DEVELOPMENT OF VIBRATION MONITORING SYSTEM FOR MARIA NUCLEAR RESEARCH REACTOR

ANDRZEJ T. MIKULSKI
National Atomic Energy Agency
ul. Krucza 16, 00-921 Warszawa
POLAND

Abstract: - The development of vibration monitoring system for the MARIA nuclear research reactor was realised in several steps. After completion of measuring equipment the systematic measurement of all signals were performed. The deviations from normal operating conditions were discovered and used for elaboration of diagnostic parameters. At present the system is operating in semi-automatic mode and is used for early warning of operating personal when any changes in diagnostic parameters is observed.

Key-Words: monitoring system, diagnostics, vibration, nuclear research reactor

1 Introduction

The work for development of the vibration monitoring system for the MARIA research reactor at the Institute of Atomic Energy at Swierk (Poland) has been started in 1995 as the continuation of the similar work performed at the EWA research reactor when it was shut down. There is no nuclear regulatory body requirements for the installation of this system but application of any technical device or procedure increasing safe operation of nuclear reactor should be applied. The main aim of this work was focused on choosing of diagnostic parameters and its constant monitoring. For the complicated construction as this reactor and being already in operation since 20 years it was a very complicated task and the theoretical approach for determination of normal technical condition was excluded. So the heuristic approach was adopted supposing normal technical conditions at the beginning of system operation and any changes may be used as symptoms of technical condition degradation. The systematic measurements were performed during all fuel cycles and when any changes in diagnostic parameters were detected, compared with other operating parameters and when they are not changed the situation was classified as deviation from normal operating condition. The realisation of the above program required the establishment of satisfactory measuring equipment suitable for this, rather complicated research reactor, preparing specialised computer programmes for collection data and elaboration of measured data in different operating situations, changing many different parameters of elaboration, etc. At the end a practical limits for diagnostic parameters were establishment based on the gained experience during seven years of operation (1995 - 2001). At present the system is in semi-automatic mode of operation. The gained experience can be easily applied for other research reactors.

2 Short description of MARIA reactor and measuring equipment

The MARIA reactor is a high flux research reactor of thermal power 20 MW. It is of channel type, each of them generating power of up to 1.6 MW with individual cooling. The channels are located in beryllium matrix surrounded by water reflector and located in an open pool-tank with separate cooling. The reactor is used mostly for isotope production, some physics experiments and neutron radiography. It is operated on one-week basis, normally 100 hours, from Monday through Friday.

The vibration diagnostic system was moved to the MARIA reactor in 1995 from the EWA reactor after its decommissioning with several modifications. The main input signals are coming from accelerometers and located at 12 bearings of fuel channel cooling engines (two accelerometers at outer and inner bearing) and pumps (previously one accelerometer between two bearings and now one at the inner bearing). At he same positions the resistance thermometers were located and its temperature was measured sequentially using a multiplexer).

The additional input consists of start-up pulse ionisation chamber (moved outside of the core for power operation but still useful for neutron measurements), pulse ionisation chamber, additional current ionisation chamber, unit for reactor power measured by nitrogen activity and several binary signals specifying: operating pumps (two out of four and their speed), number of actually connected thermometer via multiplexer, etc.

The system is operating on one-week basis, it starts at least half an hour before any pump is put into operation and stops about twelve hours after stopping the pumps, so it fully covers reactor operation. Measurements of all signals are made regularly every 3 minutes (previously it was 10 and 5 minutes), when any pump is switched-on or -off and upon operator request. The mean value signal and its RMS are calculated for each measurement of a block of 512 data measured with frequency of 2 kHz and stored on a disk. The results are shown to the operator as a table (together with minimal and maximal values and short-time linear trend) for all signals or as a plot for previous 27 hours. The up-to-date operation enabled to set the limits of RMS values and in case they are crossed the individual signal is measured and stored on a disk for further analysis (power spectral density, correlation function, etc.).

The hardware of the system is rather simple, it is a PC-computer with two lab-cards (one for analogue and one for binary signals) and a printer with uninterrupted power supply (UPS), which is very important in order to keep the system working in case of power failure. In order to verify the electronic equipment there is possibility to use a unit simulating output of an individual accelerometer or switch-on and -off the same test signal for all measuring channels and compare obtained parameters with known values.

3 Short description of computer programs

The software consists of three main programmes:

- on-line data acquisition, elaboration, recording and presentation of main information suited for simple usage by operating personnel,
- off-line analysis of diagnostic signals with many different calculating methods with full presentation possibilities for system analysts,
- off-line analysis of vibration signals for analysis in frequency and time domains also for system analysts.

During years of operation all programmes were constantly improving and including suggestions from operating personnel in order to make it user friendly as much as possible.

4 Diagnostic parameters

The diagnostic parameters used by this system and chosen upon obtained experience, are:

- root-mean-square (RMS) value for acceleration signals calculated from 512 individual measurements),
- short- and long-time linear trends of RMS value,
- value of bearing temperature,
- short-time linear trend of temperature.

They are automatically checked against thresholds, which were established upon operating experience, and in case they are crossed a special warning is generated for the reactor operator, who has the possibility to analyse on-line all signals and diagnostic parameters by making appropriate plots, comparison with results obtained during previous fuel cycles for the same detector or other detectors etc. In special situation it has the possibility to change the operating pump set (normally two sets are operating from the four available). In this situation a raw (direct measured) acceleration signal is recorded for future detailed analysis.

5 Typical results of normal operating conditions

The normal results over one-week show a constant value of RMS and very slow increase of temperature. It may happen that RMS was increasing in the range up to 20% of previous value and at the same time the temperature was decreasing about 10-15°C in the second part of a fuel cycle (Fig.1) but this situation was assumed as normal condition of operation.

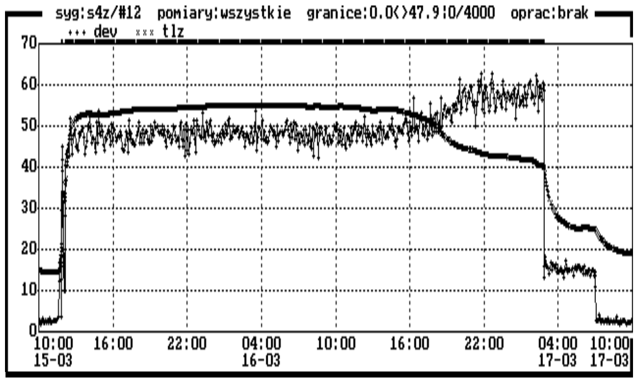
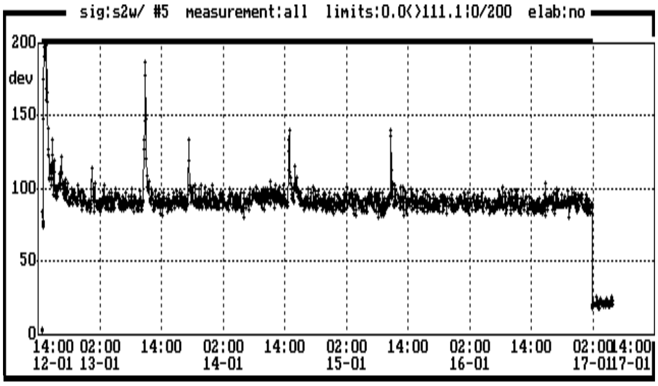


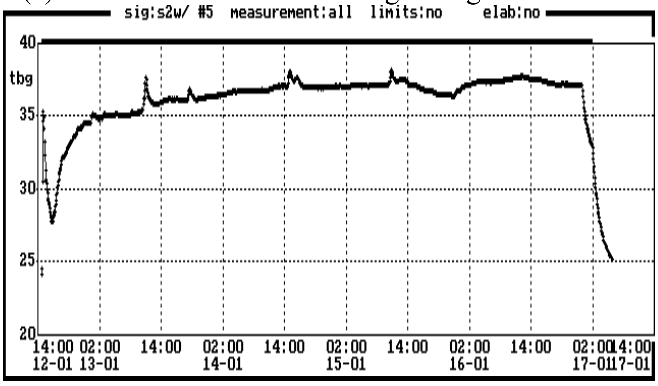
Fig.1. The RMS and temperature of engine no 4 outer bearing (file: m990315a, s4z/#12)

Frequently there were observed short time increases in RMS value and temperature (Fig.2a and 2b), but its duration was not longer than 12-15 minutes and was also assumed as normal operating conditions.

From time to time, at the beginning of a fuel cycle the increase of RMS value is observed (Fig.3) in the range up to 100% higher than during the rest of the cycle (normal value). If the RMS value decreases within two - three hours (as it has always happened until now) no message is given to the operator. These phenomena is attributed to lubrication procedure performed every week before a start-up of the engine, probably the surplus of lubricant is discarded from the bearing and vibration intensity returns to normal value. It should be noted also one short increase of RMS value similar to one shown in Fig.2.



(a) RMS value for inner bearing of engine no 2



(b) temperature for inner bearing of engine no 2

Fig.2. Typical results for one-week operation (January 12-17, 1998; file: m980112c.ndz)

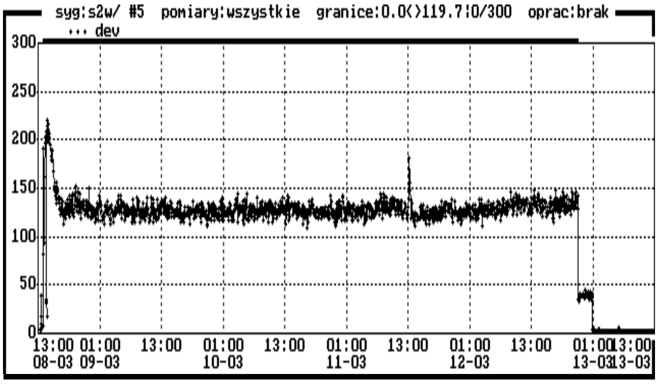
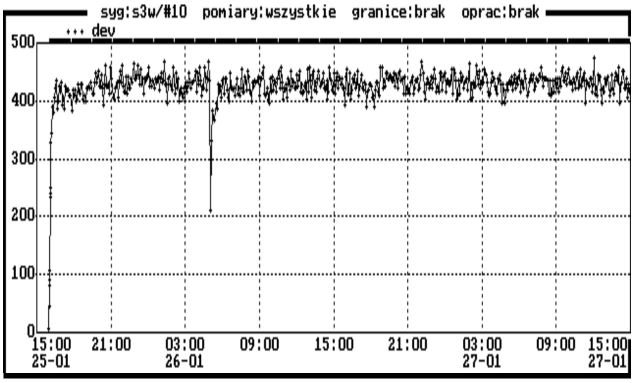
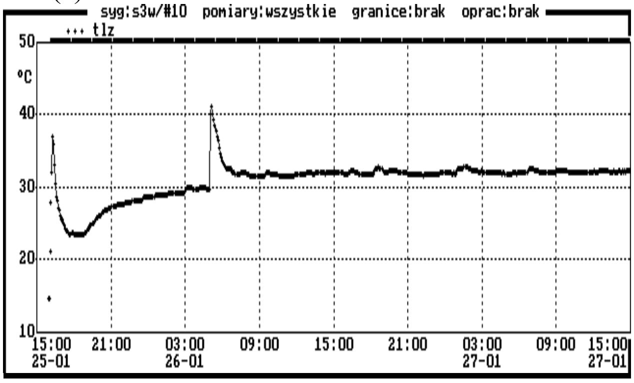


Fig.3. The RMS of inner bearing of engine no 2 (file: m990308a, s2w/#5)

Another example of deviation is shown in Fig.4. The RMS value was sharply decreasing and temperature was almost simultaneously increasing but if its duration is shorter than half an hour no message is given to the operator.



(a) RMS value



(b) temperature

Fig.4. RMS and temperature for engine no 3 inner bearing (file m990125b, s3w/#10)

Another form of diagnostic analysis is making plots of the mean RMS values for signals from accelerometers calculated off-line for the each fuel cycle by diagnostic analysts. The values should be constant or have a small systematic increase (in a range of single percentage) from cycle to cycle with increasing time of a bearing operation. This observation is true for outer bearing of the engine and the bearing of the pump but not true for inner bearing of the engine, which is the most influenced by alignment of a shaft. The typical results are shown in Fig. 5 for year 1999. It can be seen the constant values for outer engine bearing and pump bearing and decrease for engine inner bearing after 4th fuel cycle when the alignment of axis was performed and later a slow increase until the end of year.

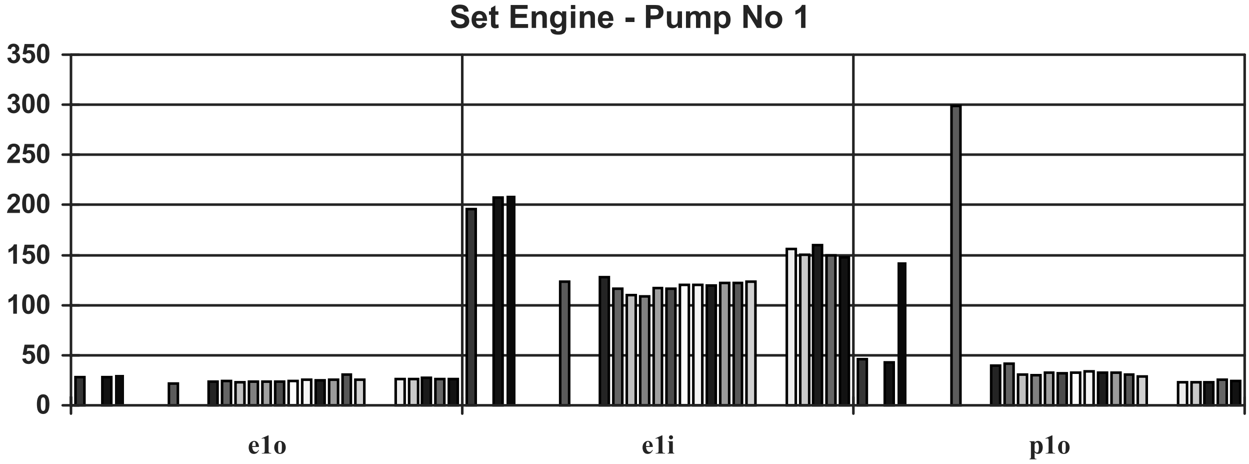


Fig.5. The RMS mean values for pump - engine set No 1 in all fuel cycles in 1999.
(e1o=engine outer bearing, e1i-engine inner bearing, p1o=pump outer bearing)

6 Example of deviations from normal operating conditions

During the seven years (1995-2001) of operating of diagnostic monitoring system for the MARIA reactors three situations were observed as deviations from normal operating conditions and only two required immediate intervention of an operator. All of them are described in following.

The first situation concerns the analysis of RMS value at the end of a fuel cycle. The RMS value for the pump no 1 increased in the period of 92 hour (one fuel cycle) almost four 3 times as shown in Fig. 6 (smoothed for the period of 50 minutes i.e. 11 measurements). Also the long-time trend (calculated from 12 hours) was showing constant value not less than 07% of mean value and reaching as high as 2% (Fig. 7). This pump was excluded from next week operation and set for mechanical inspection, which showed defect on inner bearing flange and a new one was mounted. Sometimes only alignment of engine-pump axis is required. The last example shows the situation, which may be really dangerous in case of longer operation of this or any other pump.

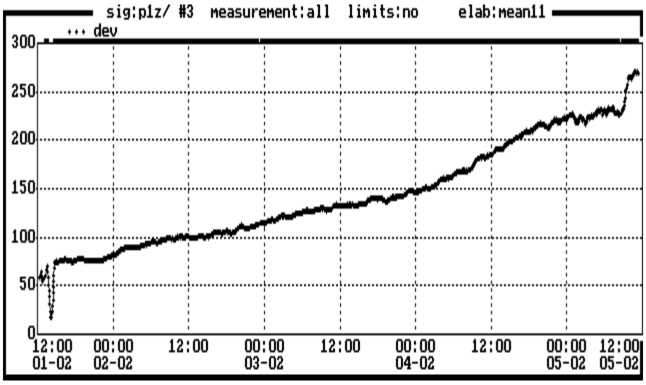


Fig.6. The smoothed RMS value of acceleration signal of pump no.1 bearing during 4th fuel cycle in 1999 (file m990201, p1z/#3)

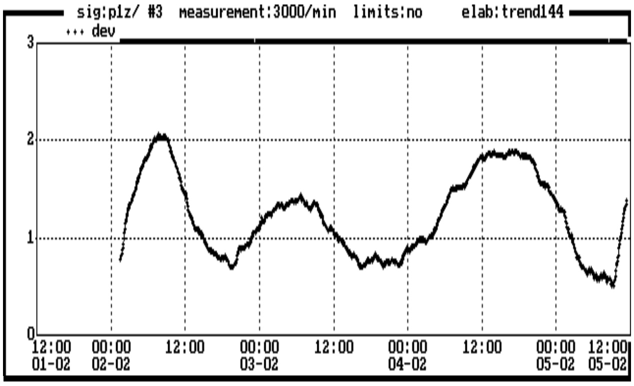


Fig.7. The trend of RMS value shown in Fig.6

The second situation concerns the increase of the RMS value observed during a fuel cycle when it increased over four times in 40 hours (about 40% of fuel cycle) for the pump no 1 (the same as above) in 17th fuel cycle in 2000. Due to immediate intervention the pump was switched-off and replaced by pump no 2. The RMS value, linear long-time trend (of 3.6 hours) and bearing temperature are shown in Fig. 8, 9 and 10. It should be noted the correlation between RMS value and temperature which linear trend was equal 0.35°C/h and the highest temperature was equal 74.2°C.

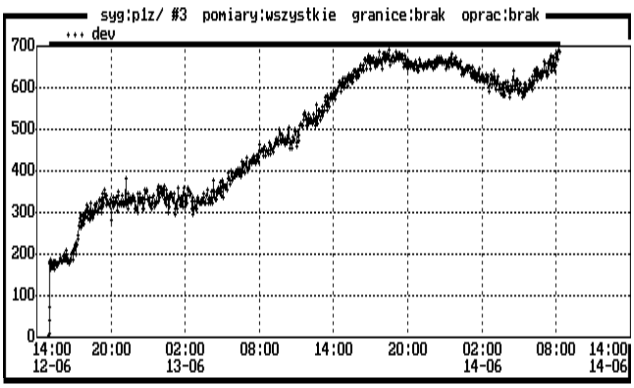


Fig.8. The RMS value of acceleration signal for pomp no 1 during 17th fuel cycle in 2000 (file: m000612a.pcx)

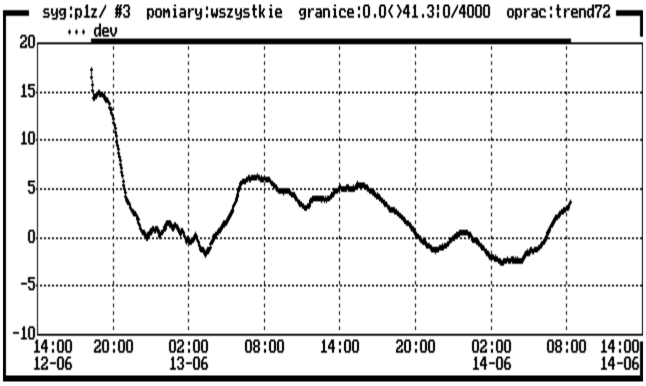


Fig.9. The trend of RMS value in Fig.7 (file: m000612d.pcx)

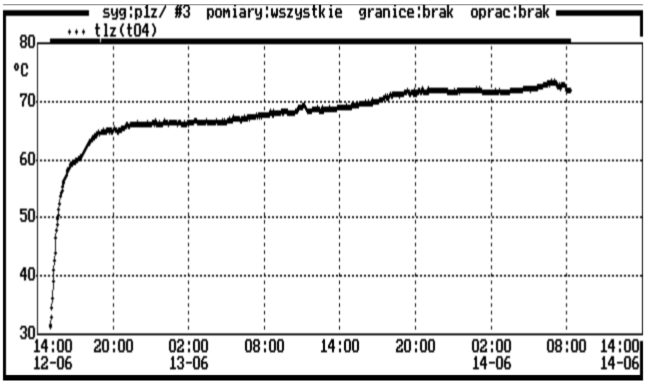


Fig.10. The bearing temperature for pump no1 as in Fig.7 (file: m000612c.pcx)

The third situation concerns the temperature of the bearing of pump no.3 (Fig.11) with very sharp increase after 56 hours of operation (the upper limit of temperature measuring unit is equal 100C and it stayed constant for 45 minutes). The calculated linear trend from the 4 previous measurement (i.e. 15 minutes) is shown in Fig.12 (the time scale was adjusted for the interesting region of 7 hours) reaching the value of 2.0°C/min, which is very high. The existing equipment had passed the warning signal to the reactor operator when the temperature have reached 80.0C and switching-off the pump took place 13 minutes later, when the temperature reached the value of 94.2°C. Using the diagnostic system and setting the trend limit to +0.8°C/min the information would be presented 12 minutes earlier (using 5 minutes interval between regular measurements) giving the operator more time for analysis of situation and taking preventive action.

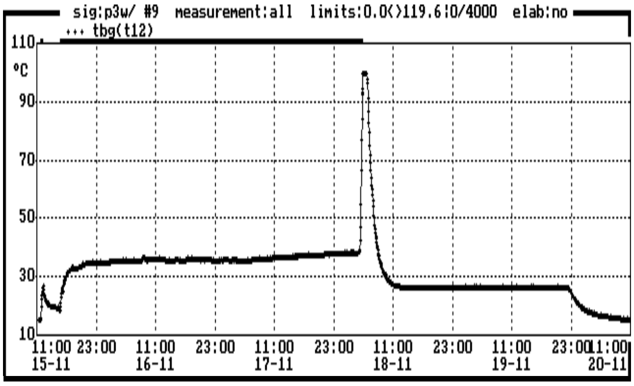


Fig.11. The bearing temperature for pump no.31 during 24th fuel cycle of 1999 (file: m991115x.pcx)

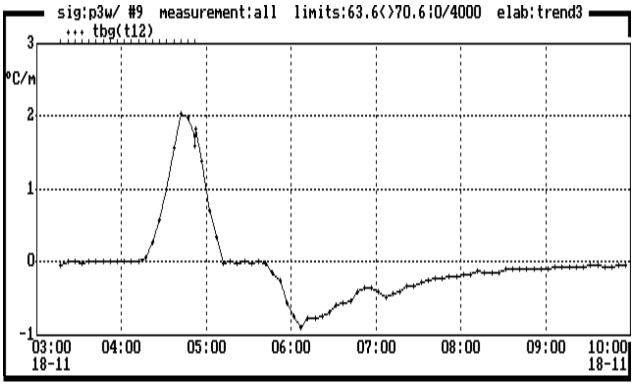


Fig.12. The trend of bearing temperature for pump no.3 shown in Fig. 9 (file: m991115y.pcx)

7 Limits of diagnostic parameters

The obtained experience enabled to set up the following limits for RMS value in absolute value but dependent upon localisation of a bearing, which is not interested in this general description of the monitoring system. The other values may be of useful during analysis of similar systems.

8 Conclusion

The main intention of this work is to establish limits of warning and alarm values for operating staff and concentrate their attention on situations, which may be dangerous. The choice of interesting situations and setting of the limits can be done rather on practical than theoretical basis as was shown above.

Table 1. Limits of diagnostic parameters for the MARIA research reactor

	RMS value			bearing temperature	
	upper limit	short trend	long trend	upper limit	short trend
time length	-----	20 min.	12 hours	-----	15 min.
threshold value	signal dependant	20%mv/h	1%mv/h	80°C	0.8°C/min
duration [ms]	3	3	10	3	3
repetition	every measurement		1 hour	every measurement	

remarks: mv = mean value of a signal
ms = measurements