NEW TECHNOLOGY FOR OPTIMIZED I&C MAINTENANCE AND MANAGEMENT OF AGEING OF CRITICAL EQUIPMENT IN NUCLEAR POWER PLANTS

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Abstract

Advanced sensors and new testing and maintenance technologies have become available over the last ten years for nuclear power plants (NPPs) to replace outdated, obsolete, and troublesome instruments, provide for management of ageing of critical plant equipment, optimize maintenance activities, reduce maintenance costs and personnel radiation exposure, and at the same time, improve plant safety and availability. These new developments are reviewed in this TECDOC. The material covered here has been summarized from NUREG/CR-5501, a 1998 report written by H.M. Hashemian and his co-authors for the US Nuclear Regulatory Commission.

1. INTRODUCTION

New equipment and techniques have been developed over the last ten years to optimize the maintenance of NPPs, provide for management of ageing of critical plant equipment, and facilitate equipment calibration and other tests that must be performed in compliance with technical specifications and regulatory requirements. This includes automated or computer-aided measurements and on-line tests (Table I). In light of recent deregulation/liberalization of the electric power industries around the world, there is increased pressure on the nuclear power industry to become more competitive. As such, the nuclear industry has concentrated on reducing operations and maintenance (O&M) costs. O&M costs in the USA are presently responsible for about 70 percent of the overall cost of nuclear energy generation, with fuel being responsible for the remaining 30 percent. Therefore, reducing O&M costs can help make the nuclear industry more competitive. This is not as easy in coal and gas power generation where about 80% of the cost of electricity generation is spent for the purchase of the fuel.

In an effort to reduce O&M costs, while maintaining and improving safety, the nuclear industry has implemented risk-based maintenance, and is also depending on new technologies such as computer-aided test and measurements and on-line calibration and on-line maintenance to reduce manpower requirements and human errors, increase accuracy and reliability, and trend the maintenance data to account for ageing effects on the performance of the plant equipment. Some of these new technologies are reviewed in this report beginning with new methods for on-line verification of calibration of pressure instrumentation channels.

With digital test equipment, trending of data can be performed automatically and conveniently to identify the onset of problems and monitor for any performance degradation due to ageing or other effects. New analytical tools such as neural networks, artificial intelligence, and pattern recognition can now be implemented on PC-based test equipment to analyze the data and interpret the results to identify even small changes in the performance of plant equipment and alert the plant personnel of any significant problem or incipient failure.

2. ON-LINE CALIBRATION VERIFICATION

According to present procedures, hundreds of instruments are manually calibrated, typically at least once every fuel cycle, in almost all NPPs. The results of these calibrations over more than 20 years have shown that a majority of the instruments do not fall out-of-tolerance between refueling outages and therefore do not need a calibration. This has motivated the nuclear industry to try to extend the instrument calibration intervals through on-line drift monitoring. This work involves recording and analyzing the steady-state output of instruments during plant operation to identify drift

TABLE I. EXAMPLES OF NEW EQUIPMENT AND MAINTENANCE TECHNOLOGIES FOR IMPROVED PLANT EFFICIENCY AND SAFETY AND MANAGEMENT OF AGEING OF CRITICAL COMPONENTS

1	On-line verification of the calibration of process instrumentation channels and incipient failure detection of I&C channels
2	On-line detection of venturi clogging
3	In situ response time testing of pressure transmitters
4	On-line detection of blockages and voids in pressure sensing lines
5	In situ calibration of primary coolant RTDs and core exit thermocouples
6	In situ response time testing of RTDs and thermocouples
7	In situ testing to verify the installation of thermocouples in WWER reactors
8	New methods for remote testing the attachment/adhesion/embedment of temperature sensors and strain gages to solid materials
9	LCSR test for sensor and circuit diagnostics
10	In situ testing of cables and connectors
11	On-line measurement of Moderator Temperature Coefficient (MTC)
12	Predictive maintenance and management of ageing of reactor internals using existing plant instrumentation
13	On-line measurement of stability margins (decay ratios) in BWRs
14	Automated measurement of drop times of multiple control and shutdown rods and automated analysis to identify rod drop time, rod speed, and detection of sticking and sluggish rods
15	Automated measurement of timing and sequencing of CRDMs
16	Measurement of core flow and detection of core flow anomalies
17	On-line reactor diagnostics and root cause analysis by passive techniques

and other abnormal problems in instrument outputs. For redundant instruments, this is accomplished by comparing the readings of the redundant instruments to distinguish between process drift and instrument drift. For non-redundant instruments, process empirical modeling using neural networks and pattern recognition principles, or other techniques as well as physical modeling are used to estimate the process. This estimate is updated frequently and compared with the output of the corresponding instruments to detect any drift in the instrument output. Process modeling is also used with redundant instruments to provide added confidence in the results and account for common mode drift. The details of the modeling techniques, are presented in [1].

Another important benefit of process modeling is in verifying the calibration of instruments over their entire range. More specifically, the models can provide the reference for verifying the calibration of instruments during plant startup and shutdown periods when the instruments are exposed to inputs that cover a wide range.

The models can use existing plant operating data from diverse sensors to estimate and track any given process parameters. For example, the reactor coolant flow may be estimated independently using data from existing temperature, pressure, and flux sensors and a model that is previously trained at steady state and transient plant conditions to track flow as a function of these other input parameters.

3. ON-LINE DETECTION OF VENTURI FOULING

In addition to on-line verification of calibration of process instrumentation channels, process empirical modeling, pattern recognition, and neural network techniques can provide an effective tool for on-line detection of performance problems in individual instruments or the plant. For example, venturi flow elements can become clogged and result in erroneous flow indication. This has both safety and economical implications. Until recently, there has been no effective way to monitor for venturi fouling. In some plants, new ultrasonic sensors are installed to monitor the flow independently and track the deviation of the venturi sensors and the ultrasonic sensors as a means of detecting venturi fouling. Although the cost of the ultrasonic sensors can be as high as one million dollars, many plants have already installed these sensors because of the importance of accurate flow measurements. Another way to monitor for venturi fouling is to use modeling techniques [1] to track the flow and compare the results with the venturi flow indication to identify venturi fouling.

4. IN SITU RESPONSE TIME TESTING OF PRESSURE TRANSMITTERS

Accuracy and response time are two of the most important indicators of performance of pressure transmitters. As such, on-line methods have been developed to monitor the calibration and response time of pressure transmitters in NPPs. The on-line calibration technology was mentioned above. For on-line measurement of response time of pressure transmitters, the noise analysis technique is used as described in [2]. This method is based on recording the random noise which exists naturally at the output of most process sensors while the plant is operating. The noise can be analyzed in the frequency domain and/or time domain to give the response time of the transmitter. As documented in [2], this method has been validated for response time testing of pressure, level, and flow transmitters in NPPs.

For in situ response time testing of force balance pressure transmitters, in addition to noise analysis technique, a method called the Power Interrupt (PI) test is also available which has been validated for use in nuclear power plants. The details are covered in [2].

Both the noise analysis and PI methods are used in many nuclear power plants around the world for response time testing of pressure transmitters. The tests are performed remotely from the control room area while the plant is operating. These tests do not interfere with plant operation and can be performed on several transmitters at a time.

5. ON-LINE DETECTION OF CLOGGING IN IMPULSE LINES

Impulse lines are the small tubes which bring the pressure signal from the process to the sensor. Typically, the length of the impulse lines are 30 to 300 meters, depending on the service in the plant, and there are often isolation valves, root valves, snubbers, or other components on a typical impulse line. The malfunction in any valve or other component of the impulse line can cause partial or total blockage of the line. In addition, and more importantly, impulse lines can become clogged due to sludge and deposits that often exist in the reactor coolant system. The clogging of sensing lines can cause a delay in sensing a change in the process pressure, level, or flow. In some plants, sensing line clogging due to sludge or valve problems has caused the response time of pressure sensing systems to increase from 0.1 seconds to 5 seconds. This problem can be identified while the plant is on-line using the analysis technique as described in [3]. Basically, if the response time of the pressure, level, or flow transmitter is measured with the noise analysis technique, the results will include any delay due to the sensing line length, any blockages, voids, and other restrictions.

6. RTD AND THERMOCOUPLE CROSS CALIBRATION

Redundant RTDs and thermocouples in NPPs can be in situ calibrated at isothermal conditions using the cross-calibration technique. This involves a multichannel data acquisition system to quickly record the temperature indications of the redundant RTDs and thermocouples. These temperatures are then averaged and the deviation of each RTD or thermocouple from the average of all RTDs (excluding any outliers) is calculated. Once the outlier RTDs are identified, they are excluded from the data and the data is corrected for plant temperature fluctuations and any temperature differences between the loops or between the hot legs and cold legs. After these corrections are implemented, a new average temperature is identified for the RTDs and the deviation of each RTD and thermocouple from this new average is calculated. The details of the cross-calibration technique is presented in [4].

The cross-calibration tests are often performed at several temperatures during plant startup or shutdown periods. With this approach, if any RTD is out-of-tolerance, a new calibration table can be developed for the RTD using the cross-calibration data taken at three or more temperatures. Also if large deviations for thermocouples are identified, they can be adjusted to bring the thermocouples in line with each other and with the RTDs.

7. RESPONSE TIME TESTING OF RTDs AND THERMOCOUPLES

The response time of RTDs and thermocouples can change with ageing of the sensor. Many factors can contribute to this ageing degradation. For example, vibration can cause RTDs and thermocouples to move out of their thermowell and result in an increase in response time. Even a very small movement can cause a large change in response time. Temperatures can also cause changes in response time. For example, inherent voids in sensor insulation materials can expand or contract and cause the response time to change. For these and other reasons, response time of RTDs and thermocouples are measured periodically in NPPs. The measurement is made using the Loop Current Step Response (LCSR) method as described in [5].

The LCSR test is performed remotely from the control room area while the plant is operating. It provides the in-service response time of RTDs and accounts for all installation and process condition effects on response time. If the RTD is used in a thermowell, the response time that is obtained from the LCSR test includes the dynamic response of the RTD and the thermowell combined. Therefore, any gap in the RTD/thermowell interface is also accounted for in the LCSR test.

To perform the LCSR test, a Wheatstone Bridge is used along with a current switching network and signal conditioning equipment. The RTD is connected to one arm of the bridge and the bridge current is switched from about 1 Milliampere (ma) to about 40 ma. The current produces Joule heating (I^2R) and results in a temperature transient in the RTD sensing element. This increases the RTD resistance gradually and results in a voltage transient at the output of the bridge. This transient is recorded and analyzed to provide the response time of the RTD. The analysis is based on a detailed heat transfer model of the RTD. With this method, although the sensor is heated internally, the response time that results from analysis of the LCSR data is equivalent to the response time that would be obtained for the RTD if the process temperature around the RTD experienced a step change. The conversion of data from internal heating to provide the response to an external change in temperature has been proven both experimentally and mathematically.

The LCSR method can also be used to measure the response time of thermocouples as described in [6]. However, this requires higher heating currents and a different test procedure than RTDs. Therefore, in some NPPs, the response time of thermocouples are sometimes tested using the noise analysis technique as was described earlier for pressure transmitters. This is because the high heating currents (about 0.2 to 0.6 amp) that are needed for LCSR testing of thermocouples may be too high in these NPPs. Unlike RTDs, thermocouples are not subject to very stringent response time requirements. Nevertheless, response time testing using the LCSR and noise analysis techniques are performed on thermocouples in NPPs as a means of verifying the health of thermocouples and providing for ageing management.

8. VERIFYING THE INSTALLATION OF THERMOCOUPLES IN WWERs

In some WWER reactors, long thermocouples are used in long thermowells to measure temperature in different regions within the core. Typically, the thermocouples are force-fit into the thermowells, and it is important for the tip of each thermocouple to reach to the end of its thermowell so that it can provide the temperature of the intended point in the core. Therefore, the LCSR and noise methods have been used in WWER reactors to measure thermocouple response time as a means of verifying that thermocouples are at the bottom of their thermowell and are therefore measuring the correct temperature. The LCSR test is used during the installation of the WWER thermocouples to identify and resolve installation problems, and the noise analysis technique is used during plant operation to verify again that the thermocouples are properly installed.

9. LCSR TEST TO DETECT BONDING DEGRADATION

Temperature sensors such as thermocouples, thin-film RTDs, strain gages, and other resistive devices are used in NPPs and other applications for measurement of surface conditions on pipes, vessels, and other components. In these applications, the sensors are bonded to a solid material. For example, strap-on or cemented RTDs are sometimes used to measure surface temperature of pipes such as sensing lines in some NPP applications.

As a result of the long-term exposure to heat, humidity, vibration, and other process conditions, the bonding of sensor can deteriorate and cause the sensor to become detached from the solid surface and float in the air resulting in an erroneous indication. As such, new methods mostly based on LCSR testing have been developed to characterize the quality of bonding between sensors such as RTDs, thermocouples, and strain gages and a solid material. [7] describes how the LCSR is used for these applications. As discussed in [7], the LCSR has been successfully used in aerospace applications for verifying the bonding of thermocouples in solid fuels in rocket engines, and for defecting bonding problems with thin-film RTDs on the fuel lines of aerospace vehicles. For example, the LCSR was used to test the bonding of RTDs in a Space Shuttle application where thin-film RTDs are used for timely measurement of temperature changes as a means of detecting fuel leaks.

10. LCSR TESTING FOR SENSOR AND CIRCUIT DIAGNOSTICS

In addition to sensor response time testing and detection of sensor-to-solid bonding, the LCSR method can be used for diagnostics of wiring and circuit problems in instrumentation systems. For example, in the early 1980s, the LCSR method was being used for thermocouple response time testing on experimental nuclear fuel assemblies at the Argon National Laboratory. In addition to providing dynamic response information, LCSR tests identified a number of reverse-connected thermocouples. The problem was manifested in unusual LCSR transients that were obtained during the response time measurements. In another instance, in a NASA project, rocket nozzle thermocouples were found by the LCSR test to be reverse connected; an event similar to that of ANL. In the same NASA project, the LCSR method identified thermocouples whose measuring junctions were not at the normal point at the tip of the thermocouple, or had developed secondary junctions. These problems would have resulted in erroneous temperature measurements in a very important application [7].

Thermocouple inhomogeneity can also be detected using the LCSR method as described in [8]. Normally, the LCSR test is performed on a thermocouple by applying an AC or DC current to heat the thermocouples measuring junction. The current is applied for a few seconds and then switched off. This allows the thermocouple to return to the ambient temperature. In the LCSR test, the thermocouple output, as it returns to the ambient temperature, is recorded and analyzed to obtain its response time. If the thermocouple contains any significant inhomogeneity along its wire, the inhomogeneity will act as a secondary junction. In this case, the LCSR transient for the thermocouple will be abnormal. With adequate experience, one can correlate the abnormal LCSR transient to the presence of inhomogeneity in the thermocouple wire. The advantage of the LCSR test for this application is that it can be performed remotely on an installed thermocouple in an operating process.

In NPPs, RTDs have been found with sensing elements that open and close randomly causing erratic behavior. More specifically, the RTD would indicate an open circuit for a period of time, and then act normally. In other instances, RTDs with damaged sensing elements have drifted up for a while, then down, and eventually began to act normal again. These problems can be diagnosed and isolated using the LCSR test.

11. TESTING OF CABLES AND CONNECTORS

The condition of nuclear power plant cables, especially I&C cables, is tested in some plants for a number of reasons such as troubleshooting to identify or describe problems, and baseline measurements for predictive maintenance and ageing management. There are electrical tests, mechanical tests, and chemical tests that can be used to monitor or determine the condition of cables. The electrical tests have the advantage of providing the capability to perform the tests in situ, often with no disturbance to the plant operation.

The electrical tests involve impedance measurements and Time Domain Reflectometry (TDR) tests. The TDR test is popular in NPPs for identifying the location of a problem along a cable. Particularly, it is often crucial to determine if a cable problem is in the containment or outside the containment. For example, RTD circuits that have shown erratic behavior have been successfully tested by the TDR method to give the maintenance crew proper directions as to the location of the problem. The TDR technique has also been helpful in troubleshooting motor and transformer windings, pressurizer heater coils, nuclear instrumentation cables, thermocouples, Motor Operated Valve (MOV) cables, etc.

To determine the condition of cable insulation or jacket material, in addition to TDR, electrical parameters such as insulation resistance, DC resistance, AC impedance, and series capacitance are measured. It should be pointed out that determining the condition of cable insulation materials is a very challenging task. The lack of a suitable ground plane for making reliable electrical measurements hampers the success of the tests.

In mechanical testing of cables, the ductility of the cable insulation or jacket material is measured to determine if the material has become dry, brittle, or prone to crack. The test equipment is referred to as a Cable Indentor. Basically, the device is used to squeeze the cable and measure its relative hardness [9].

In chemical testing of cables, a small piece of the cable insulation material is peeled off for chemical analysis in a laboratory.

12. MANAGEMENT OF AGEING OF REACTOR INTERNALS

In the last ten years, predictive maintenance through vibration analysis has become one of the most prevalent practices in industrial processes. Using accelerometers and similar sensors, the vibration of operating machinery is measured passively while the process is on-line. The results of these tests are then trended to identify deviations from expected, normal, or historical behavior. This practice has proven to successfully identify the onset of many problems with industrial equipment, especially rotating machinery, and is believed to save billions of dollars every year by preventing equipment failures and plant downtime. In some cases, the vibration test equipment is installed in the plant permanently and data is collected and analyzed continuously, and in other cases, portable vibration equipment is used to test the plant periodically.

In NPPs, measurement of vibration of reactor internals can be performed very effectively and sensitively using the existing neutron detectors. For example, the ex-core neutron detectors in PWRs can measure the vibration of the reactor vessel and the reactor vessel internals to better than one mil resolution (1 mil = 1/1000 of an inch or 0.025 millimeters). Furthermore, through cross-correlation of neutron signals and other existing sensors such as the core exit thermocouples or the reactor vessel level sensors, the flow through the reactor can be characterized to detect flow anomalies, flow shifting, flow blockages, and other problems.

TABLE II: PREVENTIVE MAINTENANCE AND AGEING MANAGEMENT MEASURES FOR NPPs.

- VIBRATION MEASUREMENTS USING NEUTRON DETECTORS
  - Core barrel vibration measurements in PWRs
  - Thermal shield vibration measurements in PWRs
  - Instrument tube vibration measurements in BWRs
  - Measurement of pump vibration
  - Fuel assembly vibration measurements
  - Measurement of reactor vessel vibration

- LOOSE PARTS MONITORING AND VIBRATION MEASUREMENTS USING ACCELEROMETERS
  - Loose parts monitoring
  - Vibration measurements to detect shaft crack in BWR recirculation pumps

- ON-LINE TESTING OF DYNAMIC RESPONSE OF SENSORS AND ASSOCIATED COMPONENTS
  - Response time testing of pressure, level, and flow transmitters
  - Response time testing of thermocouples and RTDs
  - Blockage and void detection in pressure sensing lines
  - Oil loss detection in Rosemount and other transmitters
  - Management of ageing of process instrumentation systems
  - Detection of leakage in pressure sensing lines

- FLOW MEASUREMENT
  - Cross-correlation flow measurement using existing sensors
  - Core flow measurements in BWRs using neutron detectors
  - N-16 flow measurements by cross-correlation
  - Determination of flow transmission path

- THERMAL HYDRAULIC TESTS
  - Detection of flow anomalies and flow shifting in the reactor core and the plant primary system
  - Detection of standing waves in plant piping and their consequences
  - By-pass boiling detection in BWRs
  - Measurement of stability margin (decay ratio) in BWRs

- ON-LINE MEASUREMENT OF MODERATOR TEMPERATURE COEFFICIENT (MTC) OF REACTIVITY

Accelerometers are also used in NPPs for vibration measurements and loose parts monitoring. However, for the measurement of vibration of reactor vessel and its internals, neutron detectors have better resolution and accuracy than accelerometers.

TABLE II presents a listing of some of the predictive maintenance applications of the noise analysis technique in NPPs. Most of the techniques are discussed in [1].

An essential prerequisite for a successful preventive maintenance program is a comprehensive set of baseline data that must be obtained when the plant and its equipment are either new or in good working condition. NPPs will naturally develop problems as they age and it is therefore crucial to have a library of objective information on the normal behavior of the plant to be used to track problems, identify the root cause, and develop solutions.

13. LOOSE PARTS MONITORING

Loose parts monitoring shall be performed in NPPs on a continuous basis. This work involves accelerometers that are installed in several locations in the plant such as the reactor vessel, steam generators, reactor coolant pumps, etc.

Both audio signals and noise data records are used in performing loose parts monitoring. The audio signals are used to produce alarms if there are any significantly loose parts in the system. The alarm set points are selected depending on the plant and the sensitivity of the loose parts monitoring equipment. If a loose parts alarm is activated, then accelerometer output data are analyzed to confirm the loose part and identify its size and location. The size of a loose part is estimated using baseline measurements that are made with known masses and calibrated hammers. These hammers are used to intentionally hit the plant piping and vessel from the outside to calibrate the loose parts monitoring system. The noise signatures from the baseline measurements in terms of PSDs are compared with measured PSDs after a loose parts alarm is detected. This comparison along with other interpretation steps can help determine the size of the loose part that has caused the alarm.

As for location of a loose part, signals from accelerometers in various locations are cross-correlated to identify signal transmission times. This information is then used in such techniques as triangulation to locate the loose part. These efforts together with listening to audio signals from accelerometers, can often provide good estimates as to the presence, size, and location of any significant loose parts, provided that the loose part is not trapped or lodged in a conspicuous location.

In NUREG/CR-5501 [1], AMS has introduced a method for on-line analysis of loose parts noise data that helps identify any significant loose parts quickly and with high reliability. The method involves calculating and tracking the modified amplitude probability density (MAPD) of the noise signal. This parameter has a given baseline value for when the system contains no loose parts. Any significant deviation from this reference value can be tracked to determine if there is a loose part in the plant.

14. NOISE ANALYSIS APPLICATIONS IN BWR PLANTS

The existing neutron noise signals from average power range monitors (APRMs) and local power range monitors (LPRMs) in BWRs may be used to perform reactor diagnostics and to estimate the flow through the core. The APRM and LPRM signals are also used to measure the stability margin for the core in terms of a decay ratio.

Other applications of noise analysis in BWRs include response time testing of pressure, level, and flow transmitters, testing for sensing line blockages and voids, detection of cracks in the recirculation pump shaft, instrument tube vibration measurements, by-pass boiling detection, two phase flow estimation, oil loss detection in Rosemount pressure transmitters, etc.

15. PC-BASED SYSTEMS FOR AUTOMATED TESTING IN NPPs

Computer-aided testing and PC-based measurement and test equipment are quickly finding their way into NPPs. Today, PC-based equipment are used more than ever before to test, trend, document, and produce automated reports of maintenance work. A number of PC-based test equipment are presently in use in nuclear power plants. For example, instead of using strip chart recorders and timers, computer-based systems are now used in many NPPs to measure the drop times of control and shutdown rods. The new rod drop testing technology employs a PC-based data acquisition and real time data analysis system to measure the drop time of any number of rods which are dropped simultaneously and provide additional diagnostics. In particular, the system provides rod drop time results, rod recoil data, rod speed, and other rod movement parameters. This type of system is very useful to PWR and WWER plants. Also, an automated rod drop test system is particularly useful to Russian-made RBMK reactors in which more than 200 rods are tested frequently to verify proper rod movement at appropriate speeds [10]. Accurate and reliable rod drop time measurements and rod movement diagnostics are important especially in Chernobyl type RBMK reactors. In face, the interest in rod drop time measurements in RBMK reactors have increased in the aftermath of the Chernobyl accident in the Ukraine.

With automated test equipment, the drop times of multiple control and shutdown rods are now measured accurately and precisely in typically less than one hour for 50 rods compared to more than twelve hours that it often took using conventional equipment and technologies. Furthermore, the results of the tests can be analyzed and trended to identify rod movement problems and detect sluggish or sticking rods.

A PC-based test system is also in use in NPPs to verify the timing and sequencing of Control Rod Drive Mechanisms (CRDMs). Recent events involving rods that have moved contrary to what was expected have given rise to more routine testing of CRDMs as indicated in NRC Generic Letter 93-04 entitled “A Rod Control System Failure and Withdrawal of Rod Control Cluster Assemblies.” With the new PC-based CRDM test equipment, the analysis of the data and interpretation of results can be done in a few minutes compared to hours that it took to perform the tests manually using strip chart traces.

16. CONCLUSIONS

New instrumentation and maintenance technologies have emerged over the last ten years with great potential to benefit the safety and economy of NPPs, facilitate plant life extension, and aid in the management of ageing of critical plant equipment. Some of these new developments have been summarized in this country report. The report also reviewed testing and predictive maintenance technologies. In particular, in situ methods for measurement of performance (calibration and response time) of process sensors were discussed. More specifically, the loop current step response technique for in situ response time testing of RTDs and thermocouples as installed in operating processes was described, including the ways that this method can be used for diagnostics of problems in RTDs and thermocouple circuits. Also, on-line methods that can be used to extend instrument calibration intervals in NPPs were reviewed.

The fundamentals of the noise analysis technique and its application for a variety of predictive maintenance activities in NPPs were reviewed. This includes the use of the noise analysis technique for on-line detection of voids and clogging of pressure sensing lines, on-line measurement of response time of pressure sensors, measurement of vibration of reactor vessel, core barrel, thermal shield, fuel assemblies, and other components of the reactor system, loose parts monitoring, diagnostics of flow anomalies, and determination of root cause of unusual problems in the reactor system.

REFERENCES

[1] Hashemian, H.M., et al., "Advanced Instrumentation and Maintenance Technologies for Nuclear Power Plants." US Nuclear Regulatory Commission, Report Number NUREG/CR-5501 (September 1998).

[2] Hashemian, H.M., "Long Term Performance and Ageing Characteristics of Nuclear Plant Pressure Transmitters." US Nuclear Regulatory Commission, NUREG/CR-5851 (March 1993).

[3] Hashemian, H.M., et al., Effects of Ageing on Response Time of Nuclear Plant Pressure Sensors." US Nuclear Regulatory Commission, NUREG/CR-5383 (June 1989).

[4] Hashemian, H.M., et al., "Ageing of Nuclear Plant Resistance Temperature Detectors." US Nuclear Regulatory Commission, Report Number NUREG/CR-5560 (June 1990).

[5] Hashemian, H.M., and K.M. Petersen, "Loop Current Step Response Method for In-Place Measurement of Response Time of Installed RTDs and Thermocouples", (American Institute of Physics) Seventh International Symposium on Temperature, 6:1151-1156, Toronto, Canada, May 1992.

[6] Hashemian, H.M., "New Technology for Remote Testing of Response Time of Installed Thermocouples", United States Air Force, Arnold Engineering Development Center, Report Number AEDC-TR-91-26, Volume 1 - Background and General Details, January 1992.

[7] Hashemian, H.M., C.S. Shell, and C.N. Jones, "New Instrumentation Technologies for Testing the Bonding of Sensors to Solid Materials", National Aeronautics and Space Administration, Marshall Space Flight Center, NASA/CR-4744, May 1996.

[8] Hashemian, H.M., and K.M. Petersen, "Measurement of Performance of Installed Thermocouples", Proceedings of the Aerospace Industries and Test Measurement Divisions of the Instrument Society of America, 37th International Instrumentation Symposium, pp. 913-926, ISA Paper #91-113, San Diego, California, May 1991.

[9] DOE/EPRI Report, "Ageing Management Guideline for Commercial Nuclear Power Plants - Electrical Cables and Terminations", SAND96-0344, September 1996.

[10] Hashemian, H.M., Fain, R.E., "Automated Rod Drop Time Testing and Diagnostics in Soviet Designed RBMK and WWER Reactors", Proceedings of the 1996 Nuclear Power Plant Instrumentation and Control and Human Machine Interface Technologies, Penn State University, Vol. 2, pp. 1461-1468, May 1996.

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