



AEROSPACE RECOMMENDED PRACTICE

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Horizontal Balancing Systems - Isolating Repeatability Issues in Challenging Applications

RATIONALE

The purpose of this document is to provide a foundational basis for investigating and identifying one or more sources of non-repeatability that challenge the goal of achieving repeatable data within the rotor unbalance tolerance of each unbalance correction plane. This document presents a recommended method for successful demonstration and validation of a new balancing process prior to approval for production use. This SAE Aerospace Recommended Practice will be useful to both process engineers and machine operators.

FOREWORD

Modern hard bearing balancing machines are calibrated using an SAE rotor, which is considered an ideal configuration of a symmetrical design. Then the balancing machine is subjected to a balancing machine performance test. The ideal rotor configuration of an SAE proving rotor is employed to document the performance of a balancing machine is suitable for the intended task of balancing jet engine rotors.

However, typical jet engine rotor designs are often far removed from the ideal geometry of an SAE proving rotor. When balancing a specific jet engine rotor or module, many differences between an SAE proving rotor and an actual jet engine rotor are evident. These may include:

- An asymmetric configuration
- Narrow distance between unbalance correction planes
- A cantilevered (overhung) rotor configuration with the center of gravity located outside the machine supports
- A different rotor mass
- A different balancing speed
- The influence of tooling design and behavior upon the specific balancing task
- Loose or moving components

The above characteristics make a specific balancing task significantly more challenging than conducting a balancing machine performance test. The sources of one or more obstacles to achieving a repeatable unbalance measurement in both correction planes is rarely obvious to the machine operator or the process engineer. This document serves as a guide toward establishing a method for evaluating and qualifying a rotor balancing process.

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1. SCOPE

This SAE Aerospace Recommended Practice will serve as a practical resource that offers guidance to both the machine operator and process engineer for isolating the source(s) of non-repeatability in measured unbalance data. The content of this standard addresses:

- Machine capability to achieve the specified unbalance tolerances and repeat within those tolerances.
- Tooling capability to repeat within the specified unbalance tolerances.
- Rotor characteristics that may preclude repeating within the required unbalance tolerances.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR6975	Hard Bearing Balancing Machine Technology - Proper use of Rotor Type-Specific Calibration
ARP4048	Balancing Machines - Description and Evaluation, Horizontal, Two-Plane, Hard-Bearing Type for Gas Turbine Rotors
ARP4162	Balancing Machine Proving Rotors
ARP8616	Balancing Machine Technology - Proper Use and Performance of Response Checks
AS8617	Balancing Machines - Verification Test Requirements

2.1.2 ANSI Accredited Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

ISO 21940-2 Mechanical vibration – Rotor balancing – Part 2: Vocabulary

ISO 21940-11 Mechanical vibration – Rotor balancing – Part 11: Procedures and tolerances for rotors with rigid behaviour

2.2 Definitions

CONDUCTIVE COOLING: The application of dry ice or liquid nitrogen to achieve a specific temperature by chilling a component or tool to uniformly distribute a reduced temperature throughout the component or tool interface for the purpose of achieving thermal contraction.

CROSS EFFECT: When setting a test weight to one plane for calibration, the change in unbalance indication on the other plane is identified as cross effect or plane influence. Also referred to as plane separation.

DWELL TIME: After reaching balancing speed, the time delay prior to the start of recording the unbalance measurement indication.

HEAT SOAKING: The application of heat, typically in a calibrated oven, to achieve a specific temperature that is applied to a component or tool and uniformly distributed throughout the component or tool to achieve thermal expansion.

NARROW PLANE SEPARATION: The relationship of the distance between two unbalance correction planes is short compared to the distance from each measuring plane. As a rule of thumb, distances between the two unbalance correction planes that are below 25 to 30% of the distance from either measuring plane can be characterized as having narrow plane separation.

OUTBOARD ROTOR: On a horizontal machine, the center of gravity is located outside of the machine supports. Sometimes referred to as a cantilevered rotor or an overhung configuration.

RAMP RATE: The rate of acceleration used to reach balancing speed. For balancing tasks, a slow acceleration rate is used to avoid upset to rotor components that are intended to be free to move into intended position and contact area.

RESPONSE CHECK: The application of a trial unbalance mass to determine the change in unbalance reading compared to the calculated unbalance during the beginning or the conclusion of a balancing process. This is also known as a “wax check” or “pull check.”

TRIAL MASS: A certified test weight traceable by unique serial number with documented geometry for positioning at a known location traceable to a manufacturing drawing dimension.

VALIDATION: A method of proving the effectiveness of a documented process.

3. INTRODUCTION

Modern hard bearing balancing machines are characterized as having permanent calibration. This terminology is used to distinguish a hard bearing balancing machine design from a soft bearing balancing machine design. A hard bearing balancing machine is a seismic measuring device that measures relative motion. A hard bearing balancing machine is part of a complete balancing system that includes the:

- Machine foundation
- Balancing machine with measuring instrumentation
- Balancing tooling
- Rotor assembly

Each of the above system components uniquely contributes to the integrity of the balancing process validation and ultimately, the success of the specific balancing task. Therefore, each system component must be individually examined to eliminate it as a suspected source of non-repeatable measurement data.

3.1 Machine Foundation

The machine operator is rarely familiar with the integrity of the underlying machine foundation. But the structural integrity of the balancing machine can be easily checked. Before starting any balancing task, the machine operator should check the machine bed is securely bolted to the foundation and the machine supports are securely bolted to the machine bed and tightened to the balancing machine manufacturer's specified torque.

3.2 Balancing Machine with Measuring Instrumentation

Each type of balancing machine, whether it be horizontal, vertical rotating, or vertical non-rotating is designed to conform to the appropriate SAE class for which the machine type applies. Each class of balancing machine is different from another machine class.

The specification for your balancing machine model states both the machine accuracy in micro-inches and the sensitivity of the measuring instrumentation at a specific rotational speed in gram-inches or ounce-inches. Both machine accuracy and measuring sensitivity influence the ability of your machine to repeatedly measure within the unbalance tolerances attributed to a particular rotor type.

3.3 Balancing Tooling

There are two types of balancing tooling:

- Fixed non-rotating tooling to support static, fixed structures
- Rotating tooling

Each may contribute to non-repeatability. Quite often, a rotating tooling design will be the source of unrepeatability data.

3.3.1 Fixed, Non-Rotating Tooling

Non-rotating tooling such as nozzle supports, stator supports, and the like are often adjustable for alignment with the rotor centerline and to ensure adequate clearance between rotor and stator. If the adjustment is improperly set and the non-rotating structure is misaligned with the rotor's central axis of rotation, this may result in rubbing that will cause elevated friction heat between rotor and stator. Heat buildup in a spinning rotor will result in a variable change in rotor unbalance data as the rotor temperature changes from run to run.

3.3.2 Rotating Balancing Tooling

Modern measuring instrumentations are typically equipped with tooling compensation software. Tooling compensation software is employed for any setup incorporating rotating balancing tooling. When a rotor is mounted upon a balancing machine by employment of balancing tooling, there will be an error resulting from the fit between the tooling and the rotor mounting interface. The mounting interface between the rotating balancing tooling and a rotor possesses an assembly fit tolerance, which will result in a runout between tooling and rotor.

If this fit tolerance and the resulting runout are not taken into consideration, reported unbalance will reflect this source of error. Therefore, it is advisable to verify the existence of, and to compensate for tooling fit errors and the resultant eccentricity that can adversely influence reported unbalance measurements.

However, the success of any tooling compensation process is wholly dependent upon the repeatability of the remove-and-replace fit between rotating tooling and the tolerated datums of the rotor mating interface. Tooling compensation software is of little usefulness to a particular balancing process if the tooling fit is not repeatable within the rotor unbalance tolerances. This is readily evidenced and confirmed by conducting multiple trial runs focusing upon removal and replacement of the rotating balancing tooling. Therefore, tooling repeatability trials are necessary to ensure the integrity of a balancing process where dedicated, rotor-specific rotating tooling is employed for performing each unique balancing task.

3.4 Specific Attributes Pertaining to Each Rotor Type

Each rotor design possesses specific attributes that taken together as a whole, represent a uniquely challenging balancing task. These attributes may include any one of the following characteristics, or potentially a combination of two or more of the below rotor characteristics:

- Rotor components subject to free motion
- Rotor shaft sagging
- Excessive runout of the rotor assembly
- Heat influence

4. CHECKING AND CHARACTERIZING THE INTEGRITY OF THE BALANCING SYSTEM

4.1 Checking the Structural Stiffness of the Machine Installation

All components of a balancing machine installation contribute to the stiffness of the structure that establishes a rigid connection to the underlying concrete slab serving as the interface to the machine foundation.

Should the bed bolts be loose, the validity of the machine calibration is to be questioned and warrants verification using an SAE proving rotor. Tighten the bed bolts and use an SAE proving rotor with certified trial masses to verify the balancing machine calibration remains valid. If the calibration cannot be validated, the balancing machine requires adjustment followed by a response check (incorporated in the SAE balancing machine verification test).

Should the support bolts be a little loose, the ability to transmit force may be encumbered resulting in the machine calibration being invalid until the support bolts are secured and tightened to the specified torque. A hard bearing balancing machine is designed to serve as a rigid structure, and such a design is intolerant of a soft connection to the machine foundation. Any looseness in the machine structure will affect the measured unbalance data. Use your SAE proving rotor to test the stiffness of the balancing machine structure.

The SAE proving rotor for your specific machine type and class is uniform and symmetric in its design. Its center of gravity is located to provide uniform force distribution when identical trial masses are mounted in both end planes. Using the SAE proving rotor, install each 125 A-unit trial mass in Plane 1 and Plane 2 at angular Location A (refer to ARP4162). Set up your measuring instrumentation rotor file to measure the unbalance from 90 to 120% of the SAE test speed using your SAE proving rotor. Run the proving rotor up to each speed using increments of about 50 rpm. The unbalance magnitude should not appreciably change in between 90% and 120% of your SAE test speed. The recorded angle should be both accurately reported and remain relatively constant within ± 1 degree without any sudden change reported throughout the overspeed testing process.

If the recorded unbalance data remains relatively constant during the transient speed test, the structural stiffness of the machine installation is considered sufficient. Should the unbalance magnitude or the unbalance angle change at any point during the overspeed test, you have confirmed there is an issue involving the structural stiffness of the balancing machine installation that must be investigated and addressed before the specific balancing task can begin.

4.2 Confirming Your Machine is Suitable for the Intended Balancing Task

It's human nature for one to harbor a preference for that which is known and familiar. A balancing machine operator will most often defer to the balancing machine that is most familiar and comfortable to use. A secondary consideration is the immediate availability of any balancing machine to get the balancing task completed as quickly as possible. Neither of these choices are necessarily representative of the best solution for balancing a particular rotor type. This reality justifies placing the responsibility for selecting the most appropriate balancing machine upon the shoulders of the process engineer rather than the balancing machine operator.

For instance, an available SAE Class 1000 horizontal balancing machine possesses a maximum accuracy of 15 micro-inches, below which the measured data is likely suspect, assuming the appropriate SAE proving rotor along with its certified trial masses was used to calibrate the subject balancing machine. Further, the measuring instrumentation can sense an unbalance down to 0.25 gram-inch at 900 rpm and above. The rotor unbalance tolerance actually calculates to 12 micro-inches and the rotor unbalance is 0.1 gram-inch in each plane. It's clear that the available balancing machine is not suitable for the intended balancing task. Yet, the frequency of occurrence for this particular situation is increasing.

In such a case, the only recourse is to either balance that particular rotor type at a higher balancing speed or on a lower capacity balancing machine offering greater machine accuracy. An SAE Class 300 horizontal balancing machine rated at 10 micro-inches is perhaps much better suited to achieve the specified rotor unbalance tolerances in this case than the Class 1000 machine rated at 15 micro-inches. Refer to ARP4048 to determine the machine class your horizontal balancing machine was designed to conform to, and the performance criteria established for that balancing machine class.

The measuring instrumentation is stated to have a sensitivity that yields a specific measurement capability at a particular balancing speed. If either or both of the rotor unbalance tolerances at the process-specific balancing speed is less than the capability of your measuring instrumentation supplied with that balancing machine, you will not be able to achieve the rotor unbalance tolerance using that particular balancing machine. In such a case, one potential solution is to balance that particular rotor at a higher balancing speed if the process definition offers that degree of latitude.

If the process definition states, "Balance at a minimum speed of 900 rpm," the operator may be able to balance at a somewhat higher speed to attain the level of sensitivity that is suitable for achieving the stated unbalance tolerance in each plane.

However, such a decision should not be left for the operator to decide. Balancing a rotor somewhat above the calibration speed may lead to one questioning the validity of unbalance data collected significantly above the calibration speed of the balancing machine even if the collected unbalance data appears to be reasonable. It is the responsibility of the process engineer to determine how best to define the balancing process and validate the collected unbalance data.

Before beginning the actual balancing task for a specific part or module, a commonly recommended practice is to conduct a response check to validate system repeatability with multiple unbalance measurements. This ensures the complete balancing system has been validated prior to beginning a specific balancing task (refer to ARP8616).

4.3 Conduct a Visual Inspection of the Balancing Machine

4.3.1 Before the balancing machine is started, it's wise for the machine operator to have a quick look at the balancing machine. Check the cables to ensure their connections are assured.

4.3.2 When using a saddle-mounted fixture:

- Inspect the saddle seating surface where the fixture rests in for raised metal.
- Check the saddles to ensure they are adequately mounted and tighten all bolts that seem to be loose.
- Confirm the fixture mounting clamps are available and secured in place.

4.3.3 When using twin roller carriages, do a quick visual inspection to spot any nicks, raised metal, or axial scratches, as these types of damage may result in a false unbalance indication with each rotation. Nicks, raised metal, or deep axial scratches in the roller contact surface should trigger immediate roller replacement. Do not overlook the rollers used in the design of axial thrust bearings. Any damage including nicks, raised metal, or deep axial scratches in the roller contact surface are cause for concern and should trigger an immediate roller replacement.

The roller crown exists to provide freedom of motion about the vertical axis for measuring couple unbalance, which is one vector component of dynamic unbalance. The contact area of the roller crown, as evidenced by its wear track, typically spans the middle third of the roller width. Based upon roller speed, rotor mass, and rotor material properties, the contact area of the roller crown will wear with usage. Therefore, one cannot characterize the life of a roller based upon hours/cycles/number of measurements.

As the roller wears, the wear track will grow in width, indicating consumption of the roller crown. This wear will eventually result in a flat roller.

To determine if any portion of the roller crown remains, place a precision straight edge across the width of the roller upon the peak of the crown, and then shine a penlight behind it. As long as light shines past the straight edge at each adjacent third to the center of the roller, the roller crown remains acceptable.

Roller crowns ensure some amount of angular contact freedom and can tolerate a bit of misalignment. A roller without any crown (a flat roller) will only be capable of measuring static unbalance. Further, the sharp edges of a flat roller may cause damage to the rotor journal surface if contact is less than square. Only use crowned rollers for your balancing applications. If the machine operator identifies a roller without a crown remaining, this should trigger an immediate roller replacement.