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LAND SEA AIR SPACE

AEROSPACE RECOMMENDED PRACTICE

Society of Automotive Engineers, Inc.
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ARP 1382

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DESIGN CRITERIA FOR BALANCING MACHINE TOOLING

CONTENTS

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1. PURPOSE

This document establishes design parameters for balancing machine tooling, fixtures and accessories. Adherence to the recommendations made herein will facilitate compliance with ARP 587A and 588A, as well as the attainment of the usually high degree of readout accuracy and precision balance required for jet engine rotors.

2. SCOPE

This document recommends general designs, tolerances, limits of application and suitable tooling, fixtures and accessories for mounting and driving jet engine rotors on horizontal and vertical balancing machines.

3. APPLICABLE DOCUMENTS

SAE ARP 587A	Balancing Equipment for Jet Engine Components - Compressors and Turbines - Rotating Type - for Measuring Unbalance in One or More than One Transverse Planes
SAE ARP 588A	Static Balancing Equipment for Jet Engine components - Compressor and Turbine - Rotating Type, for Measuring Unbalance in One Transverse Plane
SAE ARP 1202	Ball Type Slave Bearings for Rotor Support in Dynamic Balancing Machines
ISO/TC108/DS 1925	Balancing Terminology

4. METHODS OF SUPPORTING A ROTOR IN A HORIZONTAL BALANCING MACHINE

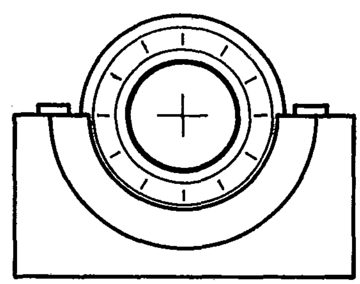
4.1 Slave Bearings: Slave bearings are rolling element bearings used in place of the engine bearings to support the rotor in the balancing machine.

4.1.1 Advantages:

- No journal scoring.
- Good load carrying capacity.
- Minimum friction and heating.
- End stops usually eliminated.
- Controllable bearing clearance.

4.1.2 Disadvantages:

- Minimum achievable residual unbalance. is limited by runout and radial clearance.
- Special design.
- Long lead time for procurement.



Bearing Support for Rotor with Slave or Engine Bearings

FIGURE 1

4.2 Engine Bearings: Engine bearings can be used in the same manner as slave bearings. All of the characteristics are the same except larger radial clearance adversely affects balancing machine sensitivity. However, errors due to inner race eccentricity are eliminated, provided the bearings are left on the rotor journals or the positions of the inner races are matchmarked before removal, and reassembled in the same position.

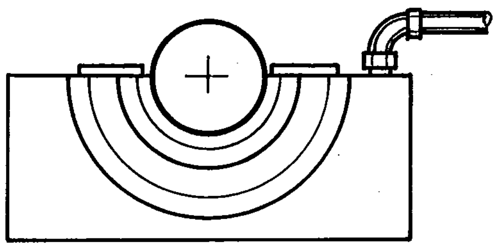
4.3 Sleeve Bearings: Sleeve type bearings are defined as bearings which are fitted to a specific journal and have no moving parts. They should provide sufficient bearing area so that bearing load does not exceed 50 lb per square inch (3.5 bar) of projected bearing area. They are lubricated by a gravity feed or low pressure oil system.

4.3.1 Advantages:

- Highly accurate.
- Low cost.
- Short lead time for procurement.

4.3.2 Disadvantages:

- Special design.
- Journal scoring possible
- High friction generated on heavy rotors, consumes drive power and affects balance.



Bearing Support with Sleeve, Gas, or Hydrostatic Bearings

FIGURE 2

4.4 Gas Bearings: Gas bearings are modified sleeve bearings which have air or nitrogen under pressure applied between the journal and the bearing. This results in the journal riding on the gas film.

4.4.1 Advantages:

- Highly accurate.
- Lowest friction of any bearing.

4.4.2 Disadvantages:

- Require extensive design and fabrication effort.
- Journal scoring possible.
- Light load carrying capacity.
- Expensive.

4.5 Hydrostatic Bearings: Hydrostatic bearings are modified sleeve bearings which have oil under pressure applied between the journal and the bearing. This results in the journal riding on a film of oil.

4.5.1 Advantages:

- Highly accurate.
- High load carrying capacity.
- Low friction.

4.5.2 Disadvantages:

- Require extensive design and fabrication effort.
- Journal scoring possible.
- Expensive.

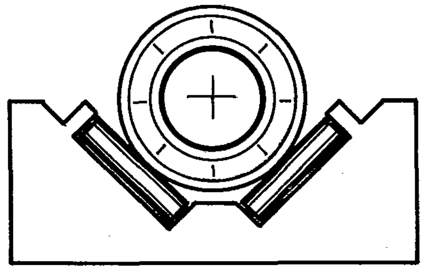
4.6 V-block Bearings: V-block bearings support the rotor journal by two point contact. Nylon or Teflon inserts reduce friction.

4.6.1 Advantages:

- Inexpensive.
- Universal.
- Accurate.

4.6.2 Disadvantages:

- Limited to light load.
- Frequent replacement of bearing material.
- High friction.
- Journal scoring possible.
- Suitable for uninterrupted surface journals only.



V-block Bearings

FIGURE 3

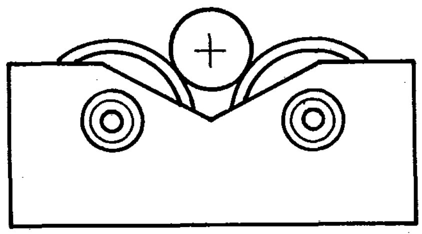
4.7 Twin-roller Bearings: Twin-roller bearings support the rotor journals on ball or roller bearing mounted rollers. Crowned outer surfaces of the rollers are required unless spherically self-adjusting bearings are used or the roller supports are connected by a tiebar or frame, permitting precise alignment. Twin-roller bearing supports are often vertically adjustable to accommodate a range of journal diameters.

4.7.1 Advantages:

- Low friction.
- Universal.
- Heavy load carrying capacity (if rotor journals are reasonably hard).
- Moderate cost.

4.7.2 Disadvantages:

- Journal scoring possible.
- Roller diameter must differ from journal diameter by more than 10%.
- Suitable for uninterrupted surface journals only.



Twin-roller Bearing

FIGURE 4

5. CRADLES, STATORS, AND TIEBARS

5.1 Balancing Machine Prerequisites: Balancing machines conforming to ARP 587 have bearing bridges with semicircular bearing halves (also called "saddle bearings") to support the workpiece. Each bearing bridge is designed to move freely not only in measuring direction (horizontally, perpendicular to the shaft) but also about a vertical axis established by a line passing through the center of the support and perpendicular to the machine bed. Such torsional freedom is required so that couple unbalance forces may be measured without misaligning the bearings in each (out-of-phase) back-and-forth movement of the bearing bridges. Without torsional freedom the bearing bridges (when connected by the rotor) could only move in unison towards the front and rear of the machine; thus only static unbalances could be measured.

5.2 Purpose: Cradles, stators, and tiebars, when used in a balancing machine, generally serve to accommodate the workpiece in its own or slave bearings, and to maintain precise alignment of these bearings to the shaft axis. To accomplish the latter, the cradles, stators, or tie bars must form a structurally rigid connection between the balancing machine's bearing bridges. Since otherwise the rotor bearings would become misaligned due to the torsional freedom of the bearing bridges. In addition, the bearing bridge resonance in the torsional mode might coincide with the balancing speed and thus adversely affect the readout.

5.3 Design:

5.3.1 General: Cradle design and use of stators or tie bars should not be attempted without first obtaining precise information on:

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.

5.3.2 Cradles, stators, and tie bars must be sufficiently rigid to prevent distortion due to unbalance forces and to prevent resonances at or near the balancing speed. They should be as light as practical to have minimum parasitic mass and thus reduce the sinsitivity of the machine as little as possible.

5.3.3 The natural period of oscillation due to the moment of inertia of the combined fixture, bearing bridge, and rotor assembly as suspended in the machine supports should be sufficiently dissimilar from the balancing speed to prevent interference with unblance readout.

5.3.4 Considerations for the design and for use of cradles, stators, and tie bars are the same for soft bearing and hard bearing balancing machines.

5.4 Cradles:

5.4.1 A cradle serves to support the workpiece in a horizontal position in the balancing machine.

5.4.2 A cradle rests on two work supports of the balancing machine.

5.4.3 A cradle must be structurally rigid and lightweight to withstand, without deflection, the forces encountered during mounting, acceleration, balancing, and deceleration of the workpiece.

5.4.4 Cradle design generally falls into two categories:

a. A single piece of machined aluminum or other light weight material.

b. An assembly of two end plates separated by thin-walled steel tubes or structural members, mechanically attached.

5.4.5 Common to all cradles, regardless of construction, are two semicircular bearing journals whose dimensions must conform to the requirements of ARP 587, Figure 1.

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

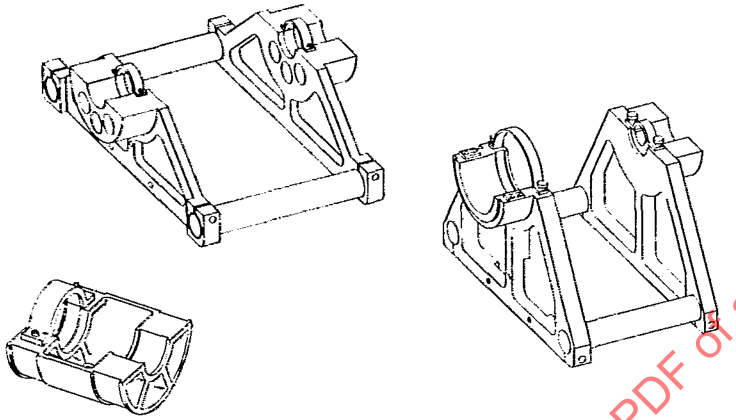
a. Entrance chamfers at the split line of the cradle's bearing journals.

b. 1/32 in. (1 mm) extra width in bearing journals.

5.4.7 Semi-Circular shaped bearing caps should be provided for each bearing journal to cover the workpiece bearings with a light pressure so that during acceleration or braking of the balancing machine the workpiece will not lift off or slip in relation to the cradle.

5.4.8 Bearing caps may be completely removable or hinged. During the balancing operation the caps should be secured to the cradle by fasteners.

5.4.9 When used on belt-drive machines, single piece cradles may require cutouts between the bearing journals, either a single one at the bottom of the cradle body or one 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.



Typical Examples of Cradles for Horizontal Balancing Machines

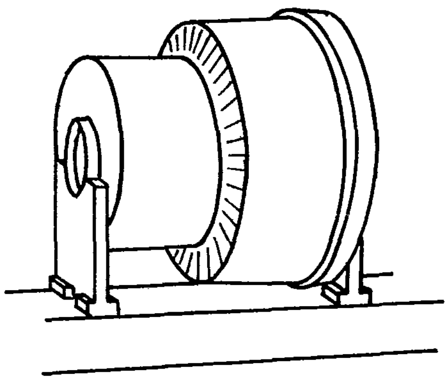
FIGURE 5

5.5 Stators:

5.5.1 If a balanced workpiece constitutes an assembled rotor which must be taken apart before it can be reassembled in the engine, new unbalance may result. If this is not acceptable, the adverse effect of assembly tolerances may be circumvented by balancing the rotor after assembly in its stator (part of engine housing). The stator then acts the same as a cradle in that it maintains precise bearing alignment and forms a rigid connection between the balancing machine bearing bridges.

Typical Stator Housing Used for Balancing a Rotor Assembly

FIGURE 6



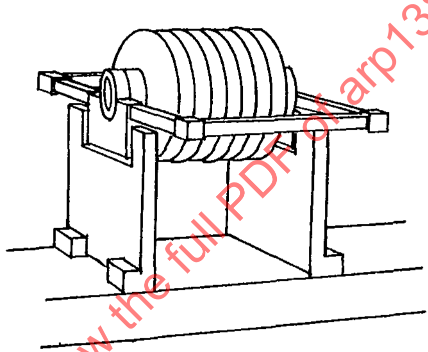
5.6 Tie Bars:

5.6.1 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 the 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 bearings.

5.6.2 Tie bars may also be used in cases where twin roller inserts with crowned roller surfaces have been mounted in the bearing halves of the balancing machines bearing bridges. The work-piece journals (or the journal-mounted inner bearing races) run directly on the twin rollers. Due to the roller surface crown and the ability of the bearing bridges to move about a vertical axis as described under 5.2, oscillation of the bearing bridge about the vertical axis may be induced, which in turn may have an adverse effect on the balancing machine readout. Tie bars prevent such unwanted oscillations.

Typical Tie Bar Setup on Horizontal Balancing Machines

FIGURE 7



6. BALANCING ARBORS

6.1 General Design and Purpose:

6.1.1 A balancing arbor serves to provide journals for a part that is to be balanced before assembly.

6.1.2 Arbors shall be rigid but as light as possible to reduce parasitic mass which might adversely affect the balance quality of the part to be balanced.

6.1.3 Journals shall be round, hardened and ground, and have a smooth surface finish. If used on twin-roller bearings or V-block bearings, both journals shall be the same size (for convenience) but never within $\pm 10\%$ of the roller diameter.

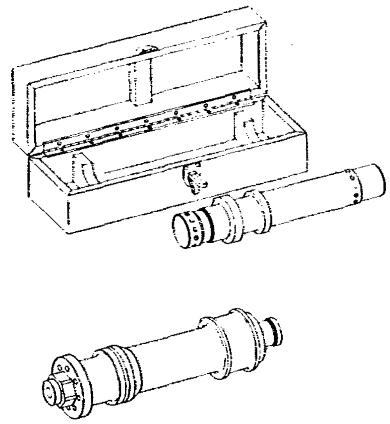
6.1.4 Means shall be provided near the arbor ends for addition or removal of mass to compensate for arbor unbalance and run-out. Correction surfaces shall have as large a radius as possible.

6.1.5 The ends of the arbor shall be flat and perpendicular to the journal surface to allow the use of thrust arrestors.

6.1.6 If rolling element bearings are used for supporting the arbor in the balancing machine, they shall conform to the requirements of Section 4.1.

6.1.7 Where greater accuracy is desired, cartridge-type arbors with preloaded angular contact bearings should be used since this design eliminates the possibility of bearing misalignment.

6.1.8 For belt driven arbors, a driving surface shall be provided (pulley). This surface shall be so dimensioned as to permit adequate torque to be transmitted at the disired balancing speed. An angular scanning mark and, if required, angular reference graduations shall be provided.



Typical Balancing Arbors
with Storage Case

FIGURE 8

6.1.9 Arbors should have a minimum of removable parts, such as locking rings, locating flanges, collars, discs, keys, etc. If removable parts are used, care must be taken to maintain the original balance condition (See also 6.1.17).

6.1.10 Provision should be made for lifting, such as removable eyebolts, if crane lift is required.

6.1.11 Provision should be made for holding arbor during rotor installation and removal. This generally would be a separate fixture.

6.1.12 End stops or shoulders should be provided for applying hydraulic or mechanical mechanisms for installing or removing rotor.

6.1.13 Rotor locating surfaces shall have a 32 micro inch (1 micro meter) or better hardened and ground surface finish.

6.1.14 Rotor locating surfaces may be made adjustable by using two fixed points and one lockable and adjustable point (eccenter) to compensate for oversized bores. With this method, 180° indexing must be used as described in 6.4.2.

6.1.15 For high precision repeatability, the locating surface should be expandable (hydraulically or mechanically).

6.1.16 Splines, keys or pins should be used to transmit driving torque and for indexing rotor.

6.1.17 All removable parts, such as clamping nuts, locating discs, or collars should be keyed or matchmarked, and their wear surfaces should be hardened and ground.

6.2 Size and Tolerances:

6.2.1 Overall dimensions should be kept as small as possible but allow clearance for shrouds and end- or belt-drive adapters.

6.2.2 All removable parts should fit the arbor with a minimum clearance to prevent repeatability errors.

6.2.3 U.S.A. Standard Transition Clearance or Interface Fits or Interference Fits may serve as guide for determining fit between arbor and rotor depending on balance tolerance requirements.

6.3 Runouts:

6.3.1 When using rolling element bearings, the axial runout between bearings should be held to a minimum to prevent bearing misalignment.

6.3.2 The axial and radial runout of the rotor locating surface in respect to the journals should be kept small to reduce a) arbor unbalance and b) the unbalance that results when the rotor is indexed 180° on the arbor.

6.4 Balance:

6.4.1 Before using the arbor its unbalance should be checked and corrected, if necessary. If the arbor unbalance is small in comparison to unbalance resulting when the rotor is indexed 180° on the arbor, it is not necessary to correct the arbor unbalance. If the unbalance resulting from indexing is unacceptable, the following procedure may be used to compensate for it by adding a dummy unbalance to the arbor.

6.4.2 Compensate arbor, using the 180° indexing method as follows:

a. Assemble rotor to arbor and mount in balancing machine.

b. Perform first balancing run and record unbalance indication for both rotor correction planes.

c. Index rotor on arbor 180°.

d. Perform second balancing run and record unbalance indication for both rotor correction planes.

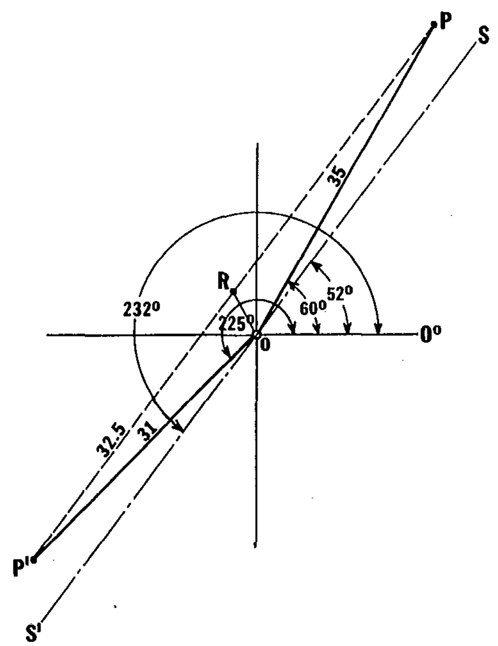
e. Calculate mean value of the two readings for each plane and correct rotor by this amount. Rotor will then be balanced and residual reading will be due to axial and/or radial runout of the arbor.

f. If desired, the residual reading can be compensated by adding or removing weight on the arbor. This will permanently compensate the arbor for a) arbor unbalance and b) the unbalance that results when a rotor of the specific design used in this procedure in indexed 180° on the arbor.

EXAMPLE

Set machine to indicate amount of unbalance and angular location (heavy spot). Assume first run indication = 35 div. at 60° second run indication (after indexing) = 31 div. at 225°

1. Plot point P (first run), using some convenient scale factor.
2. Plot point P' (2nd run)
3. Connect P and P'
4. Find mid-point R of line PP'
5. Plot a line SS' parallel to PP' and passing through center 0.
6. Determine angle of OS
7. Add a weight equal to RP (32.5 div.) at an angle equal to 52°. If required, keep adding weights at this angle until indication is at "R".
8. Repeat procedure for other plane
9. If arbor is to be corrected, add weight equal to the vector OR but in opposite direction.
10. Plot remaining residual, index rotor by 180° and make another run. Plot indication. If new distance R'P is not within tolerance, make additional correction to rotor.
11. Further indexing will show the minimum achievable residual unbalance due to lack of repeatability in locating the rotor on the arbor.



180° Indexing Method

FIGURE 9

6.5 Effect on Balancing Tolerance:

6.5.1 A rotor is being balanced about the rotational axis as determined by the arbor running in the balancing machine. This rotational axis is a straight line through the arbor's journal centers. If the rotor locating surfaces of the arbor have an axial or radial runout, the rotor is being balanced about a different axis than the one it will revolve about when mounted in its final assembly. Such discrepancies cause balance errors.

For example, assume that the rotor locating surface on the arbor has a radial runout with respect to the journals of 0.001 in.(0,025 mm) TIR, and that it is to be used for balancing a wheel weighing 100 lb (=1600 ounces), (45 kg). The arbor eccentricity will displace the rotor by 1/2 of 0.001 in. (1/2 of 0,025 mm), i.e. 0.0005 in. (0.0125 mm) from the arbor's rotational axis, causing a (static) balancing error of 0.0005 in.x 1600 oz. = 0.8 oz-in, (0,0125 mm x 45 kg = 562.5 gmm).

6.5.2 An axial runout will cause a couple or dynamic unbalance error. In all cases such errors can be detected and compensated for by indexing the rotor 180° on the arbor and following the procedure outlined under 6.4.

6.5.3 In general, the unbalance errors, introduced by an arbor (and any other tooling) should be kept as small as possible since they absorb part of the balance tolerance and therefore make balancing more expensive. It is quite common that the total of all tooling errors is equivalent to 10% or even 20% of the balance tolerance thus requiring a commensurate reduction in the residual unbalance which the operator may leave in the workpiece. It can readily be seen that balancing costs may become unacceptable if the balance tolerance has to be reduced to 1/10th of the design tolerance because tooling errors consume 90% of it. On certain production applications the tooling errors may have to be evaluated with statistical methods.

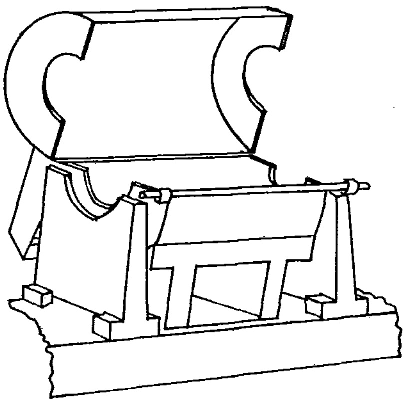
7. SHROUDS FOR HORIZONTAL BALANCING MACHINES

7.1 Purpose:

7.1.1 Protection for the balancing machine operator and the surrounding shop area.

7.1.2 Reduction of windage drag on bladed rotors, resulting in reduction of horsepower requirements and objectionable air currents in shop area.

7.1.3 Reduction of aerodynamic interference either from the rotor itself or from surroundings which might adversely affect the unbalance readout.



Typical Shroud Used on
Horizontal Balancing Machines

FIGURE 10

7.2 Design:

7.2.1 Shrouds for horizontal balancing machines usually have the shape of a closed-end cylinder, split along its' horizontal axis into a top and bottom half. The upper half (the lid) is hinged at the rear and generally counterweighed or spring suspended to facilitate opening and closing.

7.2.2 Central cut-outs should be provided in each end face to accommodate the rotor shaft or balancing arbor.

7.2.3 On large shrouds separate openings with access covers may be provided to permit addition or removal of correction weights on the rotor.

7.2.4 A shroud may be mounted to the machine's tiebars or support vibratory system. In such instances the shroud oscillates with the rotor and should be constructed as light as possible to reduce its parasitic mass.

7.2.5 A shroud may also be mounted to the pads on the machine bed as prescribed in ARP 587A.

7.2.6 Radial and axial clearances between rotor and shroud must be sufficiently large to prevent contact during the unbalance measuring cycle (acceleration, readout, deceleration) and in case of drive-belt or drive shaft failure. Shrouds mounted to the shop floor, machine beds or supports, require larger clearances if used on soft-bearing balancing machines than if used on hard-bearing machines. For shrouds mounted on the support's vibratory system or on tiebars there is no difference on clearance requirements for different machine types. Such "vibrating" shrouds require less clearance than "stationary" shrouds.

NOTE: A shroud which is entirely unattached to the balancing machine may be accidentally moved against the spinning rotor causing damage to the rotor and/or the shroud, or possibly injuring the operator.

7.2.7 Handles and clamps are generally arranged along the split opposite the hinges. Clamps or locks should be easy to operate, safe and positive since windage pressure from a rotating bladed rotor tends to force open the lid.

7.2.8 Stops should be provided to limit the travel of the open lid. They prevent damage to hinges and provide a normal reach distance for the operator. However, the lid should swing back far enough to allow unencumbered loading and unloading of the rotor.

7.2.9 Very large shrouds for outboard mounted fan rotors generally consist of a large diameter cylinder, closed at one end and open at the other. The entire shroud is rolled back and forth on a floor track to cover or uncover the fan. In closed position the shroud is attached to a stationary back plate mounted on the machine bed or support.

7.3 Safety:

7.3.1 Shrouds and machine should be equipped with electrical interlocks to prevent

a. starting of the balancing machine drive without the shroud being closed.

b. opening of the shroud before the workpiece has stopped.

8. DRIVE TOOLING - DIRECT AND BELT

8.1 General Design:

8.1.1 The mass and length of all drive adapters should be held to a minimum with sufficient strength to avoid deflection in operation.

8.1.2 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 re-assembly in other than the original position and interchanging with components from similar adapters.

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

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

8.1.5 The surfaces of the rotor to which the drive adapter assembly mates should be concentric and square to the shaft axis with sufficient accuracy so that the maximum displacement of the drive adapter assembly should, if possible, introduce no more than an error of 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 indexing is not possible, the error must be calculated. It will vary from rotor to rotor, depending upon the concentricity and squareness actually held in rotor fabrication. The magnitude is directly proportional to the mass of the drive adapter assembly and the concentricity and squareness of the rotor locating surface.

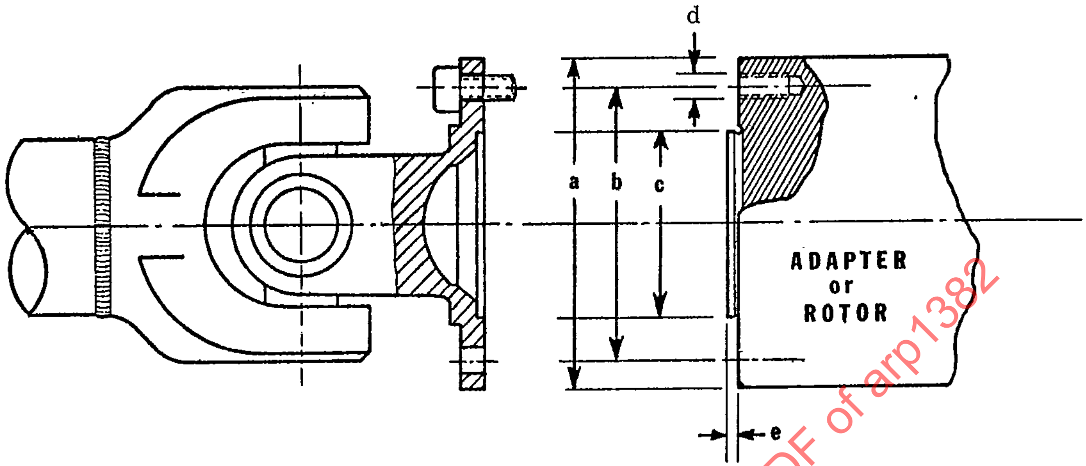
8.1.6 Provision must be included to lock the drive adapter assembly rigidly to the rotor. The locating diameter of the rotor should have a tolerance sufficiently close to permit a maximum repeatability error of 20% of the rotor tolerance when removing and reinstalling the drive adapter assembly.

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

NOTE: (2) A drive adapter assembly with an expanding fit or multiple adapters of various size may minimize the unbalance error.

8.1.7 If the balancing machine does not have reversible rotation, the drive tooling for bladed rotors should be designed for proper direction of rotation. Reduction of windage may be a consideration, although as a general rule compressors should be balanced in the same direction as engine rotation, whereas turbines should be balanced counter to engine rotation.

8.2 End-Drive Interface Dimensions: On a balancing machine with end-drive the driving torque is transmitted from the machine's headstock spindle or transmission output shaft to the workpiece via a universal joint drive shaft. The flange of the drive shaft is attached to the workpiece either directly or with the help of an adapter. Standard interface dimensions for such adapters are shown in Fig. 2A-2C of ARP 587. Alternate interface dimensions are shown in Fig. 11 below.



f = number of threaded holes, equally spaced

Interface Dimensions for End-Drive Adapters

FIGURE 11

U-Joint Driver Size	Max Torque Transmitted Ft-Lb (N·m)	Dimensions for Pilot of Adapter: a, min Inch (mm)	b +0, -.005 (-.125) Inch (mm)	c +0, -.0002 (-.005) Inch (mm)	e +0, -0.010 (-0.25) Inch (mm)	Tap Holes d	Tap Holes f
173/1	60 (80)	2.28 (58)	1.850 (47)	1.1810 (30)	0.058 (1.4)	10-24 (M5)	4
373/2	110 (150)	2.56 (65)	2.047 (52)	1.3777 (35)	0.066 (1.6)	10-24 (M6)	4
273/3	180 (250)	2.96 (75)	2.441 (62)	1.6533 (42)	0.078 (1.9)	10-24 (M6)	6
187/0	300 (400)	3.54 (90)	2.933 (74.5)	1.8502 (47)	0.098 (2.4)	5/16-18 (M8)	4
187/1	500 (700)	3.94 (100)	3.307 (84)	2.2439 (57)	0.098 (2.4)	5/16-18 (M8)	6
187/2	1000 (1400)	4.73 (120)	3.996 (101.5)	2.9525 (75)	0.098 (2.4)	5/16-18 (M8)	8
187/3	1650 (2250)	5.91 (150)	5.118 (130)	3.5430 (90)	0.098 (2.4)	3/8-16 (M10)	8
187/4	3000 (4000)	7.1 (180)	6.122 (155.5)	4.3304 (110)	0.098 (2.4)	7/16-14 (M12)	8

8.3 Belt-Drive Pulley Dimensional Tolerances: On balancing machines with belt-drive, the driving torque is transmitted from the machine's drive motor or transmission via a flat belt which runs either directly over a suitable workpiece surface or over a "driven pulley" that has been attached to the workpiece for that purpose.

The following recommendations may serve as a guide when making up the "driven pulley".

8.3.1 The locating I.D. of the driven pulley should be approximately 0.0002 - 0.0014 in.(0.005 - 0.01 mm) larger than the mating surface of the workpiece.

8.3.2 Squareness and concentricity of the pulley locating surfaces should not exceed 0.0002 in. (0.005 mm) FIR.

8.3.3 Concentricity of the pulley's pilot diameter with its belt-driven outside diameter should not exceed 0.002 in.(0.05 mm) FIR.

8.3.4 The O.D. of the pulley should be such that the resulting balancing speed falls within the machine's speed range. A tolerance of $\pm$0.010 in. ($\pm$0.25 mm) is suggested.

8.3.5 The pulley's belt-driven surface should have a crown of 0.012 - 0.240 in. height, depending on the pulley diameter. No crown is required if the driving pulley or idler pulleys are crowned.

8.3.6 The pulley's driven surface width should be 4 - 10% larger than the belt width.

8.3.7 The pulley should have shoulders approximately 2 to 3 times as high as the belt thickness and 1/4 - 1/2 in. (6.35 - 12.7 mm) wide.

8.3.8 It may be advisable to roughen the driving surface by vapor blasting or similar to increase hp transmission.

8.3.9 The pulley may have to be provided with angle reference graduations in 1° increments, labeled every 10° or 20°, if no other angle reference system is available.

8.3.10 The pulley should be as light as possible so that mounting fit tolerances do not cause unbalances greater than 20% or the rotor balance tolerance.

8.4 Drive Adapter Assemblies - Method for Balancing and Measuring Unbalance Error Introduced:

8.4.1 Balancing an End-Drive Adapter as Separate Entity: Mounting the complete drive adapter assembly on a prebalanced precision ground arbor which duplicates exactly the locating configuration of the rotor. Balance this assembly by correcting in the correction planes provided on the drive adapter assembly. Remove and reinstall drive adapter assembly on balancing arbor, preferably indexed 180° to each other for a balance verification.

8.4.2 Balancing an End-Drive U-joint Drive Shaft and Adapter While Assembled to a Rotor: With balancing machine calibrated for rotor balancing, temporarily balance the complete assembly to the minimum possible amount measurable in each correction plane of the rotor. Disconnect the machine coupling from the drive adapter, index the drive adapter rotor assembly 180° and reconnect machine coupling. If any unbalance has now been introduced, balance the assembly to one-half the indicated amount, maintaining the same location (angle) by correcting in the rotor correction planes. Remove the remaining unbalance by correcting on the U-joint drive shaft. Next, disconnect the drive adapter assembly from the rotor only, index the rotor 180° and reconnect. Again remove one-half the unbalance indicated by correcting in the rotor correction planes, maintaining the location (angle). Remove the remaining unbalance by correcting in the drive adapter assembly.

8.4.3 Balancing a Belt-Drive Pulley While Assembled to a Rotor: With balancing machine calibrated for rotor balancing, temporarily balance the complete assembly to the minimum possible amount measurable in each correction plane of the rotor. Disconnect the drive adapter assembly from the rotor only, index the rotor 180° with respect to the drive adapter assembly and reconnect. Remove one-half the unbalance indicated by correcting in the rotor correction planes maintaining the location (angle). Remove the remaining unbalance by correcting in the drive adapter assembly.

8.4.4 Alternate Method for Balancing an Adapter or Pulley While Assembled to a Rotor: With balancing machine calibrated for rotor balancing, balance rotor to approximately five times tolerance in each plane. Record amount and location or remaining unbalance in each correction plane. Disconnect drive adapter from rotor, index rotor 180° with respect to the drive adapter assembly and reconnect. Again record amount and location of unbalance indicated.

Using polar coordinate graph paper, plot the original readings as L_1 (Left), and R_1 (Right) and the second set of readings as L_2 and R_2. Connect L_1 and L_2 and R_1 and R_2 each with a straight line.

Draw a line from the origin (0) to the center of line $L_1 - L_2$ (L_c). Repeat for line $R_1 - R_2$. If the angle reference is on the drive adapter assembly, the line from the origin to L_c gives the location and scalar amount of unbalance introduced by the drive adapter assembly in the left correction plane. The same is also true for the right side. Now draw a straight line from the origin, parallel to $L_1 - L_2$ equal in length to the distance $L_c - L_2$ (one-half $L_1 - L_2$). This is the actual part unbalance. The same procedure can be followed on the right side for $R_0 - R\ 1/2$. If the location of $L_0 - L_c$ and $R_o - R_c$ are nearly in line, one correction on the drive adapter assembly may be all that is required. Use a temporary correction at the angle indicated, or 180° opposite, the new readings should approach the amount and direction of $L_o - L\ 1/2$ and $R_o - R\ 1/2$.
(See also Fig. 15.)

9. ADAPTORS FOR VERTICAL ROTATING, STATIC MACHINES

9.1 General Design and Purpose:

9.1.1 The adaptor serves to locate and hold the part to be balanced in position on the vertical spindle of the balancing machine.

9.1.2 Adaptors shall be sufficiently rigid to withstand, without deflection, the forces encountered during mounting, acceleration, and deceleration of the workpiece on the balancing machine.

9.1.3 Adaptors should be as light as possible to reduce parasitic mass which might adversely affect the balancing machine sensitivity.

9.1.4 Adaptor surfaces which locate the workpiece shall be concentric and square with the machine spindle. They may provide 360° contact with the workpiece or may consist of a number of evenly spaced points of contact such as pins, posts, or jaws. The latter must provide sufficient contact area to prevent brinelling of the workpiece.

9.1.5 Adaptor surfaces which locate the workpiece may be made adjustable to compensate for manufacturing tolerances and growth of bores during workpiece over-speeding or service life.

9.1.6 For good repeatability of the workpiece position on the balancing machine, adaptor surfaces which locate the workpiece should be hydraulically or mechanically expandable to clamp the workpiece locating surfaces. Adaptors with manually adjustable clamping surfaces generally yield a lesser degree of repeatability but are less expensive.

9.1.7 Surfaces which locate the adaptor on the spindle or which locate the workpiece should have good surface finish and should be hardened and ground.

9.1.8 Provisions should be made for positive axial location of the workpiece on the adaptor.

9.1.9 Provisions should be made in the adaptor for balance correction in one plane by addition or removal of weight.

9.1.10 Provisions should be made to lock adaptor and workpiece together so that during acceleration or braking of the balancing machine the workpiece will not lift off or slip in relation to the adaptor.

9.1.11 If the balancing machine does not have reversible rotation, the adaptors for bladed rotors should be designed for proper direction of rotation. Reduction of windage may be a consideration, although as a general rule compressor stages should be balanced inthe same direction as engine rotation, whereas turbine stages should be balanced counter to engine rotation.

9.2 Runouts:

9.2.1 Radial runout of the adaptor surfaces which locate the workpiece with respect to the machine spindle axis should be kept small to reduce

a. Adaptor unbalance
b. Workpiece unbalance caused by adaptor off-set.

9.2.2 Workpiece unbalance caused by radial runout of the adaptor surfaces may be compensated by means of 180° indexing (see Section 9.3).

9.2.3 Repeatability is of prime importance for successful compensation by 180° indexing.

9.2.4 Repeatability is the degree to which an unbalance reading can be duplicated during consecutive runs. Tooling repeatability is the ability of an adaptor to return the part to be balanced to its original position after having been released and reclamped.

9.2.5 To aid in compensation and calibration, vertical balancing machines used for balancing of jet engine components are normally equipped with one or two (electrical) compensator circuits.

9.2.6 Two-point adaptors, i.e. adaptors using two locating pins, usually spaced 90° or 120° apart, do not require adjustment for variations in part diameter. Since the part is located against the pins, similar to a "V" block, variations in locating diameters result in workpiece displacement which can be compensated.

9.3 Balance:

9.3.1 The adaptor should first be balanced. However, a precision balance is not required.

9.3.2 On a machine without electrical compensation the workpiece may then be balanced by using the 180° indexing method as follows:

a. Load workpiece by means of adaptor on balancing machine and clamp in position.

b. Perform first balancing run and record unbalance indication.

c. Index workpiece on adaptor 180°. Do not index adaptor on machine spindle.

d. Perform second balancing run and record unbalance indication.

e. Calculate mean value of the two readings and correct workpiece by this amount. Workpiece will then be balanced and any residual reading will be due to unbalance of the adaptor and/or to eccentricity of its workpiece locating diameter.

f. The residual reading can be compensated by adding or removing weight on the adaptor.