Diagnosis systems developed in NPPRI (VUJE) Trnava Inc. for NNP’s.

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Abstract
Since foundation of Nuclear Power Plant Research Institute (NPPRI) in 1977, the department of diagnostics has been dealt with problems related to the theoretical, practical and organisatory questions of operational diagnostics connected with PWR type nuclear components. This department acts directly in locality of NPP Jaslovské Bohunice, but there are performances for all NPP in Slovak or Czech Republic (Dukovany, Mochnove, and Temelin). Besides direct services and achievements for NPP there exist advisory, experts and research activities for the government and supervising authorities, too.

In 1985, NPPRI began systematically construct and verify technical means for operational diagnostics of main circulating pumps (MCP) with good results, based on own rich practical experiences and contacts with organisations abroad. In recent years NPPRI as one of recognised qualified and authorised institutions in Slovak Republic has begun to develop a new generation of diagnostic systems for NPP on high technical level but with lower procuring costs in comparison with western countries products.

This contribution deals with four following types of diagnostic systems which were not only developed but also delivered and installed on Slovak and Czech nuclear units:

- Loose part monitoring system (LPMS)
- Humidity monitoring system (HUMON)
- Reactor coolant pumps monitoring system (RCPMS)
- Primary circuit vibration monitoring system (VMS)

Main features of new generation from middle of 1990’s of these systems are described in this paper and operational experiences with them too.

1. INTRODUCTION

The operational diagnostics in the primary circuit of nuclear power plant is very important for the issues of nuclear safety and technical reliability. NPPRI (VUJE) Trnava, Inc. produces and installs various technical means including the stationary diagnostic systems which are operating in all NPPs in Czech and Slovak Republic (Jaslovské Bohunice, Dukovany and – in preparation – Mochnove and Temelin). Technical diagnostics in our institute has its own history of more than 20 years now and we have started with installations of our own diagnostic systems about 10 years ago. Our production includes the loose part monitoring system, main circulating pump monitoring system, system for the monitoring of vibrations of primary loops and humidity monitoring system.

The first generation of these systems developed at the end of 1980’s was based on then first personal computers together with simple (i.e., „one user and one task“) operating systems like DOS. We have developed the charge preamplifiers and special electronics for the signal...
conditioning and processing and have used the commercially available sensors like accelerometers, displacement sensors, humidity probes, etc. Putting it together into one diagnostic system meant to develop the controlling software on the "low end" (i.e., programmes for digital signal processors, digital antialiasing, highpass and lowpass filters, programmes for data transmission, etc.), and the user software for data manipulation and evaluation.

After installation of first diagnostic systems we have gained precious experience and obtained a lot of feedback information from diagnostic personnel in the NPPs. This process led at first to the hardware and software improvements of already installed systems. Eventually, it was clear to us that a new version of diagnostic systems would be necessary which includes all the improvements of the old version and is based on a new philosophy of data acquisition, processing and evaluation.

In this paper the new version of diagnostic systems are illustrated which are produced in NPPRI (VUJE) Trnava, Inc. from the middle of 1990's. Each system is described in detail and then the common hardware and software features of both systems are described. The existence of common features regardless to the physical background, individual for each system, means the modularity and versatility of technical solution as well as the shorter production intervals.

2. LOOSE PART MONITORING SYSTEM (LPMS)

Impact of loose parts on the walls of nuclear power equipment of reactor coolant systems in nuclear power plants provides a serious hazard of damaging this equipment. Therefore a need arises to monitor continuously natural collection locations in reactor coolant systems for occurrence of loose parts. LPMS is designed for continual loose parts monitoring.

System for diagnostics of loose parts in reactor coolant system power plant, built on modern technical hardware of "high tech" type, is one of the result of research and development activities in NPPRI. Purpose of system implementation is:
• identification of loose parts (system is capable to detect a loose part with kinetic energy of 0.1J at distance 1m from nearest sensor)
• loose part localisation
• mass estimation

2.1 Hardware and software

The system is built on modular structure of hardware and software. Possible configurations include 32 measuring channels as a maximum and the implemented multi-task operating system enables simultaneous processing of a number tasks which assures continuous monitoring function of system. System consists of:
• measuring chains (accelerometers with freq. range from 1kHz to (10-25)kHz)
• force transducers
• impulse hammers with specified and programmable settings of impulse energy
• module of digital signal processors
  • max. 32 parallel channels
  • isolation amplifiers (ampl. factor 1-100)
  • A/D converters (16bits resolution, sampling freq. max 100kHz)
  • antialiasing filters
  • digital lowpass and highpass filtering (programmable, 96dB/oct)
  • environment temperature of primary electronic up to 65°C (up to 105°C)
• evaluation and storage part (based on PC)
• modules for control of non-standard equipment (impulse hammers, generator of calibrated signal, autodiagnostics of measuring circuits)
• audio module for visual display and acoustic monitoring of measuring signals
• 2 channel oscilloscope

2.2 Working regime
• initialisation and setting of system
• calibration of system during operation
• continual monitoring
• detailed analysis of impulse events
• print-out of alarm protocols following the detection of impulse event

3. HUMIDITY MONITORING SYSTÉM (HUMON)

The HUidity MONitoring system is designated to monitor continuously the humidity in the confinement (hermetical compartments) of nuclear power plants. Purpose of system implementation is to fulfil the LBB criterion (Leak Before Break). For NPP BOHUNICE 3 and 4 it means to detect leak 4l/min in 1 hour.

3.1 Hardware and software

System consists of the following main parts:
• measurement and control part of the system
  • sensors
  • analogous-digital transmitter with 32 inputs,
  • processor for data pre-processing
  • pneumatic suction module
  • set of tubes is used
  • pneumatic valves
  • source of dry air
• central evaluation module based on PC
• software.

In the realisation for V-2 Bohunice, the measurement and control part of the system is situated in the conditionally accessible part of the confinement (reactor coolant pump platform). The pneumatic part of the system with a suck-off module, the set of fans and the generator of air with the defined humidity are situated there as well. The air is sucked from the selected parts of the confinement by means of a suction module and tubes and its humidity is then measured by means of sensors of absolute humidity situated in the measurement chambers.

3.2 Working regime and preparatory works
• anemometric air flow measurement in the steam generator (SG) compartment,
• calibration of the sensors of absolute humidity,
• determination of the dependence of the flow rate in the particular sampling lines on the negative pressure generated by the suction-off module,
• verification of the system sensitivity by simulating a leak in selected points of the SG compartment
• continual monitoring based on comparison with reference values
• detailed analysis and special testing such as signal analysis procedures, trend evaluation,
archived results management, statistic computation etc. are possible to perform under operator control
- print-out of alarm protocols following the detection of impulse event

4. REACTOR COOLANT PUMPS MONITORING SYSTEM (RCPMS)

Large emphasis has been given to the diagnostics of rotational machines on basis of measuring vibrations and ultrasonic emission with orientation mainly on reactor coolant pumps. This system, built on the same modern technical hardware of „high tech“ type as LPMS hardware, is one of the result of research and development activities in NPPRI.

System is designed for permanent monitoring of the status of all RCPs on the basis of measurement of mechanical vibrations in both acoustic and ultrasonic frequency ranges, as well as for the performance of measurements in interactive mode. Classification of the monitored object, based on comparison of actual parameters with limiting values of specified reference states, provides a part of diagnostic tests carried out automatically.

System is of a modular structure of both hardware and software so that it can be used also for the monitoring of mechanical status of other large rotating machines.

4.1 Hardware and software

The system is built on modular structure of hardware and software. Possible configurations include 84 measuring channels as a maximum and the implemented multi-task operating system enables simultaneous processing of a number tasks which assures continuous monitoring function of system. System consists of:
- measuring chains
  - accelerometers
  - ultrasonic sensors
  - optional sensors for shaft vibrations and tachometers
- module of digital signal processors
  - max. 84 channels (36 direct and others multiplexed 12x4)
  - isolation amplifiers (ampl. factor 1-100)
  - A/D converters (16bits resolution, sampling freq. max 100kHz)
  - antialiasing filters
  - digital lowpass and highpass filtering (programmable, 96dB/oct)
- evaluation and storage part (based on PC)
- modules for control of non-standard equipment (generator of calibrated signal, autodiagnostics of measuring circuits)
- audio module for visual display and acoustics monitoring of measuring signals
- 2 channel oscilloscope

4.2 Working regime and software modules

- service with special software
- configuration of system (including generation of limiting values)
- continual monitoring based on comparison with reference measurements in defined periods
- detailed analysis and special testing such as signal analysis procedures, trend evaluation, archived results management, statistic computation etc. are possible to perform under operator control
- print-out of protocols
Fig. 1 LPMS - proposal of sensor location on reactor vessel.

Fig. 2 Burst from loose part in time domain.
Fig. 3 HUMON - proposal of sensor location

Fig. 4 HUMON - structure of software modules.
5. PRIMARY CIRCUIT VIBRATION MONITORING SYSTEM (VMS)

System is designed for periodic or repetitive realisation of diagnostic vibration tests, mainly in low-frequency range (up to 100Hz). Measured or monitored objects are components of PWR coolant loops. Subject of attention is their vibration behaviour and their own modal properties. Main task is to detect and prevent an extensive dynamic load with high cyclic fatigue and changes or failures in placing of main loop components. System is capable to cooperate with the diagnostic system for reactor diagnostics and noise analysis. The system is based on:

- hardware of high-tech type
- performed theoretical calculations
- experimental works
- long term experience with vibration diagnostics

5.1 Measuring chains.

- relative vibrations
- absolute vibrations (accelerometers)
- pressure fluctuations of coolant
- neutron noise
- outputs from other diagnostic or measuring system channels

5.2 Hardware and software

Hardware and software is based on RCPMS with some special modules for the vibration monitoring of coolant loops and whole primary circuit:

- computation of FFT and cross-spectra simultaneously with sampling
- module for the extraction of operation shapes of vibration
- module for the animation of vibration modes
- multichannel spectral analysis

5.3 Working regime

- realisation of detailed diagnostic tests under operator control several times during campaign is supposed
- data collection for experimental modal analysis or operation shapes
- automatic data collection for steady-state and for transient regimes in NPP

6. COMMON FEATURES OF SYSTEMS PRODUCED BY VUJE TRNAVA INC.

**Delivery of diagnostic systems includes:**

- delivery of complete technical documentation
- preparation of projects for installation
- preparation of programmes for pre-operational tests
- personal support of pre-operational testing
- training of personnel
- technical and scientific support after warranty period

**Hardware features:**

- Permanent possibility for calibration of measurement chains
- Internal source of dry air (HUIMON)
- Internal generator of calibrated signal (LPMS, RCPMS, VMS)
- Special tools (impulse hammer for LPMS)
Signal pre-processing unit
• 16 data bit A/D converters
• digital anti-aliasing filters with 96dB/oct
• parallel processing of 32 input channels on max. sampling frequency 100kHz
• programmable input gains in the range from 1 to 100

Special processor for real-time processing:
• max. 32 input channels sampled in parallel
• real-time Fourier analysis with programmable data windows and full spectrum matrix
• thresholding of input signals on RMS value
• up to 64 multiplexed channels

Software features:
• data evaluation on industrial PC
• multitasking operating system (OS/2, WIN NT)
• graphical windows-oriented user interface
• SQL-type database (GUPTA, SYBASE)
• standard network support
• software protection
• off-line analysis of archived data during the measurement

Qualification of diagnostic systems
• Seismic qualification
• Electromagnetic compatibility
• Environmental withstanding

6.1 SYSTEMS INSTALLED OR UNDER PREPARATION

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(*) under preparation
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7. PRACTICAL EXPERIENCES

Feedback information and experience with our first diagnostic systems showed some important results:

System of users.
It is very important to divide users into at least three groups. This division is made through access rights for the operation or modification of user software. Plus our systems are blocked against the non-authorised action by means of the hardware key. This feature divided users into basic groups:

Operator - basic level for diagnostic personnel in NPP. This level is dedicated for basic tasks - printing, collection and sorting information. No important changes are allowed for this basic level.

System operator - advanced level, which enables to control system (start and stop measurement, sensor calibration, setting display and print parameters...)

Administrator - level for advanced personnel in NPP. This level enables the design and implementation of own screens and the extensive re-definition of parameters of monitoring system. This level enables to connect special software tools and watch internal software variables.

Alarms.
It is very important to reduce false alarms in systems. Too many false alarms have influence on trust in system. There are two alarm levels defined in our diagnostic and monitoring systems.

Warning level - is used to increase attention. Here is time for determination of phenomena, which have caused a problem. In many cases personnel is able to distinguish false alarm arising and prevent its occurrence.

Alarm level - is used for alarm indication of system.

Network connection
All systems now are ready to work in network environment. Today software version works with mechanism of "named pipes" from "peer-to-peer" service. This mechanism is supported in OS/2 WARP and Windows NT (Windows 95 partly) operating systems. In network environment some software must run on data acquisition computer and others everywhere on network (LAN).

Data acquisition computer - software modules responsible for data acquisition and data acquisition configuration, service and maintenance modules. Archive process with primary data.

Data display computer - software modules for data presentation, local archivation, printing, etc.

8. SUMMARY

Despite the various physical processes that are specific for each task in the NPP primary circuit, the new generation of diagnostic systems, produced in NPPRI (VUJE) Trnava, Inc., has some common features, which include:

• the orientation on the newest digital technology in data acquisition, conditioning and pre-processing by means of digital signal processors and sophisticated logical arrays;
• the principle of modularity both in hardware as well as in the software development;
• the orientation in software development on the multi-tasking environment (Windows NT, OS/2 operating systems) that is crucial in some applications (e.g., loose part monitoring)
where the measurement must be continuous regardless on the other operations performed by the operator;

- the network support which is the standard requirement nowadays.

We hope that this approach will enable us in the future to be very flexible in the design of new diagnostic tools and systems which will be needed in NPPs.