Application Note

Mechanical Measurements Using Digitizers

Measurements on mechanical devices and systems using a modular digitizer requires the use of a variety of transducers or sensors in order to convert mechanical parameters such as force, acceleration, pressure, rotational speed, and their kindred into electrical signals you can measure. This article is a primer on making such measurements using a modular digitizer.

Digitizer Selection

The bandwidth required for mechanical measurements is generally under 100 kHz. So sampling rates of 200 kHz or greater will work. Resolution should be 16 bits in order to match the dynamic range of commonly used piezo-electric transducers. Table 1 summarizes recommended Spectrum digitizers and prestidigitation's that are most compatible with mechanical measurements:

Model Family	Analog Channels	Resolution	Bandwidth (MHz)	Sampling Rates (MS/s)
M2i.47xx	8 or 16	16 bit	0.05/0.1/0.25/0.5	0.1/0.2/0.5/1.33
M2i.46xx	2, 4 or 8	16 bit	0.1/0.5/1.5	0.2/1/3
M3i.48xx	1 or 2	16 bit	30/50/90	65/105/180
M2i.49xx	2, 4 or 8	16 bit	5/15/30	10/30/60
DN2.46x	4, 8 or 16	16 bit	0.1/0.5/1.5	0.2/1/3
DN2.49x	4, 8 or 16	16 bit	5/30	10/60

Table 1: Spectrum digitizer and digitizerNETBOX families most compatible with mechanical measurements

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 Micro Electromechanical (MEMs) 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…), loading (how the transducer affects the measurement), interconnection method, and cost among others.

Most transducers require power supplies, signal conditioning, and cabling in order to use them. 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 piezo-electric accelerometer. The standard connector is the microdot coaxial connector that uses a 10-32 thread. Transducer manufacturers offer adapters and cables to get you to the more familiar BNC connectors. Let's look at a simple mechanical measurement to see how the transducers are employed with a digitizer.

Mechanical Measurement Example #1

Figure 1 is a diagram showing the connections used in making a basic mechanical measurement on a small, three bladed, cooling fan.

The digitizer used for this measurement is a Spectrum Instrumentation digitizerNETBOX model DN2.496.04 with 4 analog channels, 16 bit resolution, 60 MS/s sample rate, and a 30 MHz bandwidth. The 16 bit resolution is well matched to the large dynamic range possible from both the accelerometer and microphone. A significant advantage to the NETBOX is that it can be located remotely from the host computer, connected via an Ethernet link.

There are three transducers used for this measurement. 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.

An accelerometer is a vibration sensor and it is attached to the fan housing. Accelerometers produce a voltage output proportional to the vibration acceleration. The device used in this measurement was a piezo-electric accelerometer which uses a known mass to compress a piezo-electric 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 to 110 dB. Most practical measurements result in somewhat lower dynamic ranges as we shall see.

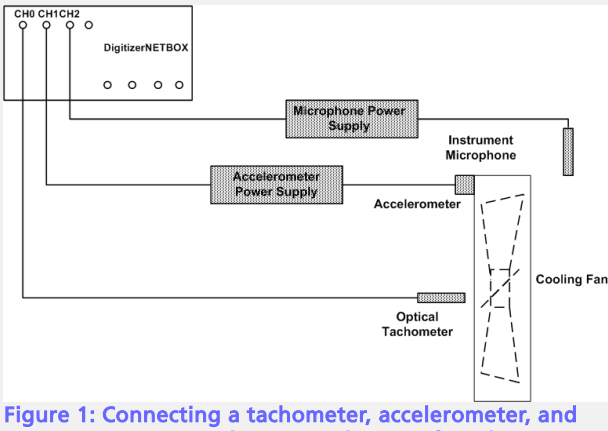

Figure 1: Connecting a tachometer, accelerometer, and an instrument microphone to a digitizer for a basic mechanical measurement of a small cooling fan.

The accelerometers 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. 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. Since the signals encountered in this measurements have bandwidths under 1 kHz this is not an issue.

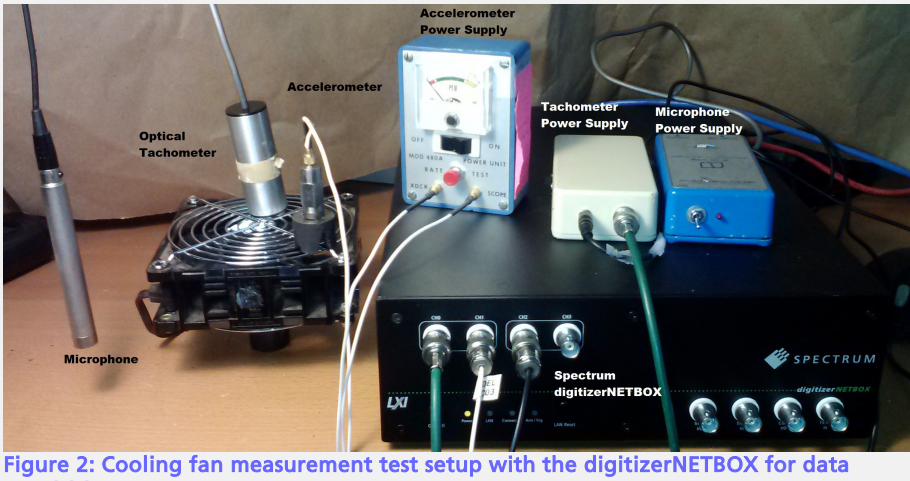

Figure 2: Cooling fan measurement test setup with the digitizerNETBOX for data acquisition

The third transducer used in this measurement is an instrument microphone. This sensor reads acoustic sound pressure and produces a voltage proportional to that pressure. The unit used in this application has a bandwidth of 100 kHz (-3dB). It also requires a battery powered supply which 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 110dB at 1 kHz for a microphone. These are useful tools for troubleshooting system errors caused by damaged cables or power supplies.

There are a great many details that arise when using transducers. It is best to 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 not only can display the acquired data with proper scaling in mechanical units but it also offers a considerable number of signal processing and measurement tools for analysis.

Figure 3 shows an example of the acquisition, analysis and measurement of the data in this experiment.

This SBench 6 screen image shows the tachometer output in the left-most grid. This waveform consist 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.

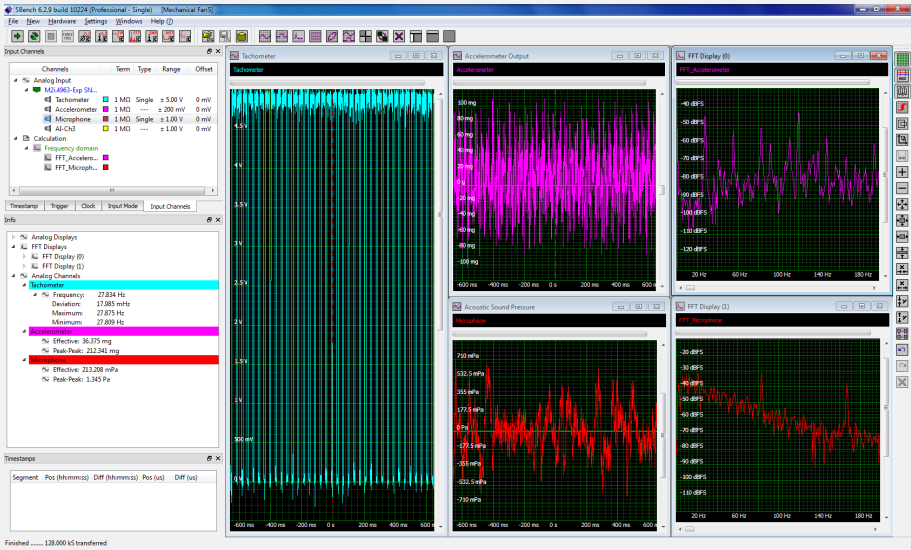

Figure 3: The measurement of the vibration and acoustic properties of a small cooling fan instrumented with a tachometer, accelerometer and microphone.

The accelerometer 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 Fast

Fourier Transform (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. The frequency domain or spectrum view of the FFT 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. So the FFT simplifies the analysis of the vibration signal.

The microphone output is shown in the center bottom grid labeled Acoustic Sound Pressure. This data has been rescaled also so as to read in units of pressure, namely Pascals. Measurements in the Info pane show the peak to peak and effective amplitudes of this signal. As in the case with the vibration signal the FFT of the acoustic provides a good deal of physical insight. Note that the two principal spectral lines are at 84 and 168 Hz. This is the blade passing frequency and its second harmonic. The primary narrow band 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.

The key specifications for the selection of the digitizer is that it have sufficient bandwidth, a number of channels equal or greater than the number of measurements you will make, and sufficient dynamic range to handle the transducers. The digitizerNETBOX, with 16 bit resolution can support up to a theoretical 96 dB dynamic range. Models are available with up to 16 analog input channels. Modular digitizers like Spectrum M2i.46xx and M2i.47xx series, each with up to 16 analog channels can also be used in this application. For an even greater number of channels a Star-Hub module can be used to link up to 16 modular digitizers providing up to 256 analog channels.

Mechanical Measurement Example #2

Figure 4 is a diagram of another mechanical measurement setup on a small air compressor. Measurements of the internal cylinder pressure, vibration acceleration and sound level are being made using a pressure transducer, an accelerometer, and a microphone.

The pressure transducer is screwed into a port that allows access to the top of the internal cylinder. This allows internal access without mechanical interference or leaks. This is also a piezo-electric based sensor where a pressure diaphragm applies force, proportional to pressure on a ceramic or crystal element. The transducer sensitivity is 100 mV per psi.

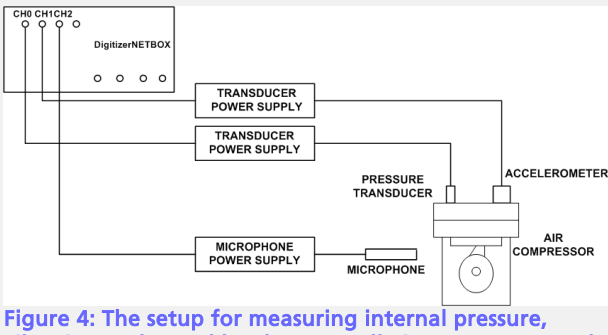

Figure 4: The setup for measuring internal pressure, vibration and sound level on a small air compressor. Each transducer has its own power supply.

The accelerometer is glued onto the cylinder head. Again, the application will determine the mounting method(s). These can vary from transducers being screwed to the device, glued, or connected using magnetic mounts. Mounting, in the case of the accelerometer, must be rigid and aligned with the desired measurement axis. Additionally, the transducers and mountings should be small and light enough to not affect the measurement. Transducer 'loading' in the mechanical world is much like probe loading in electrical measurements. Both affect the accuracy of the

measurement being made.

Figure 6 shows the digitizers data displayed during a compressor measurement. The top left trace (Pressure) is the raw output from the pressure transducer. Channel settings are used to rescale the waveform from milli volts to Pascals (Pa) by scaling the displayed values of the pressure transducer output by the reciprocal of its sensitivity.

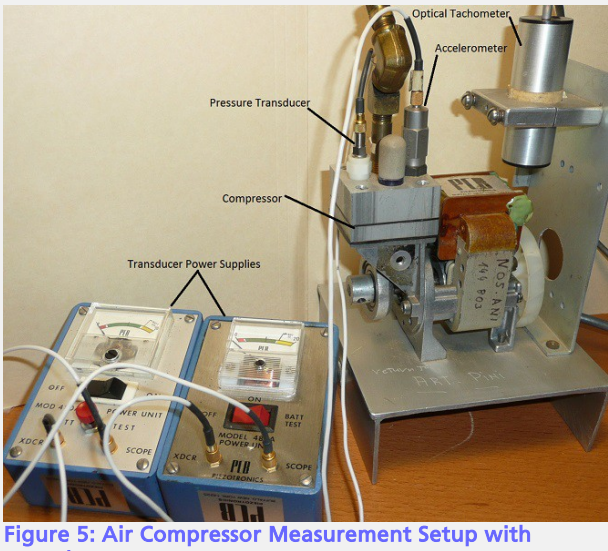

Figure 5: Air Compressor Measurement Setup with Transducers

The increase in the cylinder pressure of the rescaled pressure trace is due to the compressor's output port being closed forcing the compressor to work harder. This is manifested by an increase in cylinder pressure. The peak to peak measurement in the Info pane on the left of the display reads this maximum output pressure variation.

Note that while a tachometer is available to measure compressor rotational speed the pressure waveform is very clean and provides the same information. The frequency readout in the Info pane provides a readout of the compressor rotational speed of 53.5 Hz

The FFT of the pressure data appears in the lower left grid. The spectrum consists primarily of the 53.5 Hz rotational speed and its harmonics. Note that the harmonic peaks appear to show twin peaks. This is due to the compressor slowing down when it is loaded. The frequency variation is small at the fundamental but increases by a factor of the harmonic number for higher harmonics.

The center top grid in Figure 6 shows the accelerometer signal from the accelerometer channel, with a sensitivity of 10 mV/g, which is rescaled, using channel settings, to read acceleration in g's. Measurements in the Info pane read the peak to peak and effective amplitudes of the vibration signal. It is easy to see, from the time domain signal, that when the compressor's output port is blocked the vibration level increases. The FFT of the acceleration signal is shown in the lower center grid. Like the pressure spectrum, the vibration spectrum consists of the rotational frequency and its harmonics.

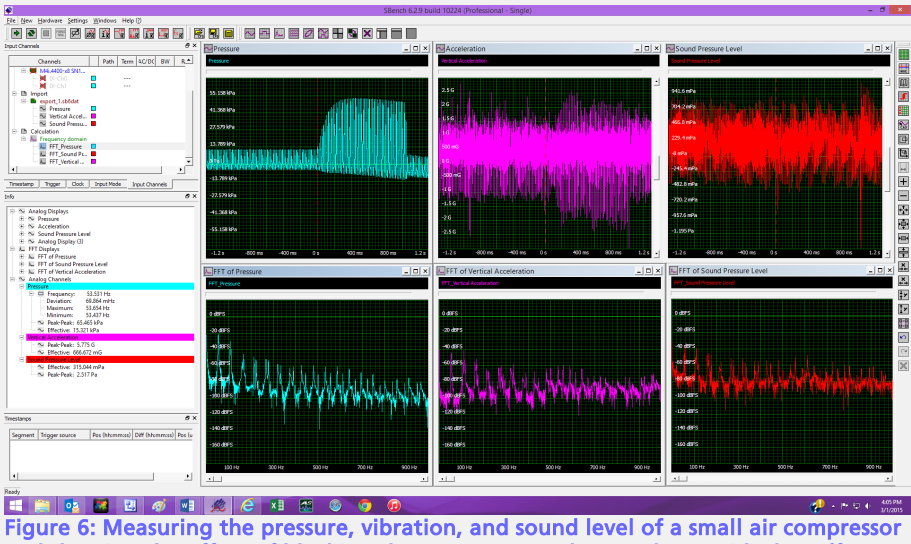

Figure 6: Measuring the pressure, vibration, and sound level of a small air compressor and showing the effect of blocking the output port. The top three grids show (from left to right) the pressure, vibration, and sound level with related FFT's shown below each.

The upper right grid contains the microphone signal showing the sound level. The microphone sensitivity is 42mV/Pa and was used to scale the vertical axis. The sound pressure level remains relatively unchanged until the discharge port is closed at that point it drops slightly accompanied by a negative spike. The spike appears again when the output port is opened. The microphone is picking up sound of the valve which closes the port. The effective (rms) sound level is recorded as 315 mPa which explains the uncomfortable noise level when the compressor is running outside of its enclosure.

The spectrum of the microphone signal appears in the lower right grid. Like the other two signal spectra it consists of the rotational frequency and its harmonics.

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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