



Primer on

Dynamic Balancing

“Causes, Corrections and Consequences”

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By

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Abstract

When man invented the wheel, he very quickly learned that if it wasn't completely round and if it didn't rotate evenly about its central axis, then he had a problem!

The wheel would vibrate, causing damage to itself and its support mechanism and in severe cases, be unusable. As the task of manufacturing a replacement was so huge and time consuming, a method had to be found to minimize the problem. Research showed that the wheel and its shaft had to be in a state of balance, i.e. the mass had to be evenly distributed about the rotating centerline so that the resultant vibration was at a minimum. This had to be achieved during the manufacturing process (and perhaps just as importantly, as wear occurred) so that maximum service life could be achieved from the system.

Modern man still suffers from the same problem – only now the problem is amplified. As machines get bigger and go faster, the effect of the unbalance is much more severe.

A level of unbalance that is acceptable at a low speed is completely unacceptable at a higher speed. This is because the unbalance condition produces centrifugal force, which increases as the speed increases. In fact, the force formula (Ref.1, page 1-6) shows that the force caused by unbalance increases by the square of the speed. If the speed is doubled, the force quadruples; if the speed is tripled the force increases by a factor of nine! It is the force that causes vibration of the bearings and surrounding structure. Prolonged exposure to the vibration results in damage and increased downtime of the machine. Vibration can also be transmitted to adjacent machinery, affecting their accuracy or performance.

Identifying and correcting the mass distribution and thus minimizing the force and resultant vibration is the technique known as dynamic balancing.

Causes

The International Standards Organization defines unbalance as:

That condition which exists in a rotor when vibratory force or motion is imparted to its bearings as a result of centrifugal forces. (Ref.2)

A more popular definition is:

The uneven distribution of mass about a rotor's rotating centerline.

The key phrase being “rotating centerline” as opposed to “geometric centerline”. The rotating centerline being defined as the axis about which the rotor would rotate if not constrained by its bearings. (Also called the Principle Inertia Axis or PIA). The geometric centerline being the physical centerline of the rotor. When the two centerlines are coincident, then the rotor will be in a state of balance. When they are apart, the rotor will be unbalanced.

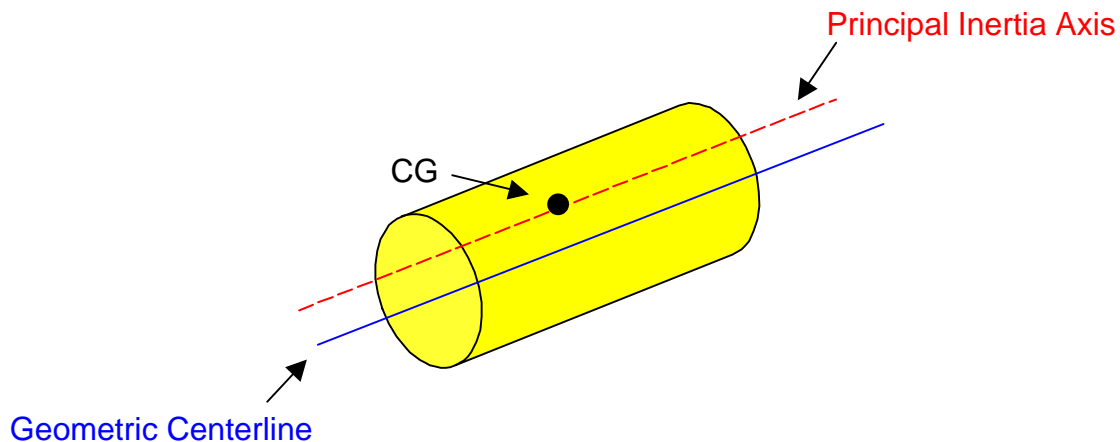


Fig 1

Different types of unbalance can be defined by the relationship between the two centerlines. These include:

Static Unbalance – where the PIA is displaced parallel to the geometric centerline. (Shown above)

Couple Unbalance – where the PIA intersects the geometric centerline at the center of gravity. (CG)

Dynamic Unbalance – where the PIA and the geometric centerline do not coincide or touch.

The most common of these is dynamic unbalance.

Manufacturing - Causes

Many causes are listed as contributing to an unbalance condition, including material problems such as density, porosity, voids and blowholes. Fabrication problems such as misshapen castings, eccentric machining and poor assembly. Distortion problems such as rotational stresses, aerodynamics and temperature changes. Even inherent rotor design criteria that cannot be avoided. Many of these occur during manufacture, others during the operational life of the machine. Whilst some corrections for eccentricity can be counteracted by balancing, it is a compromise. Dynamic balancing should not be a substitute for poor machining or other compromise manufacturing practices.

In the manufacturing process, if proper care is taken to ensure that castings are sound and machining is concentric, then it follows that the two axis will coincide and the assembled rotor will be in a state of balance.

Assembly - Causes

As previously stated, there are many reasons why unbalance occurs when a rotor is being fabricated. Principle among these is a stack up of tolerances. When a well-balanced shaft and a well-balanced rotor are united, the necessary assembly tolerances can permit radial displacement, which will produce an out of balance condition. The addition of keys and keyways adds to the problem. Although an ISO standard does exist for Shaft and Fitment Key Conventions (Ref.3), in practice, different manufacturers follow their own procedures. Some use a full key, some a half key, and some no key at all. Thus, when a unit is assembled and the permanent key is added, unbalance will often be the result. The modern balancing tolerances specified by ISO, API, ANSI and others make it imperative that the conventions listed in the ISO standard be followed. Failure to do so will mean that the low-level balance tolerances specified in these standards will be impossible to achieve.

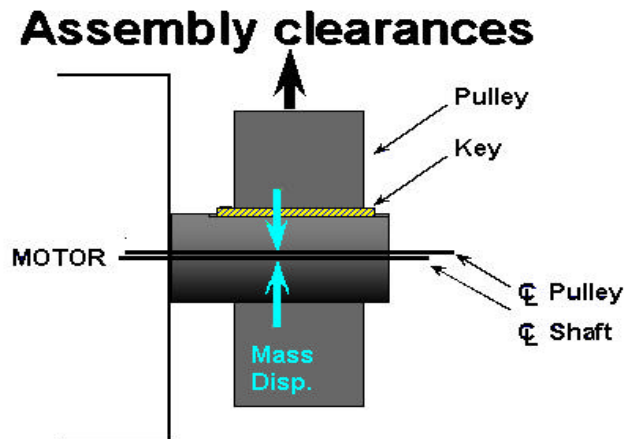


Fig.2

Installed Machines - Causes

When a rotor has been in service for some time, various other factors can contribute to the balance condition. These include corrosion, wear, distortion, and deposit build up. Deposits can also break off unevenly, which can lead to severe unbalance. This particularly applies to fans, blowers, compressors and other rotating devices handling process variables. Routine inspection and cleaning can minimize the effect, but eventually the machines will have to be removed from service for balancing.

Large unbalances will of course require large weight corrections and unless care is taken, this can have a detrimental effect on the integrity of the rotor. Concentrating a weight adjustment (whether adding or taking away) at a given point can weaken the rotor. For example paper rolls are fabricated from tubing and large additions or removal of weight can effect the strength of the walls of the roll. This may cause it to deflect when spinning at operating speed and thus induce harmful vibrations on the bearings and paper machine frame.

Other Causes

Another cause of unbalance that is not readily apparent, is the difference between types of rotors.

There are two distinct types - rigid and flexible.

If a rotor is operating within 70% - 75% of its critical speed (the speed at which resonance occurs, i.e. its natural frequency) it can be considered to be a flexible rotor. If it is operating below that speed it is considered rigid.

A rigid rotor can be balanced at the two end planes and will stay in balance when in service. A flexible rotor will require multi-plane balancing. If a rotor is balanced on a low speed balancing machine assuming it is rigid and then in service becomes flexible, then unbalance and thus high vibration, will be the result.

Typical machines, which fit this category, include steam and gas turbines, multistage centrifugal pumps, compressors and paper rolls. In the paper industry particularly, use of roll balancing methods that were satisfactory when paper machines were running at low speed, are now inadequate. As older machines speed up and new high-speed machines are installed, precision roll balancing is mandatory. Failure to do so will result in roll deflections which can effect product quality and even cause structural damage. The method used to produce a balanced roll with minimum

deflection or whip over its operating speed range is a multi-plane technique. The choice of the balancing planes along the length of the roll is vital.

Corrections

When unbalance has been identified and quantified, the correction is straightforward. Weight has to be either added or removed from the rotating element. The ultimate aim being to reduce the uneven mass distribution so that the centrifugal forces and hence the vibrations induced in the supporting structures are at an acceptable level.

Field Balancing

Many rotors can often be balanced in place, running at their own operating speed, with minimum disassembly. To balance in place, of course, a basic requirement is that the rotor has to be accessible to make corrections. Machines such as fans and blowers are good candidates. Totally enclosed motor armatures and pump impellers are not.

The technique of balancing in place is referred to as Field Balancing and it offers some distinct advantages including:

- Balancing is performed on the complete assembled machine and compensates for the assembly tolerances discussed earlier.
- Costly and time-consuming disassembly to remove the rotor to a balancing machine is eliminated.
- The effects of temperature, pressure, distortion and other environmental influences can be incorporated.
- The resultant vibration can be the tolerance applied to the rotor, rather than the published balance tolerances normally used in a balancing machine. This is particularly advantageous if the supporting structure is close to a resonance. The unbalance in the rotor may have to be adjusted to abnormally fine levels to minimize the resultant resonant structural vibration.

Modern instruments such as vibration analyzers, data collectors and portable balancers provide accurate information to assist in the balancing process. The vibration level measured at the rotating speed frequency is used as an indicator of the amount of unbalance. The location is determined by measuring the phase. Phase, (the relative motion of one part of a machine to another) is measured by means of a stroboscopic light or by an indicator in the instrument, triggered by a photocell.

It is imperative that the vibration measured is a result of the unbalance and not some other exciting force. Only a detailed, thorough, analysis can identify where the vibration measured is coming from. Many sources of vibration can occur at the rotating speed frequency. (1)

When field balancing, trial weights for balance computation and permanent weights for final correction are normally added to the rotor. Care should be taken when attaching weights. They should be attached securely so that they cannot 'fly off' when the machine is operating. They not only constitute a personnel safety hazard but also can cause damage. Loose balance weights rattling around inside a turbine for example can wreck the machine.

Factory Balancing

As part of the manufacturing process, most rotors are routinely balanced in a balancing machine. A simple definition of such a machine is:

A device that holds and spins the rotor while you balance it.

Balancing machines can be divided into two different types:

Production Machines

As their name implies, these are used in the manufacture of rotating elements. They can be highly automated for high-speed production, often designed around one part, with automatic drills or mills to remove weight or welding units to add weight. Or, they can be more general-purpose machines for low volume production, which are easily adjusted to take a variety of parts.

In some, the part is mounted horizontally like the example shown below, whilst in others the part is mounted vertically to simplify loading and unloading. The instrumentation is normally built in to the balancing machine.

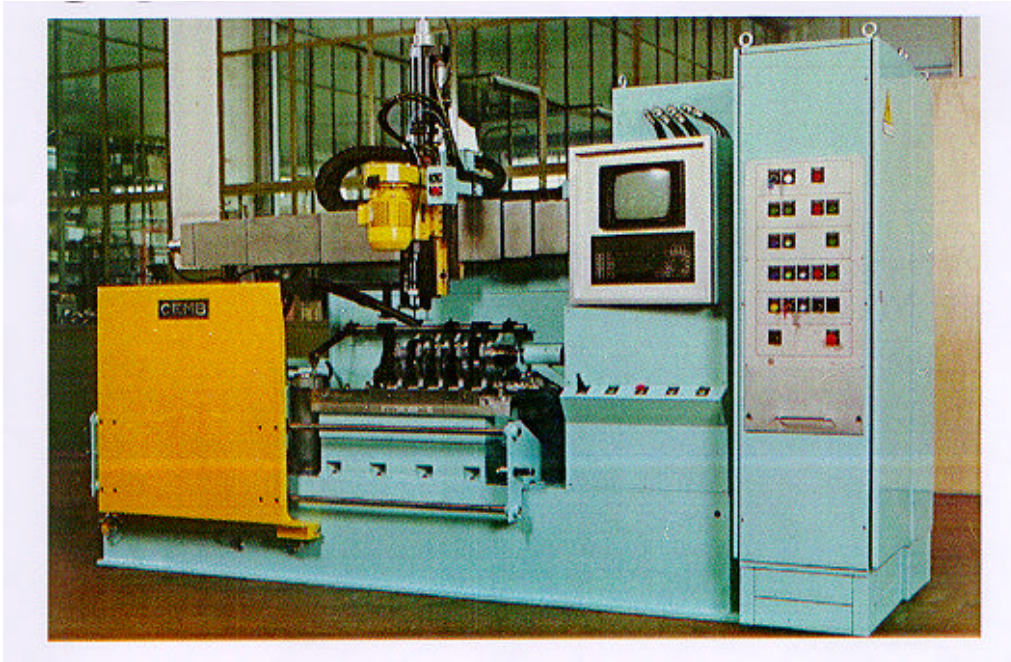


Fig 3

Fully automatic production machine with drill
For Crankshaft balancing

Maintenance Machines

These machines on the other hand are designed to balance rotors after maintenance overhauls. They are normally horizontal types with attachments and tooling designed for easy set up and adjustment. They must accommodate a wide weight range for versatility and be able to handle a wide variety of shapes and sizes of rotors. Instrumentation can be either dedicated or separate. The same instrument that is used for field balancing can also be used in the balancing machine.

Maintenance type balancing machines are a necessity in repair depots such as motor rewind shops, pump overhaul facilities and turbine repair workshops. All industrial rotors that have been overhauled should include a balance check as the last task before re-assembly.

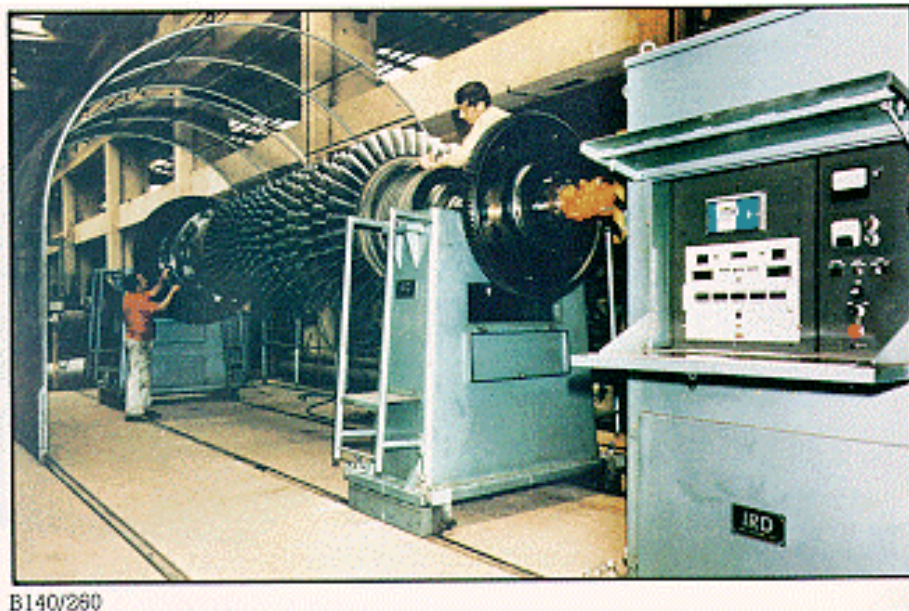


Fig 4

Large capacity maintenance type machine
For
Turbine balancing

Consequences

There are many documented “good consequences” and benefits associated with a well balanced, smooth running rotor. Included among these are:

- **Minimize vibration**

Unbalance is still the major source of machine vibration.

- **Minimize noise**

Airborne noise is often directly attributable to mechanical vibration.

- **Minimize structural stress**

The forces produced by unbalance have to be absorbed by the surrounding structure.

- **Minimize operator fatigue and annoyance**

Exposure to high levels of vibration and noise affects operator efficiency.

- **Increase machine life**

The time between outages can be extended if the machine is running smoothly.

- **Increase bearing life**

Bearings bear the brunt of the unbalance forces.

- **Increase product quality**

Minimum vibration, especially on machine tools, produces better parts.

- **Increase personnel safety**

Dangers associated with machine failure are minimized.

- **Increase productivity**

Machines running smoothly have more “uptime” availability

- **Lower operating costs**

Extra machines are not required “just in case” of breakdowns. Spare capacity is kept to a minimum. Energy consumption is reduced.

Conclusions

Everything that rotates needs to be in a state of balance to ensure smooth running when in operation.

Precision balancing is essential to the manufacture of rotating equipment and to the repair and renovation of installed machines. As machine speeds increase, the effects of unbalance become more detrimental.

Modern technology allows for accurate balancing to be performed both in the field and in the workshop.

Increased time between outages and availability for production is the prime benefit.

References

1. Entek IRD #2049 “Dynamic Balancing Handbook”
2. ISO Standard 1925 “Mechanical Vibration-Balancing-Vocabulary”
3. ISO Standard 8821:1989 “Mechanical Vibration-Balancing-Shaft and Fitment Key Conventions.”