Machinery Protection System for Large Rotating Machines

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Abstract

For vibration monitoring and protection of large rotating machines like turbines, large motors, etc, a DSP based Machinery Protection System (MPS) has been designed and developed jointly by BARC and ECIL. The system is designed to protect the rotating machines from catastrophic failures due to excessive vibration. The system provides continuous, online monitoring of vibration and related signals and meets the requirements of API 670 standard for machinery protection systems.

Introduction

Health of large rotating machinery gets reflected in the vibration signals collected from the rotating and supporting structures. Using this vibration data, it is possible to detect any impending trouble in the machine so that preventive action can be taken in time and catastrophic failures can be avoided. Continuous vibration monitoring can provide quick warning against excessive vibration and prompt the operator to take remedial action. An on-line vibration monitoring and protection system thus plays an important role in ensuring safety and economics of the plant.

With the aim to address this need for such an on-line system having state-of-art features configurable for individual plant requirements, the indigenous development of a Digital Signal Processor (DSP) based Machinery Protection System (MPS) was initiated by RCnD, BARC as a joint effort along with ECIL, Hyderabad under an MOU between BARC and ECIL.

Fig. 1: Machinery protection system
The main components of the system (Fig.1) are the front-end instrumentation consisting of transducers (for vibration, speed and process parameters) and signal conditioning, DSP based data acquisition and protection module and back-end PC-based monitoring and configuration station. The main objective of the system is to monitor all the vibration signals to detect any deviation from normal levels and to provide alarm and trip signals in case the deviations are beyond certain set limits.

System Description

The Machinery Protection System (MPS) acquires a number of dynamic input signals (like vibration, displacement, eccentricity etc.) and speed input signals from field and on detecting excessive vibration levels it provides alert signal to operator and generates contact outputs to shutdown (trip) the machine. The system can be configured to measure the following parameters:

1. Absolute Vibration (Accelerometer, Velocity Sensor)
2. Relative Shaft Vibration (Radial Measurement)
3. Absolute Shaft Vibration (Accelerometer, Proximity Sensor)
4. Shaft Position (Axial or Radial)
5. Shaft Eccentricity
6. Absolute Expansion (Casing expansion or Overall thermal expansion)
7. Relative expansion (between the rotor and the stator)

Measurement of the above parameters requires acquisition of the signals, signal validation and necessary signal processing. The signal processing and monitoring functions include:

- Processing of all dynamic channels to extract signal parameters like RMS, peak and peak-to-peak values
- Sensor health checking to monitor for broken lines or faulty components of sensors.

- Alarm processing with programmable ALARM and TRIP limits and programmable time delays and hysteresis.

Protection is achieved by generating contact output to trip (shutdown) the machine when any of the above measured parameter exceeds the set TRIP limit. The system also generates analog outputs for monitoring purpose. It sends relevant information on Ethernet for display to operator on a PC based Engineering Console. The Engineering Console also provides facility to configure various input parameters and their trip settings.

System Architecture

The Machinery Protection System (MPS) consists of an embedded system installed in 19" bin and a PC-based Engineering Console (EC), which are connected through Ethernet. The embedded system is of modular construction and is user configurable through the Engineering Console. The embedded system acquires various dynamic signals like vibration signal, displacement signals etc. and if any of these signals crosses the ALARM (alert) limit, it generates a digital alarm output and if the measured value crosses the TRIP (danger) limit then it generates a trip contact output which is used to protect/shutdown the machinery.

Apart from the protection function the embedded system also sends the acquired data to the Engineering Console for monitoring, analysis and display. The engineering console is used to configure the embedded system, to analyze the data received from embedded system and also to display the data.
in different formats. The block diagram of Machinery Protection System is shown in Fig. 2.

The Embedded System consists of various hardware modules performing signal conditioning, data acquisition, signal processing and protection functions. These modules are fabricated as standard 6U cards interfaced with VME bus and installed in the 19'' bin. The design of the system follows the guidelines given in the API Standard 670 for Machinery Protection Systems Fig. 3.

### Embedded System Hardware

The Embedded System consists of following modules.
- Machinery Protection Module (MPM)
- Input Output Module (IOM)
- Relay Output Module (ROM)
- Power Supply Module (PSM)
- System Controller Module (SCM)

The arrangement of these modules as installed in a 19'' bin with the front and rear view of the system bin is given in Fig. 4 and Fig. 5 respectively. A pair of MPM and IOM is connected back-to-back on the motherboard of 19'' bin.

#### Machinery Protection Module (MPM)

The MPM acquires analog signals, processes the acquired inputs using a DSP and if any parameter exceeds the set alarm limit, it generates alarm. If the parameter exceeds the set trip limit then it generates a trip signal to the machinery. This module consists of DSP, Microcontroller, Memory, communication controller and other peripherals. The system configuration from the Engineering Console can be downloaded to MPM through onboard communication (Ethernet) controller. The MPM also sends the processed data to the Engineering Console through onboard Ethernet. This module can be used as standalone protection unit for small systems. Maximum of six MPMs can be accommodated in one MPS Bin.

The main features of MPM are:
- It can process 4 Dynamic (Vibration) channels and 2 Speed Channels.
- It can acquire signal from DC to 3.5 KHz as per the requirement.
- It performs digital filtering using DSP with configurable filter parameters.
- It performs signal processing functions like integration and rectification and provides signal parameters like peak, RMS.
- It monitors signal parameters for alarm and trip conditions and generates Alarm/trip with configurable Time delay and Hysteresis.
• It can process Dual channel to measure input parameters from two sensors in split range mode.
• It checks Sensor and Channel healthiness.
• It supports features like Danger bypass and Trip multiply.
• It gives LED indications on front facia for alarm/trip, sensor failure, MPM board failure and Power failure.
• It gives Raw buffered input signals on front facia through connectors for external monitoring and analysis.
• MPM is Hot swappable, so faulty module can be easily replaced online with healthy module.

Input Output Module forms the input output interface of MPS. IOMs are plugged in to the back planes mounted on the rear side of the MPS. MPM and IOM module are shown in Fig. 6. Interface between IOM and MPM is through backplane as shown in Fig. 7. The inputs and outputs of the MPS are terminated on the screw terminals provided on the facia of IOM. This module provides signal conditioning for various sensors. This module also provides the power supplies to various transducers. Depending upon the type of transducer, power supplies can be selected using jumpers provided on the board. There is provision for over voltage protection and short circuit protection on input and output side. Maximum of six IOM can be used in one MPS bin.

The main features of IOM are:
• Each IOM can be interfaced with 4 Dynamic (Vibration) and 2 Speed Sensors.
• Input signal range is -18V to +18V.
• It provides built-in power supply to various types of the sensors.
• Signal conditioning features include programmable gain and Programmable Supply to Sensors.
• It has provision to test each channel through reference input.
• It generates processed analog output (0-5V/4-20mA) for dynamic and speed sensors as well as pulsed output for speed sensors.
• It generates open collector outputs for driving relays of ROM on alarm and trip conditions.
• IOM is a Hot swappable module.

Fig. 6: Machinery protection module (MPM) and Input output module (IOM) of MPS

Fig. 7: Interface diagram of MPM and IOM

Relay Output Module provides relay outputs for alert and trip (danger) conditions. This board consists of 16 relays and one pair of contacts of each relay is available on the screw terminal mounted on the facia of the board. ROMs are plugged in to the back planes mounted on the rear side of the MPS as shown in Fig. 5. The relays in ROM are driven by the open collector signals generated in IOM and available in the back plane. These relay outputs can be dynamically configured from the Engineering Console. Maximum of six ROMs can be used in one MPS bin.
Power Supply Module (PSM) provides the power at required voltages to the modules as well as to the sensors connected to the system. The MPS can operate either from a single PSM or from dual-redundant current sharing PSMs. Each of the power supplies provides a contact output, which is fed to the terminal of IOM to show the health status of power supply. Indication of power supply 'ON' status is provided on the front facia of MPM.

System Controller Module (SCM) (optional) acts as an optional interface between the embedded system and engineering console to provide user configurability, data analysis and system diagnostics. It is a VME bus based CPU module with onboard Memory, Real time Clock, Watchdog and Ethernet. This module receives the configuration from the Engineering Console on Ethernet and forwards the configuration information to the respective Machinery Protection Modules on the VME bus.

The SCM can receive the processed data from the MPMs, perform additional analysis and processing functions, if required, and send the data to the Engineering Console for display. In case of failure of any channel the SCM can be used for dynamic re-routing of signals to spare healthy channels.

PC based Engineering Console (EC) is used for configuring the MPS and it also acts as a display station for MPS. It displays the data received from MPS in different formats like tabular, bar graph, trend etc. It also displays the alert/trip, diagnostic and various system states in message and LED display format.

The EC provides following functionality for MPS:

- Real time display of signal parameters (RMS and peak values) in bar-graph and tabular format with data update rate of 1 second (Fig.8).
- Colour coded visual indication of signal parameter crossing alarm/danger limits along with messages.
- Long term trend display of RMS values of parameters and viewing of real-time trend, real-time frequency spectrum, waterfall and orbit plots Figs. 9 & 10.
- Configuration function for changing alterable parameters like signal range, alarm trip/limits under password control.
- Creation of data files of parameters for further analysis.
- Display of status/indication for Communication link, Sensor, Channel health.
- Viewing, logging and time stamping of diagnostics messages and printing of signal plots, diagnostic messages and parameter change log and history.
Special features, Interlocks and Display Functions

The system provides the following special features and interlocks:

**Trip multiply feature** There is a provision to multiply the values of alarm and trip threshold with a multiplication factor, and this is achieved by reading the status of a contact input implemented through a key switch. There is a provision to enable/disable the Trip Multiply feature from Engineering Console. The multiplication factor for trip multiply is configurable through Engineering Console.

**Danger bypass (DB) interlock** A Danger Bypass key switch is provided as a contact input to bypass the trip outputs. If the Danger Bypass input is true, system does not generate contact outputs for trip (danger) condition whereas it continues to generate the LED indications.

**Display features** The Engineering console provides an integrated display capable of displaying all measured vibration parameters, alarm (alert) and trip (danger) setpoints, DC gap voltages (for radial shaft vibration and axial position) and speed measurements. Displays of all vibration channels have a minimum resolution of 2% of full scale while the speed channels have a resolution of 1 rpm. The displays are updated once every second.

**Dynamically Re-routing feature** System has provision of Dynamic signal bus and relay signal bus on the backplane. It is possible to suppress faulty channel operation automatically (through the SCM) and dynamically re-allocate the input sensor signal or relay output signal to spare healthy channels through the backplane without affecting the system operation.

**Redundancy feature** Redundancy in power supplies allows continued system operation even in the condition of failure of one power supply module.

**Diagnostic features** MPS provides various diagnostic features to ensure correct operation of the system. The main diagnostic features are listed below:

- The system checks healthiness of connected sensors. On detection of faulty sensors, it gives LED indication on MPM front facia and a contact output and also displays a message and LED indications on EC.
- Machinery protection module (MPM) checks the health state of its components and gives contact output and indication on the facia.
- MPM has inbuilt watchdog timer which checks the software flow of the program.
- System has a provision of user-invoked test signal inputs, which are applied to each channel to check their healthiness.

**System Integration and Testing**

The design and development of the system has been completed. Documentation in the form of Design Manual and User Manual has been prepared. The system was integrated into a 19" bin along with power supply modules and sensors and acceptance testing (functional and environmental) was successfully completed at Turbovisory Lab (Fig.-11) of ECIL, Hyderabad. The system has now been shifted for field trials at one of the NTPC plants near Delhi.
Conclusion

With the above development, an indigenous, state-of-art and user-configurable system is available to meet the requirements of machinery protection in various power plants and industries. The system will be manufactured and marketed by ECIL who will also provide long term maintenance support. This indigenous development will help in reducing the dependence on imported systems.

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