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Modern Diagnostic Systems for Loose Parts, Vibration and Leakage Monitoring

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Abstract

The modern diagnostic systems for loose parts, vibration and leakage monitoring of Siemens marked improvements in signal detection, ease of operation, and the display of information. The paper gives an overview on:

- Loose parts monitoring system KÜS '95 - a computer-based system. The knowledge and experience about loose parts detection incorporated into this system can be characterized as „intelligence".
- Vibration monitoring system SÜS '95 - a fully automated system for early detection of changes in the vibration patterns of the reactor coolant system components and reactor pressure vessel internals.
- Leak detection system FLÜS - a system that detects even small leaks in steam-carrying components and very accurately determines their location. Leaks are detected on the moisture distribution in a sample air column into which the escaping steam locally diffuses.

All systems described represent the latest state of technology. Nevertheless a considerable amount of operational experience can be reported.

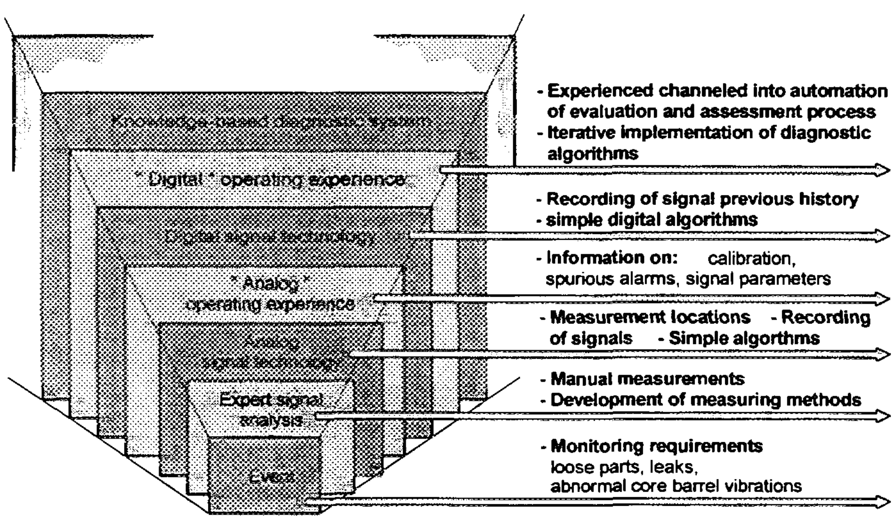

Figure 1 - System transition from monitoring to diagnostics

1 Introduction

Continous coolant-system monitoring has been used successfully in nuclear power plants for many years to increase plant reliability and availability, which in turn has improved plant operating

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economy. Monitoring systems provide early detection of abnormal mechanical vibrations, loose parts, leaks, incidents of material fatigue and changes in the condition of valves.

The monitoring systems used in nuclear power plants have undergone further development over the past three or four years, and are now complete diagnostic systems (Figure 1) which, in addition to analyzing measured data, perform an evaluation and visualize this in an easily understood form. This is particularly true of systems which monitor structure-borne noise, i.e., detect and localize loose parts, and those which monitor vibration.

2 *Technical Concept of Siemens Diagnostic Systems*

A new generation of monitoring and diagnostic systems has been developed by Siemens during the last years. The new generation, called Series '95, is based on PC. The new systems improve the reliability and quality of monitoring techniques and reduce the effort and staff needed for maintenance and evaluation.

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,
- Facilitation of fault clearing,
- Prevention of sequential damage,
- Reduction of inspection costs and radiation exposure.

The functions of the diagnostic systems include acquisition, processing, storage and documentation of the necessary data and also provision of the other aids required for quick and reliable analysis including the tools for automatic diagnosis.

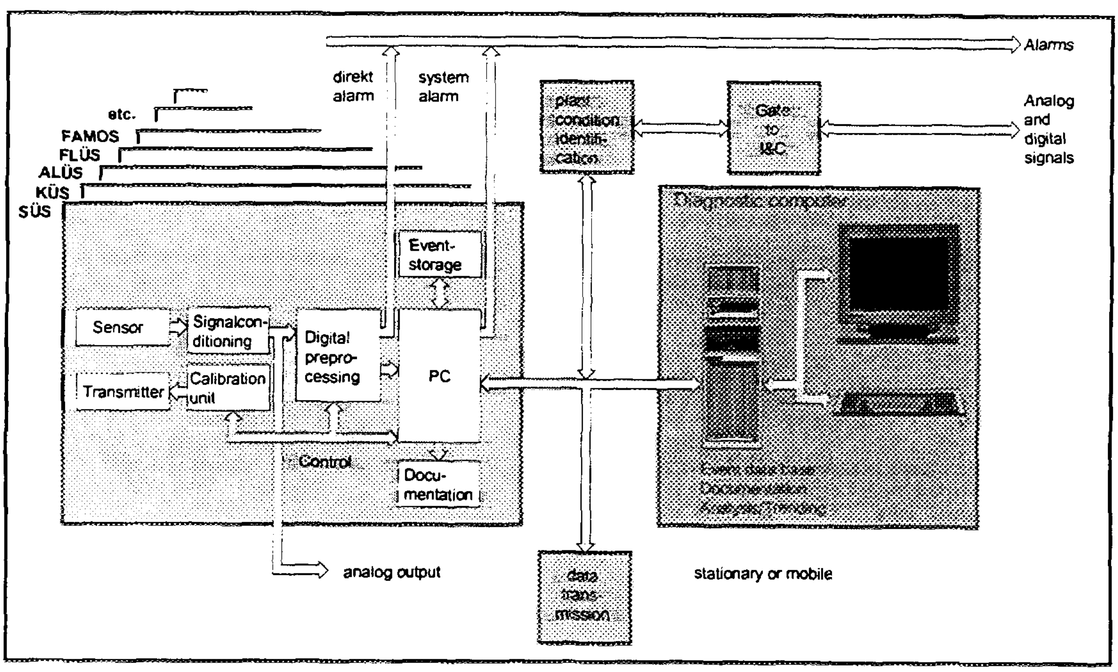

Figure 2 - Modular design of Siemens diagnostic systems

All monitoring systems (KÜS[1], SÜS[2], ALÜS[3], FLÜS[4], FAMOS[5]) follow a common technical concept in which autonomous individual modular systems perform identical functions (RMS generation,

[1]KÜS - loose parts monitoring system (Körperschallüberwachungssystem)
[2]SÜS - vibration monitoring system (Schwingungsüberwachungssystem)
[3]ALÜS - acoustic leakage monitoring system (Akustisches Lecküberwachungssystem)
[4]FLÜS - moisture leakage monitoring system (Feuchtelecküberwachungssystem)
[5]FAMOS - fatigue monitoring system

calibration, analog-digital conversion, filtering, etc.) with identical modules (Figure 2). For analyses exceeding the needs of a single system, data records may be transferred to a diagnostic computer, using remote data transmission or computer networks.

The systems features are:

- Continuous operating mode - the systems work practically without dead time. Data evaluation does not impede continued monitoring.
- All the signals sent to the systems are system captured and processed simultaneously and parallel to one another.
- Automation - the systems perform continuous monitoring without operator intervention; even complex alarm conditions can be implemented. Instrument chain adjustments, function checks, calibration, etc. are operations performed periodically and automatically.
- Comprehensive information storage - in the event of an alarm, all the necessary information, including the previous history of the event, is stored parallel and in digital form for all measuring channels.
- A detailed system documentation, supplemented by extensive evaluation and analysis functions, has been prepared for the systems and the results obtained.
- Physical calibration - a basic principle of the system design is that control is exercised over instrument chains and algorithms in order to produce physically identical variables during monitoring; i.e. for loose parts monitoring a remote impact hammer introduces periodically impact events into the nuclear power plant components.
- Informative character - a signal is transmitted to the control room, but there is no intervention in the reactor control system. Further decisions are left to the expert, whom the system supplies with the necessary tools for a rapid and reliable diagnosis.
- Inclusion of operating data - the systems can record operating data which modifies the monitoring task as a function of the operational status of the power station.
- Self-monitoring - all parts of the monitoring systems are themselves monitored by the system. Every part of the monitoring system is periodically checked for operability by the system itself, and if faults are detected the system triggers an alarm. A computer failure does not interrupt the monitoring process, but merely restricts certain functions.
- Same user interface - in line with modern PC developments, all the systems have a largely identical menu-driven user interface following Windows standard.

The various systems are based on a common technical design and are individually-working, standalone systems, equipped with the following functional components:

- Signal pickups,
- Signal conditioning unit,
- Digital pre-processing unit,
- Data acquisition computer,
- Analysis computer and peripherals.

3 *The KÜS '95 - Loose Parts Diagnostic System*

Two years after its introduction, the KÜS '95 loose parts diagnostic system for the detection and localization of structure-borne noise is already in operation in seven nuclear power plants. The system evaluates noises made by loose parts in an analysis and diagnostic phase. The main benefit of the KÜS '95 system is its ability to determine whether or not detected structure-borne noises coincide with previously recorded reference events. These reference events are used as the basis for subsequent diagnosis, however in addition they give the system the capability to decide if the noise in question is being made by a loose part or just a normal operational event, which is often the case. A normal event is filed as a „Known Event", thereby avoiding unnecessary evaluations.

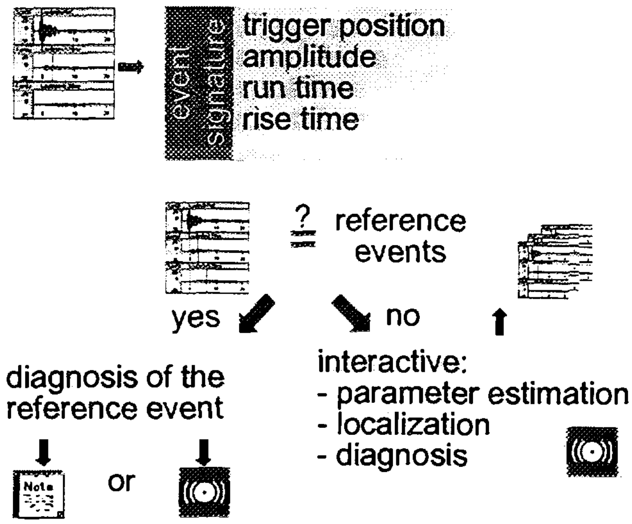

Figure 3 - Procedure of the KÜS '95 sensitive event classification to identify events

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 (Figure 4).

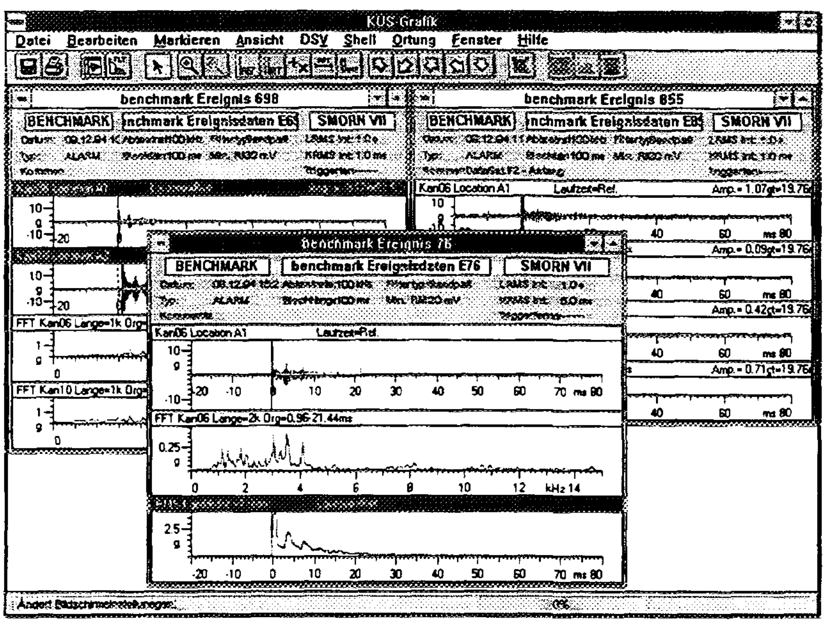

Figure 4 - Graphic analysis of an impact noise in the structure-born signal

KÜS '95 could prove its performance in the frame of the International Benchmark Test organized by the Nuclear Energy Agency of the OECD in 1995. The results were presented at SMORN VII (1995, Avignon). The data collected with KÜS '95 and Siemens evaluation methods (localization and mass estimation of different impacts) were outstanding amongst 18 participants (most of them being suppliers or developers of LPMS).

The KÜS '95 system was able to locate the points of impact to within a few centimeters. For this purpose the system measures the sound propagation time difference. It makes use of the fact that the burst induced by the impact propagates at the speed of sound, thus reaching the transducers at different times.

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. Siemens uses the frequency analysis method, which is based on the principle that the central frequency of the impact signal spectrum is indirectly proportional to the contact time (Figure 5). The KÜS '95 system was able to determine the mass to within approximately ± 30 percent - an accuracy which is perfectly adequate for practical applications.

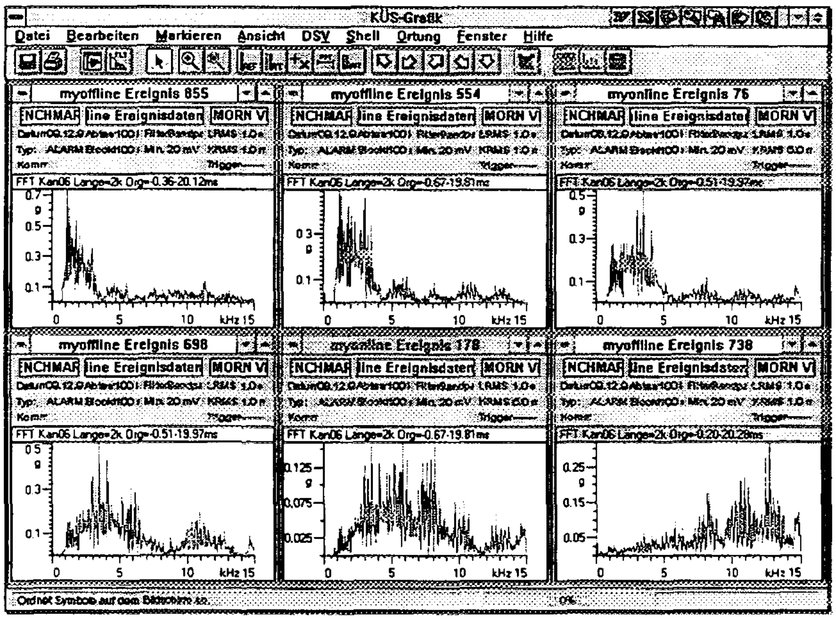

Figure 5 - Frequency spectra of impact noise of 6"-, 5"-, ... 1"-balls from the SMORN VII benchmark test - frequency spectra allow the mass estimation of the loose part

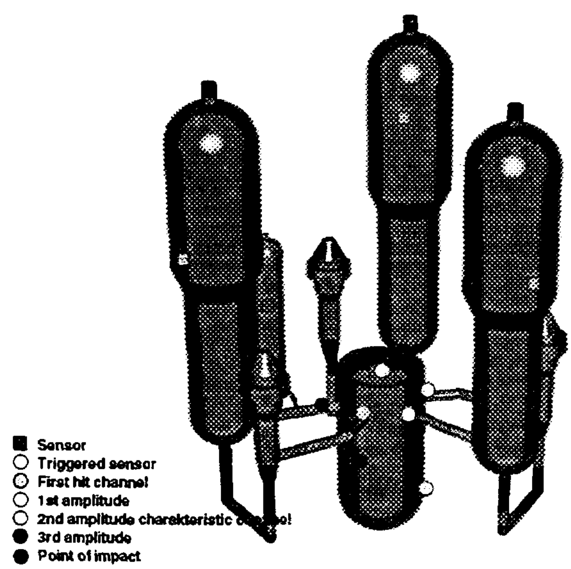

Figure 6. Depiction of event localization

KÜS '95 as well as the other modern diagnostic systems are designed for intuitive operation with clear presentation of monitoring results. The sequence in which individual channels are triggered is shown in a 3D display of the reactor coolant system which can be rotated stepwise in all three axes providing the user with virtual access to the reactor coolant system (Figure 6). The same 3D display is available for depicting the results of event localisation.

4 SÜS '95 - Complete Automatic Vibration Diagnostics

Licensing authorities require vibration measurements which must provide an early indication of changes in the vibration patterns of structures such as reactor pressure vessel internals and reactor coolant system components, as well as rotating machinery such as reactor coolant pumps. The expertise necessary to analyze the measured data has been systematically acquired and completed since the commissioning of these systems in Germany.

Previously, vibration measurements were time-consuming. The SÜS '95 vibration monitoring system now performs these necessary and routine tasks without operator intervention. The system is designed to comprise all features an automatic vibration monitoring system today can include:

- vibration monitoring of structures and rotating machines
- complete solution from the pickup through to the analysis system
- complete solution from the function test through to the results report
- complete solution from design through to service

The systematic SÜS '95 concept starts with the selection of pickups which were specially developed for the measurement of power plant components vibrations - e.g. the SAUM absolute displacement transducer - and optimized for their application in terms of sensitivity and frequency range (Figure 7). It goes without saying that they are qualified for use in the harsh conditions prevailing in nuclear power plants and can be remotely calibrated at any time.

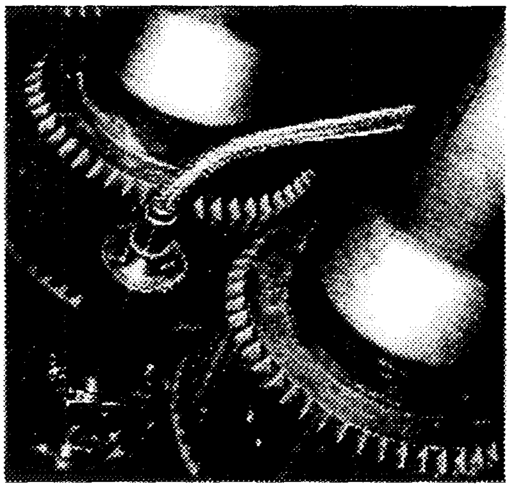

Figure 7 - The specially developed absolute displacement transducer SAUM for the measurement of power plant components vibrations.

SÜS '95 automatically performs a functional test of all instrument chains prior to each measurement, calibrates them and documents the current settings. This is the only possible way to implement a really automatic vibration monitoring procedure which excludes incorrect measurements and poorly adjusted instrument chains.The modular design of SÜS '95 guarantees service-friendliness as well as simple extensions to the system and its software.

SÜS '95 performs all the routine tasks required for vibration measurement single-handed:

- start-up of measurement at the required time (single or cyclical operation)
- selection and functional test of required instrument chains
- measurement procedure
- calculation of the required characteristic vibration variables, detection of changes and indication of threshold violations
- display of monitoring results in a 3-D image (Figure 8)

- recording of process parameters and allowance for effects of different operational conditions
- documentation of results in report form in accordance with applicable specifications (Figure 9).

The system provides comprehensive information when deviations are detected:

- designation of the affected component
- assumed cause of the change
- required action and scope of action.

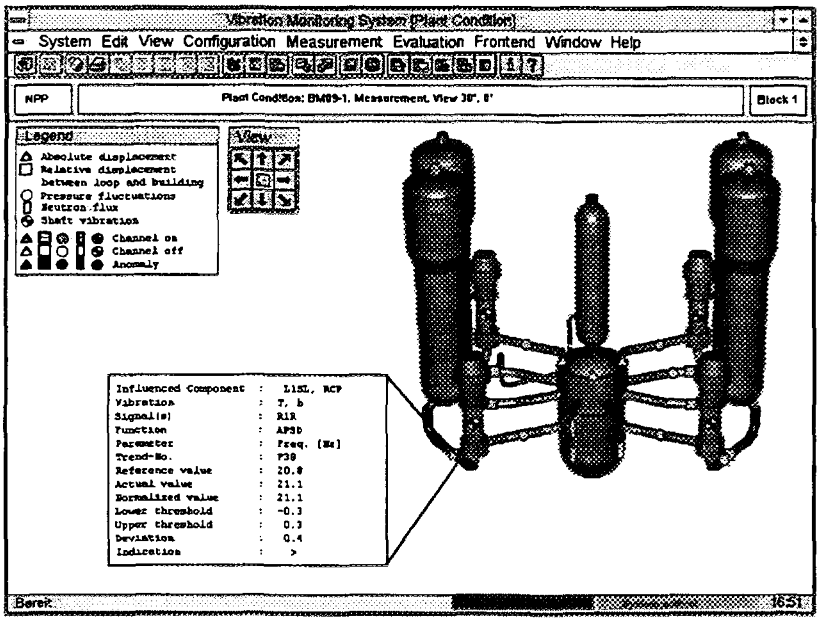

Figure 8 - SÜS '95 displays the location of an affected reactor coolant system component

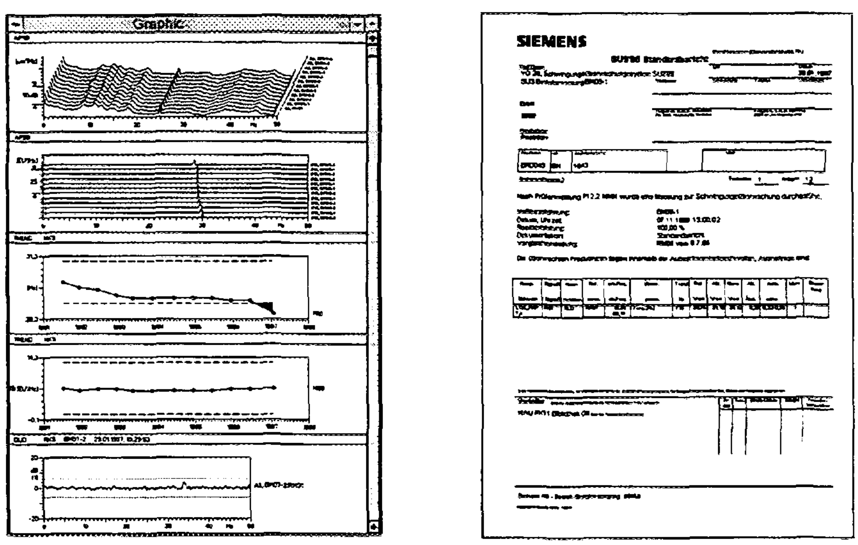

Figure 9 - SÜS '95 includes complex evaluation tools and performs automatically a standard report which presents the results of the vibration monitoring

SÜS '95 thus creates more scope for dealing with the actual plant and grants the user more time to attend to details before deviations develop into real problems.

The SÜS '95 vibration monitoring system is further enhanced by a comprehensive range of vibration monitoring services:

- concept and configuration of vibration monitoring
- development and production of systems: new systems/conversions/upgrades
- installation and commissioning
- system service and maintenance
- performance and evaluation of vibration measurements (reference measurements, repetitive measurements, special measurements)
- archiving of data, trend analysis and documentation suitable for independent experts
- dynamic tests in the vibration laboratory and in the power plant
- instruction, practical training and advice.

5 *FLÜS - Leak Detection by Monitoring Humidity*

The leak detection system FLÜS detects leaks in steam- and water carrying components, and also monitors the humidity of the ambient air. Special features of the new system include highly sensitive detection and leak localization which is accurate to within the meter range. The FLÜS system detects leaks in thermally insulated components at an early stage, and evaluates their development over time. Leakage from small cracks (leak-before-break criterion) is also detected.

FLÜS detects the humidity that builds up in the vicinity of a leak by means of a temperature- and radiation-resistant metallic tube filled with dry air and placed inside the insulation. The tube has diffusion points through which ambient humidity can pass at defined intervals. At predetermined time intervals, the air column is drawn through a moisture sensor (dew-point measurement). The moisture content of the air is measured for each diffusion point and the leakage rate is estimated based on these data. The location of the leak is determined based on the transit time and speed of the air column between the measuring location and the sensor (Figure 10).

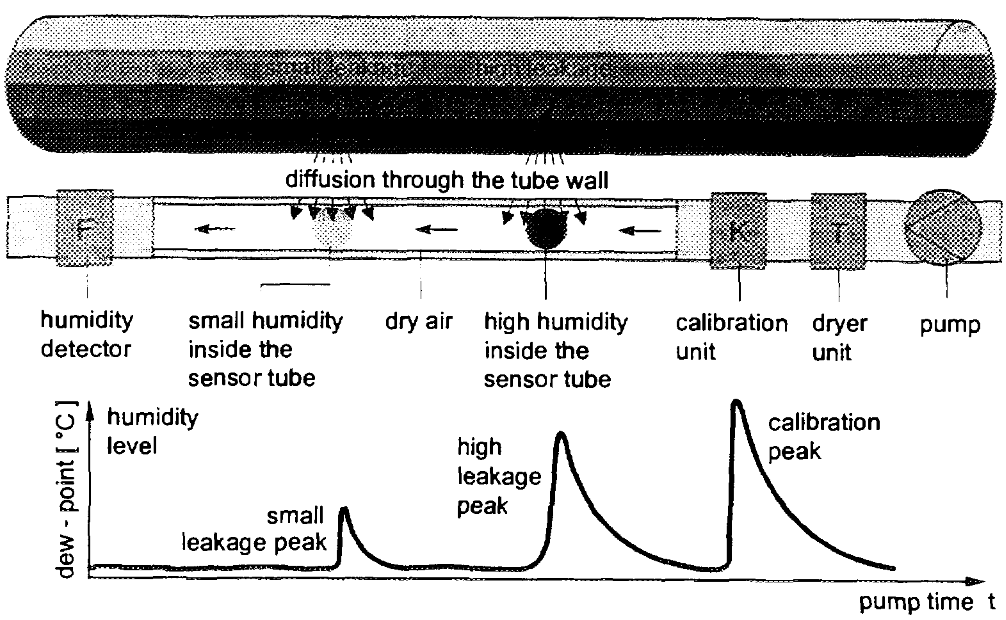

Figure 10 - FLÜS detects even small leaks in steam-carrying components and very accurately determines the location. Leaks are detected based on the moisture distribution in a sample air column into which the escaping steam locally diffuses.

The end of the air column sampled in each measurement is selectively marked by means of defined amount of steam. This test peak defines the reference values for transit time and moisture content and is also used for self-monitoring of the entire system (detector, pump, tube). A leak alarm is issued if a predefined reference curve is exceeded by a specific factor (relative alarm) or if a fixed threshold is exceeded (absolute alarm).

The modular measuring system is operated with a PC. The measured values are recorded periodically, monitored with respect to alarm criteria, and stored. If an alarm is issued, reports provide information on the leakage rate and location, and on the alarm itself.

The FLÜS measuring station, centrally located in an accessible compartment inside the containment building, can control as many as eight measuring loops, each up to 150 metres long with a spacing of approximately 0.5 metres between diffusion elements.

The FLÜS system has been applied for a German pressurized water reactor plant to detect possible leaks in the reactor pressure vessel closure head since 1995. During the qualification procedure for this application a mock-up was used to study the effects of leakage into the insulation of the reheater vessel. The results of this study confirm the excellent results:

- A leakage rate of 0.05 kg/h is reliably detected; measurable effects are already noticeable at 0.01 kg/h.
- There is a clear correlation between leakage rate and dew point. The leakage rate is quantifiable if the FLÜS indicator is calibrated for the respective insulation.
- The response time of the FLÜS monitoring system is as short as 15 minutes.
- A local increase in moisture can be localized within 1 m.

To monitor the reactor pressure vessel closure head, one sensor tube is placed inside the insulation and another outside it. The two tubes are combined, e.g., to decouple the leakage monitoring process from normal fluctuations in the ambient humidity.

6 References

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