To achieve positive rotation of cavity pipes, a sun and planetary gear system has been used. (Fig. 7) The speed of rotation of central shaft is in such a ratio, that the top cut portion of cavity pipe always faces the top, irrespective of speed.

As the indexing is required underwater during loading of the fuel bundles as well, the drive is enclosed in a hermetically sealed container, with suitable feed-throughs for electrical supply and pneumatic lines. To achieve indexing of the mechanism within allowable tolerances, a PLC with encoder has been employed. The PLC controls the motor as per a set programme and stops at every 90° rotation of the indexing mechanism. It takes feedback from the encoder mounted on the drive shaft. Additionally, a pawl and ratchet mechanism has been used, to achieve positive locking of indexing mechanism at every 90°.

The cavity pipes are held in bearings at two end plates. To avoid deflection in the pipes, these are supported at two intermediate places, with the help of plate and roller assemblies. The supporting plate rollers are guided in the recessed plates fixed to cask cavity. As this mechanism operates both, in fuel pool and in air, corrosion and radiation aspects were taken into consideration, for material selection of various components.

Acknowledgement

The author thanks Shri S. Basu, Chief Executive, NRB for his valuable guidance and continuous support in carrying out above activities. Author is also thankful to all the engineers and support staff in NRPSED, KARP and PREFRE-2, Tarapur for day-to-day interactions.

Fig. 7: Indexing Charging Cask