XA9949675

EXPERIENCE WITH DIGITAL ACOUSTIC MONITORING SYSTEMS FOR PWR'S AND BWR'S

B.J. OLMA
Institute for Safety Technology (ISTec)
Garching, Germany

Abstract

Substantial progress could be reached both in system technics and in application of digital acoustic monitoring systems for assessing mechanical integrity of reactor primary systems. For the surveillance of PWR's and BWR's during power operation of the plants, acoustic signals of Loose Parts Monitoring System sensors are continuously monitored for signal bursts associated with metallic impacts. ISTec/GRS experience with its digital systems MEDEA and RAMSES has shown that acoustic signature analysis is very successful for detecting component failures at an early stage. Methods for trending and classification of digital burst signals are shown, experience with their practical use will be presented.

1. Introduction

Assessing the mechanical integrity of reactor primary systems during power operation of the plants is performed by acoustic monitoring using loose parts monitoring systems (LPMS). These systems are designed to detect, locate and evaluate detached or loosened parts and foreign objects in the reactor coolant system. Efforts to advance the safety of nuclear power plants (NPP) using modern computer technology have led to powerful new solutions for more automated fault diagnosis systems. LPMS are capable to detect component failures at an early stage /1-3/. In the German RSK-guidelines /4/ the use of adequate measures is required in order

- to detect free and captive loose parts within the pressure retaining boundary and
- to localise loose parts as well as possible.

LPMS are installed in all nuclear power plants in Germany. LPMS have to be seen as information systems whose indications give the plant personnel enough time for adequate counter-measures. The observation of acoustical alterations or exceeding an alert level does not mean a critical situation. Therefore, technical requirements which are needed for safety relevant measurement channels must not be fulfilled in this case. On the other hand, the demand for an effective LPMS is obvious with respect to the avoidance of damage. Both the *recognition of developing failures and the possibility to evaluate these failures during plant* operation in spite of inaccessibility of the components are especially desirable for safety reasons. This is illustrated by the fact that the LPMS system software of both leading German system manufacturers Siemens (for KÜS'95 /5/) and AZT (for KAP 90 /6/) is quality assured and certified.

The task of acoustic monitoring of the reactor primary system is to monitor continuously the acoustic signals and to give an indication in the case of burst events. Acoustic burst occurrences are generated by the energy delivery from impacts of detached or loosened parts hitting the inner surface of the pressure retaining boundary of reactor coolant or reactor internals. Piezoelectric accelerometers working in the acoustic frequency range and resistant to temperature and radiation have been found to be very effective for their detection.

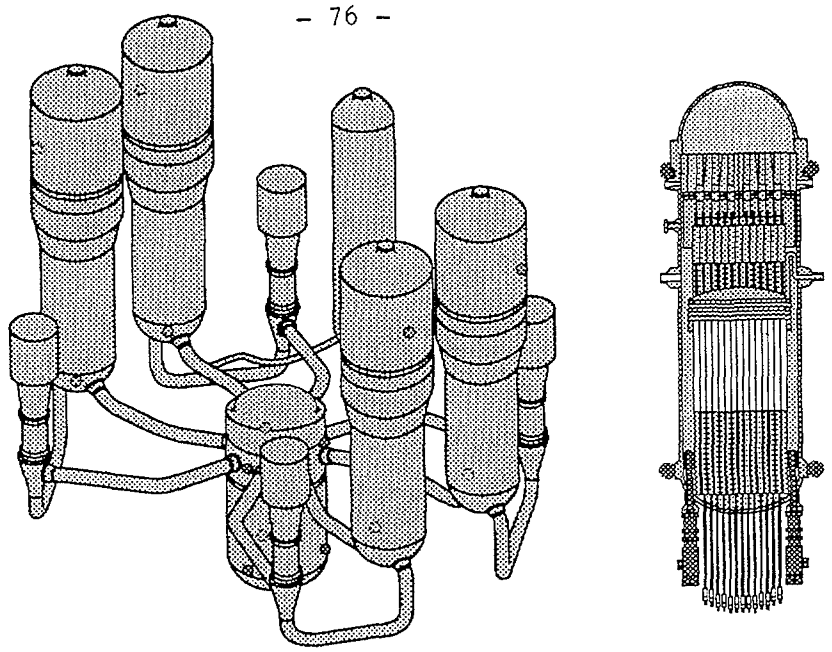


Fig. 1: Sensor positions of loose parts monitoring systems for PWR and BWR

Fig. 1 shows - marked with small circles - sensor positions of LPMS for a 1300 MW PWR and a BWR. The sensors are mounted as near as possible to the surface of the monitored structure and are positioned in different levels at areas which are natural collection rooms for loose parts (lower plenum of reactor vessel or steam generator) or which have a good detection capability for impacts of internals (upper part of reactor vessel and steam generator). The number of sensors as well as their type of adaption (magnet-adapted, screw-adapted, mixed adapted) differ from plant to plant. In a 4 loop PWR at least 14 sensors are recommended. In reality the systems are of different technical level depending on their period of construction. Fig 2 shows the number of sensors, their type of adaption and the technics of installed LPMS in German LWRs. Digital LPMS essentially comprise a data acquisition unit, which consists of a transient recorder with up to 32 channels, a high-end PC with appropriate periphery and software for the control of data flow, data storage and analysis. By the new digital LPMS acoustic signals of new quality and enhanced information supply are now available, in recent years more and more utilities have replaced old analog systems with modern digital systems.

	LPMS sensors				LPMS technics		
NPP	number	magnet-adapted	screw-adapted	mixed adapted	analog technics	analog with digital evaluation	digital technics PC based
Obrigheim	12	●	●		●	●	
Stade	17		●	●	●	●	
Neckarwestheim 1	13			●			●
Biblis A	16	●				●	
Biblis B	14	●		●			●
Unterweser	14	●					●
Grafenrheinfeld	20	●	●				●
Philippsburg 2	16		●		●	●	
Grohnde	16				●	●	
Mülheim-Kärlich	12		●			●	
Brokdorf	14	●					●
Isar 2	16		●				●
Emsland	16		●		●	●	
Neckarwestheim 2	16		●				●
Brunsbüttel	8		●				●
Isar 1	10	●					●
Philippsburg 1	10	●			●	●	
Krümmel	8		●				●
Gundremmingen B	12		●				●
Gundremmingen C	12		●				●

Fig. 2 LPMS sensors and system technics in German LWR's

2. Acoustic signal analysis systems

LPMS have been developed now to a satisfactory status. The systems work on-line and monitor the reactor coolant system with fixed and floating alert levels in order to detect detached, loosened or foreign parts. Current investigations concentrate on the improvement of on-line diagnosis methods and trending of components status.

Basic requirement for acoustic monitoring of active and passive components within the primary system of Light Water Reactors (LWRs) is the qualified analysis and detailed burst data interpretation of acoustic signals. A fast digital off-line burst processing system (MEDEA-system) has been realised in the ISTec laboratory. Its major components are a 16 channels transient recorder, a UNIX- workstation, fast data storage facilities, interactive analysis software and a burst data base (fig. 3).

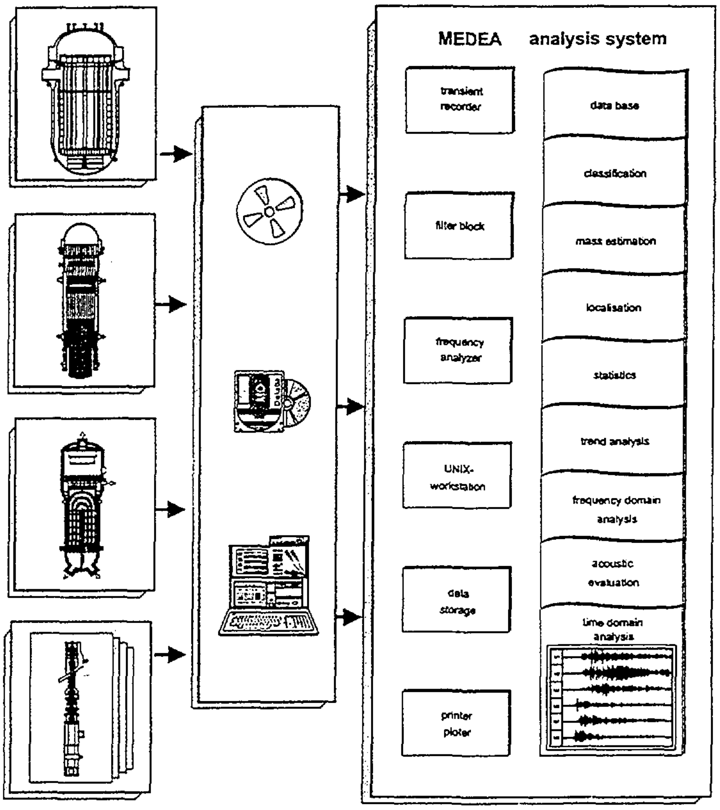


Fig. 3: MEDEA-system for off-line acoustic analysis

Plant measurement data reach ISTec laboratory by FM recordings, MO-discs or the RAMSES system (fig. 4). The Remote Acoustic Monitoring and Signal Evaluation System (RAMSES) has been developed by ISTec for on-site digital signal recording and diagnosis support to the plant. Meanwhile two RAMSES systems have been established. The most advanced is PC-based and consists of six transient recorder storage modules, a graphic display and a modem. Software packages have been implemented needed for the storage of the data to the on-site computer after event detection, the remote controlled settings of the transient storage modules via the telephone line, the data transfer of qualified signal patterns to the ISTec laboratory as well as the online diagnostic information on site.

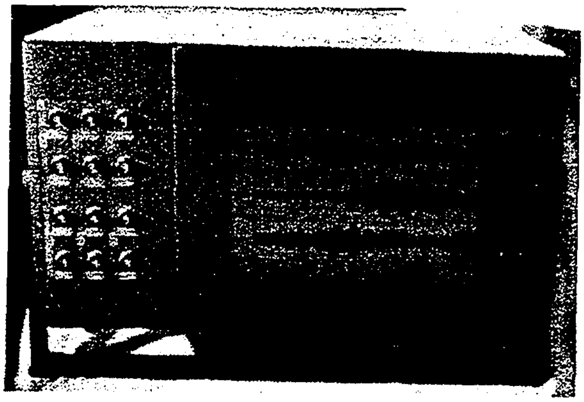


Fig. 4: RAMSES system for on-site measurements

3. Burst Signal Analysis

By the increasing use of digital LPMS in Germany, signal patterns of alert indications are stored more and more in digital form. In the following, some recent developments realised for burst signal analysis and evaluation are presented. Burst data sets are regularly copied on site for archive purposes, but also flexible discs or MOs are used for transfer of the data to separate analysis computers. Additionally to MEDEA analyses of FM recordings, ISTec has analysed digital data sets of nine different plants. Fig. 5 shows an overview of recent analyses, the rectangles mark the covered registration time and the number of analysed signal patterns.

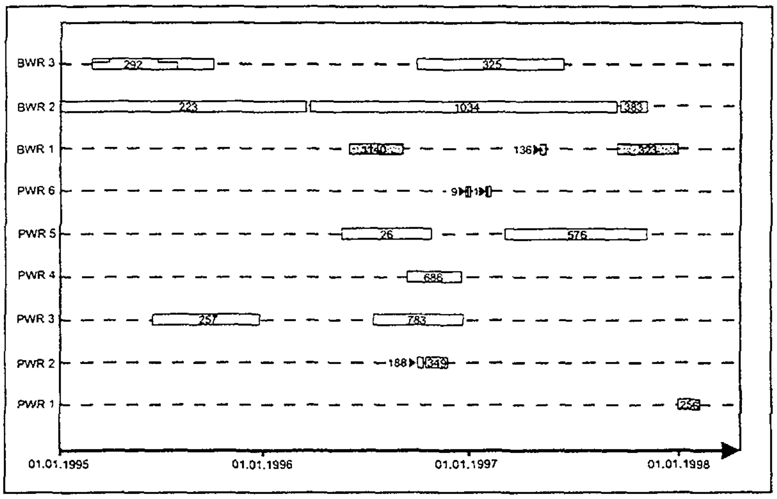


Fig. 5: Digital LPMS data sets, analysed by ISTec

The comparison of actual burst signals with reference signals is important for acoustic analyses. Due to the stochastic character of acoustic signals a direct comparison of time signals would not be reliable. In order to find adequate reference patterns, the calculation of signal parameters is necessary. The comparison is then performed on the basis of predetermined characteristic values, which can be calculated by NNCT analysis software, which is part of the MEDEA system of ISTec.

The data set formats are different for different system manufacturers, ISTec has got the knowledge of the specific data formats. For the NNCT analysis software, a data access is possible for MEDEA and RAMSES data of ISTec, for KAP 90 data of AZT, for KÜS'95 data of Siemens and famos data of imc (see fig. 6). By use of specific C input filter routines analyses of data of the different signal formats of the different manufacturers are possible in a common way. For a more automated way of burst data handling and data processing the ODBC driver is used for the data storage in a data base. These functions are integrated in the NNCT analysis software of the MEDEA system.

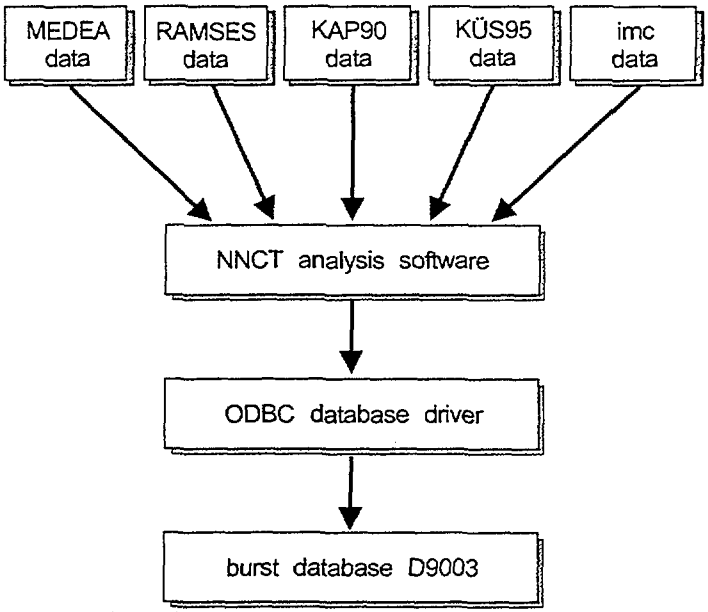


Fig. 6: Signal analyses and data storage of digital LPMS data

Acoustic signatures from measurements and analyses of 14 German LWRs with more than 11000 bursts are available. In a burst pattern data base they are characterised by the event type, measurement and signal parameters. The new burst data base D 9003 has been realised as an ACCESS data base under Windows 95. The structure is as follows. Data administration of the measurement campaigns is concentrated in a leading HEADER data set. It contains information about plant, fuel element cycles, name of the measurement, number of channels, number of bursts and measurement configuration. The results of signal analyses are stored in a RESULT data set, which is stored separately for each different plant. The RESULT data set contains signal parameters, classification values, process data, alarm type, signal amplitudes, location results and diagnosis. Fig. 7 shows the structure of the burst data base D 9003.

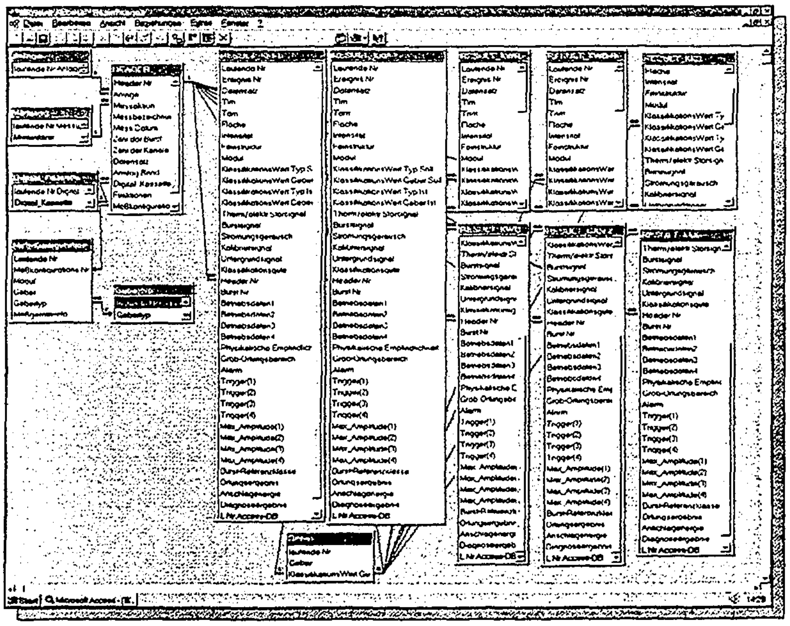


Fig. 7: Structure of database D 9003

The detailed and reliable evaluation of acoustic events requires extensive know-how and analysis efforts. Analyses are performed on the basis of short term samples. Operationally induced signal patterns have to be identified and circled out. Plant independent registration and analysis of operational experience, which has been gained on site, provide status information for components assessment. Basic significance for the interpretation of acoustic signal patterns has the evaluation of test impacts. By permanently installed automatic pulse hammers of the LPMS KÜS'95 at the four loops of PWR's, test impacts of known impact energy can be performed during plant operation, the acoustic response of the LPMS sensors is registered and can be used as a reference. Fig. 8 shows the signal pattern of a test impact performed on the hot leg of loop 2 of a 1300 MWe PWR. The pattern is presented as a 15-channel display of KÜS'95 data by use of NNCT software of ISTec.

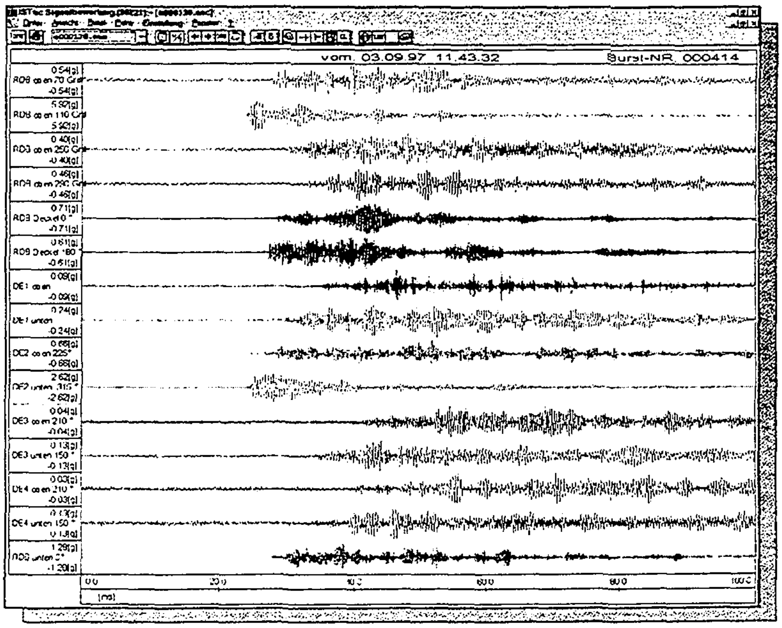


Fig. 8: Signal pattern of a test impact with an automatic impulse hammer

The important question for the origin of the sound source of a measured acoustic event can be answered by using localisation methods which are available by digital LPMS. Triangulation by means of hyperbola intersection is the standard method for localisation. For a three sensor combination the solution of hyperbola equations result in two intersection points which can be shown on a development of the structure. Is a fourth signal pattern available, a decision and identification of the intersection point can numerically be given. For cylindrical surfaces like the reactor vessel, a new direct localisation algorithm on the basis of measured path time differences has been implemented in the MEDEA analysis software. In fig. 9 a 3 channel signal pattern of a test impact on cold leg of loop 4 of a PWR, whose LPMS data were of famos data type, is shown. In the right part of fig. 9 known hyperbola graphs are shown on a development of the reactor vessel. Low variations of burst propagation speed determine the five hyperbolas. Additionally, the result of the direct localisation algorithm for the same burst pattern is shown by circles. The position of the circles is identical with the intersection of the hyperbolas and shows the correctness of the algorithm.

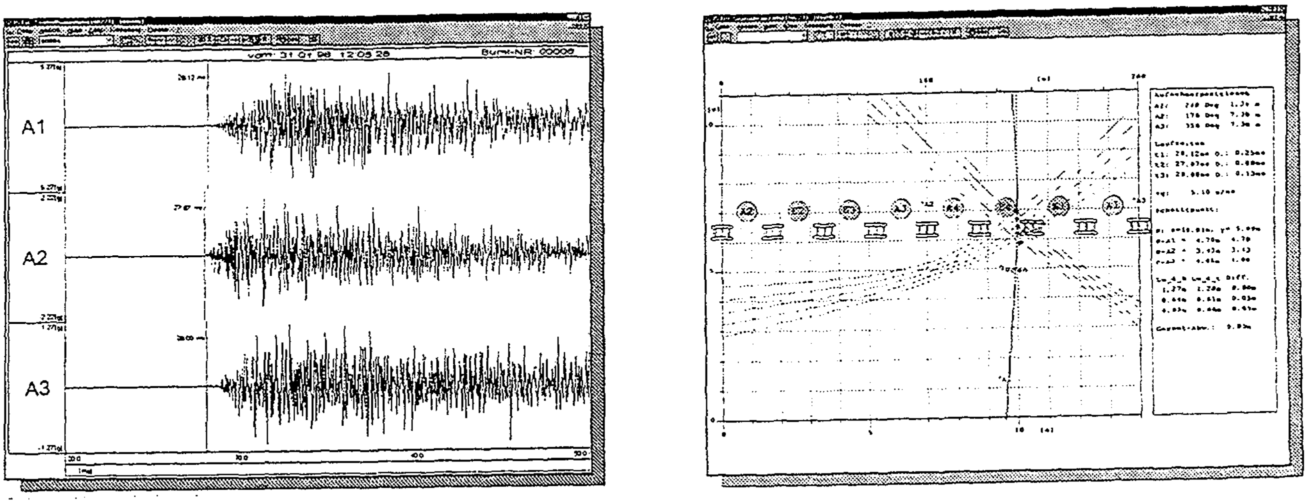


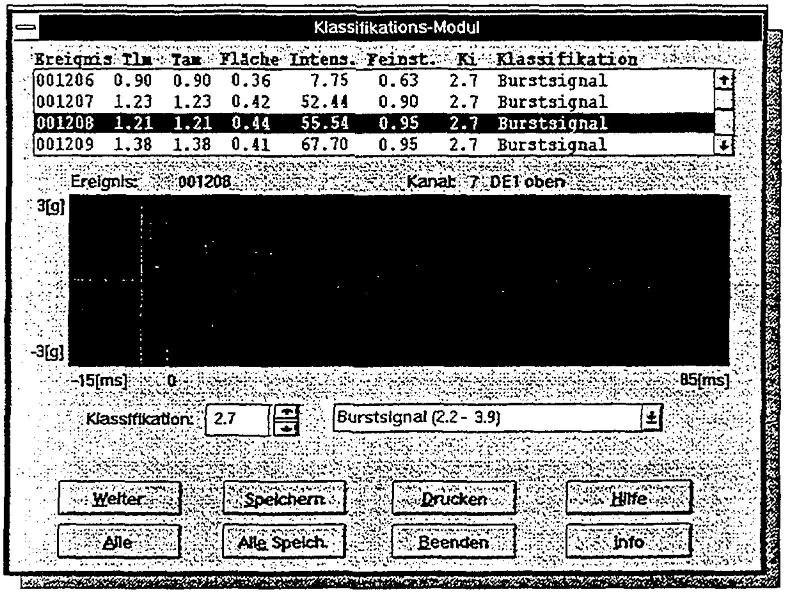
Fig. 9: Hyperbola and direct source location of a test impact

LPMS contain an alarm processing unit with absolute and variable (floating) thresholds. Due to the high sensitivity of acoustic monitoring, the detection potential for impact occurrences is comparatively high. Low energetic and minor relevant events are indicated and could be seen as precursors of real failures. They are of great value as status indicators, if they can be used for safety assessment of primary system components. On the other hand, too frequent unnecessary alarms can reduce the confidence to this monitoring technique and should be avoided by appropriate evaluation and additional measures. In order to reduce false alarms, specific zone localisation areas have been calculated for primary system of PWR's (KWU type, 1300 MWe) and BWR's (KWU type, 900 MWe), based on newly developed direct location algorithm. Table 1 shows the time differences between sensors of different measurement planes as a result for the localisation area lower plenum, calculated for symmetrical So plate waves.

TABLE 1: Calculated time differences for zone localisation area lower plenum (So plate waves)

Time difference [ms] between sensors of different measurement planes, localisation area lower plenum	BWR reactor vessel top	PWR reactor vessel top	PWR steam generator top
BWR reactor vessel down	2.8 - 3.5	-	-
PWR reactor vessel down	-	2.8 - 4.2	-
PWR steam generator down	-	1.8-2.4	2.2-2.6

Recently, ISTec has developed two software modules as add-ons for acoustic evaluation and classification of LPMS signatures. By means of the acoustic module with its signal supplement technics, an optimised audio replay of digitally stored LPMS burst signal is available, which is very convenient for practical signal evaluation /7,8/. An automated LPMS burst type classification is established by the classification module /9,10/. The classification module uses a trained neural net with 5 input nodes, two hidden layers with 5 nodes each and two output nodes. Five burstform-sensitive parameters are calculated automatically: local maximum time, global maximum time, normalised area, intensity ratio and fine structure. The output value determines the class value, which is separated in five pre-defined type classes: electrical/thermal disturbance signal, burst signal, flow induced noise, calibration signal and background. The classification module has been tested with acoustic signatures of different German NPPs and is trained ready to use. Test results and practical experience show a more than 90 % correct classification rate. Fig. 10 shows the user dialogue for multiple burst type classification.



Ereignis	Tlm	Tam	Fläche	Intens.	Feinst.	Ki	Klassifikation
001206	0.90	0.90	0.36	7.75	0.63	2.7	Burstsignal
001207	1.23	1.23	0.42	52.44	0.90	2.7	Burstsignal
001208	1.21	1.21	0.44	55.54	0.95	2.7	Burstsignal
001209	1.38	1.38	0.41	67.70	0.95	2.7	Burstsignal

Ereignis: 001208 Kanal: 7 DE1 oben

Klassifikation: 2.7 Burstsignal (2.2 - 3.9)

Fig. 10: User dialogue for multiple burst type classification

4. Experience with Acoustic Status Evaluation of Primary System Components

Interpreted case studies and well known reference patterns are the basis for the evaluation of extraordinary acoustic signatures. With a large number of occurrences ISTec/GRS has been involved for analysis and for clarification of the problem by means of acoustic analysis. The advantage of its use has become obvious in numerous cases. Their spectrum reaches from

- status assessment of the primary system and its components over
- support and optimisation of repair measures with reduction of radiation dosage to personnel up to
- flanking and accompanying measures for worst case considerations for plant operation.

The common idea of safety assessment of reactor primary system by acoustic analysis is to use acoustic signatures for an integral component status assessment. Surveillance task is always a prevention of failures or a specific precaution against damage.

Emphasis of current activities on acoustic monitoring of the primary system of BWR's and PWR's is put on the enhancement of the knowledge base for the interpretation of acoustic signatures.

A 10-channel burst signal pattern of a BWR reactor vessel, which was automatically registered and stored from LPMS after having exceeded the alert level as one of three burst occurrences, is shown in the middle part of fig. 11. The signals are displayed with overall 5-g-scaling of a NNCT display of KAP 90 data. Preceding signal parts are observed at the sensors in the area of steam line sensors M1 to M3, the rise flanks are comparably flat.

With the use of the newly developed classification module of ISTec, which is also applicable to KAP 90 data, acoustic signatures can be classified with the help of a knowledge base and can be evaluated with respect to their signal type. In the upper right part of fig. 11 the calculated burst parameters of the signal M 3, which was the trigger signal, are shown. The determined signal values are 2.59 msec for the 'local' and 'global' maximum time, 0.33 for the 'normalised area', 4.76 for the 'intensity ratio' and 0.41 for 'fine structure'. The classification value of the burst signal, determined by a trained neural net, results in 3.7. This value lies within the class of 2.2 - 3.9, which characterises real burst occurrences.

For determination of the associated cause, trend analyses of operational data, which have been measured by a turbine monitoring system, have been applied. In the lower part of fig. 11 the trend of operational data plant power (output and reactive), steam temperature and steam pressure are shown in the period of 10:00-20:00 hours of the measurement day, the time of the three burst occurrences are marked with arrows. In this period the plant power has been reduced for a test of the turbine control valve. Additional detailed analyses showed that the time of the occurrences of the burst events were well correlated with tests of individual turbine check valves. As the determined origin fits well to the signal forms and rise times of the burst signals this position is confirmed. The events can be characterised as operationally induced and externally coupled from the region of turbine control valves. Acoustic monitoring of the reactor vessel gave no indication for impacts of detached or loosened parts.

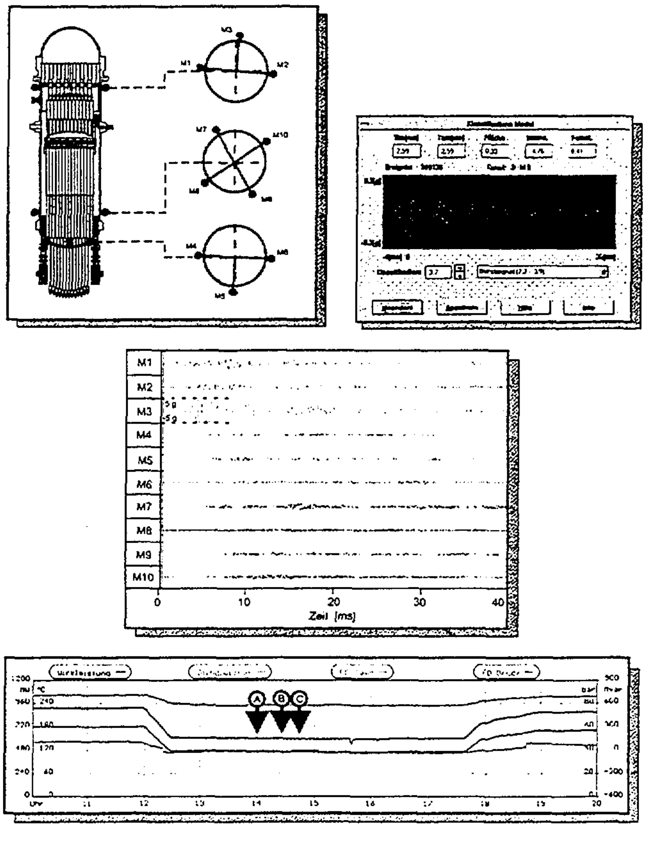


Fig. 11: Operationally induced burst signals in the sequence of a test of turbine control valve.

The experience with signal indications, if they can be supported by additional plant process parameters like pump speed, flow and pressure, which are available in addition to the burst data in the digital LPMS KAP90, is also positive. The NNCT module of ISTec provides a trend display of burst signals together with selected process signals of KAP90 data. Fig. 12 shows for one fuel element cycle a trend display of bursts together with the speed of the internal axial pumps of a 900 MWe BWR. In the lower part of fig. 12 the burst amplitudes are displayed as a function of time, the occurrence of a burst event is marked by a circle. In the upper part of fig. 12 the corresponding variable pump speed is shown. Fig. 12 confirms that there is an appreciable accumulation of operationally induced burst occurrences during transient phases of plant operation.

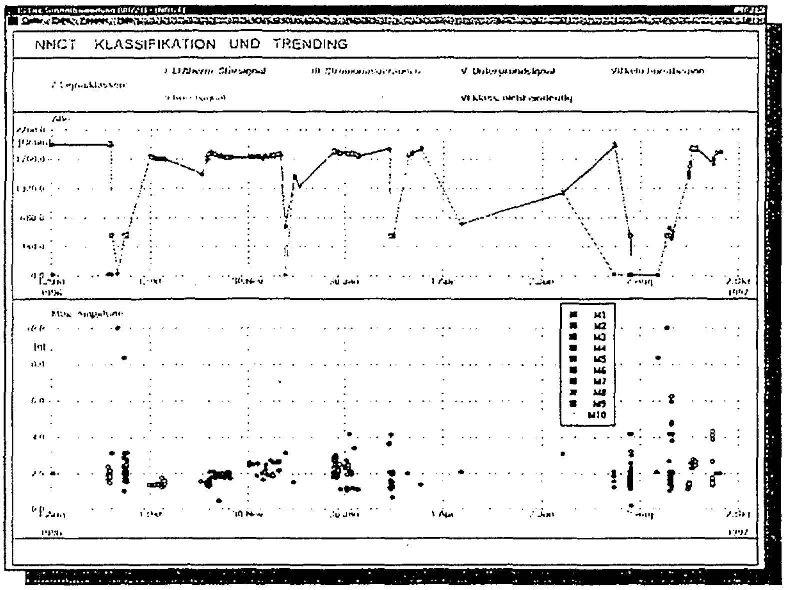


Fig. 12: Trending of digital KAP 90 data together with speed of internal axial pumps

In a PWR plant with a digital LPMS KÜS'95 256 stored signals have been analysed, which have been registered within the frame of a month. The alert indications of four sensors of reactor vessel have been analysed with NNCT module of ISTec, different signal types could be identified by the classification module of ISTec. In the lower part of fig. 13 the amplitude trend of the alert indications is shown. The upper part of fig. 13 presents the data of burst classification. It results in 122 occurrences of impacts, 4 fluid type signals and 7 electrical/thermal disturbance signals. The comparison of this trend with trends of formerly measured and analysed burst signals showed that these bursts coincide with uncritical bursts, which are already known from former fuel cycles and which occur after plant transients or after start-up phase for a limited time of about two weeks. This result has been assessed by the fact, that the transients in the burst frequency occurrence are timely correlated with operational transients of the plant.

5. Conclusions

Successful applications of acoustic status evaluation of primary system components have been described. More than the mere detection of loose parts, acoustic signal analysis has high potential for safety assessment of the primary system and its components with respect to their mechanical integrity. The high cost of unplanned shut-down of the plant can be reduced and the safety of nuclear power stations can be improved by applying such methods. Basic requirement for a reliable diagnosis is the availability of a knowledge basis for the interpretation and evaluation of acoustic signatures. Ongoing work is dedicated to further enhancement of diagnosis tools so that more automated fault diagnosis systems will be available in the near future.

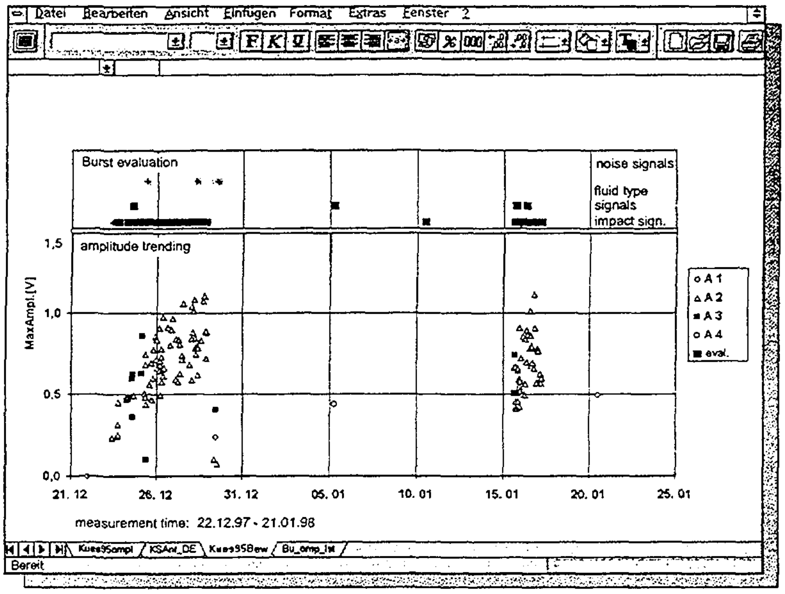


Fig. 13: Use of classification module for evaluation of acoustic events

6. References

[1] B. J. Olma, "Acoustic Monitoring of U-tube Steam Generators", proceedings of SMORN VI Symposium, Gatlinburg, USA,19.-24.5.1991, Vol. 2, pp. 74.01 - 74.13

[2] B. J. Olma, Y. Ding, R. Enders, "Operational Experiences with Automated Acoustic Burst Classification by Neural Networks", proceedings of the 7th Symposium On Nuclear Reactor Surveillance And Diagnostics (SMORN VII), Avignon, France, June 1995

[3] B. J. Olma, "Potential of Acoustic Monitoring for Safety Assessment of Primary System", IAEA Technical Committee Meeting on "Nuclear Power Plant Diagnostics - Safety Aspects and Licensing", Portorosz, Slovenia, June 23-26, 1997

[4] RSK-Guidelines for Pressurised Water Reactors, 3.Edition, October 1981

[5] B. Bechtold, W. Knoblach, U. Kunze, "The New Loose Part Monitoring System KÜS 95", proceedings of the 7th Symposium On Nuclear Reactor Surveillance And Diagnostics (SMORN VII), Avignon, France, June 1995

[6] L.Cleemann, F. Elfinger, "Loose Parts Monitoring System", proceedings of the 7th Symposium On Nuclear Reactor Surveillance And Diagnostics (SMORN VII), Avignon, France, June 1995

[7] B. J. Olma, "Audio replay of acoustic burst signals for digital loose parts monitoring systems", Kerntechnik, November 1995, Vol. 60/5-6

[8] European Patent 0 740 153

[9] B. Olma, D. Wach, "On-line classification of acoustic burst signals by a neural network - application to loose parts monitoring in nuclear power plants", 3rd IEEE Conference on Control Applications, August 24-26, 1994, Glasgow, Scotland

[10] Y. Ding, D. Wach "A fuzzy diagnosis system for automatic classification of acoustic burst events in nuclear power plants", Pre-prints of the IFAC Symposium on Fault Detection, Supervision and Safety for Technical Processes - Safeprocess '97, August 26-28, 1997, Kingston Upon Hull, United Kingdom

NEXT PAGE(S)
left BLANK