Balancing The Options

A Guide to Instrumentation for Balancing

by Victor Wowk

The majority of dynamic balancing instruments measure the vibration, or oscillation, of a stationary structure like a bearing housing. So theoretically, any vibration measuring instrument can be used for mass balancing, with the appropriate choice of method to match the capabilities of the instrument. The non-uniform mass distribution around the rotating center creates the centrifugal force that transfers to the stationary structure. The bearing gets "beat up" in the process. If the mass distribution was perfect, then there would be no centrifugal force, hence no vibration. Perfect balance is undetectable because there would be no vibration to measure. That's a little theory to stimulate your philosophical neurons.

However, the real purpose of this article is to provide some knowledge to help you make intelligent purchase decisions. Some instruments work better than others, and there is a wide range in cost. There appears to be no correlation between cost and performance. Low-cost instruments achieve just as good balance results as much more expensive ones. Low-cost instruments tend to be easier to learn and easier to use by not introducing confusion with added features.

Before introducing electronic balancing instruments, it is worthwhile to discuss the default option. It is possible to mass balance with no instruments.

No Instruments

Static balancing, whether on a stand or in-place in the machine's own bearings, is a method that requires no measuring instruments at all. It is a trial-and-error method that corrects for single-plane only, but it works.

Timed oscillation is another method closely akin to static balancing. It requires only a stopwatch and a weighing scale. It has been used to successfully balance large and heavy rotors weighing up to 20 tons[1].

The pencil-marking method only requires a pencil (or other marker) to identify the "high spot" on a rotating shaft. It was used successfully for decades prior to electronic vibration-measuring instruments, and is still described in some current manuals for equipment installation.

Generic Electronic Instruments

To measure unbalance vibration, without contamination from other sources, I need a filtered amplitude at rotating speed. Modern electronic instruments begin with a transducer that converts physical motion into an electronic voltage variation. The transducer can be an accelerometer, velocity sensor, or proximity probe. Proximity probes are only used where they come installed by the equipment manufacturer. They are never used in portable field-balancing instruments, or on balancing machines. Velocity sensors are the most sensitive, and are the preferred transducer for balancing because of their natural amplification of low-frequency motion below 61 Hz (3,660 rpm). Accelerometers have advantages of smaller size and lighter weight, to get into tight places. Both velocity transducers and accelerometers can be used for balancing with equivalent results.

The varying voltage signal from the transducer is filtered to the rotating speed. This can be done with an analog box or a digital box. The analog instruments are an older technology. They are easier to learn, less costly, easier to use, and faster. However, beware that the amplitude reading can be in error when the battery voltage drops below a lower limit.

Digital boxes maintain the correct accuracy until they blink off due to low battery voltage. The digital boxes generally cost more, but have more useful features, like averaging and memories. A low-frequency spectrum analyzer makes an excellent balancing instrument and has the added benefit of doing vibration analysis on the spot by seeing all vibrations simultaneously. It is, however, a complicated instrument to learn, and difficult to use with confidence.

If the influence-coefficient method is being used to balance, then I also need a phase measurement. This can be acquired with a strobe light or a photosensor observing reflective tape on the rotor. The strobe light requires line-of-sight access to the rotor and can be difficult to see in strong outdoor light conditions, like cooling-tower fans. The strobe light is faster to use, and typically comes with analog instruments. The photosensor requires some extra time to set and string cables. It also requires stopping the machine to attach photo tape, then restarting, before the first phase measurement can be acquired. All these extra steps with the photosensor make it slower to balance.

A weighing scale is desirable to accurately weigh test weights and correction weights. It is, however, possible to mass balance without a scale. In that case, the correction weights are a ratio of the test weights, and the balancer then has to figure out how to come up with *x* times the test weight. All professional balancers carry a portable weighing scale.

The last generic instrument is something that simply provides a means to calculate the correction weight amount and location from the vibration measurements. This could be:

a. A protractor, compass, and handheld arithmetic calculator when using the 4-run method.

b. Vector graph paper, a protractor, and handheld calculator for the single-plane influence-coefficient method of balancing.

c. A programmable calculator or laptop computer when doing 2-plane balancing.

d. The calculator capability can be on-board the balancing instrument. The balancer presses a button when he/she is satisfied with the stability of the vibration measurements. The instrument loads the new data into a matrix, then automatically calculates the correction-weight amount and location when the matrix is full.

Shop-balancing instruments are basically the same as field-balancing instruments. In fact, when purchasing a balancing machine, it is wise to only consider those machines with detachable instruments if field balancing is a possibility in your future.

Minimum Instrumentation

The minimum instrumentation to mass balance could be zero if one of the methods above under "No Instruments" is used. If I wanted to balance using a vibration measurement, then the minimum could be a velocity sensor and an AC voltmeter. This could cost as little as $ 200. With this simple amplitude measurement, I could balance very successfully single plane using the 4-run method without phase. Any overall vibration meter could do the same thing.

To refine the measurement to unbalance only, I could use a tunable-filter instrument to obtain the filtered amplitude at rotating speed. There are many older analog instruments on the used market and they work very well. If the tunable-filter instrument also had a strobe light, then I could obtain amplitude and phase measurements, and have the capability to do 2-plane or multi-plane balancing using the influence-coefficient method. The calculation capability for matrix calculations using the influence-coefficient method is now public domain software and downloadable over the internet.

Honestly, we at Machine Dynamics prefer not to use phase measurements for balancing unless it becomes necessary. Phase is the more difficult measurement to take and is the least accurate. Phase is only necessary for 2-plane balancing using the influence-coefficient method. Two-plane balancing is only required to correct for couple unbalance when serious cross effect is present. We prefer to keep things simple and single plane, which is about 70 percent of all balancing in the field.

There are also times when phase measurements are not wanted. That is when the phase is not stable (i.e., it varies 10 degrees or more). It is also prudent to abandon phase measurements when the first correction weight does not make at least a 50-percent improvement in vibration. The matrix could be ill-conditioned and the influence-coefficient method may not converge at all. All modern balancing instruments have phase-measurement capability and focus on the influence-coefficient method, sometimes exclusively. This is a warning about modern instruments.

There is another method to do 2-plane balancing without phase measurements, that compensates for cross effect and couple unbalance simultaneously[2]. The static-couple method can also be used for 2- or 3-plane balancing using single-plane calculations without phase measurements.

Maximum Instrumentation

There have been no significant improvements in balancing instruments for over 30 years. The recent introductions have been stylistic changes, with colorful displays and report-generation capability. The most significant improvement came in the 1970's with the tracking filter. This is a bandpass filter that stays centered on the rotational speed. It is usually implemented in digital instruments with a photosensor phase measurement (which provides a tach signal to measure speed). This stabilizes the amplitude and phase measurement as the machine speed changes. It also improves the stability of measurements near resonances, which have been the bane of balancing. The tracking filter came from radio technology.

I would not purchase any modern balancing instrument unless it had a tracking filter. The

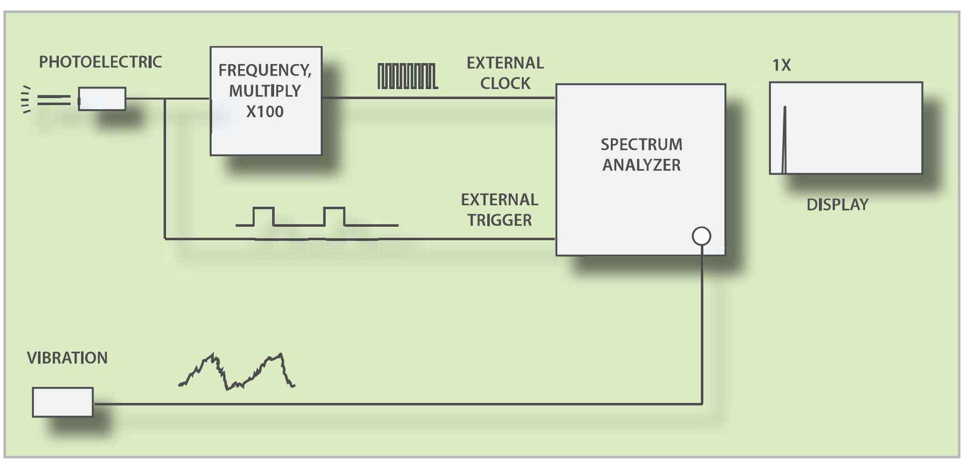

Figure 1 - Simulated tracking filter with a spectrum analyzer and a frequency multiplier.

way to test for this is to vary the machine speed and observe how much the amplitude, and especially phase, changed. A good tracking filter will show gradual amplitude changes as the centrifugal force grows or declines with speed, but negligible phase change unless a resonance is encountered. A simulated tracking filter has been incorporated into modern FFT based spectrum analyzers with a frequency multiplier and a phase locked loop, Fig 1.

Another technique to enhance the balance measurement is the wattmeter. This is illustrated in Figure 2.

A wattmeter receives voltage at one input, and current at a second input. The two are multiplied together to display power in watts. For balancing purposes, the voltage input can be from a velocity sensor and the current input from a generator, or alternator, being driven by the rotor to be balanced. The sine wave from the alternator, when applied to the complex vibration voltage, greatly emphasizes the amplitude at rotating speed. This technique, using an oscillator whose frequency is adjusted by the tach-speed signal, is still used in some balancing instruments, even though it is an old technique dating from the 1920's. It improves the signal-to-noise ratio on hard-bearing balancing machines, but is usually not necessary elsewhere.

The maximum-cost balancing instruments will have the capability for multiple sensors to do multi-plane balancing. They will also have the capability to build a larger matrix from multiple speeds and to average the data for a best-fit solution. This is useful for flexible-rotor balancing.

The best instruments will also have memories to store sensitivity vectors for one-run balancing on the same machine again in the future.

Conclusion

The instrument that measures vibration is the least significant factor determining balance results. Almost any instrument will do with the proper method. The person taking the measurements, selecting methods, and recognizing when things are not going well, is the most significant factor in obtaining good balance.

Vibration-measuring instruments are mature for balance purposes. Even 50-year-old instruments can easily measure to low enough levels to achieve excellent balance. In my opinion, no further improvements in sensitivity are required for balance instruments. There is room, however, for improvements in the methods.

*Victor Wowk, P.E., is the president of Machine Dynamics, Inc., based in Albuquerque. He is the author of **Machine Vibration: Balancing**, published in 1995 by McGraw-Hill. He teaches a two-day balancing seminar every year in Phoenix. Schedules are posted at www.machinedyn.com.*

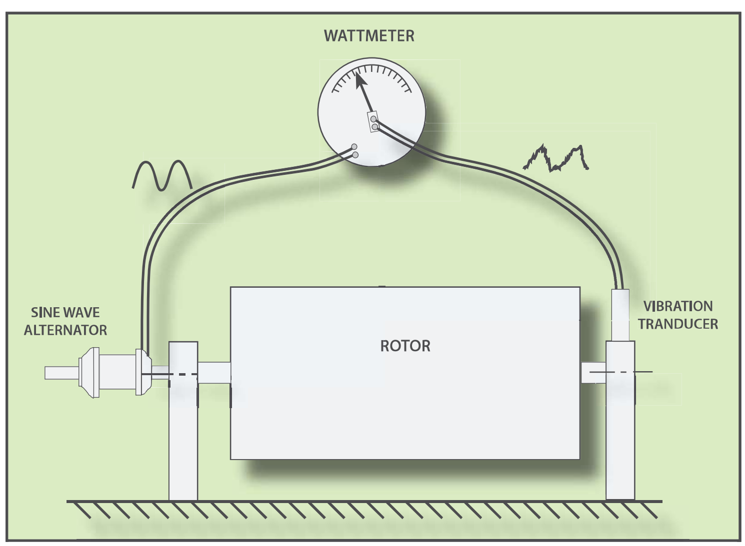

Figure 2 - The wattmeter method of measuring vibration heavily weighted to the rotating speed.

1. R.S. Beebe, MCM Consultants, Machine Condition Monitoring, 2001 reprint. ISBN 0646250884.

2. Louis J. Everett, "Two-Plane Balancing of a Rotor System Without Phase Response Measurements," Transactions of the ASME Journal of Vibration, Acoustics, Stress and Reliability in Design, April 1987, Vol. 109, pages 162-167.