ENGINEERING DATA

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Fan & Fan System Vibration

There is a trend in the fan industry that is causing significant changes in fan design and in the manner in which fans are marketed. As a result of the maturing vibration measuring instrumentation market, computer software and maintenance training programs have been adapted which equate "low vibration" with long life, higher quality, and lower maintenance costs. The fan manufacturers used to be the "vibration experts" and set the tolerance for acceptable levels of vibration. In our evolving industry, the experts are the administrators of the maintenance programs, and the equipment is expected to conform to their expectations. This has created a number of problems:

1. Specifications are being written by people who may be vibration experts, but know little or nothing about the equipment they are controlling.
2. Specifications are "all over the map" in both amplitude levels and in the manner in which the levels are specified.
3. Technical terms are used which may be foreign to the people trying to market the product, design the products, build the products, and perform field start-up and maintenance.
4. It is difficult for the manufacturer to predict the additional costs that may be incurred in achieving the wide variety of specifications.
5. The field costs incurred in conforming to an overlooked specification, (or one of unanticipated difficulty) can easily exceed the cost of the equipment.

In an attempt to restore some credibility and to alleviate some of the above mentioned problems, the fan manufacturers have fought back. Through the fan manufacturers' trade association, AMCA (Air Movement and Control Association), a standard identifying the appropriate levels of balance and vibration for fans was created. AMCA Standard 204 "BALANCE QUALITY AND VIBRATION LEVELS FOR FANS" was issued in 1998 and has been approved by ANSI. If well received and accepted (as are most of the other AMCA standards) most of the difficulties and problems will be corrected.

No matter what happens in the future, it will be necessary for people in the fan industry to become better educated in the field of vibration. Expectations for fewer vibration problems will continue to grow, just as we expect our cars to last longer and have fewer problems. We must be able to communicate with the growing community of vibration experts. In addition, we must have some knowledge as to the causes and cures of vibration problems. With this knowledge will come an understanding of the role that many parties must play in achieving low vibration requirements, and in assigning responsibilities to the appropriate parties. The field of vibration is vast and complex. This discussion will address some of the basic concepts and is specifically oriented towards practical considerations involved with fan applications.

What Is Vibration?

Forces that are not constant in amplitude or direction over time can cause solids to move repetitiously. We call this vibration. The similar motion imparted to the air is called sound. These phenomena are somewhat interchangeable since sound can cause vibration and vibration can cause sound. One difference is that sound is only dealt with when it is audible while vibration must be addressed even when it is outside the range of human perception.

Why Is Vibration Bad?

All fans must generate some vibration. They continuously rotate and, since nothing is perfect, cyclic forces must be generated. It's only when vibration reaches a certain amplitude that we call it "bad." Vibration may just be an indicator of some problem with a mechanism, or it may be a cause of other problems. High vibration can break down lubricants in the bearings and, in addition, may cause metal fatigue in the bearings. Excessive vibration can cause fasteners to loosen or can cause fatigue failure of structurally loaded components. Finally, vibration can transmit into adjacent areas and interfere with precision processes, or create an annoyance for people.

What Is the Main Cause of Vibration?

The forces which result in vibration in fans are primarily due to minor imperfections in the rotating components. The most common of these imperfections is that the center of mass does not coincide with the center of rotation. We call this "unbalance." Unbalance is corrected by adding (or removing) weight so as to make the two centers coincide.

Some fan rotor systems may have multiple planes along the axis of the shaft where unbalance exists. A fan that has a fan wheel on one end and a large sheave on the other may have to be balanced by adding weights to both the fan wheel and the sheave. This is called "two-plane balancing." A wide fan wheel should be balanced in two planes that are on the fan wheel itself. This is also called "dynamic balancing." The term dynamic balancing is often confused with a rotating balance. Balancing machines that are commonly used on fan wheels may be capable of either static (single plane) or dynamic (two plane) balancing. In both cases, the wheel is rotated to measure the amount of unbalance.

What Are Other Sources of Vibration?

There are numerous other "imperfections" that can result in vibration. Some of the more common are as follows:

1. The center of V-belt sheave grooves is not concentric with center of rotation. This can be caused by a bent shaft, a bad bushing, or an improperly machined sheave. The end result is a tugging action between the two sheaves.
2. Belts which have non-uniform hardness, a permanent set, or non-uniform wear, can also result in a tugging action.
3. Misaligned sheaves will cause the belts to try to climb the sides of the sheaves, then slip back in the groove periodically, resulting in vibration.
4. Adjustable pitch sheaves are notorious for having non-uniform groove spacing around the periphery of the sheave. This can result in severe vibration, especially when a higher horsepower is involved.
5. Sheaves may be out of balance or become out of balance due to use of a key that is not of proper length.
6. Shafts that are not straight can cause an unbalance and also may force the bearings to rock or twist in an oscillatory manner.
7. Shaft keyways cause nonsymmetric stiffness in the shaft. When the keyway is at the top or the bottom in an Arrangement 3 fan, the wheel will drop slightly due to the fact that the shaft is slightly weaker in this position. Internal shaft flaws can cause a similar response. Analysts have at times misinterpreted this symptom as being caused by a cracked shaft.
8. Bearing flaws are a common source of vibration. Flaws on inner race, outer race, balls or rollers tend to generate vibration at predictable higher frequencies.
9. Contamination in the bearings generates high frequency vibrations.
10. Bearing mounting surfaces that are not flat can twist or distort the bearings. The rolling elements passing through these nonsymmetric surfaces will result in vibration.
11. Some self-aligning ball bearings take considerable force to align themselves. If forced to operate with trapped misalignment, vibration results. (This can often be cured by tapping on the bearing with a lead or plastic hammer.)
12. Setscrew mounted bearings can trap some misalignment between the bearing bore and the shaft. Sometimes this can be corrected by loosening one bearing, running the fan for a few seconds, then retorquing the setscrews. Repeat on the other bearing if required. Misalignment can also be trapped by having more than two bearings on a single shaft, and in this case it may be difficult to correct. The bearings can be aligned with the fan stationary, but the misalignment will reappear in operation.
13. Undersized shafting can induce unbalance, as well as cause distortions of bearings.
14. Imperfect fan wheel shapes can cause non-uniform pressure generation and result in vibration.
15. Turbulent or eccentric airflow on the fan inlet (and sometimes the discharge) can excite vibrations.
16. Operating the fan at flows lower than where the peak pressure occurs can cause instabilities that result in vibration.
17. Rotating components that make contact with stationary parts (rubbing) can result in major noise and vibration.
18. Coupling misalignment tends to generate forces that commonly result in vibration in the axial direction.
19. Loose or leaking access doors or insufficiently rigid panels in the air system may flutter and result in vibration that permeates the system.
20. The fan wheel impacting with solids or liquid in material conveying systems can shock load the fan into very high vibration.
21. Motor eccentricities, unbalance, electrical unbalances, or magnetic abnormalities are sources of vibration energy.
22. Grease may churn and excite vibration on new equipment and immediately after relubrication.
23. Wind blowing on a roof mounted fan can excite large amplitude vibrations due to vortex shedding.

Variation of Vibration Levels Over Time

So far we have been identifying potential sources of vibration for new and undamaged equipment. It is not uncommon for vibration levels to drift or change over time or in varying operating conditions. Some of the more common causes of this are:

1. Abrasive wear or corrosion.
2. Water buildup in hollow airfoil blades.
3. Material buildup on the blades.
4. Deformation of fan components due to impact.
5. Deformation of fan components due to exposure to temperature.
6. Bearing deterioration.
7. V-belt drive deterioration.
8. Fatigue type failure in fan components due to continued exposure to abnormal loads or vibration.
9. Loosening of hardware on the fan or deterioration of the structure and hardware supporting the fan.
10. Fan wheels may not be perfectly symmetric and may become out of balance due to a change in RPM or in temperature.
11. The fan wheel may "throw" a balance weight.

Vibration Detective Work

All fans are exposed to a variety of vibrational forces. Fortunately, most of the forces mentioned above are relatively small and cause no problems. However, as specified vibration levels are pushed lower and lower, more factors come into play. Each of these must be investigated before they can be excluded.

A common characteristic of fans is that they tend to be large, bulky, and relatively light and flexible for their size compared to other rotating machinery. The impact of this is that small forces can result in large motions. Acceptance criteria are based on the magnitude of the motion, not on the force that creates the motion. Therefore, vibration energy must constitute a very small percentage of the total energy consumed by the fan.

The cumulative effect of many small sources of vibration is the creation of a background (lower limiting) vibration level. Once this background level is achieved, finer balancing is futile. In order to consistently achieve lower vibration levels than that typical to the fan many things may have to be done. The precision level of all fan components must be improved. The fan rigidity may need to be increased. The fan mounting arrangement must be very solid. Finally, air turbulence through the fan must be minimized.

If a fan is already built, and the specified levels cannot be achieved by balance, the fan vibration detective must go to work. All parts of the fan must be examined for precision, and any possible contributor to vibration energy must be considered and corrected if required. This is an expensive, time-consuming effort that can have severe negative consequences to a manufacturing shop's production effort because of its unpredictability.

Paying More for Less

At some point someone must answer the big question: How much vibration is acceptable? With the current situation, there are many people who think they know the right answer to this question but few who are competent to answer it accurately. A well thought out vibration specification should take into account the following issues:

1. The added cost of the equipment caused by low vibration specifications must be offset by reduced maintenance cost, longer life, reduced downtime, or some other economic benefit.
2. Any supplier can only be responsible for those items that they provide or have an opportunity to integrate into an assembly. A near perfect fan mounted to a substandard base may have substandard vibration levels.
3. The terminology used should be precise and appropriate to the instruments and the procedures commonly employed in the trade.
4. Tolerance levels should be different based on the type of equipment involved. The tolerance for a V-belt driven fan needs to be higher than for a direct driven fan. Large horsepower fans may have tighter tolerances than small horsepower fans. Fans mounted on springs (soft-mounted) need to have higher limits than those mounted on concrete slabs.

As stated above, using proper terminology is critical in this very technical field. Before addressing vibration specifications some of the more common terms used in the trade need to be defined.

Definitions

The terms that are defined below represent a combination of true scientific terms as well as terms that have evolved based on the capabilities and settings of the instruments commonly used to measure vibration:

1X, 2X, 3X, ETC. — For a 1X vibration measurement a filter is used so that only that part of the vibration that is moving at the operating speed of the fan (or motor) is measured. A 2X vibration is filtered to look at the component only at two times the operating speed, etc.

ACCELERATION — A value of vibration amplitude that is usually specified in G's. It is the time rate of change of velocity. Many vibration meters will read this value, but it is not very useful for establishing a vibration tolerance. Acceleration is sometimes used for monitoring the degradation of bearings.

BALANCING — The process of adding (or removing) weight on a rotor in order to move its center of gravity towards its center of rotation. One or more planes along the axis of the shaft may be selected for balancing. The object of balancing is to eliminate the unbalance forces that cause vibration. (See also Static Unbalance and Dynamic Unbalance.)

BALANCE QUALITY GRADE — This is a term used to define the limits of residual unbalance in many international standards. It represents the product of the eccentricity (in millimeters) times the operating frequency (in Hertz). A balance quality grade of G6.3 is appropriate to most fans. A grade of less than G2.5 is usually only achievable on very special equipment.

DISPLACEMENT — This represents the maximum distance (and direction) of a vibrating body from its neutral or unexcited position. (See also Mils, Peak, and Peak to Peak.)

DYNAMIC UNBALANCE — This type of unbalance requires at least two different planes along the shaft to correct. To create a true dynamic unbalance on a centrifugal fan wheel, first add a weight on the inlet side of the fan wheel. At the same time add an equal weight (at the same radius) on the back side of the wheel with the second weight rotated 180 degrees from the first weight. This is also called "couple unbalance." (See Static Unbalance and Figure 3.)

ECCENTRICITY — One way of defining unbalance. It is the distance between the center of rotation and the center of gravity of the rotational components of a fan.

FILTER — Vibration, like sound, is composed of a multitude of different frequencies. A filter is a device used to separate the vibration into its individual components on the basis of frequency. All good quality vibration instruments will have a way of filtering vibration data.

FILTER IN — Refers to vibration measured only at one frequency. Normally this is the operating frequency (or RPM) of the fan (or the motor). A "filter in" reading with the filter set at the operating speed measures the "1X" response.

FILTER OUT — This refers to overall vibration or the sum of all frequency components (or at least over a very wide range of frequencies).

FLEXIBLE SUPPORT — A type of foundation design that usually involves the use of springs or rubber isolators. Vibration levels tend to be higher on this type of support since there is little resistance to motion. By definition, a flexible support has its first natural frequency well below the operating frequency. (See also Rigid Support.)

FOUNDATION — This is the component of a system to which the fan (or fan and motor) is attached. Foundations must be designed to have sufficient rigidity to avoid resonance (where vibration can amplify dramatically) and to maintain proper alignment of all components. (See also Flexible Support and Rigid Support.)

FREQUENCY — In vibration, this is the number of complete cycles of motion that a body moves in a second (Hertz) or in a minute (CPM or RPM). (CPM = Hertz x 60)

MILS — A unit used for the measurement of displacement. One mil equals .001 inch.

NATURAL FREQUENCY — The frequency that an object would continue to vibrate at if quickly released from a deformed position. Every fan has a multitude of natural frequencies. It is common to measure natural frequencies by a "bump test" where the vibration response is measured after impacting with a hammer.

PEAK — A term used in the measurement of displacement, velocity, and acceleration that refers to the maximum deviation from zero (or the undisturbed value).

PEAK TO PEAK (P-P) — A term that refers to the total distance traveled in one cycle of vibration. It is used in the measurement of displacement only, for example, four mils P-P equals 2 mils Peak. (See Figure 2.)

RESIDUAL UNBALANCE — The amount of unbalance remaining after balancing.

RESONANCE — A condition where an operating frequency (or other exciting frequency) coincides with a natural frequency. At resonance, relatively small sources of vibration energy can result in large amplitude responses because the energy is stored and added together. (Another characteristic of resonance is unsteady "phase" which is beyond the scope of this article.)

RIGID SUPPORT — A type of foundation design usually characterized by a firmly supported concrete slab. By definition, a rigid support must be so strong that the first natural frequency of the system is well above the operating frequency.

RMS (ROOT MEAN SQUARE) — International standards often give limits of vibration using RMS values. Vibration instruments must be capable of integrating the vibration over a period of time to arrive at this value. For sinusoidal motion the RMS value is about 71% of the peak value. It is normally assumed that fan vibration is sinusoidal in order to convert between specifications. (See Figure 2.)

ROTOR — This is a body capable of rotation (normally within a pair of bearings). It includes the fan wheel, the shaft, the fan sheave (or coupling), and that part of the bearings that rotates with the shaft.

SPEED — A term referring to how fast the fan will rotate, usually given in RPM. We also have:

BALANCING SPEED — The speed at which the rotor is balanced.

DESIGN SPEED — The maximum speed at which the fan can be safely operated.

SERVICE SPEED — The speed of the fan in its normal intended duty.

STATIC UNBALANCE — A form of unbalance that can be corrected by adding a single correction weight directly opposite the heavy spot on the rotor. Static unbalance can be detected by setting the rotor on knife edges and letting the heavy spot bottom out. Dynamic unbalance cannot be detected in this manner. (See Figure 3.)

TRIM BALANCE — This refers to balancing done on a fan assembly (even though the individual components have been previously balanced). It compensates for minor unbalance induced by the fit-up between parts.

TRI-AXIAL SET — This term refers to the common practice of taking three vibration readings at each bearing. The vibration transducer is positioned so that each reading has an orientation that is perpendicular to the other two readings. (Normally, horizontal, vertical, and axial readings are taken.)

UNBALANCE — A condition of a rotor that results in forces being applied to its supporting bearings when the rotor is spinning.

VELOCITY — In vibration work, velocity is a measurement of the speed at which an object moves during its cyclical motion. It is a vector quantity (having both an amplitude and a direction). A common vibration specification limit is 0.157 in/sec peak filter-in.

VIBRATION AMPLITUDE (or VIBRATION LEVEL) — For fans, this usually refers to the magnitude of the vibration motion at or on the fan bearings. It is usually given in units of displacement or velocity. When given in "in-sec peak", the maximum velocity that the bearing moves during a cycle of motion is identified. (See also Mils, Peak, Peak to Peak, Displacement, and Velocity.)

VIBRATION SPECTRUM — Vibration instruments can often display an X-Y plot of vibration frequency vs. vibration amplitude. A mathematical technique called a Fast Fourier Transform (FFT) is used to yield this vibration spectrum. (See Figure 1.)

VIBRATION TRANSDUCER — A device used to sense vibratory motion and convert it into a signal for the purpose of measurement.

Typical Vibration Specifications And Their Consequences

The following list identifies items that may appear on a vibration specification, and how the fan manufacturer may view their impact on compliance:

1. "xxx inches per second filter-out (over-all)" — Any specification that requires filter-out levels raises "red flags" with a manufacturer. Many components of the fan that are purchased, such as motor and drive, can affect the overall vibration levels, yet the fan manufacturer has little control over the precision of these components. In addition, the fan manufacturer typically designs fans so that the first natural frequencies are somewhere between 1.25 and 2.0 times the design speed. Many things can generate small forces at even multiples of the operating speed, and it is not rare for one of the higher order natural frequencies to be excited to vibrate at significant amplitudes.
2. "Maximum vibration shall not exceed 0.01 inches per second peak" — In this example, a vibration level that is less than one-tenth of the levels normal to the industry is specified. This is virtually impossible to achieve. Any special vibration consideration should not be less than one-half of the level normal to the type of equipment involved.
3. Any vibration specification where the fan manufacturer is not supplying all components of the fan including its motor, drive, and the fan base. In this case, only tolerances for the residual unbalance of those components supplied is appropriate.
4. Any vibration specification that does not state the operating condition for which the fan is expected to achieve the specified levels. Is the stated value to be in the manufacturer's plant, on their test stand, or mounted on springs at the final installation site?
5. Any vibration specification that employs units or terms that are strange or unfamiliar. For example, some specifications limit vibration to "1.0 gSE". Even if this unit is known, it is unlikely that the manufacturer will have enough experience to estimate their likelihood of success.

Recommended Vibration Tolerances

It is strongly recommended that AMCA Standard 204 be used to establish tolerances. Otherwise the following guidelines are suggested for vibration tolerances:

1. Conditions of measurement and units:
   a. Vibration amplitudes are in inches/second-Peak. All values are filter-in at the fan speed.

b. Vibration levels will be measured with the fan mounted to the factory test floor. Larger fans may have inlets blocked to limit horsepower.

c. A tri-axial set of readings will be taken for each fan bearing (or near each motor bearing on Arr. 4 fans).

2. Vibration limits will be per the table below.

Table 1. Vibration Limits

FAN DESCRIPTION	LIMITS	
	STD.	EXTRA LOW
All V-Belt Driven Plug Fans & DWDI Fans	0.157	0.140
Other V-Belt Driven Units Up To 1200 RPM	0.157	0.050
Other V-Belt Driven Units 1201 To 1800 RPM	0.157	0.080
Other V-Belt Driven Units Over 1800 RPM	0.157	0.100
All Direct Drive Units Up To 1200	0.157	0.030
All Direct Drive Units 1201 To 1800 RPM	0.157	0.050
All Direct Drive Units Over 1800 RPM	0.157	0.080

Note: For fans on flexible supports (on springs) multiply the “EXTRA LOW LIMITS” by 1.5.

Final Warnings

As you may have surmised by now, we are on a slippery slope until we can get universal acceptance on what the appropriate vibration specifications for fans should be and how they should be measured. One loaded technical word in a specification that gets overlooked can cost untold thousands of dollars. Once again, it is strongly recommended that AMCA Standard 204 be universally adapted. But as general guidelines:

1. Be knowledgeable about what the potential sources of vibration are.
2. Consider what parties have control of each source so that appropriate responsibilities can be assigned.
3. Be aware of the time (and costs) of diagnosing abnormal vibration sources.
4. Be knowledgeable about vibration terminology in order to communicate with the experts.
5. The standard limits given above will give long fan life and are suitable for the vast majority of fan applications.
6. Be prepared for added cost where lower limits are required; limits lower than the “extra low limits” shown above are practically unachievable.

Figure 1. Vibration Spectrum

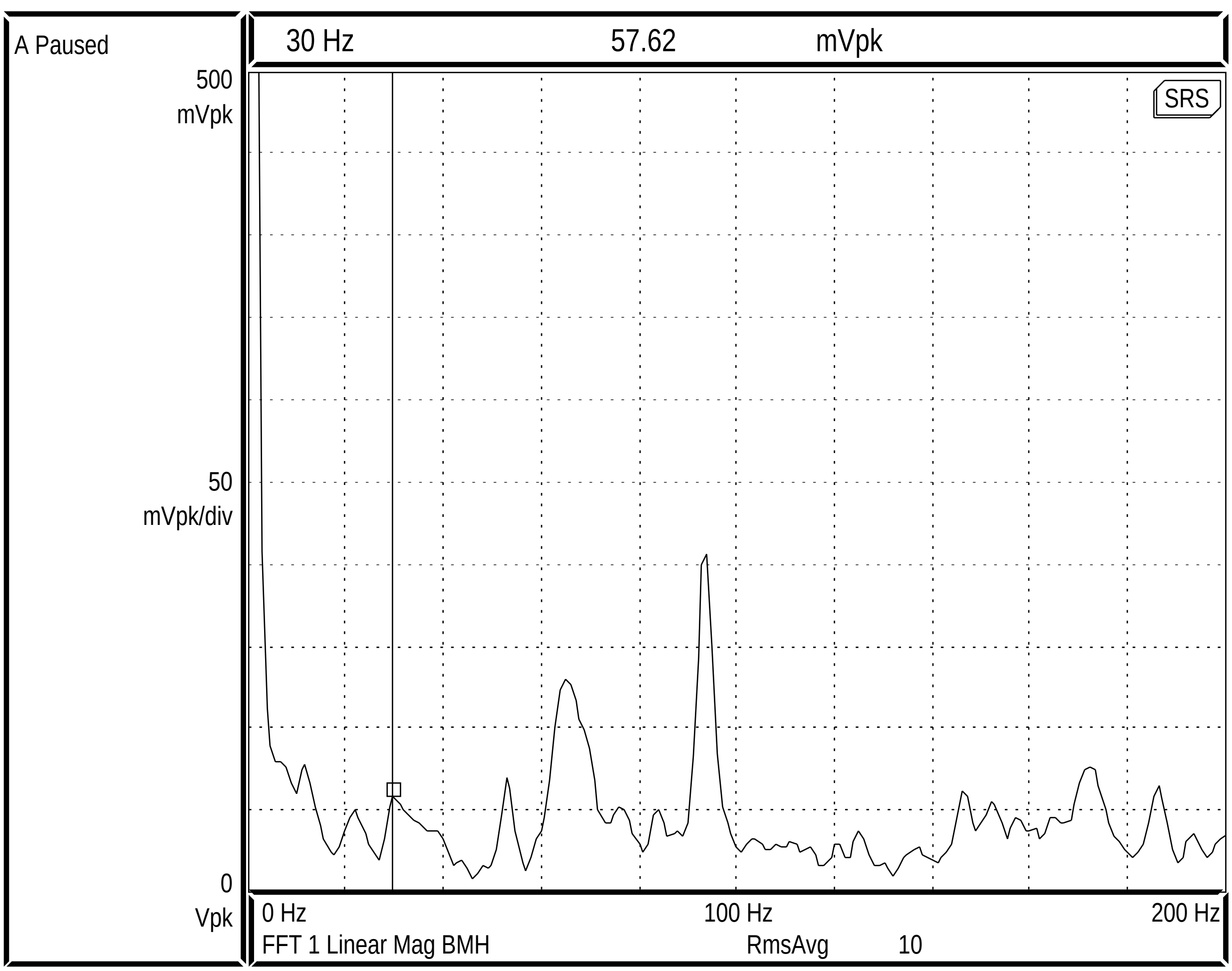


Figure 2. Cycle of Vibration

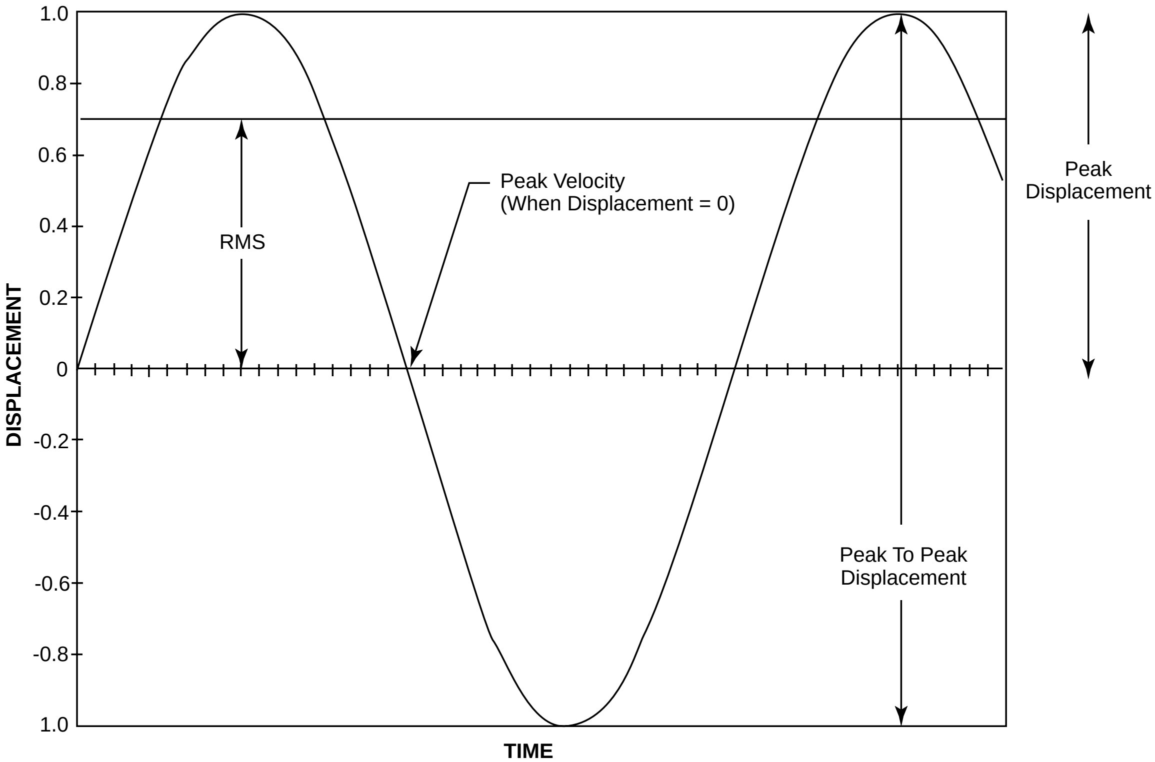
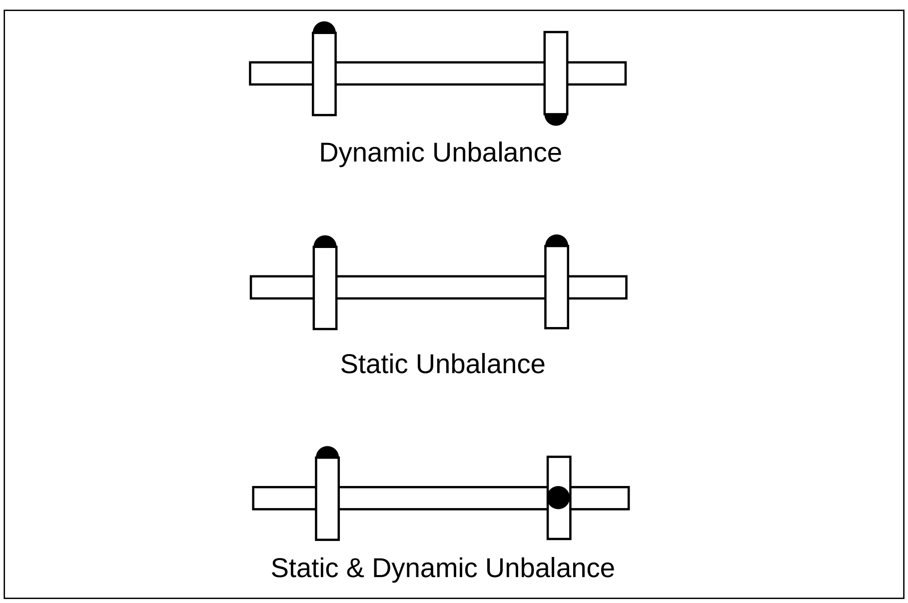


Figure 3. Types of Unbalance Related to Number of Planes



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