1 Installation and Operating Experience

Using the VM600 online Protection and Condition Monitoring System to monitor the supervisory parameters and the rotor air gaps at SENECA pumped storage facility in Warren, Pennsylvania.

1.1.1 Background and description of the plant

Fig 1: Aerial view from the East (Wikipedia)

The Seneca pumped storage facility is located in Warren, Northern Pennsylvania, in a remote and wooded location within the Allegheny National Forest.

Built by the US Army Corp of Engineers and completed in 1965, the Kinzua dam is 179 feet high and 1877 feet long and contains a reservoir on the Allegheny River some 25 miles long.

It was originally designed as a flood control device to regulate the flow of water and to prevent flood damage especially in central Pittsburg, further down the river.

The generation capability was installed later, and the plant entered commercial operation in 1970, with an installed capacity of nearly 500 mw from three hydro generation units – two rated at 225 mw and a smaller black start unit rated at 35 mw.

The two larger units are designed and configured to operate in two modes – either generation or pumping - and during off-peak times, these two units are used to pump water from the reservoir up to the holding pond, some 800 feet above the main rotors of the units.

During peak demand periods, the stored water is released through the units providing up to 6 hours of full load generation.

Fig 2: Aerial view from North (Wikipedia)

The Seneca facility is currently operated by First Energy who have a second pumped storage plant at Yards Creek in New jersey. First Energy's main generating capacity is from Nuclear, and they operate the Beaver Valley, Davis-Besse and Perry plants.

1.1.2 Generating mode vs. Pumping Mode

The two larger units at Seneca are designed to spin in both directions depending on the operational mode – either generating or pumping - and as they do so, distinct differences in the vibration signatures are observed.

The existing BN3300 protection system had been in place for a number of years, and presented various challenges to the machine diagnostics engineers from First Energy. In addition, this modular system is now obsolete and maintenance and support was becoming problematic.

Being an older analog style system, there was no facility to store data of any kind, so operational or post-event analysis and machine health diagnostics was impossible, except by bringing in and connecting an external data recorder / analyzer.

Whilst this method was acceptable for short periods, a further major issue was that the existing system had no means of determining the direction of rotation – and therefore the operating mode - for Units 1 and 2. Thereafter, in any vibration analysis which was done, it was impossible to distinguish the rotational direction from the data recordings of the operational periods.

1.1.3 Objectives of replacement system

Historically, hydro machines have enjoyed one of the lowest costs per MW of any machines on the grid, and have typically been used for base loading, only reducing load or coming off line when maintenance was required. In this mode, hydro units have operated successfully and reliably for long periods with only routine scheduled maintenance and minimal condition monitoring.

However, in the modern deregulated power sector, with various concerns over water quality and the environment, and taking into account the inherent flexibility of these machines, hydro units are now often used as load-following or peaking units, which usually means that units are subject to continuous load changes and partial load operation. This is particularly the case for pumped storage units which often experience multiple starts and stops each day.

This regime in turn creates operational stresses including rough zone operation, cavitation and efficiency drop-off, and continuous load cycling introduces thermal, mechanical and electrical stresses, which were probably not considered when the machine was originally designed and installed. Cost cutting and de-manning have exacerbated the situation by forcing operators to reduce or even to eliminate maintenance outages, and the effect has been to adversely affect reliable operation and condition of hydro units in general, and clearly the need for condition monitoring has never been more important and relevant.

For all of these reasons, First Energy implemented a project to replace the existing obsolete equipment with an all new digital system, which offered combined protection and condition monitoring, data storage and a usable graphical user interface (gui) which would provide a comprehensive view of the plant and the various parameters on a series of fully customized plant and machine mimics.

An important requirement of the new system was that it should provide a means of separating the generating data from the pumping data for Units 1 and 2, and a simple way of selecting that data, thereby making post-event diagnostics much simpler.

Two plane bearing vibration had previously been installed for the three main bearings for Units 1 and 2, but there was no thrust bearing monitoring, and the smaller Unit 3 had no supervisory or protection installed at all.

Therefore, the scope of the new supervisory system was to include the supply and installation of thrust monitoring probes for U1 and U2, and the installation of vibration monitoring on the three main bearings and thrust monitoring, all for Unit 3.

With changes in operational regimes, it has become increasingly important for operators of hydro generating machines to monitor the rotor-to-stator air gaps to ensure the continued good health of the machines. Therefore the new system was also to include the addition of Rotor Air Gap monitoring for all three units.

1.1.4 Equipment and Vendor Selection

First Energy had previous operational experience both with the selected equipment and with the selected equipment vendor, having used both for the supervisory replacement installation at the company’s nuclear plant at Beaver Valley. However, the project was put out to competitive tender.

After appropriate due diligence, the equipment selected comprises components for more than one company, but it is based primarily on the VM600 Vibration Monitoring System – manufactured by the Vibro-Meter division of Meggitt Sensing Systems.

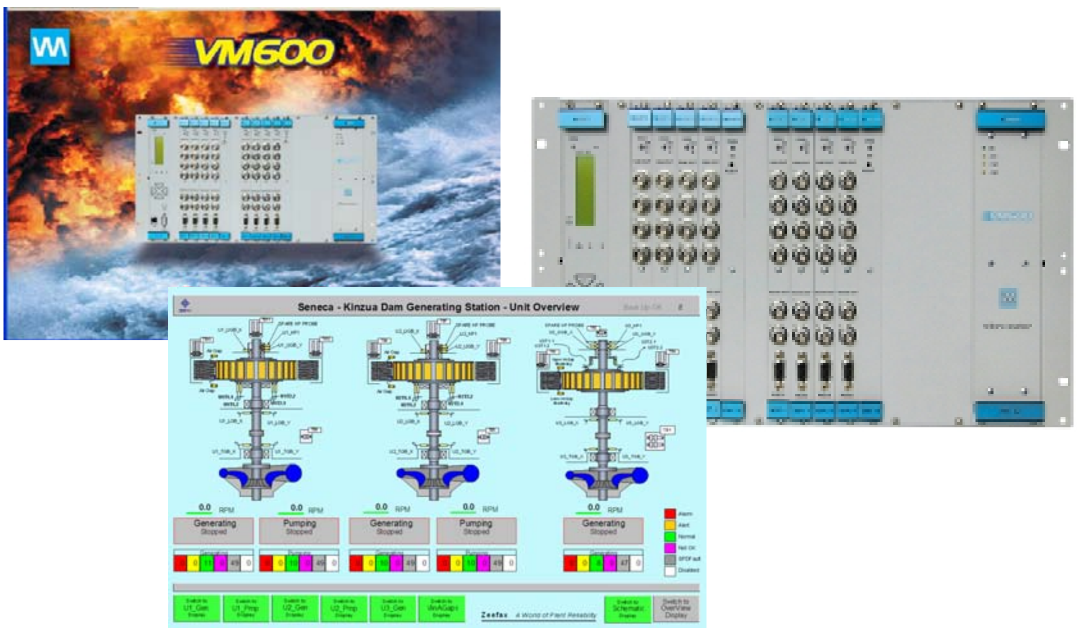

Fig 3: VM600 Images
Note Seneca Mimic from installed system

The vendor selected was Zeefax inc, the Pipersville based system integrator, which specializes in Turbine Supervisory Systems, and is an approved VAR for the Vibro-Meter VM600 systems.

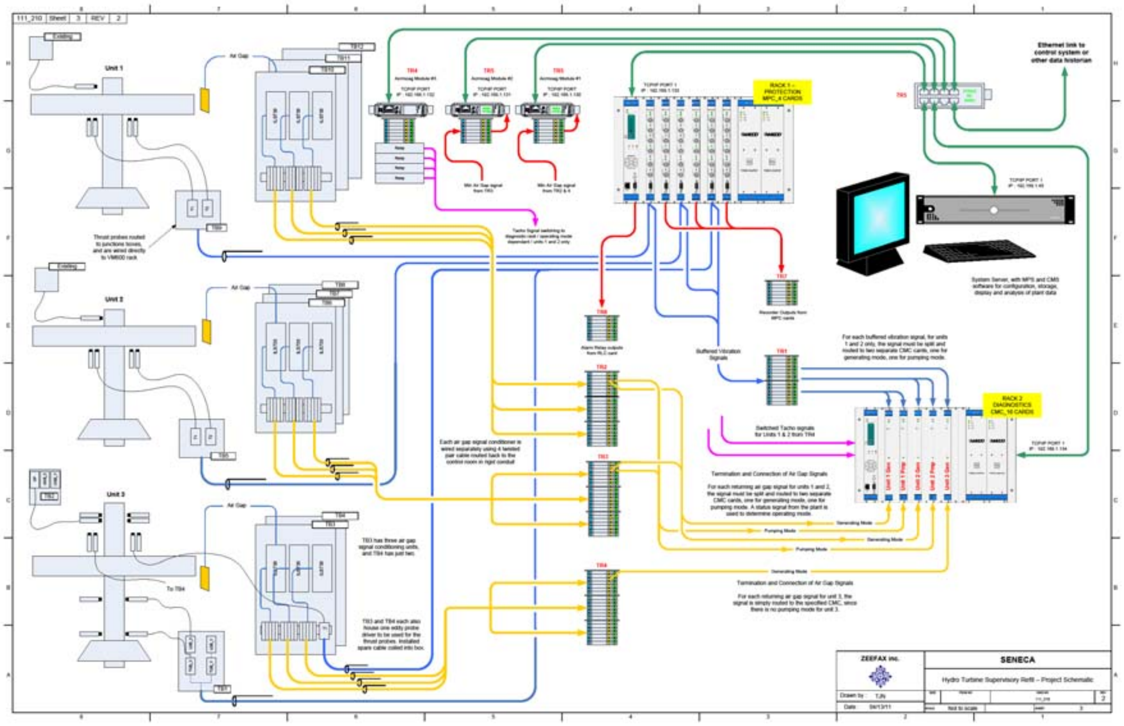

Fig 4: System design

The system was designed and integrated by Zeefax, including all customized parts such as transducer mounting brackets, panels, junction boxes and the complex wiring regime which was required.

A range of transducers and instrumentation is also used, including proximity sensors from SKF for vibration and thrust measurement, and the Air Gap sensors are from Vibro-Meter.

As part of the scope of supply, the electrical and mechanical installation together with the subsequent system start-up was supervised and fully supported by Zeefax engineers.

Within the VM600 system, it is the machine key phase signal which enables or disables the monitoring and the data acquisition process; a proposal was made to use this feature in an ingenious arrangement to segregate the generating data from the pumping data within the database, making analysis and reporting much simpler than it had previously been.

This solution combination was selected by First Energy based on significant cost advantage, and also upon a demonstrated ability to meet the detailed requirements by providing a fully working demonstration and a series of detailed design drawings prior to contract placement.

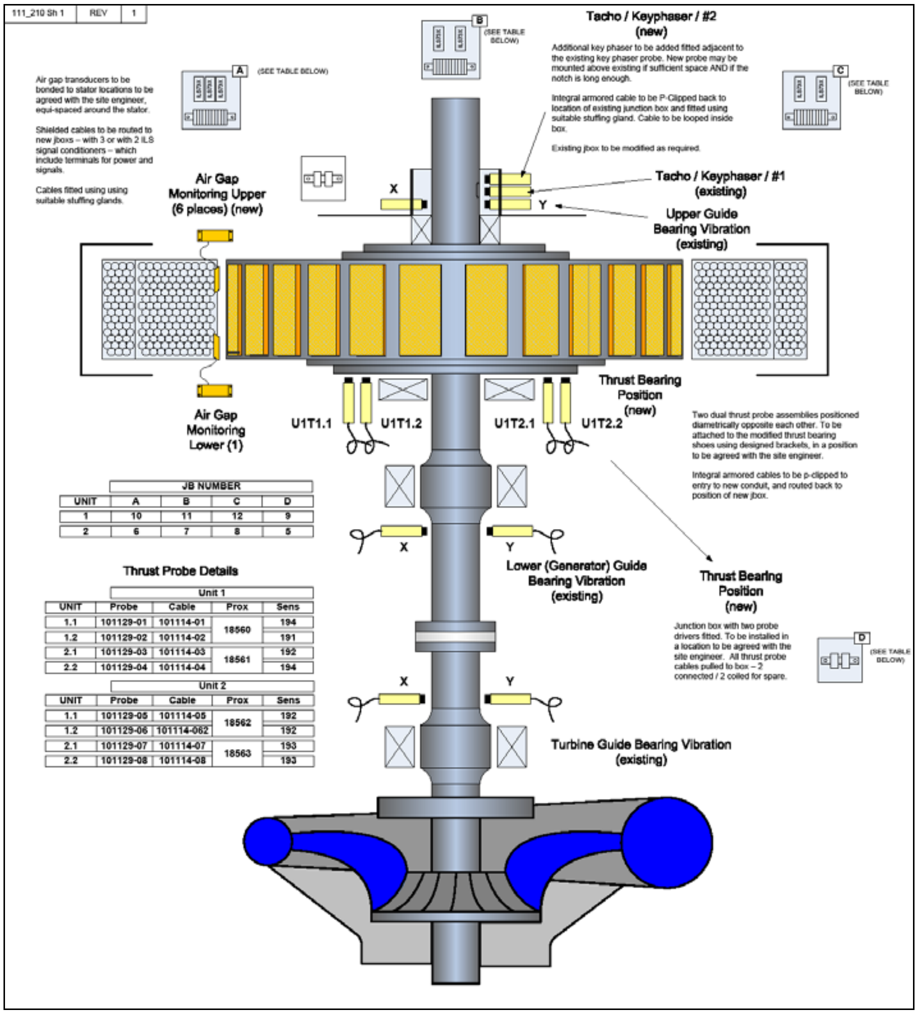

Fig 5:   Proposed detail of work to be done on Units 1 and 2

1.1.5 Installation

The installation of the new supervisory system was performed during a major outage at the plant, during which a range of mechanical and electrical work was done on Unit 3, including removal of the generator rotor, removal and replacement of the turbine and the convolute case and replacement of protection and over-speed relay systems.

1.1.5.1 Thrust bearing position monitoring probes

For all three units, thrust shoes where removed and machined to accept new dual probe holders.

For units 1 and 2, the thrust bearings consist of 12 shoe pieces, positioned below the main rotors, in between the rotor and the turbine. They are very heavy and require special low profile lifting gear to remove them in the very restricted space available. Once removed, the shoes were inspected and machined to accept the new dual thrust probe holders, which were positioned so as to look at the rotating thrust collar, located just below the main generator rotor.

When fully reassembled and supporting the full weight of the turbine and with the rotor at rest, the newly installed thrust probes were gapped and zeroed in the monitoring software to suit.

The thrust bearing case is an extremely hostile environment, being filled with hot oil during operation, and the probes and cables require enhanced mechanical protection in this area.

Egress of the armored and sealed probe cables was through an existing custom built bulkhead cut into the 1” thick thrust bearing case, which provides an oil seal around the probe cables. This bulkhead is also used to bring out the existing numerous thermocouple and load cell cables, which are also used to monitor the condition and performance of the thrust bearings.

The thrust bearings on Units 1 and 2 are a considerable size - measuring some 8 feet in diameter, with each of the 12 shoes weighting up to 1000 pounds; it can support the full weight of the rotor/turbine assembly at rest, which is approaching 1200 tons!

The 6-shoe thrust bearing for unit 3 is positioned above the rotor so it is slightly easier to access, but the process was basically the same.

For each thrust bearing, two shoes were selected and machined to accept the new dual probe holder. The probes were installed and wired in place and the integral cables carefully routed and clipped back to the access point. Two probes are fitted onto each shoe (4 in total) providing redundancy in case of damage or failure in the future.

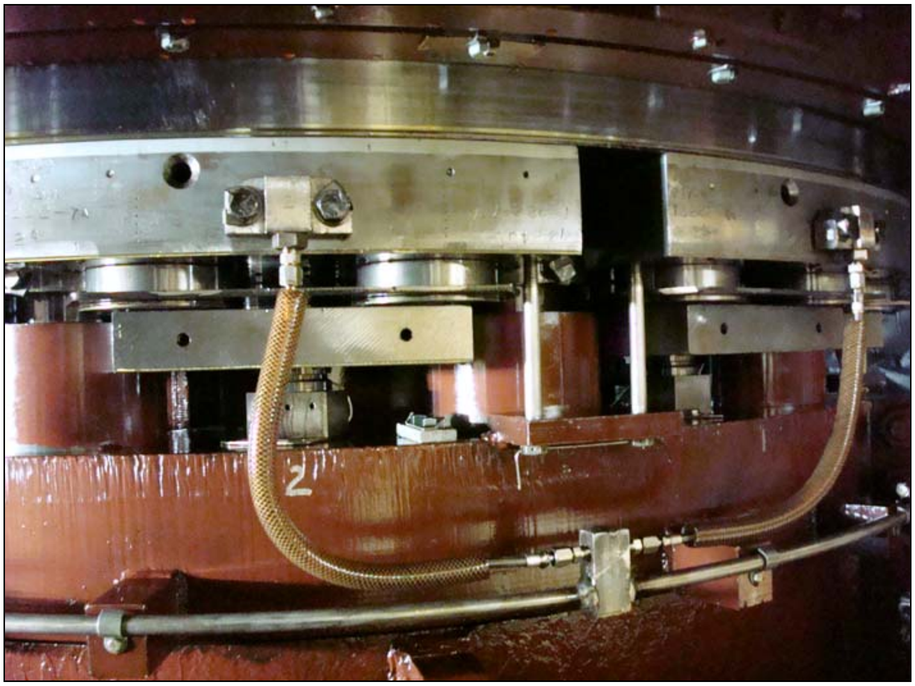

Fig 6: Unit 1 (2) thrust bearing detail

The purpose of installing the thrust probes is two fold: firstly to provide a permissive to operate following start-up and the ‘lifting’ of the rotor by the high pressure oil film which is pumped to each shoe, and secondly, to provide indication of rocking or misalignment during operation.

1.1.5.2 Installation of X and Y probes on Unit 3

One of the challenges faced by Zeefax during this installation was the lack of detailed mechanical component and assembly drawings relating to the installed Hydro Units. Although some drawings where available, they had been hand drawn on paper in the early 1960s, and many were in poor condition. Because of this, in most cases, the required dimensions, hole centers and other details had to be measured or derived directly from the units.

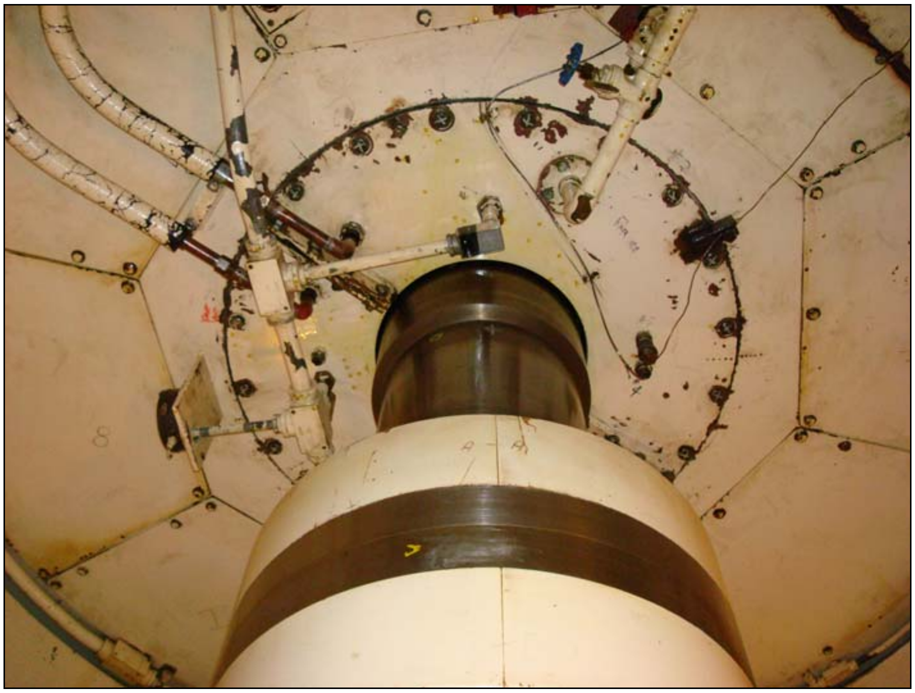

Fig 7:   Lower guide bearing as found

Using careful measurement, trigonometric extrapolation and photography, a series of mechanical drawings were constructed for each bearing. These drawings were then used to assist with the detailed design of the probe mounting brackets, to help locate the positions of various access points which were required and to establish final mounting positions of the transducers.

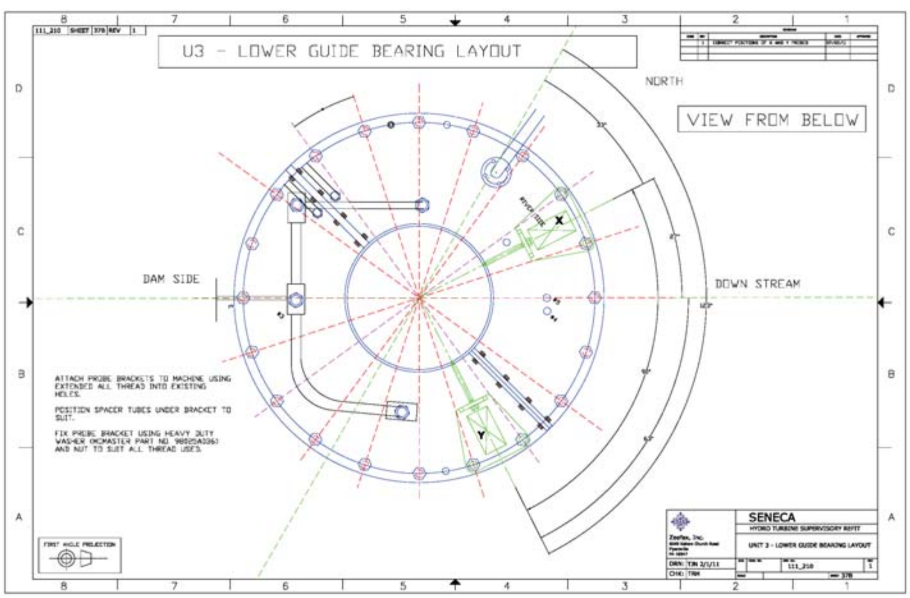

Fig 8:   Constructed scale drawing of Lower Guide Bearing Cover Plate

The constructed scale drawings were used to establish dimensions for the brackets and mounting arrangements, and detailed bracket drawings were produced.

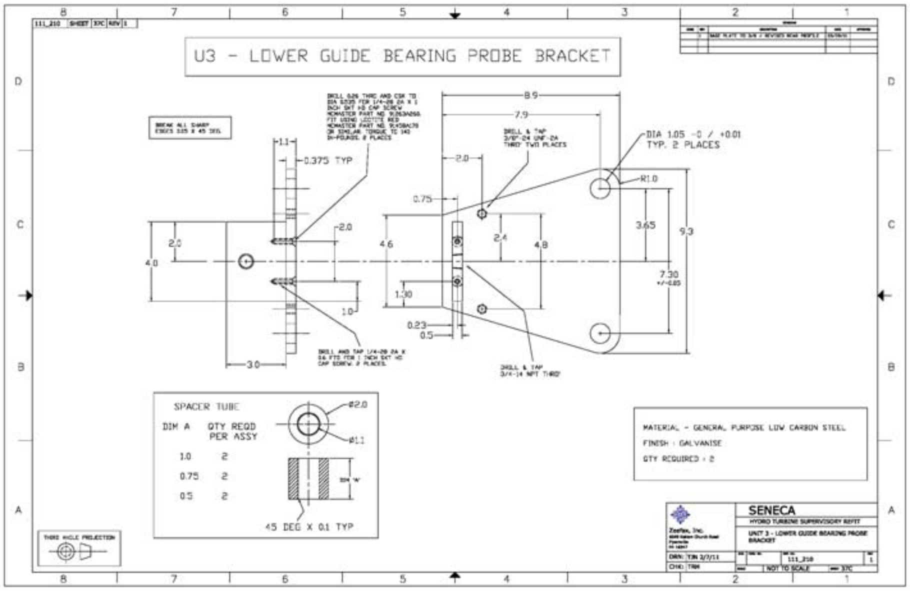

Fig 9: Lower Guide Bearing Detail

Each actual probe was also fitted inside an adjustable stinger, which was used to help with probe gapping following mounting of the brackets in the difficult to access locations.

The completed assemblies were then bolted in place, probes gapped, and cables pulled back to the interposing marshalling box inside flex-conduit. In all instances, the brackets fitted out-of-the-box with no additional re-work required!

1.1.5.3 Installation of air gap probes on all three units

Conventional wisdom stated that it was necessary to remove the generator rotor in order to install the Air Gap sensors, but in this outage, First Energy did not intend to remove the rotors for Units 1 and 2, and yet the Air Gap sensors were still required to be installed.

For unit 3, which had been fully dismantled, the process was relatively simple, using a long spreader across the inside diameter of the stator, but Units 1 and 2 posed a further challenge for Zeefax and the electrical contractor. How was this to be done?

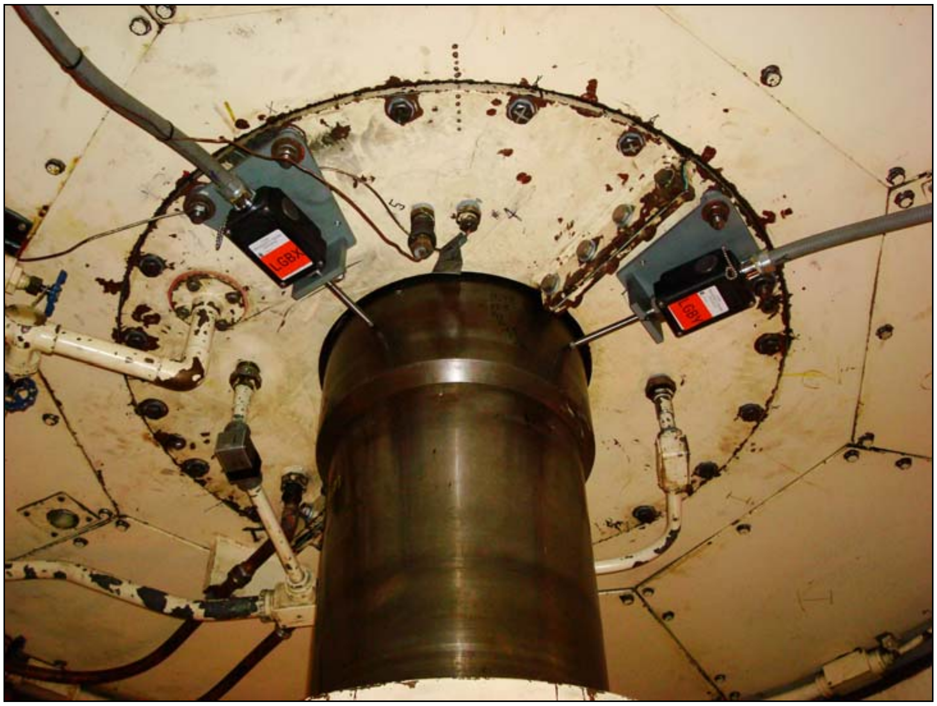

Fig 10: New X/Y Probes fitted to LGB Cover

Once again, due to lack of adequate assembly drawings, a series of dimensional drawings had to be constructed in order to locate the angular positions, distances and availability of inter-pole gaps in which air gap sensors could be installed.

It was also necessary to design and manufacture the special tooling required to clamp the air gap sensors onto the inside face of the stator while the special adhesive cured, yet without being able to access the outer face of the stator and with the rotor still in place.

The adhesive used is a slow curing, high temperature rated, two part resin based product, which allows for some flexing when dry, yet is very strong in tension. Therefore, tooling had to be designed and built which would allow the Air Gap sensors to be clamped in place for 24 hours, yet would fit into the available space between the rotor poles.

When measuring Air Gap, it is also desirable to position the sensors at about 1x the length of the probe **below** the top edge of the stator, making almost 10 inches in this case.

All of these considerations had to be taken into account, measurements taken, angular positions plotted and agreed, and importantly, the sensor installation technique had to be established and tested prior to full implementation.

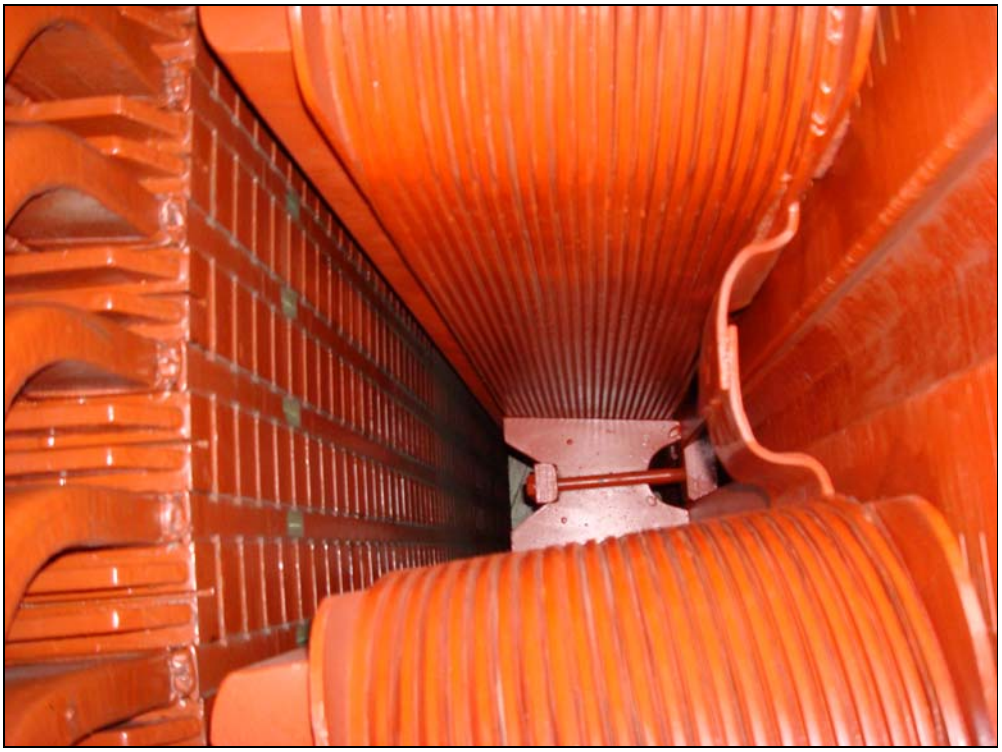

Fig 11: Inter-pole gap looking down
Rotor to the right, stator to the left

In the final analysis, the rotor being in place helped us by giving a solid surface against which the specially designed and manufactured expander tool could push to hold the probe in place against the stator.

However, it was a somewhat tricky operation to engineer the inner surface of the stator on which to bond the air gap sensors. Located at 8-10 inches below the top edge of the stator in between the pole pieces of the rotor, it was necessary to prepare the surface to accept the sensor, by removing the varnish and de-grease the surface. In this very limited space, working well below 'foot' level, the Air Gap sensors were then maneuvered into position and clamped in place; dust sheets and lanyards were used to secure anything which might drop, since extraction cwould have been difficult!

(photo of spreader tool)

When all sensors had been installed, it was then necessary to carefully document exactly where the Air Gap sensors where located, since the VM600 software requires configuration of the actual angles relative to the position of the key phase probe.

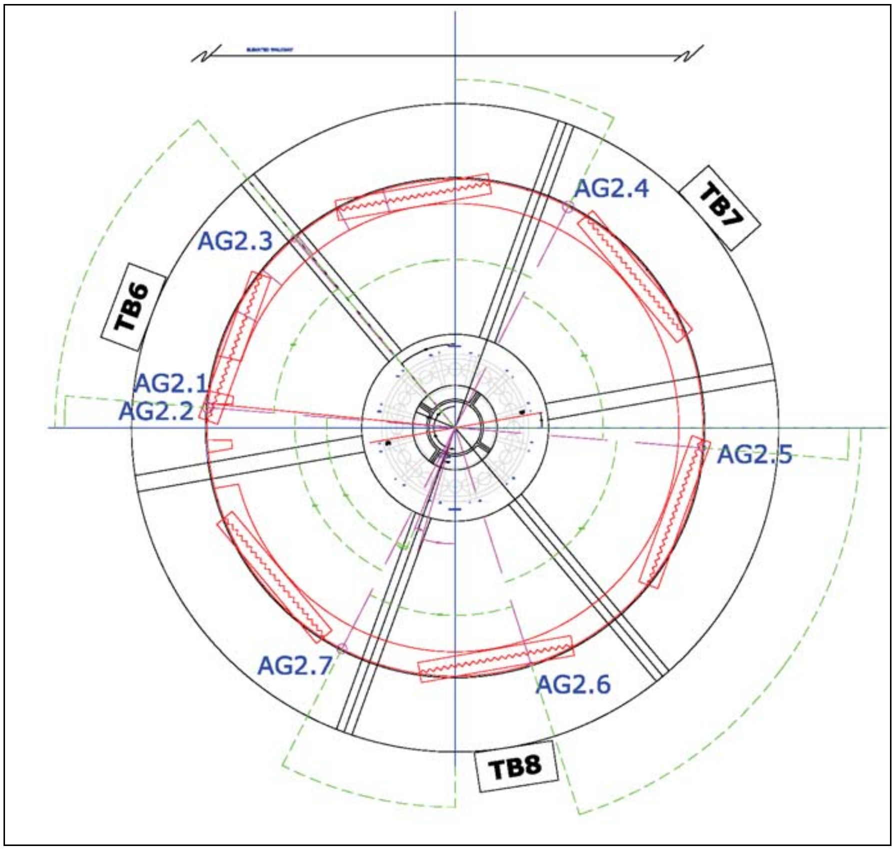

Fig 12: Relative Air Gap Positions for Units 1 an 2

The image shows the relative positions of the air gap sensors, with all angles identified, and the externally mounted signal conditioning / marshalling boxes. The drawing also positions the unit correctly in the turbine hall making identification of specific items easy.

1.1.5.4 Control Panel Work

The old vibration protection rack was carefully removed from the Main Control Room (MCR) panel. The existing vibration sensor wiring and panel cut out was used to accommodate the new VM600 **Protection Rack**, and an additional panel cut out was made to accept the new **Condition Monitoring Rack**.

In the rear of the MCR panel, the existing vibration signal cables were re-connected directly onto the new protection rack together with the cables from the various new sensor cables from all units.

A feature of the VM600 Machine Protection Card (MPC) is ability to re-transmit the buffered raw input signals, and these buffered vibration signals were then routed to the input of the Condition Monitoring Cards (CMC) installed in the second rack.

For units 1 and 2, each vibration signal was routed via a splitter to two condition monitoring channels – one for generating duty and one for pumping duty. Unit 3 signals were connected directly to the condition monitoring rack since it has only generating duty.

Likewise for the new air gap signals; for units 1 and 2, the signals were split and connected to two analysis channels and for unit 3 only a single connection per channel was made.

1.1.5.5 Important VM600 Technical Background

The VM600 condition monitoring system uses the machine key phase probe signal to enable the data collection for that particular machine; therefore, if a key phase is present, the virtual machine becomes active, and the VM600 system monitors and acquires data for all of the channels associated with that virtual machine; if the key phase is not present, the virtual machine is inactive, with no data collection.

In order to achieve separation between **pumping** and **generating** duty, two virtual machines were created for each of units 1 and 2 – namely, unit1_gen, unit1_pmp, unit2_gen and unit2_pmp.

The split unit1 signals where then routed to both unit1 virtual machines and the same for unit2, and the single key phase signal for each unit was routed to each virtual machine via a control relay.

By making use of unit status signals from the main plant control system, the control relay automatically switches the key phase ‘on’ and ‘off’ for each virtual machine. In this way, the virtual machines are ‘enabled’ or ‘disabled’, thereby separating the ‘generating’ data from the ‘pumping’ data.

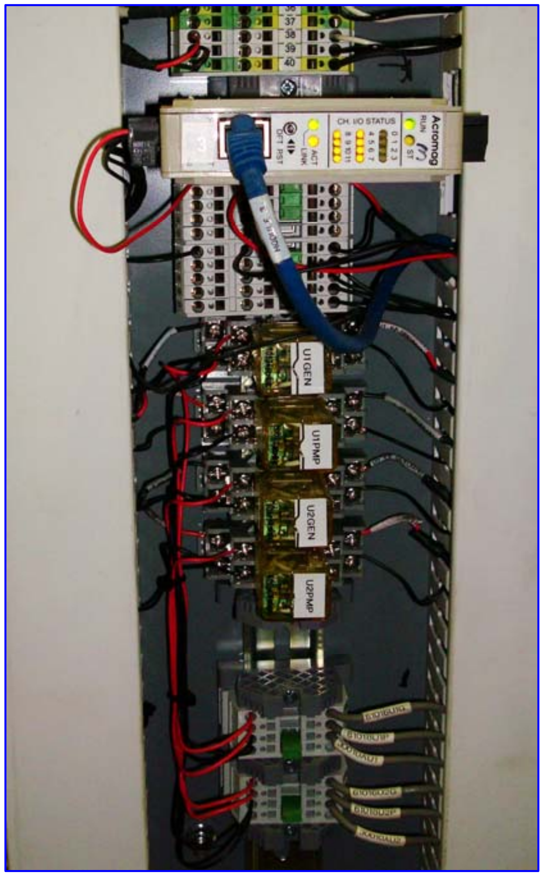

Fig 13: Key Phase Input Control Relays

This innovative and never before used technique totally separates the generating data from the pumping data within the database, allowing the First Energy machine analysts to quickly interpret the different signatures associated with the two operating modes for units 1 and 2.

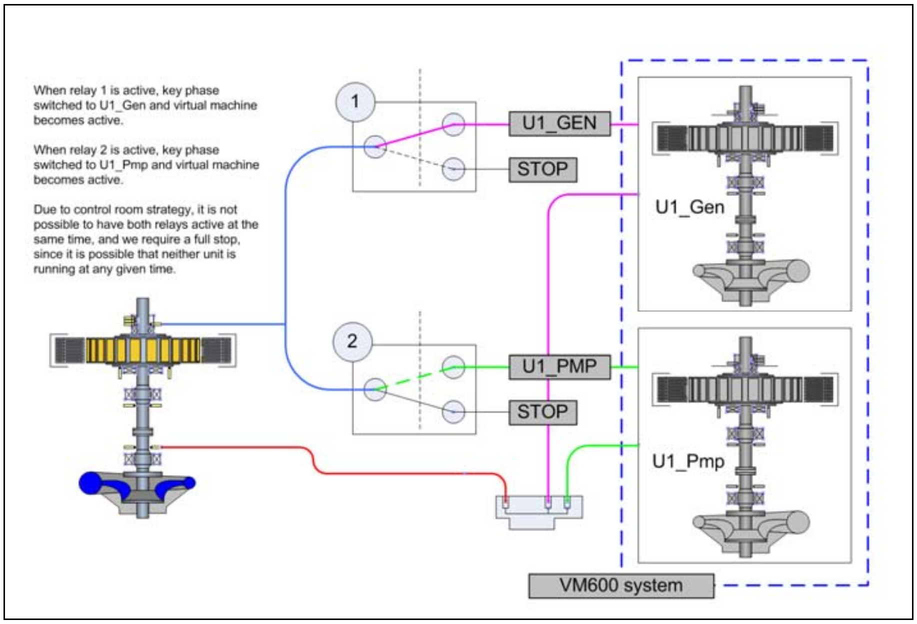

Fig 14: Key Phase switching for units 1 (U2 identical)

1.1.6 Start-up

The necessities of having to construct drawings to establish key dimensions made the mechanical design more difficult than it might have been, but all new mechanical items and all modifications to the existing items went without hitch.

The complexities of providing separate signals for generating and pumping for units 1 and 2, and the associated switching caused the wiring system to become much larger and more complex than it might otherwise have been.

However, the new monitoring system was installed, tested and operational in time to catch the first starts following the outage at the end of July 2011, and worked ‘out-of-the-box’.

1.1.7 Operational Experience & Data View

Being a pumped storage unit, this plant is used primarily for peaking, and therefore is typically subject to multiple starts each day.

Since the start-up in early august, the VM600 system has captured data from many starts and short operating periods, and has established a series of baseline characteristics for the three units in each available operating mode.

Interpretation of the data and assessment as to how to approach using this data are still ongoing.

This plot shows the VM600 data analysis tool, clearly showing the segregation between the generating and pumping mode data.

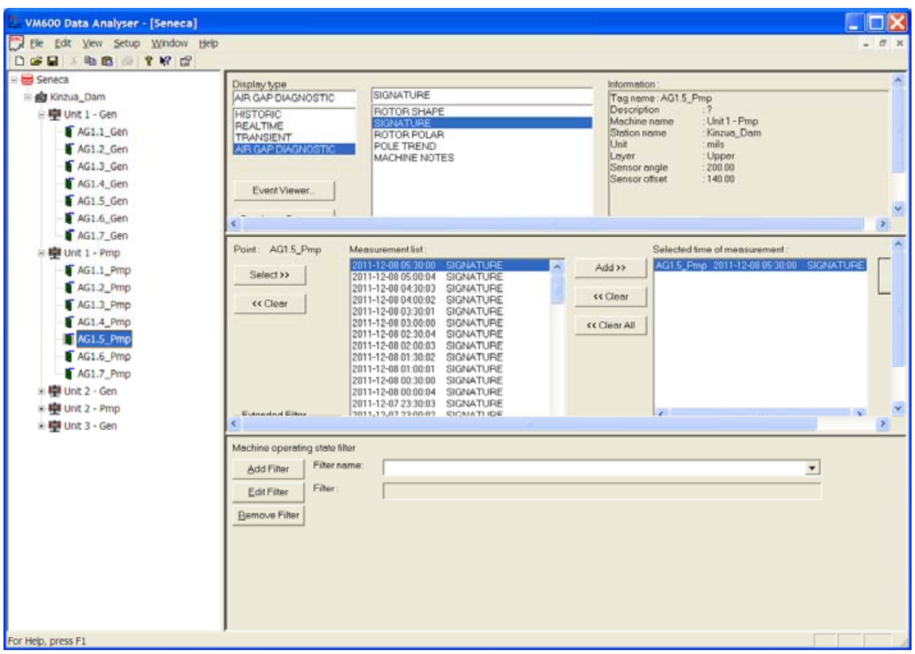

Fig 15: VM600 data analyzer / Segregation of Gen and Pmp Data

As an example, the following plots show the Rotor Signature for Unit 1 according to Air Gap Sensor number 5.

The apparent horizontal reflection seen is produced as a result of the change of rotational direction between the Generating and Pumping modes

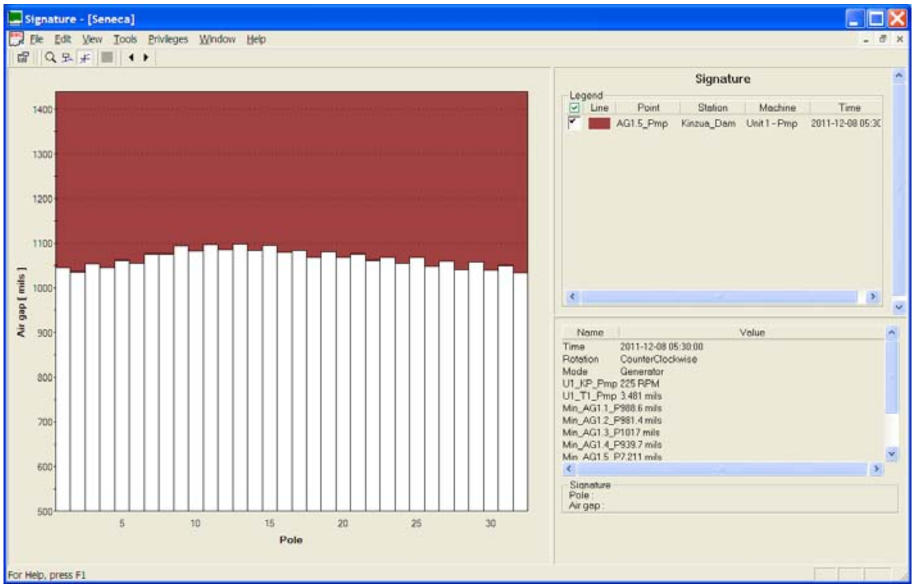

Fig 16: Signature / AG1.5 in Pumping Mode / CCW

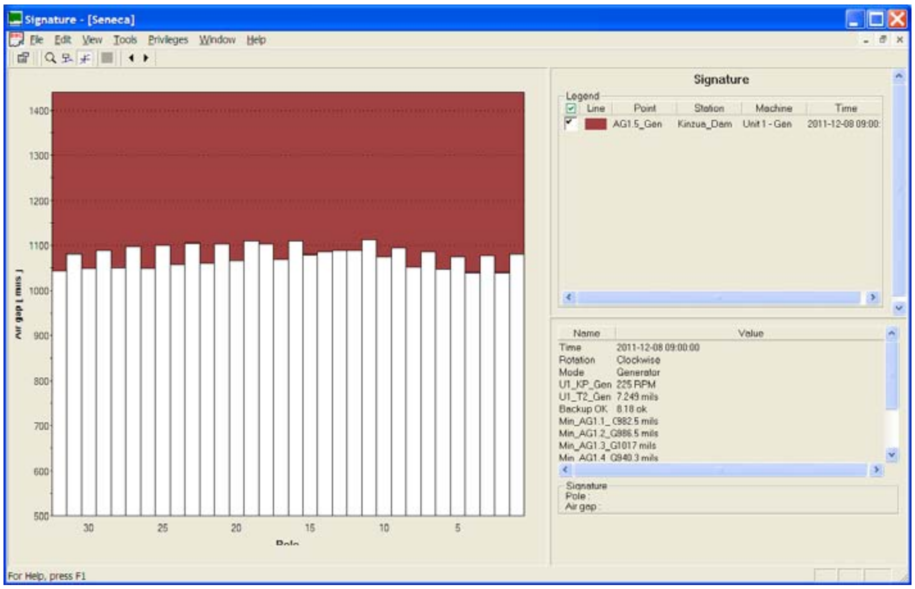

Fig 17: Signature / AG1.5 in Generating Mode / CW