Dynamic Balancing Terms & Fundamentals

Why Balance? Rotating components experience significant quality and performance improvements when balanced. Balancing is the process of aligning a principal inertia axis with the geometric axis of rotation through the addition or removal of material. By doing so, the centrifugal forces are reduced, minimizing vibration, noise and associated wear.

Virtually all rotating components experience significant improvements when balanced. Consumers throughout the global market continue to demand value in the products they purchase. They demand performance - smaller, lighter, more efficient, more powerful, quieter, smoother running and longer lasting. Balancing can contribute to each of these and is one of the most cost effective means of providing value to the consumer.

FUNDAMENTAL TERMS

For a better understanding of balancing, it is necessary to have an understanding of its terminology and its fundamental concepts. For additional terminology see ISO 1925, Mechanical Vibration - Balancing - Vocabulary.

MASS CENTER

The center of mass is the point about which the total mass of a rigid body is equally distributed. It is useful to assume that all the mass is concentrated at this one point for simple dynamic analyses. A force vector that acts through this point will move the body in a straight line, with no rotation, according to Newton's second law of motion. The sum of all forces acting on a body, cause a body to accelerate at a rate, a, proportional to its mass.

CENTER OF GRAVITY

For normal commercial balancing applications, the mass center and the center of gravity occur at the same point. This does not hold true for applications involving a non-uniform gravitational field, however, the scale of most balancing applications is very small with respect to gradients in the earth's gravitational field and the terms are synonymous.

AXIS OF ROTATION

The axis of rotation is the true centerline of rotation - the instantaneous line about which a part rotates. It is also referred to as the shaft axis or the geometric axis. The axis of rotation is generally determined by geometric features on the rotor or by its support bearings. The quality of the mounting datums greatly influence the ability to balance a part. Non-circular surfaces, non-flat surfaces, irregular or loose bearings all allow or cause variations in the position of the rotation axis. Any variation of the axis appears to be motion of the mass center with respect to the axis and contributes to non-repeatability.

CENTRIFUGAL FORCE

A particle made to travel along a circular path generates a centrifugal force directed outward along the radial line form the center of rotation to the particle. As the particle rotates about the center point, so does the centrifugal force.

With rigid bodies the unbalance remains the same although an increase in speed causes an increase in force. The increased force will in turn cause increased motion depending on the stiffness of the shaft or the shaft supports. Force increases exponentially as the square of the change in speed. Twice the speed equates to four times the force and four times the motion.

MOMENT AND COUPLE

A couple is a system of two parallel forces, equal in magnitude and acting in opposite directions. A couple causes a moment or torque proportional to the distance between the parallel forces. Its effect is to cause a twisting or turning motion.

WEIGHT AND MASS

The units of weight and mass are often used interchangeably and somewhat loosely in balancing. This is generally acceptable provided the balance computer displays units that are consistent or easily converted to those of the weights in use or the scale used to make the weights. The distinction between weight and mass becomes an issue when calculating unbalance force. It should be understood that weight and force have the same units; Newtons (N) in the metric system and pounds (lbs) in the English system. Mass has the units of grams (g) or kilograms (kg) in the metric system and slugs in the English system.

TYPES OF UNBALANCE

The location of the mass center and the principal inertia axes are determined by the distribution of mass within the part. Unbalance exists when the axis of rotation is not coincident with a principal inertia axis.

It is important to draw a distinction between unbalance and balance correction. Unbalance is a mass property. It becomes a characteristic of the part when an axis of rotation is defined. Balance correction is a means to alter the mass properties to improve the alignment of the axis of rotation with the mass center and/or the central principal axis. Both can be expressed as weights and radii and have shared terminology. This section discusses unbalance as a mass property.

STATIC UNBALANCE

A condition of static unbalance exists when the mass center does not lie on the axis of rotation. Static unbalance is also known as Force Unbalance. As defined, static unbalance is an ideal condition, it has the additional condition that the axis of rotation be parallel to the central principal axis - no couple unbalance.

Static unbalance can be corrected with a single weight. Ideally the correction is made in the plane of the mass center and is sufficient to shift the mass center onto the axis of rotation. It is important to align the correction with the initial unbalance to move the mass center directly towards the axis of rotation.

Static unbalance can be detected on rotating or non-rotating balancers.

COUPLE UNBALANCE

Is a specific condition that exists when the central principal axis of inertia is not parallel with the axis of rotation. Couple unbalance is often presented as dynamic unbalance in engineering classes, however this term is defined otherwise by ISO 1925 and is reserved for the more general case of combined static and couple unbalance. As defined, couple unbalance is an ideal condition. It carries the additional condition that the mass center lie on the axis of rotation - no static unbalance.

Couple correction requires that two equal weights be added to the workpiece 180 degrees apart in two correction planes. The distance between these planes is called the couple arm. Whereas static unbalance can be measured with a non-rotating balancer, couple unbalance can only be measured on a rotating balancer.

DYNAMIC UNBALANCE

The most general case of unbalance in which the central principal axis is not parallel to and does not intersect the axis of rotation.

Dynamic unbalance is also referred to as two plane unbalance, indicating that correction is required in two planes to fully eliminate dynamic unbalance. A two plane balance specification must include the axial location of the correction planes to be complete. Dynamic unbalance captures all the unbalance which exists in a rotor.

This type of unbalance can only be measured on a rotating balancer since it includes couple unbalance.

QUASI-STATIC UNBALANCE

A special form of dynamic unbalance in which the static and couple unbalance vectors lie in the same plane. The central principal axis intersects the axis of rotation, but the mass center does not lie on the axis of rotation.

This is the case where an otherwise balanced rotor is altered (weight added or removed) in a plane some distance from the mass center. The alteration creates a static unbalance as well as a couple unbalance. Conversely, a rotor with quasi-static unbalance can be balanced with a single correction of the right magnitude in the appropriate plane.

UNITS OF UNBALANCE

Balance corrections are normally specified as a weight added or removed at a radius. The weight or mass units can be any convenient units of measure. The most commonly used weight units are ounces or occasionally pounds and the most common mass units are grams (g) or kilograms (kg). The capacity and accuracy of the weighing equipment available must be taken into account to ensure that weight precision is sufficient to the task. The most common combinations used to specify unbalance are ounce inches, gram inches, gram millimeters, gram centimeters, and kilogram meters.

MOTION OF UNBALANCED PARTS

What is the effect of unbalance on a rotating part? At one extreme, if the rotor mounts are rigid, the forces exerted at the bearing supports can be very high and potentially damaging. The forces are a function of the unbalance. They are the centrifugal forces described earlier. At the other extreme, with flexible mounts, the part is loosely constrained and may exhibit large amplitudes of displacement. The amplitude of vibration is proportional to unbalance and limited by the distance between the mass center and the axis of rotation. Most applications are a combination of both.

BALANCING EQUIPMENT

Balancing machines fall into two major classes - those that spin the workpiece and those that don't. These are known as dynamic and static balancers respectively. A dynamic balancer is also known as a centrifugal balancer. Dynamic balancers are further separated into two distinct classes - soft bearing and hard bearing balancers. This distinction is made according to the relative stiffness of the measuring system. Each is discussed further below.

Static balancers depend totally upon the force of gravity to detect unbalance. Consequently, they are only sensitive to static unbalance and are completely unable to detect couple unbalance. A dynamic balancer with 2 sensing elements is required to sense couple unbalance.

STATIC BALANCERS

Static balancers do not spin the part and do not depend on centrifugal force to measure unbalance. Their operation is based on gravity generating a downward force at the mass center. The downward force causes the part to gently rotate or roll until the mass center is down and at its lowest point. In this way the location of the heavy spot is identified and corrections can be made. This type of balancing is often done on level ways or rollers. Typically, with level way balancing, the unbalance amount is not known with precision and the part is corrected by trial and error until the part no longer rotates. Although extremely time consuming, this method is effective at minimizing static unbalance. It is possible to measure unbalance amount on a level way balancer by rotating the heavy spot up 90° and measuring the moment or torque required to keep the heavy spot at 90°. The torque measured is equivalent to unbalance.

DYNAMIC BALANCERS

Dynamic balancers rely on the effects of centrifugal force to detect unbalance. They are capable of detecting all forms of unbalance - static, couple, dynamic or quasi-static. The distinction between soft and hard bearing is made based on the natural frequency of the suspension and the relative speed of operation. Those balancers operating at speeds below the natural frequency of the suspension (usually less than half) are classified as hard and those operating at speeds above the natural frequency are classified as soft (usually more than double).

DYNAMIC SOFT SUSPENSION BALANCERS

Soft suspension balancers are also referred to as soft bearing balancers. The soft suspension balancer operates above the resonant frequency of the balance suspension and measures the displacement associated with unbalance. With this type of balancer the part is force free in the horizontal plane and rotates about the central principal axis. The amplitude of vibration is measured at the bearing points to determine the amount of unbalance.

The most significant drawback to the soft suspension is the requirement to recalibrate for each unique part. Left and right bearing outputs are heavily influenced by the total weight of the workpiece and its mass distribution. Calibration requires that weights be alternately placed in the right and left correction planes. Each weight normally causes vibration at both supports. The ratio of amplitudes can be used to quantify the crosstalk between planes or their independence. This is known as the correction plane interference ratio or plane separation. Plane separations of 100:1 can be achieved with some difficulty. Each calibration is speed dependent and unique to the part used for calibration.

DYNAMIC HARD SUSPENSION BALANCERS

Dynamic suspension balancers are also referred to as hard bearing balancers. The hard suspension balancer operates at speeds below the suspension resonant frequency and measures the force generated by the spinning rotor. The amplitude of vibration is very small, and the centrifugal forces potentially very large.

Hard suspension balancers employ rigid work supports and are typically easier and safer to use. Tooling can be configured to hold almost any type of part and there is no restriction that the mass center lie between cradles as there often is with soft suspensions.

QUASI-HARD or QUASI-SOFT SUSPENSION BALANCERS

In between hard and soft suspensions is a class of balancers known as Quasi-Hard or Quasi-Soft. These balancers use natural resonance to amplify output and take advantage of a mechanical gain to boost sensitivity. Performance in this region can be non-linear and unpredictable. Precise speed control is required to preserve amount and angle accuracy as both change rapidly at resonance. With more modern electronics, transducer outputs can be processed with adequate gain and this region is typically avoided for the benefit of a more stable operating range.