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TEST CHARACTERISTICS OF A WELDED ROTOR IN A 36 000-RPM LUNDELL ALTERNATOR

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • NOVEMBER 1973

1. Report No. NASA TM X-2944	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle TEST CHARACTERISTICS OF A WELDED ROTOR IN A 36 000-RPM LUNDELL ALTERNATOR		5. Report Date November 1973
		6. Performing Organization Code
7. Author(s) Stacy Lumannick, David W. Medwid, and George Tulisiak		8. Performing Organization Report No. E-7535
		10. Work Unit No. 503-35
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Two four-pole Lundell-type rotors consisting of magnetic and nonmagnetic materials were fabricated by weld-depositing Inconel 625 between two sections of AISI 4617 steel. The rotors had a major diameter of 8.28 cm (3.26 in.). Saturation curves for load and no-load conditions with one of the rotors installed in a 1200-Hz Brayton-cycle research alternator are presented. The other identical rotor was spin-tested to a speed of 63 000 rpm, which was equal to 175 percent of the rated speed.

17. Key Words (Suggested by Author(s)) Lundell rotor; Rotational stresses; Welded-rotor characteristics		18. Distribution Statement Unclassified - unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 14	22. Price* Domestic, $2.75 Foreign, $5.25

* For sale by the National Technical Information Service, Springfield, Virginia 22151

TEST CHARACTERISTICS OF A WELDED ROTOR

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SUMMARY

Two four-pole Lundell-type rotors consisting of magnetic and nonmagnetic materials were fabricated by weld-depositing Inconel 625 between two sections of AISI 4617 steel. The rotors had a major diameter of 8.28 centimeters (3.26 in.). Saturation curves for load and no-load conditions with one of the rotors installed in a 1200-hertz Brayton-cycle research alternator are presented. The other identical rotor was spin-tested to a speed of 63 000 rpm, which was equal to 175 percent of the rated speed. The test was terminated at 63 000 rpm because of failure of the test-rig turbine drive spindle.

INTRODUCTION

A Brayton-cycle space power system being tested at the NASA Lewis Research Center has a 1200-hertz four-pole Lundell alternator. The rotor (fig. 1) for this alternator consists of two separate magnetic sections with north poles on one section and south poles on the other section. A third section between the two magnetic sections consists of a nonmagnetic metal. These three sections are bonded together by brazing (ref. 1). Overspeed testing of such a brazed rotor to failure at 90 000 rpm (ref. 2) revealed that the failure occurred in the braze area; the strength of the rotor was more than adequate for the design speed of 36 000 rpm.

In an attempt to develop an alternative method of fabricating this type of rotor, Inconel 625 (ref. 3) was weld-deposited between two sections of AISI 4617 steel. When only a small number of rotors are to be fabricated, welding is generally easier and less expensive than other methods of fabrication.

The objective was to meet the magnetic requirements with weldable materials that could be subjected to high rotational stresses. Spin testing to failure would provide a strength comparison with other methods of fabrication. A secondary objective was to develop a method of fabrication that might be applicable to similar rotors in future space power systems.

DESCRIPTION OF ALTERNATOR AND ROTOR

The 1200-hertz Brayton-cycle research alternator is a three-phase 120/208-volt machine. Rated output at 36 000 rpm is 14.3 kilovolt-amperes with a 0.75 lagging power factor (ref. 4). For the test results presented in this report, all the alternator field coils were connected in series. The brazed rotor for this alternator has magnetic sections consisting of AISI 4340 steel separated by a nonmagnetic section of Inconel 718. A tie bolt hole drilled through the entire length of the rotor is included. In the space power system application, a tie bolt through the hole attaches a turbine on one end and a compressor on the other end of the rotor.

Magnetic AISI 4617 steel and nonmagnetic Inconel 625 were selected for the welded rotor. Compared to AISI 4340, the AISI 4617 has a lower magnetic resistance (reluctance) and a lower yield strength. However, the lower yield strength was still more than adequate for the overspeed specifications for this alternator. Overspeed specifications were 120 percent of the design speed of 36 000 rpm. Inconel 625 was selected because it is less susceptable to cracking than Inconel 718 in this type of welding application.

ROTOR FABRICATION

The cross-sectional area of the magnetic section of the rotor varies axially. Templates were made which duplicated these cross-sectional areas at several axial locations. The templates were then attached to a common base at intervals equal to the rotor-axial-location intervals. The spaces between the templates were filled with a plastic material to form a mold with a smoothly varying contour from template to template. With this mold as a duplicating guide, the contour was machined into two AISI 4617 steel billets (figs. 2 and 3).

The nonmagnetic section was fabricated by depositing uncoated Inconel 625 wire on the two machined billets by the gas-tungsten-arc-welding (GTAW) method (figs. 4 and 5). This depositing of the Inconel 625 was continued until the required distance between the two magnetic sections was established (fig. 6) and the gap completely filled. Periodic ultrasonic and fluorescent liquid penetrant inspections were made of the deposited weld material to check for cracks. The completed billet was then heat-treated at 621° C (1150° F) for 1 hour and machined to the final configuration. Final machining included a 1.27-centimeter- (0.50-in.-) diameter tie bolt hole drilled through the length of the rotor. Additional ultrasonic and fluorescent inspections were made after final machining.

APPARATUS

A schematic diagram of the magnetic test setup is shown in figure 7. The test facility consisted of a dynamometer running at 1440 rpm and two stepup gear boxes. The externally colled gear boxes each have a stepup ratio of 5:1. A separate system using MIL-L-7808 oil cooled the alternator. An air-oil mist lubricated the alternator bearings.

A three-phase resistive and reactive load bank was used to absorb the power output of the alternator and to establish the power factor. Short-circuit switches were used to connect the three-phase fault to the alternator.

The facility used for the spin test consisted of an air-driven turbine mounted in a vertical position on the top of a vacuum chamber. Reverse nozzles on the turbine were used for braking. A magnetic pickup on the turbine measured speed. The vacuum chamber had an inner liner of steel plates for shrapnel protection.

The spin test assembly (fig. 8) consisted of a vertically suspended rotor and attaching hardware. A lower catcher bearing with a tapered bore was mounted below the rotor in case the drive-turbine shaft failed. A journal catcher bearing with a 0.30-centimeter (0.12-in.) diametral clearance was mounted at the upper end of the suspended rotor.

PROCEDURE

Two rotors were fabricated for the tests. Micrometer measurements of the diameters of the two rotors were made before and after spin testing of the locations shown in figure 9.

One rotor was proof tested by accelerating at approximately 60 rpm per second to 50 000 rpm in several stop-and-measure steps. After 10 minutes at 50 000 rpm, measurements of the rotor revealed no yielding. This rotor was then installed in a research alternator for magnetic testing.

During the magnetic testing the following measurements were made: (1) shaft speed, (2) electrical frequency, (3) voltage and current for each phase, (4) power output, and (5) field current and field voltage. Data for the three-phase short-circuit test were taken by connecting a balanced three-phase fault to the alternator terminals.

For the spin-to-destruction test of the second rotor, the catcher bearings were removed. This rotor was accelerated at approximately 60 rpm per second to 50 000 rpm; the test was then stopped for measurements of the rotor diameter. The stop-and-measure procedure continued at 3000-rpm intervals between 50 000 rpm and the turbine drive spindle failure at 63 000 rpm. Spinning time at each interval was 10 minutes.

RESULTS AND DISCUSSION

Magnetic Testing

Saturation curves for open-circuit and for three-phase short-circuit characteristics are shown in figure 10. For comparison with the original brazed rotor, the dashed line curve from reference 4 is presented.

The same research alternator was used in these tests and in the tests of reference 4. This research alternator also has two windings per field coil, one for series excitation and one for shunt excitation. In these saturation tests and in the saturation tests of reference 4, the series and shunt fields were connected in series.

Load-saturation curves are shown in figure 11. For the design point of 120 volts, the welded rotor required a field excitation of 1850 ampere-turns at unity power factor and 2150 ampere-turns at a power factor of 0.75. The dashed-line curve from reference 4 shows the original brazed rotor required a field excitation of 2000 ampere-turns at unity power factor and 2500 ampere-turns at a power factor of 0.75. These performance curves indicate the welded rotor is more than adequate magnetically.

Spin Testing

At 63 000 rpm, the turbine drive spindle (fig. 12) failed. The alternator rotor was recovered, and, although dented and scratched, the rotor itself was intact. The rotor had survived at 63 000 rpm (175 percent of rated speed). For comparison, rotor failure occurred at 95 000 rpm for the brazed rotor and 110 000 rpm for the composite cast rotor (table I).

The cause of the spindle failure was not apparent, but it may possibly have resulted from some deformation of the alternator rotor. On the other hand, post-test inspection of the tie bolt hole revealed no out-of-tolerance growth in diameter or elliptical deformation.

The equation (ref. 5) used to calculate the maximum tangential stress at the periphery of the tie bolt hole was

$$S_t = \frac{1}{4}\,\frac{\gamma\omega^2}{386.4}\left[(3 + v)R^2 + (1 - v)r^2\right] \times 0.69$$

for SI units, or

$$S_t = \frac{1}{4}\frac{\gamma\omega^2}{386.4}\left[(3 + v)R^2 + (1 - v)r^2\right]$$

for U. S. customary units, where γ is the density of the material, ω is the rotational speed, v is the Poisson ratio, R is the outer radius, and r is the inner radius.

Based only on the calculated tangential stress of 48 100 newtons per square centimeter (69 000 $\mathrm{lb/in.}^2$) at 63 000 rpm, the periphery of the tie bolt hole was in the yield range of the AISI 4617 material. Additional ultrasonic and fluorescent penetrant inspection revealed no obvious material separation. Hardness tests also showed no abnormal material situation (fig. 13). Thus, 175 percent (63 000 rpm) of the rated speed was achieved, but, within the strength limit of the AISI 4617 steel, a higher speed might not have been achievable.

SUMMARY OF RESULTS

As an alternative to brazing AISI 4340 steel and Inconel 718 for a four-pole Lundell-type rotor, two rotors were fabricated by weld-depositing nonmagnetic Inconel 625 between two sections of magnetic AISI 4617 steel. One rotor was proof tested at 50 000 rpm and then installed in a research alternator. The magnetic characteristics of this welded alternator exceeded those of the original brazed-construction rotor.

The second identical rotor was spin-tested to 63 000 rpm (175 percent of the rated speed) and was still intact, compared to the brazed and composite rotors, which failed at 95 000 and 110 000 rpm, respectively.

At 63 000 rpm, the turbine drive spindle of the spin rig failed and the testing was discontinued. At speeds above the 60 000 rpm level, the calculated stresses at the periphery of the tie bolt hold were in the yield range of the AISI 4617 steel, which suggested that the rotor burst speed may not have been substantially higher than the achieved testing speed.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 3, 1973,
503-35.

REFERENCES

1. Dunn, James H.: The 1200-HZ Brayton Electrical Research Components. Rep. APS-5286-R, AiResearch Mfg. Co. of Arizona (NASA CR-72564), Mar. 19, 1969.
2. Davis, J. E.: Design and Fabrication of the Brayton Rotating Unit. NASA CR-1870, 1972.
3. Anon.: Handbook of Hunington Alloys. Hunington Alloy Products Div., International Nickel Co., Inc.
4. Repas, David S.; and Edkin, Richard A.: Performance Characteristics of a 14.3-Kilovolt-Ampere Modified Lundell Alternator for 1200 Hertz Brayton-Cycle Space-Power System. NASA TN D-5405, 1969.
5. Roark, Raymond J.: Formulas for Stress and Strain. Third ed., McGraw-Hill Book Co., Inc., 1954.

TABLE I. - PUBLISHED VALUES OF ROTOR AND MATERIAL CHARACTERISTICS

Rotor	Failure speed, rpm	Magnetic material	Yield strength of magnetic material[a]		Nonmagnetic material	Yield strength of magnetic material[a]	
			N/cm^2	lb/in.^{2}		N/cm^2	lb/in.^{2}
Welded	63 000	AISI 4617	[b]42 700	[b]62 000	Inconel 625	[b]44 800	[b] 65 000
Brazed (ref. 2)	95 000	AISI 4340	45 100	65 400	Cast Inconel 718	75 800	110 000
Composite cast (ref. 2)	110 000	AISI 4340	[b]42 700	[b]62 000	Cast MAR M211	[b]86 200	[b]125 000

[a]Yield strength varies with optimized heat treatment for each material combination.
[b]Handbook value.

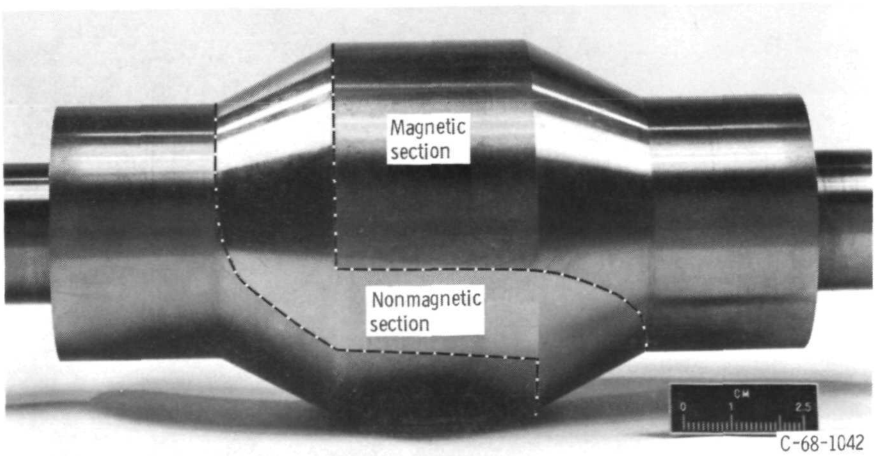

Figure 1. - Alternator rotor.

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Figure 2. - Machined billet of AISI 4617.

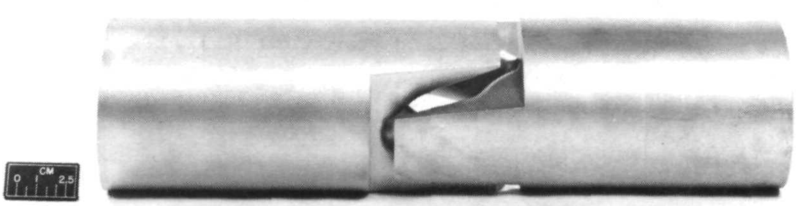

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Figure 3. - Relative positions of AISI 4617 billets before welding.

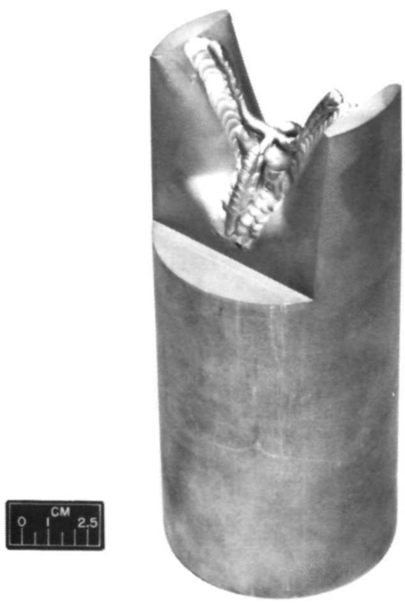

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Figure 4. - Machined billet with deposited Inconel 625.

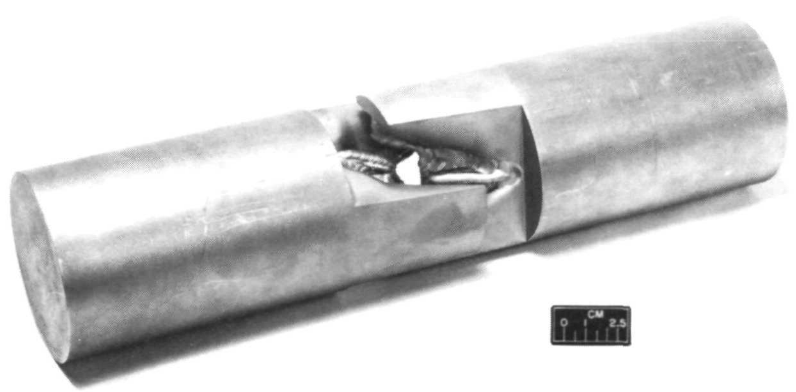

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Figure 5. - Relative positions of billets with deposited Inconel 625 before joining.

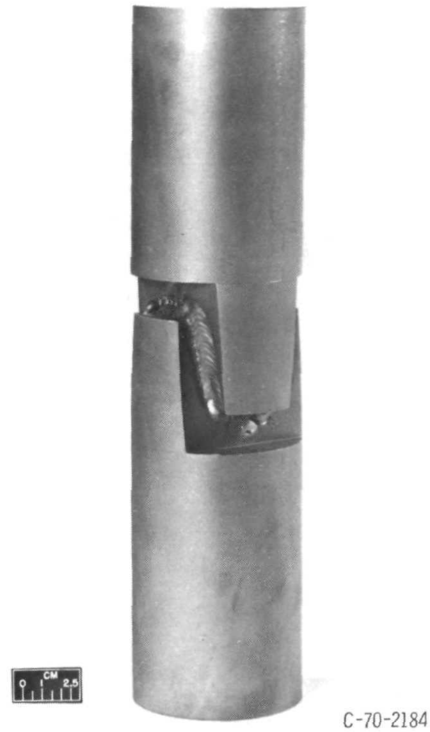

Figure 6. - AISI 4617 billets joined by Inconel 625.

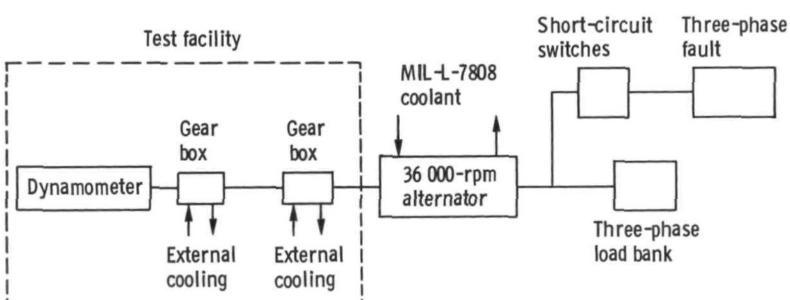

Figure 7. - Magnetic test setup.

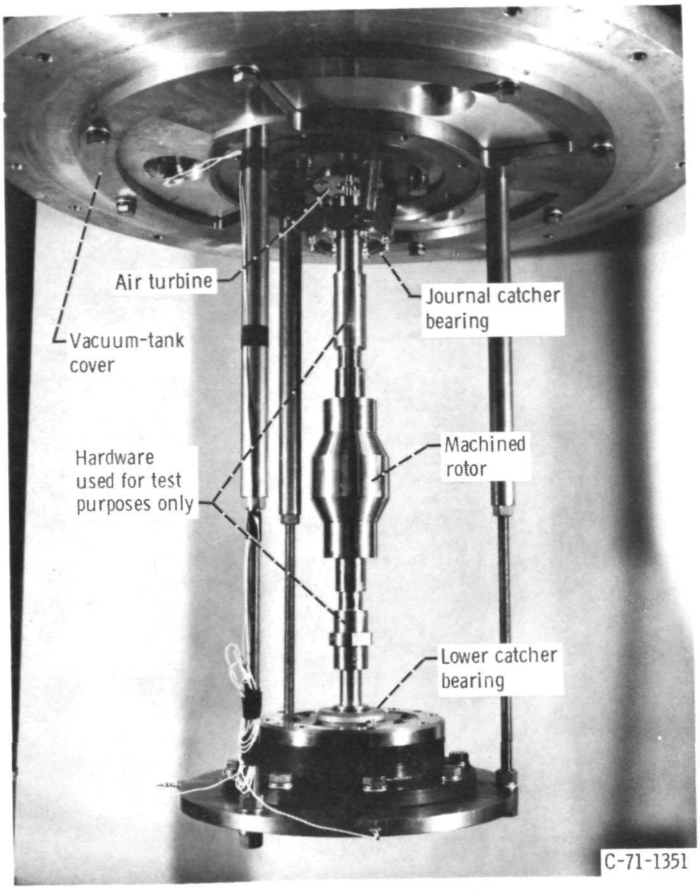

Figure 8. - Spin-test assembly.

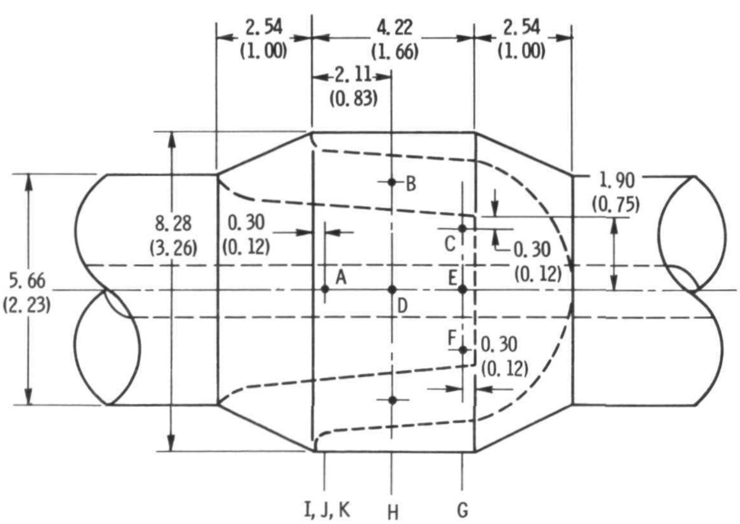

Figure 9. - Rotor diameter measurement locations. (Dimensions in centimeters (in.).) (From ref. 2.)

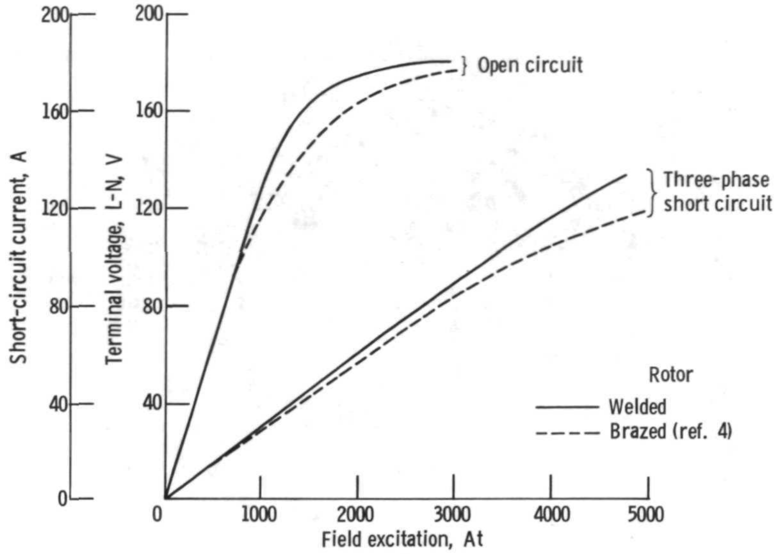

Figure 10. - No-load saturation curves for 1200-hertz Lundell alternator with welded rotor compared with those for brazed rotor of reference 4.

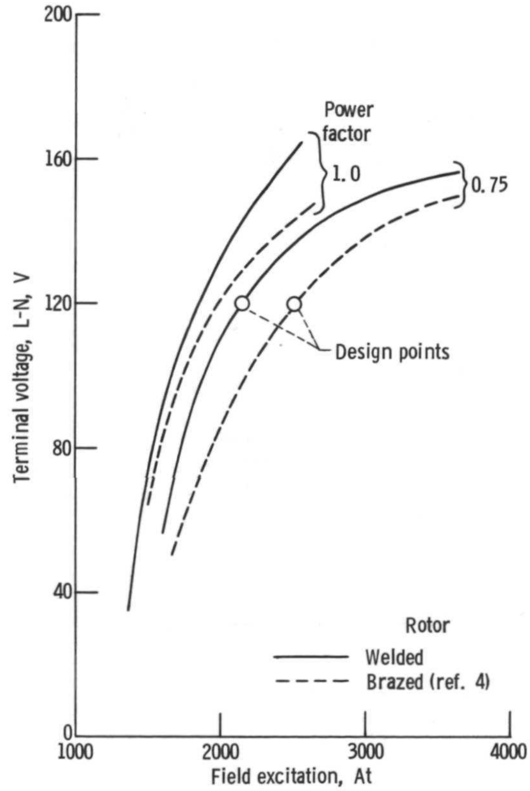

Figure 11. - Load-saturation curves for 1200-hertz Lundell alternator with welded rotor compared with those for brazed rotor of reference 4. Rated current, 39.7 amperes.

Figure 12. - Failed spindle of drive turbine.

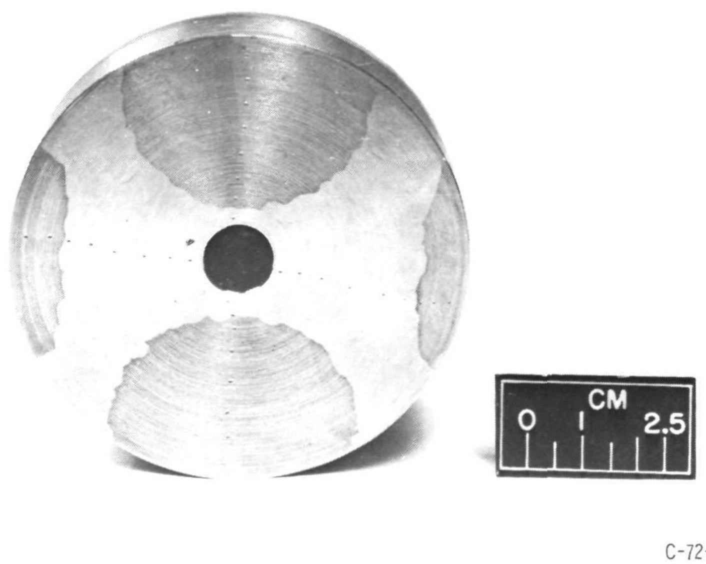

Figure 13. - Cross section of spin-tested rotor.

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