(R) Balancing Machines - Description and Evaluation
Vertical, Single-Plane, Hard-Bearing Type
for Gas Turbine Rotors

RATIONALE

SAE Document ARP5323 is being revised from current to update references to other documents, incorporate verbiage that permits the use of new and proven computer-based technology, and potentially amend references to machine classification, particularly to eliminate Class 25 vertical balancing machines from inclusion in this document. The proposed changes serve to refresh and update ARP5323 to reflect how this document is currently used within the Aerospace Industry.

ARP5323A has been reaffirmed to comply with the SAE Five-Year Review policy.

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1. SCOPE

1.1 Characteristics of vertical hard-bearing balancing machines are described which make such machines suitable for gas turbine rotor balancing.

1.2 This document specifies:

a. General dimensions and capacities

b. Performance requirements

c. Balancing speed ranges

d. Drive power requirements

e. Balancing machine spindle flange dimensions

f. Test procedures

1.3 Proving rotors and associated test masses required for the performance tests are described in ARP4162.

1.4 Test procedures are described in detail and test log samples along with a polar diagram for evaluating the test results are furnished.

1.5 The document ARP588 for vertical, single-plane, soft-bearing balancing machines, the document ARP4050 for vertical, two-plane, hard-bearing balancing machines, ISO 2953, ISO 21940-21:2012, and the available technology of hard-bearing balancing machines have been considered in the preparation of this document.

1.6 This document was developed for hard-bearing balancing machines but may also be used for existing soft-bearing balancing machines.

1.7 Purpose

The purpose of this document is to delineate the technical specifications for vertical, rotating type, hard-bearing balancing machines for measuring the amount and angle of unbalance corrections required in a single plane to balance gas turbine rotors (for Glossary of Terms and Nomenclature, see ISO 1925).

Hard-bearing machines have been used for gas turbine rotor balancing for several years. They have largely replaced soft-bearing machines. Hard-bearing machines provide permanent calibration (see ISO 1925) with first-run readout, simpler operation, easy adaptation to computerization, and eliminate support locking requirements and windage fluctuations.

This document also delineates performance tests to ensure compliance with the document.

This document was prepared to give a general description of balancing equipment capable of balancing gas turbine rotors either now in service or to be put into service in the foreseeable future. Standardization of balancing machine to rotor interfaces is intended to enable a set of tooling for a particular component to be used on a variety of machines in one capacity range.

This document may also be used as a general specification for purchasers in procuring suitable vertical single-plane balancing machines.

The performance and test requirements may be used for periodic tests and/or after repairs that may have affected the balancing machine's performance. The test procedure shall be the same as described in this document.

The performance and test requirements have been written in terms of "e_{mar}" (minimum achievable residual specific unbalance), and A-units rather than fixed physical values, such as grams, millimeters, ounces, or inches (see ISO 1925).

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 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.

ARP588   Balancing Machines - Description and Evaluation Vertical, Single-Plane, Soft-Bearing Type for Gas Turbine Rotors

ARP1382   Design Criteria for Balancing Machine Tooling

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

ARP4163   Balancing Machines: Tooling Design Criteria

ARP6217   Balancing Machines – Description and Evaluation Vertical, Single-Plane, Non-Rotating Type for Gas Turbine Rotors

2.2   ANSI Publications

Copies of these documents are available online at http://webstore.ansi.org.

ISO 1925 -2001   Balancing Vocabulary

ISO 21940-21:2012   Mechanical vibration – Rotor balancing – Part 21: Description and evaluation of Balancing Machines

ISO 21940-23:2012   Mechanical vibration – Rotor balancing – Part 23: Enclosures and other protective measures for the measuring station of balancing machines

3. GENERAL PERFORMANCE REQUIREMENTS

3.1   The balancing machine shall indicate the amount and angle of the resultant (static) unbalance in one selected plane in the rotor.

3.2   Couple Unbalance Interference

The balancing machine shall sufficiently suppress the effects of the couple unbalance from the resultant (static) unbalance indication. Requirements are outlined in 5.10.

3.3   Unbalance Indication

3.3.1   Analog devices indicating amount of unbalance shall have at least 0.125 inch (3 mm) pointer movement for measurement of 1 A-unit over a range of 20 A-units.

3.3.2   Digital devices indicating amount of unbalance shall have a resolution of at least 10% of 1 A-unit.

3.3.3   The angle resolution shall be at least 1°.

3.3.4   The amount and angle indication shall be simultaneous.

3.3.5   The amount and angle readout shall be provided on the first spin up of the rotor.

3.3.6   The radius setting shall be selectable, with a minimum of 1 inch or, alternatively, of 10 mm.

3.3.7   Amount indication shall be available in metric and/or English units (grams, ounces, and fractions thereof).

3.3.8   Unbalance indication shall be available for clockwise and counterclockwise direction of rotation.

3.4   Balancing Machine Construction

3.4.1   The machine must be constructed for floor mounting. The supporting floor / foundation must be in accordance with machine manufacturer recommendations.

3.4.2   The appropriate size of shroud must be provided and interlocked for operator safety. The shroud shall be designed to meet or exceed ISO 21940 Part 23 requirements for vertical machines.

3.4.3   The machine must be equipped with the appropriate spindle mounting flange as specified in Appendix A.

3.5   Drive for Workpiece

3.5.1   The drive system shall include all components necessary to drive the proving rotor.

3.5.2   The drive system shall be functional in both directions of rotation.

3.6   Speed of Rotation During Balancing

The machine shall be capable of operating at variable speeds within the range shown in Table 1, 4.5.2.

3.7   Drive Motor and Controls

The machine shall be capable, within the agreed upon time period, of making six consecutive starts and stops to the balancing speed of the rotor requiring the most drive power.

4.   DIMENSIONS AND CAPACITIES:

Table 1 lists the required dimensions and capacities for each machine size and associated proving rotor.

Table 1

	Characteristic	Dimensions and Capacities	Dimensions and Capacities	Dimensions and Capacities	Dimensions and Capacities	Dimensions and Capacities
4.1	Machine Class	50	100	250	500	1000
4.2	Load Capacity (lb)					
4.2.1	Maximum[a]	50	100	250	500	1000
4.2.2	Minimum[b]	2	4	10	20	50
4.2.3	Maximum $W \cdot h^2 \cdot n^{2}$[c] ($lb \cdot ft^2$ x rpm^2 x 10^6) (kgm^2 x rpm^2 x 10^6)	32 1.4	45 2.0	140 6.0	325 14	400 17
4.3	Rotor Dimensions (inch)					
4.3.1	Maximum Diameter	24	39	57	70	82
4.3.2	Maximum Height at Maximum Diameter	10	10	20	20	24
4.3.3	Rotor Envelope	See Appendix A	See Appendix A	See Appendix A	See Appendix A	See Appendix A
4.3.4	Spindle Flange (Figure) Machine Class	A3 50	A3 100	A3 250	A3 500	A4 1000
4.4	Unbalance Measurement (microinch)					
4.4.1	Required e_{mar} (equal to 1 A-unit)	30	30	50	50	50
4.4.2	Required URR	95%	95%	95%	95%	95%
4.5	Drive and Balancing Speeds					
4.5.1	Drive Power (hp)[d]	2	5.0	7.5	10	15
4.5.2	Balancing Speed Range (rpm)	750 1500	600 1200	600 1100	600 1100	400 900
4.5.3	Test Speed Range (rpm)	900 1300	800 1100	800 1000	800 1000	600 900
4.6	Proving Rotors (see ARP4162 for details)					
4.6.1	Mass (lb)	25	25	80	250	250
4.6.2	Interface Diameter (inch)	4.5	4.5	4.5	4.5	4.5

Table 1 (continued)

a   Total mass (rotor and tooling), mounted to machine spindle

b   Approximate guideline. Minimum rotor limits are generally governed by the spindle flange dimensions and the required e_{mar}.

c   The maximum Wh^2n^2 value, specified by the machine manufacturer, should have the stated capacity as a minimum requirement.

       W = Rotor + tooling mass, expressed in pounds (kilograms).
       $h = h_1 + h_2$, where h_1 is the height from the spindle flange to the rotor + tooling mass center, expressed in feet (meters), and h_2 is an assumed machine constant of 0.33 feet (0.1 m).
       n = Balancing speed (test speed) in rpm.

       If the balancing speed is given in units of 1/minute, the units of the equation are $lb \cdot ft^2/min^2$ (kgm^2/min^2).

d   Approximate guideline. The user should specify to the supplier the horsepower requirements at specific balancing speeds.

5. VERIFICATION TESTS

5.1 Requirements for Tests

To verify the claimed performance of a balancing machine, separate tests are required. The first test is for minimum achievable residual specific unbalance (e_{mar} test), the second is the test for unbalance reduction ratio (URR test), and the third is the test for couple unbalance suppression. The first two tests represent a minimum test procedure designed to establish essential compliance with the requirements for minimum achievable residual unbalance, and for combined accuracy of amount of unbalance indication and angle indication. The third test establishes compliance with the requirements that the balancing machine shall sufficiently suppress the effects of the couple unbalance from the resultant (static) unbalance indication. The test procedure will not prove compliance with all the requirements over the full range of variables nor will it define the exact reason in case the machine fails to comply.

If the machine is equipped with a compensator, its performance shall be tested.

Equipment parameters, including physical inspection of various dimensions, features, instrumentation, tooling, and accessories, shall be verified.

5.2 Duties of Supplier and User[1]

5.2.1   For these tests, the user shall provide an examiner trained in the use of balancing machines.

5.2.2   The examiner shall record the unbalance indication off the machine's instrumentation, log the values, and subsequently plot them or log the readings electronically with proven software. The supplier shall be entitled to check the accuracy of the examiner's work.

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[1] The supplier is understood to be the balancing machine manufacturer and/or supplier. The user is understood to be the prospective or actual user of the machine.

5.2.3   The supplier as well as the examiner shall be allowed to verify the condition of the proving rotor, the correctness of the test masses, and the location of the test masses.

5.3   Requirement for Machine Spindle Mounting Flange

The female location pilot of the drive spindle flange shall have a radial runout not to exceed 0.0005 inch FIR. The axial runout of the locating surface shall not exceed 0.0005 inch FIR (0.001 inch for class 1000 flange). Each reading should be taken using five complete revolutions of the spindle and be taken with a low friction dial indicator with a resolution of 0.0001 inch/division.

5.4   Requirement for Proving Rotor

The machine shall undergo the following tests with the appropriate proving rotor described in ARP4162. The correction planes on the rotor are designated:

Plane 1: Lower Plane
Plane 2: Upper Plane
Plane 3: Center Plane

5.5   Requirement for Weighing Scale

A calibrated weighing scale shall be available having sufficient accuracy to verify the correctness of the test masses.

5.6   Test and Rechecks

When a machine fails either the e_{mar}, the URR test, the couple unbalance interference test, or Compensator test, adjustments shall be permitted to the machine, after which a complete retest shall be made and the machine shall then pass. If it does not, it is considered not acceptable.

5.7   Balancing Speed for Test

The balancing speed for tests must fall within the range specified in 4.5.3.

5.8   Test for Minimum Achievable Residual Specific Unbalance (e_{mar} Test)

5.8.1   Perform the mechanical adjustment, calibration, and/or setting of the machine for plane 3 of the proving rotor, ensuring that the unbalance in the proving rotor is smaller than 10 A-units.

NOTE: Appendix D, Figure D1 gives examples to convert A-units to units of unbalance.

5.8.2   Enter the requested data in log Figure D2, so that the test conditions are permanently recorded.

5.8.3   Readings: Unbalance readings for successive runs are recorded on the test sheets, i.e., logged and subsequently plotted or recorded electronically with proven software.

5.8.4   Add unbalance mass (such as balancing clay) to the rotor. After adding the unbalance mass, the unbalance of the proving rotor shall be equivalent to 10 to 20 A-units.

Record the unbalance readings in log, Figure D3, under "Initial Unbalance".

5.8.5   Balance the rotor as well as possible (following the standard procedure for the machine) using four runs. Record the readings of all four runs on log, Figure D3.

NOTE: If residual unbalance after four runs is more than 1 A-unit, the machine will not pass the following tests.

5.8.6   Attach the test mass of 10 A-units sequentially to each of the positions in plane 3, using a sequence that is arbitrary. Record in Figure D4 of the e_{mar} test sheet (see Appendix D) the amount-of-unbalance readings in plane 3 for each position of the mass.

5.8.7   Calculate the arithmetic mean value by adding the values of each reading and dividing the result by 12. Log arithmetic mean value into Figure D: "Mean Value".

Divide each reading by the "mean value" and log the results into Figure D4 under: "Multiples of Mean Value".

5.8.8   Plot the logged readings into Figure D5, "Residual Specific Unbalance Diagram" of the e_{mar} test sheet (see Appendix D).

5.8.9   The horizontal line (mean value) represents the arithmetic mean of the readings in plane 3. Two dotted lines represent ±12% of the arithmetic mean, which account for 1 A-unit + 20% for the effects of variation in the position of the masses and scatter of the test data.

5.8.9.1   The machine is deemed to have passed the e_{mar} test, i.e., the claimed minimum achievable residual unbalance has been reached, if the following condition is met:

At least 11 of the 12 points are within the range given by the two lines representing ±12% of the arithmetic mean line.

5.9   Test for Unbalance Reduction Ratio (URR Test)

5.9.1   This test is intended to check the combined accuracy of amount-of-unbalance indication, and angle indication.

This test consists of a set of 11 runs. The test is run with a stationary 25 A-unit test mass ($U_{stationary}$) and a travelling 125 A-unit test mass in plane 3.

5.9.2   Readings: Unbalance readings for successive runs are recorded on the test sheets, i.e., logged and subsequently plotted, or recorded electronically with proven software.

5.9.3   Preparation of Test Sheets (Appendix E)

Prepare the test logs on the test sheet prior to making the actual runs so that test data are entered in proper order.

Preparation of the test log required the following steps:

a.   Enter the requested data in log Figure E1, so that the test conditions are permanently recorded.

b.   Arbitrarily choose one of the 12 mass positions in plane 3 for the stationary mass and enter the degree value in the "Plane 3 Stationary" column on the "Run No. 1" line of the log (Figure E2).

c.   Arbitrarily choose one of the remaining 11 positions as the starting position for the traveling test mass in plane 3 and enter the degree value in the log (Figure E2).

d.   Enter successive positions for successive runs in the log for the traveling mass, letting it travel in ascending 30° intervals. Skip the stationary mass position, since both masses cannot occupy the same position.

5.9.4   Test Procedure

a.   Perform steps described in 5.8.1 through 5.8.5, unless an e_{mar} test has immediately preceded this one.

   NOTE: If residual unbalance after four runs is more than 1 A-unit, the machine will not pass the following tests.

b.   Add the stationary and travelling test masses in starting position (Run No. 1 line) to plane 3 of the proving rotor as shown in the respective log (Figure E2).

c. Make 11 successive runs. After each run record the readings for plane 3 in the log, and advance the travelling test mass to the next position as shown in the log.

   NOTE: Record amount and angle readings in the log, Figure E2.

d. Divide amount readings by the value of the stationary mass to obtain values in multiples of the stationary mass.

   Enter these in the columns "Multiples of U$_{stationary}$" of the log. Figure E2.

5.9.5   Plotting the Test Data

a. The test sheet (Figure E3) contains a diagram with 11 sets of concentric URR limit circles. From the inside outwards, the concentric circles designate the limits for URR values of 95, 90, 85, and 80%. If a test point falls within the innermost circle (or on the line), the reading qualifies for a 95% URR. If a test point falls between the 95% and the 90% circle, the reading qualifies for a 90% URR.

b. Enter the angular position of the stationary test mass in plane 3 on the short line above the arrow in the URR limit diagram. Mark radial lines in 20° intervals by entering degree markings in 20° increments (rising clockwise) on all short lines around the periphery of the diagram.

c. Using the amounts (multiples of e$_{mar}$) and angle values from the log, plot the results of plane 3 (multiples of U$_{stationary}$, Figure E2) in the form of test points (dots) on the URR diagram, using the amount scale as shown next to the vertical arrow.

5.9.6   Evaluation of Plotted Test Points

The test points on the test sheet shall lie within the URR limit circles that correspond to the value stated in 4.4.2. However, one test point is allowed to lie outside. If these requirements are not met, the machine fails the test, in which case the rules given in 5.6 apply.

5.10   Test for Couple Unbalance Influence

5.10.1   This test is intended to check the influence of a couple unbalance in the proving rotor on the indication of the resultant (static) unbalance.

5.10.2   Performance Requirements

The machine shall indicate 6.25 A-units or less of resultant (static) unbalance, when two tests masses of 125 A-units each are added to plane 1 and plane 2 of the proving rotor simultaneously at opposite angles.

5.10.3   Test Procedure

a. Remove all test masses from proving rotor.

b. Perform steps described in 5.8.1 through 5.8.5 unless an e$_{mar}$ test or URR test has immediately preceded this one.

   NOTE: If residual unbalance after four runs is more than 1 A-unit, the machine will not pass the following tests.

c. Apply one 125 A-unit test mass at 60° in plane 3 of the proving rotor.

d. Run the machine, and record the unbalance amount readings in the test log Figure F1.

e. Repeat steps 5.10.3.c and 5.10.3.d three more times, each time moving the 125 A-unit test mass to the angles shown in the test log Figure F1.

f. Calculate the arithmetic mean value by adding the values of each reading and dividing the result by 4. Log arithmetic mean value into Figure F1: "Mean Value: (=Sum/4)".

g. Remove the 125 A-unit test mass from plane 3 of the proving rotor.

h. Apply one 125 A-unit test mass at 60° in plane 1 of the proving rotor, and another 125 A-unit test mass at 240° in plane 2.

i. Run the machine, and record the indicated resultant (static) unbalance in the test log Figure F1 ("Test Run 5-8, Amount Reading Plane 3")

j. Repeat steps 5.10.3.h and 5.10.3.i three more times, each time moving the test masses to the angles shown in the test log.

k. Multiply each reading by 100, then divide the results by the "mean value", and log these results into Figure F1 under: "Percent of Mean Value".

l. Conformance requirement: All four values "Percent of Mean Value" shall be equal to or less than 5.00.

5.11   Compensator Test

5.11.1   Specific Performance Requirements

The compensation shall provide a consistent readout of 1 A-unit or less at the end of the compensation procedure.

NOTE: This test checks the compensator by simulating the indexing of a rotor by only moving test masses.

5.11.2   Test Procedure

a. Use the balanced proving rotor (after 5.8.1), or ensure that the unbalance is smaller than 10 A-units.

b. Log the unbalance readings in test sheet Figure G1 under "Initial Unbalance".

c. Apply one 25 A-unit test mass at 30° and one 125 A-unit test mass at 150°, both in plane 3.

d. Run the balancing machine and set the compensator for the first step, according to the manufacturer's manual.

e. Stop the machine, move the 125 A-unit test mass from the 150° position to 330°, (180° shift) to simulate the indexing procedure.

f. Run the balancing machine and set the compensator for the second step, according to the manufacturer's manual.

g. Stop the machine, remove the 125 A-unit test mass located at 330°.

h. Run the balancing machine and set the compensator to read rotor unbalance.

i. Log the unbalance readings in test sheet under Figure G1 under "Unbalance with Compensation".

5.11.3   Conformance Requirements

The compensator conforms if readings are 1 A-unit or less with the remaining test mass of 25 A-units at 30°.

NOTE: Appendix D, Figure D1 gives examples to convert A-units to units of unbalance.

6. NOTES

6.1   Revision Indicator

A change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY SAE SUBCOMMITTEE EG-1A, BALANCING OF
COMMITTEE EG-1, AEROSPACE PROPULSION SYSTEMS SUPPORT EQUIPMENT

APPENDIX A - ROTOR ENVELOPE ABOVE SPINDLE FLANGE IN
ENCLOSURE/SPINDLE FLANGE DIMENSIONS
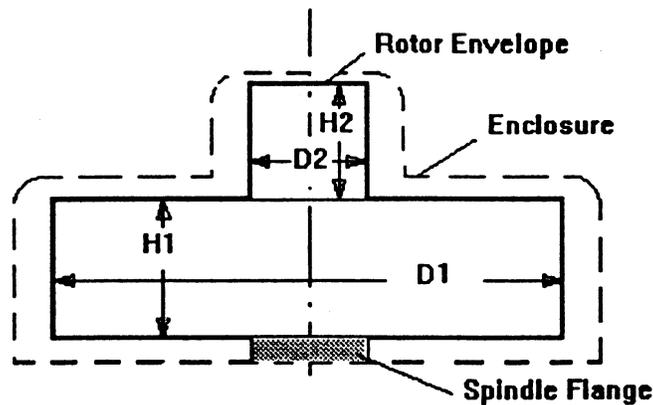
Figure A1 - Rotor envelope

Table A1 - Maximum rotor envelope dimensions in enclosure

Machine Class	D1	H1	D2	H2
50	24	10	-	-
100	39	10	-	-
250	57	20	10	16
500	70	20	10	16
1000	82	24	10	16

NOTE 1: Dimensions given in inches. For specific applications dimensions of the enclosure should be agreed upon between user and supplier.

NOTE 2: For safe operation with bladed rotors the enclosure should be interlocked with the drive and have a zero speed interlock to prevent the enclosure from being opened when the rotor is turning.

NOTE 3: Design of enclosure is to conform to the requirements of ISO 21940 Part 23 Balancing Machines - Enclosures and other protective measures for the measuring station of balancing machines.

Figure A2 - Deleted

6.00 MIN.
DIA

5.250
DIA

.03 X 45°

$\dfrac{4.5000}{4.5002}$ DIA

OPTIONAL
BORE

$\dfrac{0.200}{0.180}$

3/8-16 UNC-2B
TAP (4) HOLES
EQUALLY SPACED
MIN. 1.0 DEEP

UNDERCUT .030 WIDE
X .010 DEEP

DIMENSIONS IN INCHES.   TOLERANCE ± .005 UNLESS
                                         OTHERWISE NOTED.
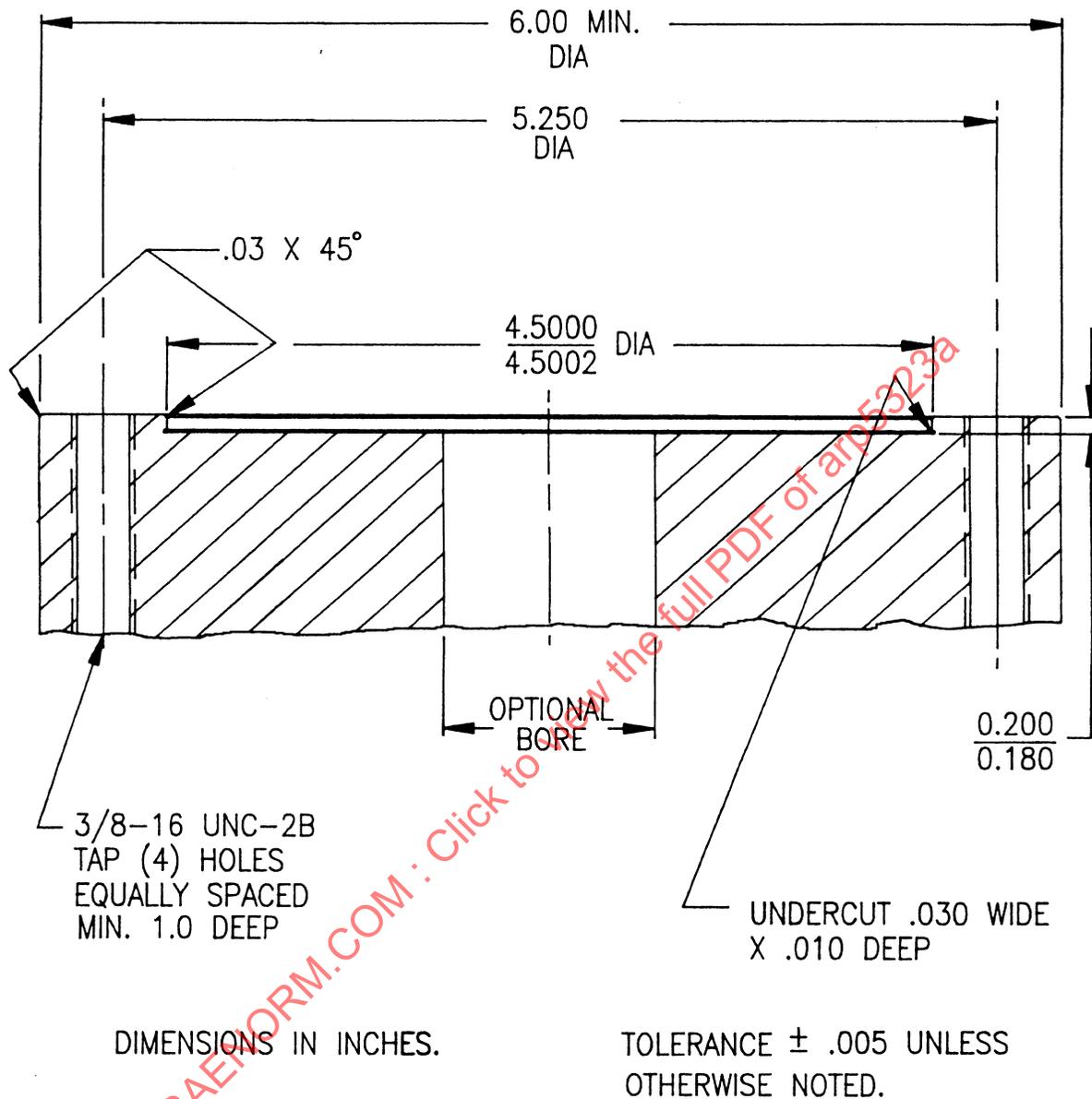
Figure A3 - Spindle flange, machine class 50, 100, 250, 500

8.50 MIN
DIA

7.750
DIA

5.250
DIA

.03 X 45°

4.5000
4.5002 DIA

0.200
0.180

OPTIONAL
BORE

UNDERCUT .030 WIDE
X .010 DEEP

3/8-16 UNC-2B
TAP (4) HOLES
EQUALLY SPACED
MIN 1.0 DEEP

3/8-16 UNC-2B
TAP (6) HOLES
EQUALLY SPACED
MIN 1.0 DEEP
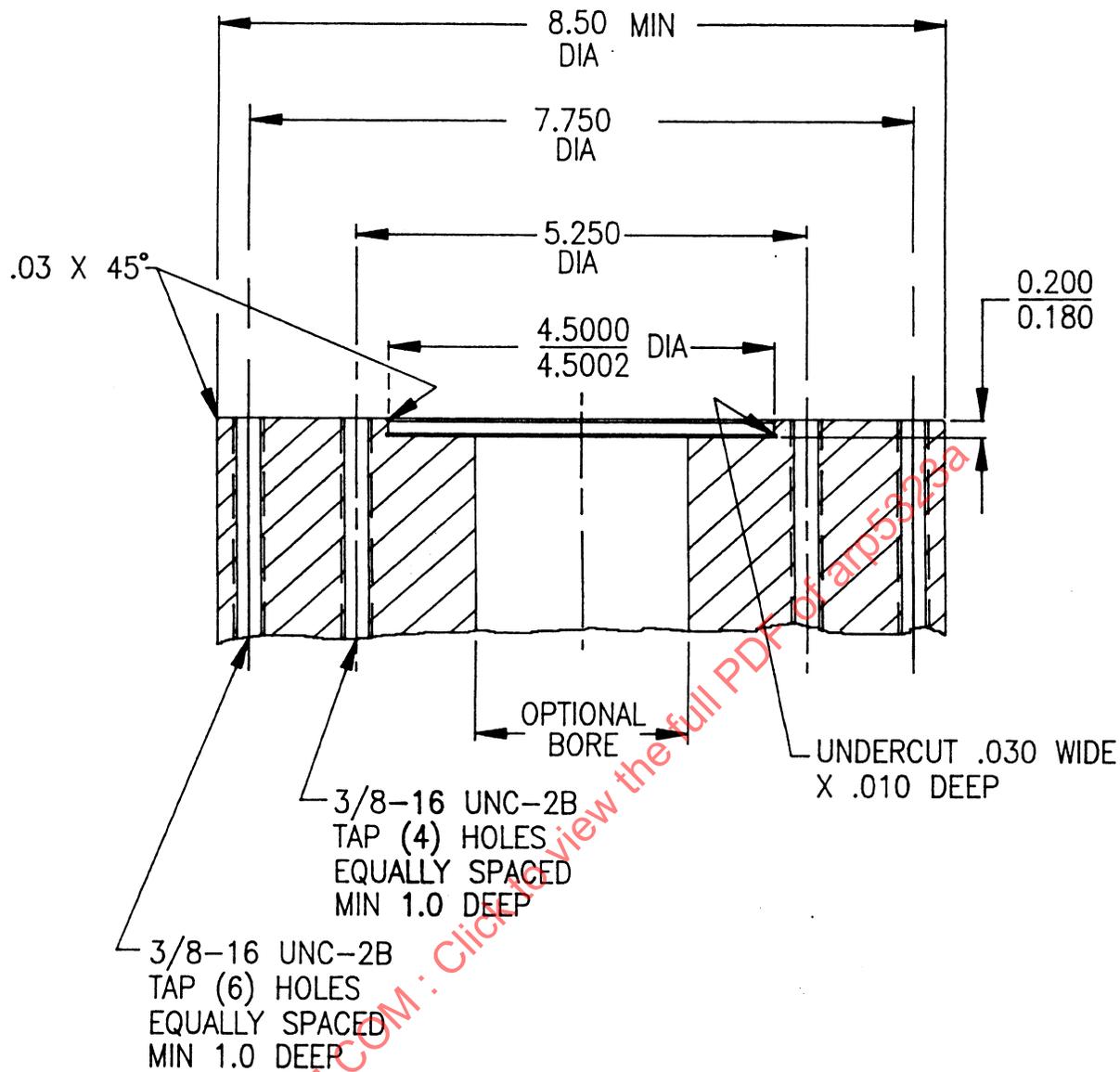
DIMENSIONS IN INCHES.

TOLERANCE ± .005 UNLESS
OTHERWISE NOTED.

Figure A4 - Spindle flange, machine class 1000

APPENDIX B - DETAILS FOR CONTRACTUAL NEGOTIATIONS

B.1   The following paragraphs should help the buyer and the seller of balancing machines during contractual negotiations. The xx-values may be adjusted for any particular requirement. Test procedures to ensure compliance with these requirements are beyond the scope of this document.

B.1.1   The balancing machine should operate in a satisfactory manner over an ambient temperature range of xx to xxx °F, and at xx% relative humidity.

B.1.2   The machine should comply with all applicable local, state, and federal electrical, mechanical, and safety code and standards.

B.1.3   The electrical system should operate satisfactorily with line voltage variations up to ±xx%, line frequency variations up to ±xx% and waveform harmonic distortion of up to xx%.

B.1.4   All electrical systems should be arranged for operation from a supply of xxx V ± xx V, x-phase, xx cps.

B.1.5   Any need for radio interference suppression should be specified.

B.1.6   Balancing machine performance is sensitive to environmental vibrations. No general requirement can be specified due to the wide range of environmental frequencies and amplitudes, and due to the varied response of different balancing systems to these excitations.

B.1.7   The prospective balancing machine user should specify the rotor envelope, if deviating from Table A1.

B.1.8   The prospective balancing machine user should specify the required horsepower at specific balancing speeds (see 4.5.1).

B.1.9   By mutual agreement, all tests should be run either at the supplier's plant before shipment and/or at the user's plant after installation. Proving rotors, test masses, etc., for all tests are to be provided by the supplier or the user. See ARP4162.

B.1.10   Installation and service.

B.1.11   Operating and maintenance personnel training.

B.1.12   Operating manual, maintenance manual, circuit diagrams, spare parts ordering information.

B.1.13   Balancing machines are sensitive to foundation conditions. For optimum performance, manufacturer's instructions for foundation requirements are to be followed.

APPENDIX C - PROVING ROTORS

C.1   A full description of proving rotors and test masses to perform the described tests can be found in ARP4162.

Masses and interface diameters of related proving rotors for balancing machine classes 50 to 1000 can be found in 4.6.

APPENDIX D - TEST SHEETS FOR E$_{MAR}$ TEST

D.1   For explanation of the test, i.e., logging and plotting of readout and evaluation of the results, see 5.8.

1 A - Unit	Mass of Proving Rotor	Units of Unbalance	Amount of Unbalance
(a) microinches	(b) lb	ounce-inch (oz-in)	(a) x (b) x 16 x 10^{-6}
		gram-inch (g-in)	(a) x (b) x 454 x 10^{-6}
		gram-millimeter (g-mm)	(a) x (b) x 11.5 x 10^{-3}

Example 1:

1 A - Unit = 30 μin
Mass of Proving Rotor: W = 25 lb
Units of Unbalance: gram-inch (g-in)

$$U = (a) \times (b) \times 454 \times 10^{-6}$$

$$U = 30 \times 25 \times 454 \times 10^{-6}$$

$$U = 0.3405 \text{ g-in}$$

Example 2:

1 A - Unit = 50 μin
Mass of Proving Rotor: W = 250 lb
Units of Unbalance: gram-millimeter (g-mm)

$$U = (a) \times (b) \times 11.5 \times 10^{-3}$$

$$U = 50 \times 250 \times 11.5 \times 10^{-3}$$

$$U = 143.75 \text{ g-mm}$$

Figure D1 - Conversion from A-units of unbalance

Date of test:..Location of test:...

Machine operated by: ....

Readings taken and logged by:...

Machine tested, make:.............................. Model:...

Proving rotor, type:..................................... Serial Nr.:...

Proving rotor, mass:..............lb ....kg

1 A Unit = ...μin Test speed:.......................................rpm

10 A Unit test mass...................oz Effective radius ....in

........................g ....mm

Effective unbalance...[1]

[1] Units of effective unbalance in oz-in, g-in, or g-mm

Figure D2 - Log for e$_{mar}$ test

	Plane 3	
	Amount	Angle
Initial Unbalance		
Run 1		
Run 2		
Run 3		.
Run 4		

Figure D3 - Balancing of proving rotor - log

Position of Test Mass	Amount of Unbalance	Multiples of Mean Value
Angle	Plane 3	Plane 3
0^0 (360^0)		
30^0		
60^0		
90^0		
120^0		
150^0		
180^0		
210^0		
240^0		
270^0		
300^0		
330^0		

Sum	
Mean Value	

Figure D4 - Test log