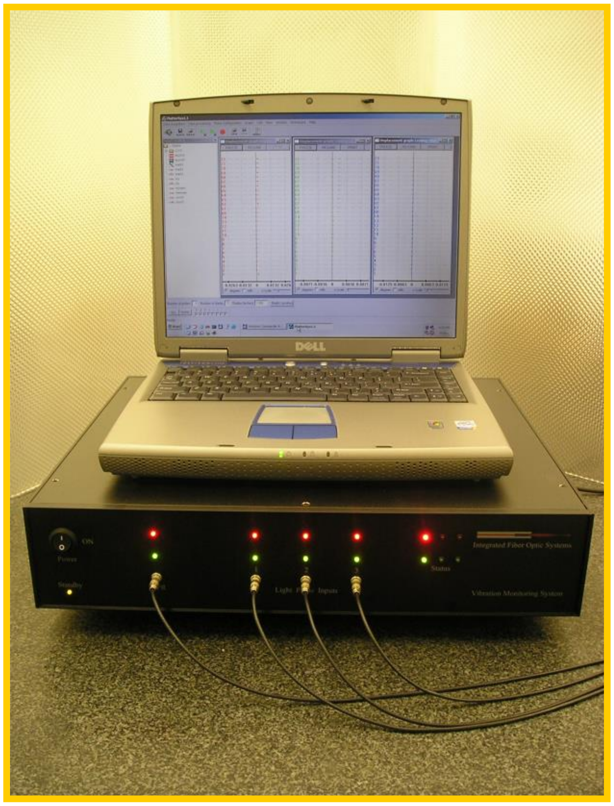
VIBRATION MONITORING SYSTEM FOR ROTATING MACHINERY (WHITE PAPER)



EXECUTIVE SUMMARY

Failure of rotating machinery, particularly, aircraft engines can have catastrophic consequences. Reliable prediction of failure is crucial to extending the life cycle of engines. In addition to prevention, non-intrusive evaluation of engines in service can reduce operating costs and downtime. Characterization of the vibrational modes of rotating machinery can provide valuable information leading to the prediction of high/low cycle fatigue; detection of cracks; monitoring the overall health of engines and blade stress. Through the use of integrated fiber optic light probes and high speed data acquisition, the VMS2000 portable platform makes these goals accessible.

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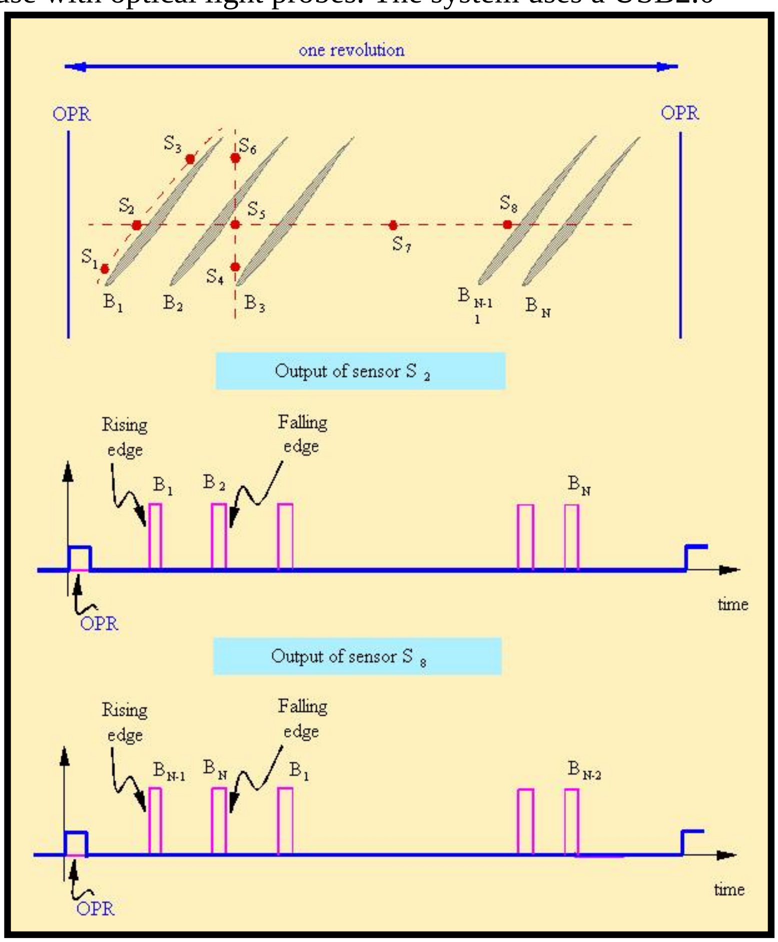
INTRODUCTION

Blade tip timing techniques are gaining wide acceptance as viable means for characterizing vibrations of bladed systems in rotating tubomachinery. Non-intrusive evaluation of the blades provides vital information for the long term durability of engine performance. Time event history of every blade can be obtained through the use of either capacitive, magnetic, eddy current, or optical probes, however, the latter, being more robust and accurate, are generally preferred in the electrically noisy environment of engine testing facilities. In recent years, considerable effort has been devoted to characterizing both synchronous and asynchronous behavior of blades. Much of this effort has been targeted toward improving the appropriate theoretical models, which are necessary for retrieving the mode structure of the blades.

The VMS2000 vibration monitoring system is an entirely digital, high resolution, three channel, time-of-arrival processor, which can be used for real time measurement of blade tip timing in rotating turbomachinery. Blade tip timing information can be converted to either tangential, or radial, or axial displacements. A combination of blade tip sensors positioned in the engine casing can be used for real time monitoring of both asynchronous and synchronous vibrations. Blade tip timing measurements are becoming critical in non-contact measurements of blade stress and in assessing the long-term failure modes of bladed structures.

The vibration monitoring system can be interfaced to any generic blade tip timing sensor. The system is specifically designed for use with optical light probes. The system uses a USB2.0 data interface to provide control of the instrument from any computer. A graphical user interface adds real time capability for displaying instantaneous and normalized vibration amplitudes of all blades, from all light probes. Additionally, the GUI has a real time display of rpm and an off-line processing feature, which allows the data to be output in a standard spread sheet format.



BACKGROUND

This figure shows possible location of blade tip sensors S1 to S8. These sensors, together with the appropriate electronics, produce a voltage waveform corresponding to the blade passage past the field of view of the sensor. Such sensors include optical and capacitive types. The sensors can be located in a number of configurations. For example, along the circumference of the engine casing, that is, S2, S5, S7 and S8; or parallel to the axis of the rotor, that is, S4, S5 and S6; or parallel to the blade chord, that is, S1, S2 and S3. Each sensor produces a sequence of pulses representing each blade tip. The VMS2000 timing board measures time location of each blade edge, referenced to the once-per-revolution (OPR) signal. Each time event is measured using a 50 MHz oscillator and is represented by a 24 bit count vector,

$$\left(n_{SBE}\right)_j$$

where subscripts S, B, E, are the sensor number, blade number and edge code, respectively. The subscript j denotes the revolution number. The blade number indicates the temporal arrangement of the bladed rotor system, that is, blade 1 being the first blade arriving after the OPR pulse. For any light probe sensor, the instantaneous angular blade position in the rotating frame is

$$\left(\theta_{SBE}\right)_j = 2\pi \frac{\left(n_{SBE}\right)_j}{\left(n_{OPR}\right)_j}$$

where $\left(n_{OPR}\right)_j$ is the number of counts representing the period of j'th revolution. Real time monitoring of the vibration amplitude of each blade tip requires acquisition of a reference file, which stores the nominal angular position of all blades for each sensor. The reference file is created by taking the average of the angular position over a finite number of revolutions RevT. Thus, the time average angular position is

$$\left\langle \theta_{SBE} \right\rangle_{RevT} = \frac{1}{RevT} \sum_{j=1}^{RevT} \left(\theta_{SBE}\right)_j$$

The asynchronous vibration (flutter) amplitude is obtained by subtracting the nominal value from the instantaneous amplitude,

$$\left(\Delta\theta_{SBE}\right)_j = \left(\theta_{SBE}\right)_j - \left\langle \theta_{SBE} \right\rangle_{RevT}$$

The VMS graphical user interface (GUI) can display the vibration amplitude for all blades in a single plot, giving the capability for real time monitoring of asynchronous amplitude

Characterization of synchronous vibration requires obtaining estimates of the amplitude, frequency and phase of each blade during each revolution. Typically, a minimum of four blade tip sensors are required to extract the necessary information from the time stamp data. However, it is possible to combine timing data from three blade tip sensors to retrieve the same information.

SOFTWARE

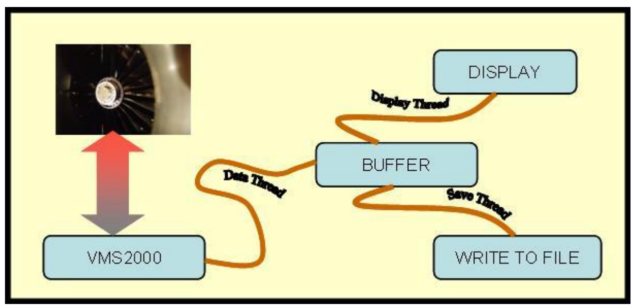
The graphical user interface is a windows based platform that allows for both real time acquisition of blade tip timing data and for on-line and off-line processing of the raw data. Program features include storage of raw timing data, real time display of blade position, rpm, and flutter amplitude. Additionally, the system can be configured to display the vibration amplitude from all blades in single display window.

The software is designed to allow the user to acquire real time blade tip timing data from three light probes located at arbitrary locations in the test engine casing. Time stamp data comprises the recording of the rising and falling edges of all blade tips, referenced to the OPR edge. Raw data is stored in a binary file, which can be converted to a spread sheet format using the post-processing capability built into the GUI. The GUI uses multi-thread programming techniques to deliver real time performance for test engines generating data at rates approaching 50 MB/s. In general, the data rate (DR) is given

DR [Bytes] =8 x number of probes x number of blades x RPS

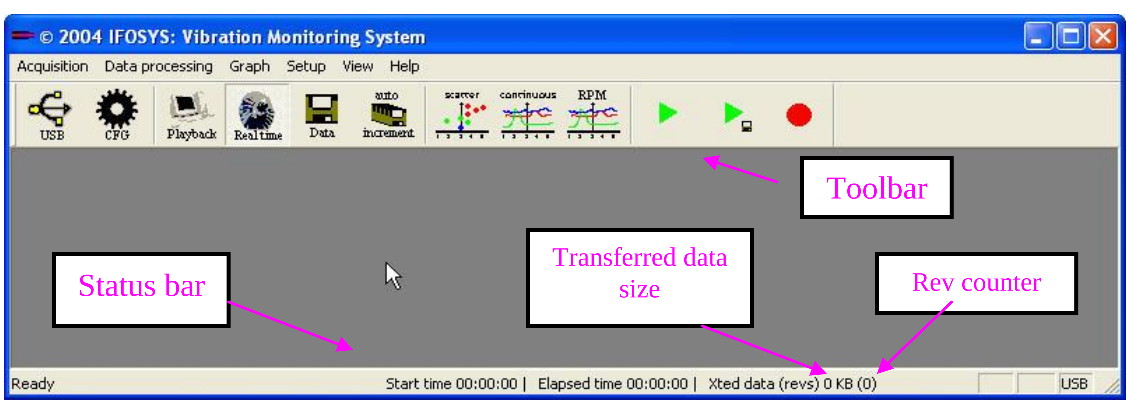
For example, an engine with seventy-two blades, operating at 15000 rpm (250 rps) with three light probes generates data at a rate of 432 kB/s.

Multi-thread programming techniques allow multiple processes to be executed in a parallel mode. For example, *the data thread* acquires contiguous timing data from the hardware, while *the display thread* accesses the buffer to process and display some of the data in real-time. *The save thread* is used to write the raw data to file for subsequent post-processing.



Main window: menu commands, toolbars and shortcuts

The main window illustrated here has a toolbar at the top with buttons which can be used to perform various tasks as outlined in the previous section. A Status bar at the bottom of the



window shows the start time, elapsed time, size of data transmitted to the buffer (or file), revolution counter, and three system state boxes, which indicate state of the system, that is, **USB** connected, **ACQ** – acquiring data and **REC** – saving to file. The left area of the main window can be used to view current workspace, which shows all the files.

SPECIFICATION

Hardware

Input:

One-per-revolution, minimum width of 500 ns
Three blade-tip timing inputs

All input signals must be voltage pulses conforming to TTL specifications.
5 ns minimum pulse width at 1.6 V. Other voltage levels available with external converters

Output:

One clock output (rear) (BNC receptacle)
USB2.0 receptacle (rear)

Power:

90-240 VAC 50/60 Hz

Minimum rpm:	200
Maximum rpm:	185,000 (spot diameter of 50 μm)
Time resolution:	20 ns

Maximum number of Blades: 1000 for on any blade tip input

Software

Targeted personal computer (PC) must have a USB 1.1 or 2.0 port and run Windows 2000 Professional or Windows XP Professional operating systems. For expected data rates below 100 kB/s, USB1.1 may suffice. A computer equipped with Pentium 4, fast hard drive (for example, Ultra DMA 66/100 or SCSI) and at least 128 MB RAM would be sufficient for running the current configuration of a flutter measurement system operating at its limits.

Recommended system requirements

- PC with Pentium - 4 or compatible processor with USB 2.0,
- Windows 2000 Professional, Windows XP Professional. Latest service packs (at least SP4 and SP1, respectively) required for both systems.
- 128 MB or larger RAM,
- Ultra DMA 66/100 or better with 10 MB free disk space (for program only). Considerably more disk space is required if data is to be archived.

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