# MECHANICAL POWER TRANSMISSION ASSOCIATION

## Elastomeric Coupling Division
## Technical Information Bulletin

# BALANCING PRIMER

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## INTRODUCTION

**Many users of elastomeric couplings are being presented with the need for increased balancing. This subject is mentioned in trade articles, trade shows, seminars, by consultants and engineering schools. The reason often given for increased coupling balance is noise, shaft and bearing wear, and vibration. Many of the proponents of tighter balancing, speak of values of balance which can significantly increase the product cost and may produce no observable benefit to the application. All manufactured couplings have balance to some value or class. The amount of balance required varies from application to application. This is a result of the fact that every coupling is but one component of a rotating system of many components manufactured by several manufactures. It is often the characteristics of these other components which determine the amount of required coupling balance. Very often, the user of couplings specifies a value of balance based upon a source which has no knowledge of their unique system. The risk is that the value of balance specified may be beyond the user's application needs. Because the responsibility for the selection of proper coupling balance lies primarily with the purchaser of the coupling, this "primer" was written to aid that user in determining the value or class of balance needed in their own unique application.**

**This "primer" is divided into two sections. Section I 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.**

**Section II 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 a significant cost due to over specification.**

# INDEX

## SECTION I FUNDAMENTALS OF 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 II.

Every rotating object has balance or more properly, some degree of unbalance. It is financially prohibitive to have a rotating object 100% in balance. The original design of a coupling is such, that it is 100% balanced. Some unbalance, however small, results from the manufacture of the coupling. Machined parts more closely match the original design balance, while cast parts, due to the casting process of metal, are inherently less balanced. 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 must understand what is meant by unbalance before he knows what amount his application can allow.

### WHAT IS UNBALANCE?

Anyone who has ever used a clothes washer 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.

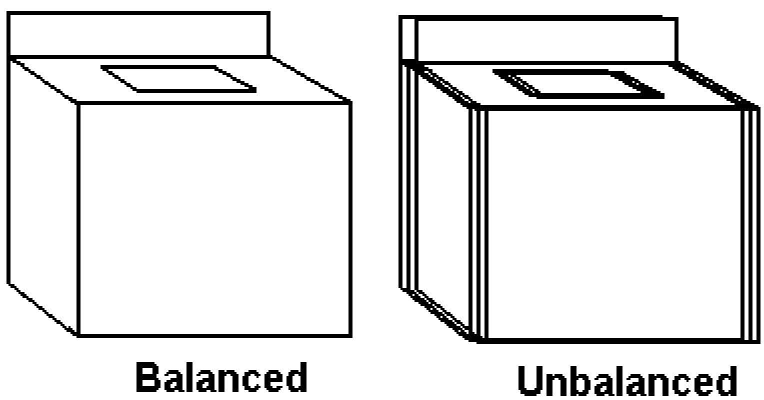


Figure 1

The adding or removing of material shifts the center of gravity of the coupling.

*"The center of gravity is that point in a body or system around which its mass or weight is evenly distributed or balanced and through which the force of gravity acts." (Webster's New World Dictionary)*

In the above 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 in the center of the group of clothes. When you spread the clothes around the drum, you alter 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 absolute balance. (See Figure 3)

Coupling manufacturers optimize the balance of their products by specifying close dimensional tolerances. Even the best of machining practices will allow 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 the coupling. This is called the concentricity of the bore to the coupling (shown in Figure 2).

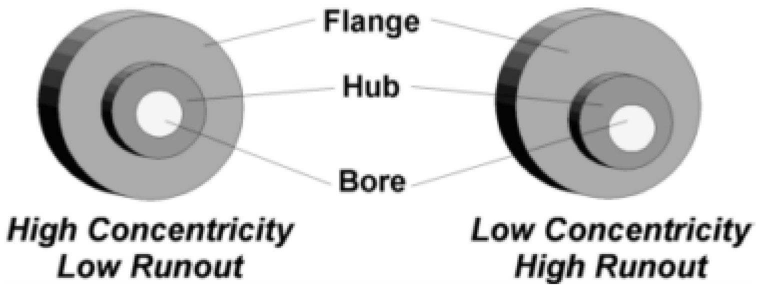


Figure 2

The higher the concentricity (low or minimum runout), the closer the coupling will be to a balanced condition. When the bore is not in the geometric center of the coupling, the center of gravity is shifted off the center of rotation. That is, the material or mass of the coupling is shifted away from its geometric center. This is unbalance. In a coupling this shift is due to many factors. For instance, the density of the part may vary from section to section, as in a gray iron casting. The flow of the molten metal or the cooling rate may change the density of the metal in the completed casting. The mass shift may also be due to the clearance between the hub bore and the shaft, allowing the hub to be mounted off-center. In a coupling, excessive unbalance may cause vibration, noise, poor life and/or high fatigue stresses to the various components of the drive.

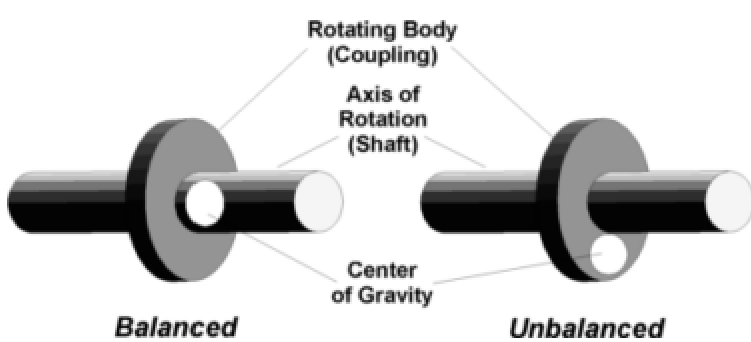


Figure 3

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, their 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. To correct, you lean inward, thereby moving your own center of gravity closer to the center of rotation. If the speed becomes too high, you are thrown off the merry-go-round. This force pulling you off, is centrifugal force.

If you stood at the very center of the merry-go-round, you would not have difficulty regardless of speed (you would still get dizzy though) because your center of gravity would be located on the geometric center of rotation. Thus, the effect and strength of centrifugal force is dependent upon rotational speed (RPM) and distance between the center of gravity and the geometric center of rotation and the mass or weight.

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

The force also, increases directly with weight. If you double the weight of the unbalance, you will find that the force will double. Because of this, the greatest influence on coupling balance is its rotating speed, though weight and/or distance are significant.

In a coupling, centrifugal force or the pull is felt by the shaft and bearings (shown in Figure 4) in the form of vibration. If the vibration is too large, damage will result to various components of the drive train.

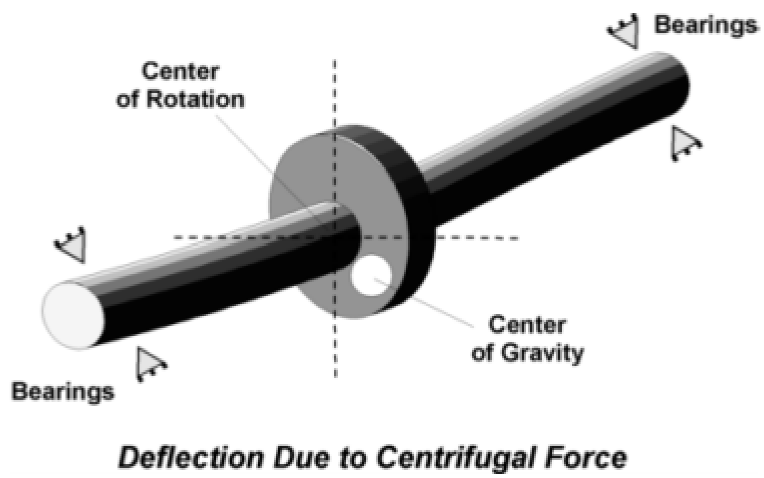


Figure 4

**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, that the greatest single influence is the rotating speed of coupling.

Several standards and industrial organizations (for example, American Gear Manufactures Association, International Organization for Standardization (ISO), DIN) 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 must 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 primer 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.

| Preferred Term | Non-Preferred Terms |
|---|---|
| SINGLE PLANE | STATIC BALANCE |
| TWO PLANE | COUPLE or DYNAMIC BALANCE |

Figure 5

Static Balance is an easily misunderstood term and should be avoided when describing Single-Plane Balancing. Often balancing is done by rotating the coupling in a balancing machine at a specific speed (RPM). Thus, there is little static about single-plane balancing of couplings. The part is rotated and the effect of centrifugal force is measured, thereby determining the unbalance amount and location. This value is called the residual unbalance of the coupling (Section II explains the significance of this value). Without rotating the part, the centrifugal force cannot be easily measured. (Other methods are used, but this is the most representative.)

Because most coupling balancing is done by rotating the part, the term Static Balance should be avoided. Instead, the term Single-Plane Balance should be used to avoid confusion or mis-understanding. Further, since the term Dynamic Balance could be readily confused with Single-Plane Balancing due to the motion involved, it should not be used.

**SINGLE PLANE BALANCING**

Single-Plane Balancing is best represented by thinking of a disk which is placed on a machine and rotated to a specific speed. If the disk were to have a hole located off the geometric center, it would be out of balance because the hole would shift the center of gravity off the center of rotation (see Figure 6). 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.

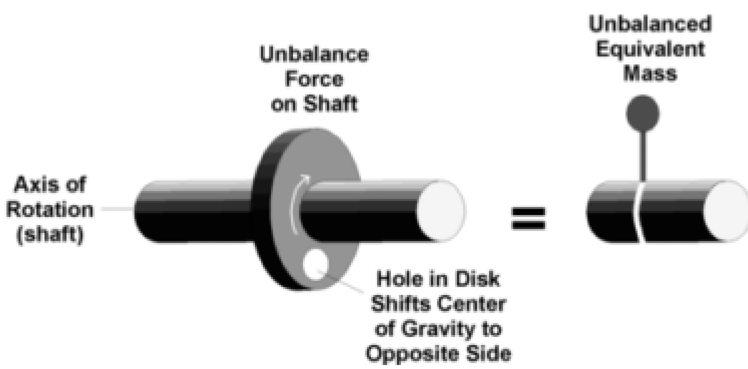


Figure 6

As the weight rotates it causes the shaft to feel the pull due to the centrifugal force of the ball. To correct this pull (centrifugal force), a counter weight is located exactly opposite the unbalance (see Figure 7). 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 balance each other and cancel out the two centrifugal forces. This is called single-plane balancing. In an actual coupling, material is either added or removed to equal the unbalanced pull.

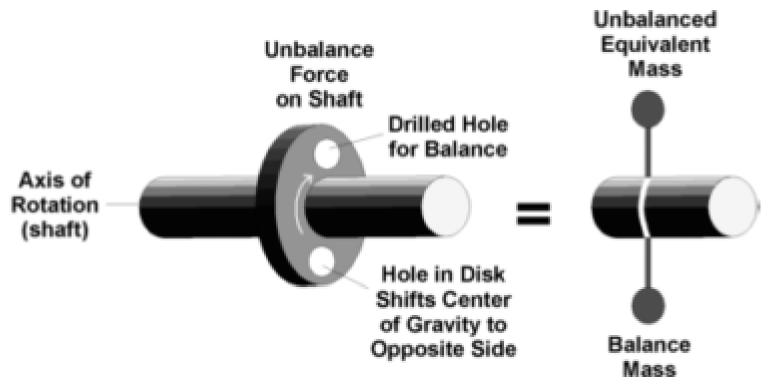


Figure 7

**TWO PLANE BALANCING**

Two-plane balancing is an operation where balance corrections are made at two locations or planes on the coupling 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" or some 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 narrow 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 two disks spaced on a shaft with each disk rotating (see Figure 8). 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 with no vibration and will be in balance.

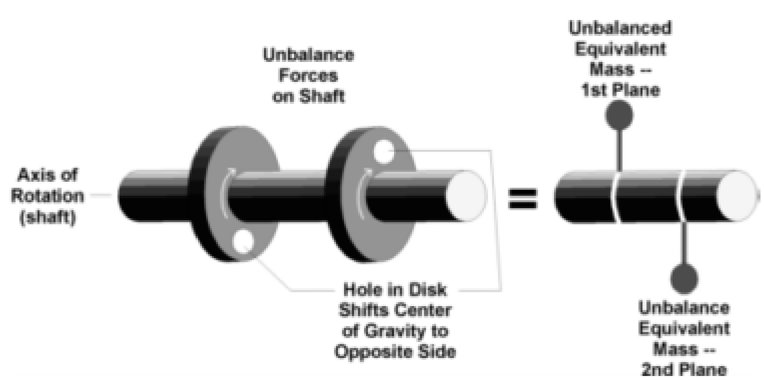


Figure 8

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. Only when the balance along the length of the coupling is considered, would the true unbalance be seen. The holes may actually be different sizes, in which case the forces will pull unequally and not only pull the shaft, but will "rock" the entire assembly lengthwise. 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 wear and damage.

In two-plane balancing, each component is balanced and the center shaft does not vibrate (see Figure 9). If the two hubs (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 along the axial length affect the amount of unbalance. It should be noted, that it is the length of the coupling or component and not the number of parts which creates the need for two-plane balancing. The weight causing the unbalance is not necessarily due to the different components as much as the varying density within a part or component.

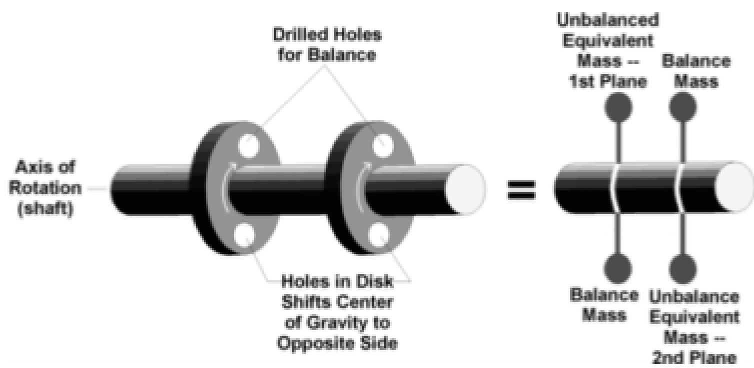


Figure 9

The type of balancing, single-plane or two-plane, is usually determined by the axial length of the coupling. For specific length guidelines, contact the coupling manufacturer.

**BALANCING COUPLINGS**

In requesting balance for a coupling, the user must determine the speed of the application and the sensitivity of the system to unbalance. Further, the complexity of the coupling and system will determine the need for specifying residual versus potential unbalance (see Section II for an explanation of these terms). The coupling manufacture should specify the residual unbalance of the components to obtain the desired potential unbalance of the coupling. Consideration must be given to service replacement of components of a coupling in determining balancing need.

In an elastomeric coupling it is not practical to balance the elastomeric element. As manufactured, it is well 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. Because of these, the centrifugal force produced will be lower than a comparable metal part and as such may usually be neglected.

Finally, it must be remembered that many couplings are sufficiently in balance by design and manufacture, thus no further balance correction is needed for many applications.

# SECTION II – ADVANCED BALANCING INFORMATION

## BALANCING STANDARDS

There are two prime 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 1940/1-1986 (E), 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."1 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, with 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, e x w)

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-C90, "describes potential coupling unbalance and identifies its sources. The standard breaks down the requirements into usable groups 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 may occur in the product, thereby producing unbalance.

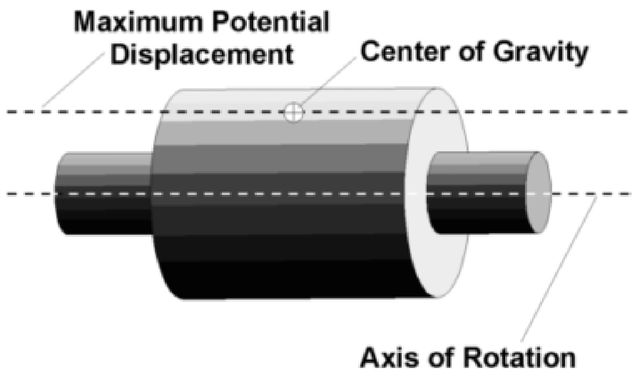


Figure 10

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 one-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 have. Prior to these standards, the coupling industry informally used a permissible unbalance of 0.1 oz-in per plane as a standard. Often this value is still used.

The use of standards allows the coupling user and the manufacture 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 6. These are based upon current usage and industry practices. They were selected so that they balance functionality with economy. If the user were to specify a value of ISO 15 or AGMA 6.5, the product cost would increase due to the special nature of the grade while the product performance would improve insignificantly. For greatest economy 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 equipment or the coupling for further help and information.

**UNITS OF BALANCE**

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

| Units | English | Metric |
|---|---|---|
| Weight | OUNCES (OZ) | GRAM |
| | POUNDS (LBS) | KILOGRAM |
| Unbalance | OZ - IN | GRAM - 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 |

Figure 11

## POTENTIAL versus RESIDUAL UNBALANCE

The term potential and residual unbalance has been mentioned many times in this primer. A proper understanding of these terms will prevent any misunderstanding between the user and the manufacturer of the coupling .

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

*"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." (AGMA)*

It is important to understand the differences in the above 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 bolt 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 the same value. The likelihood of such a condition is small. Thus, the potential unbalance will always be a greater value than the residual unbalance. Therefore, the end user should specify the potential unbalance whenever possible and the vendor will calculate the residual unbalance needed to allow for assembly variation at the end user's location. The value of the residual unbalance is chosen in such a way as to anticipate final assembly variations and still maintain the planned balance.

If the item being balanced is a single piece, such as a hub, the residual and potential unbalance values are almost identical. Thus, the significance of residual and potential is greatest in couplings consisting of several components.

For a good discussion of the various balancing terms used by the industry please refer to Section 2 of the AGMA standard.

## SYSTEM SENSITIVITY

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

*"Inherent Unbalance - is the value of unbalance of a product as it leaves the manufacturing floor prior to shipping or balancing on a balance machine." (AGMA)*

This inherent balance 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. The purchaser may seek help from the coupling supplier, however, since the needs are determined by the characteristics of the specifically connected machines and their supporting structure, they are best determined by the manufacturers of those machines. Additionally, the following gives some suggested System Sensitivity Factors to aid in this determination.

**System Sensitivity Factors (ASTM)**

SHAFT END DEFLECTION - Machines having flexible shaft extensions that produce large deflections are relatively sensitive.

BEARING LOAD DUE TO COUPLING WEIGHT RELATIVE TO TOTAL BEARING LOAD - 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).

SYSTEM NATURAL FREQUENCIES - Machines or systems operating near the natural frequencies of rotor or support systems are sensitive.

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

SHAFT EXTENSION RELATIVE TO BEARING SPAN - Machines having a short bearing span relative to their shaft extensions are sensitive.

For further information or help do not hesitate to contact your elastomeric coupling supplier.

## SUMMARY

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

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

If the coupling user wishes to use unique values or grades/class beyond typical usage, the cost of the product will 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.

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