PROTECTION AND MONITORING SYSTEM FOR HYDROELECTRIC GENERATING SETS

Brite-Euram project BE-7289- PROMOSHYGES BRE2-CT94-0937

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Summary.- The aim of this Brite-Euram project is the predictive maintenance of large hydro T-G sets through the correlation between vibrations, failures and defects. New low and medium frequency optical fiber and integrated optics accelerometers based on intensity modulation, are under development with the aim of overcoming the typical problems related to the hostile electromagnetic environment. A dynamic data acquisition and signal processing unit -DASPU- capable of simultaneous sampling, digital filtering, transformation of asynchronous sampled data into equivalent synchronous sampled data and reconstruction of orbits has been designed and developed. The DASPU analyses measured signals and the information is sent to a host computer, through a digital communication link where different concurrent and/or alternative techniques may be used to detect changes in the behaviour of the parameters indicative of the development of a fault: statistical techniques (multiregression and Kriging) and and artificial intelligence software package, based on a neural network approach. Finally, the host computer software, supported by commercial standards, controls the data acquired and transmitted by the DASPUs, builds a data base from the recorded data and stores and displays the data to use for data trend analysis. The system can operate as a stand alone prediction maintenance system or be integrated in a larger corporative system.

1.-Introduction

This project is being financed by the Commission of the European Union, Direction General XII, under the Brite-Euram programme. The project started in June 1994 and the duration is three years.

Maintenance optimization at hydro power plants is a major area where efforts are being made to reduce costs and refine procedures, with a view to optimizing the overall performance.

In general most of the maintenance is done on a fixed time basis (preventive) and corrective when a problem arises. The transition from

preventive to predictive is clearly an effective way of achieving future costs savings. By carrying out repair work only when it is needed, based on the analysis in time of different components, it will become possible to extend the life of equipment and components, preventing unexpected failures and the consequent loss of production.

Normally hydro power plants commissioned in recent years have installed different types of predictive maintenance tools depending of their size and expected production, being the most popular vibration monitoring because of its capability of detecting most of the mechanical, electrical mechanical related and hydraulic malfunctions.

Retrofit of older machines with vibration monitoring systems is being done at a very slow rate for different reasons:

- Most of the existing systems in the market have been developed for other applications (in many cases with success) and later on have been extrapolated to hydro machines with poor results.
-Elevated prices for multichanel systems.
-They are normally stand alone systems.
-Accelerometers do not perform well at low frequencies.
-Tools for diagnosis have been developed for other purposes.

The aim of the project is the predictive maintenance of large vertical hydro T-G sets developing a system to overcome the afore mentioned drawbacks. The new system will perform through the dynamic monitoring of the line axis with determination of the relative motion between shaft and bearings and the absolute motion of the bearing support. A prototype of a trend monitoring and protection system based on the study of vibration behaviour has to be developed. In this project new accelerometers, based on advanced optical technologies, will be used. They should be capable of the measurement of low frequency (lower than 1 Hz) and medium frequency vibrations in a hostile electromagnetic environment. These sensors measure the vibrations of the guide bearing supports and other specific items like core and end winding. An advanced dynamic data acquisition and signal processing unit capable of reconstructing the orbits and of analysing the sensor signals is also being developed. To estimate the error between the measured and predicted vibrations a correlation analysis with the working parameters of the T-G sets is required. The system is complemented with instrumentation already existing in the power plant for detection of static parameters such as water level, opening of the distributor, active power, power factor, temperature of the different components of the machine, pressure, etc. This monitoring system must solve the following problems:

- Instantaneous protection of the machines.
- Prediction of catastrophic risks.
- Real time detection of mechanical failure generating electrical faults or defects.
- Early detection of possible failures.

Both electrical power utilities and manufacturers of power machines will obtain benefits. The electrical utilities because of the increment of the operational life of the machines, the avoidance of catastrophic risks and also

the reduction of the maintenance time. The power machine manufacturers because of the availability of operational data which allows a better oriented design and manufacture. Also the manufacturers of transducer and signal processing units could find a new market.

2.- General Description of the Monitoring System

The project is addressed to the design, fabrication, installation and qualification of a prototype of a protection and monitoring system for the supervision of the behaviour of low speed Hydro T-G sets, turbine and pump turbine generator sets.

The aim of the system is to achieve effective management of vibration, plant status and static data by combining the advantages of a dedicated sub-system with extensive software packages that provide tools for data display, data interpretation, data trend, long term storage and alert management.

The following measures will be implemented in the prototype:

- Static data (i.e., active and reactive power,hydraulic head, temperatures, flows, levels,....)
- Alarm and alert signal from the "Protection System"
- Dynamic data : relative and/or absolute displacement at the guide bearing level, acceleration of the bearing support;
- Winding end turn vibration

The measured signals are acquired, processed, stored, displayed and reduced in order to obtain :

- information on status of the monitored machinery;
- short term history;
- long term history;
- data trend.

The system will be formed by a complex of modular functional blocks, fig. 1. The main functional blocks are:

- data acquisition;
- data analysis and reduction;
- management of the data and information flow that includes data display, data trend, alert and alarm function;
- on line diagnostic analysis (off - line diagnostic analysis will be developed in the future);
- interfaces with the local operator and with central offices;
- interfaces with local equipment (alert and alarm signals).

The monitoring strategy, fig 2 is based on:

continuous surveillance of the group carried out at predetermined time intervals with the machine in "steady state regime"; detection of alert / alarm

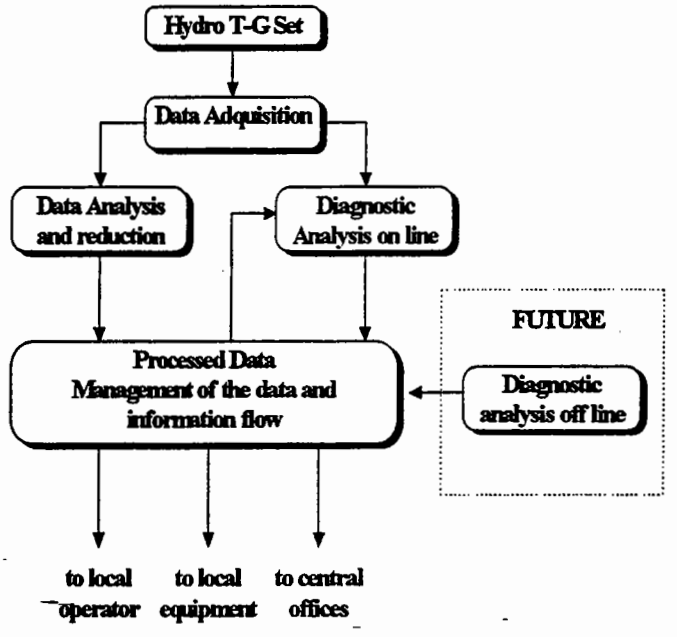

Fig. 1: Simplified functional block of the system

signals generated by the "Protection and Control system"with the subsequent acquisition of the measured data at defined time intervals, for a predetermined time duration or up to the alert/alarm signal go down.

The proposed monitoring system is a hierarchical, distributed system, which is composed of several DASPU's connected to a host computer by means of a digital communication network, Fig. 3.

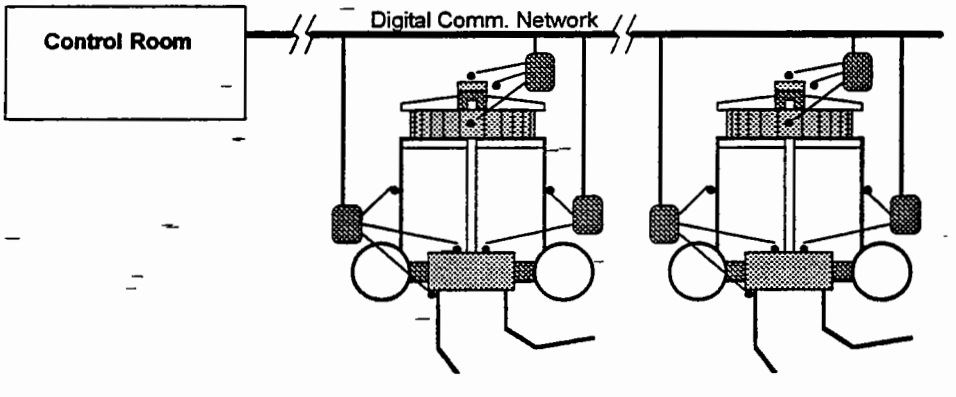

Figure 3. Proposed Monitoring System

The main advantages of this approach are: distribution and easy expandability, easy maintenance and moderate cost. There are many different types of signals that the system should acquire and process; therefore, two types of DASPUs are considered:

- Static DASPU: processes signals of very low bandwidth (less than 1 Hz), processes the obtained samples (comparing them with the alarm levels) and transmits the necessary information to the host computer.

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- Dynamic DASPU: processes signals of a bandwidth up to 450 Hz, ensuring simultaneous sampling up to bandwidth of 80 Hz.

For the static DASPU, the use of a commercial unit, available on the market, has been decided. The other parts of the system : dynamic DASPU, communications network and host computer software are described in the following sections.

3.- Dynamic DASPU

The dynamic DASPU is a specific unit that implements high complexity digital signal processing algorithms. It should process 16 channels with a bandwidth up to 450 Hz. It should be able to simultaneously sample these 16 channels up to a bandwidth of 80 Hz, and also convert space-asynchronous sampled data (samples obtained through periodic sampling) in space-synchronous sampled data with respect to a keyphasor that gives us the rotation speed of the shaft. Moreover, it should be able to implement several digital signal processing algorithms: digital filtering, decimation, interpolation, spectral analysis, etc. The dynamic DASPU complies with the specifications shown in Table 1.

esolution	12 bits
Channels	16
Sampling rate (per channel)	up to 16 Ksamples/s
Alias attenuation	>70 dB
Analog antialiasing filters	Butterworth four poles
Hardware simultaneous sampling	every 2 channels
Simultaneous sampling	16 channels (up to 80 Hz)
DSP	TMS320-C30
Programmable gain	No (fixed ±5 volts)
Digital inputs	1 (Keyphasor)
Alarm output	1 per channel
Digital Signal Processing	Digital filtering, FFT, decimation, interpolation, spectral estimation...
Digital communication	RS-485

Table 1: Specifications of the Dynamic DASPU.

In its final design the dynamic DASPU is composed of two boards, connected with a high speed serial line. The first board, the Acquisition Unit (AU), depends on the type of signals that have to be acquired and implements the continuous-time signal processing (antialiasing filtering, multiplexing and analog to digital conversion). It contains two Analog to Digital Converters (ADC), thus allowing simultaneous hardware sampling of each couple of orthogonal transducers. The second board, the Signal Processing Unit (SPU), carries out the digital signal processing algorithms

and can be connected to different types of AU's. This board is based on the TMS320C30 Digital Signal Processor. It includes fast access memory (20 ns) up to a maximum of 2 Mbytes, and normal access dynamic memories (70 ns) allowing a maximum of 16 Mbytes of storage. For the digital signal processing algorithms, their main characteristics are:

- Simultaneous temporal sampling is obtained by linear interpolation of high oversampled signals.
- After a first decimation stage, asynchronous to synchronous conversion is obtained again by linear interpolation. The information necessary to perform this conversion is provided by a keyphasor that gives one pulse per revolution.
- An FFT algorithm is applied to obtain the spectra; moreover the system includes a method for obtaining frequencies, amplitudes and phases of the fundamental frequency and the largest harmonics; this information is necessary to reconstruct orbits described by the shaft.
- Other values such as RMS value and vibration level of the main harmonic and subharmonics are also calculated.

Finally, all this information is transferred to the host for storage, display and further processing.

4.- Digital Communication Network

The communication network for the dynamic DASPU follows the standard RS-485, data rate will be around 100 Kbps to insure fast data transfer between DASPUs and the host computer. Because of this high rate, the serial link of a PC computer can not be used and a special board has to be added to the PC. Up to 32 DASPUs could be installed and the distance cannot reach more than 1200 metres without repeaters.

The commercial unit that has been chosen to process the very low frequency channels (static DASPU) can not communicate at such a high rate, therefore a second low speed line, will be provided. This network will work at a bit rate of 9600 bps.

5. Host Computer Software

The monitoring software processes the information from all the DASPUs and does the following main tasks: configuration of the system, data transfer from the DASPUs, data storage in a signal data base, statistical data analysis, neural network data processing and alert and alarm display.

The software continuously monitors the status of the DASPUs, static or dynamic, by means of a master/slave communication protocol. In the simplest form the message is very short, avoiding delays between DASPUs, indicating only if there is some variable out of alert/alarm ranges. When an alert/alarm condition occurs, a flashing and acoustic warning will appear on the operator terminal.

Twomodes of operation will be possible, manual and automatic: in the manual mode the operator can monitor a particular DASPU to perform data acquisition and analysis on any selected point; in the automatic mode the host monitors the status of all DASPUs, stores the behaviour of the plant in the data base and obtains, processes and stores a selected subset of the possible data.

The host computer software will include a neural networks based approach to perform monitoring and fault detection prediction. Neural networks are models composed of many non-linear computational elements called neurons or nodes. These nodes are connected via weighted links that are typically adapted during training to increase performance. A network is trained to perform a specific task by modifying the weights. For this application the selected neural network topology is the Multilayer Perceptron and it will be trained with the backpropagation algorithm.

Specifically, the neural network can work as a predictor, in this configuration the neural network is trained to predict vibrations or displacements using past samples as inputs along with some static variables defining the status of the machine. Based on the prediction error a decision about alert/alarm states is made. It is expected that if the network is properly trained with data corresponding to safe behaviour, the development of a fault will produce an increase in error prediction.

Alternatively, the neural network can be trained to work like a signature classifier; a key point of this alternative is to extract optimal features from the spectra of the vibration and displacement signal, a reasonable choice could be: energy of the spectrum in some frequency bands, overall energy vibration and frequencies, amplitudes and phases of the fundamental frequency and some harmonics. Both approaches are expected to have similar performance.

6. Optical sensors

Two optical sensors systems have being developed. Both are based on intensity modulation and differential detection techniques. One has been developed using all fiber technology, and the other one using integrated optic technology.

The sensor based on optical fiber technology consists of one emitting optical fiber and two receiving ones in front of it. The emitter fiber, which is mobile, modulates the light entering the receiver fiber according to the movement of the support, and a differential detection of this modulation is made in order to increase accuracy of the sensor. The system is able to measure accelerations along one axis. The general scheme of the system is shown in figure 4. The electronic part, on the right, has been separated from the optical one, on the left, integrated by the sensor head and the transmission channel (optical cable).

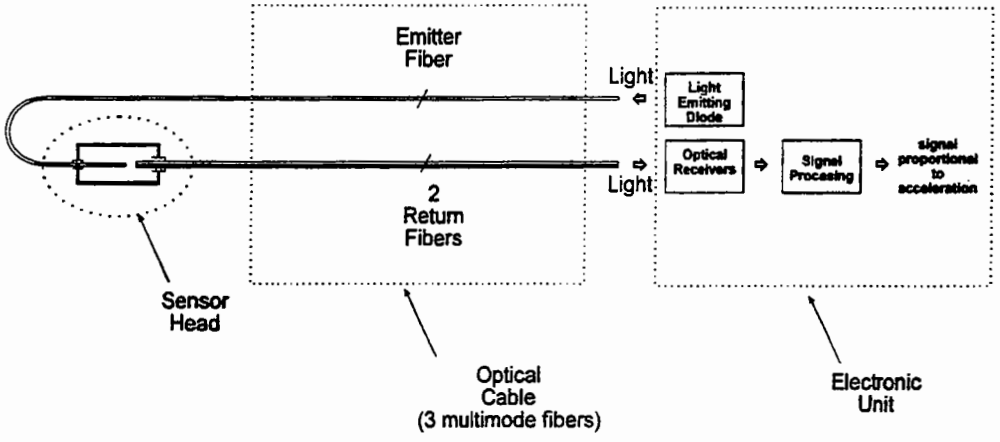

Fig. 4. Architecture of the intensity modulation-based optical sensor.

Figure 5 shows the structure of the sensor head in detail, where the mobile beam and the two receiver fibers can be seen. The link between the acceleration to be measured and the optical information we get from the sensor head is the mechanical vibration behaviour of the emitter fiber. A complete theoretical study has been made to characterise that behaviour and this study has shown that the transverse displacement of the fiber end is proportional to the acceleration applied to the head. This displacement is detected optically, by means of the light coupled into the two static fibers. A differential detection of the light collected by them is made, since it allows a high transverse insensitivity and a more accurate measurement.

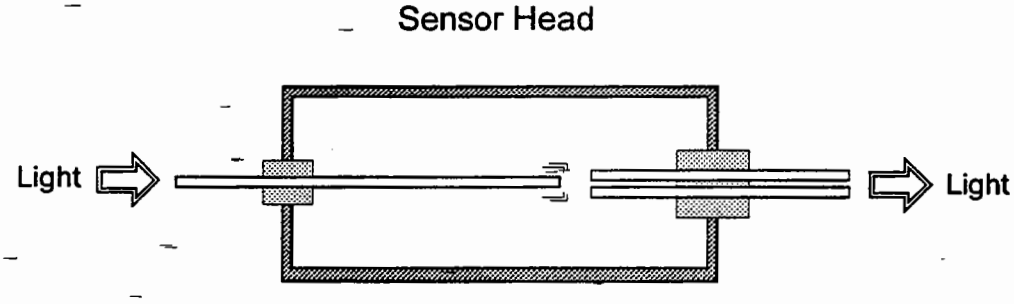

Fig. 5. Optical sensor head.

The results obtained by the first prototypes showed substantial agreement with the theoretically determined values and follow the specifications established in the project.

The integrated optics version of the above mentioned all fiber sensor consists of one moving waveguide in front of two static output waveguides. Under vibrations, the cantilever beam moves and light coupling is varying in the two output waveguides. A third output waveguide allows for monitoring the input light power in the optical head. The figure below shows a view of

the sensitive part. The butterfly like part is the seismic mass that was obtained by special etching process.

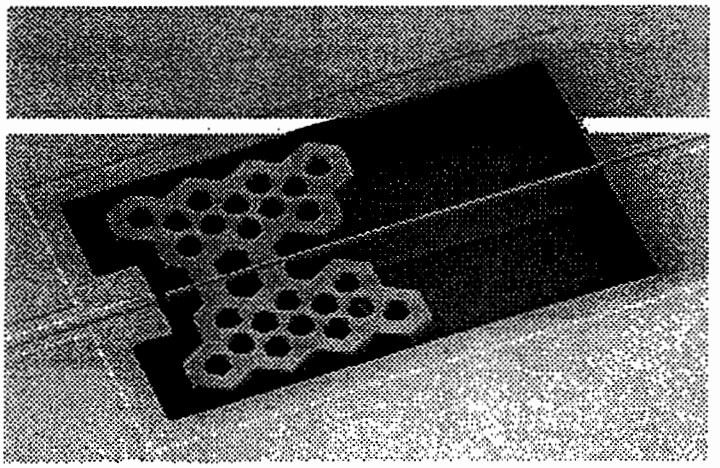

Fig. 6 Integrated Optic sensor head

7.- Conclusions

A monitoring system for predictive maintenance of hydro T-G sets is being developed. The system's general characteristics and specifications have been defined and taking them into account the system has been designed and the main parts have been developed and tested. The important parts of the system are the advanced dynamic data acquisition and signal processing unit, the host computer software and the optical fiber sensor systems.

The project is at the end of its second year and the main achievements according to the wokprogramme are being reached on time. The developed system will be installed at the demonstration site shortly and it is expected to operate for one year collecting data that will be used for the improvements of the components as well as for the implementation of the statistical and neural network approaches.

The application has been developed for the predictive maintenance of low speed hydro T-G sets but with small modifications could be used in other industrial plants such as thermal, cement, papers, etc.

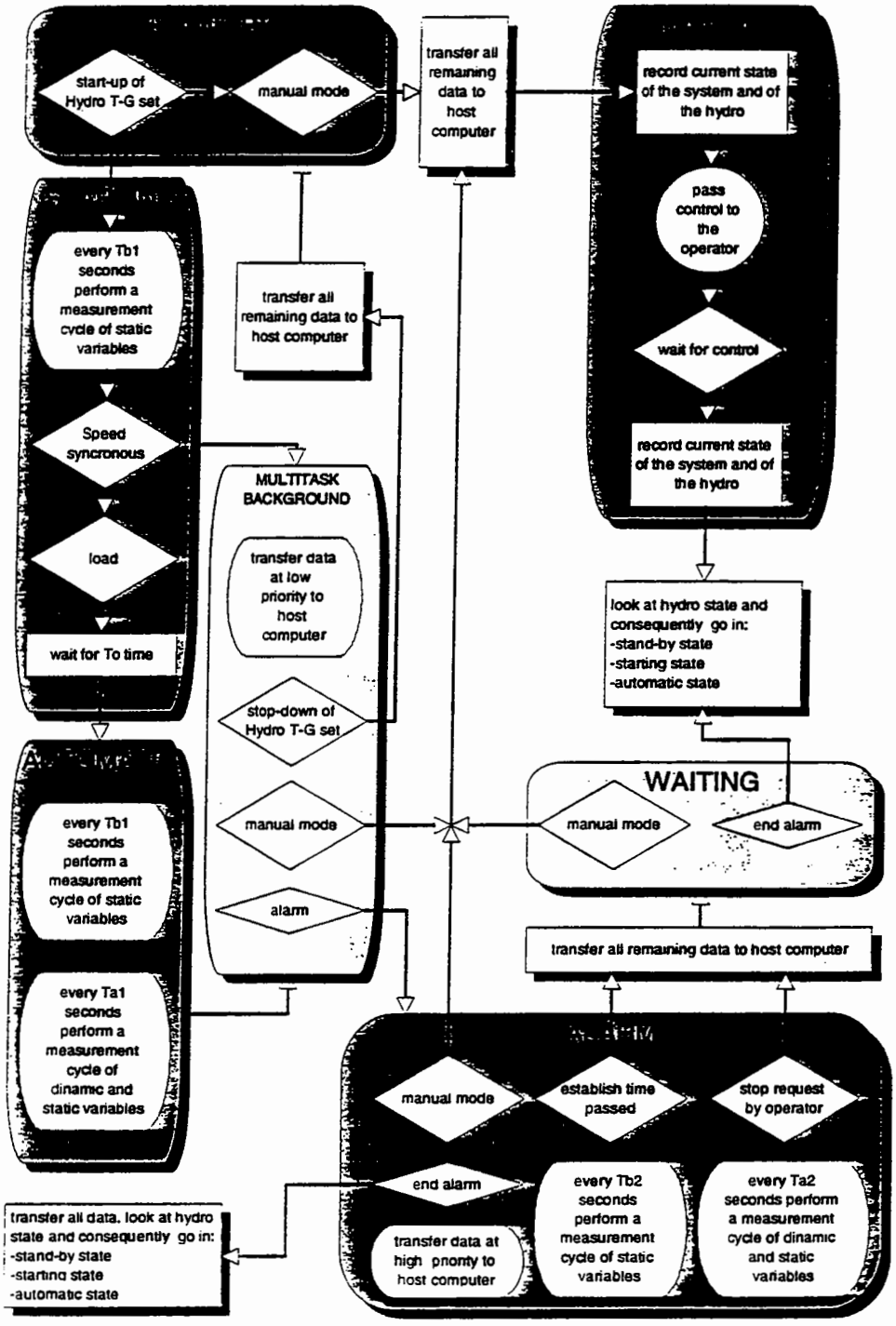

Fig. 2 Block diagram of the monitoring system