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Application Note

Case study – Off-line monitoring played an important role at the Ignalina nuclear power station

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ABSTRACT

The maintenance department at the Ignalina nuclear power station has the responsibility to ensure the ageing power station equipment operates safely, reliably and cost-effectively to meet the rapidly growing energy demands of the country. The Vibro-Diagnostic Laboratory of the Engineering Support Department serves a vital function in this effort, as they are responsible for condition monitoring of all rotating machinery in the power station. One of the important functions of the Vibro-Diagnostic group is monitoring 393 pumps, 897 fans and their respective motors using portable "off-line" data collectors and analysers.

Before the Vibro-Diagnostic Laboratory was established, only about 30% of the fans were operating within the allowable vibration limits due to various problems such as unbalance, misalignment and wear. Nearly all the fans are now operating in the allowable zone. Several examples are given in this paper where off-line monitoring was not only used to detect developing faults, but also provided the diagnostic capability for effectively finding the root cause of the problem. This has resulted in several machine design modifications to the particular fans and pumps to prevent the problem from recurring.

RBMK plant optimized for safety

The large Ignalina nuclear power station (INPP) provides 85% of Lithuania's total energy needs. Each of the power station's two units consist of two 750 MW turbine-generators which have been operating successfully and safely since they were synchronized with the grid, unit 1 in 1984 and unit 2 in 1987. The RBMK-1500 units (RBMK is a Russian acronym for "Channelised Large-power Reactor") at INPP are one of the largest in the world with a net generating capacity of 1500 MW each. Some of the 4800 MW thermal energy capacity is used for district heating in the nearby town.

Figure 1. Ignalina nuclear power station has the world's largest reactors. Photo: Hans Blomberg.

This is a pressurized, boiling-water reactor (BWR) with individual fuel channels using ordinary water as a coolant and graphite as a moderator. There are currently 13 RBMK units built with one later plant added in Kursk. The RBMK-1500 units at INPP are based on the most modern RBMK reactor former Soviet Union have been considerably modified to improve safety since the Chernobyl RBMK-1000 reactor accident of 1986.

Since 1992 numerous international studies were done by specialists and institutes for assessing the

safety issues at INPP. These resulted in the implementation of two concurrent, comprehensive safety improvement programmes that benefited from the technical resources and financing of a number of countries. After completion these programmes have greatly improved the safety and reliability of the plant.

Modern maintenance and condition monitoring strategy

The predictive maintenance strategy at INPP has been significantly improved over the years, partly with support from the safety improvement programmes. Time-based maintenance is still used for a few machine components, such as lubrication, replacing seals, pump body corrosion control, etc., but most maintenance decisions are now condition-based.

The Vibro-diagnostic Laboratory of the Engineering Support Department is responsible for condition monitoring of all rotating machinery. Although the group uses several types of monitoring techniques in their daily routines, vibration monitoring is the principle technique used.

Off-line vibration monitoring is done using four portable data-collector/analysers for a total of 393 pumps and 897 fans. There is a total of about 14 000 measurement points, where each bearing is monitored in the x-and y-and axial directions.

One engineer is responsible for monitoring fans and another for pumps for each unit (four altogether) together with two assistant technicians. Fans are monitored once every 6 weeks and pumps every 4 weeks between repairs. All new and overhauled machines are tested by extensive vibration measurements before being taken into service.

Figure 2. The offline monitoring section of the Vibro-diagnostic Laboratory collects data for 1290 machines on a routine basis.

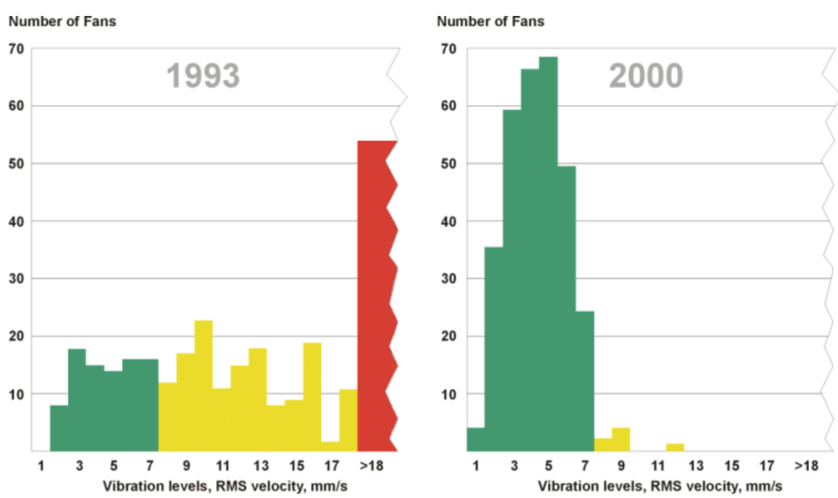

Figure 3. Offline monitoring has considerably reduced maintenance on the 897 fans. The number of fans operating within the allowable vibration levels (shown as green) according to ISO 2372 in 2000 has increased significantly since 1993.

Monitoring is done in three basic machine operational modes:

- Disconnected electric motor at running speed
- Entire machine train at minimal load (test mode)
- Entire machine train at full load

There are two monitoring alarm limits established for all machines, i.e. 'Acceptable' and 'Not acceptable'. If an 'Acceptable' alarm limit is exceeded, the machine is monitored by specialised diagnostic measurements more often, e.g. weekly or daily depending on the severity of the fault. If a 'Not acceptable' alarm limit is exceeded, the machine is immediately stopped for repair.

In all cases the Vibro-diagnostic group works closely with the Maintenance and Operation groups to inform them on the condition of the machines and those machines that require repair. Many machine faults have been detected and diagnosed over the years using the off-line instruments, as described in the following sections.

Maintenance savings on 897 fans

It was determined that only about 30% of the fans in the plant were operating within the acceptable vibration limits when the Vibro-diagnostic Laboratory was started, as seen in Figure 3. Around 30% of the fans were actually operating in the unacceptable zone due to various problems such as unbalance, misalignment and wear! This often resulted in bearings failing prematurely. This problem has since been corrected by implementing an effective off-line monitoring strategy. Most of the high vibrations at the fans were due to unbalance, worn bearings or misalignment, but the excessive vibration detected on the horizontal belt-driven fans was due to other reasons. It was later determined that the vibration problem for these type of fans could only be eliminated by stiffening the support structure of the belt drive, as shown in Figure 4.

Coupling re-design for the accident-confinement pumps

These pumps are critical and have to be ready to function for abnormal plant operation. In the event of an accidental discharge of high-pressure steam-water mixture from the primary cooling circuit, the accident-confinement system suppresses pressure build-up and prevents radioactive gases from being released to atmosphere. This is done partly by condensing some of the released steam in pools of water and by water spray. The accident-confinement pumps are used to pump the heated water from the condensing pools into heat exchangers to cool it down and to pump water into the spray systems. Each 320-kW motor-driven pump has a flow capacity of 1250 m^3/hr at 1500 rpm.

After measurements were taken one day on one of the accident-confinement pumps, it was seen that after repair the running frequency vibration amplitudes had increased from 4-7 mm/s to 13-18 mm/s on the bearing housing on one of the pumps (see top in Figure 7).

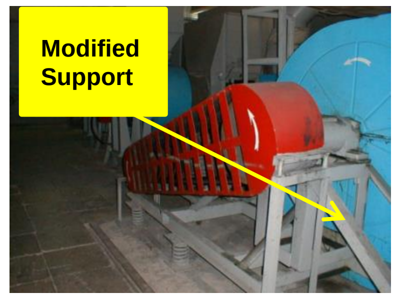

Figure 4. Horizontal belt-drive support modification for those fans that had excessive vibrations due to lack of structural stiffness.

Figure 5. There are six accident confinement pumps for each reactor unit in the condenser tray cooling system. Each 320-kW motor-driven pump has a flow capacity of 1250 m3/hr at 1500 rpm.

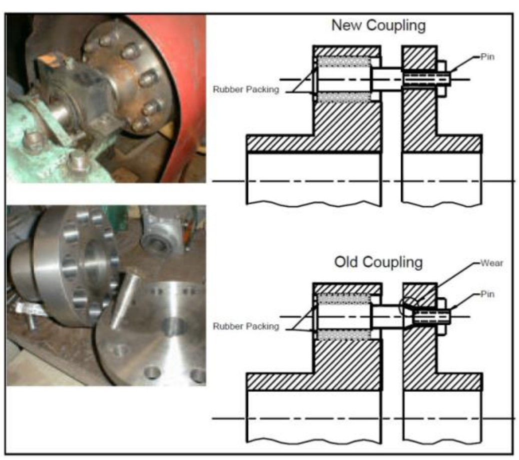

Figure 6. Flexible coupling of the accident confinement system pump showing newly designed pump-end flange and bolts.

Inspection after disassembly revealed that the pump-end coupling flange had worn coupling bolts and bolt holes. This extra transverse clearance resulted in excessive vibrations. Further investigation revealed that there was similar wear on all the accident-confinement pumps. The coupling design was changed as shown in Fig. 6. The CPB spectrum before and after implementing the new coupling design on one of the pumps is shown in Figure 7.

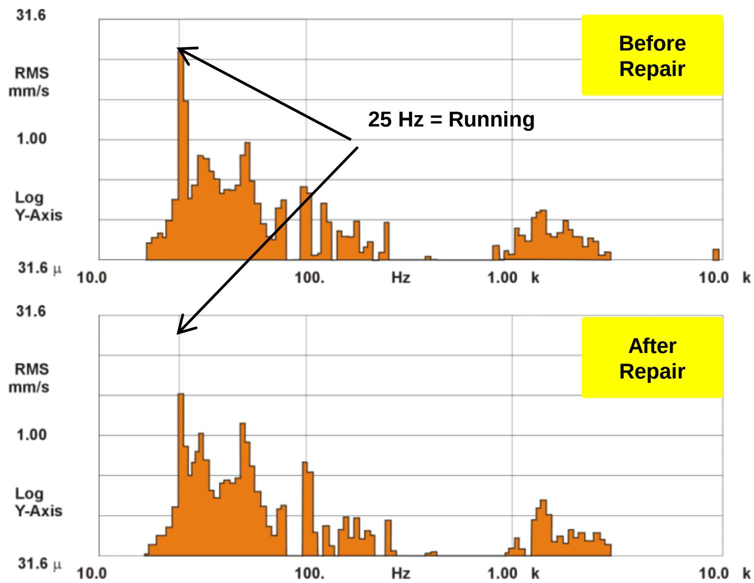

Figure 7. Constant percentage bandwidth spectrum (CPB) of the accident containment system pump before (above) and after (below) replacing the coupling with a new design.

Impeller damage on the purification and cooling system pumps

These pumps circulate water in the purification and cooling system of the main circulation circuit during start-up and shut-down of the reactor (the pumps are not used during normal operation of the reactors).

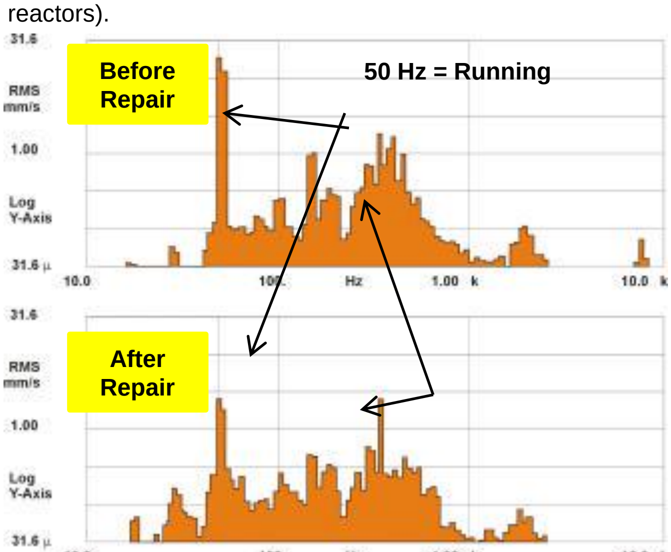

Figure 9. CPB spectrum of the purification and cooling system pump before (above) and after (below) replacing the impeller.

Figure 8. There are two purification and cooling system pumps for each reactor unit. Each 500-kW motor-driven pump has a flow capacity of 500 m3/hr at 3000 rpm. A damaged shroud is shown to the below.

The purification and cooling system performs a number of functions, but is primarily intended to pre-cool the reactor coolant flowing into the water purification system for removing corrosion products and soluble salts, and for supplying coolant to the reactor core during normal shutdowns and in emergencies.

Each 500-kW motor-driven pump has a flow capacity of 500 m3/hr at 3000 rpm.

The suspicion that the impellers were damaged was verified upon opening the pumps.

Examination revealed that the impeller and shroud were damaged by foreign metal object ingestion (see Figure 8). To prevent a future recurrence of the same type of problem from metal particles passing through the pump special filters were installed on the suction side.

Excessive vibration was detected at the running speed and the blade-pass frequency for both pumps on both reactor units. The high vibration amplitude, especially of the running speed component, is shown in the top CPB spectrum in Figure 9. The vibration amplitude of the running speed component after replacement of the impeller is shown in the bottom CPB.

Bearing damage on the demineralised, contaminated-water pumps

There are three demineralised, contaminated-water pumps for each reactor unit. Each 55 kW motor-driven pump has a flow capacity of 90 m3/hr at 3000 rpm. These machines pump demineralised, contaminated water from the main circulation circuit to the water purification facility.

In Figure 11 the overall vibration level trend can be seen for bearing N4 on one of the pumps between December 2000 to September 2001. Up until April 2001, the overall vibration was approx. 2.7 mm/s. The pump was serviced in April, after which the vibration was reduced to 1.1 mm/s. However between June 14 and July 11 the vibration suddenly increased from 1.6 to 4.3 mm/s.

As indicated by the diagram in Figure 12, the envelope spectrum measured on June 14 already showed early signs of damage to the inner race of the bearing (246.2 Hz) and its harmonics (492.4; 738.6 and 984.8 Hz).

As the damage progressed, the envelope spectrum showed increased vibration amplitudes in the high frequency range. The ball-pass frequency and its harmonics for the inner race are clearly seen in the envelope spectrum diagram in Figure 13 below.

After replacement of the damaged bearing, the vibration returned to acceptable limits as shown in Figure 14. The high frequency vibrations and the peaks associated with the ball-pass frequency for the inner race and its harmonics are virtually completely eliminated.

The replaced bearing was disassembled and examined to confirm the damage to the inner race. Figure 10 shows the premature damage on the inner race that had begun to spread to the rolling-elements.

Figure 10. There are three demineralized contaminated water pumps for each reactor unit. Each 55 kW motor-driven pump has a flow capacity of 90 m3/hr at 3000 rpm. Damaged bearings are shown in the picture to the left.

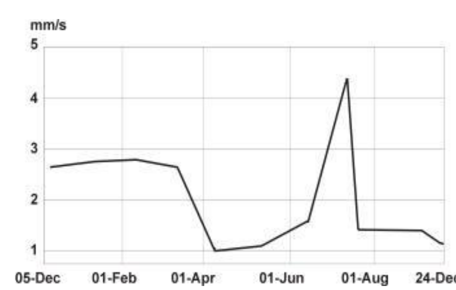

Figure 11. Vibration on the N4 bearing of the pump has increased from 1.6 mm/s June 14 to 4.3 mm/s July 14.

Conclusion

The importance of an off-line vibration monitoring strategy in a nuclear power station such as INPP is often underestimated. Although the need for a permanently installed on-line system is crucial for monitoring the critical, non-redundant machines, it would be prohibitively expensive to permanently monitor the other 1290 machines. Moreover, it would be unnecessary since there is minimal risk to the technicians and engineers who collect the data, and most of these machines have backups.

After eight years of operating experience with the off-line monitoring strategy, the portable instruments not only proved themselves effective in detecting and diagnosing faults in their early stage of development, but are also effective analysis tools for determining the root causes of faults. This allowed machine components to be modified where necessary to eliminate the problem.

The implemented off-line strategy has proven to be very effective for early detection of developing faults yet poses no safety risk to personnel who take the measurements. This has resulted in significant maintenance cost savings and increased machine availability. As all the non-critical machines are backed up with minimal safety risk if they inadvertently fail, there is no need to replace the off-line strategy for these machines with an expensive on-line system -which translates into further cost savings.

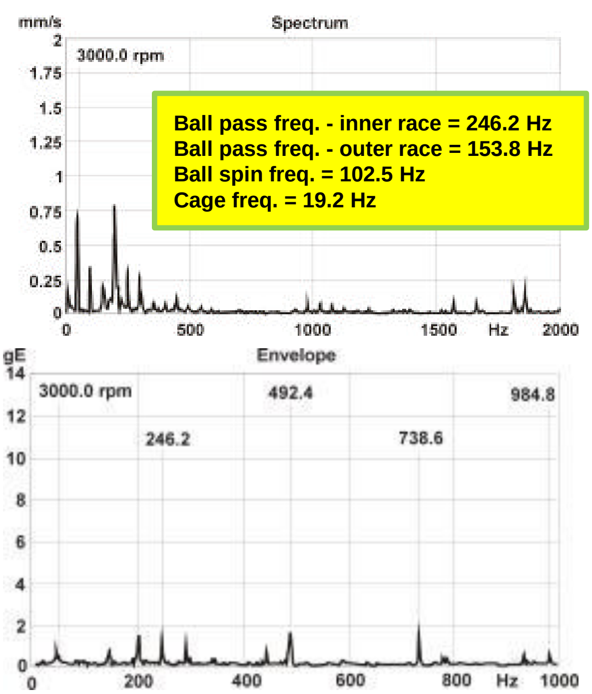

Figure 12. Before Repair (June 14): There is already evidence of damage to the inner ball bearing race as seen by the prominent ball passing frequency for the inner race (246.2 Hz) and its harmonics (492.4, 738,6 and 984.8 Hz).

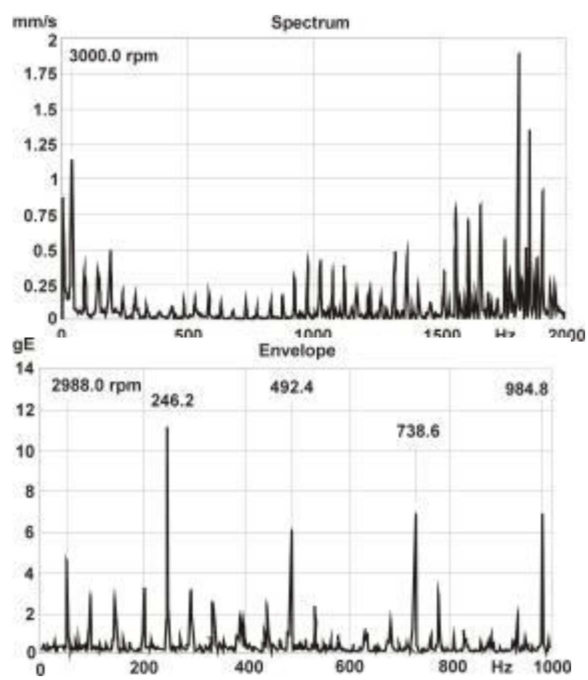

Figure 13. Before Repair (July 1): As the damage progresses, the spectrum plot shows increased vibration amplitude in the high frequency range. The ball passing frequency for the inner race and its harmonics are clearly seen in the envelope plot.

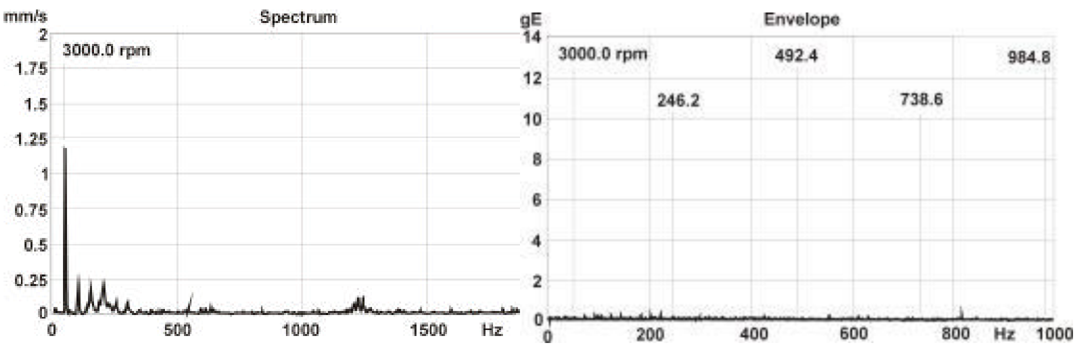

Figure 14. After Repair (July 20): The high frequency vibrations are reduced significantly in the spectrum plot, as are the peaks associated with the ball passing frequency for the inner race and its harmonics in the envelope plot.

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