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Balancing Machines: Tooling Design Criteria

RATIONALE

ARP4163 has been reaffirmed to comply with the SAE five-year review policy.

FOREWORD

Tooling for balancing machines is a complex subject with many requirements that have been developed over a considerable period of time. The definition of balancing tooling covers a wide range of items from drive shafts and bearings to complete fixtures for locating engine modules.

This document was prepared by the SAE EG-1A committee, it supersedes ARP1382.

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1. SCOPE:

This document establishes general design criteria, tolerances, and limits of application for tooling, fixtures and accessories for mounting and driving gas turbine engine rotors on horizontal and vertical balancing machines.

For your own safety, while using balancing tooling, regard the safety instructions of the individual supplier.

1.1 Purpose:

The purpose of this document is to provide a set of tooling and fixture design parameters for balancing machine tooling that will facilitate the understanding of the high degree of readout accuracy and precision balance required for turbine engine rotors, and will assist in achieving compliance with the testing requirements as listed in applicable ARP specifications for balancing.

1.2 Equipment Selection for Specific Applications:

Rotor type, size, mass, moment of inertia, windage, and balance tolerance are determining factors in the selection of both the balancing machine and the required tooling.

This document describes tooling and accessories to adapt the engine component to the balancing machine.

Balancing machines for gas turbines are defined and specified in ARP587, ARP588, ARP4048, and ARP4050. These documents include details of standard machine classes that cover most engine sizes and should be used to assist with selection of an appropriate balancing machine. These specifications also define the standard interfaces for rotor support and drive.

2. 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 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP587	Balancing Machines - Description and Evaluation, Horizontal, Two-Plane, Soft Bearing Type for Gas Turbine Rotors
ARP588	Balancing Machines - Description and Evaluation, Vertical, Single-Plane, Soft Bearing Type for Gas Turbine Rotors
ARP1202A	Balancing Machines, Dynamic, Ball Bearing Type Slave Bearings for Rotor Support
ARP4048	Balancing Machines - Description and Evaluation, Horizontal, Two-Plane, Hard Bearing Type for Gas Turbine Rotors
ARP4050	Balancing Machines - Description and Evaluation, Vertical, Two-Plane, Hard Bearing Type for Gas Turbine Rotors
ARP4162	Balancing Machine Proving Rotors
ARP5323	Balancing Machines - Description and Evaluation, Vertical, Single Plane, Hard Bearing Type, for Gas Turbine Rotors

3. METHODS OF ROTOR SUPPORT IN A HORIZONTAL BALANCING MACHINE:

3.1 Twin-Roller Bearings:

A twin-roller bearing assembly supports a rotor journal on a pair of rollers mounted to a plate or carriage, which attaches to the balancing machine support. Crowned outer surfaces of the rollers are required unless spherical self-adjusting bearings are used or a tiebar or frame, permitting precise alignment, connects the roller supports. Twin-roller bearing supports are usually adjustable to accommodate a range of journal diameters.

To eliminate the influence of any eccentricity or unbalance of the rollers on the unbalance measurements the roller diameter should differ from the journal diameter by more than 10%.

The roller bearing alignment affects the axial thrust of the rotor, and consequently can adversely affect the unbalance measurement.



FIGURE 1

3.2 V-type Bearings:

V-type bearings support the rotor journal or bearing by two point contact. These bearings are typically used for light loads, or for supporting rotors in their own bearings.

3.3 Engine Bearings:

Engine bearings can be used for balancing rotor assemblies. Their large radial clearance at ambient temperature adversely affects balancing accuracy.

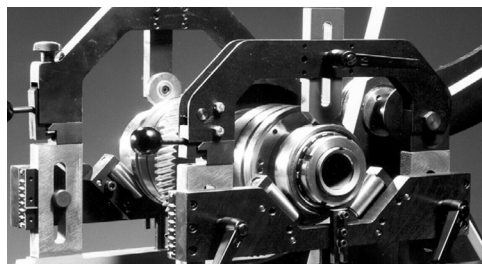


FIGURE 2

3.4 Slave Bearings:

Rolling element bearings used in place of engine bearings to support the rotor in the balancing machine. Slave bearings are variants of engine bearings designed to have minimum clearances at ambient temperature.

In the case of roller bearings the engine bearing inner race and rollers may be used in conjunction with a slave bearing outer race (reference ARP1202A for additional information).

3.5 Slave Races:

Precision inner races that are mounted on engine journals to protect the journal surfaces from damage during the balancing process.

3.6 Sleeve Bearings:

Sleeve type bearings are non-rotating journal supports which are fitted to specific journals. Sleeve bearings may be self-lubricating, or have a liquid or gaseous supporting medium. Contact area, alignment, and overall stiffness, including the stiffness of the supporting medium, are critical factors in sleeve bearing design.

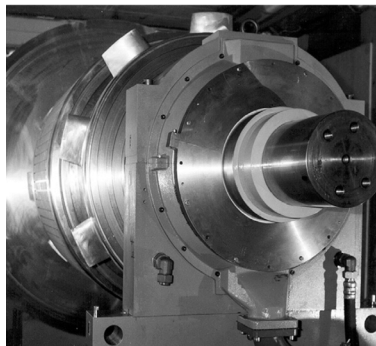


FIGURE 3 - Bearing Support With Sleeve Gas or Hydrostatic Bearings

3.7 Swivel Bearing Bridges:

Balancing machines conforming to the requirements of ARP587 and ARP4048 can be fitted with swivel bearing bridges with semicircular bearing halves (also called "saddle bearings", or "half shell bearings") to support a cradle and/or rotor. Swivel bearing bridges enable the balancing machine to give correct two plane unbalance readings when operated with cradles, stators, or tiebars.

Swivel bearing bridges provide torsional freedom about a vertical axis established by a line passing through the center of the support and perpendicular to the machine bed.

Torsional freedom is required to de-couple forces resulting from bearing swash (bearing track not perpendicular to the shaft axis) from the measuring system. If the bearing bridges are rigidly connected by a cradle and/or rotor the measuring system can only detect static unbalance, but with an apparent couple unbalance due to the coupling of bearing swash into the measuring system. Such apparent couple unbalance readings do not respond to mass corrections and vary inversely with balancing speed.

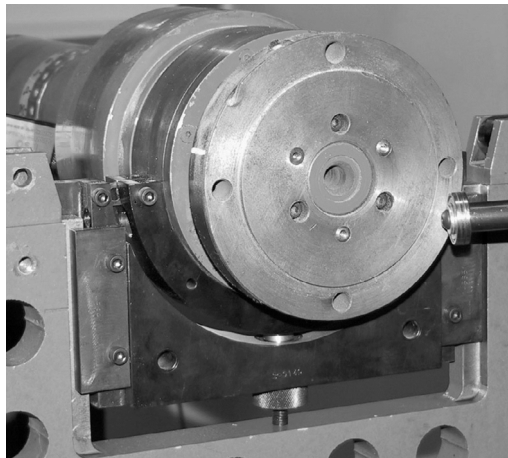


FIGURE 4 - Swivel Bearing Insert

3.8 Negative Load Devices:

- 3.8.1 Purpose: Rotors with their center of gravity outboard of the balance machine supports generate a negative or upward force at one support. These rotors must be restrained with a negative load device. This device must be attached to the vibrating part of the support, must not restrict its movement, and must be able to absorb the negative load specified in ARP587 or ARP4048.

3.8.2 Types of Negative Load Devices:

3.8.2.1 Negative Load Bearing With Single Roller: This is usually furnished as a machine accessory and is designed for a range of journal sizes. Pressure applied by the negative load roller assembly is used to maintain rotor journal contact with both of the rollers of the twin roller bearing assembly.

3.8.2.2 Negative Load Bearing With Twin Rollers: An inverted twin roller bearing can be used as a negative load device.

NOTE: This device cannot be used in positive load applications.

NOTE: To eliminate any influence on the unbalance measurements of eccentricity, or unbalance, of any rollers in contact with the bearing journals, the roller diameter should differ from the journal diameter, usually by more than 10%.

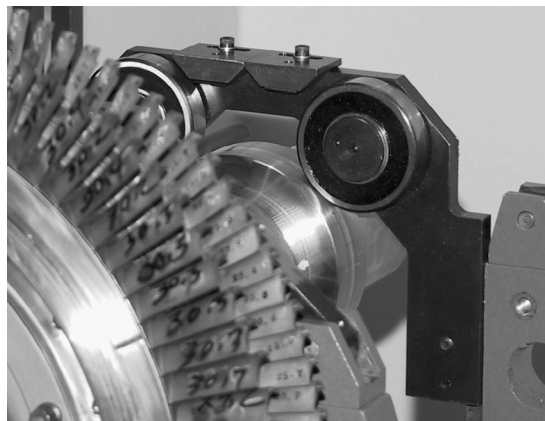


FIGURE 5 - Twin Roller Negative Load Device

3.8.2.3 Sleeve Bearings: Full sleeve bearings may also be used as negative load devices if they are designed to accept upward forces (see 3.6, Figure 3).

3.9 Axial Thrust Stops (End Stops, Thrust Arrestors):

3.9.1 Purpose: When a rotor is driven by belt drive, or by compressed air drive, the axial motion of the rotor must be controlled. If the support bearings do not include integral thrust bearings then axial thrust stops must be provided.

3.9.2 Mounting of Axial Thrust Stops: Any axial thrust stop should preferably be attached to the vibrating part of the balancing machine support and should be adjustable in both axial and radial directions. The axial thrust stop should have minimum effect on the free rotation of the rotor. The contact area between the rotor and the axial thrust stop should be smooth, as close as possible to, and square with the rotor axis of rotation.

- 3.9.3 Types of Axial Thrust Stops: There are different designs of axial thrust stops. A typical design using an antifriction bearing at the end of an adjustable rod is shown in Figure 6.

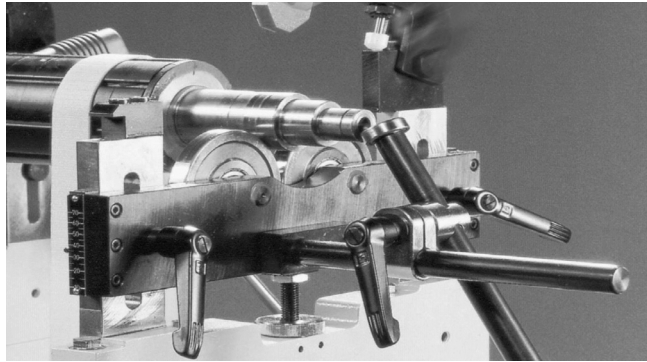


FIGURE 6 - Axial Thrust Stop

4. CRADLES, STATOR TOOLING, AND TIEBARS:

4.1 Purpose:

Cradles, and stator tooling, are used in a balancing machine, to support a rotor with engine bearings or slave bearings, and maintain precise alignment of these bearings to the shaft axis.

Engine stators need tooling to enable mounting to the balancing machine swivel bearings and this effectively makes the stator and tooling assembly into a cradle.

Tie bars may be used when there is a requirement to maintain alignment of rotor bearings mounted directly in swivel bearing bridges.

NOTE: Many hard bearing balancing machines can function without tiebars. The balancing machine manufacturers recommendations should be followed if there is any doubt over requirements.

4.2 Design Prerequisites:

The design of cradles, stator tooling or tiebars take into account the following:

- a. Workpiece weight and dimensions, including location of correction planes, method of correction, and balance tolerances.
- b. Required balancing speed and drive power.
- c. Method of drive and location of drive surfaces.
- d. Balancing machine capacity, including workpiece envelope and interface dimensions, minimum achievable residual unbalance, type of drive, speed range and drive power, and weight/speed capacity.

Cradles, stator tooling, and tie bars must be sufficiently rigid to prevent distortion due to unbalance forces and to prevent resonance at or near the balancing speed. They should be as light as practical to have minimum parasitic mass.

4.3 Machine and Rotor Interface:

Cradles mount to balancing machine bearing inserts (saddle bearing, swivel bearing, or half shell types that have torsional freedom) and must conform to the dimensional requirements of ARP587, Figure 1, or to ARP4048 Appendix A.

To facilitate loading of the rotor bearings into the cradle it is recommended to provide:

- a. Entrance chamfers at the split line of the cradle's bearing journals.
- b. 1/32 inch (1 mm) extra width in bearing journals.

To ensure operational safety bearing retainers with sufficient strength to secure the rotor are required.

When used on belt-drive machines, cradles may require cutouts between the bearing journals, either a single opening at the bottom of the cradle body or openings on each side, to accommodate the balancing machine's drive belt. All edges of the cutout should have a generous radius or chamfer to minimize belt fraying.

4.4 Engine Stators: Assembly Balancing:

If an assembled rotor must be taken apart after balancing and reassembled in the engine, new unbalance may result. To eliminate these errors the rotor may be balanced in its stator (part of engine housing) after assembly. The stator then performs the function of a cradle in that it maintains precise bearing alignment and forms a rigid connection between the balancing machine bearing bridges.

An engine stator usually requires end plates and drive adapters to enable mounting in the balancing machine.



FIGURE 7 - Cradle for Horizontal Balancing Machine

4.5 Tie Bars:

Tie bars are employed in place of cradles or stators when the workpiece bearing outer races are directly mounted in the semi-circular bearing halves of a balancing machine's bearing bridges. The tie bars connect the bearing bridge of the left machine support to the bearing bridge of the right machine support, thus forming a sufficiently rigid connection to maintain precise alignment of the workpiece. (An exception to this requirement occurs when the machine supports of hard bearing balancing machines have adequate torsional stiffness without tie bars. This requirement should be verified with the appropriate balancing machine manufacturer for individual situations).

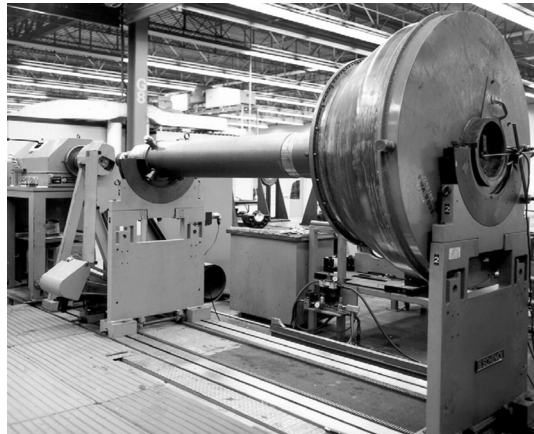


FIGURE 8 - Typical Stator Housing With Adapters for Mounting in a Balancing Machine

- 4.5.1 Use of Rollers With Tie Bars: Tie bars may also be used in cases where twin roller inserts with crowned roller surfaces have been mounted in the bearing halves of a balancing machine's swivel bearing bridges. The workpiece journals (or the journal;- mounted inner bearing races) run directly on the two rollers. Due to the roller surface crown and the ability of swivel bearing bridges to move about a vertical axis as described under 3.7 oscillation of the bearing bridge about the vertical axis may be induced and this in turn may have an adverse effect on the balancing machine readout. Tie bars prevent such unwanted oscillations.

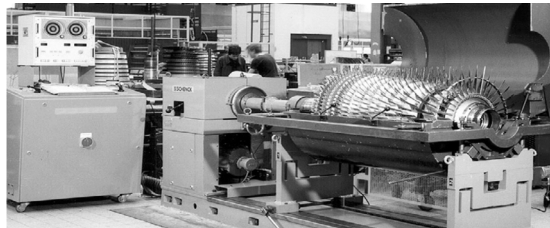


FIGURE 9 - Typical Tie Bar Setup on Horizontal Balancing Machine

5. DRIVE TOOLING - DIRECT AND BELT:

5.1 General Design:

The mass and length of all rotor drive adapters should be held to a minimum consistent with maintaining sufficient strength to avoid deflection in operation. The design should be as simple as possible with a minimum of removable components.

All removable components should be keyed and match-marked to preclude reassembly in other than the original position or interchange with components from similar adapters.

5.2 Balancing:

Provision must be made for balancing the complete drive adapter assembly in one or two correction planes (depending upon the adapter and balancing machine coupling design) by addition or removal of mass.

5.3 Material:

Wear surfaces should be of steel AISI 4140 - 4150 or equivalent, with a hardness of RC 38 to 46.

5.4 Mounting Interface:

The surface of the rotor to which the drive adapter assembly mates should be concentric and perpendicular to the shaft axis with sufficient accuracy so that the maximum displacement of the drive assembly should, if possible, introduce errors no greater than 20% of the rotor tolerance in each correction plane.

NOTE: Any error thus introduced reduces the balance tolerance available to the operator.

NOTE: The magnitude of this error can only be found by 180° indexing of the drive adapter to the (balanced) workpiece at which time it will be indicated at twice its actual value. It may then be appropriately eliminated by correcting one-half of the unbalance on the adapter, the other half on the workpiece. If there is a lack of mounting repeatability then 180° indexing will leave substantial remaining unbalance.

If indexing is not possible, the error must be calculated. It will vary from rotor to rotor, depending upon the concentricity and squareness actually achieved in rotor fabrication. The magnitude is directly proportional to the mass of the adapter assembly, the concentricity, and the perpendicularity of the rotor locating surface.

5.5 Rotor Connection:

Provision must be included to fasten the drive assembly rigidly to the rotor. The locating diameter of the rotor should have a tolerance sufficiently close to permit a maximum repeatability error of 20% of the rotor tolerance when removing and reinstalling the drive adapter assembly.

NOTE: (1) When using bolts to fasten the drive adapter assembly to the rotor, the bolts shall be match marked or be of equal weight as to minimize their contribution to the repeatability error.

NOTE: (2) A drive adapter assembly with an expanding fit, or multiple rigid adapters of various sizes, may be needed to meet above requirements.