fact sheet

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BALANCE - WHEN AND WHY

INTRODUCTION

The main purpose of this discussion is to provide a working background as to the basic considerations on balancing and the criteria to be used in its application. The amount of unbalance will manifest itself by producing a vibration response.

Machinery vibration is the largest single contributor to equipment breakdown. As such, it is a needless cost in both equipment spares and production losses.

Many original equipment manufacturers as well as the ultimate users have recognized the relationship between vibration and equipment performance. To build quality into their product, many manufacturers have taken the first step of balancing. It then becomes the responsibility of the user to maintain his equipment in order to achieve optimum performance goals and be cost effective. When dealing with rotating equipment, it is necessary to have a basic understanding of the origins of vibration. With this understanding will come the recognition of the means to reduce the source.

SOURCES OF VIBRATION

Vibration is not a mystical phenomenon. There are reasons for vibration, most of which are readily apparent. The most common source by far is unbalance. The causes for unbalance or "heavy spots" are many. For practical purposes, an element as used herein can be a motor armature, roll, fan, pump impeller, grinding wheel, turbine rotor, to name a few.

Some of the sources are:

A. Inconsistency in material - some of the most common causes are porosity in plate material and blowholes in castings.

B. Journal Centers (bearing journals) - machined with the center of gravity displaced from the true journal center.

C. Lack of Symmetry in the Product - due to limitations in the design and manufacturing process. Machine fixtures for lathes and other adaptors are prime sources for unbalance.

D. Dimensional difference of mating parts, for instance a shaft with a diameter that is thousandths of an inch smaller than a corresponding bore of the rotor to be mounted. Mounting with point to point contact different than when balanced, creates a new unbalance.

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E. Bent shafts - which locate the rotor off center from the axis of rotation.

F. Machining "errors" - for example, a rotating element may be mounted in the lathe for machining its outside diameter but its journal centers are both displaced in the same direction from the center by a few thousandths of an inch. This results in more material being removed from one side of the diameter - along its total length - than from its other side. The few thousandths of an inch removed, multiplied by the total length of the element can result in several pounds of unbalance.

Considering the outside diameter relative to its centers, the element could be cocked. Therefore, at one end, more material would be removed; for example, from the topside, whereas from the other end more material would be removed from the bottom-side. Assuming the lathe is cutting straight, a curved wedge of metal is removed from opposite ends - 180° opposite each other, resulting in a very large "couple" unbalance.

G. Assembly errors - referred to as "assembly errors" is not the stacking of tolerances, but the relative placement of each part's center of gravity. A balanced element can be mounted on a balanced shaft and together there is a resultant high unbalance. This can happen due to alignment during assembly, shifting of masses after assembly and other factors.

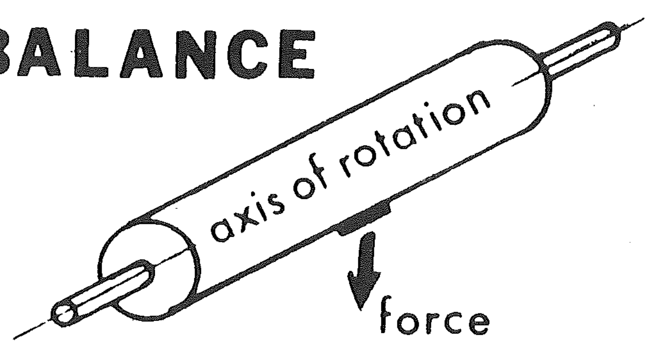
TYPES OF UNBALANCE

Unbalance has been shown to develop from various manufacturing, metallurgical and assembly conditions. Unbalance can be broken down into two basic types, static and dynamic. For the purpose of this standard, any type of unbalance can be categorized in one of these classifications:

Static unbalance - is a condition where the only force acting on the element is gravity.

FIGURE 1

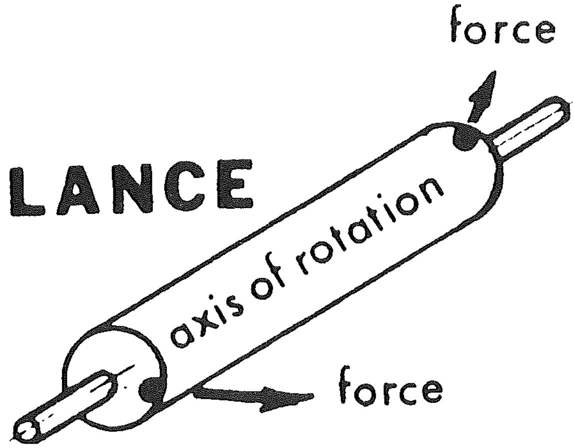
STATIC UNBALANCE



Dynamic unbalance - is a condition where the element rotating at its design speed will cause a centrifugal force that tends to displace the mass center of gravity and results in a vibration.

FIGURE 2

DYNAMIC UNBALANCE



Static unbalance can usually be detected by using a conventional gravity type knife edge balancing method, while dynamic unbalance necessitates the use of special balance machines requiring special skills and experience to accomplish a satisfactory balance condition.

VIBRATION DUE TO UNBALANCE

As noted earlier, most rotating equipment will produce a vibration. The frequency content of that vibration is dependent on all aspects of the system (the rotating element, the structure, the bearings, the coupling).

When the operating speed is increased, a corresponding increase in the vibration level will occur. The increase is many times the amount anticipated since the centrifugal force due to the unbalance varies as the square of the speed increases. Doubling the mass of the unbalance or radius will double the centrifugal force.

A close look at the following will aid in understanding the above statements.

$$F = \frac{W}{g} \times \omega^2 \times r$$

Where F = Centrifugal force in pounds

W = Unbalance weight in pounds

g = Gravitational constant 32.17 ft/sec^2

r = Radius in feet

ω = Omega-rotational speed in radians/sec = $\frac{\pi n}{30}$

The above reduced to an easier form is:

$$F = .00034 \, (W \times n^2 \times r) \text{ where } n = RPM$$

A cursory look shows that n (RPM) is to be squared; therefore, if you double the RPM, i.e. from 500 to 1000, the value of n^2, as well as F, quadrupled.

WHEN, AND TO WHAT TOLERANCE SHOULD YOU BALANCE

There are no hard and fast rules that can be used to determine when to balance. However, some basic "rules of thumb" can be established to serve as guidelines.

They are as follows:

a. Elements operating at speeds in excess of 180 RPM
b. Elements with outer diameters of five inches or greater
c. Elements that must operate near their critical speed (resonance).
d. Elements that in operation must maintain a specific space relationship with other parts.

At a minimum, any element that will be rotated should be statically balanced. If the speed of rotation is to exceed 180 RPM, then dynamic balancing should be considered. In fact, Military Standard 167B states that dynamic balancing should be performed over 150 RPM. The degree to which an element must be balanced can best be determined by considering the basic parameters of speed, weight and physical size. If the speed is low (less than 180 RPM), the weight small and the O.D. narrow (less than 5") only a static balance need be considered.

For elements operating at high speeds (greater than 180 RPM) and an O.D. greater than 5 inches, a dynamic balance must be achieved. Figure 3 (reference - theory of balancing - published by Schenck Trebel) is a nomograph that can be used to obtain a precision balance tolerance for each element. The column on the left is operating speed, while the column on the right is the weight of the element. It should be noted that the two parameters required to achieve a precision balance are contained in the formula presented above. A precision tolerance is used to minimize the vibration and to give a longer trouble-free operating life for the element and its companion systems.

As a matter of practicality and cost, there is little difference in the trouble or cost to achieve a precision balance over commercial (tolerances approximately 2.5 times closer). The difference in operating performance and quality reflection is significantly better using precision specifications.

OTHER CONSIDERATIONS

We have discussed many aspects of the parameter that should be used when specifying the balance requirements. There are several other factors that will influence the complexity of achieving the desired tolerance. These must be considered early since they will substantially influence the design and balance philosophy. The factor to be considered is - is the element rigid or flexible.

There are many terms used when discussing rigidity or flexibility. One of these that most have heard is "whip". These terms basically refer to the point or speed at which the element becomes flexible and whips much like a noodle. The point or speed at which this happens is called the "critical" speed.

The critical speed of the element is determined at the time of design. This critical will remain the same during the life of the element unless alterations are made to the design.

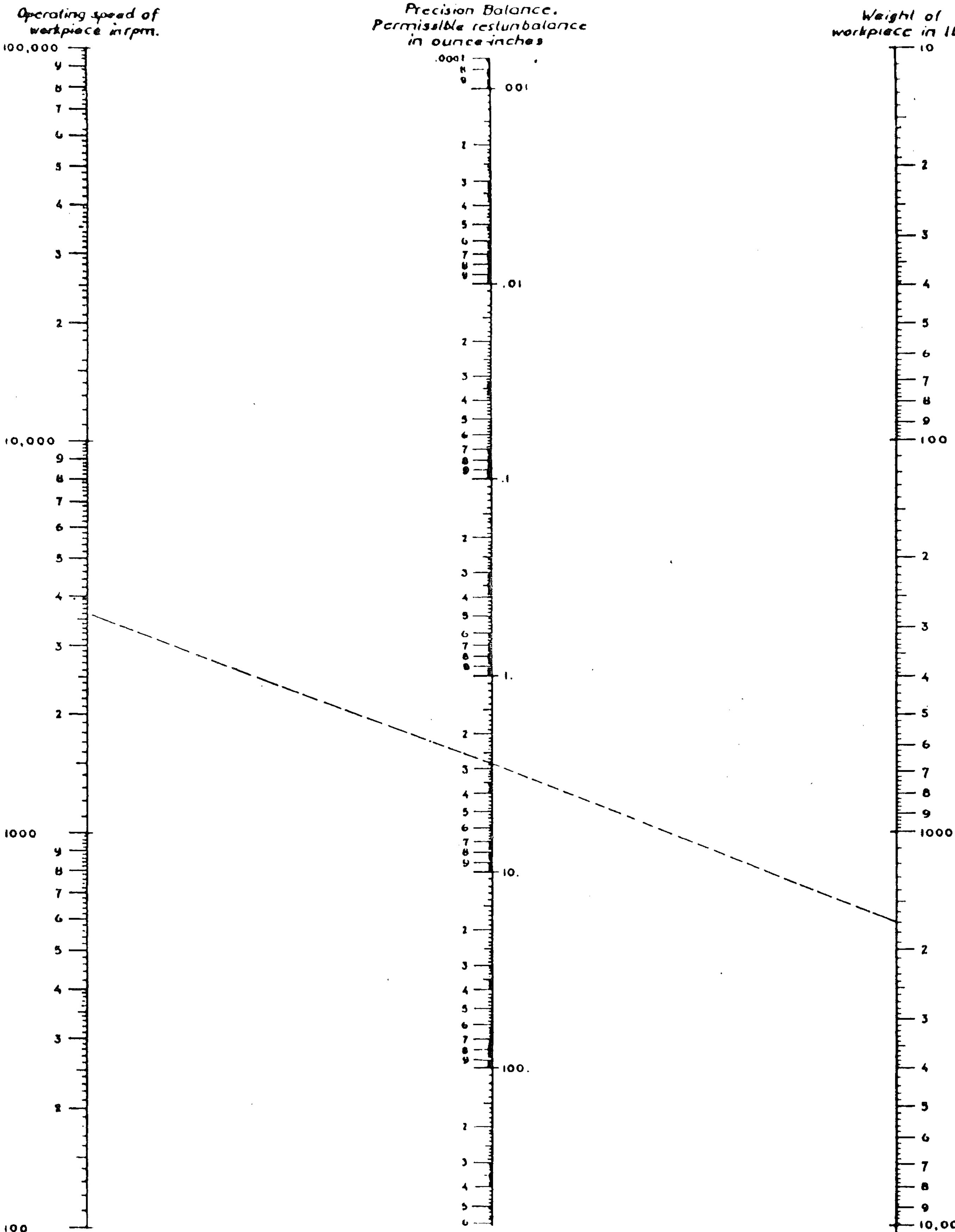
It is important to realize that all rotating elements have a speed where they become flexible. The term has become more important in recent years, however, due to the pressure on most manufacturing operations to achieve greater production.

Due to this objective, operations are speeded up. In some cases, the speeds are increased beyond the critical speed. When this happens, the characteristics of unbalance are different than when operating as a rigid body. Thus, the means of correcting an unbalance condition differ when an element is operating near its critical speed.

According to practical experience, one must take into consideration the flexibility of the element if its operational speed is to be 50 percent or more of its critical speed. The rotor behavior, as the two speeds approach being equal is dependent on the magnitude of the internal bending moment. In the area of its first critical, an element will deform in a V shape, near the second critical, it will approach an S shape and at the third critical it will approach a W shape . Each require a different correction technique and must be accounted for in the balance specification if satisfactory operation is to be anticipated.

LATER FACT SHEETS WILL GO INTO GREATER DETAIL ON RIGID AND FLEXIBLE ELEMENTS.

Nomogram for Balancing Tolerances



The permissible restunbalance refers to each of two correction planes in a workpiece to be corrected in two planes.

Example: A 1700 lbs steam turbine rotor operates at 3600 rpm Permissible restunbalance in each (of a total of two) correction planes 2.84 oz.-in.

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