ACOUSTIC EMISSION LEAK MONITORING SYSTEM LMS-96

Jiří Liška, Martin Cvrček - ŠKODA NUCLEAR MACHINERY Ltd., Plzeň
Luděk Müller - University of West Bohemia, Plzeň
Czech Republic

Abstract

On-line acoustic emission leak monitoring under industrial conditions of nuclear power plant is a problem with specific features setting specific demands to the leak monitoring system. The paper briefly reviews those problems (attenuation pattern of a real structure, acoustic background, alarm system etc.) and solution of some of them is discussed. An information about Acoustic Emission Leak Monitoring System LMS-96 developed by Škoda Nuclear Machinery is given. System function is shortly described.

Introduction

A number of industrial applications of acoustic emission method for leak detection is growing up. Industrial application, especially on nuclear power plant, brings some specific problems to be solved. Škoda Nuclear Machinery has been working in this field since 1989. The multichannel leak monitoring system type LMS-96 has been developed. The main diagnostic parameter used for leak monitoring is RMS value of AE signal. Some problems solved during development are discussed below.

Requirements for Industrial Leak Monitoring System

Required features for industrial acoustic leak monitoring system can be summarized in following points:

- High reliability
- Adaptability to the real structure geometry
- Adaptability to the changes of acoustical background
- Reasonable extent of automation
- Self diagnostic function including automatic testing of measuring lines
- False alarm reducing leak alarm system
- Transparent form of output information

Discussion of Some Problems and their Solution

Reliability of measuring lines

It is well known that the reliability of the system is strongly dependent on the reliability of measuring lines. Main difficulties:

- Long term stability of sensor-to-structure acoustical coupling
- Severe environment (temperature, humidity, radiation)

LMS-96 solution: Integral waveguide/sensor design and welding of waveguides to the surface of the structure.

System adaptation to the conditions of a real structure

For acceptable accuracy of leak localization certain mathematical model must be employed. Generally used model can be expressed as

$$U(d) = A - B\,d$$

where **U** is RMS value of AE sensor signal in dB, **d** is AE source-to-sensor distance, **A** is AE source intensity in dB and **B** is attenuation coefficient in dB/m.

However, there are usually various circumstances causing the values measured on a real structure sometimes do not correspond sufficiently with that model, namely:

- Deviations of transfer characteristics of measuring lines
- Different attenuation along the structure
- Reflections of acoustical waves
- Superposition of various modes of acoustical waves

In such a case certain system adaptation should be carried out to improve localization accuracy.

The method has to be chosen considering individual structure. An adaptation procedure which can be applied to an „almost homogeneous" linear structure (e.g. piping) with obstacles (e.g. valves) is explained below.

Considering a system disposing with dual function measuring lines (sensor/exciter) we can obtain through step-by-step excitation the „response matrix" of the whole sensor net to excitation in each measuring point. Supposing linear dependence **U** vs. **d** an adaptation procedure calculating gain corrections in measuring lines is performed based on modification of matrix elements so that a correspondence with linear-law attenuation would be achieved.

Principle of the procedure:

- Making **U** vs. **d** graph using all elements of response matrix
- Fitting regression line to points of the graph, estimate of **B**
- Calculation of differences between measured and theoretical values
- Calculation of average differences for individual measuring channels (both sensor and exciter function taken into account) representing corrections of gain in individual channels
- Application of corrections both to the rows and columns of response matrix
- Repetition of the procedure keeping the same **B** value

Note: The response matrix has to be in some cases masked, e.g. in case of matrix elements „contamination" by signal reflections or if sensor-to-exciter distance is too great, etc.

Final gain correction is the sum of corrections in individual steps.

An effect of using the method is demonstrated by the result of experiment on a pipe of length cca 5 m with 4 transducers installed. AE signal was simulated by gas jet. The results are summarized in the table below:

Excitation point No.	Actual coordinate x [cm]	Case 1		Case 2		Case 3	
		x_1 [cm]	Error [cm]	x_2 [cm]	Error [cm]	x_3 [cm]	Error [cm]
1	47	0	- 47	2	- 45	24	- 23
2	93	2	- 91	10	- 83	27	- 66
3	187	61	- 126	73	- 114	123	- 64
4	233	3	- 230	24	- 209	240	7
5	327	363	36	343	16	356	29
6	373	423	50	423	50	423	50

The table includes a comparison of three cases of evaluation differing by:

- Calculation of B (from elements of unmasked and/or masked response matrix)
- Corrections (used and/or not used)

Case 1: Unmasked matrix, corrections not used

Case 2: Masked matrix, corrections not used

Case 3: Masked matrix, corrections used

The best locality estimate in Case 3 is obvious.

In case of existence of obstacles (e.g. valve on the piping) the procedure can be applied too. In the first step, in addition to B estimate, signal drop on obstacles must be estimated and U vs. d graph must be linearized.

For more complicated geometry (e.g. reactor vessel cover) more sophisticated methods must be used, e.g. neural network method.

Testing of measuring lines

A comprehensive multichannel system should be equipped with an automatic calibration and testing module. The reason is reaching maximal objectivity, reproducibility and elimination of errors.

If there are dual mode lines at disposal, the response matrix described above can be determined any time during operation and compared with reference matrix. By its evaluation the fault line can be found out.

Acoustical background, alarm generation

Acoustical background existing on any real structure can not be considered as constant. The reason of its change are various operational activities (e.g. opening and closing valves), change of operational parameters during non-stationary conditions etc. The system should be able to work under such conditions.

LMS-96 disposes with a library of various acoustical background reference patterns corresponding with identified operational activities. This library can be added during normal operation according to operator's decision. When signal level in any channel exceeds adjusted threshold (Alert signal) the situation is evaluated as:

- Change of a acoustical background
- Leak occurrence

Standard procedure after Alert generation:

- Measurement of representative sample of signal pattern
- Looking for corresponding background pattern in the library

  Found ⇒ applied, Alert off

  Not found ⇒ Leak Alarm

Leak Monitoring System LMS-96

Purpose and application

Monitoring of leak of gas or liquid media through the pressure envelope of pressure retaining devices, e.g.

- Monitoring of leaks on the primary and/or secondary circuit of nuclear power plant
- Monitoring of leaks of steam on the boiler of conventional power plant
- Monitoring of leaks on steam lines
- Monitoring of through-valve leaks etc.

System structure

- Measuring lines (piezoelectric sensors, preamplifiers)
- Local Measuring Units (industrial PC based)

  Function: Signal digitization, RMS calculation, testing of measuring lines
- Data Processing Unit (PC - Pentium)

Basic technical data

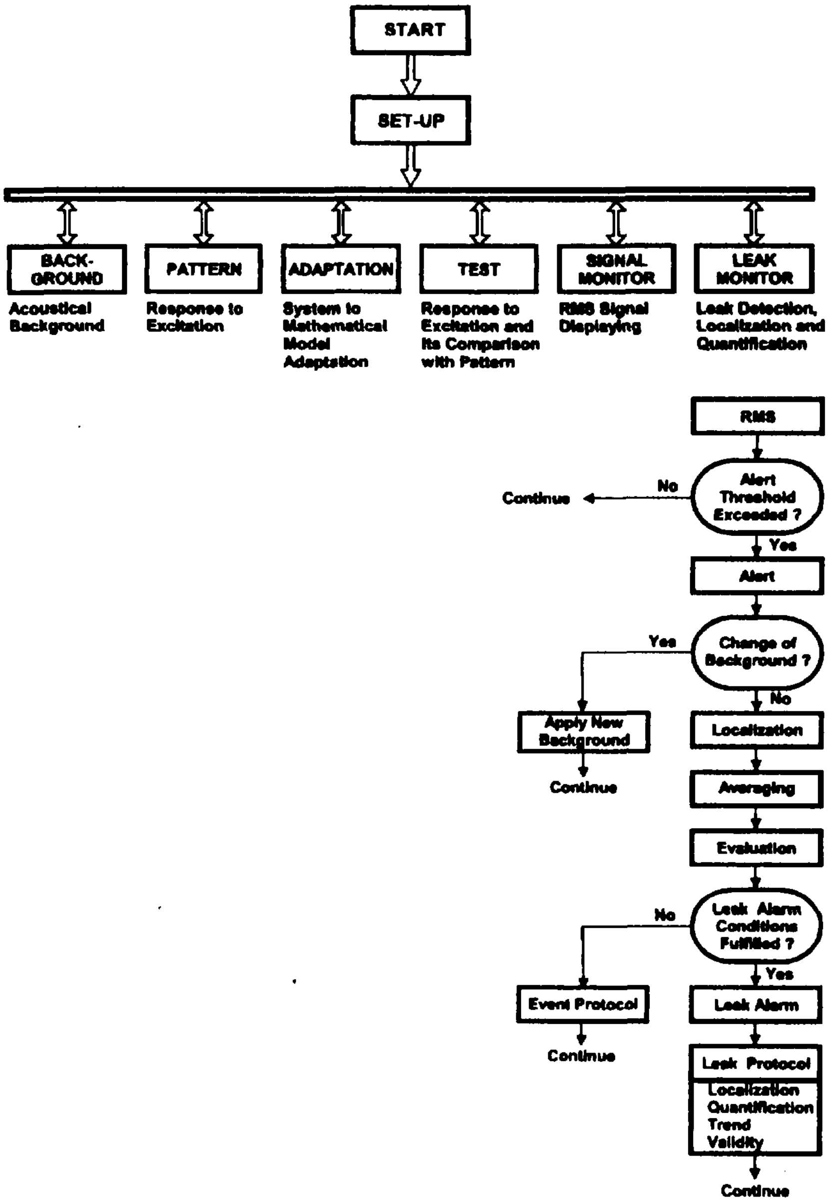
- Sensor: piezoelectric (integral design with waveguide), resonance frequency ca 230 kHz
- Number of input channels of Local Measuring Unit: 16
- Maximum number of input channels of the whole system: 128 (8 Local Units)
- Channel sensitivity: 5 μV
- Dynamic range: 66 dB
- Leak detection threshold (operational conditions): 0.1 - 0.5 l/min
- Localization error: max. ± 50% of sensor distance
- Communication of Measuring Unit with Data Processing Unit through Ethernet bus
- Software:
  Local Measuring Unit (operation system: DOS, programming language: C)
  Data Processing Unit (operation system: Windows NT, programming language: Visual C++)

Benefits

- Sensors for severe environment inside containment of nuclear power plant
- Long term stability of acoustical coupling
- Dual function of measuring lines (sensor/exciter)
- Digital signal processing
- PC based Local Measuring Unit - simple and flexible structure
- Automation of testing of measuring lines
- Up-to-date software environment (Windows NT)

System function

Simplified functional diagram see below:



Form of output information

(illustrated by output protocols issued during an experiment on the pipe with crack)

PATTERN & TEST

Pat M.lck

PATTERN

(Start time: Monday, December 09, 1996 13:04:43
End time: Monday, December 09, 1996 13:06:31)

Group 0, U0 = 70.55[dB], B = 2.252[dB/m]

Pattern		S			
		0	1	2	3
E	0		65.8	62.8	64.0
	1	67.6		66.9	64.3
	2	64.5	68.5		66.7
	3	63.8	62.9	65.3	

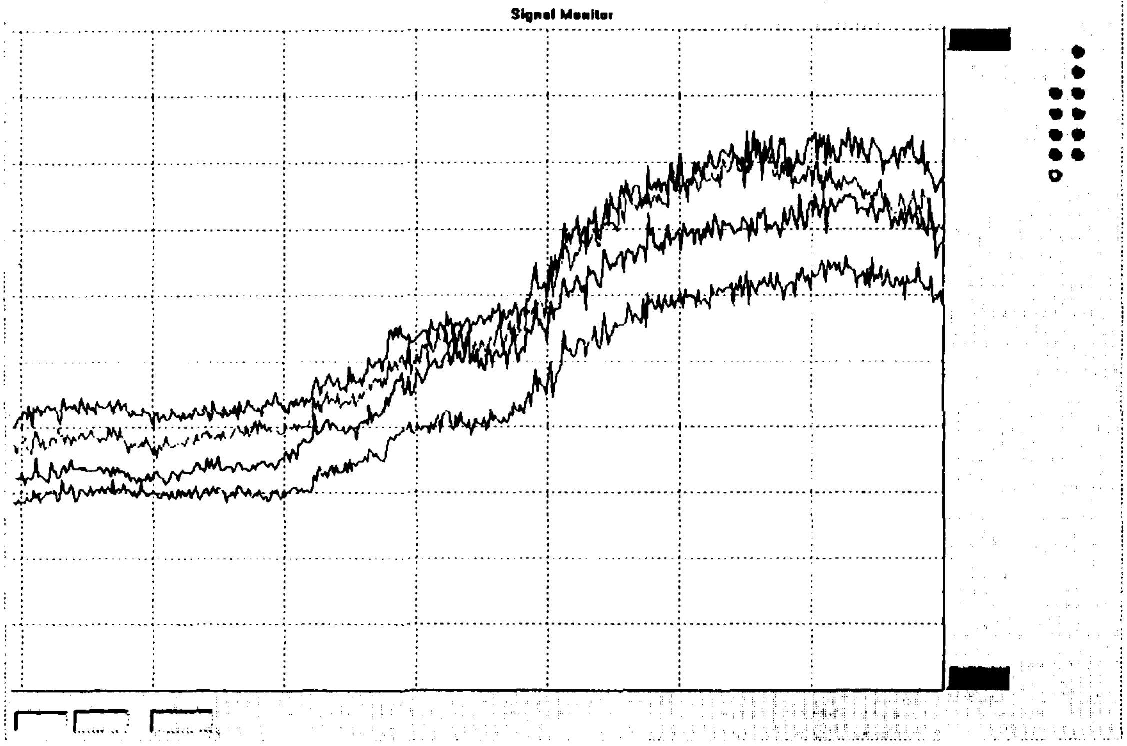
Group 0, U0 = 68.336[dB], B = 2.11834[dB/m]

Test		S			
		0	1	2	3
E	0		62.3	62.3	60.5
	1	64.2		67.5	63.1
	2	64.5	68.6		67.2
	3	61.2	62.8	66.3	

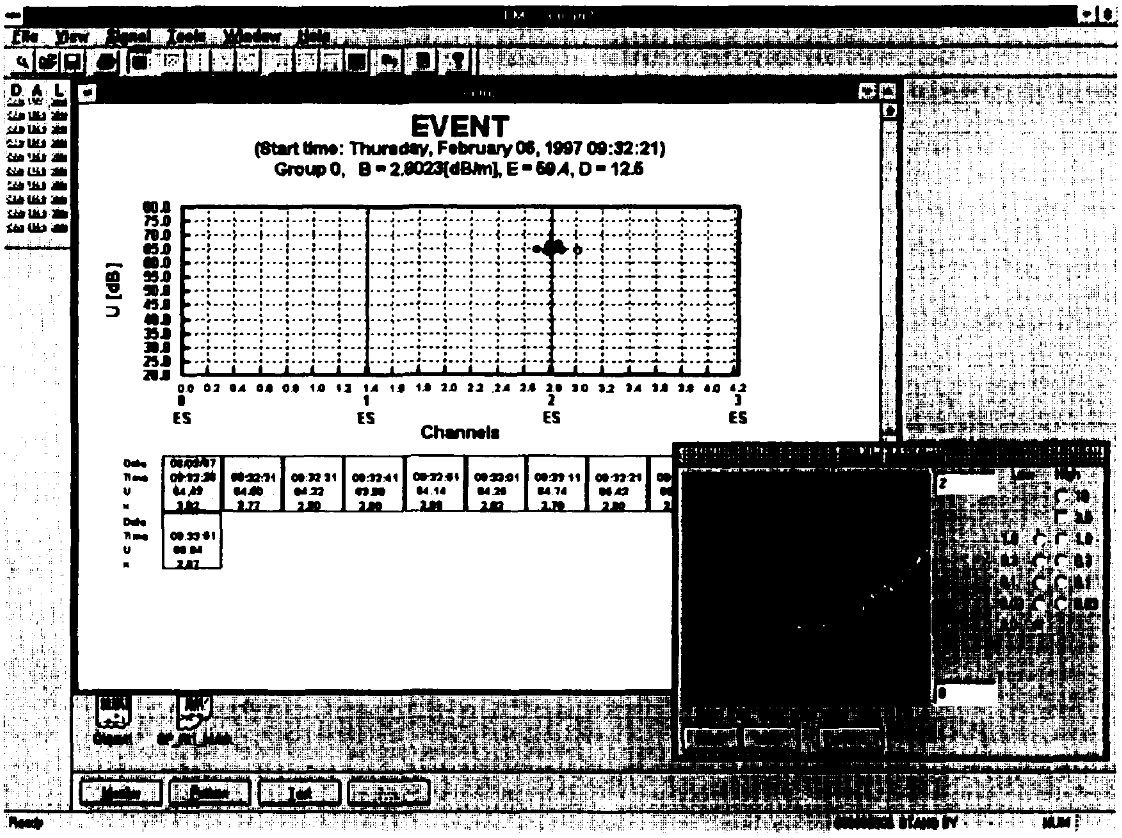
Pattern		S			
		0	1	2	3
E	0		60.9	60.8	59.5
	1	62.5		67.8	62.4
	2	62.5	69.0		66.6
	3	60.2	61.8	66.3	

Difference		S			
		0	1	2	3
E	0	[illegible]	1.4	1.6	1.0
	1	1.7	[illegible]	-0.3	0.8
	2	2.0	-0.4	[illegible]	0.6
	3	0.9	0.9	-0.0	[illegible]

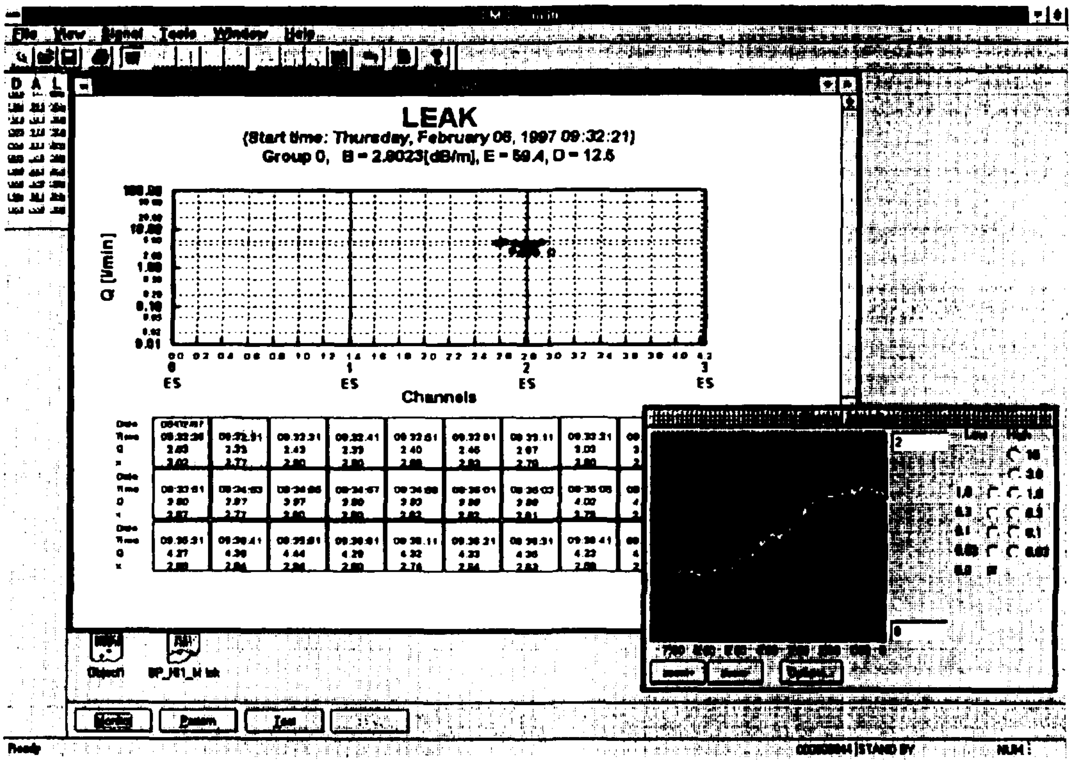
SIGNAL MONITOR



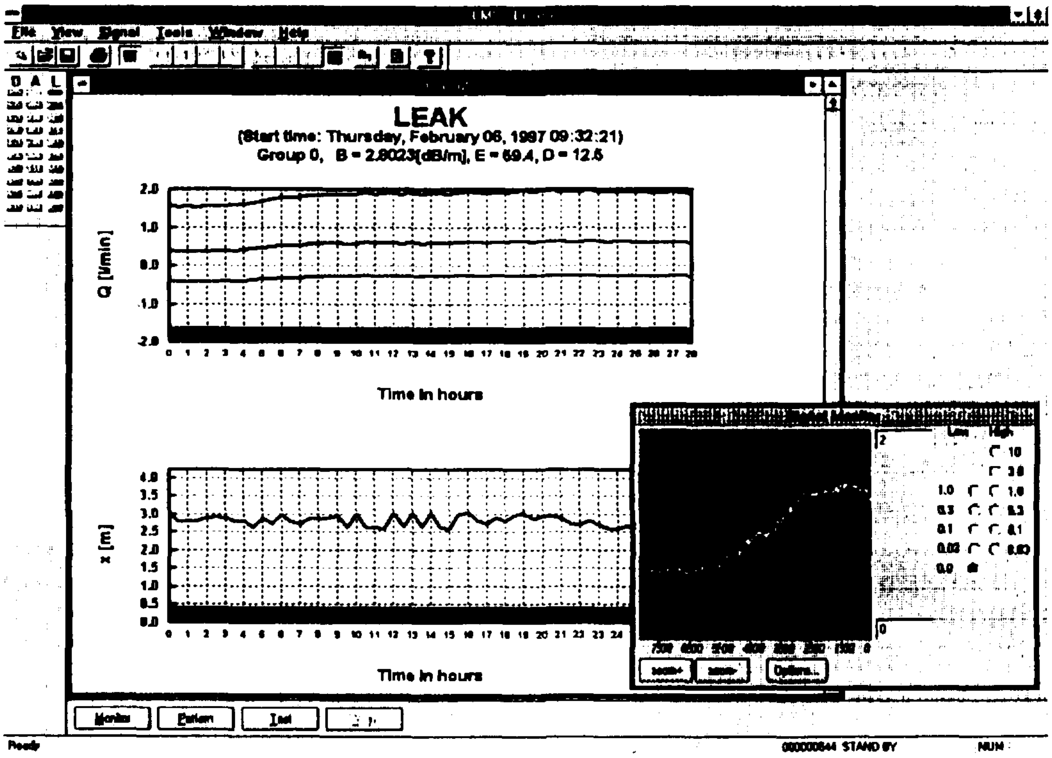
EVENT PROTOCOL



LEAK PROTOCOL - LEVEL 1



LEAK PROTOCOL - LEVEL 2



LOG PROTOCOL

28-10-96 13:39:42				LastDropW: 0	
28-10-96 13:41:18					Monitoring ON
28-10-96 13:42:34		Group 0		To Diot.	pozadi
28-10-96 13:42:34		Group 0		App Bokg.	
28-10-96 13:42:34	RESET	Group 0	E/L OFF 0		
29-10-96 13:46:40	Alert ON	Group 0	New Alert 0 ON		
29-10-96 13:46:41		Group 0	New E/L Protocol 1		
29-10-96 13:48:19	Leak ON	Group 0	New Leak 1		
29-10-96 13:53:01		Group 0		To Diot.	unik
29-10-96 13:53:01		Group 0		App Bckg.	
29-10-96 13:53:01	RESET	Group 0	E/L OFF 1		
29-10-96 13:55:02	Drop ON	Group 0			
29-10-96 13:56:42	Drop ON	Group 0			
29-10-96 13:58:23		Group 0		To Diot.	41
29-10-96 13:58:23		Group 0		App Bokg.	
29-10-96 13:58:23	Init Drop	Group 0			
29-10-96 14:00:05	Alert ON	Group 0	New Alert 1 ON		
29-10-96 14:00:06		Group 0	New E/L Protocol 2		
29-10-96 14:02:15		Group 0		App Bokg.	
29-10-96 14:02:15	RESET	Group 0	E/L OFF 2		
29-10-96 14:03:26	Drop ON	Group 0			
29-10-96 14:05:25		Group 0		App Bokg.	
29-10-96 14:05:25	Init Drop	Group 0			
29-10-96 14:06:46	Alert ON	Group 0	New Alert 2 ON		
29-10-96 14:06:46		Group 0	New E/L Protocol 3		
29-10-96 14:08:26	Leak ON	Group 0	New Leak 3		
29-10-96 14:13:33					Monitoring OFF

Conclusions

LMS-96 was designed with the aim to give an operator reliable, concentrated and transparent information for easy and objective decision in case of leak occurrence. Leak detection is a problem which is in direct connection with an application of LBB philosophy for selected components of nuclear power plant and acoustical leak monitoring system is always taken into account as one of the three independent leak detection systems needed for LBB application. At the end of 1996 LMS-96 was subject to qualification tests within the Phare program „Leak Detection System Qualification Program" - contractor: ENAC (Framatome, Ansaldo, Empresarios Agrupados), sub-contractor: Nuclear Research Institute Řež. In 1997 a reference installation in nuclear power plant should be realized. LMS-96 is ready for industrial installation and is already commercially offered.

Supplementary information

Besides LMS-96 ŠKODA NUCLEAR MACHINERY offers the system ACMS (Acoustic Crack Monitoring System) for monitoring of crack rise and growth in the material of the structure. Such system is now being delivered to Nuclear Power Plant Temelin.