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Safety Aspects of Neutron noise diagnostics and Loose parts monitoring in WWER reactors

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Introduction

There are several methods making use of fluctuating processes and acoustic noises which have been developed during the part twenty years to serve diagnostics of malfunction of nuclear facilities or equipment of nuclear power plants. Some of those might be of academic interests but many of them are really useful for operation and maintenance purpose of nuclear power plant management. There are also quite a few methods which might have direct impact on the safety of nuclear power plant, but most of the other methods have also impact on safety if we consider safety in wide sense.

In this paper our aim is to give very short introduction on different types of well selected noise diagnostics methods and then mentioning their occurrence in WWER reactors we analyse what impact they might have to operational safety and for ageing (which also affects on safety of the installations).

We do not deny, that one of our main aim is to call the attention of management staff of NPP, which deals with safety, safety culture, maintenance and operation proving, that such methods and system can give not only benefit to economy but also impact on safety of nuclear installations.

Core barrel Motion Detection

Soviet built WWER reactors suffer very frequently from core barrel motion. Their is no question about the safety aspects of core barrel motion monitoring, since it is clear

[1] Earlier working at Atomic Energy Research Institute of CRIP on the same subject

that if the core barrel[2] is going to have a large pendular movement it may touch the reactor vessel, which is dangerous. One of the most prominent case reported until now was the core barrel motion registered in NORD NPP (Greiswald) in 1988. This occurrence has been largely analysed in details (see the following publications [1],[2]) The analysis of this event has not been ended yet. Researchers from ZFR have just published their finite analysis on the subject[3]. From detailed description it was clear a hold down spring was the cause of the problem This lead to a near pendular motion of the core barrel. Core barrel was swinging and touching the guide lug(s). One of the guide lug was worn to half during the fuel campaign. One of the role of these guide lugs is to prevent that core barrel would directly knock the wall of the reactor vessel. From the detailed description of the occurrence it becomes clear that noise diagnostics methods based on frequency analysis of neutron flux fluctuation measured by state excore neutron detector were able to notice, the register the beginning of the motion, then to analyse its measure and to follow it during the whole fuel campaign, proving that there are still some part of the guide lug which prevent the motion from the free motion, therefore it is still tolerable from the point of view of safety of the reactor vessel. This is an outstanding example of the usefulness and power of the noise diagnostics methodology.

The methodology which is used to detect and measure the pendular core barrel motion based on spectral analysis of the measurable neutron flux fluctuation. Usually the excore neutron detectors are used (see Fig.1.), which are part of the safety channels as well. But in addition some other sensors (like in-core neutron detectors or accelerometers positioned on the reactor vessel) are also involved [2],[4].

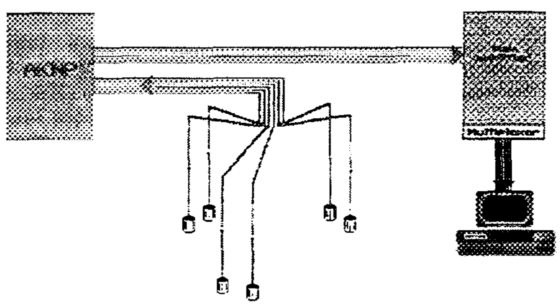


Fig.1. Electronics using state excore ionisation detectors of the AKNP safety system for core barrel monitoring in WWER type reactors

In Hungary two Units of Paks Nuclear Power Station have been equipped with reactor noise diagnostics system containing a half automated core barrel monitoring software package [5], [6]. Here we give some examples of their display (Figs 2a and 2b).

It is well known, that core barrel motions have occurred in several WWER[3] reactors. One of them was reported earlier from Rheinsberg at IAEA Meeting [7]. But we have heard about core barrel motion from Khemnitsky, from Kola, and from other sites as

[2] It is important to clarify that in this respect the terminology might differ due to different translation. We understand under core barrel the holder, which is hanged from the upper flange (Russian terminology is: шахта)

[3] We always use terminology WWER instead of VVER, since it serves for abbreviation of Water cooled Water moderated Energy Reactors

well. We have reported about core barrel motion from a WWER-1000 type reactor as well [8]. Originally there used to be a test for core barrel motion prescribed by main constructor bureau during the installation process for all WWER reactors. But this was carried out before the first load yet using accelerometer. Unfortunately those records were partly secret, partly they were not fulfilled for each WWER Unit in spite of the regulation. Nevertheless there is only one well investigated and easy to access method to build a continuos monitoring for this purpose and this is based on spectrum analysis of neutron flux fluctuations.

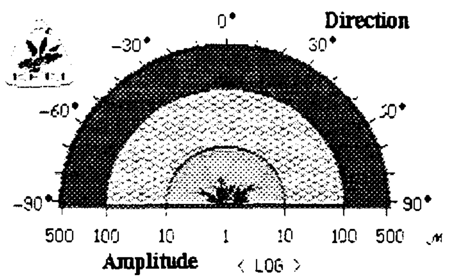


Fig.2a. Core barrel motion less then 10 micron (no motion) was observed

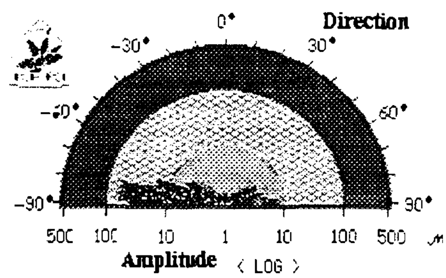


Fig.2b. Core barrel motion larger then 10 microns (less then 100 microns) was detected into 80 degree direction

This methodology is healthy not only for soviet built WWER reactors but for other types as well. Since they construction is different they have less tendency to dangerous motion. Usually they do not knock directly the walls. But usually the have core support and sometime they have also measuring tubes inserted from the bottom of the reactor vessel. Therefore in spite the fact that the amplitude of their motion is usually less, then those of the WWER reactors (since the core support serve as a damping), these smaller amplitudes are enough to damage those guide tubes for measuring installations. We have heard about such occurrences in German reactors as well as in French pressurised water reactors. Breaking those tube can lead to leakage and what is more dangerous one can loose those measuring channels

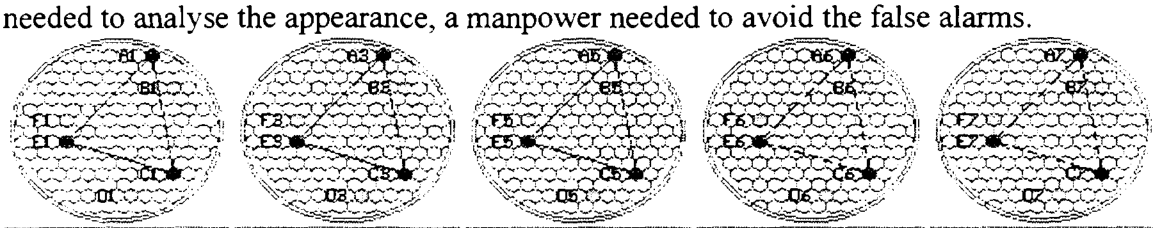
Therefore we believe that core barrel motion monitoring is one of the methods to be introduced to automatic noise diagnostics systems.

In-core vibration monitoring

WWER-440 type reactors have absorber assemblies. Their driving apparatus might be jammed. Such case was reported in 1995 from Paks NPP. Their excessive vibration can cause failure of their moving apparatus as well as damages of neighbouring fuel assemblies. Reports of excessive vibration of such control elements have been published earlier [9].

There are not accelerometers available in the core of WWER reactors. The first such test has been published just recently in one of German reactors, but still their burn out rate is too high, they can withstand radiation only for a couple of months. Today the only reliable information on in-core vibration can be achieved using in-core self powered neutron detectors, which are state composite of WWER reactors. In WWER-440 reactors there are 36 strings containing 7 spnd above each others in the core. In WWER-1000 type reactors there are 56 strings in a core. As it has been proved by numerous successful observation each string can see it own fuel assembly excellently, good visibility was reported from the neighbouring fuel assemblies, while poor visibility was reported for transport effect from further assemblies but still acceptable for horizontal correlation. The latter means that in case of an excessive vibration one of the control assemblies acceptable coherence and phase was achieved [9] between far standing spnd on distance of 4 to 6 fuel assemblies (each assembly has diameter of 144 mm).

The main sign of a control assembly vibration was the appearance of opposite phase with certain coherence between horizontally placed in-core neutron detectors. The task is obvious: we need software with automatic control of phase. Experience shows, that all combination between in-core detectors should be checked first. Once antiphase has been detected a manual package is needed to analyse the nature of that effect. Only owning with such manual package an expert can say something about the nature of that antiphase. The expert should take into account all previous lessons learnt during normal operation. Antiphase can appear due to erroneous connection of cables, due to transport effects, due to bad statistics, due to transients, etc. In principle it is possible to built in a knowledge based support system for experts. This system would contain knowledge and lessons learnt from previous experiences, still an expert is needed to analyse the appearance, a manpower needed to avoid the false alarms.



Уровень 1.	Уровень 3.	Уровень 5.	Уровень 6.	Уровень 7.
A1-C1 FCSA1C14.42S	A3-C3 FCSA3C34.42S	A5-C5 FCSA5C54.42S	A6-C6 FCSA6C64.42S	A7-C7 FCSA7C74.42S
1.4 Гц : 14.8 %	1.6 Гц : 27.9 %	1.5 Гц : 25.4 %	1.6 Гц : 34.1 %	1.6 Гц : 31.7 %
2.3 Гц : 15.1 %	2.2 Гц : 28.5 %	2.1 Гц : 11.6 %	2.1 Гц : 43.9 %	2.4 Гц : 41.5 %
3.4 Гц : 7.5 % 4.6 Гц : 167.6 гр.	3.5 Гц : 18.0 % 4.4 Гц : 162.0 гр.	3.1 Гц : 9.9 % 4.5 Гц : 120.8 гр.	3.1 Гц : 29.1 %	4.3 Гц : 31.6 %
A1-E1 FCSA1E14.42S	A3-E3 FCSA3E34.42S	A5-E5 FCSA5E54.42S	A6-E6 FCSA6E64.42S	A7-E7 FCSA7E74.42S
1.2 Гц : 8.4 %	1.1 Гц : 23.2 %	1.1 Гц : 27.6 % 1.5 Гц : 131.6 гр.	1.1 Гц : 41.1 %	1.1 Гц : 43.0 %
2.3 Гц : 13.6 %	2.5 Гц : 13.2 %	2.7 Гц : 11.7 % 2.2 Гц : 139.3 гр.	2.6 Гц : 28.7 %	2.4 Гц : 43.8 %
3.9 Гц : 9.6 % 4.4 Гц : 172.6 гр.	4.2 Гц : 8.5 % 4.4 Гц : 158.2 гр.	4.4 Гц : 13.0 % 3.3 Гц : 147.2 гр.	3.5 Гц : 29.0 %	3.5 Гц : 31.7 %
C1-E1 FCSC1E14.42S	C3-E3 FCSC3E34.42S	C5-E5 FCSC5E54.42S	C6-E6 FCSC6E64.42S	C7-E7 FCSC7E74.42S
1.4 Гц : 12.4 %	1.5 Гц : 14.2 %	1.6 Гц : 19.2 %	1.6 Гц : 25.3 %	1.4 Гц : 38.3 %
2.9 Гц : 10.2 % 2.4 Гц : 130.7 гр.	2.8 Гц : 25.0 % 2.4 Гц : 170.6 гр.	2.1 Гц : 10.2 % 2.6 Гц : 120.9 гр.	2.1 Гц : 38.1 %	2.2 Гц : 41.5 %
3.6 Гц : 13.2 % 4.2 Гц : 173.6 гр.	3.7 Гц : 11.4 %	4.3 Гц : 21.4 %	3.2 Гц : 24.5 %	3.4 Гц : 26.0 %

Fig.3. An example of the expert support display. Solid lines show in phase dash lines show antiphase behaviour at different elevations between spnd signals at different frequencies (see table)

Conclusion is that since several in-core vibration were reported in WWER type reactors and also since their detection and analyses was solved successfully with existing system it is recommended to have such system for safety purposes. Since many aspects of data analysis cannot be automated such systems cannot be a part of the safety system but it can be an important part of the operator support systems or information machines.

Reactivity coefficient monitoring

Reactivity coefficients are regarded as important parameters for operation and safety of nuclear reactors. Safety margins for the reactivity temperature coefficients are not monitored today on-line at all. Only the sign of that is checked during the start up process. We wish to underline the importance to follow the changes of that parameter since its large negative value is also dangerous for reactor operation in case of emergency halt. Earlier this was not considered as a safety point but today it became clear that in case when the emergency system inject cool water into the reactor core it can response with positive reactivity jump.

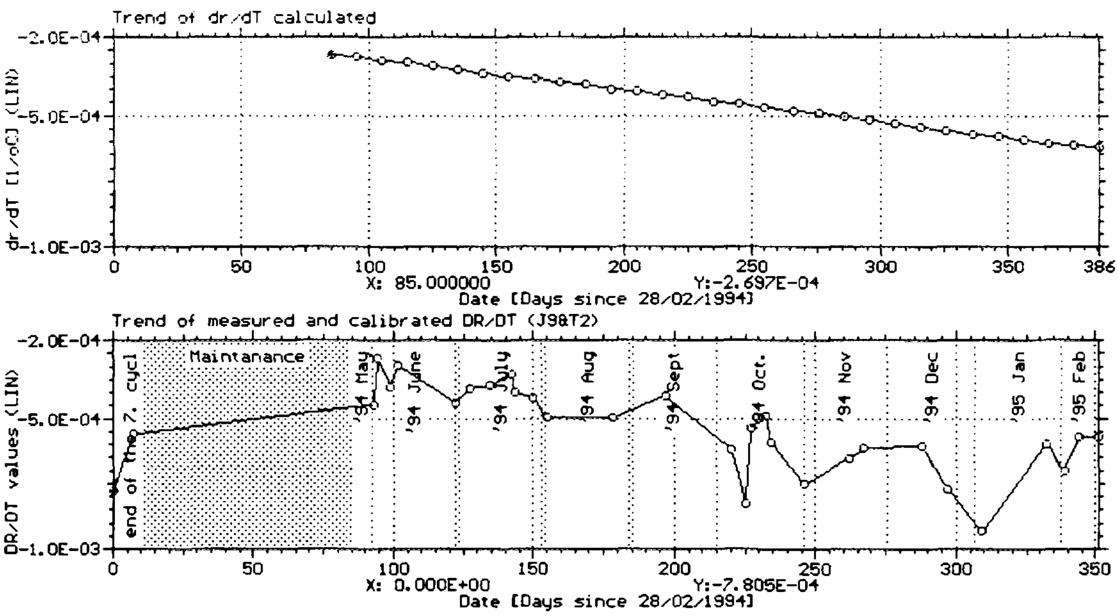


Fig. 4. Estimated and actually measured (using noise method) values of temperature reactivity coefficient during a fuel campaign

To set safety margins for reactivity coefficient during normal reactor operation becomes possible only if one can continuously monitor the changes of that important parameters. Nobody would like to introduce a thermal jump each day to check if that parameter is still inside the allowed margins. Noise monitoring methods are good in that sense that they do not disturb the normal operation at all.

There are two methods which have been reported to follow successfully the changes of reactivity coefficients during normal operation in a whole fuel campaign [10], [11]. They are only partly independent, but they contribute to each other rather well. It has been demonstrated the general change of the reactivity coefficient could be followed rather well during a fuel campaign in spite the fact that there were even disturbing effects. Consequently we can state that such computer based reactivity coefficient follower can be built in as an operator support measuring device in each Unit. Once we have an equipment which is capable to follow the changes of that parameter we can request limits for the given parameter. This is a task now for national authorities.

Temperature sensor positioning

Top of core thermocouples are very important sensors for core monitoring and diagnostics of WWER reactors, but hey are equally important in each PWRs. Their malfunction as well as their bad positioning would affect very much on reactor calculation as well as on detecting hot spots or other effects important for safety of the reactor core. Noise diagnostics technique is capable to test the correct displacement of the thermocouple and also to monitor its ageing or malfunction. We can reach this goal combining two methods.

The first method is based on phase between the temperature sensor and one of the neutron detectors [12].The second method uses the autoregressive modelling of the single output of the tested thermocouple. Using the autoregressive model one can estimate the thermocouple response on single step. From this curve one can estimate the time constant of the thermocouple in situ during normal operation without disturbing the operation or function of the reactor or that of the thermocouple. Time constant of the thermocouple is informative for its position as well as for its ageing, corrosion etc. therefore it can be used for the validation of the thermocouple both its positioning and correctness. This methodology has been applied fruitfully in several nuclear power plant and today simple versions built in a PC are available. We can recommend that for thermocouple diagnostics and signal validation.

Safety aspects of loose parts found in primary circuits and in the core

Loose parts (forgotten objects) found in WWER reactor has been told not too dangerous from direct safety point of view for WWER. Recently a rather large (about 8 kg) object has been forgotten in the steam generator of Unit 2 of Paks NPP. This steel plate was broken into small pieces during a year of operation when impacting the wall of the collector of the steam generator. The surface of the collector was just a little damaged. Tube inlets were notice to be worn. Some small pieces from that steel object was stuck in the tubes of steam generator. This lead to a tremendous work during maintenance period at the end of the fuel campaign. Thos cost of this maintenance work was rather huge and it caused also a delay in restarting the Unit. But in the first plan these are minor consequences from the point of view of safety of the nuclear installation. In the same time small broken pieces were swept away toward the reactor vessel.

It shows on the careful planning and good material of WWER rectors that no real damage was found either in the main coolant pump or on main closing valves. But also small fragments of forgotten object have been found in the reactor core and on the top of the reactor core. since it was difficult to wash them due to high radiation about 41 fuel assembly was removed from the core. No real damage of fuel pins was observed. But during the operation one of the regulating rod was stuck in a middle position. It has not been proved that these two effects are in direct correlation, but one suspect that this was one of the possible causes of the failure of the movement of the control rod. And this has a direct impact on the safety of the nuclear installation.

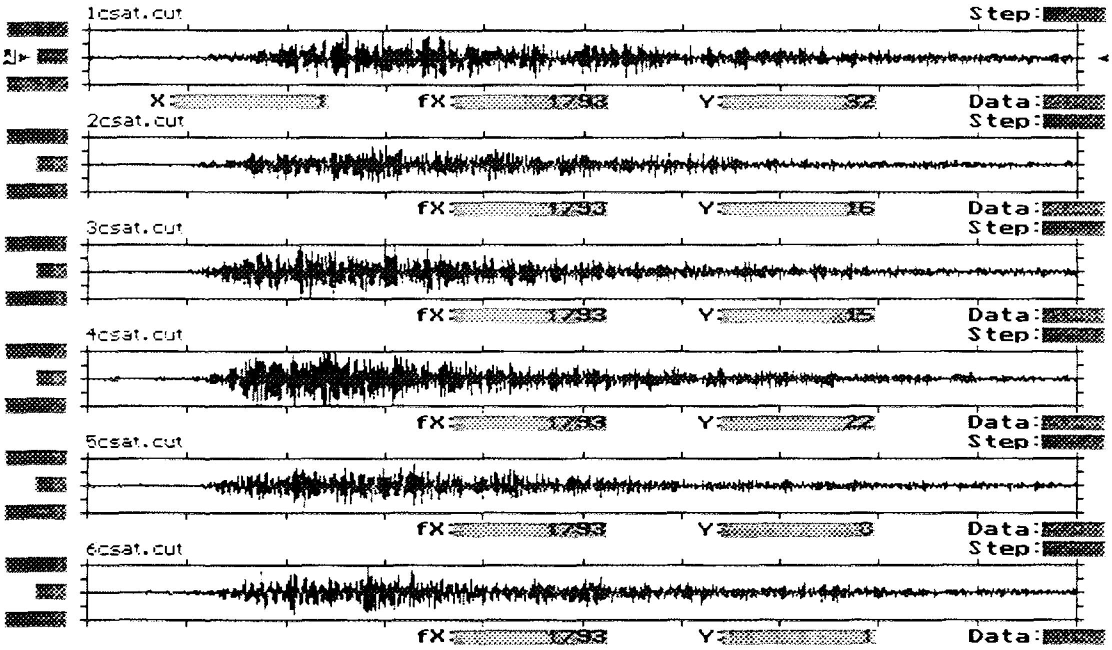


Fig. 5. Screen of the HELPS loose part monitoring system during analyse of the event

Consequently even if we can conclude that WWER reactors were design to withstand rather large loose parts from material point of view, still loose parts monitoring during the start up (and during normal operation as well) is advisable to avoid such cases, which might have direct impact on safety. Since we are talking about continuous monitoring process we believe that such analysing picture as it is shown on Fig.5. is good for experts when the event has to be found [13]. But for continuos monitoring we use an expert system which gives recommendation directly (see Fig.6. which was borrowed from HELPS -Hungarian Expert Loose Parts system [14])

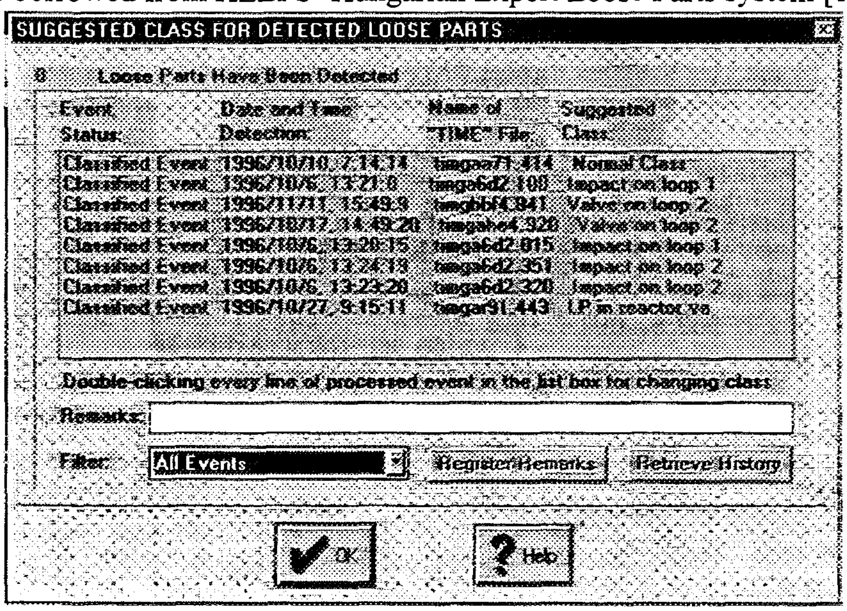


Fig. 6. Example of the expert system display of HELPS loose parts monitoring system

How to organise the diagnostics in NPP

There are different point of view on diagnostics of nuclear power plants. Some people claim that diagnostics is only the normal checking which is prescribed by manufacturers of the main components of the nuclear power plant. they disregard the developments in data collection systems and computer aided expert diagnostics systems. Some other people tends to order a ready made, rather sophisticated, fully automated, intelligent, expert system, which would give them guarantee that if their is a beginning of malfunction then it gives warning, later alarm, and if it says everything is OK then it is 100% OK. they do not like such terms as missed alarms or false alarms. They are used to safety systems, and they believe that they should get a system which acts automatically.

We believe that both attitude toward diagnostics is erroneous. What we need today is the following. We can and we have to purchase diagnostics systems based partly on fluctuation of different measurable parameters or on vibrations. Recordings and primary data evaluation should be done automatically. The most time consuming data analysis work as well as those expert analysis which can be automated should be automated. As a product of such system we get warnings that something is getting wrong with some indication what can be the cause, where to start further analysis, or we can get a message that everything was unchanged in the measured parameters.

Here starts the role of the experts which should analyse the warnings coming from the automated system with manual methods and comparison with the plant data. Such activity cannot be automated in the future as well since there is always a chance that one get something new, a new effect or new problem, which had not been before, consequently no way to learn it for any intelligent learning system. We believe that we cannot miss the careful analyse made by expert today and in the future as well.

The human factor has an overwhelming importance in diagnostics. They are the best to avoid false alarms. Also they are able to present the results in a form which is acceptable for others: for maintenance work, for management, for safety people etc. This is a second task, and it is as important as the first one. One of the biggest problem today is to make comprehensive report which would be east to understand by other specialists. If the expert tries to explain his or her conclusion using terminus of noise diagnostics, like spectra, coherence, autoregressive modelling etc. then the others cannot follow that and they will not accept the conclusion, they will not take actions. If expert gives only the final conclusion without explanation then nobody believes that plus it does not corresponds to the requirements of the quality assurance as well. This later gives the correct solution to this problem. According to the quality assurance program it is essential that the types of the report, their routes to the interested persons their contains and how to use it will be prescribes in details. Expert should have a detailed plan that in case of a loose part where and to whom make the report. What should be the contains of that report. It is clear that each case differs from another case. There must be a part, which is flexible. But this must be the smaller part of those reports (less than 20% of the total report). It cannot be the task of the expert to define to whom send the report. Also the action to be taken by addressee should be a part of the plant regulations. And this is a task for the plant management to organise now this part of noise diagnostics.

Conclusion

Technical part of noise diagnostics can be regarded as well analysed, mathematically solved. Many well organised noise measuring systems are working in different NPPs. They usually have more or less expert parts as well. We presented some areas, which have overwhelming importance for WWER diagnostics and which can be regarded as well understood, and also which have proved that methods used in noise diagnostics can contribute a lot to the safety of nuclear installation. We conclude, that most of the technical part has been solved or is in progress. The human factor and the reporting on the results of noise diagnostics is one of the most vulnerable part of this methodology today. The most important task for plant management and also for diagnostics today is to work out regulation, reporting system, limits and action plan for given plant which is in accordance with quality assurance programme.

Acknowledgements

Most of the reactor noise methods were developed while author was working at Atomic Energy Research Institute, Budapest, while loose parts system was elaborated in INT. The contribution of co-workers are highly appreciated.

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APPENDIX

Diagnostics Based on Fluctuation and Vibration Measurements in Nuclear Power Plants and its Impact on Nuclear Safety

Proposal for publication of a Review book of methods, systems and achievements

Edited by G. POR

Main

In the past twenty years noise diagnostics methods developed from laboratory tools to state system for nuclear power plants. The main area of these systems are as follows:

- Loose parts monitoring systems
- Acoustic based leakage monitoring
- Vibration monitoring of main components of primary loops
- Vibration monitoring of secondary loop components with main accent on turbine diagnostics
- Reactor diagnostics using neutron, temperature and pressure fluctuations
- Diagnostics of rotating machines

Methods includes:

- Conventional FFT spectra and their interpretation
- Alarms based on time signals and its moments (average, rms., etc.)
- Autoregressive modeling
- More advanced modeling methods: fuzzy logic, wavelet technique, neural network
- Interpretation models for different kind of events

Very valuable results have been presented in many areas of noise diagnostics and interpretation. Nevertheless in the present book we shall emphasize on achievements in practical use of the methods and analyses listed above since one of our main goal is to convince managers of nuclear power plants about usefulness of application of this methods and systems. Therefore contributions informing about the practical use of such methods and systems are most welcome.

Collecting information and papers

Reviewing book is considered to be the best collection of the present methodologies ready to be applied in nuclear power plants. Therefore the methodological part of the book is planned to collect by addressing the most prominent specialist in given subject. Selection will be made mainly on previous publication activity (surveying SMORN, IMORN and other Conferences /ANS, IMORN, NPIC&HMIT/ Meetings /like IAEA TC/). Nevertheless we shall also announce the preparation of the forthcoming book inviting anybody who wishes to contribute. Papers submitted for this book will be selected, accepted or rejected by a special committee.

To give information on his existing system(s) will be free for everybody, but the size will be limited. For longer information we shall have progressive charges. For a single page information we shall charge only 10 dollars but for each consecutive pages we double the charge. Systems will be surveyed thoroughly and in those survey we keep the rights also to criticize or to compare presented systems with existing other ones. Firms wishing to present their system should agree beforehand the critics without any right to oppose it on business base.

Editing

We request camera ready version in generally accepted worldwide PC based editors program like WORD for WINDOWS. Editing will be made by editor, but he will have an advisory group of specialist from different countries. All correspondence and discussion will be made via e-mail system.

Publishing

We consider to publish a book. Therefore it is desirable to involve a publishing company at the final period of the preparation of the book. IAEA would support this book but financing would come form publishing company (selling the book).