UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
WASHINGTON, DC 20555-0001

November 20, 2006

NRC INFORMATION NOTICE 2006-26: FAILURE OF MAGNESIUM ROTORS IN MOTOR-OPERATED VALVE ACTUATORS

ADDRESSEES

All holders of operating licenses for nuclear power reactors, except those who have permanently ceased operations and have certified that fuel has been permanently removed from the reactor vessel.

PURPOSE

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice (IN) to inform addressees of recent failures of motor-operated valve (MOV) actuators that were attributed to the oxidation and corrosion of the magnesium motor rotor fan blades and shorting ring resulting from exposure to high humidity and temperatures. This IN serves to reaffirm the necessity of adequate inspection and/or preventive maintenance on MOV actuators manufactured with magnesium rotors to ensure the safe operation of nuclear power facilities. It is expected that recipients will review the information for applicability to their facilities and consider actions, as appropriate, to avoid similar problems. However, suggestions contained in this IN are not NRC requirements; therefore, no specific action or written response is required.

DESCRIPTION OF CIRCUMSTANCES

A recent NRC staff review of MOV actuator failures at certain plants identified the following examples:

1. Failure of a Main Feedwater Isolation Block Valve to operate automatically (Crystal River 3; October 28, 2005; Licensee Event Report (LER) 50-302/2005-004-00). The licensee attributed this failure to the corrosion and oxidation of the magnesium fan blades and shorting ring of the motor rotor as a result of exposure to high humidity and temperatures.

2. Failure of the Residual Heat Removal (RHR) Cold Leg Injection Valve to open when placing RHR in operation for cooldown (Turkey Point 3; March 6, 2006; LER 50-250/2006-003-00). The licensee attributed this failure to the corrosion and oxidation of the magnesium fan blades and shorting ring of the motor rotor as a result of exposure to high humidity and temperatures.

3. Failure of a Recirculation Pump Suction Valve to operate (Browns Ferry 3; January 15, 2006; documented in the licensee's corrective action program). The licensee attributed this failure to the corrosion of the motor rotor fan blades and shorting ring.

BACKGROUND

Many safety- and non-safety-related MOVs utilize Limitorque actuators with Reliance motors or a similarly styled design by a different manufacturer. Based on torque requirements, aluminum and magnesium alloy cast-squirrel-cage rotors are utilized in MOV actuators. Valve actuators with a motor maximum torque of 40 foot-pounds force (54 Newton-meters) are typically aluminum, and magnesium actuators are used for applications requiring greater than 60 foot-pounds force (81 Newton-Meters).

The typical magnesium rotor is made of stacked, steel punched core plates with AM100A magnesium alloy (approximately 90% magnesium, 10% aluminum, 0.1% manganese) components—the conductor bars, end rings, and cooling fan blades—cast to complete the rotor. While magnesium provides higher torque through its higher resistivity, this relatively brittle cast alloy is susceptible to shrinkage cracking and gas porosity. Specifically, magnesium rotors are susceptible to three main failure mechanisms: galvanic corrosion, general corrosion, and thermally induced stress.

The first failure mechanism is galvanic corrosion. Following manufacture, the electrical potential difference between the magnesium and the steel core is 1.9 volts creating the conditions for galvanic corrosion, with the most vulnerable area being the interface between the steel core and the magnesium end ring. Most manufacturers alleviate this by protecting the magnesium end rings with a paint and/or lacquer coating. Though the rotor might be initially protected, even the smallest scratch or chip in this exterior coating will cause localized, accelerated corrosion in the form of magnesium hydroxide (MgOH) powder. The formation of MgOH powder leads to rotor cracks that add to the existing problems of shrinkage cracking, gas porosity, and MgOH volume difference. Motor overheating events (typically due to locked rotor conditions) accelerate this coating degradation. A propagating crack at the interface between the stacked core and the end ring causes a high resistance connection with the end ring, which in turn causes a high current density (due to current redistribution) on the opposite side of the rotor. This increased current density increases the temperature on that side of the rotor resulting in thermal stress. At the steel-magnesium interface, the higher temperature may melt the magnesium into small beads. These thermally-stressed rotor areas and the melted magnesium beads then provide new opportunities for coating degradation and cracking resulting in new areas of high resistance between the stacked core and end ring and new areas of the rotor with a higher current density. This cycle of events can then repeat around the rotor.

The second major failure mechanism affecting magnesium rotors is general corrosion. Most actuator motors for safety-related MOVs that are located in potentially harsh environments have T-drain pipe plugs to allow moisture to escape. These same plugs allow moisture to enter and condense inside the motor. This moisture leads to the formation of MgOH and magnesium oxide (MgO_2). The white MgOH powder can form a light haze on the inside of the motor without impacting its operation. However, MgOH and MgO_2 can form beads between core plates (from the magnesium conductor bars) and at the interface between the stacked core and the end ring causing high resistance points and the high current density phenomena stated above and even further cracking. The rate of general corrosion increases in a higher humidity operating environment.

The third major failure mechanism affecting magnesium rotors is thermally induced stress which reveals itself in different ways. First, because galvanic corrosion is thermally catalyzed, the corrosion rate increases with temperature, with a significant increase in the corrosion rate occurring at temperatures above approximately 93 °C (200 °F). The rate of galvanic corrosion increases when the motor is located in a higher temperature environment, as well as during general motor high-current conditions and/or within the high current density regions mentioned earlier. Secondly, magnesium has twice the thermal expansion coefficient of steel. This produces uneven axial and radial forces across the rotor causing further cracks in the magnesium and its paint and/or lacquer coating. Finally, many rotors experience significantly higher temperatures because their thermal overloads are set higher than the recommended 10 to 15 seconds for locked rotor current conditions (in order to ensure safety-related function as given in NRC Regulatory Guide 1.106, Revision 1, “Thermal Overload Protection for Electric Motors on Motor-Operated Valves”). For example, some rotors reach 700 °F (371 °C) in 15 seconds, and temperatures of 700 °F to 850 °F (371 °C to 454 °C) cause a significant loss of magnesium yield strength.

Various laboratory tests have been conducted to better understand magnesium rotors. General Electric (GE) tested-to-failure 3 motors in varying aged and environmental conditions, with the most limiting failure being a new motor which failed after 43 days in a high temperature environment under a maximum temperature of 223 °F (106 °C). The Institute of Electrical and Electronics Engineers (IEEE) inspected 14 magnesium rotors and discovered 5 showing varying levels of degradation. Finally, IEEE reviewed plant motor failure rates and found magnesium rotors failing at three times the rate of aluminum rotors.

The following documents address similar MOV failures with related technical details:

- NRC Information Notice 86-02, “Failure of Valve Operator Motor during Environmental Qualification Testing,” January 6, 1986: this IN reported on the results of the previously discussed GE laboratory test on three motors in response to issues at the River Bend and Nine Mile Point 2 nuclear power stations. In addition to the technical details stated earlier, the NRC within this IN suggested that licensees review the qualification of these motors in their Design Basis Event applications.

- NUREG/CR-5404, ORNL-6566/V1, “Auxiliary Feed Water Aging Study,” July 1993: while this report is extensive and covers many wide-ranging aspects, Section 4.5 (Alternate Methods of Valve Actuator Motor Testing) reviews two methods for the preventive maintenance of magnesium rotors.

- NUREG/CR-6205, ORNL-6796, “Valve Actuator Motor Degradation,” December 1994: this NUREG provides a detailed review of the technical phenomena citing all of the failure mechanisms with insights from the GE test and the IEEE report.

- IEEE Transactions on Energy Conversion, Vol. 3, No. 1, "An Investigation of Magnesium Rotors in Motor Operated Valve Actuators," March 1988: this IEEE report provides a detailed, technical analysis of the failure mechanisms and material impact of magnesium rotors. This analysis includes the review of various laboratory tests and licensee database reviews. This report includes a detailed inspection procedure for user guidance.

The IEEE report, NUREG/CR-5404, Crystal River LER 50-302/2005-004-00, Turkey Point LER 50-250/2006-003-00, and the operating experience from Browns Ferry provide some specific methods for preventive maintenance:

1. The IEEE report and the LER's from Crystal River and Turkey Point provide detailed inspection procedures with acceptance criteria. They specifically discussed boroscopic inspections of MOV actuators through the T-drain pipe as a preventive maintenance method.

2. The Crystal River LER also provides detail on performing electrical Polarization Index inspections from measurements of the motor winding insulation resistance.

3. NUREG/CR-5404 reviews motor current signature analysis as a method for revealing broken or distorted rotor bars.

4. The IEEE report reviews ideal thermal overload setpoints in order to avoid the thermally induced stresses discussed earlier but also proposes graduated inspection criteria if these setpoints are not met.

5. Operating experience from Browns Ferry describes their consideration of duty cycle limitations to ensure the motors are not actuated without a proper cooldown interval in order to avoid or not exacerbate thermally induced stresses.

DISCUSSION

Recent failures of MOV actuators as a result of galvanic corrosion, general corrosion, and/or thermally induced stress highlight the particular vulnerabilities of motor actuators with magnesium rotors, particularly when the motor is located in a high humidity and/or high temperature environment. These MOV failures illustrate the necessity of adequate inspection and/or preventive maintenance on actuators manufactured with magnesium rotors.

CONTACTS

This information notice requires no specific action or written response. Please direct any questions about this matter to the technical contacts listed below or the appropriate Office of Nuclear Reactor Regulation project manager.

/RA by Theodore Quay for/

Michael J. Case, Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Technical Contacts:

James Polickoski, RII
803-345-5683
E-mail: jtp@nrc.gov

Scott Stewart, RII
305-245-7669
E-mail: jss1@nrc.gov

Tom Morrissey, RII
352-795-7677
E-mail: txm1@nrc.gov

Robert Monk, RII
256-729-6196
E-mail: rlm2@nrc.gov

Note: NRC generic communications may be found on the NRC public Web site, http://www.nrc.gov, under the Electronic Reading Room/Document Collections.