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AHRI Guideline G-2016 (I-P)

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2016 Guideline for

Mechanical Balance of Impellers for Fans



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MECHANICAL BALANCE OF IMPELLERS FOR FANS

Section 1. Purpose

1.1 *Purpose.* The purpose of this document is to provide fundamental information and to guide the industry on Balance as applied to Impellers used in air moving systems. It includes terminology used and methods of Balancing practiced by the industry.

1.1.1 *Intent.* This document is intended for the guidance of component suppliers and equipment manufacturers.

1.1.2 *Review and Amendment.* This document is subject to review and amendment as technology advances.

Section 2. Scope

2.1 *Scope.* This document is intended to apply specifically to system vibration and mechanical Balancing as related to Impellers for Fans. The principles presented can however be generally applied to many rotating components (Rotors).

This document covers Impellers and propellers while fan systems are covered by Air Movement and Control Association International, Inc. (AMCA) Standard 204. For information on system vibration, see Appendix C.

Section 3. Definitions

All terms in this document will follow the standard industry definitions in the *ASHRAE Terminology* website (<https://www.ashrae.org/resources--publications/free-resources/ashrae-terminology>) unless otherwise defined in this section.

3.1 *Balance.* The unique and ideal condition of a Rotor when it has neither static nor dynamic Unbalance. Such a Rotor does not impart any vibratory force or motion to its Bearings as a result of centrifugal forces.

3.2 *Balancing.* A procedure by which the mass distribution of a Rotor is checked and, if necessary, adjusted in order to ensure that the vibration of the Journals and/or forces on the Bearings at a frequency corresponding to operating speed are within specified limits.

3.2.1 *Dynamic (Two-plane) Balancing.* A procedure by which the mass distribution of a Rigid Rotor is resolved into two planes and adjustments made by adding or removing mass in those planes in order to reduce the primary force and secondary force couple caused by the initial Unbalance.

3.2.2 *Static (Single-plane) Balancing.* A procedure by which the mass distribution of a Rigid Rotor is resolved into one plane and adjustments made by adding or removing mass in that plane only in order to reduce the initial Unbalance force.

3.3 *Balancing Machine.* A machine that provides a measure of the Unbalance in a Rotor which can be used for adjusting the mass distribution of that Rotor.

3.3.1 *Centrifugal (Rotational) Balancing Machine.* A Balancing Machine that provides for the support and rotation of a Rotor and for the measurement of once per revolution vibratory forces or motions due to Unbalance in the Rotor.

3.3.2 *Gravitational (Non-rotating) Balancing Machine.* A Balancing Machine that provides for the support of a Rigid Rotor under non-rotating conditions and provides information on the amount and angle of the static Unbalance.

3.3.3 *Dynamic (Two-plane) Balancing Machine.* A Centrifugal Balancing Machine that furnishes information for performing Two-plane Balancing.

3.3.4 *Static (Single-plane) Balancing Machine.* A Gravitational or Centrifugal Balancing Machine that provides information for accomplishing Single-plane Balancing.

Note: Dynamic (Two-plane) Balancing Machines can be used to accomplish Static (Single-plane) Balancing, but Static Machines cannot be used for Dynamic Balancing.

- 3.4** *Bearing.* A part which supports a Journal and in which the Journal rotates.
- 3.5** *Correction (Balancing) Plane.* A plane perpendicular to the Shaft Axis of a Rotor in which correction for Unbalance is made.
- 3.6** *Critical Speed.* The speed that corresponds to a Resonance Frequency of the Rotor when operating on its own Bearings and support structure.
- 3.7** *Fan.* A device that uses a power-driven rotating Impeller to move air.
- 3.8** *Field (Trim) Balancing.* The process of reducing the vibration level of a rotating assembly after all the rotating components, such as an Impeller or Propeller, motor armature or rotor assembly, or Bearings and pulleys, are assembled to their respective shaft(s). Such Balancing is employed to compensate for the vibrational effects of the tolerances of the drive components.
- 3.9** *Impeller.* The assembled rotating component of a Fan, designed to increase the energy level of the airstream.
- 3.10** *Journal.* The part of a Rotor which is in contact with or supported by a Bearing in which it revolves.
- 3.11** *Propeller.* A type of Impeller that produces a useful thrust of air in the direction parallel with the Shaft Axis.
- 3.12** *Resonance.* Resonance of a system in forced vibration exists when any change, however small, in the frequency of excitation (such as rotor speed) causes a decrease in the vibration amplitude.
- 3.13** *Resonance Frequency.* A frequency at which Resonance occurs in a given body or system or in a Rotor at Critical Speeds. This is often called natural frequency.
- 3.14** *Rotor.* A body, capable of rotation, generally with Journals which are supported by Bearings.
- 3.15** *Rigid Rotor.* A Rotor is considered rigid when it can be corrected in any two (arbitrarily selected) planes (refer to Section 3.5) and after that correction, its Unbalance does not significantly exceed the Balancing Tolerances (relative to the Shaft Axis) at any speed up to maximum operating speed and when running under conditions which approximate closely those of the final supporting system.
- Note: A Rigid Rotor has sufficient structural rigidity to allow Balancing corrections to be made below the operating speed.
- 3.16** *Shaft Runout.* The wobbling motion produced by a shaft that is not perfectly true and straight. Shaft Runout is often abbreviated as TIR (Total Indicated Runout, a measurement of how much a shaft wobbles with each revolution).
- 3.17** *Shaft Axis.* The straight line joining the Journal centers.
- 3.18** *Should.* “Should” is used to indicate provisions which are not mandatory but which are desirable as good practice.
- 3.19** *System Balance.* System Balance includes the entire rotating assembly mass, operating speed, and the application.
- 3.20** *Unbalance.* That condition which exists in a Rotor when vibratory force or motion is imparted to its Bearings as a result of centrifugal forces.

3.20.1 *Residual Unbalance.* Unbalance of any kind that remains after Balancing.

3.20.2 *Unbalance Amount.* The quantitative measure of Unbalance in a Rotor (referred to a plane) without referring to its angular position (refer to the Unbalance Angle). It is obtained by taking the product of the Unbalance Mass and the distance of its center of gravity from the Shaft Axis.

3.20.3 *Unbalance Angle.* Given a polar coordinate system fixed in a plane perpendicular to the Shaft Axis and rotating with the Rotor, the polar angle at which an Unbalance Mass is located with reference to the given coordinate system.

3.20.4 Unbalance Mass. That mass which is considered to be located at a particular radius such that the product of this mass and its centripetal acceleration is equal to the Unbalance force.

3.20.4.1 The centripetal acceleration is the product of the distance between the Shaft Axis and the Unbalance Mass and the square of the angular velocity of the Rotor in radians per second.

3.21 Unbalance Limit. In the case of Rigid Rotors, that amount of Residual Unbalance with respect to a radial plane (measuring plane or Correction Plane) which is specified as the maximum below which the state of Unbalance is considered acceptable.

Section 4. Instrumentation and Measurement

4.1 Instrumentation to Measure Vibration. Vibration meters and stroboscopic equipment are used on complete systems with the Impeller or Rotor on its own Bearings and supporting structure rather than a Balancing Machine. This is commonly referred to as Field Balancing.

Vibration meters used should be capable of electrically filtering the vibration signal so that it can be tuned to the rotating frequency of the Rotor being balanced. The vibratory motion caused by Unbalance occurs at this frequency. The use of a tunable vibration meter will allow the operator to determine if the maximum vibration is at the rotating speed or from some frequency due to other causes of vibration.

Many hand held vibration meters do not have electrical filters and only measure total vibration amplitude. These meters are of questionable value in solving vibration problems.

Vibration levels can be measured in terms of displacement, velocity or acceleration. Velocity as a measure of vibration is coming into general use and is favored for several reasons. The destructive forces generated in a machine because of Unbalance depends much more on velocity than on displacement or acceleration. Such electronic instrumentation will pick up the vibration signal, convert it to a convenient unit, such as ounce-inches and locate the point of Unbalance.

4.2 Instrumentation to Measure Unbalance. There is a variety of instrumentation available to measure Unbalance Amounts in Rotors. This instrumentation varies from simple knife edge or roller ways to complex electronic production Balancing. The following outlines the variety of equipment and instrumentation available and their normal use and application.

4.2.1 Balancing Machines: Normally used for production or inspection of Impellers and Rotors.

Machines available are:

4.2.1.1 Non-rotating Types. i.e. knife edge, roller ways and vertical arbor (single-plane, non-rotating).

4.2.1.2 Rotating Types. i.e. horizontal arbor (single-plane, rotating), horizontal arbor (two-plane, rotating), vertical arbor (single-plane, rotating) and vertical arbor (two-plane, rotating).

4.2.2 Rotating Balancing Machines equipped with either hard or soft Bearings.

4.2.2.1 Hard (stiff suspension) bearing machines use force transducers to measure the force(s) exerted on the Bearings due to centrifugal force(s) acting on the Unbalance Mass(es).

4.2.2.2 Soft (flexible suspension) bearing machines use motion transducers to measure the Bearing motion caused by centrifugal forces acting on the Unbalance Mass(es).

4.2.2.3 To evaluate the accuracy of Balancing Machines, refer to ISO Standard 21940-21.

4.2.3 Measuring Units for Unbalance. All Balancing Machines provide information on the magnitude of Unbalance and a location where correction is to be made. Unbalance is usually reported in oz-in.

Section 5. Balancing Methods

5.1 *Types of Balancing.* A Rotor can be balanced either by Static Balancing or by Dynamic Balancing. The method chosen is dependent upon many factors such as physical size, shape, mass, and unbalance limit requirements (see ISO Standard 1940).

For instance, Dynamic Balancing would usually be employed if a Rotor is relatively wide, compared to its diameter, so that measurements and adjustments can be made in two axially separated Correction Planes. Static Balancing, however, would be employed on a narrow Rotor, where measurements and adjustments can be made in only one Correction Plane. It is important to note that, Static Balancing can be accomplished by either rotating or non-rotating means while Dynamic Balancing can only be accomplished by rotating means.

5.2 *Methods of Balancing.*

5.2.1 *Non-rotating.* The simplest method of Static Balancing consists of a Rotor mounted with its axis horizontal and allowed to pivot about its Shaft Axis. Any deviation of the center of mass relative to the Shaft Axis will cause it to pivot. Mass can then be added to or subtracted from the Rotor until there is no pivoting.

The latest technology for non-rotating Static Balancing utilizes a vertical arbor or axis, and uses the force of gravity to provide electronic signals to indicate the amount of correction required and its location.

5.2.2 *Rotating.* Dynamic Balancing is normally accomplished with an electronic Balancing Machine which usually has a rotating horizontal arbor, with either hard or soft Bearings (refer to Section 5.2.2), capable of measuring the amount and location of Unbalance in each of two axially separated planes.

Two-plane rotating Balance is the preferred method for Balancing Impellers when the width to diameter ratio is greater than 0.30.

The narrow width of propeller Fans and narrow Impellers make plane separation impractical, and corrections are only made in one plane.

When an Impeller is balanced dynamically, corrections are made in each of two correctional planes. This compensates for the “couple” effect caused when the Unbalance locations for each plane are out of phase with each other.

5.3 *Correcting for Unbalance.* Correcting for Unbalance is accomplished by adding or removing an appropriate amount of mass from one or more locations on an Impeller.

5.4 *Summary of Balancing Methods.* Refer to Table 1.

Table 1. Summary of Balancing Methods		
Type of Balancing	Method	Instrumentation (Section 4.2)
Static Balancing	Single-plane Non-rotating	<i>Horizontal</i> Knife edge, Roller ways
		<i>Vertical</i> Pendulum (electric or non- electric read-out)
	Single-plane Rotating (centrifugal)	Electronic Balancing Machine (horizontal or vertical arbor)
Dynamic Balancing	Two-plane Rotating (centrifugal)	Electronic Balancing Machine (usually horizontal arbor)

Section 6. Unbalance Limit

6.1 When an Impeller or Propeller is balanced separately as a component, Balancing is done as described in Section 5 and the Unbalance Limit is expressed in mass displacement units.

6.2 Unbalance Limits that result in acceptable vibration levels for most applications are shown in Table 2. Because of a wide range of variables involved in applying a component to a system, including a poorly designed system, the vibrational effect of the Residual Unbalance cannot be predicted unless all the system variables are considered (refer to Appendix C).

Table 2. Unbalance Limits			
For Propeller Fans		For Centrifugal Impellers	
Propeller Diameter ¹ , in	Amount of Unbalance, oz-in	Impeller Diameter ¹ , in	Amount of Unbalance per Plane, oz-in
8	0.10	≤ 4	0.07
9	0.10	6	0.10
10	0.10	7	0.13
10	0.10	8	0.13
11	0.10	9	0.15
11	0.10	10	0.15
11	0.10	11	0.15
12	0.10	12	0.25
14	0.10	14	0.25
14	0.10	15	0.25
16	0.15	16	0.45
18	0.15	18	0.68
20	0.20	20	0.92
22	0.25	22	1.15
24	0.30	24	1.39
26	0.30	26	1.74
28	0.40	28	2.09
30	0.45	30	2.43
36	0.60	32	2.78
42	1.00	34	3.13
48	1.40	36	3.48
54	1.50	38	3.82
60	2.00	40	4.17
Notes:			
1. The propeller or impeller diameter shown is the nominal value.			

APPENDIX A. REFERENCES – NORMATIVE

A1 Listed here are all standards, handbooks and other publications essential to the formation and implementation of the standard. All references in this appendix are considered as part of this standard.

None.

APPENDIX B. REFERENCES – INFORMATIVE

B1 Listed here are all standards, handbooks, and other publications which may provide useful information and background but are not considered essential. References in this appendix are not considered part of the guideline.

B1.1 AMCA Standard 204-05, *Balance Quality and Vibration Levels for Fans*, 2005, Air Movement and Control Association International, Inc., 30 West University Drive, Arlington Heights, IL 60004, U.S.A.

B1.2 *ASHRAE Terminology*, <https://www.ashrae.org/resources--publications/free-resources/ashrae-terminology>, 2016, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

B1.3 ISO Standard 1925:2001, *Mechanical vibration -- Balancing -- Vocabulary*, 2014, International Organization for Standardization, Case Postale 56, CH-1211, Geneva 21 Switzerland.

B1.4 ISO Standard 1940-1:2003 Cor. 1:2005, *Balance quality requirements for rotors in a constant (rigid) state -- Part 1: Specification and verification of balance tolerances*, 2005, International Organization for Standardization, Case Postale 56, CH-1211, Geneva 21 Switzerland.

B1.5 ISO Standard 21940-21:2012, *Mechanical Vibration – Mechanical vibration -- Rotor balancing -- Part 21: Description and evaluation of balancing machines*, 2012, International Organization for Standardization, Case Postale 56, CH-1211, Geneva 21 Switzerland.

APPENDIX C. SYSTEM VIBRATION – INFORMATIVE

C1 *General.* All equipment with rotating components will have some vibration. The amount of vibration present is the cumulative effect of factors such as Residual Unbalance and alignment of all the rotating components (including shafts, pulleys and Bearings) and the dynamic characteristics of the complete assembly.

C2 *Effects of Resonance.* The dynamic characteristics of the assembly often create vibration problems that are erroneously attributed to Unbalance. This situation occurs when the equipment is operating at, or near, Resonance Frequency (the rotational frequency is too close to the Resonance Frequency of one or more of the equipment's components). This results in high vibration amplitudes even when the driving forces due to Unbalance are small. Another characteristic of such a system is that large changes in vibration level occur with small changes of input frequency (operating speed).

Usually, such a vibration problem cannot be solved by reducing the Balancing Tolerance, since there are limits to the reduction of the driving force which can be achieved in practice. The user or designer should consider the fallacy in this approach in that small changes in System Balance due to damage from mishandling, shipping, field service, or normal buildup of dirt may result in the return of high amplitudes of vibration.

C3 *Analyzing Resonance.* The equipment designer can determine if a Resonance problem exists by running a series of tests to determine the sensitivity of the complete unit to Unbalance in the rotating components. With the unit running at its design speed, the Rotor should be balanced to the minimum achievable Residual Unbalance. The Rotor is then unbalanced by small amounts of increasing size and the resultant displacement or velocity is recorded for each increment of Unbalance. This process should be continued until the effects of the Unbalance can be detected above the level of other disturbances or until the Unbalance noticeably and adversely affects the running smoothness or function of the unit. With the Rotor unbalanced at an acceptable level at operating speed, the vibration level should then be measured at various speeds above and below the operating speed. This can be accomplished by varying the voltage, line frequency or pulley ratio while measuring the vibration level at some reference point on the unit. The vibration level determined in the first test should be plotted versus the Unbalance Amount and versus speed for the second test. Large changes in vibration level caused by small changes in speed indicate resonant condition in the support structure.

The use of a variable speed drive generator to power the motor on direct drive equipment is very useful since the system can be operated up through synchronous speed and above. This will indicate if a Resonance is just above the operating speed and, with manufacturing tolerance, the possibility of this point dropping into the operating range. Another useful aspect of the ability to have a large speed range capability during tests is the advantage of excitation above a Resonance at the operating speed. This dramatically shows the effect of the exciting frequency since the vibration level will be reduced substantially with an increase in unit speed.

C4 *Recommendations.* By understanding the effect of system characteristics on vibration levels, the designer can avoid the special Balance requirements, which are costly in terms of initial product and potential future field problems.

Below is a partial listing of some common factors to be considered to minimize vibration problems:

C4.1 Structural support must be adequate. The structural Resonance Frequencies of the system must not coincide with the frequencies of excitation caused by the rotating components.

C4.2 Single phase motors have an inherent torque pulsation at twice line frequency (sometimes referred to as “single phase hum”). This vibration can be isolated by proper mounting techniques.

C4.3 Vibration from electronic speed controllers, permanent magnet motors, and some advanced motor types may be mitigated by restricting the speed range or tuning the switching frequency of the electronic controls.

C4.4 Assembly methods using screws or other fasteners must follow specified hole size, alignment and tightening torques to prevent unwanted vibration at various operating speeds.

C4.5 Drive components can be a source of vibration problems. Characteristics such as Shaft Runout (TIR), Balance of the pulleys and the condition of the belt(s) can be factors.

C4.6 Proper field installation of the equipment is important.