REMOTE MACHINE CONDITION MONITORING BASED ON WIRELESS CONNECTIVITY

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Implementation of systems for diagnostics and monitoring of dynamical behavior allows identification of possible potential problems prior an equipment failure. Early machine monitoring systems determined the need of maintenance, however, modern systems also assist with severity assessment, avoid false positives, and help with process optimization.

The subject of the present paper is an intelligent system for measurement of acceleration. It is based on micromechanical sensors with digital and/or analog outputs. The system is 8-channel, allowing measurements in extended dynamic specter. The implementation is based on the low-cost microcontroller PIC18F422. A combination of measurement techniques, such as continuous self-calibration and multi-port measurement are used to obtain high accuracy and long-term stability. A data logging feature is also included allowing to store and lately analyze measurement results. Additionally, it is provided a connection with a PC for computing and visualizing the data. The software, realizing the communication and analysis is built as an upgrading and extending part of LabVIEW environment. The latter offers excellent possibilities to perform a narrow band spectrum and fractional-octave analysis of the vibration signals.

1. PREDICTIVE MAINTENANCE AND SENSORS

Predictive maintenance method has several advantages over the other maintenance methods. Machinery can be assessed for maintenance while it is still running. The assessment uses non-invasive methods which are accurate and relatively inexpensive to install. From the running assessment maintenance, an action can be planed to take place at a time convenient to both machine and maintenance staff. The predictive maintenance requires continuous monitoring of the machines. This is achieved through the utilization of different sensing devices. The sensors are integrated within the machine system and give the required information on the actual condition of the system. Different types of sensors may be required to do this. For example, force sensors, pressure sensors, accelerometers and so on.

Vibration is often the signal of interest for machine condition monitoring. Vibrations are usually caused because of unbalance and misalignment in moving parts of the mechanical devices. Left without correction, they lead to decrease of durability, and reliability of machine units, unpleasant noise and increasingly high maintenance expenditures. The implementation of systems for diagnostics and monitoring of dynamical behavior allows early identification of possible potential problems leading to the equipment failure. Hence, the vibration measurement is a vital part of predictive and preventive maintenance programs that seek to reduce cost and unplanned downtime.

Common sensors for vibration measurement include accelerometers, velocity probes, and displacement probes. Microphone sound data and dynamic pressure measurements are frequently used as well [4]. Accelerometer sensors dominate modern vibration measurement systems. They are the most popular vibration sensors due to their freedom of placement, wide frequency range, and wide dynamic amplitude range. In addition, data can be easily converted among displacement, velocity, and acceleration information as part of the signal processing process. This is particularly true in the frequency domain where the FFTs for these three parameters are related through simple algebraic formulas [9].

2. VIBRATION MEASUREMENT FOR MACHINE CONDITION MONITORING

2.1. Acquisition Requirements

Measurable vibration is actually a composite of the vibrations that originate from the components of the machine. The sum of the vibration from the diverse components constitutes the overall vibration, which is measured, and so this variety of sources is responsible for the signal complexity.

A measurement of vibration depends on the appropriate sensors mounted on the machine. When the vibration measurement is completed starts calculation of the dynamic parameters of the received signals. Reducing the amount of the information contained in one measurement to one value, such as peak-to-peak, average or RMS, ignores much of the information contained in the signal. An alternative is to analyze the frequency content of the signal. When the frequency content of vibration or any other dynamic signal is examined, an alternative representation of the time-domain signal is observed.

Software tools with high-level functions (e.g., LabVIEW) convert signals to the time-frequency domain and analyze their spectral content. For frequency analysis, the new representation is a method to construct the original signal using a set of sinusoids with varying frequency and phase. With a power spectrum, the recipe is a list of frequencies on the X axis and amplitudes on the Y axis.

Frequency analysis relies on superposition, which means that the signal is actually a sum of many sub-signals. Superposition fits nicely with vibration analysis because many of the components that sum up to make the measured signal will be result of repetitive motion of the machine elements. The repetitive motion will create vibration components at frequencies that can be related to the rotational speed of the machine being monitored [3].

2.2. Comparing power spectrums

If the design of the monitored machine is known, the signal at specific frequencies can be easily associated with particular components of the machine. Concerning the machine condition monitoring, this additional information focuses the monitoring on the particular machine components by trending the individual signal levels at the specific element frequencies. The technique is more robust than trending an overall signal level because the focus is on a selected subset of frequency components of the signal.

Trending with frequency analysis starts the definition of a signature or baseline, which specifies the minimums and maximums expected for each of the frequency components of interest. By defining this set of limits, while the machine is in good operational order, a basis for comparison for either continuous or periodic monitoring is obtained.

Fractional-Octave Analysis (FOA) is used to realize the software for diagnostics of states of machines. The fractional-octave analysis is an alternative that examines the frequency content of a signal by dividing the spectrum into well-defined regions called octaves or fractional octaves. The results are commonly presented on a logarithmic frequency scale as a bar graph, with bar heights that correspond to the energy contained in each octave band.

Octave analysis is also useful in monitoring because it simplifies comparison. Using the standard power spectrum it is difficult to completely characterize every frequency component of the vibration that the machine generates. If the monitoring system examines specific frequency components of a power spectrum, there's a chance that an important frequency component will be overlooked. By grouping frequencies into bands, octave analysis enables monitoring that watches more of the frequency domain [6].

3. THE MEASUREMENT SYSTEM

3.1. The Sensors

The sensors of the proposed system are micromachined devices fitted in a single integrated circuit. The chosen sensors are the ADXL2xx family from Analog Devices. For digital output sensors, for each axis, an output circuit converts the analog signal to a duty cycle modulated with a resolution of about 5 mg. This digital signal can be easily decoded with a counter/timer port of a microprocessor. In case of using ± 50 g sensors (ADXL250) the change is about 38 mV per g, at bandwidths of up to 1 kHz, with a resolution of about 10 mg. The ADC of the microcontroller is used to measure the signal of the analog output sensors.

3.2. The Measurement Unit

The functional diagram of the measurement system is shown on Figure 1. The vibrations of interest are low frequency up to 250 Hz. The implementation was realized on the low-cost microcontroller PIC18F422.

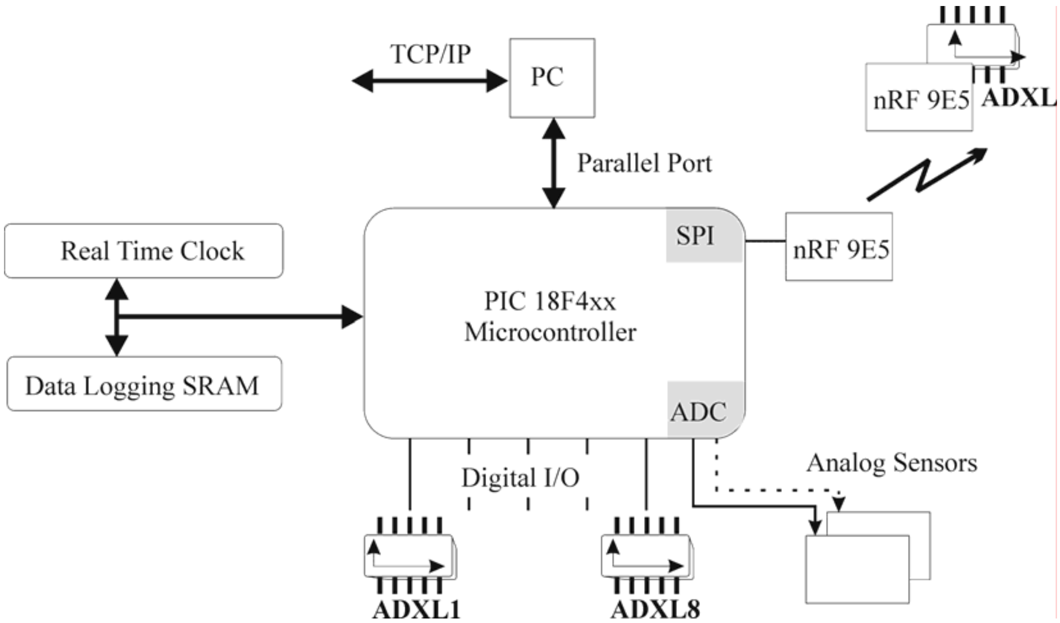

Figure 1. Functional layout of the measurement system.

The amount of axes for the current system is limited to 16 channels. They were spread into 8 two-axis channels. The initial calibration was performed via on-board temperature measurement. Software was provided to read and display real time acceleration data. A data-logging feature was also included, allowing storing and lately analyzing measurement results. Several additional channels are possible to be added over a wireless connection based on nRF9E5 IC. nRF9E5 is a true single chip system with fully integrated RF transceiver, 8051 compatible microcontroller and a 4 input 10bit 80ksps AD converter. The circuit has embedded voltage regulators, which provides maximum noise immunity and allow operation on a single 1,9 V to 3,6 V supply. nRF9E5 is compatible with FCC standard CFR47 part 15 and ETSI EN 300 220-1.

The nRF9E5 is designed to offer the user an ultimate solution, with an ease of use, integration and performance that is groundbreaking. Every effort has been paid to details which are typically encountered as a difficulty, in both of PCB and software development.

All critical passive components are integrated on the chip, easing hardware layout issues, as well as lowering the Bill of Material. The RF transceiver unit has a separate protocol pre-processor, performing address decoding, CRC checking and buffering of data in receive and transmit. This is coupled tightly with the on-chip 8051 core enabling a unique low power design and an easy radio protocol design. Also included in the nRF9E5 is a state of the art low power multi channel ADC, and extensive I/O peripherals for the ultimate balanced design.

The nRF9E5 is manufactured in an ultra modern 0.18μm CMOS process, and offered in an extremely small 5x5mm QFN for high volume production. This extremely small footprint for such a device gives us the biggest advantage – a small PCB with a robust RF connection.

Thanks to the digital I/O ports and onboard ADC, connecting variety of sensors is an easy job. The sensors might have a digital output, frequency output, and even an analog value. Together with a cell battery of 3V and a sensor and the mandatory nRF9E5 makes a wireless node. If two acceleration sensors are used on the wireless node, mounted on 90 degrees each against each, converts this node into a 3 dimensional (3D) positional sensor. Once, zeroed to a particular XYZ position, the future position of the observed spot will be available to the user. Through the use of wireless connectivity and 3D sensors, the behavior of an industrial machine in total movement can be monitored without the use of a single wire.

3.3. The System Software

When the measurement system is powered on, it checks for sensors, counts them, in case they are not calibrated, the system goes into calibrating mode, and then starts the acceleration measurement. It sends the measured values through a parallel port either to a memory for storing or to a personal computer.

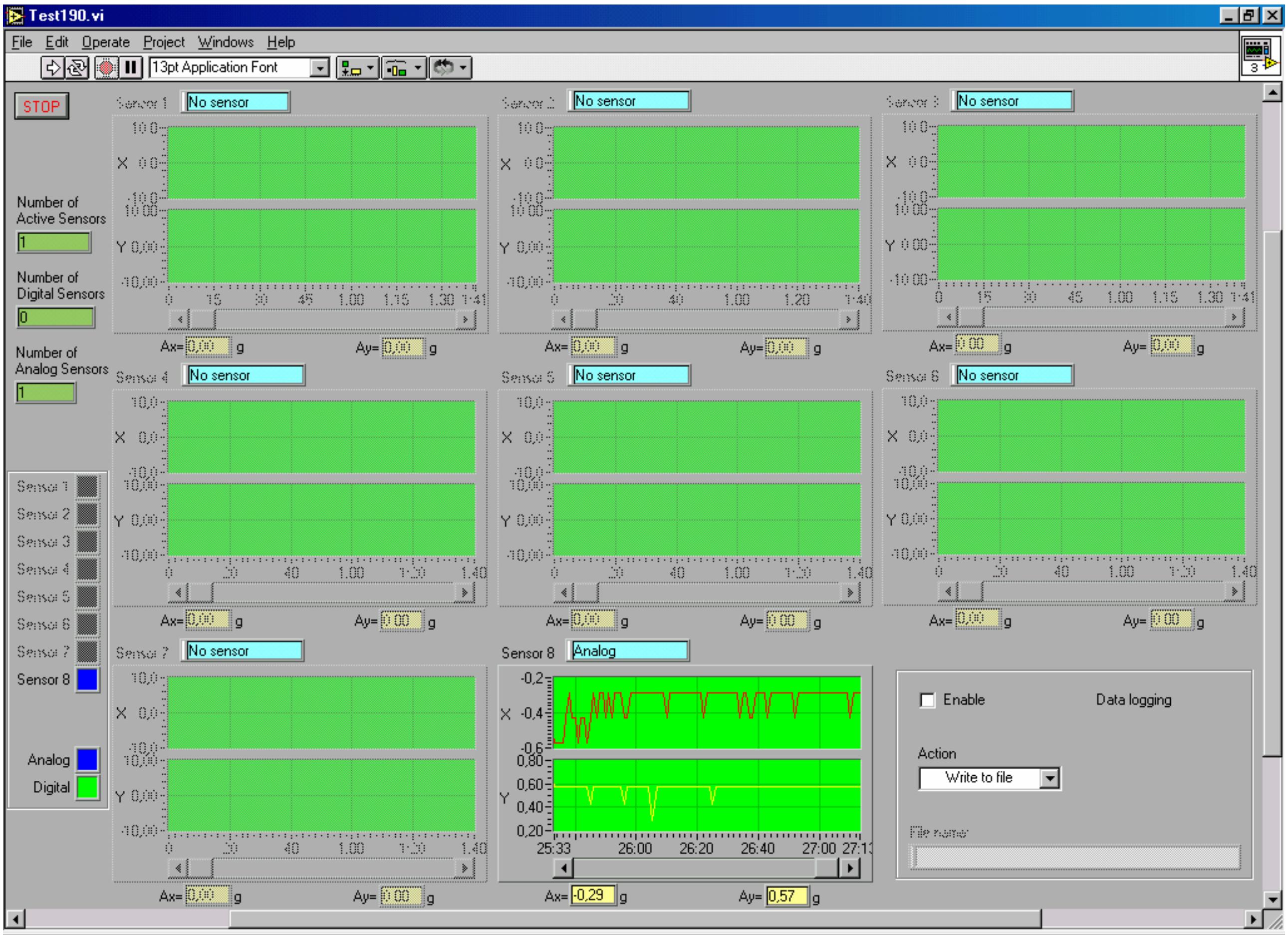

Figure 2. Sample view of the measurement system based on LabVIEW.

The software system on the PC is built using LabVIEW environment (Fig. 2). It is used for visualization of the time domain signals, for transformation of the signals to the frequency domain and for narrow band analysis of the spectral content. The application supports also TCP/IP communication for interaction with web-based architectures in remote vibration monitoring and diagnosis.

FFTs performed on the sampled acceleration a(t) time function produce frequency domain data sets that are characterized by amplitudes at discrete frequencies. The discrete frequencies are separated by some fixed increment, Δf. In practice, an FFT is performed on short bursts of data having a time period T, of usually 1 – 10 s duration, depending on the available data storage capacity and desired sampling parameters and accuracy.

For the frequency analysis a definition of a “signature” - baseline is needed. It specifies the minimums and maximums that are expected for each of the frequency components of interest. By defining this set of limits when the machine of interest is in good operational order, a basis for comparison for continuous monitoring is obtained.

4. CONCLUSION

Modern condition monitoring systems require state-of-the-art vibration measurement as well as powerful analysis capability. Micromachined accelerometers offer a low-cost alternative to piezoelectric vibration sensors, particularly for sophisticated on-line diagnostic systems requiring a large number of transducers. The combination of low cost MEMS accelerometers and microcontrollers opens the door to economically feasible condition monitoring and diagnostic equipment for widespread use in industrial environments where financial considerations today still limit it to monitoring tasks. The presented intelligent module supports the development and evaluation of new and cost-effective alternatives for some of the existing solutions.

5. REFERENCES

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