DEVELOPMENT TRENDS FOR DIAGNOSTIC SYSTEMS IN NUCLEAR POWER PLANTS

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1 ABSTRACT

Monitoring systems used in nuclear power plants have made remarkable progress over the past four or five years. Development has followed the trends and changes in philosophy for the purpose of monitoring systems in nuclear power plants: They are no longer expected to fulfill only safety tasks, the plant personnel require information on which to base condition-oriented maintenance.

A new generation of monitoring and diagnostic systems has been developed by Siemens recently. This new generation, called Series '95, is PC-based. An overview is given for the KÜS '95 loose parts diagnostic system, the SÜS '95 vibration monitoring system, the FLÜS leak detection system and the SIPLUG valve diagnostics system.

The objectives behind the development of these new systems are both safety-related and economic.

The new systems improve the reliability and quality of monitoring techniques and incorporate better detection and diagnostic capabilities. Progress has also been made in automation of the systems so as to reduce routine work, give higher sensitivity for the monitoring task and reduce the scope of maintenance.

2 CHANGES IN OBJECTIVES OF MONITORING AND DIAGNOSTIC SYSTEMS

Monitoring systems used in nuclear power plants have made remarkable progress over the past four or five years. Development has followed the trends and changes in philosophy for the purpose of monitoring systems in nuclear power plants: They are no longer expected to fulfill only safety tasks, the plant personnel require information on which to base condition-oriented maintenance.

The experience gained from backfitting a large number of monitoring systems with digital recording and diagnostic units during the last three years can be summarized as follows:

- Costs for system implementation, system operation and maintenance must be weighed against the benefits of reducing potential risks of damage through monitoring and other benefits from the operation of the diagnostic systems, and should yield positive results.

- Monitoring and diagnostic systems should be standard I&C equipment. The costs for their operation and servicing must be of the same order as those for other I&C systems.
- Monitoring and diagnostic systems should provide information about the behavior of the plant to allow condition-oriented maintenance of plant components and to prevent unplanned outages due to failures.

A new generation of monitoring and diagnostic systems has been developed by Siemens recently. This new generation, called Series '95, is PC-based.

The objectives behind the development of these new systems are both safety-related and economic. They include:

- Early detection of faults, and hence minimization of damage,
- Enhancement of trouble-shooting features,
- Prevention of sequential damage,
- Reduction of periodic inspection costs and radiation exposure and
- Compliance with licensing requirements.

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3 FROM LOOSE PARTS MONITORING TO DIAGNOSTICS

For more than 20 years now, nuclear power plants in the U.S., Germany and other western countries have been required to install and operate loose parts monitoring systems. In 1990 IEC 988 "Acoustic monitoring systems for loose parts detection - Characteristics, design criteria and operational procedures" was elaborated and published. Despite this, loose parts monitoring is not a standard requirement for nuclear plants worldwide.

Reasons for this could be as follows:

- The first loose parts monitoring systems suffered from low sensitivity and a high rate of false alarms,
- Loose parts occur very seldom and most of them can be avoided if reactor coolant system maintenance is carefully performed (the experience of the last two years would not appear to corroborate this statement),
- Loose parts monitoring systems involve additional expense (implementation, operation and servicing).

Recent developments in loose parts monitoring systems have improved the capabilities of these systems, allowing the risk of damage to primary circuit components as a result of loose parts to be reduced significantly. Operation and servicing of the system is almost fully automated in order to reduce the related time and expense.

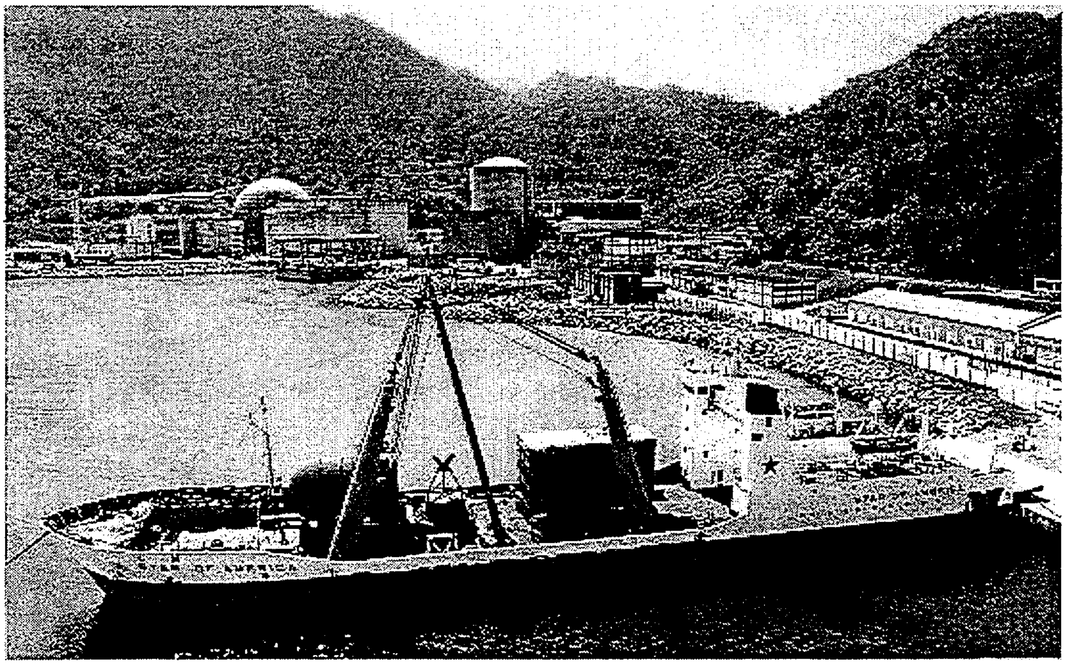

Figure 1 Angra 2 (Brazil) is one of more than ten plants equipped with the KÜS '95 loose parts monitoring system

The new Siemens KÜS '95 loose parts diagnostic system for the detection and location of structure-borne noise evaluates noises made by loose parts in an analysis and a diagnostic phase. The main benefit of the system is its ability to determine whether or not structure-borne noises detected coincide with previously recorded reference events. These reference events are used as the basis for subsequent diagnosis. In addition, they also give the system the ability to decide if the noise in question originates from a loose part or is just a normal operational event, such as is often the case. A normal event is filed as a 'Known Event', thereby avoiding unnecessary evaluations.

If the event is relevant or unknown, however, a KÜS system alarm is triggered. The operator can then either assign the event to one of the known classes of reference events in an off-line evaluation process, or can define the event as a new reference class and perform a corresponding diagnosis. The system incorporates all the analysis tools required for this process.

The system performs:

- Reliable detection of loose parts and minimization of data and spurious alarms through diagnostic capabilities for burst classification,
- Determination of the point of impact: The system measures the signal transit time difference. This makes use of the fact that when a loose part impacts with the wall of the reactor coolant system, a burst is produced which propagates at the speed of sound, thus reaching the structure-borne noise sensors at different times. The point of impact is determined on the basis of the geometry of the reactor coolant system, the speed of sound and the transit time differences for the individual signals produced by the same impact event. At the 1995 international benchmark test organized from the Nuclear Energy Agency of the OECD, KÜS '95 was able to locate the points of impact to within just a few centimeters. The results are displayed with the aid of a 3D view of the reactor coolant system and can easily understood (this view is similar to the sketch in Figure 2).

- Estimation of the mass of the loose part: The structure-borne noise signals also contain information on the mass of the impacting object. The underlying physical principle is explained by Hertz's law, which states that the time during which two bodies remain in contact following an impact is a function of their masses and velocities. During the above benchmark test, KÜS was able to determine the mass of 6 different bodies in the range between 50g and 15kg to within approximately 30 percent, an accuracy which is perfectly adequate for practical applications.

- Automatic in-service inspection of whole system: A basic principle of system design is that control is exercised over instrument chains and algorithms in order to produce physically identical variables during in-service inspection and calibration; i.e. for loose parts monitoring a remote impact hammer produces impact events on the nuclear power plant components. The system features complex self-monitoring functions which range from pure hardware monitoring (power failure) to complex functional monitoring (watchdog functions) which also cover the software. All data relating to system component malfunctions are visually annunciated on an alarm unit. Such malfunctions are also recorded by the system and logged.

4 COMPLETE VIBRATION MONITORING THROUGH TO THE RESULTS REPORT

Damage to reactor coolant system components in nuclear power plants as a result of mechanical vibrations is very rare. When an event of this type occurs, the result to date has normally been an extended outage with costly repairs. Vibration monitoring systems make it possible to detect changes in the vibration behavior of reactor coolant system components, reactor pressure vessel internals and reactor coolant pumps in pressurized water reactor plants at an early stage. Implementation and operation of vibration monitoring systems is required in nuclear safety standards (e.g. in KTA 3201.4, KTA 3204 and DIN 25475/2 for Germany).

A change in the vibration behavior of a component is one of the most sensitive indicators for changes in its mechanical condition, e.g.

- Relaxation of tensioning for flow baffle mounting bolts
- Reduction in the stiffness of core barrel holddown springs
- Damage to journal bearings in a reactor coolant pump or
- Shaft cracking in a reactor coolant pump.

An extensive knowledge base is available on the correlation between the vibration behavior of reactor coolant system components and their associated mechanical condition for Siemens plants. This is due to the fact that baseline vibration measurements are taken during commissioning in Siemens plants, supplemented by many years of feedback of experience from operation of vibration monitoring systems at Siemens and other vendor plants. This knowledge was not implemented in the vibration monitoring system previously, so that vibration measurements were time-consuming.

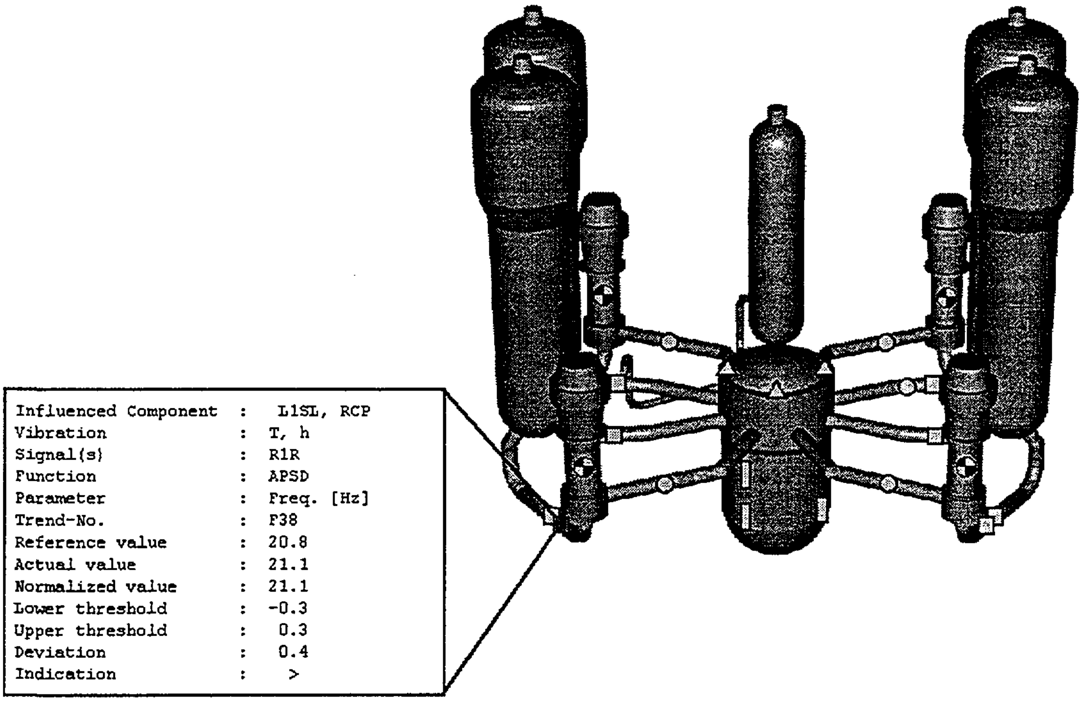

Figure 2 SÜS '95 displays the location of an affected reactor coolant component

The new SÜS '95 vibration monitoring system now performs these necessary and routine tasks without operator intervention. It performs the complete measurement procedure automatically at preselected time intervals, the procedure ranging from calibration of the instrumentation chains, analysis of the signals and monitoring of preset limits to evaluation of the measured data, any documentation of the results required and updating of the vibration measurement database to include the most recent data. If desired, the system can generate a standard report in Word for Windows format, this presenting the results of monitoring in the form of plain text, tables and diagrams. In the event of deviations, the affected reactor coolant system component and the abnormal vibration waveform are specified and indicated on a view of the reactor coolant system (Figure 2). The advantages of the SÜS '95 system are a drastic reduction in necessary resources, well-founded analysis of the mechanical state of components and visualization of results of the analysis.

5 SAFETY THROUGH DIFFERENT PRICIPLES FOR DETECTION AND LOCATING REACTOR COOLANT SYSTEM LEAKS

Analysis of events at nuclear power plants shows that it is impossible to completely rule out leaks at flange connections, valves, isolation valves, etc. Fluid escaping from external leaks can sometimes result in considerable system contamination. Plant safety considerations also make it essential to avoid even internal leaks (such as from safety valves to the pressurizer relief tank), with the result that suitable leakage monitoring systems must be provided.

These risks can be minimized with leakage monitoring systems. Early detection of leaks from cracks in line with the leak-before-break criterion is an appropriate method of preventing a reactor coolant line rupture. According to this criterion, once a through-wall crack has developed, a considerable period of time under stress will elapse before the crack reaches a critical length resulting in a pipe rupture. It should be emphasized that although such off-normal conditions involving "leaks-before-breaks" are extremely unlikely to occur, the plant should nevertheless be monitored for such conditions on the basis of the general safety considerations outlined above.

In terms of plant availability, on the other hand, leakage monitoring systems are important for detecting the considerably more realistic cases of leaks which occur during operation or start-up. Prompt identification and localization of these leaks can limit consequential damage and reduce possible outage times.

Discussion has started again recently, especially in Europe, on improvements to leak detection and on monitoring requirements. One approach of a new quality in the field of leak monitoring is the use of different monitoring principles in parallel.

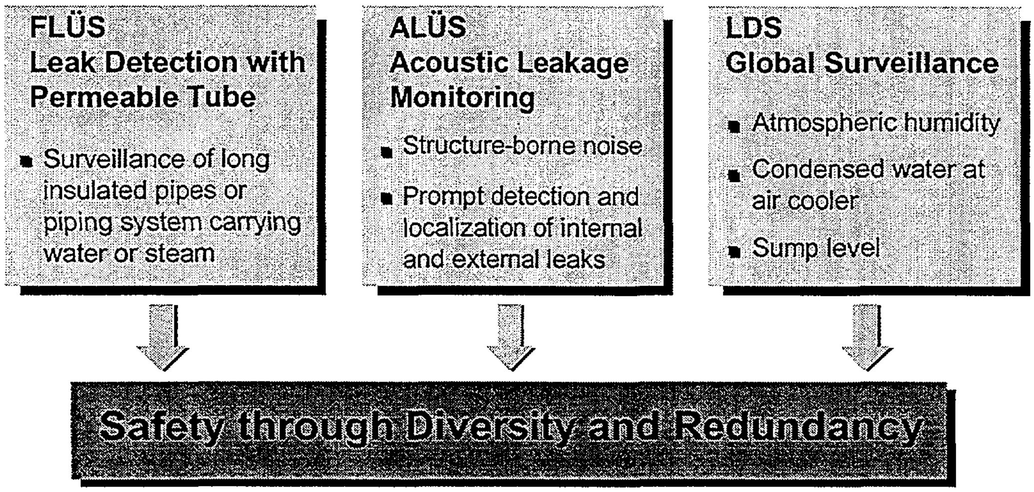

Figure 3 Reliable leak detection through different physical principles

This explains the reasons behind Siemens' development of three different systems for the detection and localization of reactor coolant system leaks in PWRs (Figure 3). These systems are as follows:

- "FLÜS", a moisture leak detection system,
- "ALÜS", an acoustic leak monitoring system and
- "LDS", leak detection system with humidity measurement equipment.

These three systems operate according to completely different physical principles (diffusion of water molecules, acoustic emission and humidity in the containment) and complement one another in terms of their application. The systems are based on the same design concept as PC-based instrumentation systems with modern user software and follow the same standardized strategy in terms of alarm philosophy, self-monitoring and user reliability.

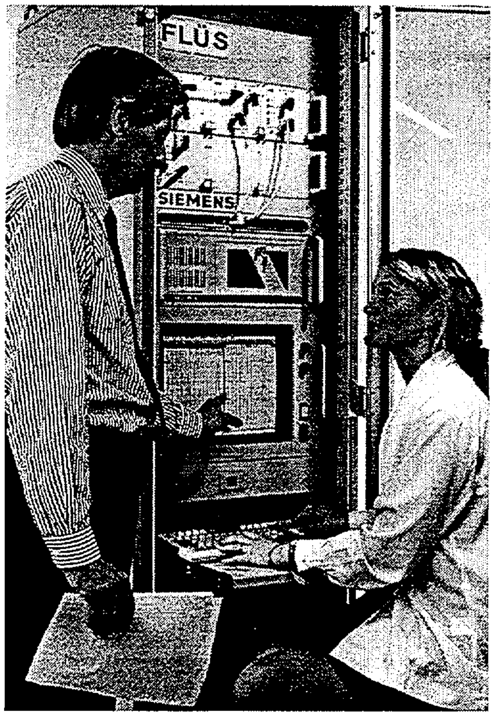

Figure 4 FLÜS leak detection system with extremely high sensitivity of better than 1 kg/h

An innovative and interesting solution is implemented in the FLÜS system (Figure 4): Humidity is detected in the vicinity of a leak by means of a temperature and radiation-resistant metallic tube filled with dry air and positioned either inside the thermal insulation (local monitoring of components) or inside the equipment compartment (global monitoring). The sensor tube has diffusion points (Figure 5) through which ambient humidity can pass. At predetermined time intervals, the air column from the tube is drawn through a moisture sensor. The system measures the moisture content of the air as a function of time and the speed of the air column. Using these data, it determines the leakage rate as well as the leak location. In parallel with this action, the air in the tube is replaced by dry air for the next diffusion interval. The system can detect extremely small leaks with leakage rates as low as 1 kg/h by the end of 15 minutes at the latest, an outstanding sensitivity.

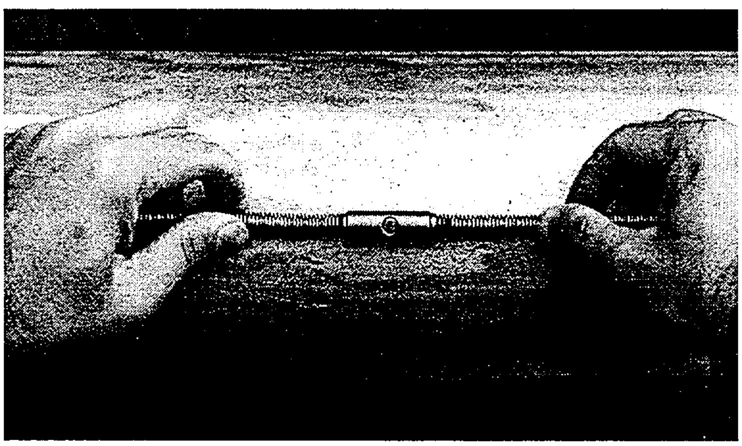

Figure 5 FLÜS sensor tube with diffusion element through which ambient humidity can pass

The end of the air column sampled in each measurement is selectively marked by a defined amount of moisture (test leak). This defines the reference values for transit time and moisture content and is also used for self-monitoring of the entire system.

Although FLÜS is a very new system, two such systems have been already implemented, at Obrigheim (Germany) and Ringhals 1 (Sweden).

As already mentioned, leakage detection in a nuclear power plant should be based on a combination of the ALÜS, and FLÜS and LDS systems. FLÜS is used to monitor the reactor coolant pressure boundary for leaks to the outside, LDS for global monitoring of equipment and operating compartment humidity, while ALÜS provides redundancy and serves above all to monitor critical valves for internal leaks.

6 VALVE DIAGNOSTICS DURING POWER OPERATION

Almost 90 percent of the mechanical components in a power plant comprise valves. The ability to function and readiness to function for valves has a decisive impact on the availability and reliability of the industrial systems of which the valves form a part.

Recent developments led to a valve performance concept that comprises an analytical section that must be performed once and includes:

- The model for function describing the required positioning forces and torques for actuation and considers the relevant parameters with tolerances
- The model for stress analysis covering the load-carrying capacity of valve components and
- Design evaluation covering the limits and weak points for the parameters relevant for function

Verification of ability to function is followed by periodic testing to verify readiness to function. These tests assure early detection of faults over the entire service life of the valve and allow timely performance of maintenance and repair measures to avoid problems. The approach used for monitoring performance of a valve and its associated electric actuator comprises the measurement of active power for the actuator. This parameter allows fast evaluation via the motor control center(MCC) and diagnostic measurements in the event of out-of-tolerance situations. (Beside active power measurement, detailed measurements at the location of the valve are also used to check the parameters for the mechanical equipment.)

To allow the required periodic testing of valve actuators to be performed during normal plant operation, Siemens developed the mobile microprocessor-controlled data logger SIPLUG for recording active power.

All the components are housed in a standard, compact plug-in module of the type found in power plants. SIPLUG remains in the standby mode until the valve is actuated and is then activated automatically. It then measures the current, voltage and control parameters, calculates active power and stores the values in its internal memory. The memory is sufficient for a recording time of approximately 400 s, which means that multiple valve actuation can be easily recorded.

At periodic intervals, SIPLUG is hooked up to a PC which reads and evaluates the stored data.

SIPLUG valve diagnostics thus allows changes in the condition of a valve and its actuator system (including the controls) to be reported during power operation. The measurements are performed under operating conditions and from the motor control center, so there is no additional valve testing, no radiation exposure and reduced cost. The unit can be easily installed on MCCs from a wide range of different manufacturers.

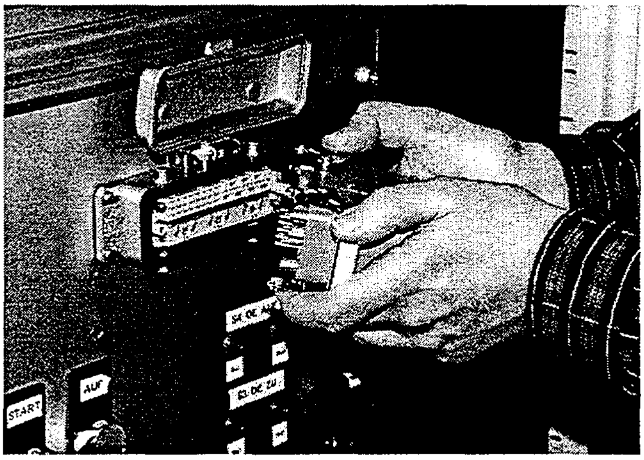

Figure 6 SIPLUG is connected with valve actuator control unit in the MCC

7 BENEFITS FROM EXPERIENCE

Siemens, as a manufacturer of power plant components, already has more than 20 years of experience with monitoring systems applied in Siemens and other vendor plants. The new developments exploit this extensive experience which has been integrated into the evaluation procedures of the systems.

Development trends are toward diagnostic systems for reactor coolant system component monitoring that are no longer restricted to use by specialists. They bring the systems closer to standard I&C and offer valuable information about plant component behavior, particularly with a view to introducing modern maintenance strategies.