MPTA-C3c-2019

BALANCING

MPTA INFORMATIONAL BULLETIN

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Disclaimer Statement

Abstract

Many users of elastomeric couplings are being presented with the need for higher levels of coupling balancing. This subject is mentioned in publications, trade shows, seminars, by consultants and universities. The stated benefits often given for balancing a coupling is to reduce vibration, seal and bearing wear and to extend equipment life. Proponents for higher levels of balance in many cases may only be adding significant cost to the coupling cost while offering no observable benefit for the rotating equipment.

All couplings have an inherent level of balance. The amount of balance required varies from application to application as a result of the fact that the coupling is but one component of a rotating system of many components manufactured by many entities; it is often the characteristics of these other components which determine the level of coupling balance required. It is not uncommon for coupling users and OEM's to specify a value of balance based upon limited information about the actual needs; the risk is the level of balance specified may serve only to add unnecessary expense or worse yet, may not be needed at all. The responsibility for the selection of proper coupling balance lies primarily with the user of the coupling, this bulletin was written to aid that user in determining the value or class of balance needed in their application.

Copyright Statement

Foreword

This foreword is provided for informational purposes only and is not to be construed to be part of any technical specification. This Informational bulletin is divided into two sections.

The first section covers fundamentals of balancing. These subjects are for the person with little or no understanding of balancing. The discussion employs "everyday" illustrations of balancing. It demonstrates that everyone already has some knowledge of balancing and merely needs to learn the proper terms being used in the industry in order to better communicate their needs to their supplier.

The second section is designed to provide some of the fundamental information needed to select a balancing value or class. Based upon the knowledge obtained in Section I and the specifics of Section II, the user will be able to communicate comfortably with the coupling supplier to obtain the coupling which will more than satisfactorily operate in their system. Using this information, the amount of balance specified will meet their needs without imposing excessive cost due to over specification.

Suggestions for the improvement of or comments on this publication are welcome. They should be emailed at www.mpta.org.

Scope
This Informational Bulletin contains information for use to the industry but is not a standard. This Bulletin is made available to the public via the MPTA website.

Definitions
Coupling Weight Relative to Total Bearing Loads - Machines having lightly loaded bearings or bearings loaded primarily by the overhung weight of the coupling are relatively sensitive. (Machines having overhung rotors or weights are often sensitive). (ASTM)

Inherent Unbalance - is the unbalance of a homogeneous body caused by geometric concentricity tolerance which result in displacement of the center of gravity relative to the axis of rotation. (ANSI/AGMA 9000)

Machine Separation - Systems having widely separated machines (for instance, those employing floating shaft couplings) are relatively sensitive. (ASTM)

Potential Unbalance - is the maximum amount of unbalance that may exist in a coupling assembly, whether corrected or not corrected. (ANSI/AGMA 9000)

Residual Unbalance - is the final amount of unbalance that remains in a coupling component or assembly after balancing, prior to removal from the balancing machine. (ANSI/AGMA 9000)

Shaft End Deflection - Machines having flexible shaft extensions that produce large deflections are relatively sensitive. (ASTM)

Shaft Extension relative to Bearing Span - Machines having a short bearing span relative to their shaft extensions are sensitive. (ASTM)

System Natural Frequencies - Machines or systems operating near the natural frequencies of rotor or support systems are sensitive. (ASTM)

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1. Balancing Theory

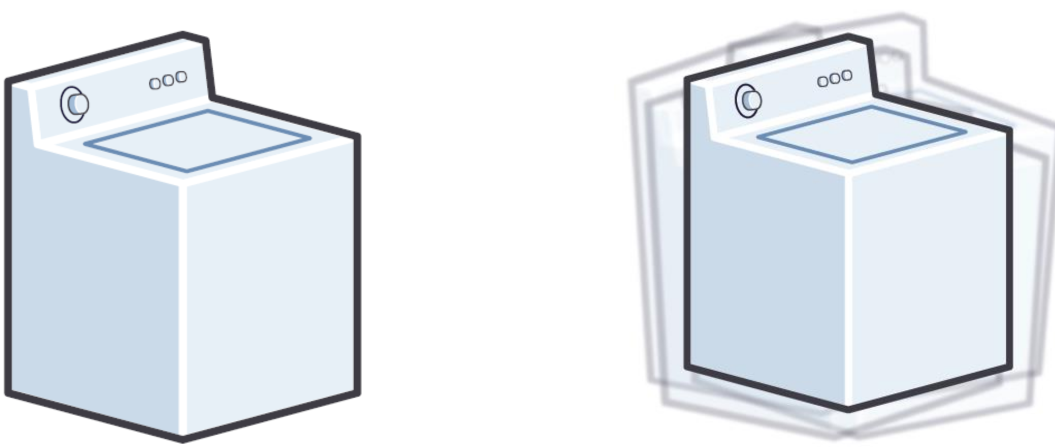
1.1 Balancing

It is understood that some users are well informed about the subject of balance and unbalance. They readily understand what causes unbalance. The following section is for those who yet need this understanding. If the terms of balancing are well understood it is suggested that the reader proceed to Section 2.

Every rotating object has balance or more properly, some degree of unbalance. It is not achievable to have a rotating object with perfect balance. The original design of a coupling is such, that it is perfectly balanced. Some unbalance, however small, results from the manufacture and installation of the coupling; for example, machined parts more closely match the original design, while cast parts are typically less precise. Thus, the real question is "how much unbalance can an application have and still perform in a satisfactory manner?" In order to answer this, the user of a coupling should understand what is meant by unbalance before specifying an amount the application can allow.

1.2 What is Unbalance?

Anyone who has ever used a clothes washer (Fig.1) has experienced the effects of unbalance. Who has not heard the familiar "thump...thump..." during the washer spin cycle? The annoying noise is stopped by opening the washer door and moving the clothes around the drum instead of allowing them all to be located on one side of the drum. Without knowing it, this person is balancing the washer much as is done with a coupling. For a coupling, the "moving of the clothes" is the addition or removal of material to the coupling. The adding or removing of material shifts the center of gravity of the coupling.



Balanced Unbalanced

Fig. 1

1.3 What is Center of Gravity? What is Concentricity?

"The center of gravity is that point in a body or system around which it's mass or weight is evenly distributed or balanced and through which the force of gravity acts." (Webster's New World Dictionary) In this definition, the coupling "body" may be the hub or other component. The "system" would include the entire coupling with all of its components. Ideally, the center point would lie on the axis of the shaft which is the geometric center of the shaft. In the washer illustration, the center of rotation is in the center of the drum and the center of gravity is located towards the group of clothes. When you spread the clothes around the drum, you shift the center of gravity of the clothes to more closely coincide with the center of the drum (the axis of rotation of the drum). If the center of gravity of a rotating body exactly coincides with the axis of rotation of the shaft upon which it is mounted, the part is in perfect balance (Fig 2).

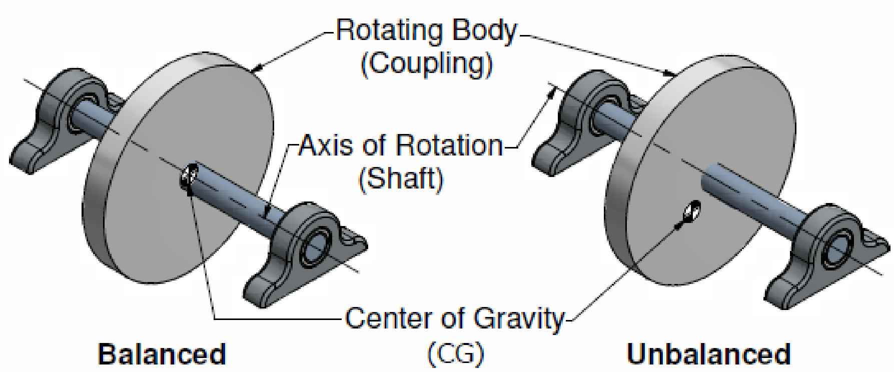


Fig 2

Coupling manufacturers optimize the balance of their products by specifying close dimensional tolerances. Even the best of machining practices will introduce some variation within a part and thus its center of gravity can vary. This is seen particularly in the relationship of the bore to the outside diameter of a coupling hub. This is often referred to as bore to outside diameter run-out or bore concentricity (Fig 3).

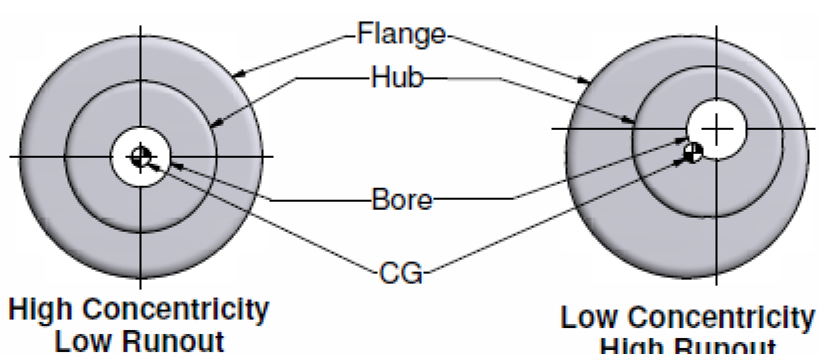


Fig 3

Generally speaking, a part with a low bore-to-outside diameter run-out is defined as having good concentricity, which is one of the key requirements to achieving a high level of balance. When the bore is not in the geometric center of the coupling hub, the center of gravity is shifted off the center of rotation. That is, the mass of the coupling is shifted away from its rotational center. This is unbalance. In a coupling this shift may be caused by many factors. For instance, the density of the part may vary from section to section, as can be the case with a cast iron material. The flow of the molten metal or the cooling rate may change the density of the metal in the completed casting, voids or porosity associated with the casting process may also introduce variation in density. The rotational center of the part will also be shifted due to clearance between the hub bore and the shaft. In a coupling, excessive unbalance may cause vibration, noise, poor life and/or high fatigue stresses to the various components of the drive.

1.4 What is Center of Gravity? What is Concentricity?

In more technical terms, the unbalance is caused by centrifugal force acting upon each particle in the coupling. "Centrifugal force is an apparent force tending to pull a thing outward when it is rotating around a center." (Webster's New World Dictionary) Each particle is pulled from the center of the rotating part. If, for every particle on one side of the part, there is an equal particle directly opposite it, the two centrifugal forces cancel out.

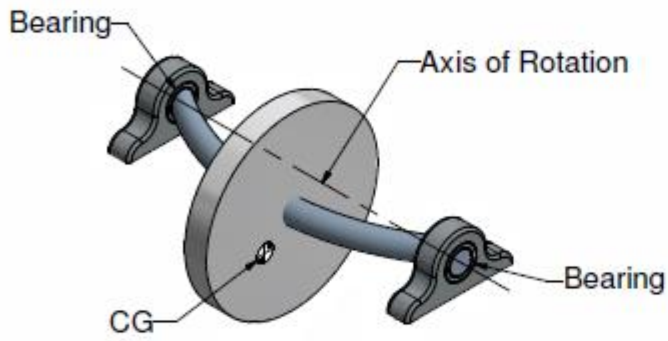
Centrifugal force is the force you feel when you are riding a merry-go-round. When the merry-go-round first starts, you feel a slight force pulling you out from the center. You represent that particle being pulled out. Your center of gravity is not located at the center of rotation. As the speed increases, you feel a greater pull and you find it more difficult to stand straight. In an effort to create a counter acting force so you can remain on the merry-go-round, you lean inward.

If you stood at the center of the merry-go-round, you would no longer feel that outward pulling force, regardless of the speed, because your center of gravity would be located on the rotational center. Thus, centrifugal force is dependent upon the mass of the object, the rotational speed and the distance between the center of gravity of the object and the geometric center of rotation of the rotating object

Mathematically it is found that the unbalance or, more properly, the centrifugal force varies with the square of the speed. That is, if you double the speed of rotation, the force will increase four times. If you triple the speed of rotation, the force will increase nine times!

The force also increases directly with the mass and distance between the center of gravity of the part and the rotational centerline. If you double the mass of the unbalance or the distance, the force will double. In summary, applying these principles to rotating couplings, the greatest influence on coupling balance is its rotating speed, with lesser unbalance contributions from mass and distance between mass and rotational center.

In the rotating equipment context, centrifugal force or the pull that is felt by the shafting and bearings (Fig 4) is in the form of potentially damaging vibration



Deflection Due to Centrifugal Force

Fig 4

1.5 Types of Balancing

It has been shown that all manufactured objects which rotate do have unbalance. The application determines if corrective balancing is needed. The weight and concentricity of the object or coupling can affect its balance, but as discussed above, the greatest single influence is the rotating speed of the connected equipment and coupling.

Several standards and industrial organizations such as, American Gear Manufactures Association (AGMA) or International Organization for Standardization (ISO) give guidelines for determining when speed or weight becomes significant and corrective balance is required. Once it is determined that balancing is needed, the allowable unbalance value or class may be determined.

Many industries specify balancing and as a result, several different terms are used for the two types of balancing. The terms used in this informational bulletin are those used by all members of MPTA and use of them will eliminate any miscommunication between user and manufacturer. There is significant difference between the two types of balancing and their respective costs, therefore, it is very important to use those terms which clearly define what is needed (Table 1).

Preferred Term	Non-Preferred Terms
Single-Plane	Static Balance
Two-Plane	Couple or Dynamic Balance

Table 1

Static Balance is an easily misunderstood term and should be avoided when describing single-plane balancing. Most often, balancing is done by rotating the coupling in a balance machine and the resulting centrifugal force is measured. As the part is in motion, the term Static Balance should be avoided; the term single-plane balancing is preferred to avoid misunderstanding. In addition, the terms Couple or Dynamic Balance can also be misinterpreted and should likewise be avoided

1.5.1 Single Plane Balancing

Single-plane balancing is best represented by visualizing a disk placed on a shaft rotated to a specific speed. If the disk were to have a hole cut out of it, it would be out of balance because the hole would shift the center of gravity off the center of rotation (Fig 5). This unbalance can be thought of as a weightless rod connected at one end to a shaft and having a large iron ball equal in weight to the amount of unbalance, at the other end. The unbalanced weight (mass) rotates in a single plane of rotation.

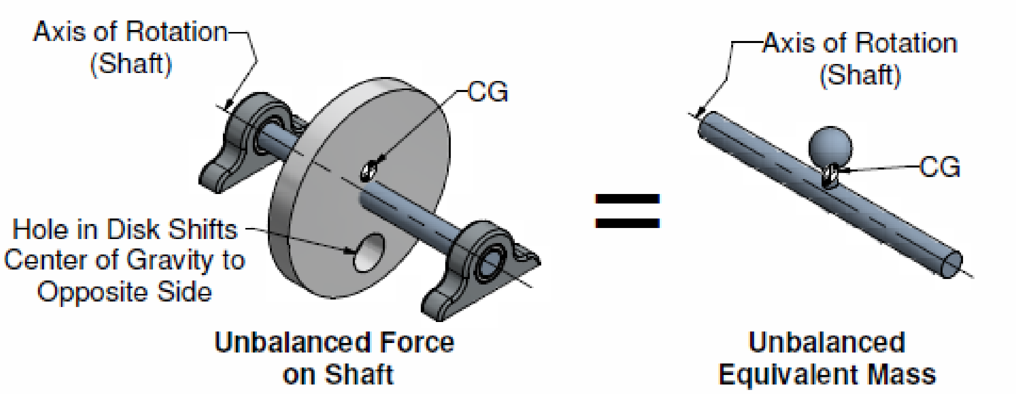


Fig 5

As the weight rotates it causes the shaft to deflect due to the centrifugal force of the ball. To correct this pull (centrifugal force), a counter weight is located exactly opposite the unbalance (Fig 6). The product of the added weight and its distance from the center of rotation must be equal and opposite to the product of the unbalanced weight and its distance from the center of rotation. When these conditions are met, the pull of each weight will cancel out the two centrifugal forces. This is called single-plane balancing. To correct for this, general practice is to add or remove mass to cancel the unbalanced pull.

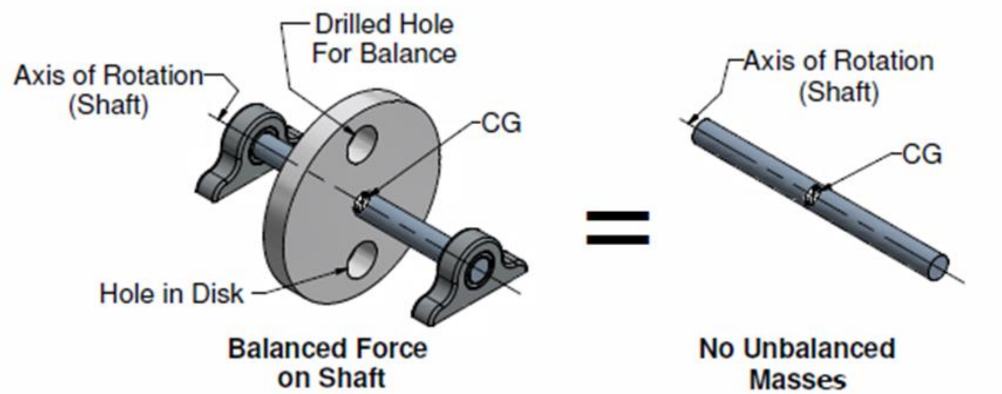


Fig 6

1.5.2 Two-Plane Balancing

Two-plane balancing is a process where balance corrections are made at two locations or planes on the coupling rotational axis. These locations must be well separated to effectively produce a two-plane balance. This separation makes part length a prime factor in determining whether single-plane or two-plane balancing is required. Generally, the longer a coupling or component is relative to its diameter, the greater the possible need for two-plane balancing. Because some manufacturers recommend any part longer than 6 inches while others use a diameter to length ratio, it is recommended that the reader contact the manufacturer to determine when two-plane balancing is required.

In two-plane balancing, the unbalanced particles or masses do not lie within a single plane; instead they are spread along the length of the coupling. For example, a coupling consisting of two elements and a floating shaft could be represented as a shaft with two disks (Fig. 7). If both disks are perfectly uniform, then each of their centers of gravity would be located on the center of rotation. They will therefore spin without vibration and will be in balance.

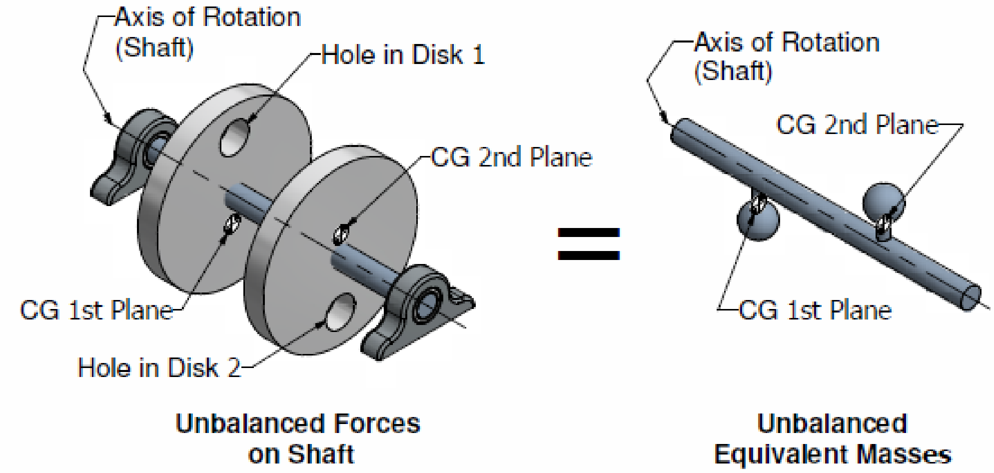


Fig 7

As in the case of single-plane balancing, if each disk has a hole in it, each disk will be out of balance and vibrate as it rotates. If checked for single-plane balance, they would appear to be in balance, but will "rock" the entire assembly as a result of two-plane unbalance. Once again we will represent an equivalent system using a rod and iron ball on each end of the shaft. When they are rotated, not only does the weight cause a pull on the first rod, but because there are two rods, each pulling at each end of the shaft, the rotating shaft also vibrates. The unbalance is located in two planes (each rotating mass forms a plane) in this case. The result is that the coupling will vibrate both the drive and driven components with resultant bearing and seal wear and damage.

In two-plane balancing, each component is balanced and the center shaft does not vibrate (Fig 8). If the two disks (planes) are very close together, the unbalanced effect is lessened. Thus, in two-plane balancing, the mass of unbalance, its location from the center of rotation, the speed (RPM), and the distance between unbalance planes along the axial length affect the amount of unbalance

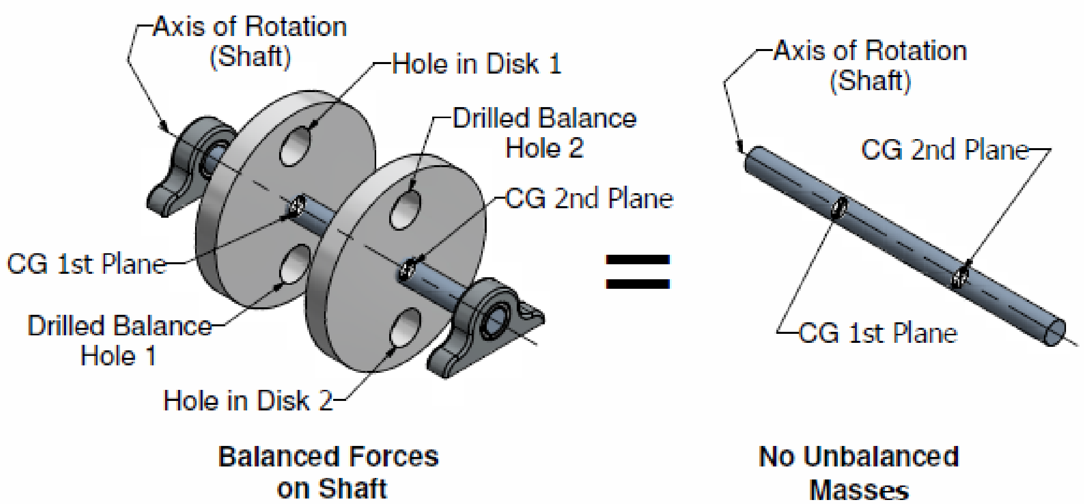


Fig 8

The type of balancing, single-plane or two-plane is usually determined by the axial length of the coupling or a length/diameter ratio. For specific balance recommendations, contact the coupling manufacturer

1.6 Balancing Couplings

"The center of gravity is that point in a body or system around which it’s mass or weight is evenly distributed or balanced and through which the force of gravity acts." (Webster‘s New World Dictionary) In this definition, the coupling "body" may be the hub or other component. The "system" would include the entire coupling with all of its components. Ideally, the center point would lie on the axis of the shaft which is the geometric center of the shaft. In the washer illustration, the center of rotation is in the center of the drum and the center of gravity is located towards the group of clothes. When you spread the clothes around the drum, you shift the center of gravity of the clothes to more closely coincide with the center of the drum (the axis of rotation of the drum). If the center of gravity of a rotating body exactly coincides with the axis of rotation of the shaft upon which it is mounted, the part is in perfect balance (Fig 2).

It is generally not practical or required to balance elastomeric couplings. As manufactured for their applications, they are within most balancing requirements. This is due in part to the materials used for the elements; the elastomeric nature of the material, its low density (weight per cubic inch), its low mass and the generally lower published speed ratings.

2 Balancing Application

2.1 Balancing Standards

There are two balancing standards used in the coupling industry. They are the International Organization for Standardization (ISO) and the American Gear Manufactures Association (AGMA) standards. The AGMA standard was adopted by the American National Standards Institute (ANSI) in 1990 and bears both the ANSI and AGMA designation.

The ISO standard, ISO 1940/1-2003, makes recommendations concerning the balance quality of rotating rigid bodies particularly as it relates to the permissible residual unbalance as a function of the maximum service speed. This standard is designed for any rotating rigid body. The ISO standard reflects usage principally in metric systems. The primary emphasis in this standard is upon integral single components. For assemblies, it requires that "the unbalances of the component parts shall be added vectorially and any unbalances resulting from inaccuracies of assembly shall be taken into account, particular attention being paid to the fact that the parts may be assembled later in a different position from that in the balancing machine." All values given by this standard are based upon residual unbalance. This standard incorporates recommended ISO balance grade values ranging from G4000 to G0.4 (mm/sec) for rotating components; the lower the number the better the degree of balance. The ISO system (ISO 1940/1) bases its balance value upon three prime factors:

1. Mass (weight)
2. Rotating speed (rpm)
3. Permissible unbalance (ISO grade)

This standard primarily covers single-plane and two-plane balancing for individual components. This standard is widely used in Europe and sees use in the United States.

The AGMA standard, ANSI/AGMA 9000-D11, describes potential coupling unbalance, defines the requirements, and outlines how to calculate the potential unbalance of the coupling (Abstract of the Standard). Its method relates directly to flexible couplings, including assemblies (Section 1.1 of the Standard). For balancing of individual components (hubs etc.) the AGMA standard refers back to the ISO 1940/1 standard for residual unbalance selection. For assembled couplings the AGMA standard considers the balancing fixture inaccuracies and the changes which can occur when the coupling is disassembled and reassembled. Thus, the AGMA standard is much more inclusive for assemblies. In addition to those prime factors used by the ISO, a new term, maximum potential displacement is employed. The maximum potential displacement is the linear distance between the axis of rotation and the center of mass (gravity) that is present in the assembly that creates unbalance (Fig 9).

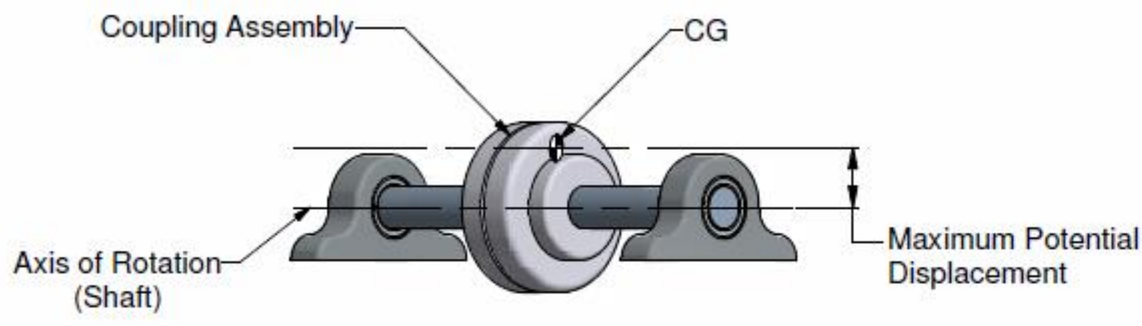


Fig 9

The AGMA standard specifies the unbalance in terms of Coupling Balance Class ranging from 4 to 11 based upon maximum potential displacement; the higher the number the greater the degree of balance. It is a very thorough standard, covering single-plane and two-plane balancing. It allows the user to determine the potential unbalance of the coupling. The AGMA standard is very popular in the United States.

Both standards can be very helpful in determining the permissible unbalance which a user can tolerate. Prior to these standards, the coupling industry informally used a permissible unbalance of 0.1 oz-in per plane as a standard. On occasion, this value is still used.

The use of standards allows the coupling user and the manufacturer to "talk" on common ground. It is suggested that wherever possible the balance grades/classes be expressed in one of the standard systems. For greatest economy, choose a standard class or value for the permissible unbalance. Most manufactures do production balancing based upon standard numbers, for example ISO grade 16 or AGMA Class 6. These are based upon current usage and industry practices. For the best value, the user should consult the standards for recommended balance grades and discuss it with the manufacturer. This will minimize confusion and cost for everyone. If a coupling user has any questions, he should feel free to contact the manufacturer of the system or the coupling for further help and information.

2.2 Units of Balance

The following is a list of the most commonly encountered units in reference to unbalance (Table 2).

Units	English	Metric
Weight	Ounces (oz)	Gram (g)
	Pounds (lbs)	Kilogram (kg)
Unbalance	oz·in	Gram-millimeters (g·mm)
Eccentricity or Concentricity	Inches (in)	Millimeters (mm)
ISO grade balance quality	in/sec	mm/sec
AGMA maximum potential displacement	Micro inches	-------------
Rotating Speed	RPM	RPM

Table 2

2.3 Potential vs. Residual Unbalance

The term potential and residual unbalance has been mentioned in this informational bulletin. A proper understanding of these terms will prevent any misunderstanding between the user and the manufacturer of the coupling. Reference the definitions on page 4.

It is important to understand the differences in the definitions. When a component or a coupling is balanced on a balancing machine, the unbalance is corrected by the removal or addition of material while the coupling is still on the machine. After correction, the unbalance is again measured. If the amount of unbalance is within the balance tolerance zone (defined as the permissible residual unbalance) the piece is removed from the machine and delivered to the user. The user then mounts it on their application; because they have mounted it on a different shaft, with different shaft tolerances and/or clearances than the way it was mounted on the factory balance machine, the permitted unbalanced mass is relocated. The coupling now affects the total system in a slightly different fashion than it affected the factory balance machine. This new unbalance or rather the affect of the unbalance is defined as the potential unbalance of the coupling. If the coupling could be mounted on the total system in an identical manner and position as it was on the factory balance machine, the residual and potential unbalance would be equivalent.

2.4 System Sensitivity

In selecting a balance grade or value for a coupling, it is very helpful for the user to understand what makes a coupling system sensitive to unbalance. Significant numbers of couplings leave the factories every day in the inherent unbalance state.

This inherent unbalance state is more than sufficient for most applications. In applications requiring balancing, it is the purchaser‘s responsibility to specify the grade, Class or value of balance. The purchaser may seek help from the coupling supplier; however, since the needs are determined by the characteristics of the specifically connected machine, they are best determined by the manufacturer of the machine. The following are some suggested System Sensitivity Factors to aid in this determination per (ASTM) and defined on page 4;

- Shaft End Deflection
- Coupling Weight Relative to Bearing Load
- System Natural Frequncies
- Machine Separation
- System Extension Relative to Bearing Span

For further information please contact your equipment or coupling supplier.

3 Summary

The most economical balance specification is one where a standard is used and the balance level chosen is commonly accepted.

The economical specification should ask for no better balance than is required for the system.

If the coupling user wishes to use unique values or Grade/Class of balance outside normal practices, the costs will likely increase.

If a product does not require two-plane balancing, specification of two-plane balancing is wasted effort and expense. Therefore, it is very important that the coupling purchaser give careful consideration to the balance level needed and effectively communicate it to the manufacturer.

4 Bibliography

American National Standard Flexible Couplings - Potential Unbalance Classification, ANSI/AGMA 9000C90 (American Gear Manufacturers Association)
International Standard Mechanical Vibration - Balance Quality Requirements of Rigid Rotors ISO 1940/11986 (International Organization for Standardization)
Webster‘s New World Dictionary (World Publishing Company, NY)

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