[Analyze mechanical measurements with digitizers and software]

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Measurements on mechanical devices and systems using a digitizer often require a variety of transducers or sensors. Such sensors convert mechanical parameters such as force, acceleration, pressure, rotational speed, and their kindred into electrical signals. Digitizer selection must match the transducer characteristics. Additionally, In order to read mechanical data out in the correct units, the amplitude values must be rescaled to read those units. We present a primer on making such measurements with a modular digitizer. You can, though, apply the concepts presented here to most measurement applications.

Digitizer selection
The bandwidth required for most mechanical measurements is generally under 100 kHz. Thus, sampling rates of 200 kHz or greater will work. The digitizer's resolution should match the dynamic range of your sensors, with 16 bits being the most common today. The number of channels should reflect the number of individual measurements you need to make. Keep in mind that if your transducers use differential outputs you will need two channels for each transducer.

Transducers
Time-honored transducers are available in a wide variety of form factors and interconnection types. They offer mature technology and high reliability and are generally used for developmental measurements. Newer MEMS (MicroElectroMechanical sensors) are available in smaller packages at lower cost and are intended for mass market applications. Transducer selection depends on the specific application. Considerations include the dynamic range (maximum and minimum values of the measured parameter), bandwidth, environment (wet, dry, explosive, etc.), loading (how the transducer affects the measurement), interconnection method, and cost.

Most transducers require power supplies, signal conditioning, and cabling to connect to instrumentation. Transducer suppliers will have all the necessary hardware to connect the transducer to the digitizer or other measuring instrument. Cabling can be a bit bothersome as many transducers use connectors which are not common in the electronics world. Take, for instance, a piezoelectric accelerometer shown in **Figure 1**. The standard connector is the microdot coaxial connector that uses a 10-32 thread. Transducer manufacturers offer adaptors and cables to get you to the more familiar BNC connectors.

Figure 1. A typical piezoelectric accelerometer needs its own power supply. Source: PCB Piezotronics

Let's look at a simple mechanical measurement to see how the transducers are employed with a digitizer.

Figure 2 shows the connections used in making a basic mechanical measurement on a small, three bladed, cooling fan. This will serve as a simple example of the basic process of making this kind of measurement.

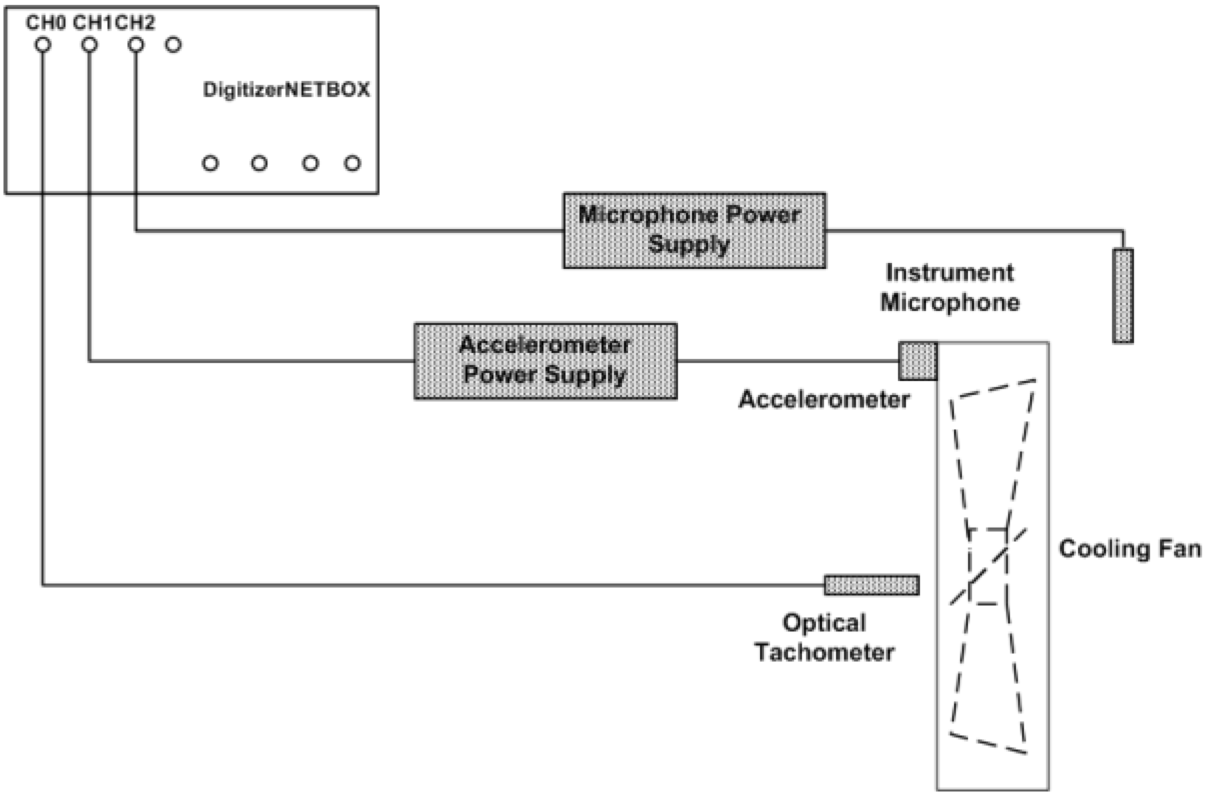

Figure 2. Connecting a tachometer, accelerometer, and an instrument microphone to a digitizer for a basic mechanical measurement of a small cooling fan.

A photograph of this setup is shown in **Figure 3**.

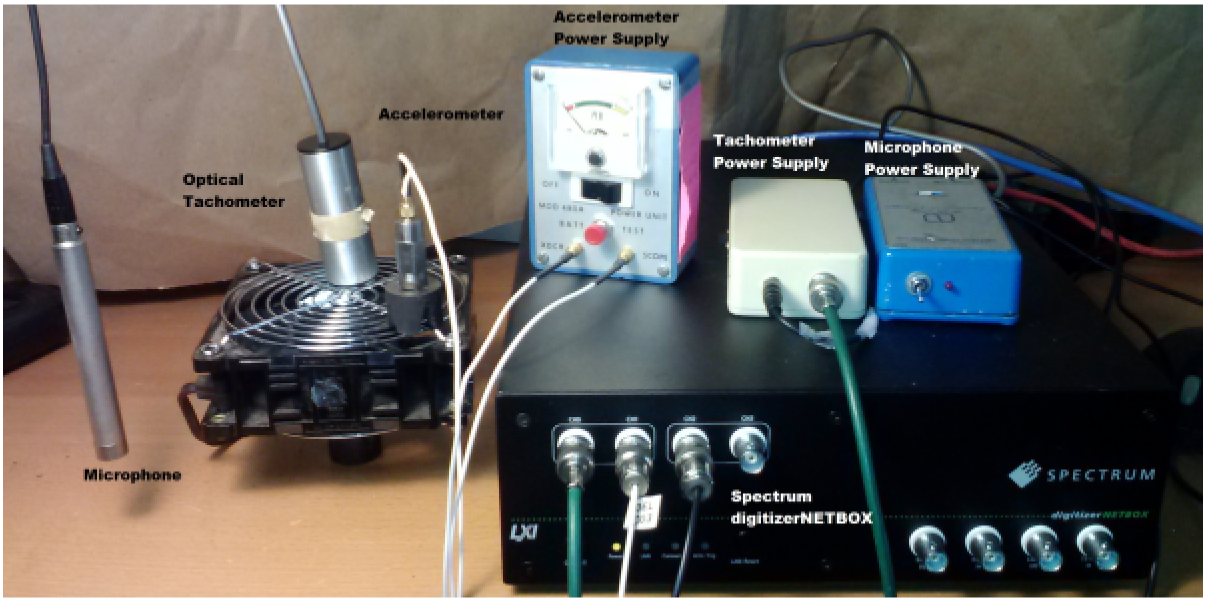

Figure 3. A simple mechanical measurement setup showing the basic sensors and their respective power supplies.

The digitizer used for this measurement is a Spectrum Instrumentation digitizerNETBOX model DN2.496.04 with four analog channels, 16-bit resolution, 60 Msample/s sample rate, and 30 MHz bandwidth. The 16-bit resolution is well matched to the large dynamic range possible from both the accelerometer and microphone.

Measurement transducers

This measurement uses three transducers. The first is an optical tachometer. This sensor reads the rotational frequency of the fan by beaming a light from the sensor to a reflective strip on the fan hub. The reflected light is picked up by a photo-transistor and produces a once per revolution pulse. You can also use self-powered reluctance pickups for measuring machine speed. They use a magnetic "pot" core with a coil wrapped around it and an open gap to sense a Ferro-magnetic material closing the gap. Generally, they sense a set screw, gear tooth, or other steel part on a shaft. A shaft encoder can also be used, although it must be coupled to the machine shaft. The advantage to the shaft encoder is that in addition to sensing shaft rotational speed, it can sense output shaft angular position.

An accelerometer is a vibration sensor and one is attached to the fan housing. Accelerometers produce a voltage output proportional to the vibration acceleration. The device used in this measurement was a piezoelectric accelerometer, which uses a known mass to compress a piezoelectric element such as a ceramic or quartz element. This produces a sensor with relatively high dynamic range limited on the high end by the power supply voltages (typically ±5 V) and on the low side by the preamplifier noise levels. The dynamic range of a typical piezo-electric accelerometer is on the order of 85 dB to 110 dB. Most practical measurements result in somewhat lower dynamic ranges, as we will see.

The accelerometer's sensitivity specifies the output voltage per g of acceleration. The unit used in this experiment has a sensitivity of 100 mV/g. It has a bandwidth of 10 kHz based on the frequency at which the output falls outside 5% of the low-frequency output level. This bandwidth specification is quite different from the one used in electronic circuits where the half power point or 0.707 of the low frequency response is used. That is a 30% amplitude tolerance at bandwidth.

Note that the accelerometer requires a power supply/preamplifier to drive the digitizer input. These units are usually battery powered to minimize pickup and ground loops. Accelerometer power supplies may also include signal-processing features such as amplification, filtering, and integration. Amplification is useful in matching the output of the transducer to the input range of the digitizer. Integration is used to convert acceleration into velocity. A second integration converts velocity into displacement. Integration can also be performed, numerically, at the output of the digitizer.

The accelerometer is attached to the fan housing using a magnetic mount. Mounting affects the bandwidth of the transducer. Direct mounting, having the accelerometer screwed into the device being tested, produces the best response. Gluing or using wax are also commonly used mounting methods, again with reduced bandwidth. Becuase the signals encountered in these measurements have bandwidths under 1 kHz, bandwidth loss isn't an issue for this experiment, which uses an accelerometer with a bandwidth of 10 kHz.

The third transducer is an instrument microphone, which reads acoustic sound pressure and produces a voltage proportional to that pressure. The unit used in this application has a bandwidth of 100 kHz (-3 dB). It also requires a battery powered supply that also includes a 20 dB gain amplifier.

The microphone is placed off axis from the fan's air flow to minimize direct pickup of the pressure variation in the fans output air flow. The idea is to measure the acoustic sound pressure level and not the pressure variations in the fan's airstream.

Transducer calibration
Although transducer manufacturers supply calibration documentation for their products, many mechanical transducers can be calibrated before use by using portable calibrators. These devices, usually battery powered, are light and compact. Most produce a fixed frequency sine waveform of known amplitude such as 1 g peak at 1 kHz for an accelerometer or 110 dB at 1 kHz for a microphone. These are useful tools for troubleshooting system errors caused by damaged cables or power supplies.

A great many details arise when using transducers. You should consult the supplier’s data sheets, application notes, and recommendations when selecting a transducer for a particular measurement.

Experimental data and analysis
The digitizerNETBOX was controlled using Spectrum's SBench6 software. This is a full featured software tool for acquiring data using the digitizer. It can display the acquired data with proper scaling in mechanical units and it offers numerout signal processing and measurement tools.

Figure 4 shows an example of the acquisition, analysis and measurement of the data in this experiment. It uses SBench 6’s parameter measurements, FFT (Fast Fourier Transform), and rescaling capabilities.

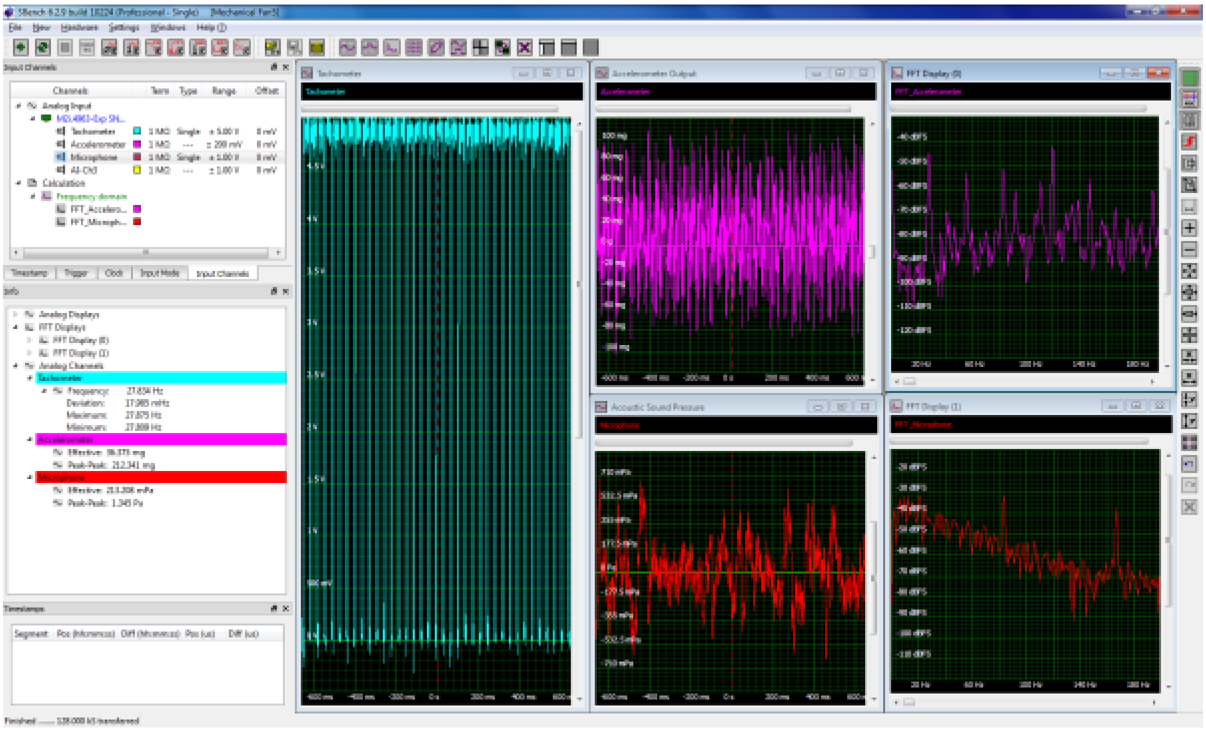

Figure 4. The measurement of the vibration and acoustic properties of a small cooling fan instrumented with a tachometer, accelerometer, and microphone.

The screen image shows the tachometer output in the left-most grid. This waveform consists of one pulse per revolution of the fan. The fan speed is read by measuring the frequency of this signal. The Frequency readout in the Info pane on the left center of the figure reads this frequency as 27.8 Hz (revolutions per second). Multiplying this frequency readout by 60 gives the rotational speed of the fan as 1668 revolutions per minute (RPM). Statistical readouts showing the minimum, maximum, and deviation of the frequency appear below the frequency readout.

The accelerometer's output appears in the upper center grid labeled "Accelerometer Output." A custom scale has been setup using the analog channel settings to read directly in g’s. Measurements of the signals peak to peak and effective (rms) amplitudes appear in the Info pane. This time domain view of the signal is somewhat difficult to interpret so the FFT of this signal is computed and shown in the upper right hand display grid.

The FFT shows the frequency components that make up the acceleration signal. A spectral view provides easier physical interpretation because it separates the various frequency components. The left most peak occurs at 27.8 Hz, the rotational frequency of the fan motor. There are also harmonic components at 56, 83, 111, and 140 Hz. The third harmonic at 83 is higher than the others because it is also the blade passing frequency. As each of the three fans blades passes the fixed struts that support the motor in the fan housing, they induce vibration into the frame. The large peak at 120 Hz is vibration due to the rotating magnetic field in the induction motor.

The microphone output is shown in the center bottom grid labeled Acoustic Sound Pressure. The data has been rescaled to read in units of pressure, namely Pascals. Measurements in the Info pane show the signal's peak-to-peak and effective amplitudes. As in the case with the vibration signal, the FFT of the acoustic signal provides a good deal of physical insight. Note that the two principal spectral lines are at 84 Hz and 168 Hz. This is the blade passing frequency and its second harmonic. The primary narrowband acoustic signals are related to the movement of the fan blades. Low-frequency mechanical vibration and broadband "air noise" make up the raised baseline of this FFT.

Conclusion
Mechanical measurements can be easily made with a digitizer, all you need are appropriate transducers and accessories. The basic setup and operation of some simple mechanical measurements have been shown along with the use of some helpful digitizer software tools for analysis of data. This includes parameter measurements in appropriate units of measure and extraction of useful information, like variation in rotational speed, from the raw data.

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