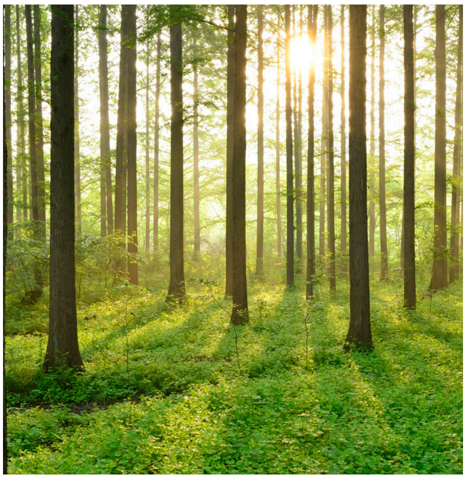
MAPPING OF CONDITION MONITORING SYSTEMS IN OLKILUOTO NUCLEAR POWERPLANTS

REPORT 2021:785



NUCLEAR

VIBRATIONS IN NUCLEAR APPLICATIONS

Energiforsk

Mapping of Condition Monitoring Systems in Olkiluoto Nuclear Powerplants

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Foreword

Condition monitoring systems have advanced significantly during the past years and new methods and systems are constantly being developed. The price of the equipment needed for vibration monitoring and analysis is decreasing. With vibration data as a base, a number of analyses on the plant health and behaviour during operation can be carried out.

When building a new nuclear power plant condition monitoring systems is a natural and integrated part of the design to facilitate monitoring of both large singular key components and small basic components used by the dozen. Installing condition monitoring systems in existing nuclear power plants is also possible, it just takes more effort to adapt the installation to the preconditions in the plant.

In this study vibration experts Lassi Koivunen and Jaakko Rostedt from Trendion OY have mapped the condition monitoring systems in the three nuclear power plants units in Olkiluoto. The project was carried out within the Energiforsk Vibrations in nuclear applications research program. The stakeholders of the Vibrations program are Vattenfall, Uniper, Fortum, TVO, Skellefteå Kraft and Karlstad Energi.

Summary

The condition monitoring in Olkiluoto is at advanced level and the overall understanding of the plant units' condition is high quality due to high level of expertise and wide range of condition monitoring systems and methods used.

Olkiluoto 3 plant unit is a modern nuclear power plant and the latest NPP in the world to receive its license of operation. Because of its modernity, OL3 plant unit is equipped with multiple monitoring system that go way beyond the traditional vibration monitoring of rotating machinery. Among the traditional vibration monitoring systems that monitor the large machinery, OL3 is equipped monitoring systems such as primary and secondary systems monitoring, loose parts monitoring and fatigue monitoring.

Even though Olkiluoto 1 and Olkiluoto 2 are much older plant units and don't have such advanced monitoring system as OL3 has, thanks to highly skilled personnel, high-quality instruments and innovative methods the condition monitoring in older plant units is high quality. For example, even though OL1 and OL2 don't have online primary circuit monitoring system, the investigation of the main steam lines is still possible due to permanently installed transducers and high-class portable analyzers.

The basis of condition monitoring and vibration measurements in all plant units located in Olkiluoto is the mobile route measurements that are performed by vibration familiarized fitters and are carried out with certain time intervals. The other foundation of condition monitoring are comprehensive special vibration measurements that are performed with portable analysers by skilled vibration specialist.

List of content

1 CONDITION MONITORING SYSTEMS AND METHODS

Mapping of monitoring system was commenced to get a comprehensive image of different kind of monitoring systems used in Nordic nuclear power plants. This study covers the monitoring systems and methods in Olkiluoto 1, Olkiluoto 2 and Olkiluoto 3 nuclear power plants located in Eurajoki, Finland.

Condition monitoring beholds nowadays a lot more than just the traditional vibration measurements that consist of monitoring the vibration of bearings and shafts. One more resourceful than the other methods has been invented and monitoring systems provide nowadays a comprehensive understanding of the plants condition.

In addition to traditional vibration monitoring the condition monitoring systems and methods in Olkiluoto nuclear power plants provide information of condition of main components and structures, possible loose parts in systems, phenomena that causes fatigue for the piping and for example a understanding of torsional vibrations affecting the turbine at sub-synchronous frequencies.

However, the basis of condition monitoring and vibration measurements in all plant units located in Olkiluoto is the mobile route measurements that are performed by vibration familiarized fitters and are carried out with certain time intervals. The other foundation of condition monitoring are comprehensive special vibration measurements that are performed with portable analysers. The mobile vibration measurements are presented in chapter 5 of this study.

Keywords

Monitoring system, Condition monitoring, Vibrations, Vibration measurement, Turbine monitoring, Pipe vibrations, Fatigue monitoring, Loose parts monitoring, Mobile vibrations measurements

Abbreviations

- BWR – Boiling Water Reactor
- EPR – European Pressurized Water Reactor
- HP – High Pressure
- ICP/IEPE - piezoelectric sensors which contain built-in impedance conversion electronics
- LP – Low Pressure
- MCR – Main Control Room
- OL1 – Olkiluoto 1 nuclear powerplant
- OL2 – Olkiluoto 2 nuclear powerplant
- OL3 – Olkiluoto 3 nuclear powerplant
- RCP – Reactor Coolant Pump
- RPV – Reactor Pressure Vessel
- RMS – Root Mean Square
- SG – Steam Generator
- TVO – Teollisuuden Voima Oyj

2 CONDITION MONITORING SYSTEMS IN OL1 AND OL2 NUCLEAR POWERPLANTS

Olkiluoto 1 (OL1) and Olkiluoto 2 (OL2) are Finnish BWR-type nuclear power plants located in Eurajoki, Finland. The net output of OL1 and OL2 was 660 MW but after multiple modernization projects the net output has increased up to 890 MW.

The construction of OL1 was commenced on 1st of February 1974 and the plant unit was connected to the national grid for the first time on 2nd of September 1978. The commercial production was started on 10th of October 1979. The construction of OL2 was started year later than OL1 on 1st of November 1975. The first connection to grid was done on 18th of February 1980 and the commercial production was started on 10th of July 1982.

The current operation licence is valid for both plant units until 2038 but the plants units will most likely be in production even further. The cross section of OL1/2 is presented in figure 1 and technical data of plant units is presented in table 2.1.

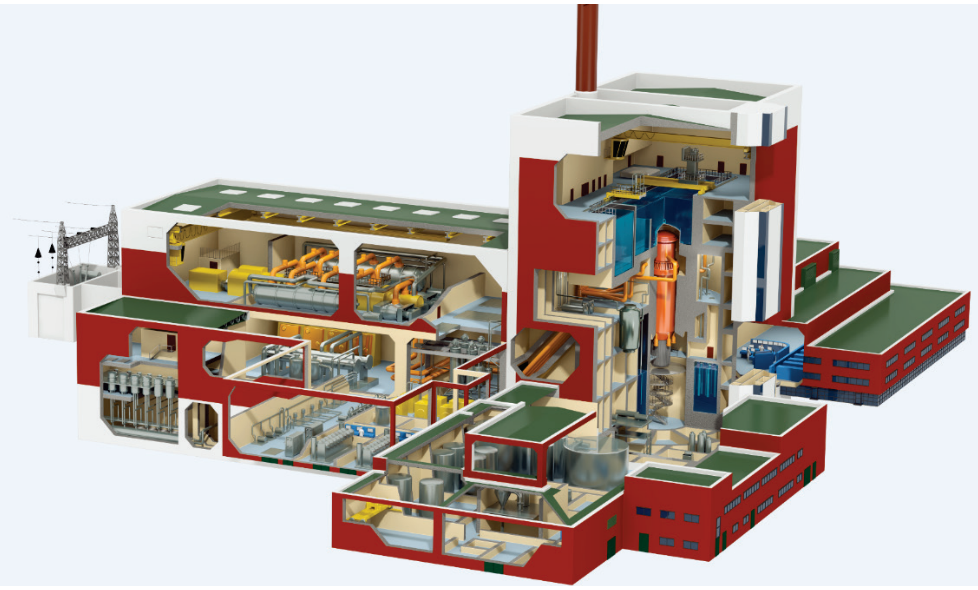

Figure 1. Overview of OL1 and OL2 structure

Even though OL1 and OL2 plant units don't have same kind of comprehensive monitoring systems as there are in OL3 it doesn't mean that the condition monitoring in OL1 and OL2 wouldn't be extremely high-quality and comprehensive. Skilled professionals and high-quality measuring equipment enable comprehensive condition monitoring on the older plant units in Olkiluoto.

Table 2.1. Technical data of OL1 and OL2 plant units

Reactor thermal power	2500 MWth
Electrical power, net	880 MWe
Efficiency	ca. 35 %
Feedwater temperature	185 °C
Steam temperature	286 °C
Operating pressure	70 bar
Turbines	HP, 4x LP
Sea water flow	38 m^3/s
Electricity output per year	ca. 7 TWh

2.1 TURBINE VIBRATION MONITORING SYSTEM – VIBROCAM

The turbine vibration monitoring system in Olkiluoto 1 and Olkiluoto 2 plant units is manufactured by Siemens and is called VibroCam 5000. The system is first of its kind and both TVO and Siemens put huge effort when developing the user interface on top of Siemens' SPPA 3000 system. The systems installed in Olkiluoto monitor the vibration behaviour of turbines, generators stators and main circulation pumps.

The development work done with the VibroCam in Olkiluoto was so valuable that similar system with updated software has been installed in many other nuclear powerplants.

At the beginning of commissioning the VibroCam vibration monitoring system it run as a parallel system with old VibroView. The installation of VibroCam was completed and measurements were started in OL1 on 23rd of May 2012. The old VibroView remained as a parallel system until the outage R116 on 2016. VibroCam was taken in operation at OL2 on 14th of January 2013 and old VibroView was dismantle not until outage R217 on 2017.

2.1.1 Operational functions of VibroCam

VibroCam vibration monitoring system provides valuable information for operators and vibration specialist of the condition of turbogenerator and main circulation pumps.

Turbine vibration monitoring system is also extremely critical during the turbine run ups since the VM600 protection system measures only the vertical vibrations of bearing pedestals. In OL1 and OL2 there is a procedure that vibration specialist is always present during run ups monitoring the vibration overall behaviour but especially the shaft vibrations. With flexible rotor it is crucial that the rotor is aligned, straight and has no rubbing when rolling over the critical frequencies.

The user interface of VibroCam is extremely visual and user friendly and the user can with a single look get a comprehensive understanding of the turbogenerators and main circulation pumps condition with the clear and informative mimic display, see figure 2.1. When clicking any of the pump icons at the lower section of mimic display the pumps mimic display opens, see figure 2.2.

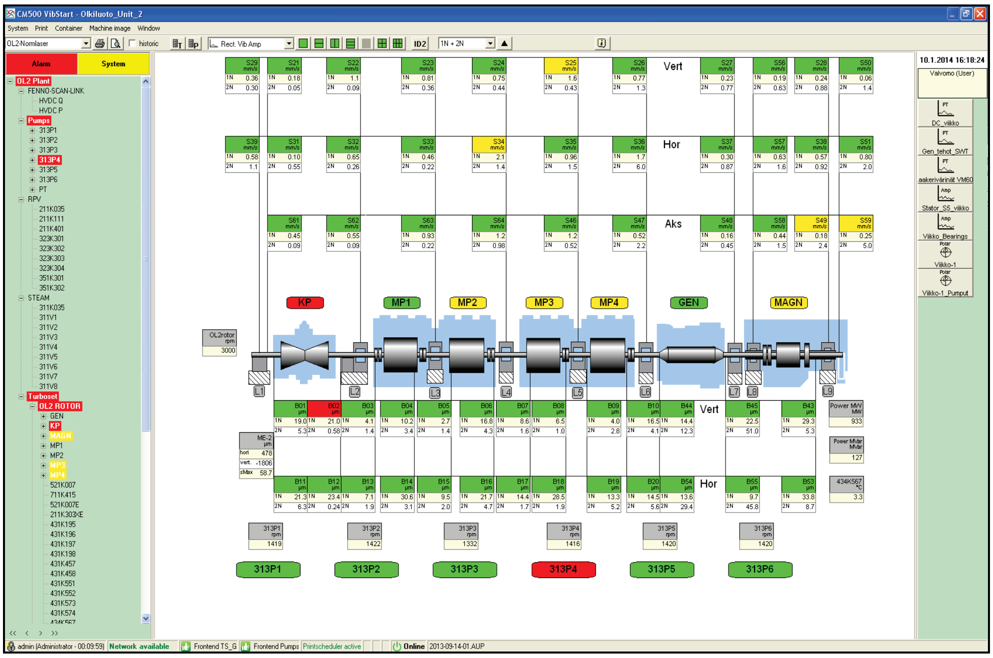

Figure 2.1. Main mimic display of VibroCam

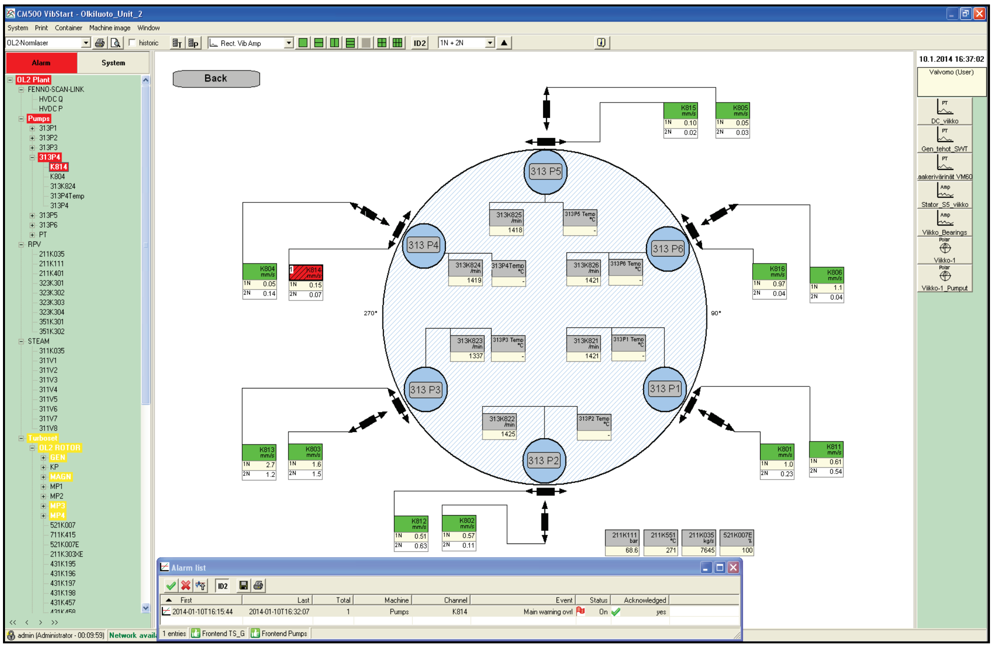

Figure 2.2. Pump mimic display

VibroCam is based on order tracking and presents trends of overall vibrations (mm/s RMS for bearing pedestals and pump frame vibrations and μm$_{0\text{-peak}}$ for shaft vibrations), orders from 1xN to 4xN and ResV component that includes all non-harmonic frequencies. The system also shows the phase angle from 1xN to 4xN orders. Spectrum, time waveform, orbit and spectra map are also available with VibroCam. There's also a huge amount of process signal imported to VibroCam that enables the combined graphs with vibration and process data. Different graphs available from VibroCam are presented in figures 2.3-2.9.

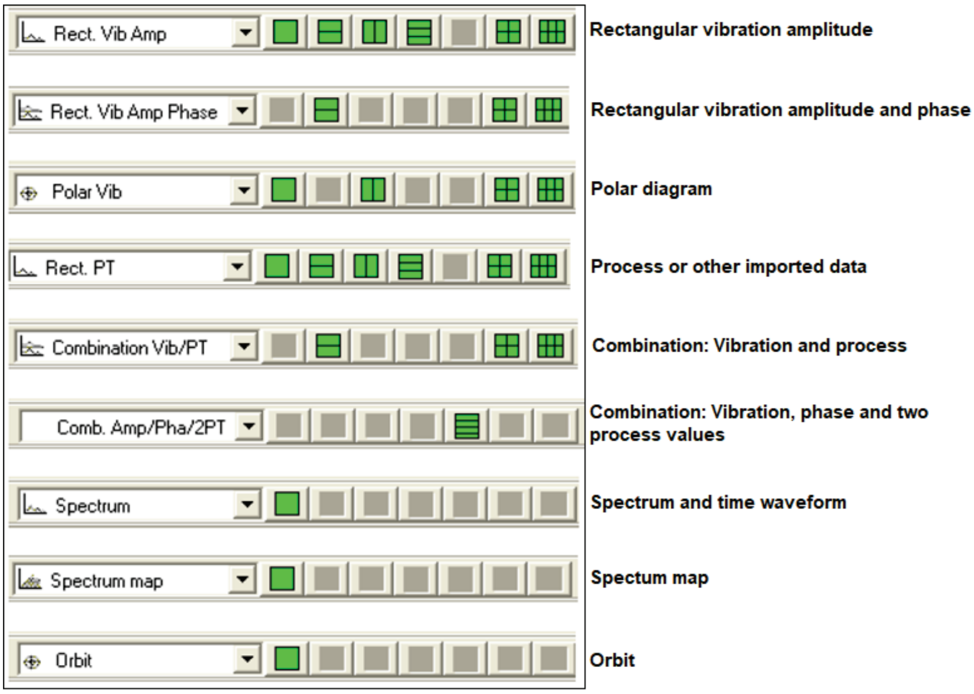

Figure 2.3. General picture of different kind of graphs

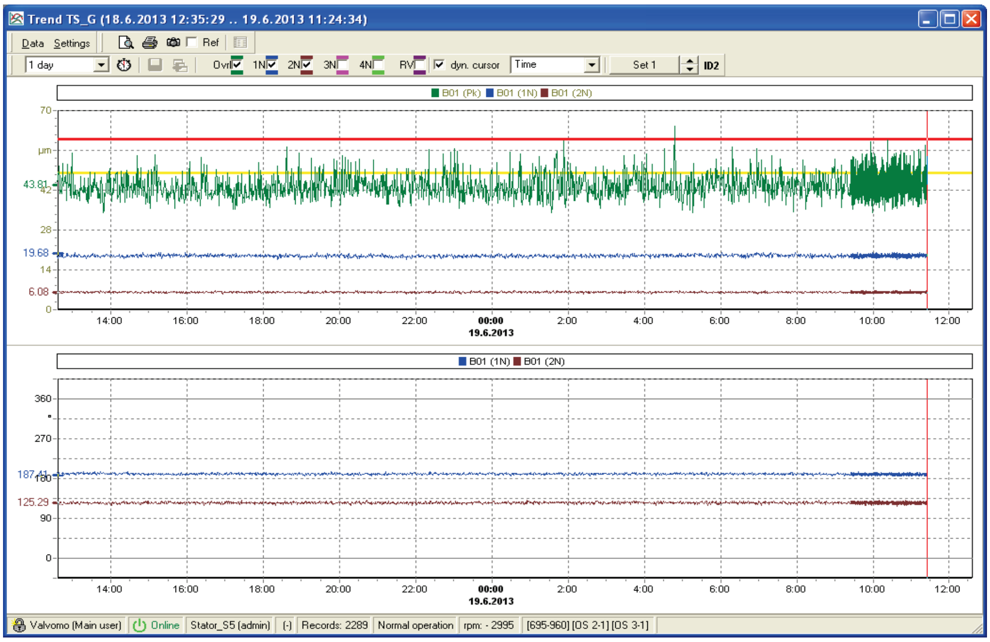

Figure 2.4. Rectangular vibration amplitude and phase

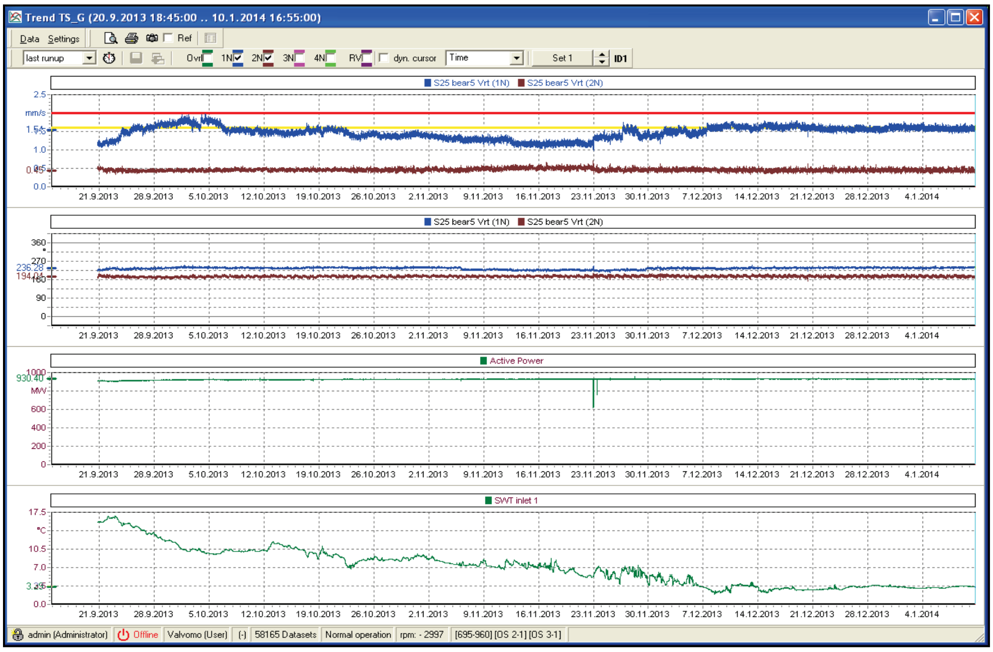

Figure 2.5. Combination: Vibration amplitude, phase and two process signals

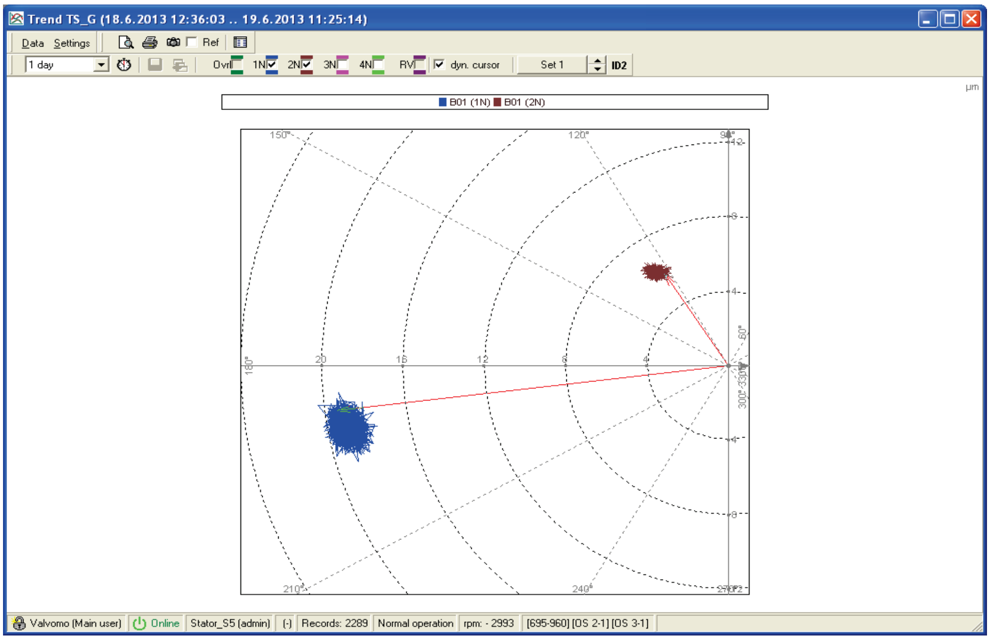

Figure 2.6. Polar diagram

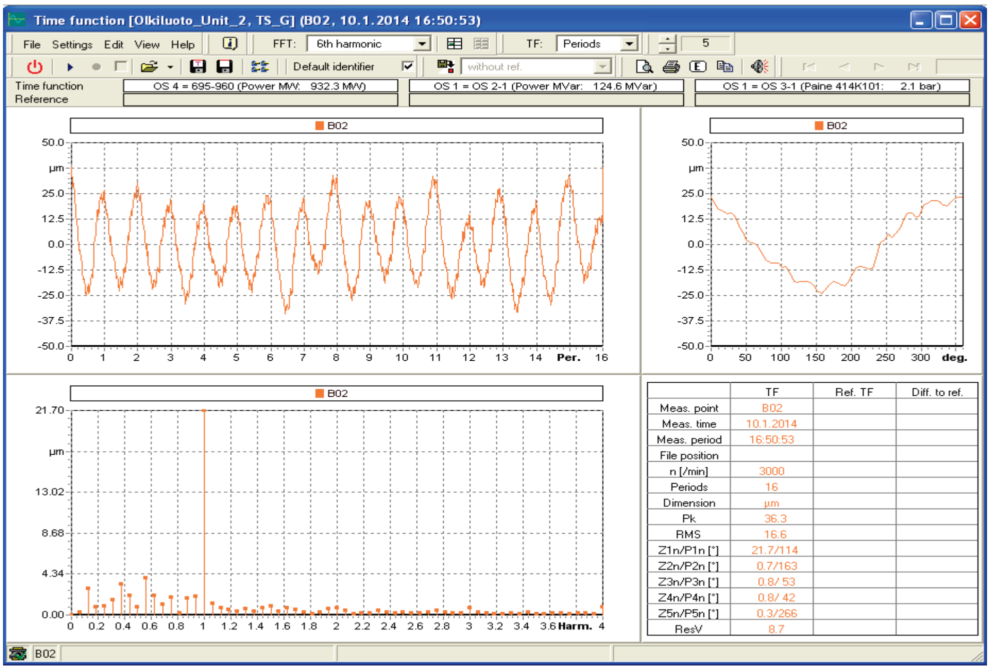

Figure 2.7. Spectrum and time waveform

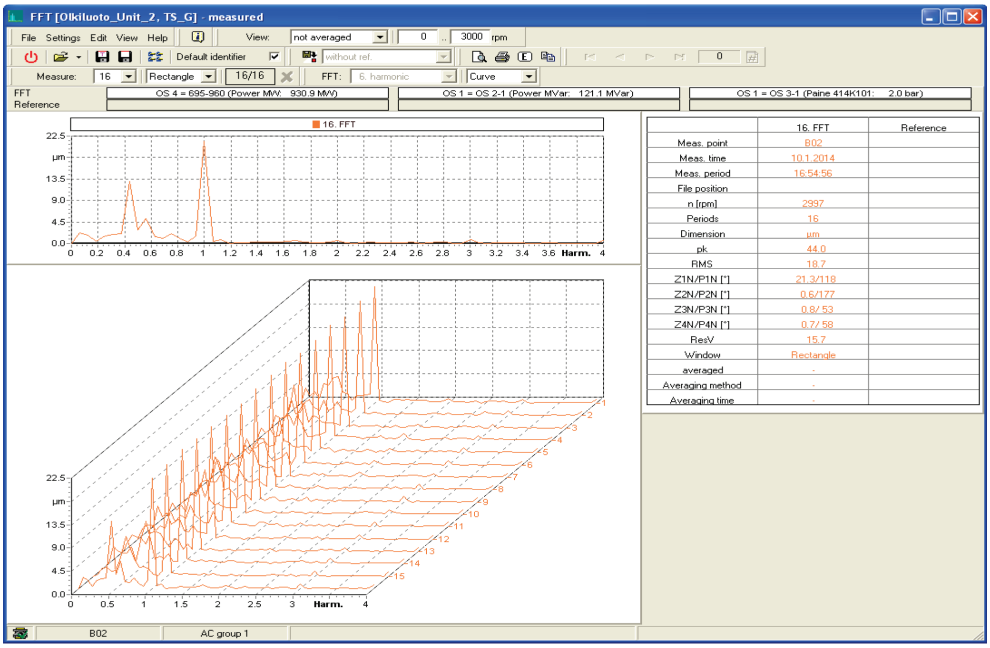

Figure 2.8. Spectrum map

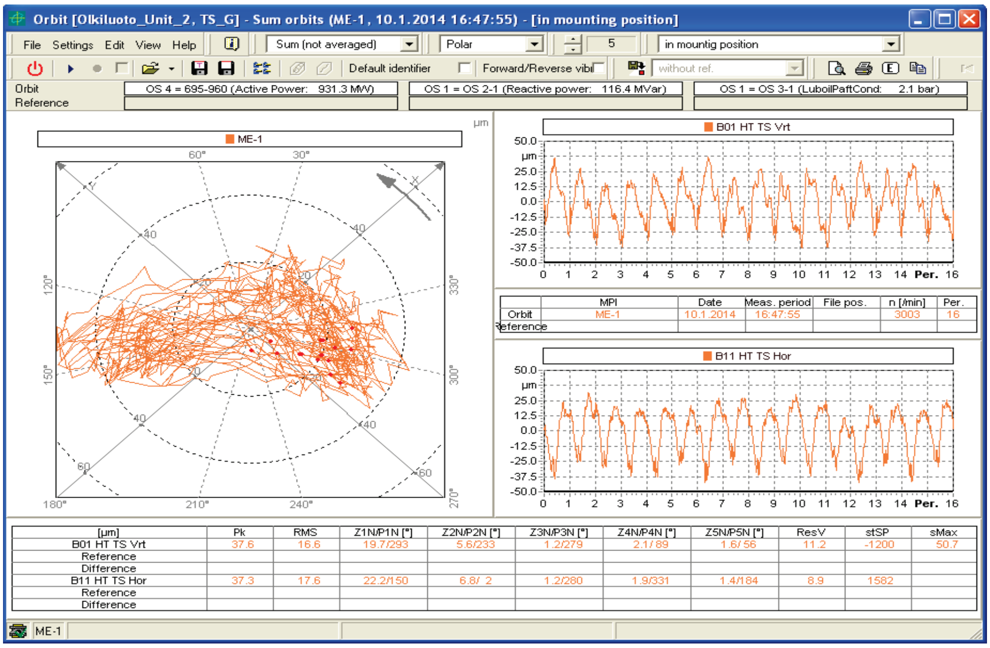

Figure 2.9. Orbit

VibroCam also has a wide selection of different kind of alarms available. There are two main type of alarms, system alarms that indicate a fault in signal or frontend and alarms that indicate a violation of a threshold, see figure 2.10.

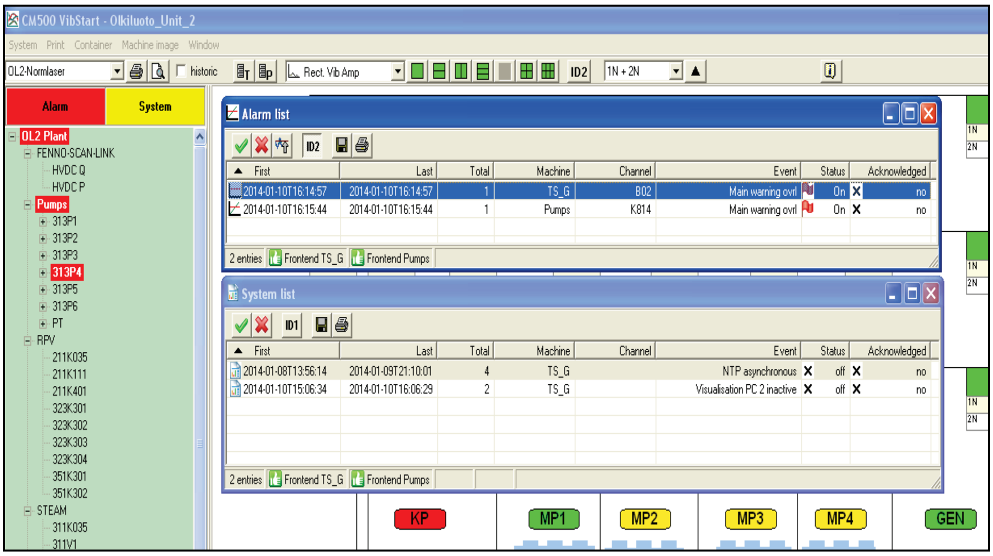

Figure 2.10. Alarms

There are many different kinds of thresholds and limits available in VibroCam. Vibration overall amplitude has absolute warning and alarm limits that when exceeded an alarm is triggered. There is also a band limit that has maximum and minimum limits for vibration overall amplitude. For 1xN and 2xN orders there are circle alarms that limit both amplitude and phase of the measured signal. Alarms are presented in figure 2.11.

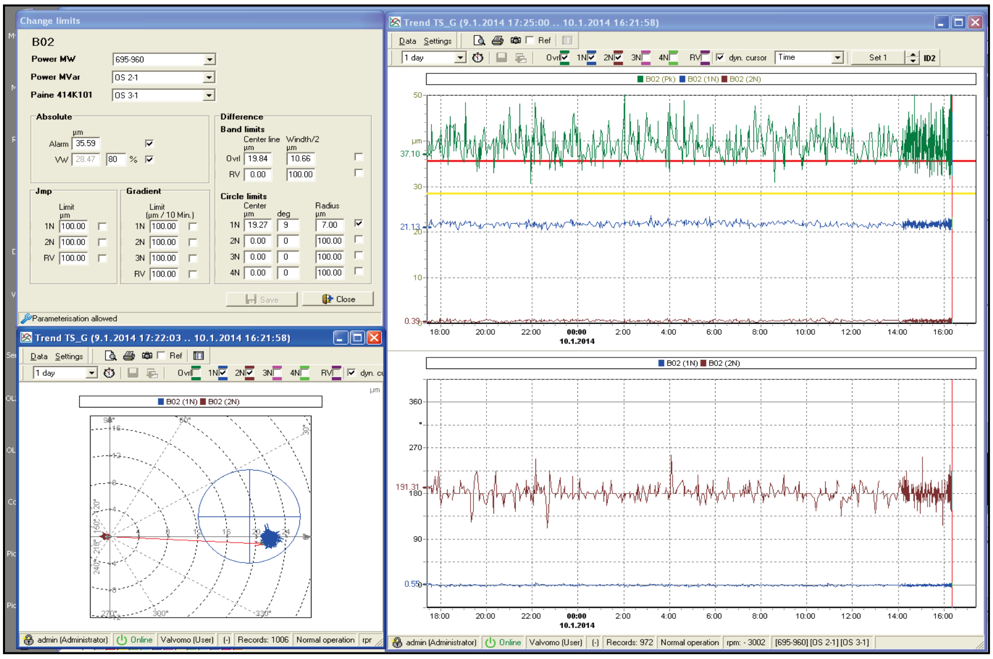

Figure 2.11. Different alarms on VibroCam

VibroCam monitoring system also has a batch-print tool that allows to print different kinds of graphs from pre-determined containers. Each user may create their own containers that have the selected kind of diagrams form selected transducers. The batch-print tool is a significant help in reporting.

VibroCam has a build in tool called Normal list that can be customized by the user. Normal list contains all valuable data from the current vibration situation and they are stored every 5 minutes. Normal lists can be examined on visualisation PC's or they can be printed out.

VibroCam also has a Shortlist tool that gets its data straight from the frontend and doesn't depend on the function of visualisation PC's. Shortlist is provided by an old line printer which operation is built in system.

2.1.2 System description

VibroCam 5000 consists of the following main component:

- VD5000 data collection units or so called frontends
- CM500 software package, with TVO modifications
- Normal Windows PC's

Turbine and main circulation pumps monitoring systems are same at both plant units but some deviations exist in stator measurements. All vibration signal in both plants are gathered in one cabinet at I&C room next to the main control room. From this cabinet the signals are wired to the cabinets nearby where the VibroCam frontends are located.

Turbines, generator and pumps all have their own frontend. All frontends have huge number of signals wired and brought from process computer via link. The number of signals is listed below:

- Turbine frontend has 64 out of 64 wired AC-signals and 48 analog DC-signals
- Generator frontend has 64 out of 64 wired AC-signals, 48 analog DC-signals and 118 DC-signals via Ethernet form PMS
- Pump frontend has 12 out of 24 wired AC-signals, 96 analog DC-signals and 104 DC-signals via Ethernet from PMS

VibroCam assembly also includes in addition of frontend two visualisation PC's, a laser printer and line printer. Visualisation PC1 is located at the back of MCR and Visualisation PC2 is in turbine operators table. The VibroCam system is illustrated in figure 2.12.

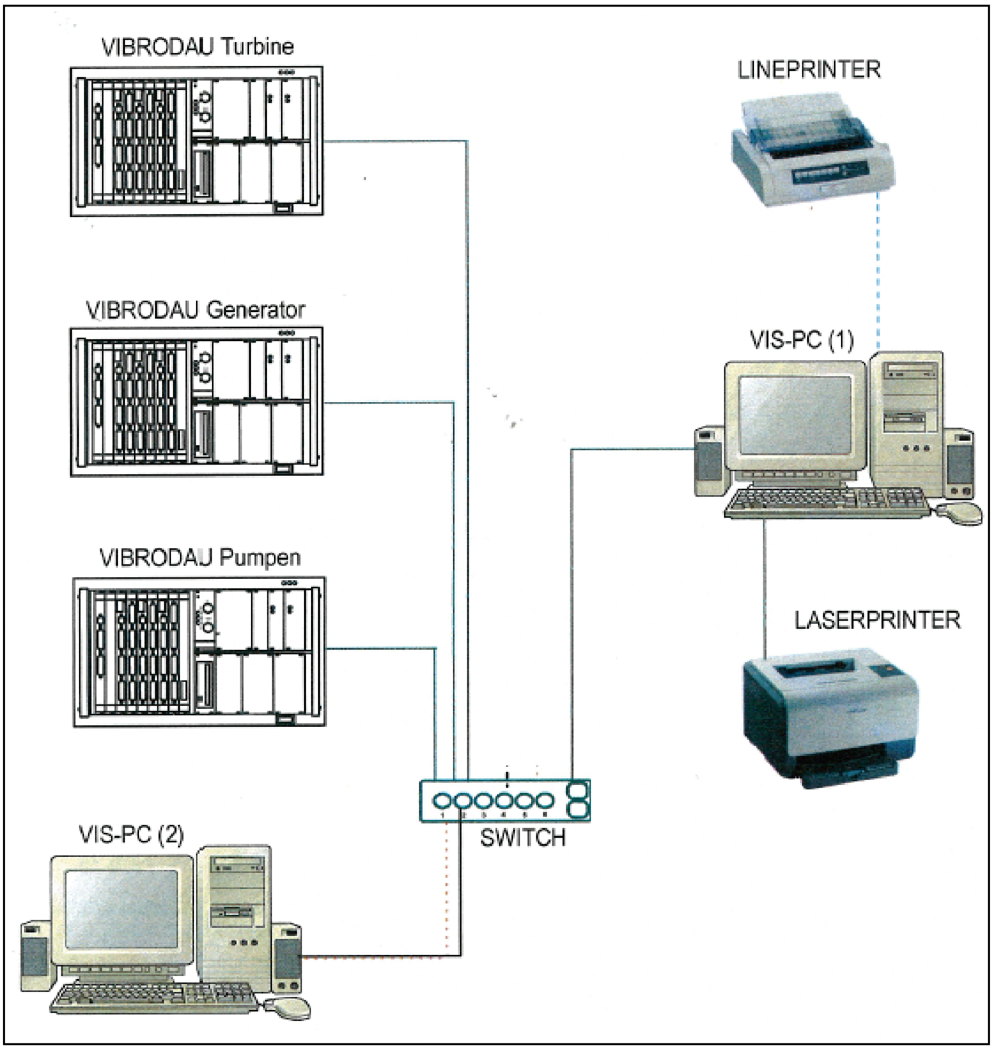

Figure 2.12. VibroCam main components

VibroCam vibration monitoring systems uses BK Vibro's VS-068 and VS-069 type velocity transducers to measure vibrations in every bearing pedestal, governor and water device. In every other measuring location except in governor the vibrations are measured in vertical, horizontal and axial direction. The shaft vibrations are measured using BK Vibro In-081 proximity probes. The keyphasors are traditional proximity probes manufactured by SKF typed CMSS668. The transducer locations are presented in figure 2.12.

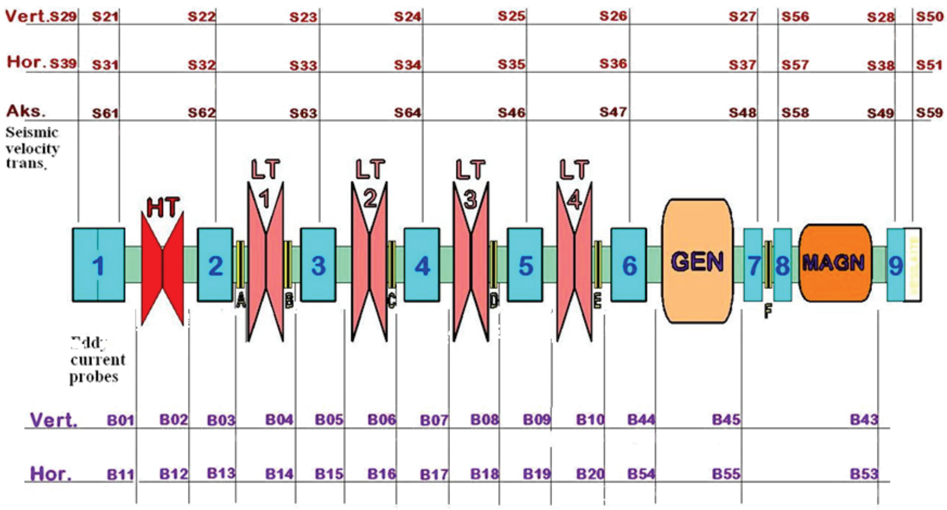

Figure 2.12. VibroCam transducers

2.1.3 User experiences of Vibrocam vibration monitoring system

The VibroCam has pointed out to be extremely suitable for turbogenerators and pumps vibration monitoring and full fills all system requirements. It is easy to use but still has all the function required.

Issue with the current VibroCam is that even though the system has been the primary and only vibration monitoring system since 2016 and 2017 the hardware is getting old and spare parts are not so easily available. However as long as assistance is received from the manufacturer the system can be trusted to provide accurate data of plant units turbogenerators and main circulation pumps condition for years to come.

2.1.4 VM600 protection system

The VM600 protection system is completely separate system from VibroCam vibration monitoring. VM600 measures vertical vibration velocity overall amplitude from bearing pedestals. Each bearing pedestal has three MEGGIT CV214 velocity transducers side by side. When two of the three transducers overall vibration amplitude exceeds the threshold, an alarm is triggered. Protection systems warning (H1) limit is 7.5 mm/s RMS and the turbine trip limit (H2) is 9 mm/s RMS. The vibration amplitudes are displayed in process computer and the signals are brought to VibroCam via link.

The VM600 and VibroCam velocity transducer are presented in figure 2.13.

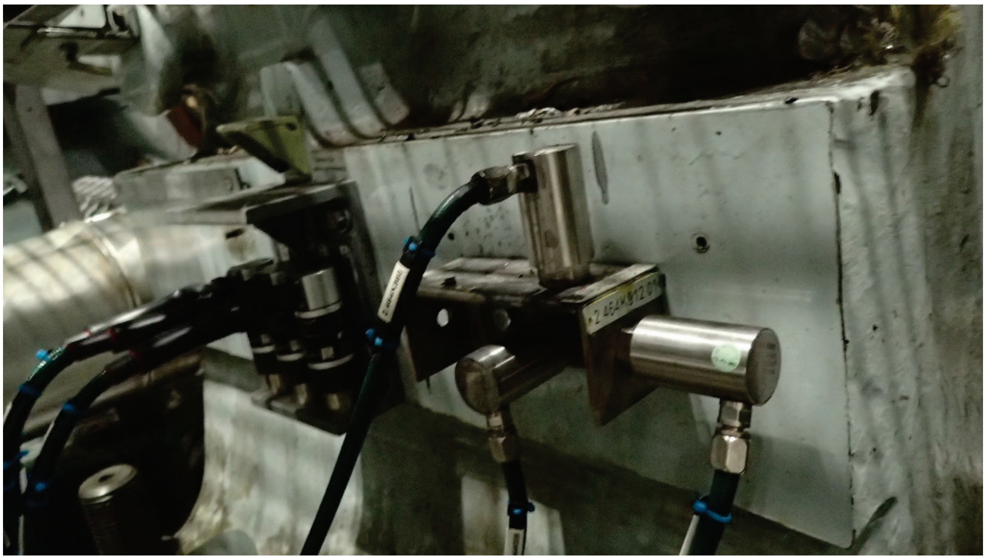

Figure 2.13. VM600 and VibroCam transducers in bearing pedestal

2.2 TEMPORARY CONDITION MONITORING SYSTEM OF FEEDWATER PUMP 2.445P303 AT OLKILUOTO 2

The vibrations of feed water pump 2.445P303 has been measured and the data collected with a specially modified Trendion Online V5 measuring device from 10th of March 2020. The system was installed to gather vibration data for condition-based maintenance project and to investigate the pumps shafts axial displacement. The pumps installed have suffered from seal breakages during quite a lot during the past decades that has even caused production losses. This pilot is the first time during the plants operation when the displacement has been studied and vibration data gathered this comprehensively.

The regulations of the power plant forbid external connection from the restricted plant area. Due to this all external connections such as 4G were removed from the measuring device. Usually, the measuring device would automatically upload the vibration data to server and the data would be available for all users who have user IDs in online. But in this case, due to regulations the data is manually retrieved form the measuring device with a customized laptop, brought out of plant manually and then uploaded to the server.

The used measurement instrument was equipped with 12 dynamical input channels. For these input channels, 11 accelerometers and one proximity probe were installed. For more details about transducer locations, please refer to figure 2.14.

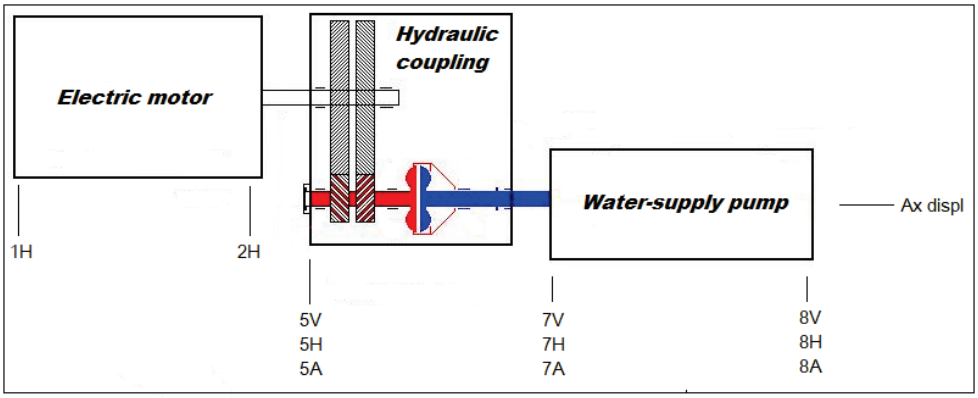

Figure 2.14. Transducer's locations on feedwater pump

The measuring device was configured to monitor the following parameters:

- Overall vibration as velocity, V_{rms} (mm/s RMS, 10–1000 Hz)
- Peak value of acceleration, A_{peak} (m/s^2)
- Accelerometers DC voltage, V_{dc} (Bias voltage)
- Axial displacement, (µm)
- DC voltage of axial displacement, V_{dc} (Voltage)
- Time waveforms and spectra

A_{peak} and V_{rms} were measured with the maximum sampling frequency of 52 kHz. The length of the A_{peak} sample was 0.5 s whereas the length of the V_{rms} sample was 1.25 s. The resulting signal bandwidth was approximately from 2 Hz to 25 kHz with the used sampling settings.

Axial displacement was measured with a sampling frequency of 1.625 kHz, and the sample length was set to 0.5 s. The resulting signal bandwidth for the axial displacement measurement was approximately from 2 to 800 Hz.

Measurements are performed continuously, but the calculated parameter values are stored approximately every 5 minutes for all parameters. Spectra and time waveforms are measured once in 24 hours.

The user interface of online portal is illustrated in figure 2.15.

Figure 2.15. Trendion Online

2.2.1 User experiences

TVO wanted to figure out what sort of device is suitable for long term vibration monitoring with temporary installation and what it demands. The installation of Trendion Online V5 was easy and fast excluding the installation of axial shaft displacement measurement. The measurement results are easily accessible with online browser and using the online portal has been easy. The only challenge has been retrieving the data from plant manually. The measurement data has been good quality but so far no faults in pumps condition have occurred.

2.3 VIBRATION MONITORING OF HIGH-PRESSURE AUXILIARY CONDENSER PUMPS

High-pressure auxiliary condenser pumps were installed few years ago in OL1 and OL2 plant units. The purpose of the pumps was to increase the power of plant units and enable operating the plant at 100 % of power using three feedwater pumps. There are three similar pumps installed in both plant units.

The pumps have four pairs (total of 8) proximity probes installed to measure the shaft vibration, two proximity probes to measure the axial displacement of shaft and one velocity transducer to measure the vibrations on pumps drive end. Pumps are also equipped with multiple pressure-, flowrate- and temperature measurements. Axial displacement measurements and the vibration overall amplitude (mm/s RMS) in pumps drive end have protective features and when a threshold is exceeded the pump will trip.

Vibrations are only monitored from the process computer (PMS) which why the only data available is the overall amplitudes. This excludes all possibilities to do any deeper analyses with the permanent measurements. All the system produces is trends without any scales where you can examine individual values, see figure 2.16.

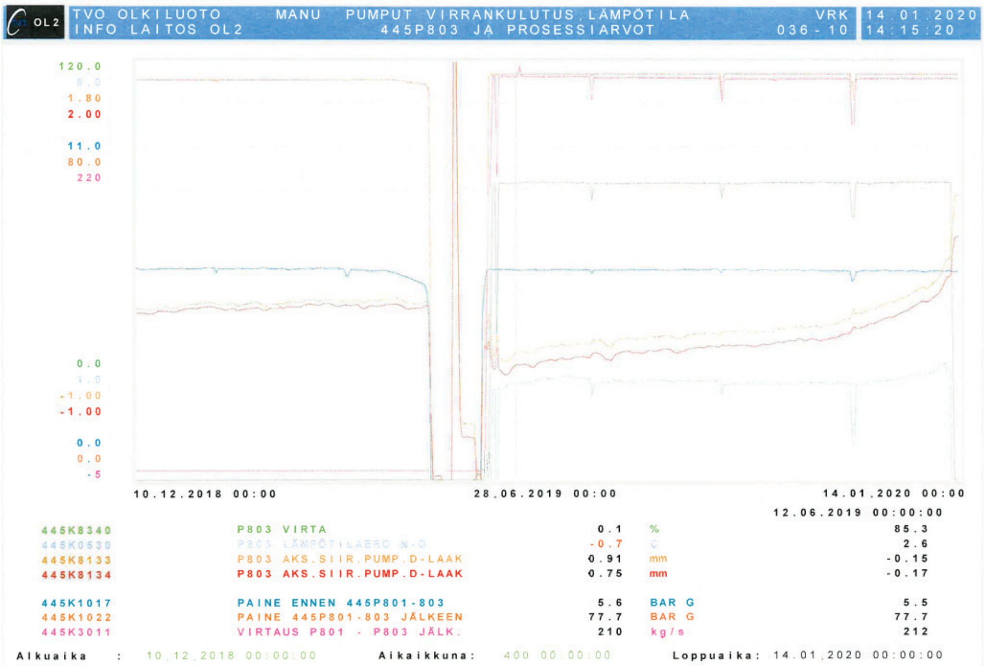

Figure 2.16. Trends on PMS display from 2.445P803

Luckily the signals are available in the amplifier cabinets that allows using a portable analyzer. TVO has carried out additional analyses using Beran 766 vibration analyzer to investigate the vibration behavior of the pumps. Measurements has been carried out also straight from the pumps using CSI 2140 portable vibration analyzer and accelerometers.

The pump’s structure, transducer locations and main features are presented in figure 2.17.

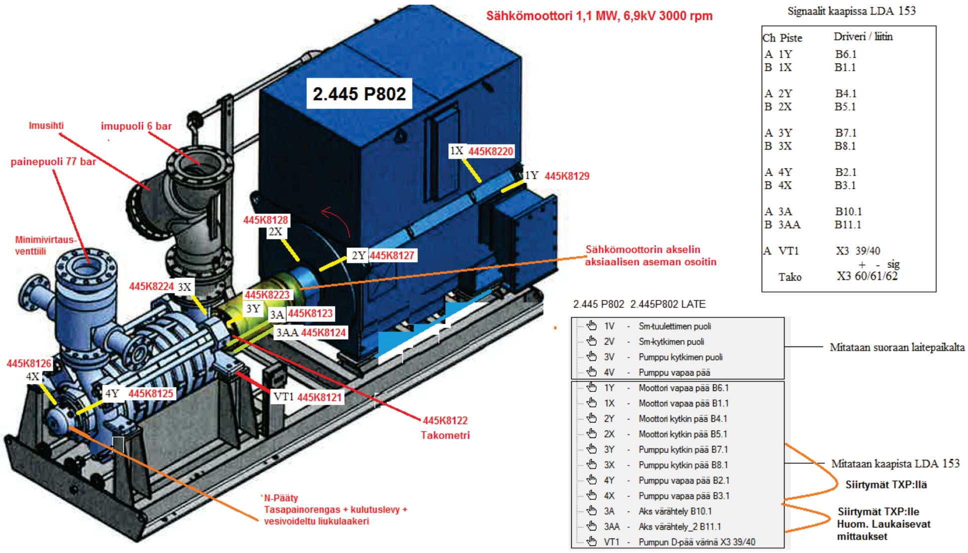

Figure 2.17. 2.445P802 structure and measuring points

2.4 VIBRATION MONITORING OF X.725F1-4 CIRCULATION FANS INSIDE THE CONTAINMENT

The circulation fans inside containment are equipped with old Tillquist velocity transducers. The system is primitive analog technology from the 70's. The measures vibration from the fans structure and when a threshold limit is exceeded it send an alarm to the main control room (MCR). The only information MCR receives is that the limit has been exceeded. The amplitude is only available from the local displays where the amplitude is presented with pointer at a rough scale. Even though the transducer measures velocity (mm/s) the signal is integrated in to displacement (µm). The main components, transducer, I/U converter and local display are presented in figure 2.18.

Figure 2.18. Transducer, I/U converter and local display

As the past decades have shown in OL1 and OL2 plant units, all that a high-quality vibration analyses require is a transducer inside the plant when the component is not accessible. Few years ago, when vibrations of one of the fans caused an alarm, vibration specialist was able to investigate the vibration behavior of the fans using modern CSI 2140 portable analyzer by taking the vibration signals from I/U converters. With the portable analyzer the specialist able to measure vibration overall amplitude, spectra and time waveforms to perform a comprehensive analysis so that the maintenance organization was able to plan the overhaul during the next outage. The measurement arrangement is presented in figure 2.19.

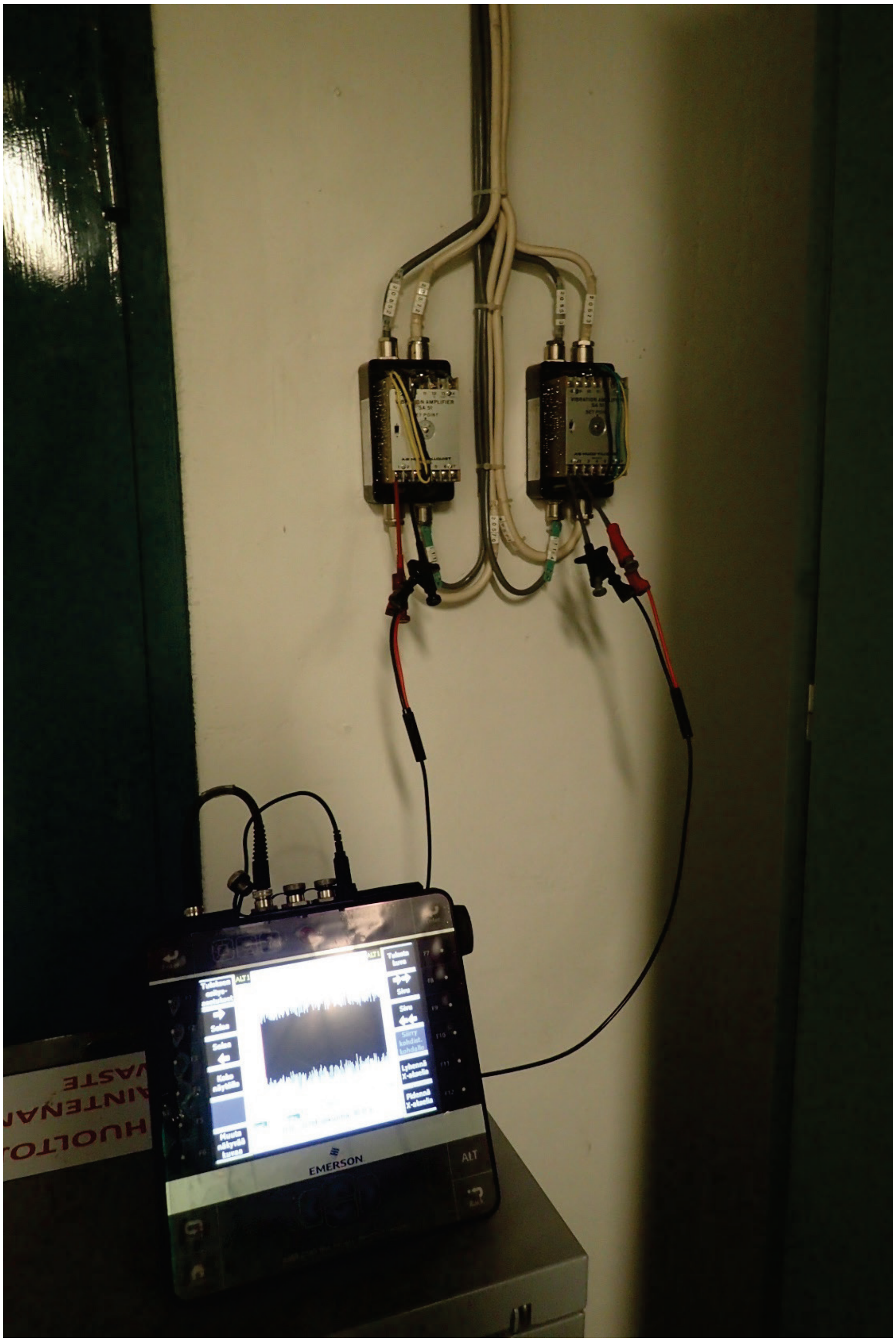

Figure 2.19. Measurement arrangement of circulation fan

2.5 ACCELEROMETERS IN MAIN STEAM LINES IN OL1 AND OL2

In OL1 and OL2 plant units there are multiple vibration measurements installed in main steam lines inside containment and in turbine sides steam lines. OL1 has total of 39 accelerometers installed and OL2 has 59 accelerometers. In addition to transducers installed in steam lines, the HP-adjustment valves also have one accelerometer each.

The vibrations aren't being continuously monitored and the measurements are done using portable vibration analyzer. The vibrations are measured usually once or twice in year but in case some investigation or phenomena needs to be studied that might affect the vibration behavior of steam lines a comprehensive measurement will be done using Beran 766 analyzer for example.

The transducers have been installed either on support structures or to the pipe using special made fitting clamp. The signals from containment are wired to a cabinet at I&C room next to the MCR. The signals in turbine steam lines are wired to cabinet on plant that has no radiation and is accessible during the normal plant operation. The transducers' locations in OL2 are presented in figures 2.20 and 2.21.

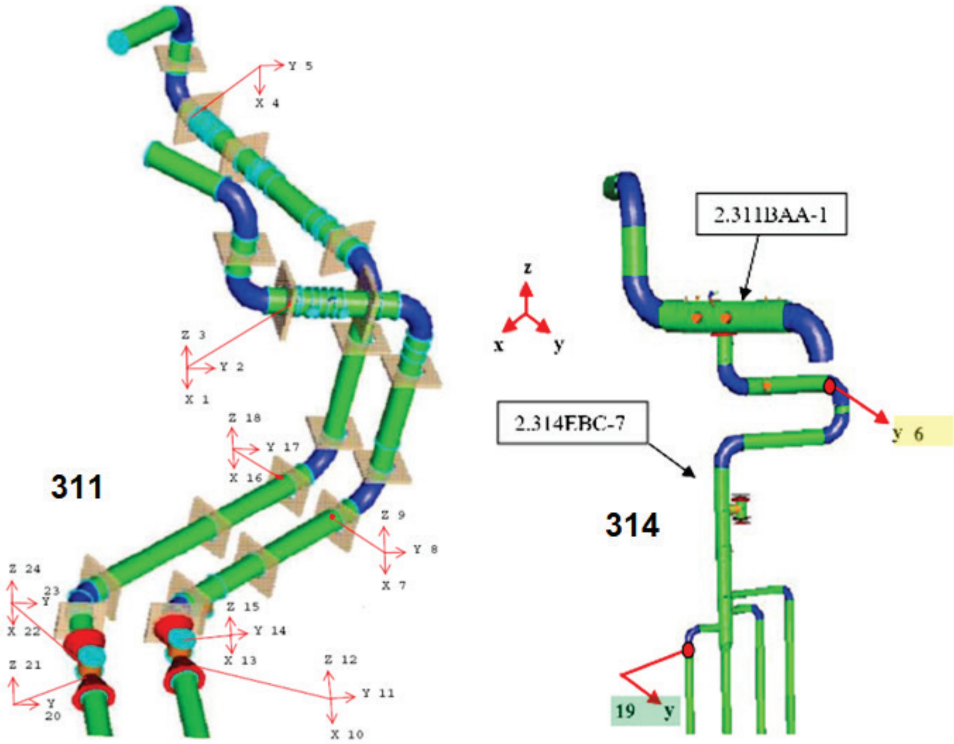

Figure 2.20. Transducers inside OL2 containment

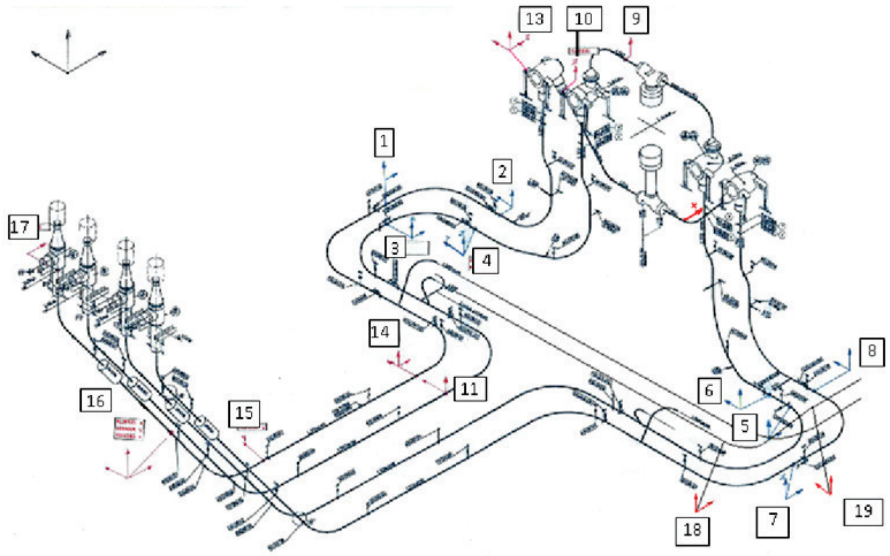

Figure 2.21 Transducers in OL2 turbine steam lines

At OL1 the accelerometers inside containment are B&K type 8315 accelerometers and the accelerometers inside OL2 are PCB made 357B53 or -B54 type radiation protected and suitable for high temperature environments up to 288 °C. In turbine side steam lines at OL1 all transducers are typed Monitran MTN 1020F and are attached to the support structure. In OL2 also PCB 357B53 and -54 transducers are being used. Monitran transducer is presented in figure 2.22 and PCB 357B53 in figure 2.23. The long term experience of monitoring the vibration behavior of main steam lines has shown that Monitran accelerometers resist the radiation poorly and malfunction in few years when installed in location with high levels of radiation.

Figure 2.22. Monitran MTN 1020F accelerometer

Figure 2.23. PCB 357B53 accelerometer

2.6 ACCELEROMETERS IN TURBINE PILLARS

At the beginning 2000's the vibration behavior of turbine pillars was monitored during the turbine run ups and run down. There are 15 accelerometers installed in both plants in mid and upper parts of pillars, see figure 2.24.

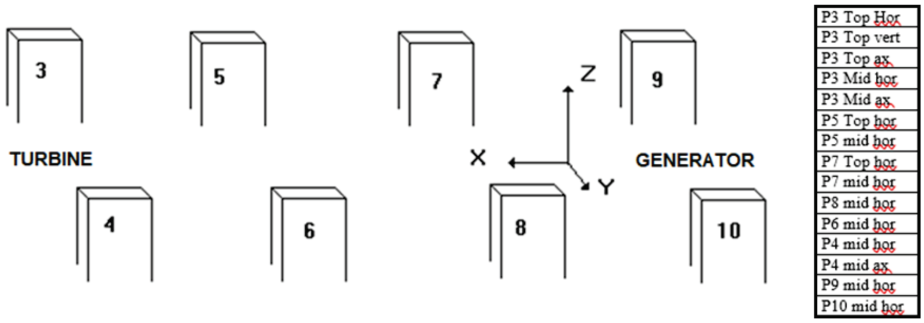

Figure 2.24. Accelerometers in turbine pillars

Half of the installed transducers are B&K type 4831 charge accelerometer that are connected to an 8-channel B&K charge amplifier. The other half of transducers are the Monitran MTN 1020F type ICP accelerometers.

Nowadays the turbine pillar vibrations aren't monitored but the transducer are still installed. The turbine pillars transducers are wired to the same I&C next to the MCR where steam line signals are wired. Recently the wiring of turbine pillars has been used when measuring other components and the get the signals out of the condenser space that has high level of radiation during normal operation.

3 CONDITION MONITORING SYSTEMS IN OL3 NUCLEAR POWERPLANTS NUCLEAR ISLAND

Olkiluoto 3 is a power plant unit located in Eurajoki, Finland with a Pressurized Water Reactor (PWR) with an output of approximately 1,600 MWe at Olkiluoto. The type of the unit is commonly known as a European Pressurized Water Reactor (EPR). The unit is being built by a consortium formed by AREVA NP and Siemens. AREVA NP is delivering the reactor plant and Siemens is delivering the turbine plant.

Olkiluoto 3 is considerably more modern plant unit than Olkiluoto 1 and 2 plants. Its construction was commenced in August 2005, over 20 years after OL1 (10.10.1979) and OL2 (10.7.1982) were synchronized to national grid and started their commercial production. Because of its modernity, OL3 also has several condition monitoring systems which do not exist in the older units.

Originally OL3 was supposed to start its commercial production in June 2009. Due to different delays the schedule to start commercial production is now in early 2022. The Finnish authority STUK granted permit to load the reactor on 26th of March 2021. The delay has had an effect on condition monitoring systems installed in OL3. Due to major delay, many of the condition monitoring systems are beginning to be at the end of their lifecycle and modernization has already begun in some of the systems.

The general technical data of Olkiluoto 3 nuclear power plant is presented in table 3.1 and structure in figure 3.1.

Table 3.1. General technical data of Olkiluoto 3 NPP

Reactor thermal power	4300MWth
Electrical power, gross	1720 MWe
Electrical power, net	1600 MWe
Efficiency	ca. 37 %
Primary coolant flow	23135 kg/s
Coolant temperature in pressure vessel	312 °C
Coolant temperature in hot leg	328 °C
Coolant temperature in cold leg	296 °C
Electricity output per year	ca. 13 TWh
Sea water flow	57 m^3/s
Service life	ca. 60 years
Building volume	1000000 m^3
Containment volume	80000 m^3
Containment design pressure	5.3 bar

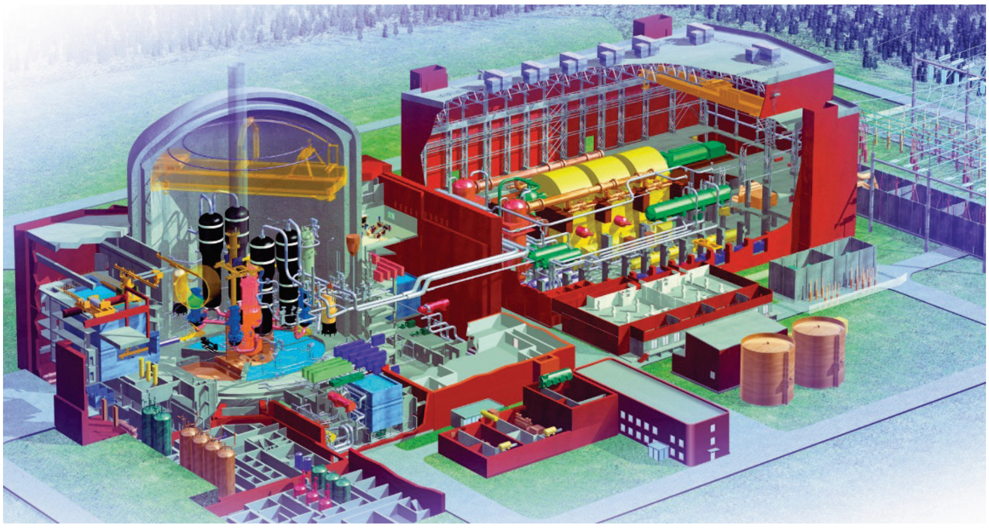

Figure 3.1. Olkiluoto 3 NPP

Since OL3 plant unit is still under commission the user experiences of multiple monitoring systems installed in plant are minimal or do not exist. The monitoring systems installed at OL3 are presented in this study but it's already known that after the fuel loading (FLG) in addition of using the installed monitoring systems, portable analysers will be used to verify the results of these systems and to study the vibration behaviour of different systems by using the transducers of permanently installed monitoring systems.

3.1 JYG – CONDITION MONITORING OF PRIMARY CIRCUIT AND REACTOR COOLANT PUMPS

The JYG condition monitoring system monitors and detects changes in the vibration behaviour of primary circuit including reactor pressure vessel, pressurizer, main coolant lines aka hot legs and cold legs, steam generators and reactor coolant pumps. The primary circuit is illustrated in figure 3.2.

Figure 3.2. Main circuit of OL3

The vibration behaviour of a component is one of the most sensitive indicators of changes in mechanical condition of plants components. The vibration monitoring system, JYG, provides the plant operator and specialists information about changes in condition of the monitored components at a very early stage in order to plan and initiate inspection and maintenance activities in time. Hereby the vibration monitoring system helps to detect incipient damages and to prevent consequential damages and forced outages.

3.1.1 Operational functions of JYG vibration monitoring system

The vibration behaviour of reactor pressure vessels (RPV) internals and primary circuit components, at this point excluding the reactor cooling pumps, is acquired by transducers for measuring mechanical vibrations at the outside of the pressure retaining boundary, excore neutron flux noise and pressure fluctuations of the coolant. The JYM vibration monitoring setup and procedures are carried out according to DIN 25475-2.

Primary circuits components behave as a vibrating coupled multiple-mass system. Depending on the degree of coupling each of these measurement variables provide information of vibration behaviour of several components.

At the beginning of OL3 operation the vibration monitoring of RPV internals and primary circuit components is carried out with three operational measurements per fuel assembly cycle that are performed at approximately 100% thermal reactor power and steady state primary circuit conditions: one measurement at beginning, in the middle and at the end of a fuel assembly cycle. These operational measurements are started by the specialist manually and then the JYG vibration monitoring system executes the measurement automatically.

The following vibration signals are used in operational measurements of RPV and primary circuit components:

- 4x vertical absolute displacement vibrations at RPV closure head
- 8 x excore neutron flux noise signals in the biological shield
- 8 x horizontal relative displacement vibrations between cross over legs and building near RCPs
- 4 x horizontal relative displacement vibrations between hot legs and building near SGs
- 4 x vertical relative displacement vibrations between hot legs and building near SGs
- 4 x pressure fluctuations in the cold legs
- 1 x pressure fluctuation in the hot leg of Loop 20

With each operational measurement the measured vibration signals are synchronously acquired, digitized and filtered in the frequency range of 0-50 Hz and 0-200 Hz. The determined signal is turned in to spectra with FFT in which the component's vibrations appear as magnitude peaks.

The most important matter monitored in primary circuits components is the change in measured peaks of spectra, see figure 3.3a. The JYG vibration monitoring system automatically calculates the latest peaks and compares the deviations on the reference values. The system trends amplitudes of selected peaks from certain frequencies and detects the changes in frequencies and increasements and decreasements of amplitudes.

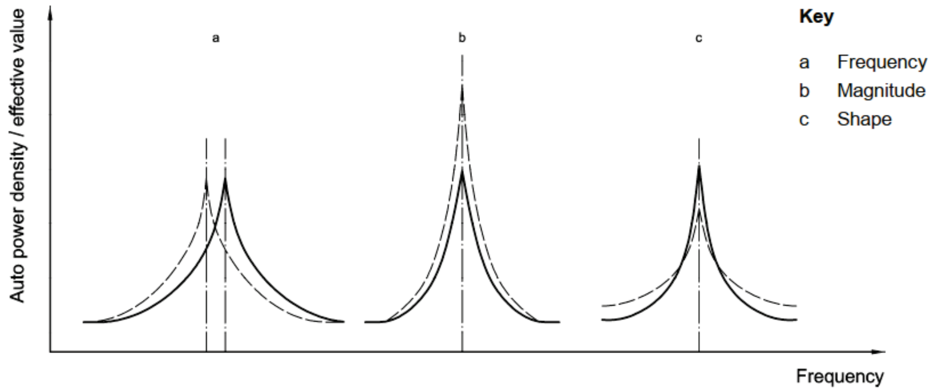

Figure 3.3b. Example of changes monitored

The frequency deviations measured and calculated are compared with attention thresholds that are empirically determined. They characterize the normal scatter band of the monitored parameters for which no damages can be associated to the monitored components. The system automatically provides a report of carried out measurements.

The transducer locations are illustrated in figure 3.3b.

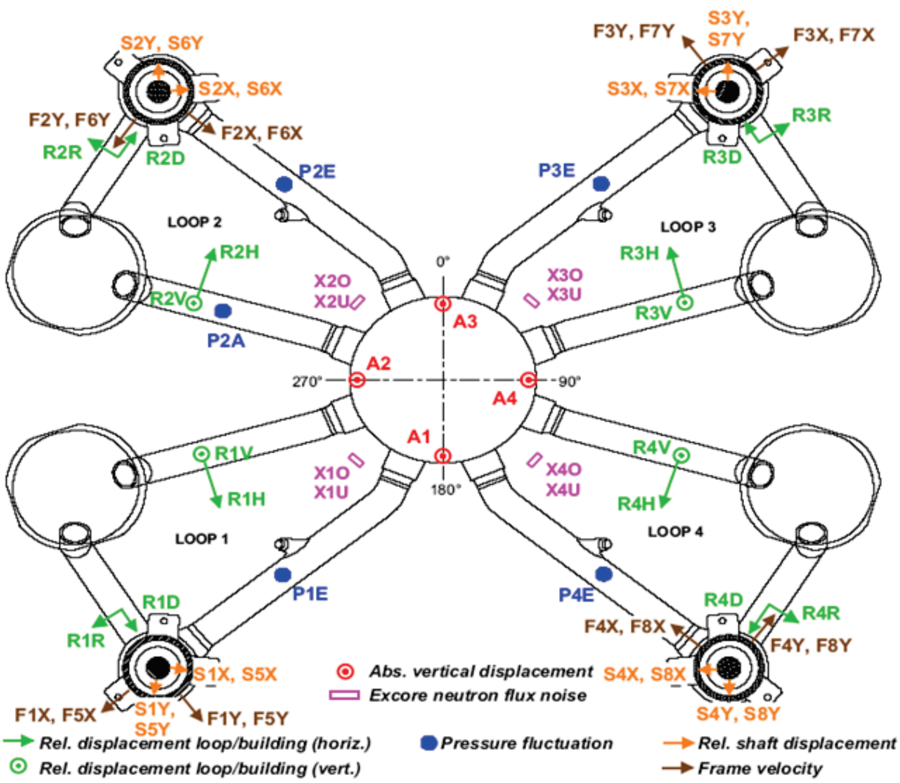

Figure 3.3b. JYG vibration monitoring systems transducers in primary circuit components

JYG system also monitors the vibration behaviour of reactor coolant pumps (RCP). The reactor coolant pumps provide forced circulation of water through the reactor coolant system. The circulation removes heat from the reactor to the steam generators, where it is transferred to the secondary circuit. In all four loops of the primary circuit, the RCP locates between the steam generator outlet and the reactor inlet. The reactor coolant pumps have hydrostatic bearings, which purpose is to lower vibration level.

RCP consists of three main parts: the pump itself, the shaft seals and the motor. The pump hydraulic cell consists of the impeller, the diffuser and the suction adapter. The pump shaft is in two parts connected by a spool piece. The shaft is supported on three bearings: two oil-lubricated bearings in the motor and one hydrostatic bearing at the impeller. There is a double-action thrust bearing at the top of the motor shaft, under the flywheel, to compensate axial forces. Since RCPs at OL3 are extremely large and complex machines that are crucial for plants operation and safety, they are equipped with comprehensive condition monitoring system. The structure of RCP is illustrated in figure 3.4.

Pump	
Number of pumps	4 pcs
Design pressure	176 bar
Design temperature	351°C
Primary coolant flow	28,330 m³/h
Design head	100.2 m ± 5%
Seal water injection	1.8 m³/h
Seal water return	0.680 m³/h
Speed	1,465 rpm
Total height	9.3 m
Total weight without water and oil	112 t
Motor	
Rated power	9,000 kW
Frequency	50 Hz
Main circulation pipes	
Internal diameter	780 mm
Wall thickness	76 mm
Material	Z2 CN 19-10*
Pressurizer connection pipe	
Internal diameter	325.5 mm
Thickness	40.5 mm
Material	Z2 CN 19-10*

*low carbon stainless austenitic steel

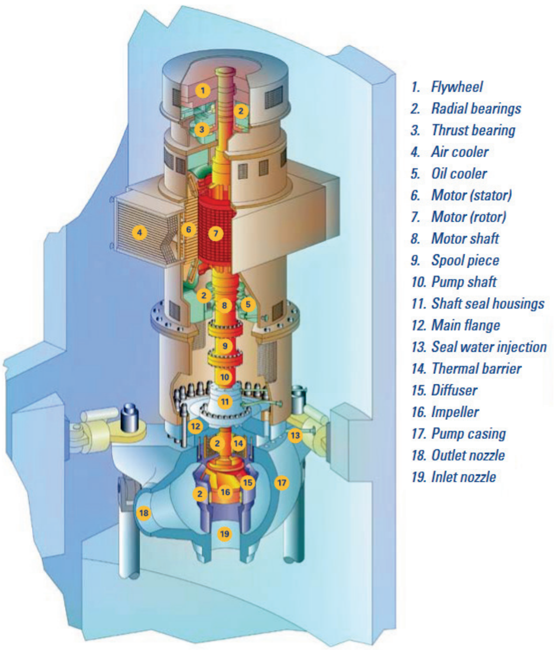

Figure 3.4. The structure and main components of OL3 RCP

The vibrations of the reactor coolant pumps are measured by velocity transducers that measure absolute frame vibration and relative shaft displacements between shaft and frame. The RCP shaft's low speeds are measured by proximity probe. RCPs are also equipped with keyphasors to measure the vibration behaviour of orders that provide valuable information to specialists analysing the pumps vibration behaviour.

3.1.2 System description

JYG vibration monitoring system main components are its transducers, preamplifier stations inside containment and system cabinets next main control room. JYG provides all necessary monitoring and measurement functions such as signal acquisition, conditioning, calibration, analyses and monitoring, data storage and archiving, data display, documentation, announcements of system faults and threshold violations.

JYG monitors the vibration behaviour of primary circuit using absolute displacement transducers, relative displacement transducers, pressure fluctuation transducers, relative shaft vibration transducers and absolute velocity transducers. The system measures, monitors and evaluates variables at 0.5 to 200 Hz bandwidth.

The systems transducers that measure the primary circuits components, excluding the RCPs, are presented more thoroughly below:

The absolute seismic displacement transducer is equipped with magnetic relief that measures the absolute vibration of reactor pressure vessel. The transducers are mounted at reactor pressure vessels closure head with special mounting device and three screws. The transducers most important components are a casing, a spring-type hanging mass in it, a solenoid coil and an inductive sensor arranged between casing and mass. The transducers can be remotely calibrated from the system cabinet. The solenoid coil is supplied with constant direct current. The magnet forces relieve the springs from the weight of the seismic mass. The inert mass can be moved by varying the direct current against a transducer specific lower and upper mechanical stop. The absolute seismic displacement transducer is presented in figure 3.5.

Figure 3.5. Absolute seismic displacement transducer SAUM

The relative displacement transducer is an inductive displacement sensor with straight-lined guided, spring-loaded sensing tip for the measurement of loop piping vibrations near the reactor coolant pumps and steam generators. The transducers cylindrical casing is rigidly mounted with a special mounting device at the building. The sensing feeler presses against the trace bloc which is installed by a special tightening strap and tensioning device at the main coolant line. The sensing feeler follows the relative movement between main coolant line and reactor building. The relative displacement transducer has a measuring range of 50 mm respectively 100 mm. In addition to the relatively small operational vibrations, the quasi-static movements can be followed when it appears as a result of thermal expansions of the loop components while heating up and cooling down the reactor coolant system. The relative displacement transducer can be remotely calibrated with a calibration head that can be controlled manually or computer-aided in the signal conditioning cabinet. The relative displacement transducer is presented in figures 3.6a and 3.6b.

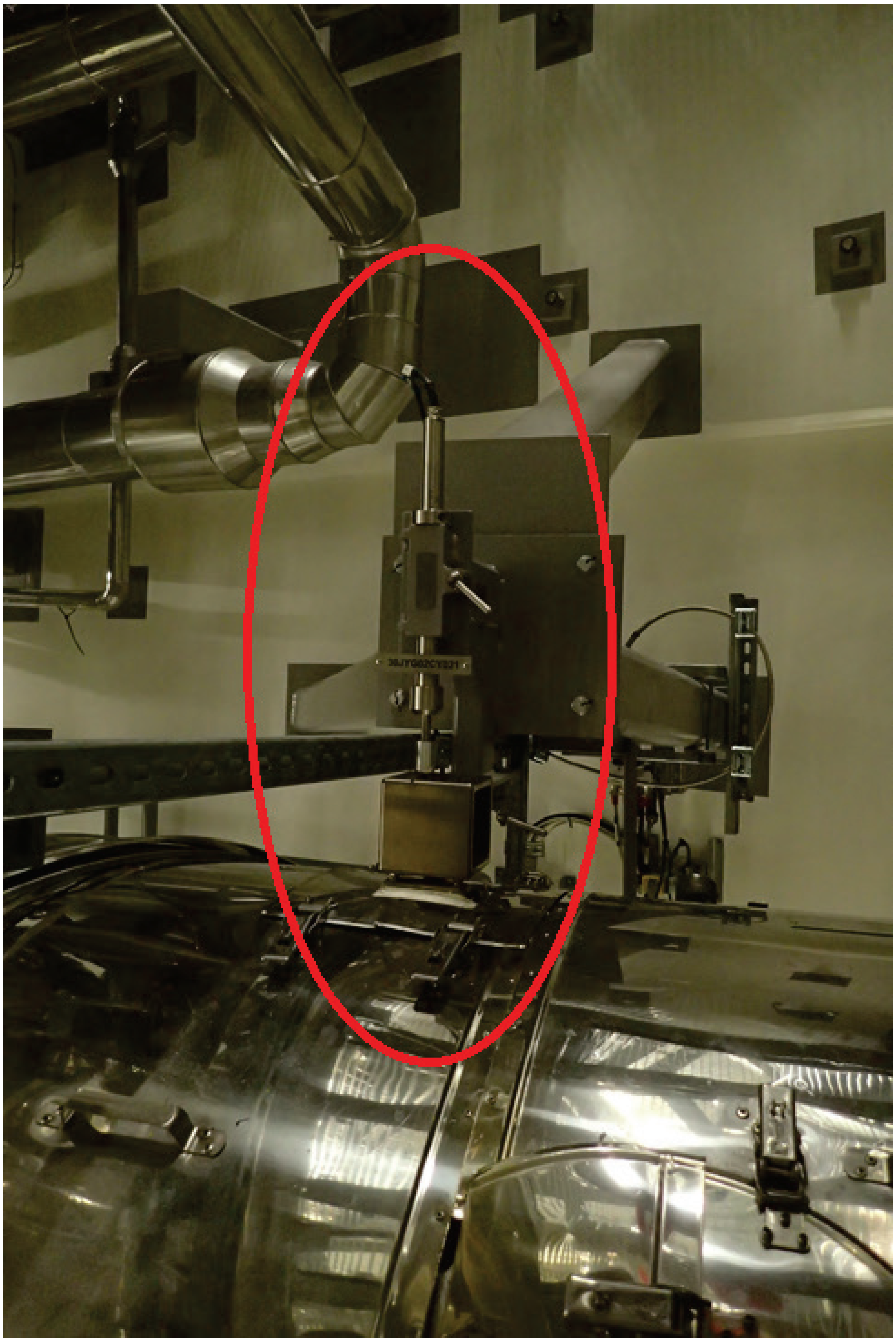

Figure 3.6a. The relative displacement transducer

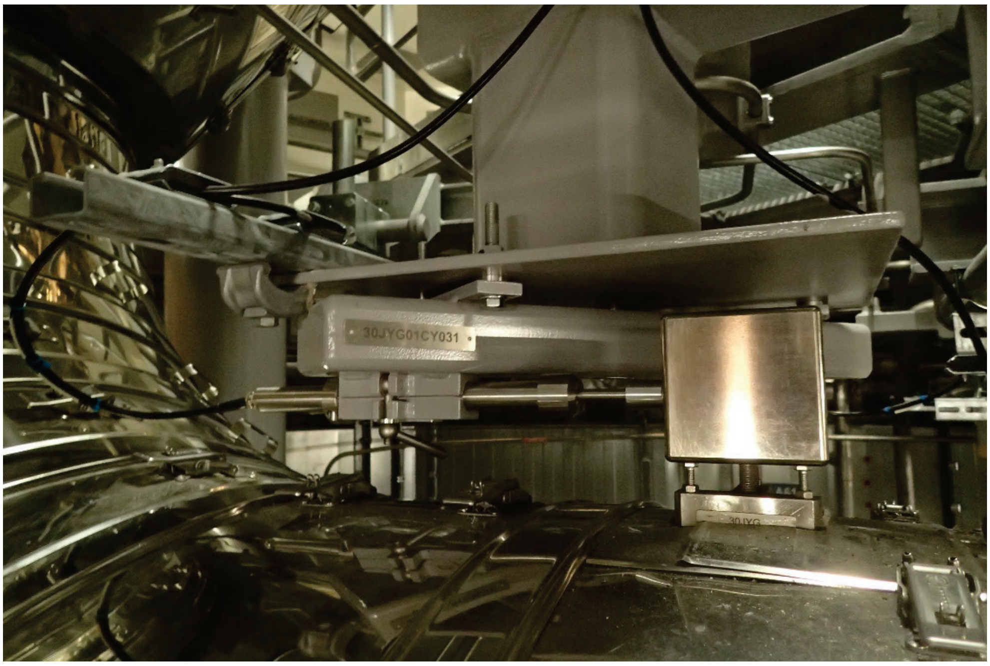

Figure 3.6b. The relative displacement transducer

Type SD-052 proximity probe works according to the eddy current principle and measures the shaft vibration of a reactor coolant pump. The non-contacting measuring transducer, the extension cable and the oscillator comprise a measuring chain. The transducer works when oscillator generates a high frequency carrier signal which is supplied to the coil of the transducer that induces there as an electromagnetic field. An electrically conductive body, such as reactor coolant pumps shaft, that is brought in this field causes an attenuation of the coil. From this the oscillator generates a standardized signal proportional to the measured value which corresponds to the distance of the body to the coil. This type of transducer is used for measuring relative RCP shaft vibrations and RCP low shaft speed as well as for providing a keyphasor signal.

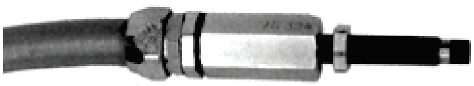

Figure 3.7. SD-052 proximity probe for RCPs shaft vibrations

The velocity transducers installed in reactor cooling pumps are BK Vibro VS068 or VS069 depending of the installation direction and operate in accordance with the electrodynamic principle. A voltage that is proportional to the vibratory velocity is being induced in a coil that moves in the field of a permanent magnet. The coil is suspended, free of any friction, on two leaf springs and forms a spring-mass system.

The VS068 transducer is presented in figure 3.8.

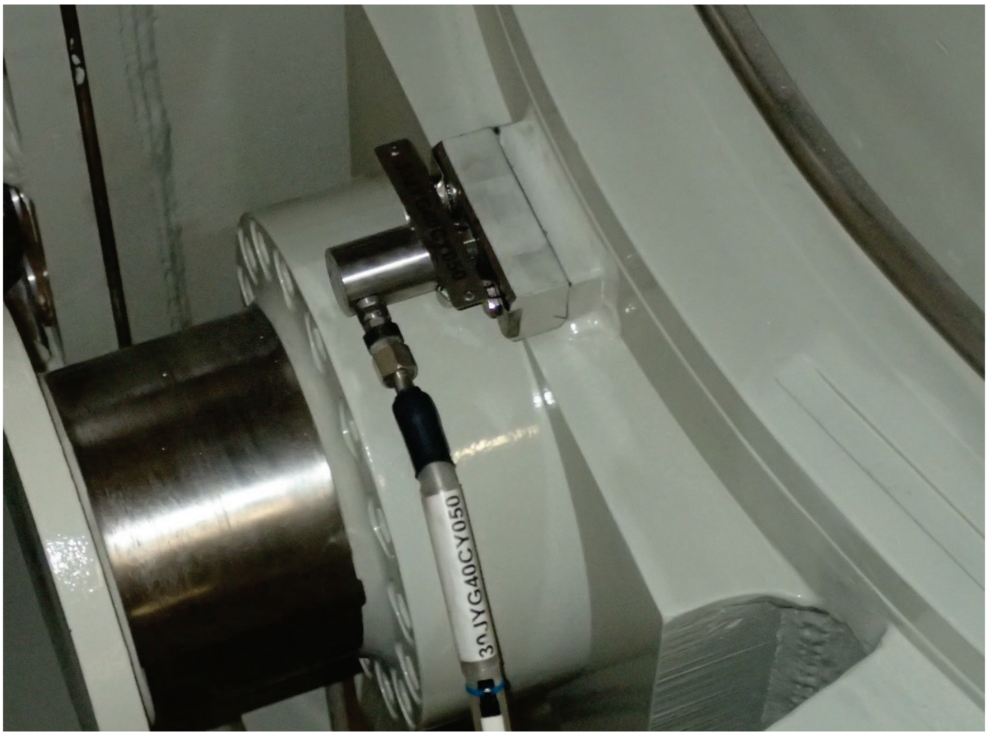

Figure 3.8. Velocity transducer of RCP frame vibrations

The reactor coolant pumps are equipped with five proximity probes and five velocity transducers. One of the proximity probes measures the axial movement of the shaft and the remaining four measure the shaft vibration in pairs. The locations of the measurements are illustrated in figure 3.9.

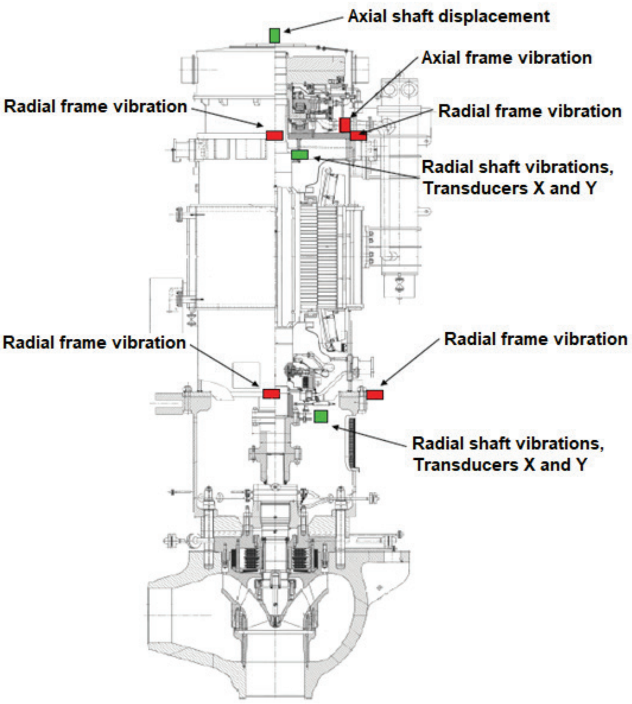

Figure 3.9. The transducer locations in reactor coolant pump

The DFLA type pressure fluctuation transducer contains a quartz crystal sensor to measure the pressure fluctuations in the reactor coolant lines. The constructive arrangement of the transducer housing allows the direct installation into the reactor coolant line by flange connection. The pressure fluctuation transducer is illustrated in figure 3.10.

Figure 3.10. DFLA pressure fluctuation transducer

The vibration monitoring systems main computer is an industrial PC. All system functions as for example calibration, adjustment or compensation of the measuring chains, starting of measurements, defining of measuring orders, analyzing, monitoring, storing and documentation are controlled by this main computer. The user can operate the main computer via monitor, keyboard and mouse. The vibration monitoring systems application software SÜS+ operates under the standard operating system MS Windows XP Professional and uses for protocol purposes the standard software MS-WinWord and for data management the standard software MS-Access.

The signal processors were especially developed for vibration monitoring and provide up to 33 signal inputs for analog vibration signals. The signal processor digitizes the vibration signals in the time domain and transforms them in the frequency domain 0-50 Hz and 0-200 Hz in order to determinate auto spectra and cross spectra. One signal processor is used for structural vibration monitoring of RPV with internals and primary circuit components. The second channel signal processor is used for vibration monitoring of the RCP shaft and frame vibrations in frequency domain.

The RCP online monitoring device is designed as a separate device for online monitoring of the following parameters for each RCP in time domain: shaft vibrations in two directions in µm peak-to-peak, maximum frame vibrations in two directions in µm peak-to-peak and shaft low speed between 0 and 400 rpm.

The general layout of JYG vibration monitoring systems is presented in figure 3.11.

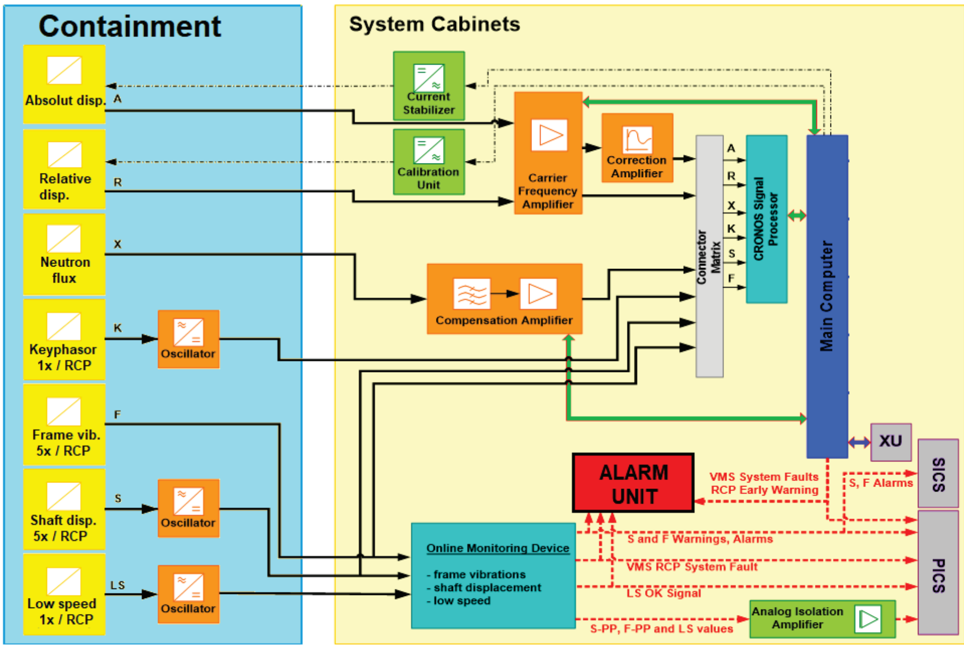

Figure 3.11. System layout of JYG vibration monitoring system

3.1.3 User experiences and plans for future actions of JYG

JYG vibration monitoring system isn't officially in operation yet. The system was installed in 2018 and has been in temporary use since then. The commissioning personnel and vibration specialists from the plants supplier have been using the system during commissioning phase. TVO has not have any opportunities to use the system personally. The only experiences TVO personnel have is based on the reports provided by AREVA and Framatome.

When the plant unit is in operation the main users of JYG will be technical department, maintenance department and operations department. Technical department monitors and analyses the vibration behavior, maintenance keeps the system running and up to date and operations department monitors that no alarms occur and informs engineering department in case any deviations appear.

When technical departments vibration specialists have analyzed the results of measurements, they can provide valuable information to electrical-, mechanical- and automation maintenance departments.

Since data is only available from I&C room next to MCR, the specialist needs to go and retrieve it with permitted USB-drive. The data isn't in commonly known format and due to this, special tools are required to access and analyze the data.

3.2 JYM – VIBRATION MONITORING SYSTEM (SECSÜS)

JYM vibration monitoring system monitors the vibration behaviour of secondary circuit that is directly connected to the reactor coolant system. JYM monitors the vibration behaviour of main steam lines (MSL) and main feedwater lines (MFWL) inside the containment and main isolation valves vibrations outside of containment.

The acquisition of JYM was started on 2005 when Finnish authority STUK required to expand the vibration monitoring system from primary circuit to behold main steam line and main feedwater lines.

The user can check and monitor the long-term behaviour of the piping by displaying the trends of the vibration parameters such as the effective value of the vibration velocity. In case a change in vibration behaviour is observed, a measurement of characteristic functions in frequency domain can be initiated. These spectra are determined by Fast Fourier Transformation (FFT) of the measured time signal. They show maximum amplitudes at frequencies of excited eigenmodes of the system or if harmonic excitation mechanisms work on the structure. Changes of the spectra can either be assigned directly to changes of the piping vibration behaviour or to changes of the excitation mechanisms.

The JYM vibration monitoring systems transducers are all traditional accelerometers and the measured raw acceleration signal is integrated in to velocity that is presented and evaluated as RMS value in time domain and as velocity spectrum in frequency domain. The original JYM vibration monitoring system has 36 accelerometers. The locations of accelerometers have been presented in figures 3.12a and 3.12b.

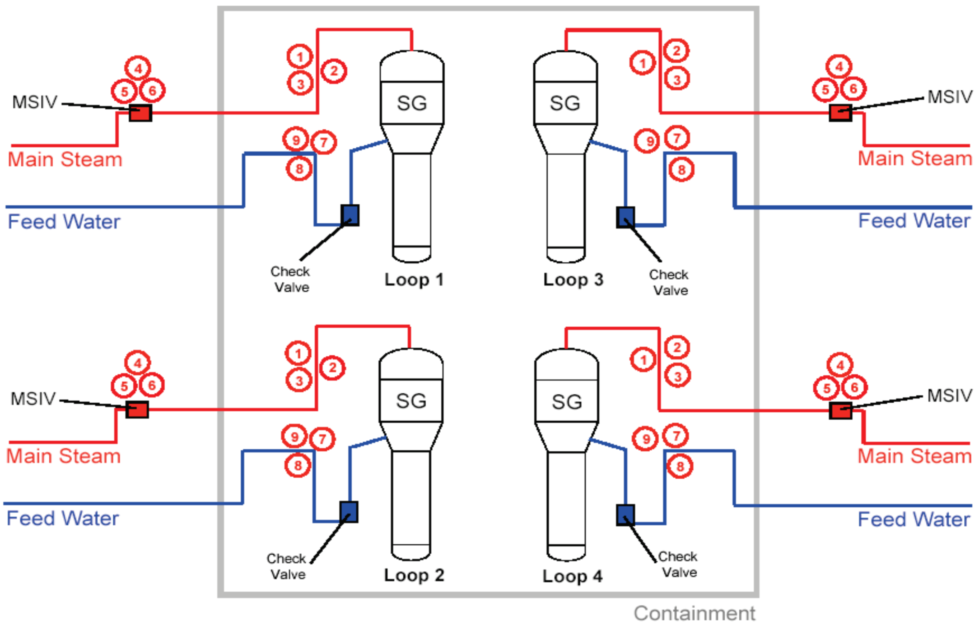

Figure 3.12a. JYM accelerometer locations

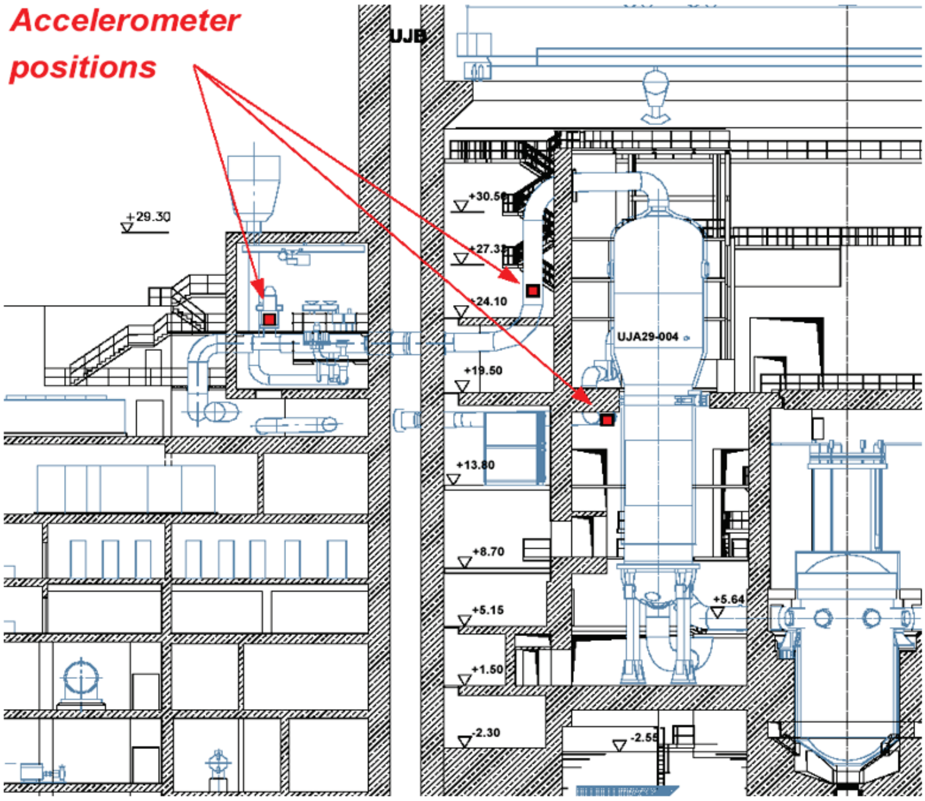

Figure 3.12b. JYM accelerometer locations

JYM also monitors the pressurizer surge line vibrations since all the channels in JYG system are in use and accelerometers used in JYM vibration monitoring system are suitable for monitoring the vibration behaviour of the surge line.

3.2.1 Operational functions of JYM vibration monitoring system

The secondary circuits vibration monitoring system JYM is fully automated stand-alone system that provides wide range of monitoring and measurement function. JYM's main functions are signal acquisition, signal conditioning, signal analysis and monitoring, data storage and archiving, data display and documentation, announcement of system faults and threshold violations.

JYM vibration monitoring system is designed to monitor the loads on secondary circuits piping by measuring the maximum vibration velocity. The principles of load monitoring are presented below:

- Surveillance of thresholds on vibration monitoring
- Trending of the effective vibration velocity
- Analysis in frequency domain in case of threshold violations and significant trends in the vibration velocity
- Quasi-static process signals from I&C system (TXP)
- Treatment identical to RMS-values of sensors

The secondary circuit can be considered much more simple plain system than the primary circuit especially when compared to the RPV and its internals. Therefore, the main task of JYM is load monitoring in time domain that is based on ASME ANSI-OM3 stress/velocity relationship. The threshold definition for a straight homogeneous empty pipe, with no isolations, excited harmonically in one of its eigenfrequencies, the maximum stress is proportional to the maximum vibration velocity, see figure 3.13.

$$\sigma_{\max} = v_{\max} \frac{\phi_k''}{\phi_k} r_a \sqrt{\mu E / I} \quad \Rightarrow \quad v_{allow} \sim \sigma_{allow}$$

v_{max}	*maximum vibration velocity*
Φ_k	*k^{th} eigenform*
Φ_k''	*second derivative, k^{th} eigenform*
r_a	*radius of the piping*
E	*elastic modulus of the piping material*
μ	*mass per length unit*
I	*geometrical moment of inertia*

Figure 3.13. The threshold definition by ASME ANSI-OM3

Since in practice, the piping isn't homogenous and straight and is covered with insulations the maximum stress can not be calculated directy and corrective factors need to be used, see figure 3.14.

$$v_{allow}^{eff} = \alpha \frac{C_1 C_4}{C_0 C_3} \frac{0.8\sigma_{allow}}{C_2 K_2}$$

The following effects are covered:

RMS-to-peak factor	→ C_0
The effect of concentrated masses	→ C_1
Stress intensification factors	→ C_2K_2
Added mass effects	→ C_3
The geometry of the pipe	→ C_4
Dimensional factor	→ α=13.4 mm/s/MPa

Figure 3.14. Corrective factors for ASME ANSI-OM3

The corrective factors can be calculated individually for every pipe segment. To ease the load of work, conservative values are usually used for the non-dimensional parameter, see figure 3.15.

$$\left.\begin{array}{l} C_0 = 3.5 \\ C_1 = 0.12 \\ C_2K_2 = 4.0 \\ C_3 = 1.5 \\ C_4 = 0.7 \end{array}\right\} \longrightarrow V_{allow} \sim= 12{,}7\ mm/s_{0\text{-}peak}$$

Related to σ_{allow} approx. 300 N/mm^2

Figure 3.15. Conservative values used as corrective factors to calculate the maximum peak value of allowed vibrations

3.2.2 System description of JYM

JYM vibration monitoring system uses Vibro-Meters CA 952 accelerometers to monitor the vibration behaviour of the secondary circuit of OL3. There are total of 36 transducers installed in MSL and MFWL piping. The accelerometers are designed for long-term monitoring in extreme conditions. The accelerometer can sustain in temperatures up to 650°C. The transducers are installed in piping using mounting blocks. Each mounting block has three transducers installed on.

The charge signals of the accelerometers are transformed into voltage signals by means of charge amplifiers in the preamplifier stations. The voltage signals are led potentially isolated to the JYM vibration monitoring system cabinet. The amplifier provides also signal conditioning in terms of low-pass filtering of the data.

Each measurement channel consists of charge amplifier, DC/AC insulation amplifier, low-pass filter and a separate power supply from the system cabinet.

The system cabinet on I&C room next to the MCR contains the following components:

- Alarm unit that indicates system faults and threshold
- Oscilloscope
- SPU, the signal processing unit serves for signal conditioning of the accelerometer signals and contains modules for remote supply and remote calibration of the connected charge amplifiers in the preamplifier stations.
- Connector matrix that picks up the analog signals to watch them on line on different devices such as oscilloscope. The BNC-connectors make fast access to all signals possible easily.
- Power supply unit
- Signal processor that digitizes continuously the vibration signals in the time domain, integrates the acceleration signals and calculates the effective values for all signals. During special measurement is carried out, it receives and digitizes a set time domain data and transforms them in the frequency domain in order to determinate auto spectra and cross spectra.

- Control and evaluation computer aka the main computer that is an industrial PC and serves as the user interface with the system using Microsoft Windows XP Professional operating system. All system functions such as starting of measurements, defining of measuring orders, analyzing, monitoring, storing and documentation are controlled by this main computer in I&C rooms cabinet.
- Display monitor, keyboard, mouse and a laser printer

The main principle of JYM vibration monitoring systems layout is presented in figure 3.16.

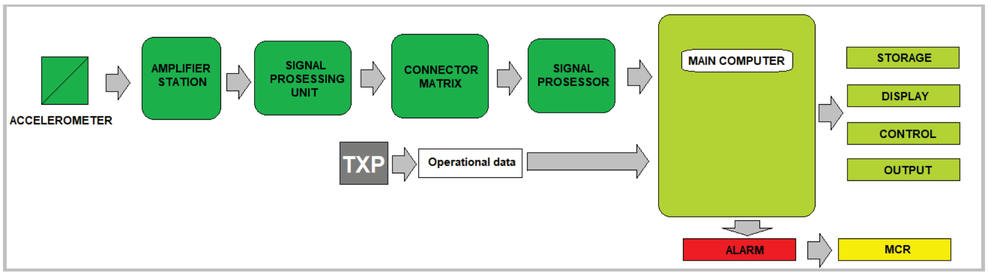

Figure 3.16. JYM system layout

3.2.3 User experiences of JYM

JYM secondary circuits vibration monitoring system isn't officially in operation yet. The system was installed in 2018 and has been in temporary use since then. Some renewals were done to the system in 2019, but the material available didn't identify what was done. The commissioning personnel and vibration specialists from the plants supplier have been using the system during commissioning phase. TVO has not have any opportunities to use the system personally. The only experiences TVO personnel have is based on the reports provided by AREVA and Framatome.

When the plant unit is in operation the main users of JYM will be technical department, maintenance department and operations department. Technical department monitors and analyses the vibration behavior, maintenance keeps the system running and up to date and operations department monitors that no alarms occur and informs engineering department in case any deviations appear.

When technical departments vibration specialists have analyzed the results of measurements, they can provide valuable information to electrical-, mechanical- and automation maintenance departments.

Since data is only available from I&C room next to MCR, the specialist needs to go and retrieve it with permitted USB-drive. The data isn't in commonly known format and due to this, special tools are required to access and analyze the data.

3.3 JYE – MONITORING SYSTEM OF ROTATING MACHINERY (DIROM)

Rotating machinery's monitoring system JYE, commercial name DIROM, is online monitoring system of OL3 nuclear island's rotating machinery that produces information of the machinery's current condition. DIROM measures vibrations on housings of running machinery and saves data periodically or when limit value is exceeded for post analyses. DIROM doesn't have any protection features and is purely a monitoring system.

In addition to vibrations, DIROM also monitors via process automation system (TXP) bearings and stator coils temperatures of over 130 kW electric motors. Also, other variables such as pressures or flow rates can be imported to the system.

DIROM monitors total of 32 most important safety related pumps. The monitored pumps and amounts are presented in table 3.2 and an example of transducers installed in pump in figure 3.18.

Table 3.2. Pumps monitored by JYE – Rotating machinery's monitoring system

KKS:	Function:	Power (kW):	RPM:	Amount (pieces):
FAK11/12/21/22 AP001	Fuel pool coolant pumps	115	1500	4
KBA31/32 AP001	High pressure charging pumps	480	3000	2
KAA10/20/30/40 AP001	Component cooling water system pumps	635	1500	4
KAA50/80 AP001	Dedicated component cooling water system pumps	120	3000	2
PEB10/20/30/40 AP001	Essential service water system pumps	405	500	4
PEB50/80 AP001	Dedicated essential service water system pumps	110	3000	2
JNG10/201/30/40 AP001	Low head safety injection pumps	350	1500	4
JND10/20/30/40 AP001	Medium head safety injection pumps	500	3000	4
LAS10/20/30/40 AP001	Emergency feedwater pumps	550/525	3000	4
JMQ10/40 AP001	Containment heat removal system pumps	280	1500	2

3.3.1 System design

Due to safety guidelines identical pumps are located in different building divisions as are the signal acquisition modules. To reduce the amount of cabling, the connection to the central data concentrator is carried out using a single network cable.

The system consists of 146 acceleration sensors, 32 junction boxes, 7 acquisition units and server that is located in electronics room next to the MCR. The system design is visualised in figure 3.17.

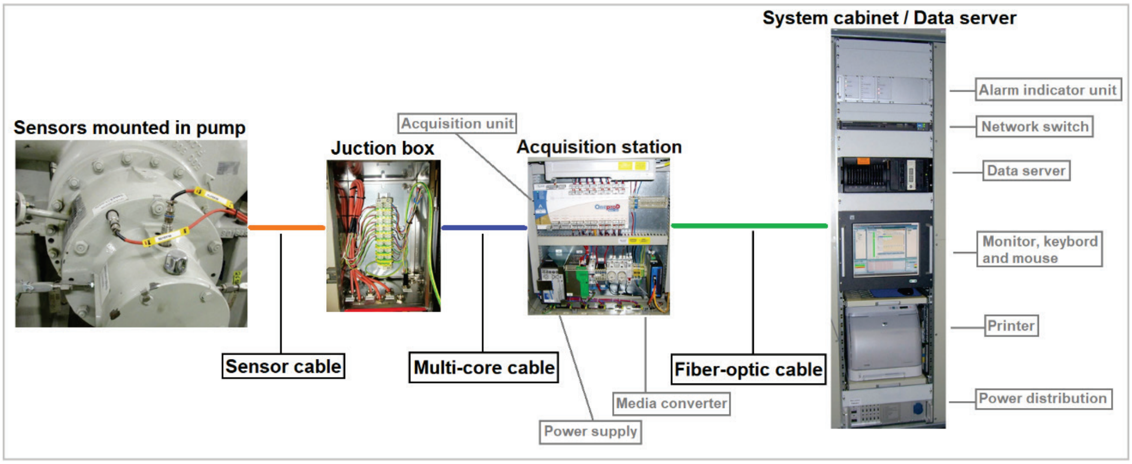

Figure 3.17. System design of JYE

The design parameters and general features of DIROM are listed down below:

General system features:

- Based on MS Windows® Server 2003.
- DIROM evaluation software and database (XPR-300).
- Interactive operation with standard menus (supported by dialog boxes).
- Automatic execution of functions.
- Watchdog timer for the monitoring of hard and software errors.
- Automatic measurement function.
- Automatic online signal evaluation for each measurement with data assessment and comparison with limit values.
- Automatic storage of measurement and evaluation result on a server to determine trends and for statistical purposes.
- Time synchronization about plant master clock over local area network 30 CYL

Accelerometers used are IEPE sensors with integrated electronic parts. The nominal sensitivity of sensors is 10 mV/(m/s^2). Measuring range is ± 500 m/s^2 and frequency range (± 3 dB) is from 1 to 12000 Hz. Shock limit of the sensors is 9810 m/s^2 pk. The sensors are connected to the system using 2-pin MIL-C-5015 connectors and protected cabling and to the pump by using ¼-28 UNF-2B mounting stud. Example of transducers installed in a pump is illustrated in figure 3.18.

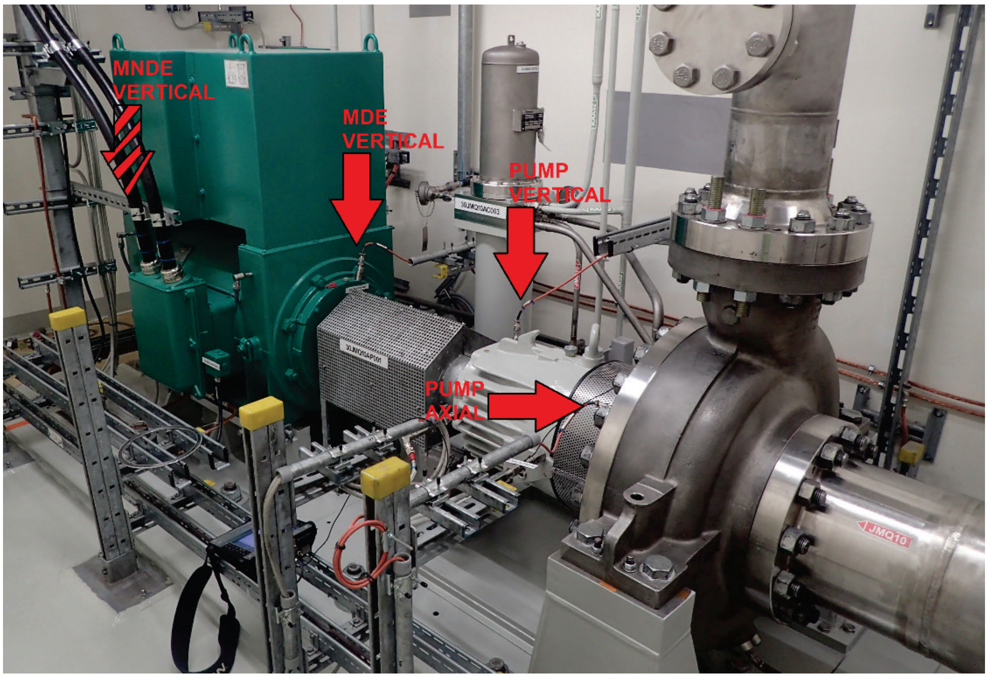

Figure 3.18. JYE accelerometer in 30JMQ10AP001

The acquisition unit module gathers and monitors the signals, calculates the monitoring values and stores them with a sampling rate from 1 Hz to 50 kHz. The measurement range is ±10 V and the resolution is 24 bits. The acquisition module integrates the acceleration signal to velocity and calculates the spectrum with FFT. The windowing is traditional and commonly used Hanning with overlap of 0, 50 or 75 %.

The system has multiple alarm and warning limits for online monitoring available to notice the change in vibration behaviour at early state:

- warning value low
- warning value high
- alarm value low
- alarm value high
- warning value high with reference value

3.3.2 Operational functions of JYE

Mechanical vibration in machines and equipment is not only a consequence of operation but it may be an indication of faults or damages. DIROM measures overall vibration amplitude and trends it. In addition, DIROM also measures spectrum and time waveform that are essential to recognise different changes in machinery's condition. Different parameter can be calculated or observed from spectrum and time waveform, such as peak value, amplitude of certain frequency, different peaks in spectrum to identify and target changes in machinery's condition in to a specific part of machine. With these methods multiple different faults and damages can be observed before they cause fatal damage to machinery.

From the analysed measurement results a skilled condition monitoring specialist can find faults and damages such as:

- imbalance
- misalignment
- bearing faults
- soft foots
- gear faults
- resonance situations

The vibrations are evaluated by using the ISO 10816-3 standard "Evaluation of machine vibration by measurements on non-rotating parts as a guideline.

3.3.3 User experiences of JYE

DIROM has been in operation since the end of 2019 and the final operating license was granted in December 2020. Since the plant unit isn't in operation the user experiences are non-existent.

The system responsible of JYE is the automation maintenance of OL3, but the main users are from mechanical maintenance and occasionally the condition monitoring professionals of powerplant engineering. JYE also provides valuable information for the operation department of OL3.

According to the main users from OL3 mechanical and automation maintenance representatives the system is already old technology that includes the basic features for analysing the vibration behaviour of rotating machinery. The current system installed is basically an alarm system based on ISO 10816-3 standard. The system doesn't fulfil the requirements of a modern condition monitoring system. Also, the hardware is aged and for example urge for more internal memory is required to perform more measurements with higher frequency band.

The principal place of use is in the electronics room at plant where the latest info is available. With limited tools the data is also available in other premises at plant but any deeper analysing requires entering the system cabinet in electronics room. Primarily the measurement data and results are is brought out of plant by printing the required document or with USB-drive by taking print-screens. To get the raw data out of the system, a manufacturers software is required. Individual measurement results can be converted to csv-form and exported out of the system but this method is extremely laborious.

The operating system of DIROM is presented in figure 3.19 and 3.20.

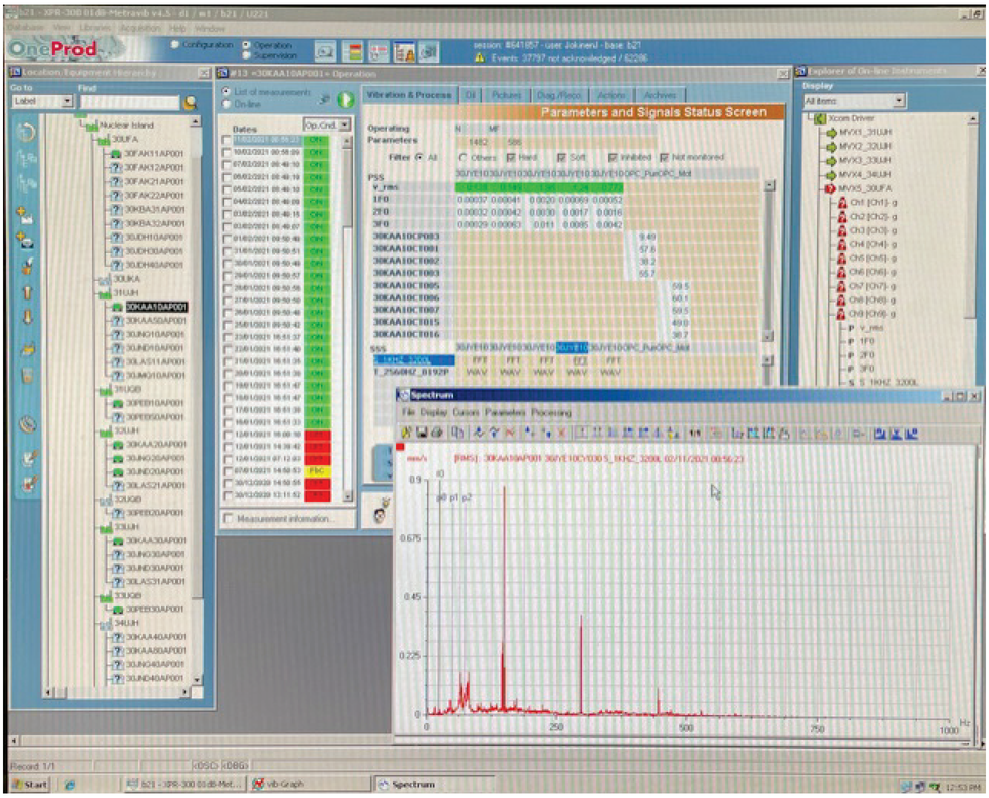

Figure 3.19. DIROM operating system

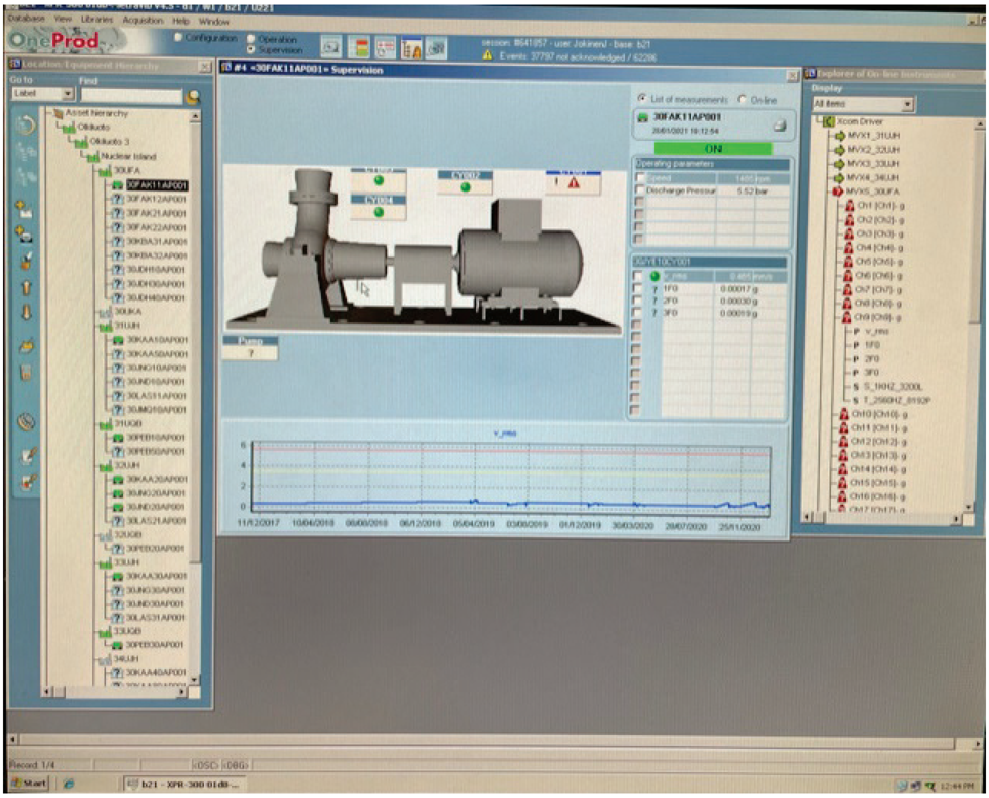

Figure 3.20. Pump window in DIROM operating system

3.4 JYV – VALVE MONITORING SYSTEM (ADAM/SIPLUG)

Valve condition monitoring system is separated in three different parts. JYV means only the solidly installed online monitoring system of valve monitoring system that monitors the motor operated valves (MOV) and solenoid operated valves (SOV).

The measurement is carried out by SIPLUG measuring modules and the results are processed and analysed in ADAM software. The system measures power according to operation time in motor operated valves and current according to time in solenoid operated valves.

Other parts of valve condition monitoring are the portable monitoring device and test bench for safety valves. With the portable monitoring device, it is theoretically possible to measure condition of any valve in the plant.

Valve monitoring methods are presented in figure 3.21.

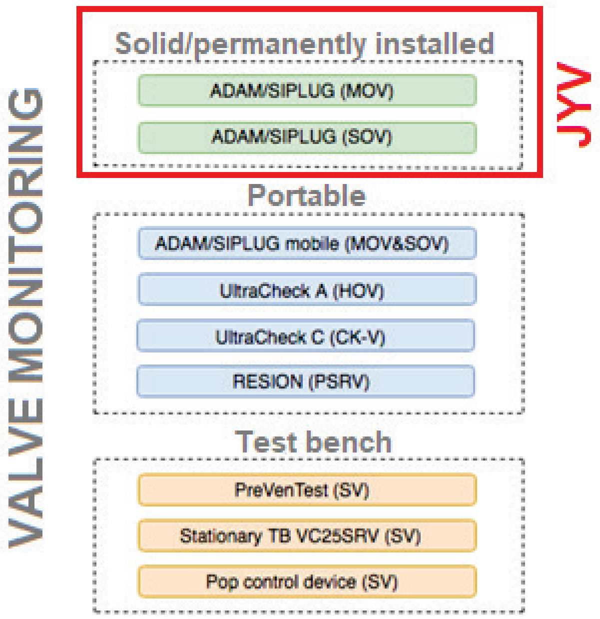

Figure 3.21. Valve monitoring methods

JYV valve monitoring system operates fully automatically and performs measurement every time the valve is operated. The measurement results are saved to servers located in plant where they can be examined afterwards. Currently the measurement results are only available on plant and cannot be transferred out of plant electrically. The only option is to manually download the data to portable flash drive, manually bring it out of plant and upload it to PC that has ADAM software to examine the results.

ADAM/SIPLUG diagnoses is based on comparing the measurement results to the baseline measurements. If the measurement results graphs or values deviate from the baseline measurement can be suspected that the valves condition has changed.

The properties to determine the condition of MOV and SOV valves monitored are presented in table below:

Table 3.4. JYV properties

Unit:	Method:
Motor current (A)	Saved as RMS value
Motor voltage (V)	Saved as RMS value
Motors real time power (kW)	Calculated from current and voltage
Close/Open control signal	Saved in binary form
Operating time (sec)	Calculated from the measurement
Switching signal operation delay (sec)	Calculated from the measurement

Motor current, motor voltage and control signals status are measured units. Real time power is calculated from current and voltage and saved as a digital signal. Operating time and switch delay are calculated and saved using the power signal and operating signal. Different graphs can be created from these signals, see figure 3.22 and table 3.5.

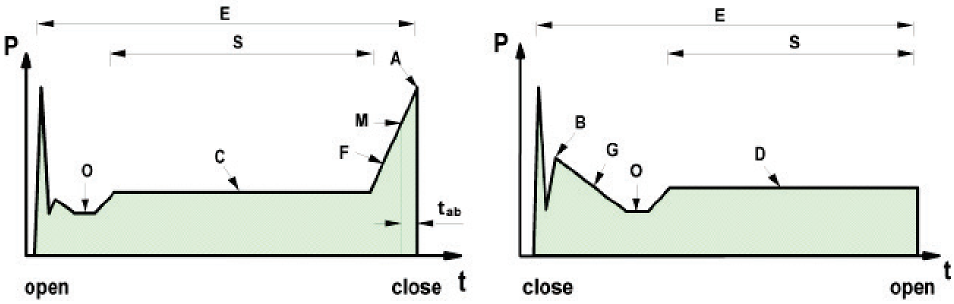

Figure 3.22. Graphs from valves actuators power as function of time when opening and closing the valve

Table 3.5. Symbol explanationas

Symbol:	Explanation:
O	Power without load
C	Average power (closing)
D	Average power (opening)
M	Switching power
A	Max. power
B	Power at the start of loosening the spindle compression
F	Power gradient with spindle compression
G	Power gradient, with loose spindle compression
S	Duration of the impact
E	Actuators operating time
t_{AB}	Shut-off switch delay from shutdown to engine shutdown
(A-O)/(B/O) or F/G	Closing / opening -ratio

3.4.1 System description of JYV

A simplified layout of JYV valve monitoring system is presented in figure 3.23.

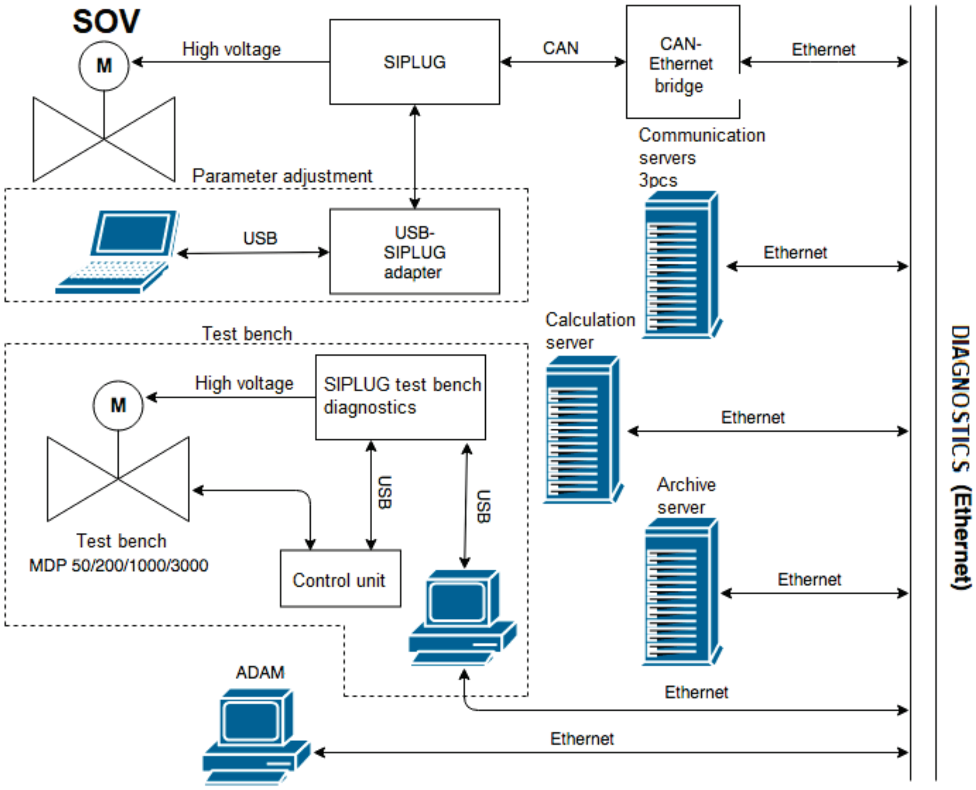

Figure 3.23. JYV system layout

3.4.2 User experiences of JYV

According to TVO representative, the system is running but not under TVO's control. However, the data and software are available for TVO personnel. The system has produced significant number of measurements and alarms of which huge amount are faulty. Even though the system has given multiple wrong alarms and faulty measurement results there are also real alarms and faults among.

The current procedure has been that if any faults has been detected when overhauling a valve, the measurement data from JYV has been checked afterwards. In most cases the fault was seen in the measurements.

The software is still laborious to use due to lack of training it can be assumed that it will take few years before the system is fully part of condition-based maintenance. The systems measuring results and how to evaluate them causes issues and due to this the measurement data can't be fully trusted yet. TVO doesn't have procedures how to use the JYV valve monitoring system yet and the system might need some development. However, TVO entrusts that the valve monitoring system will be one of the most important key factors when transforming the maintenance from periodical maintenance to condition based maintenance in the future.

3.5 JYF – LOOSE PARTS MONITORING SYSTEM (KÜS)

JYF, Loose parts monitoring systems main purpose and operational function is to identify loose parts in the reactors cooling system. The shortage KÜS is a German acronym for the "Loose Parts Monitoring System" that stand for the German word "**K**örperschall**Ü**berwachuhngs**S**ystem".

The main objective of the loose parts monitoring system is to detect and localize loose or loosened parts in the reactor's coolant system to prevent consecutive damages of the primary components and fuel elements. The detection of loose or loosened parts is based on recording of the structure born noise and by providing a tool to assess the captured events.

During normal plant operation when the plant unit is in operation the system doesn't need a continuous attendance of an operator or a specialist. Interaction with the system is only necessary in the case of in-service inspections or if a loose parts alarm is detected in MCR.

3.5.1 General description of JYF monitoring systems functions

Strikes and impacts caused by a loose or loosened part inside the reactor coolant's pressurized system cause single noise events. These sounds generated by impacts propagates as structure-borne noise in the components of the primary coolant circuit. Accelerometers attached to the outer side of the pressurized boundary of the reactor coolant circuit, register these structure-born noises and convert them into electrical charge signals.

In addition to the structure-borne noise caused by loose or loosened parts, stationary background noise from fluid or steam flow, pump operation etc. is also generated. This background noise is made up of a monotonous basic noise. In addition, individual noise events such as valve operation, control rod movements etc. can also occur. Background noises generated by plant's operation procedures are usually low frequency signals up to approximately 1000 Hz when the frequency range of an impact signal goes up to 10 kHz or higher frequencies. In order to enhance the sensitivity for noise components generated by loose parts the JYF monitoring system filters the noise signal in the with band pass filter of frequency range between 1 and 10 kHz.

The Loose Parts Monitoring System (LPMS) permanently compares the short-term RMS value of the signals of each measuring channel with a channel-specific fixed threshold and a channel-specific relative threshold related to the long-term Root Mean Square (RMS) value.

The use of the short-term RMS value prevents alarm being triggered by spikes and other disturbing effects. In the case of an event trigger the JYF system records the time signal of all channels monitored and stores the acoustical event.

The alarm signal to the control room can be initiated either directly after threshold violation or after a sophisticated evaluation by the diagnostic software.

Regardless the necessity of JYF loose parts monitoring system, it has no safety classified functions.

The current installed JYF, loose parts monitoring system fulfils the requirements of the following standards: DIN 25475 Part 1, IEC 60988, NRC 1.133 and ASME OM 12.

3.5.2 System design

The current installed JYF loose parts monitoring system has 21 accelerometers, 15 junction boxes and four preamplifier station located inside containment. The accelerometers are installed in primary components of reactor coolant system. The locations of the transducers, junction boxes and preamplifier station are presented in table 3.6.

Table 3.6. Accelerometers of loose parts monitoring system

Component:	KKS:	Room:	Location:
Accelerometers	30 JYF 10 CS 001	30 UJA11-001	RPV bottom 0°
	30 JYF 10 CS 002	30 UJA11-001	RPV bottom 120°
	30 JYF 10 CS 003	30 UJA11-001	RPV bottom 240°
	30 JYF 10 CS 004	30 UJA11-001	RPV upper level 45°
	30 JYF 10 CS 005	30 UJA11-001	RPV upper level 135°
	30 JYF 10 CS 006	30 UJA11-001	RPV upper level 225°
	30 JYF 10 CS 007	30 UJA11-001	RPV upper level 315°
	30 JYF 10 CS 008	30 UJA15-003	SG1 bottom
	30 JYF 10 CS 009	30 UJA15-004	SG2 bottom
	30 JYF 10 CS 010	30 UJA15-007	SG3 bottom
	30 JYF 10 CS 011	30 UJA15-008	SG4 bottom
	30 JYF 10 CS 012	30 UJA29-003	SG1 feed water nozzle
	30 JYF 10 CS 013	30 UJA29-004	SG2 feed water nozzle
	30 JYF 10 CS 014	30 UJA29-007	SG3 feed water nozzle
	30 JYF 10 CS 015	30 UJA29-008	SG4 feed water nozzle
	30 JYF 10 CS 016	30 UJA15-001	RPV disclosure 90°
	30 JYF 10 CS 017	30 UJA15-001	RPV disclosure 180°
	30 JYF 10 CS 018	30 UJA15-002	RCP1 bottom
	30 JYF 10 CS 019	30 UJA15-005	RCP2 bottom
	30 JYF 10 CS 020	30 UJA15-006	RCP3 bottom
	30 JYF 10 CS 021	30 UJA15-009	RCP4 bottom
Junction Boxes	30 JYF 10 GA 001	30 UJA11-005	
	30 JYF 10 GA 002	30 UJA11-006	
	30 JYF 10 GA 003	30 UJA11-002	
	30 JYF 10 GA 004	30 UJA18-006	
	30 JYF 10 GA 005	30 UJA18-009	
	30 JYF 10 GA 006	30 UJA18-002	
	30 JYF 10 GA 007	30 UJA18-005	
	30 JYF 10 GA 008	30 UJA11-002	
	30 JYF 10 GA 009	30 UJA11-005	
	30 JYF 10 GA 010	30 UJA11-006	
	30 JYF 10 GA 011	30 UJA11-009	
	30 JYF 10 GA 012	30 UJA23-003	
	30 JYF 10 GA 013	30 UJA23-004	
	30 JYF 10 GA 014	30 UJA23-007	
	30 JYF 10 GA 015	30 UJA23-008	
Preamplifier station	30 JYF 10 GU 001	30 UJA18-013	
	30 JYF 10 GU 002	30 UJA18-014	

Component:	KKS:	Room:	Location:
	30 JYF 10 GU 003 30 JYF 10 GU 004	30 UJA18-015 30 UJA18-016	

From the preamplifier stations the signal goes to signal processing unit that provides filtering and supply for the preamplifiers. From signal processing unit the signal goes to transient recorder that sends the data to alarm unit and evaluation computer. The basic design of JYF loose parts monitoring system is presented in figure 3.24.

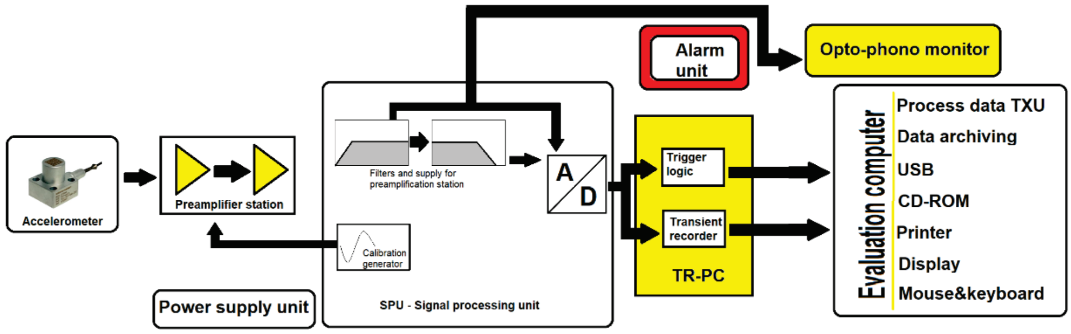

Figure 3.24. System design of JYF

3.5.3 User experiences of JYF

Since Olkiluoto 3 isn't in operation yet, there are no user experiences from the current loose parts monitoring system. Most likely, according to the TVO personnel, when the fuel is loaded to the reactor and plant starts its operation the loose parts monitoring system will most likely be used only as an alarm system for operations department and maintenance.

Most likely in case of an alarm is noticed and identified as a real a specialist from power plant engineering monitoring team will evaluate the situation and issue a report of the event. The final operational practices will be clarified when plant is in operation and more user experiences will be gathered.

3.6 JYH – LEAKAGE MONITORING SYSTEM

JYH leakage monitoring system detects all leakages from systems hot water or steam inside the containment and in main steam valve rooms. JYH also detects leakages from whole main steam lines outside the containment.

On contrary, leakages from systems containing cold water will rise the water level in the floor drain tanks which are monitored by the Nuclear Island vent/drain system.

JYH is stand-alone alarm system that doesn't require any attention during normal operation.

JYH contains 6 systems that are presented in table 3.7.

Table 3.7. JYH leakage monitoring systems

System	Description of system functions	YVL safety class
JYH10/20	Detection and monitoring of the reactor coolant system leakages	SC3
JYH30	Detection and monitoring of steam leakages in the main steam valve rooms	SC3
JYH40/50	Detection of leakages from sub-critical cracks in main steam lines (between the containment penetrations and the fixed points downstream main steam isolation valves) where break preclusion is implemented	SC3
JYH80	Detection of leakages from sub-critical cracks on selected welds of main steam lines and main feed water lines where break preclusion is implemented.	SC3

JYH Provides the operator early warning of conditions which might result in loss of integrity of components so that operator may take corrective actions in order to avoid losses of coolant, to protect personnel and assets, to prevent severe plant damages and reduce repair costs.

The leakage monitoring system is an operational monitoring system with safety related functions that consists of two independent methods of measurement (humidity measurement and condensate flow measurement). The minimum detectable leak rate from the primary system of 0.06 kg/s is required

The user experiences of JYH weren't available.

3.6.1 System description of JYH

JYH leakage monitoring system beholds 23 humidity measurements and total of 12 condensate flow measurements.

The simplified system layout is presented in figure 3.25.

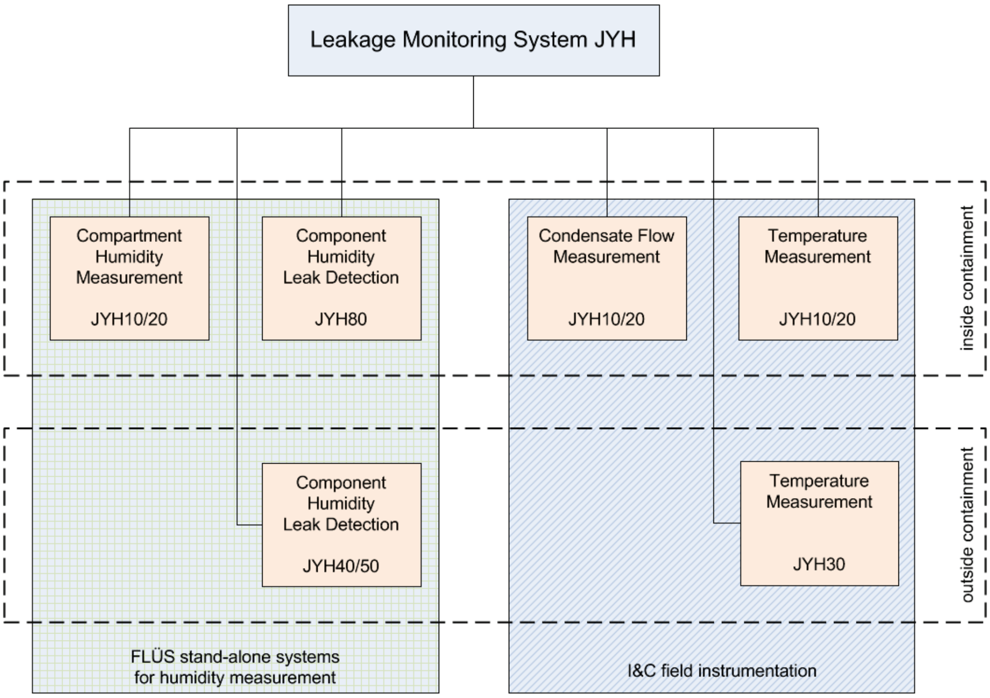

Figure 3.25. JYH leakage monitoring system

Compartment humidity measurement that measures room air humidity is presented in figure 3.26 and component leak detection measurement that monitors air humidity inside the thermal insulation is presented in figure 3.27.

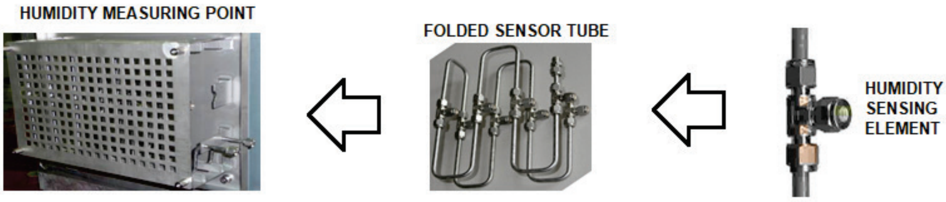

Figure 3.26. Room air humidity measurement

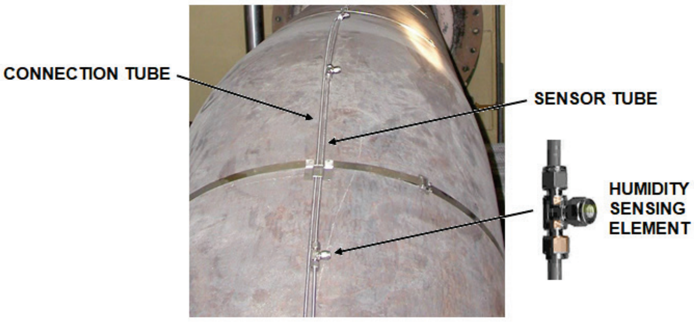

Figure 3.27. Component leak detection measurement

3.7 JYL – FATIGUE MONITORING SYSTEM (FAMOS)

FAMOS provides temperature measurements in addition to other operational measurements. The temperature measurements of FAMOS have been installed on specific locations in OL3 plant unit and its main task is to monitor local cyclic temperature fluctuations that can cause fatigue damages. FAMOS enables the strength- or monitoring specialist to have a better understanding of the possible damage on the fatigue sensitive areas such as pipes, nozzles and branches.

The main task and reason why FAMOS was installed in OL3 was to monitor uneven thermal distribution that pipe experiences. Uneven thermal distribution might cause fatigue inducing phenomena's that require immediate attention such as thermal stratification, slug flow, thermal striping and thermal mixing.

FAMOS uses at least two thermocouples to measure the temperature difference between the top and bottom section of a pipeline. The thermocouples are installed on outer surface of pipe. There are four different variations of how the thermocouples are installed around a pipe. In case there are two thermocouples they are installed 180° from each other. When there are seven thermocouples in measuring point, they are installed with 30° clearance to the previous except in hot leg measurements where thermocouples are installed so that six measurements are in the top-right quarter and one at the bottom of the pipe. One measurement section in the hot leg has eight thermocouples that are installed evenly around the pipe so that each thermocouple is 45° apart from previous. The installation set-ups are presented in figure 3.28.

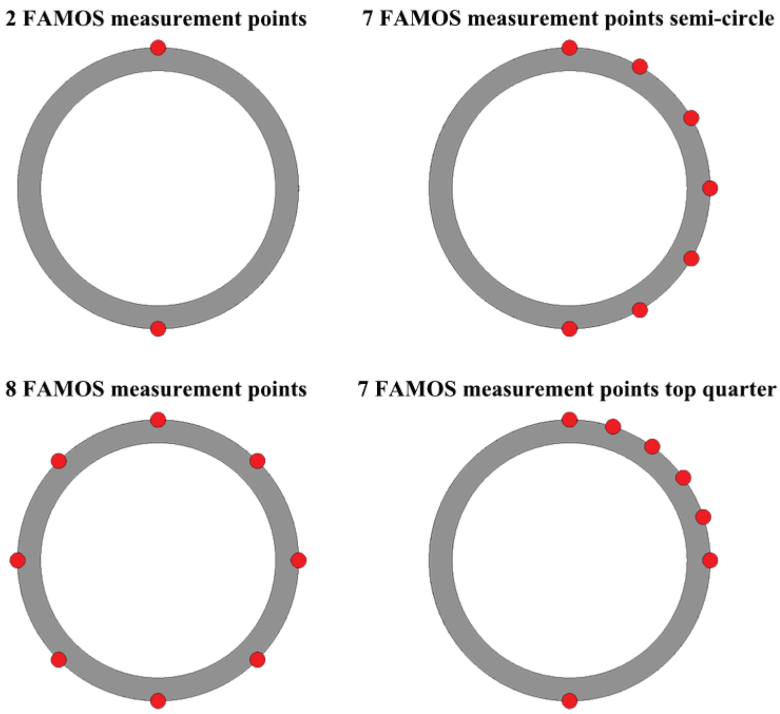

Figure 3.28. Thermocouple's installation set-ups

There are total of 168 thermocouples in 36 different measuring locations in OL3 plant unit. The locations of thermocouples are presented in figure 3.29 and in table 3.8.

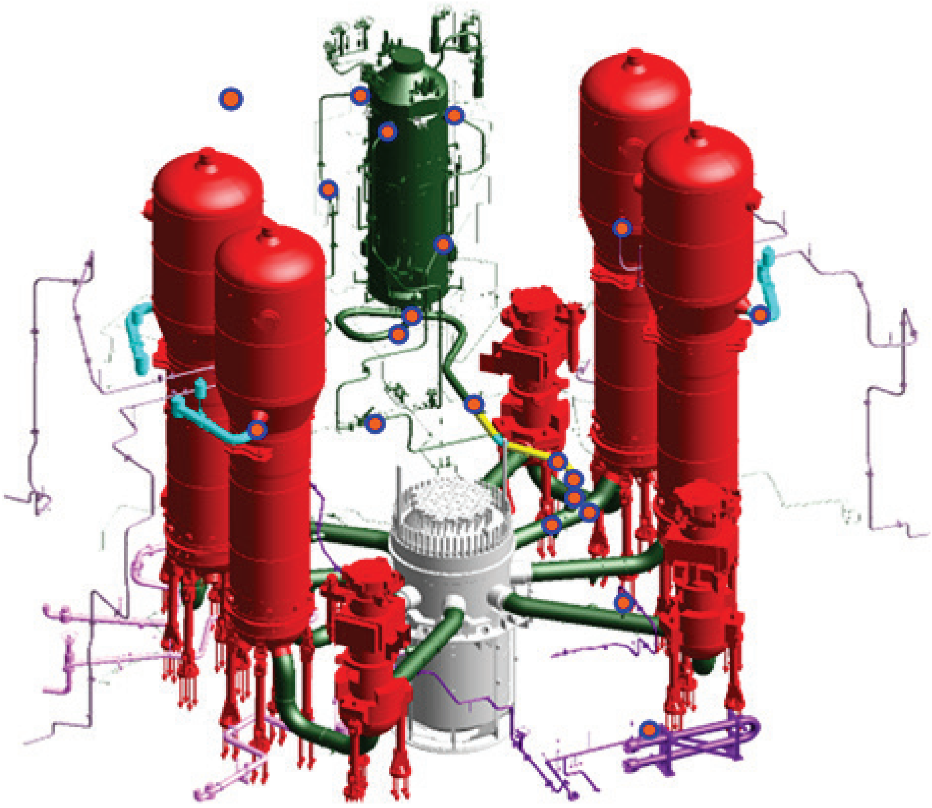

Figure 3.29. Thermocouple's locations

Table 3.8. Thermocouple's locations

Location	**Number of measurement section**	**Number of thermocouples in each measurement section, respectively**
Hot leg 3	1, 2, 3	7, 7, 8
Surge line	6, 7, 8, 9, 10, 11	2, 7, 7, 7, 2, 2
Normal spray lines	12, 13, 14, 16, 17, 18	7, 7, 2, 7, 7, 2
Auxiliary spray line	19	7
KBA extraction lines	21, 22	2, 2
KBA injection lines	23, 25, 27	2, 2, 2
JNG injection lines	29, 31, 32	7, 2, 2
JNA extraction lines	37, 38	7, 2
EFWS lines	41, 42, 43, 44	7, 2, 2, 2
MFWS lines	45, 46, 47, 48, 49, 50	7, 7, 7, 7, 2, 7

The installation set-up of thermocouples is presented in figures 3.30 and 3.31.

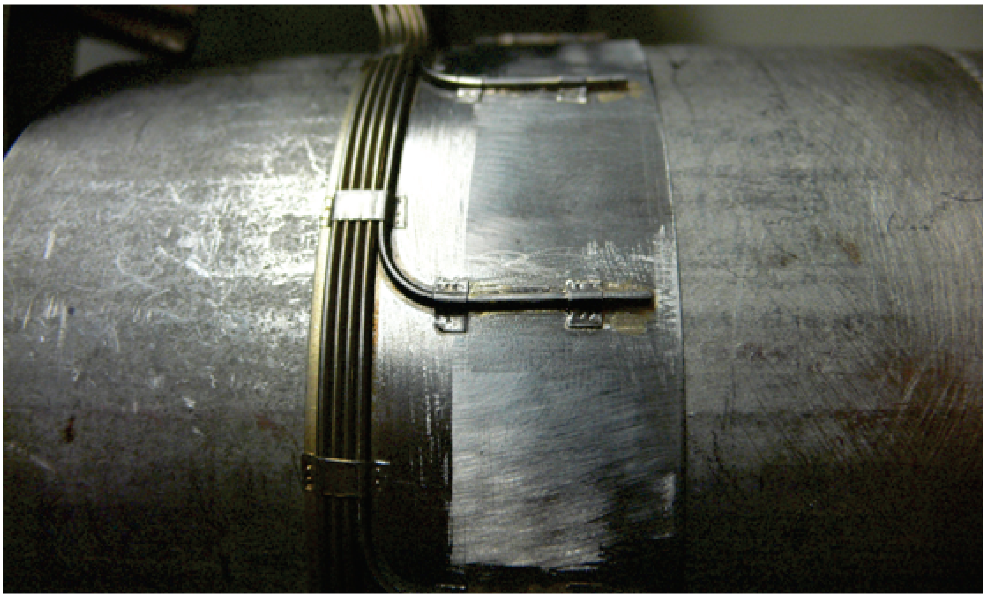

Figure 3.30. Thermocouples in outer surface of pipe

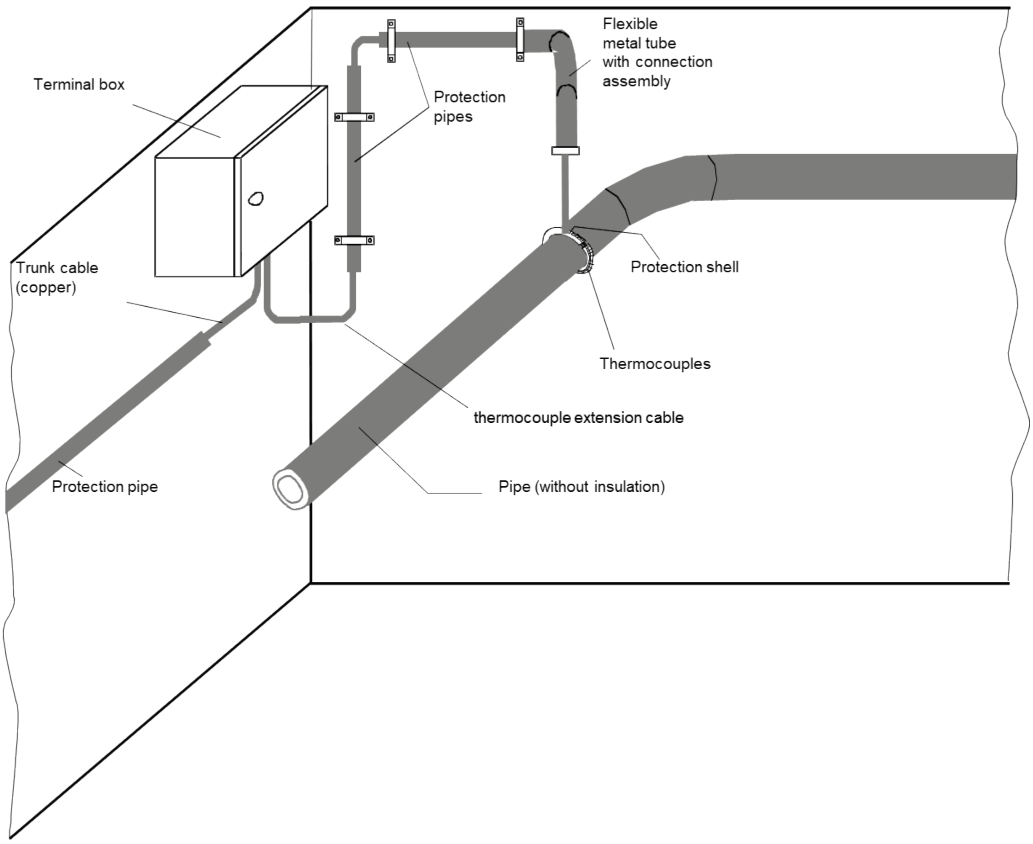

Figure 3.31. FAMOS measurement installation set-up

3.7.1 User experiences of JYL

Benefits of the FAMOS are yet to be realized, since the fatigue monitoring requires couple of years' worth of data before the fatigue analyses can be performed. However, during the commissioning phases, FAMOS temperature measurement data has been compared to the equivalent operational measurements and results are consistent. Measurements during the commissioning phases have also proven that FAMOS can detect some events that conventional operational measurements can't. Thus FAMOS might become an important tool in the load event monitoring.

4 CONDITION MONITORING SYSTEMS IN OLKILUOTO 3 TURBINE ISLAND

Since OL3 plant unit is pressurized water reactor there is no radiation in turbine island and therefore it won't affect the monitoring systems installed as it does on nuclear island.

The turbine island has a lot fewer monitoring systems than nuclear island does but all major components and large machinery are monitored at some level.

The main machinery in turbine island is the turbine train that consists of one HP-turbine, three LP-turbines and generator, see figures 4.1a-b. In addition to the turbine train, also many of the plant units' largest pumps such as main feedwater pumps and sea water pumps are located in turbine island.

Figure 4.1a. OL3 turbine hall

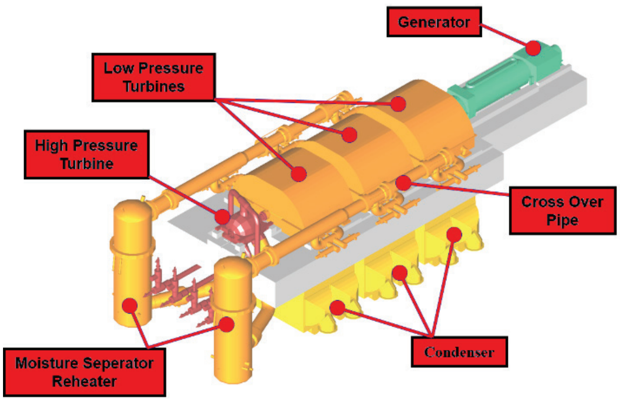

Figure 4.1b. OL3 turbine main components

4.1 CONDITION MONITORING SYSTEMS OF TURBOGENERATOR

4.1.1 CKA – Vibration monitoring system and VM600 – Protection system of turbogenerator

The current turbine monitoring system, CKA, installed in Olkiluoto 3 plant unit is Siemens's WIN_TS Vibration analyses "VIPER" with VM600 CMS. The system monitors the vibration behaviour of HP and LP turbines shaft vibrations, bearing pedestals vibrations and expansions. Stator end windings are also equipped with accelerometer but the signals aren't brought in to the vibration monitoring system but only to process computer. Therefore, the stator vibrations are only available from PICS display of process computer.

The condition monitoring system uses the same transducers and VM600 frontends for vibration monitoring and WIN_TS is only the software to examine the measured vibrations. Based on the TVO's vibration specialists experiences the current WIN_TS-system does not serve its purpose nearly as well as the VibroCam system in OL1 and OL2 plant units. Therefore, TVO is currently acquiring a new vibration monitoring system to OL3 plant unit. The purpose is to take the signals from VM600 frontends and use the same transducers as the protection system uses. However, in the new system the vibration monitoring would be performed on separate system and only connection to VM600 would be using the signals. The stator measurements will also be brought to the new turbine monitoring system.

The need to renew the current turbine monitoring system appeared after the first hot functionality test (HFT), when Siemens presented the vibration measurement results that had been measured with portable SPPA3000-system that is equivalent system of VibroCam.

Due to renewal of turbine vibration monitoring system the presentation of the current system isn't necessary. The new vibration monitoring system will also use the transducers of VM600. The OL3 plant unit's turbines have multiple transducers installed due to the protection feature so the picture of vibration behavior of the turbine will be comprehensive. There are total of 77 vibration measurements installed in OL3 that measure the vibration behavior of bearing pedestals and shaft vibrations. In addition to the vibration measurements there are also multiple expansion measurement and two keyphasors.

Each bearing pedestal has 10 accelerometers installed, five in each end and four proximity probes, two on each end. The installation setup of vibration transducers in turbine and generator bearing pedestals are presented in figures 4.2. and 4.3.

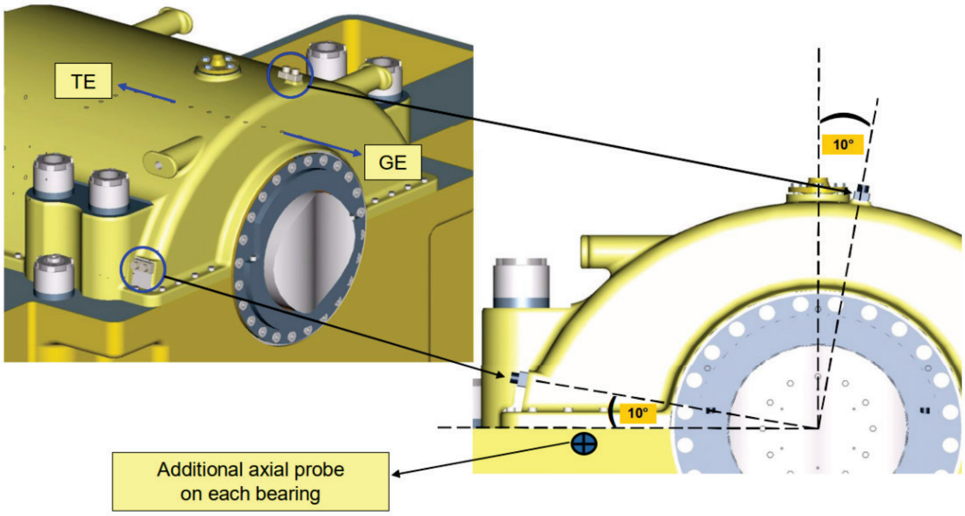

Figure 4.2. Accelerometers in bearing pedestals

The vertical and horizontal accelerometers are installed 90° apart from each other. Both transducers are 10° away from straight horizontal and vertical lines. The proximity probes are installed the same way, see figure 4.3.

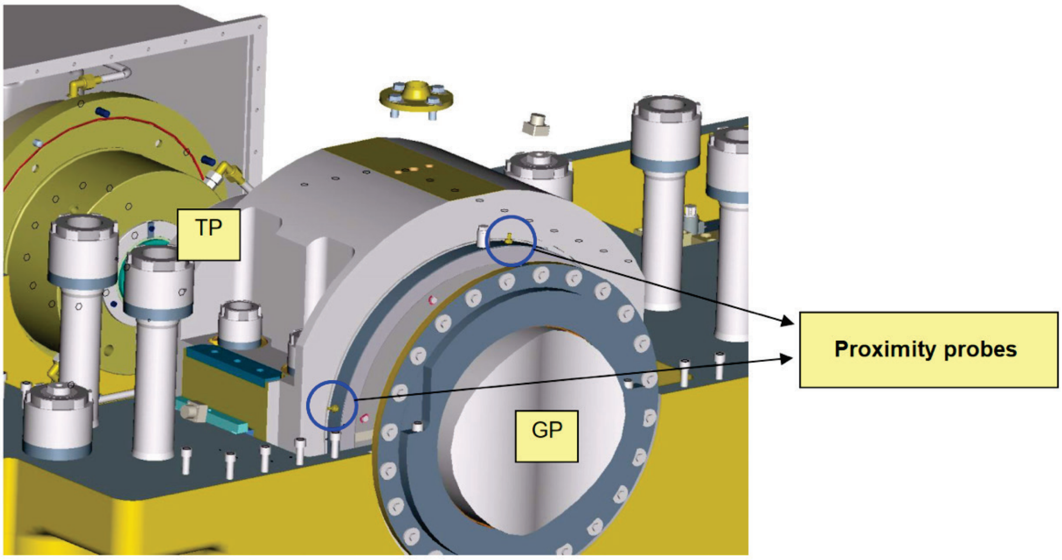

Figure 4.3. Proximity probes in bearing pedestal

The locations of vibration sensors, accelerometers, proximity probes, keyphasors and expansion transducers are presented in figures 4.4 and 4.5.

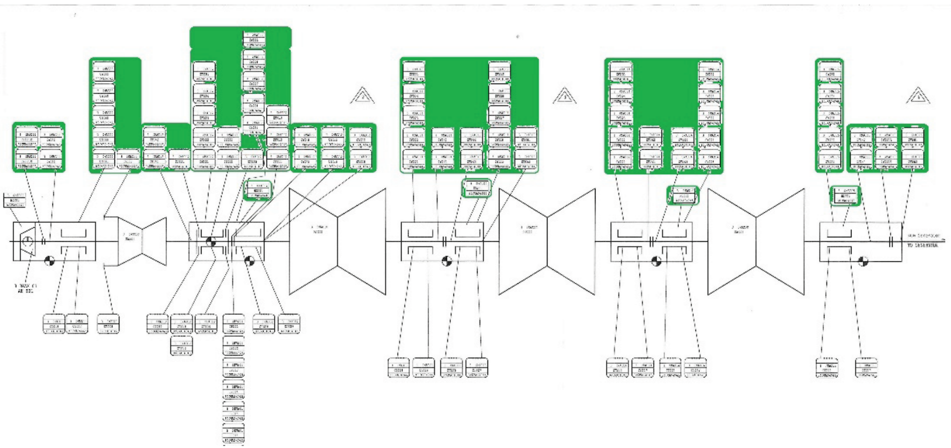

Figure 4.4. Transducer locations on turbine side marked green

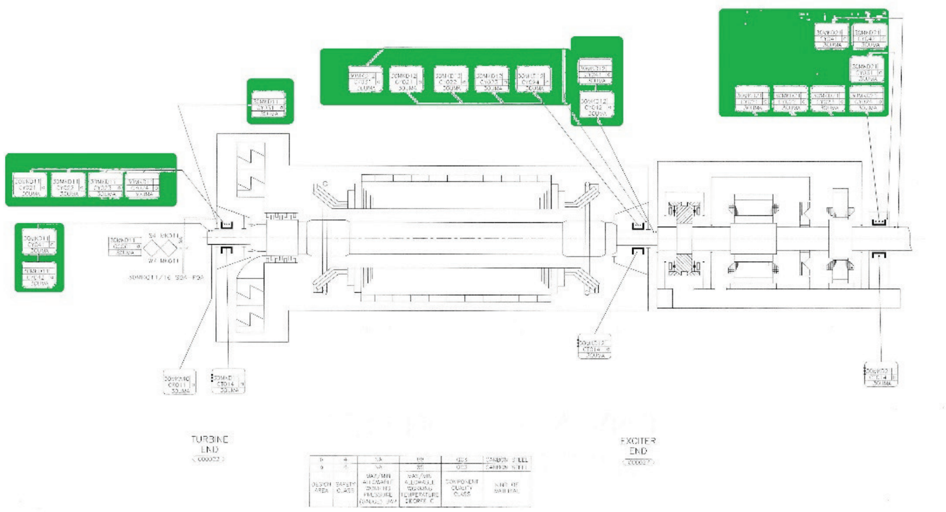

Figure 4.5. Transducer locations on generator side

Turbine train is also equipped with comprehensive temperature measurements that are also intended to be brought to the new vibration monitoring system. The amount of signals that will be brought to new turbine vibration monitoring system is 98 AC-signals and at least 4 via ethernet. The new timeline for commissioning the new system is still open.

4.1.2 BeSSI – Blade vibration monitoring system

BeSSI blade vibration monitoring system was installed in OL3 plant unit to monitor the blade vibrations on low pressure (LP) turbines. BeSSI monitoring system monitors the vibration behaviour of the largest LA-0, last stage blades of LP1, LP2 and LP3 turbines and also in LP3 LA-1 stage blades. The locations of measuring points is presented in figure 4.6.

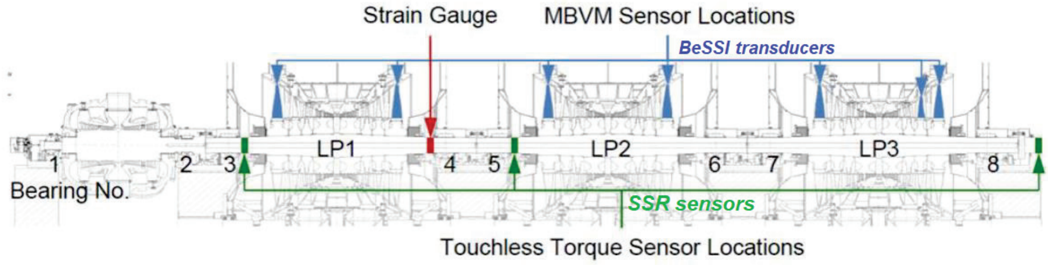

Figure 4.6. BeSSI measuring locations

BeSSI blade vibration monitoring system is based on measuring the time of arrival (TOA) of each blade in the instrumented stage. More common name of this kind of monitoring method is blade tip timing (BTT). The BTT's Technology and principles behind systems can be considered quite old since the method has been developed and in use since the 1980s.

The BeSSI blade monitoring system operates by measuring the time of arrival of each blade and compares this to the expected time of arrival. The expected time derived from steady state non-vibrating condition. If the time of arrival has too large deviation from the expected time, then it can be assumed that there is a deflection at the blade tip due to vibration. This deflection is calculated from the time signal. In OL3 there are two sensors per stage and in addition to the two sensors at the casing, there is also a key phase sensor at every LP turbine, which provides the OPR, once per revolution pulse. The OPR pulse is used as a reference signal for the BeSSI transducers to calculate the time difference. The assembly of BeSSI measuring setup is presented in figure 4.7.

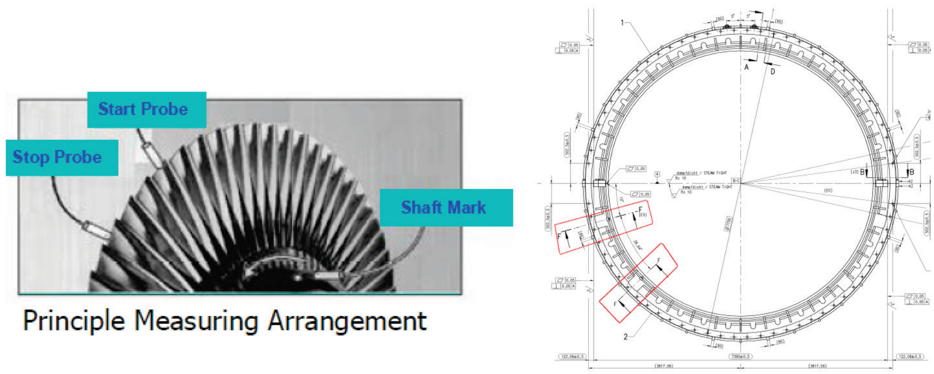

Figure 4.7. BeSSI measuring setup

BESSI monitoring system in OL3 plant unit has been updated after the HFT. During the update at least the signal conditioners, master PC and the analysis software have been updated. The new analysis software includes some new features such as possibility to see more detailed information about the individual vibratory modes.

The data acquisition and analysis hardware consist of ATC9000A analog time converter and BeSSI master PC that runs the analysis software. The blade tip timing sensors (BTT) and once per revolution (OPR) sensor are connected to the ATC9000A that calculates the time difference needed for the deflection calculation. The conversion from time difference to deflection and other analysis is performed at the BeSSI -master PC. The raw timing signal is possible to be recorded from the ATC9000A analog time converter where the BeSSI -master PC offers analyzed deflection and trend data.

The benefit of the BTT method is when compared to strain gauges, it does not require any instrumentation on the blade itself and it can measure all the blades of one stage during one revolution.

4.1.3 SSR – Sub-synchronous resonance monitoring system

Sub synchronous resonance (SSR) is a result of oscillating energy exchange between electrical and mechanical system. When an electrical oscillation hits to an eigenfrequency of the shaft, the mechanical oscillations may arise strongly and in consequence shaft damage or at least high shaft loads and fatigues may occur. SSR events usually have frequency under the frequency of the grid, which is 50 Hz.

The SSR monitoring system has three touchless torque sensors installed in LP1 turbine side, LP2 turbine side and LP3 generators side, see figure 4.8. The touchless sensor is presented in figure 4.9.

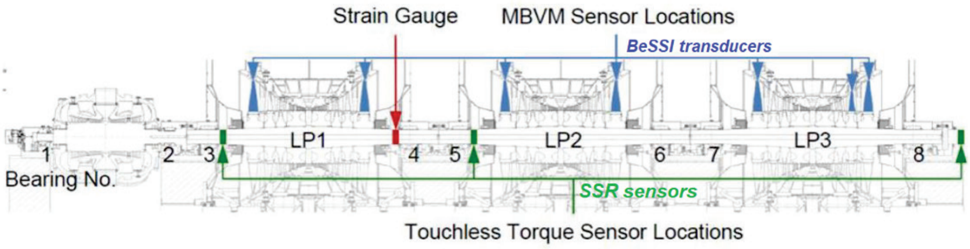

Figure 4.8. SSR sensor's locations

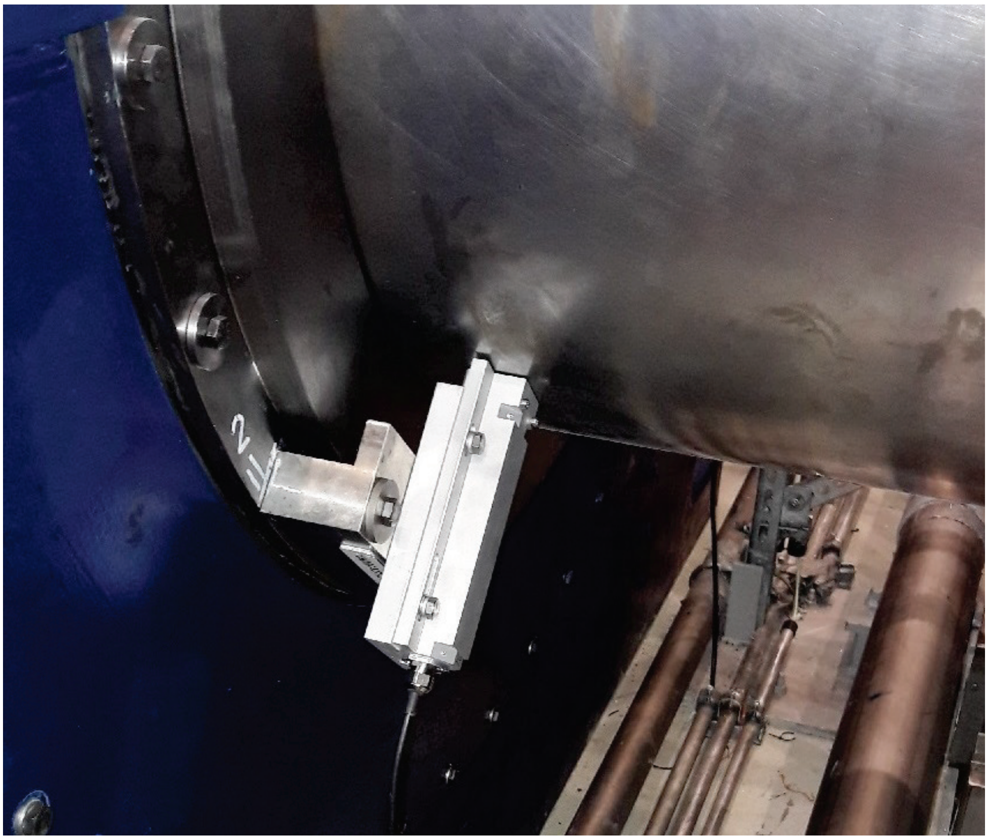

Figure 4.9. SSR touchless sensor

The signals from the SSR transducers go to individual VM600 frontend and are currently available in WIN_TS -monitoring system. However, Siemens has used a separate system to measure and evaluate the signals. The simplified system layout of SSR monitoring system is presented in figure 4.10.

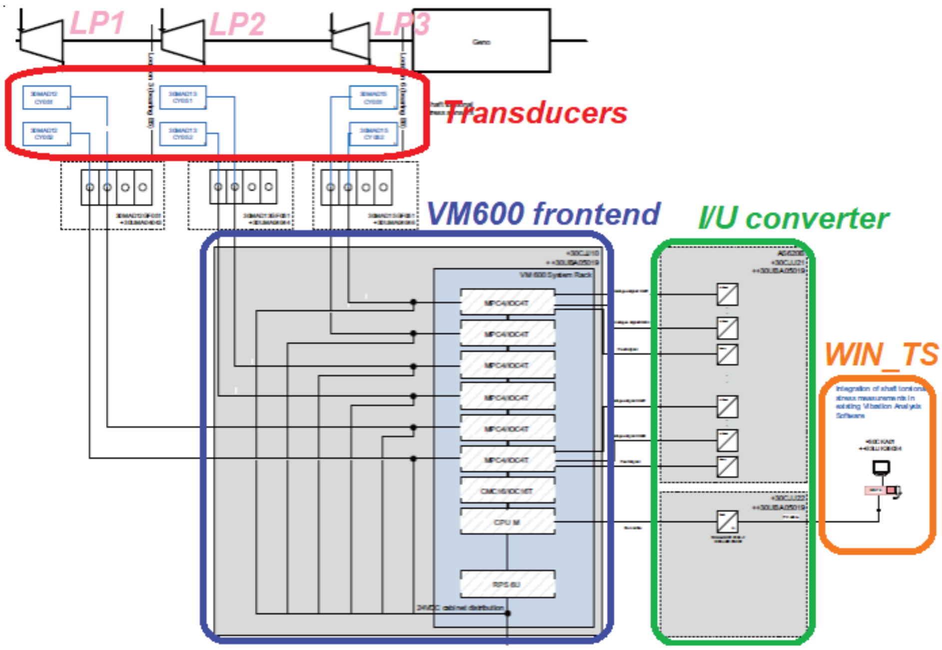

Figure 4.10. SSR monitoring system layout

When under stress, the turbine shaft material is subject to inverse magnetostrictive effect that changes the magnetic permeability of material in direction of applied stress. Shaft torque gives rise to unchanging shear stress on the surface of a shaft and this shear can be understood as a combination of equal tensile and compressive stresses in ±45^0 diagonal directions. The magnetic permeability of the shaft material and strength of magnetic coupling between two coils near the shaft surface will differ between the stretched and compressed ±45^0 directions.

The torque in the shaft can be inferred from the difference in power transfer efficiency of two electric transformers with transformer coils arranged along different diagonal directions relative to the shaft, both transformers using the shaft surface as the transformer core. Operating principle is presented in figure 4.11.

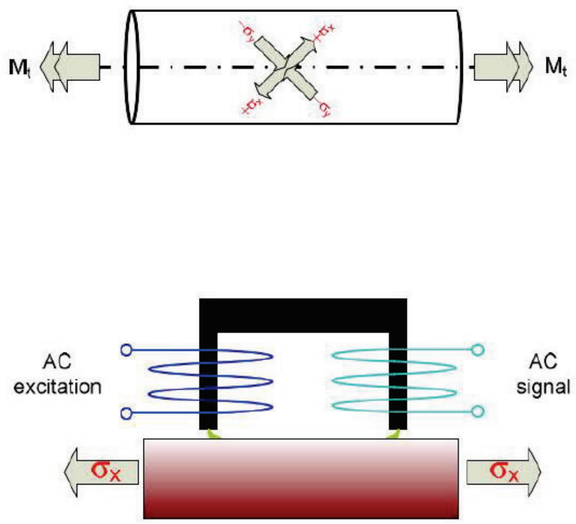

Figure 4.11. Operating principle of the touchless torque sensor technology

According to Siemens the main purpose of the system is to detect the SSR events only. The SSR sensors are placed on the shaft so that all the relevant torsional modes for SSR events can be clearly identified. These are the rotor natural modes from 0 to 50 Hz and are listed in table 4.1.

Table 4.1. OL3 rotor normal modes under 50 Hz

Mode:	Frequency (Hz):
1	6.0
2	10.8
3	14.4
4	23.4
5	36.7
6	38.0
7	39.0

Band-width filters are used in the system to filter out unwanted frequencies. This is favourable for detecting only SSR events, but might prevent the use for overall torque measurement. If unfiltered signals are also available this will increase to usability of the system since that would enable monitoring of overall torque of the shaft.

4.1.4 Additional strain gauge measurements

In order to support the SSR measurements and to get more thorough understanding of torsional vibrations, TVO ordered two additional strain gauges from Siemens. Strain gages were installed during winter 2021 at the generator end of LP2 and LP3.

Since Siemens' task was only to install the strain gauges, TVO requested VTT, Technical Research Centre of Finland, to perform the measurements and analyses from strain gauges and SSR transducers when the operation starts after the fuel is loaded to reactor (FLG phase).

The measurement setup and responsibilities are illustrated in figure 4.12.

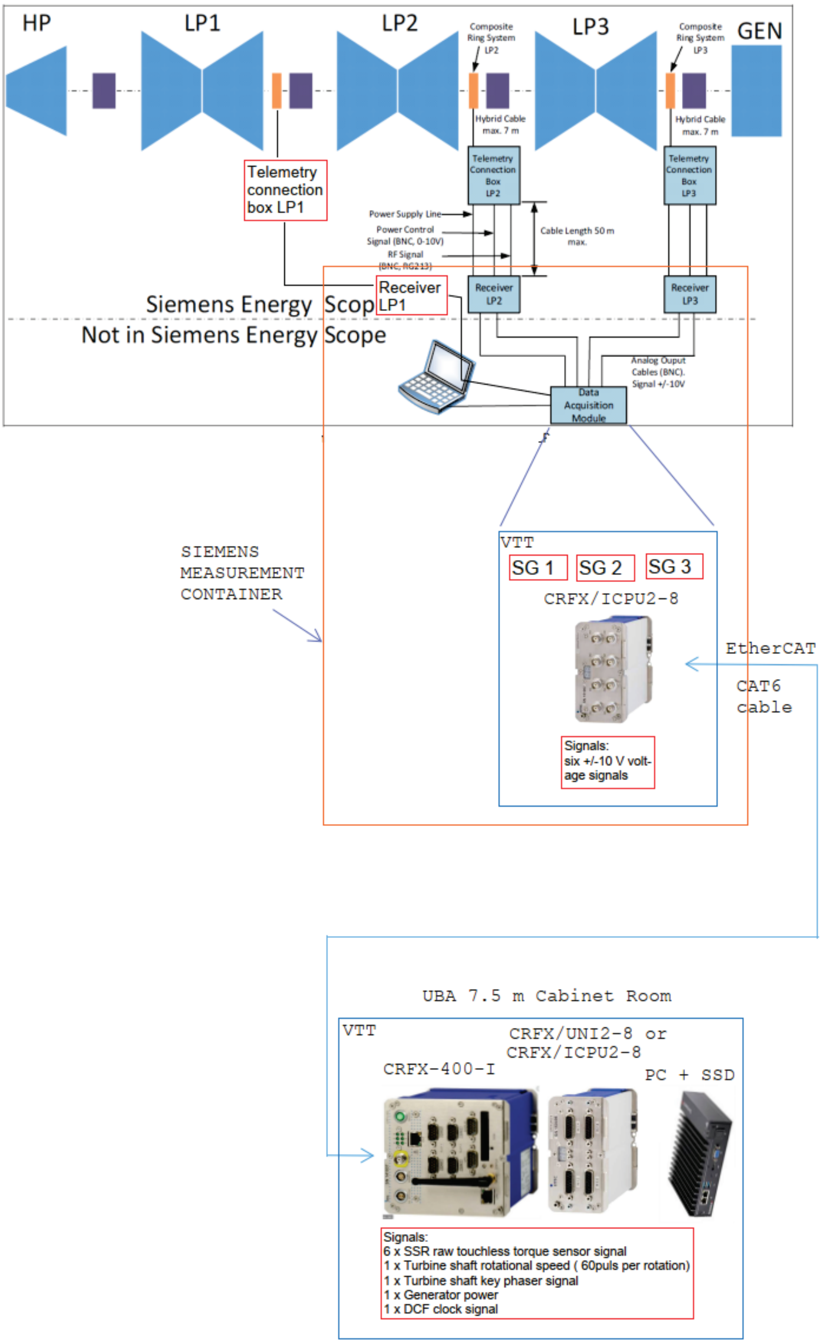

Figure 4.12. Measurement setup and responsibilities of strain gauge measurements

4.2 CONDITION MONITORING OF MAIN FEEDWATER PUMPS

There are four similar main feedwater pumps in OL3 plant unit that consists of electric motor, gear box, booster pump and pump. The vibrations of main feedwater pumps are monitored with PRÜFTECHNIK VIBREX VIB5.762 that is part of plants main automation system.

The system measures only the vibration overall amplitude in mm/s RMS. After the signal is processed in measuring cards the overall vibration amplitude is presented in PICS display of process computer. The system is primitive and doesn't provide any other information except the vibration overall amplitude.

Each main feedwater pump is equipped with seven accelerometer that are listed below:

- 2x Pruftechnik VIB 6.132
- 4x Pruftechnik VIB 6.125R
- 1x Pruftechnik VIB 6.122

The locations of accelerometers are presented in figure 4.12.

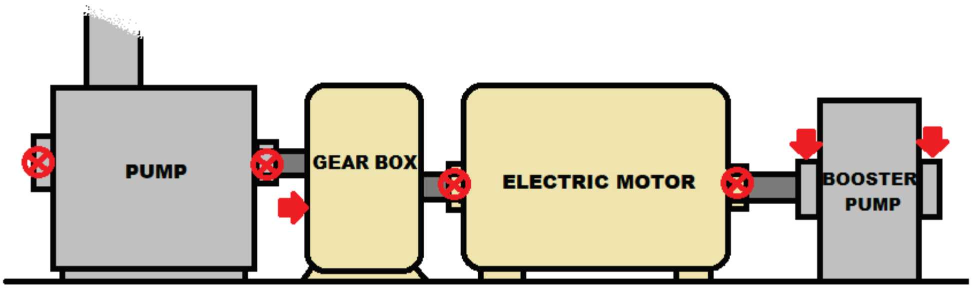

Figure 4.12. Accelerometer's locations and direction in main feedwater pumps

5 MOBILE VIBRATION MEASUREMENTS ON OL1, OL2 AND OL3 PLANT UNITS

5.1 ROTATING MACHINERYS SCHEDULED ROUTE VIBRATION MEASUREMENTS

The basis of condition monitoring and vibration measurements in all plant units located in Olkiluoto is the mobile route measurements that are carried out with certain time intervals.

There are approximately 370 rotating machinery combined at OL1 and OL2 plant units which condition is monitored by performing vibration measurements with portable vibration analyser. The interval of measurements is based on the criticality of the machinery. The interval is usually between 8 and 26 weeks. In OL3 there's alone approximately 380 rotating machinery which condition is monitored using portable analyser.

In OL1 and OL2 the measurements are scheduled by ENKKU software that is part on the maintenance planning program. A list of running machinery that is scheduled to be measured is downloaded from the software to tablet so that the fitter responsible of route measurement knows which machinery will be running and need to be measured. At some point the same procedure is intended to take in use at OL3 plant unit.

The route measurements are performed with portable Emerson CSI 2140 vibration analyser. The analyser is illustrated in figure 5.1.

Figure 5.1. Emerson CSI 2140

The CSI 2140 analyser is a four-channel analyser with keyphasor input. The most common measuring setup is performing the measurements with one single axis accelerometer but in some cases a triaxial accelerometer needs to be used. The most common transducers used are PCB 603C01 and Monitran MTN 1020F accelerometers. In case a triaxial transducer is needed the most common accelerometer is PCB 356A32 triaxial transducers. Usually, all transducers used have the sensitivity of 100 mV/g and ICP/IEPE type accelerometers.

The measuring setup and parameter are pre-determined in AMS Machinery Health Manager software and the route is then downloaded to the analyser. When the measurements are performed, the measured route is uploaded to AMS Machinery Health Manager software where the results can be analysed more accurately. The general view of AMS Machinery Health Manager software is presented in figures 5.2a and 5.2b.

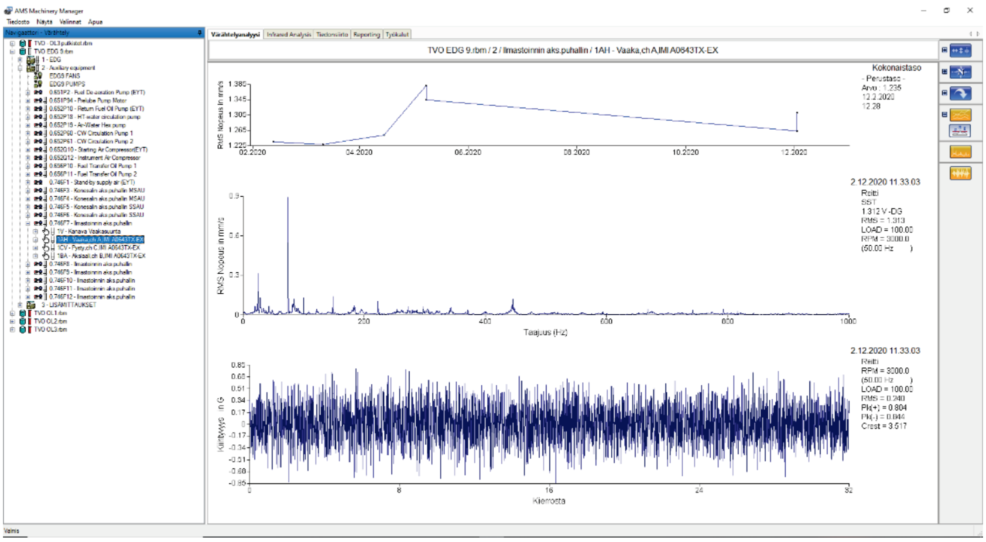

Figure 5.2a. General view of AMS Machinery Health Manager software

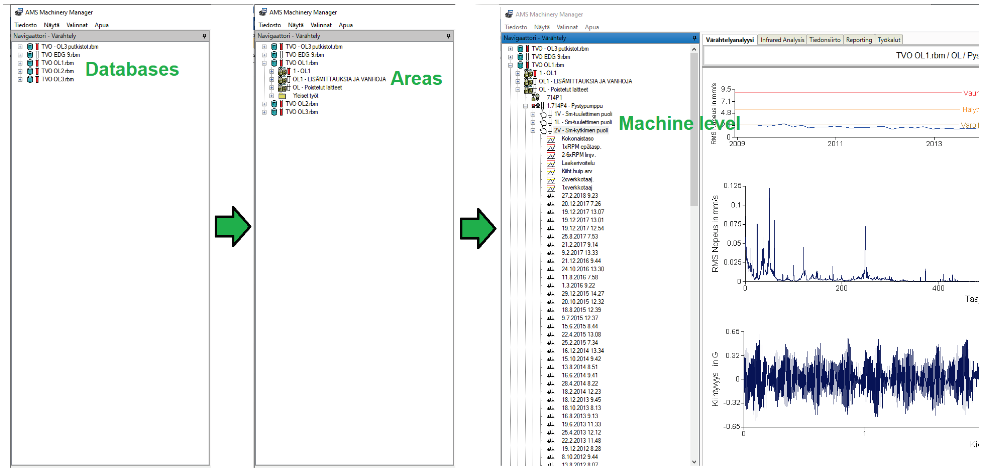

Figure 5.2b. The tree structure of AMS Machinery Health Manager software

When the fitter who performs the measurements detects even a beginning fault in the machinery measured, he informs the foreman or equipment responsible so that the planning of maintenance or overhaul can be started. If the fitter's knowledge of vibration monitoring isn't enough to analyse the results or more comprehensive measurements are required, the fitter, foreman or equipment responsible contacts the vibration specialist who performs more extensive measurements and analyses. In case only a slight issue is detected, lack of lubrication for example, the corrective actions can be performed immediately and after the corrective action the machine is measured again to see if the action had any affect.

5.2 VIBRATION MEASUREMENTS AND STUDIES PERFORMED BY VIBRATION SPECIALIST

The vibration specialists perform the special measurements that require deeper understanding. The vibration specialists use different kind of instruments in their works such as Beran 766 Plant monitoring system that also works as redundant system for VibroCam if needed, Oros OR38, LMS Scadas, Emerson CSI 2140 portable vibration analysers and different kinds of loggers and recorders in addition to software’s that are suitable for root cause analyses, modal analyses and software’s that suit for examining a particular vibration phenomena.

Some of the vibration analyses that vibration specialists have performed lately are listed below:

- Root cause analyses
- Acceptance testing and vibration measurements for rotating machinery and piping during commissioning
- ODS and OMA -analyses for structures, pipes and rotating machinery
- ODS for OL1 and OL2 plant units’ generators internals
- Structural concrete - displacement measurements during the pressure test of containment
- Investigation of valves springs spring constant for strength analyses with special devices.
- Structure vibration measurements during periodical testing of out blow system (314) from the reactor pool sides to provide more information and verification to earthquake fatigue analyses.
- High frequency pressure pulsation measurements
- Calibration of transducers and measurement chains using Beran 455 calibrator

It can be concluded that all sort of condition monitoring is carried out in Olkiluoto nuclear power plants, one more complex than the other. Due to the high level of expertise the condition monitoring in Olkiluoto is at advanced level and the overall understanding of the plant units’ condition is at high quality.

MAPPING OF CONDITION MONITORING SYSTEMS IN OLKILUOTO NUCLEAR POWERPLANTS

Condition monitoring systems have advanced significantly during the past years and new methods and systems are constantly being developed. The price of the equipment needed for vibration monitoring and analysis is decreasing. With vibration data as a base, multiple analyses on the plant health and behaviour during operation can be carried out.

When building a new nuclear power plant condition monitoring systems is a natural and integrated part of the design to facilitate monitoring of both large singular key components and small basic components used by the dozen. Installing condition monitoring systems in existing nuclear power plants is also possible, it just takes more effort to adapt the installation to the preconditions in the plant.

In this project, the condition monitoring systems of the Olkiluoto nuclear plant have been mapped. The plant has two older units commissioned in 1979/1982 and one new plant that is scheduled for regular operation starting 2022. The condition monitoring in Olkiluoto is at advanced level and the overall understanding of the plant units' condition is high quality due to high level of expertise and wide range of condition monitoring systems and methods used.

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