Motors in Radiation-Intensive Environments

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Motion control in radiation-intensive environments poses a serious challenge to the design engineer. Conventional step and microstepping motors are susceptible to high-energy gamma radiation particles that will attack non-metallic materials. As a result, lubricants, varnish, lamination bonding, and cable insulation will all deteriorate over time and finally crumble.

A new generation of radiation-hardened step motors, however, has greatly expanded the design opportunities in highly radioactive environments. One new motor design recently assisted Oak Ridge National Laboratory (ORNL) in developing a significant new methodology for reprocessing spent nuclear fuel.

An important step in the fuel recycling process is the separation of spent fuel oxides from their cladding by dissolving the oxides in nitric acid. Responsible for the development of nuclear fuel reprocessing technologies, ORNL -- in collaboration with the Power Reactor and Nuclear Fuel Development Corporation of Japan (PRN) -- recently developed a new concept for facilitating this separation process.

Previous fuel pin dissolvers have been "batch" systems, which used metal baskets to drop the fuel pins into a series of acid solutions. The batch systems were relatively inefficient, since directing concentrated nitric acid at the hardest-to-dissolve fuel segments could not be effectively accomplished. The new concept devised by ORNL is a "multistage continuous rotary dissolver" that operates as a continuous, rather than batch-type, process. The new design provides a counter-current of nitric acid that is constantly forcing itself against the hardest-to-dissolve areas of the fuel pins, and with the highest acid concentrations.

The drum in the new multistage dissolver resembles an Archimedes screw, consisting primarily of a horizontal auger enclosed by a cylindrical shell -- eight stages are formed by the turns of the helical walls of the auger. Sheared nuclear fuel pins segments are fed into the first stage of the dissolver. After a period of agitation to assist the dissolution process, the drum is rotated 360° to transfer the undissolved fuel and cladding to the next stage. Another charge of fuel pin segments is added to the first stage, and the process continues. As the fuel pins are being processed from stage #1 to stage #8, the product stream, consisting of nitric acid and dissolved fuel oxides, flows counter-currently to the solids through the holes in the auger, which are drilled concentrically about the shaft of the drum.

The prototype's components were required to be able to withstand the extremely hostile environment in which the dissolver would have to operate: massive radiation and the continuous presence of nitric acid. The key component to the prototype's success was the drive unit, which serves three primary functions: 1) provides controlled forward and reverse motion for the stage-wise transfer of fuel pin segments, 2) allows precise positioning of the drum for discharging and loading of pin segments, and 3) agitates the drum, using a rocking motion profile, to aid the dissolution process.

The design requirements for the prototype dissolver motor specified that a torque had to be produced that was sufficient to accelerate the dissolver drum at 40 rpm/s to a speed of 10 rpm. Positioning accuracy within 1/3 of a degree was also required for loading pin segments. The presence of nitric acid required that a sealed motor be specified, in order to prevent damage from corrosive acid vapors. Finally, the motor and the associated in-cell components had to be radiation-hardened to withstand a total accumulated dosage of 108 rads gamma radiation.

ORNL was able to find only one motor design that could withstand accumulated radiation dosages of 108 and which had all of the required performance specifications, a radiation-hardened hybrid permanent magnet step motor from Empire Magnetics, in Rohnert Park, Calif. Empire's step motor was submitted to prolonged testing in a radiation environment, and was ultimately deemed suitable for use in the prototype dissolver when it successfully survived 109 rads gamma radiation for a prolonged period.

The Empire motor was a zero backlash model that features an in-line 87 to 1 cycloidal gear reducer, a design feature that increases motor output torque without lessening motor life. A radiation-hardened brushless resolver is connected to the gearbox output shaft, the resolver providing angular positioning capability with a resolution of 4,096 steps per revolution of the dissolver drum. The motor, gearbox and resolver are mounted inside a lead box to enhance the existing radiation resistance.

The in-cell motor is controlled by a remote motor control station out-of-cell. The motor is driven by a bipolar chopping drive that is controlled by the motor control computer, which functions as a slave device and is intended to receive instructions from a host computer via a serial RS-232 communications link. The heart of the motor control computer is the indexer, which manages the basic motor motion profiles. Parameters such as as distance, direction, speed, and acceleration are set by forming command sequences of ASCII mnemonics. These command sequences define a motion profile and are programmed into the indexer via the serial communications link.

The motor control computer also performs certain I/O functions. A thermistor inside the motor housing provides an indication of motor temperature as well as over-temperature protection. The motor control computer monitors the motor temperature and initiates motor power cutoff if the motor temperature exceeds the high temperature setpoint. Feedback from the resolver is monitored and provides position information for use by the motor control system. This position information is also available to the operator. Numerous other system status reports are available to the operator, including on/off status and a signal to indicate that a move was successfully completed. These features enable the integration of the motor control functions with dissolution process system operation.

The prototype multistage dissolver has been in uranium testing at ORNL since April 1991, and the testing will continue until the fall of '92. To date, the various motion control and other components have functioned well within the required parameters. A current judgement on the success of the project is that the Power Reactor and Nuclear Fuel Development Corporation, which contracted for the dissolver design and testing, is presently building a facility in Japan for final testing, optimization and finally, production. According to ORNL, the significance of the new dissolver design is threefold: greater efficiency due to the multistage, continuous design; substantial cost savings as a result of minimizing radioactive waste generation; and conservation of a natural resource that is being effectively recycled.

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