

Rehabilitation of 64-Meter-Antenna Radial Bearing

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The performances of the radial bearings on three 64-meter antennas are presented. Explanations for the distortion of the bearing at DSS 14 are made and the repairs are described. Recommendations for future tests and action are given.

I. Introduction

The radial bearing of the 64-m antenna is composed of two basic assemblies, namely, the track assembly which is attached to the antenna foundation, and the three wheel assemblies which are equally spaced on the alidade structure. The wheel assemblies are radially preloaded against the vertical cylindrical surface of the track, thus forming a vertical axis bearing capable of resisting horizontal forces applied to the antenna. The track assembly base or runner is a mild steel ring having a mean diameter of 8.96 m and a cross section 114 mm wide by 508 mm high. This ring was fabricated as four equal circular arc pieces, having mitered ends, which were permanently joined by five shrunk-in shear pins and four tension bolts. Ten alloy steel wear strips with mitered ends and counterbored holes are bolted to the mild steel ring. The wear strips are 35 mm thick and 310 mm high and their outer surfaces form the 8.144-m-diameter bearing race.

Each wheel assembly is composed of two wheels mounted in a pivoted frame attached to the antenna alidade base structure. Each wheel is 914 mm in diameter and 292 mm wide.

After being assembled on the ground, the track ring was hoisted up and placed around the collar at the top of the antenna pedestal. Alignment bolts, as shown in Fig. 1, were adjusted so as to obtain level, circularity, and concentricity.

At DSS 14 the grout used between the ring and pedestal was EMBECO. After the installation of the track the rest of the antenna was built over it. The details of the parts shown in Fig. 1, as well as the wheel assembly parts, are shown on JPL drawing 9437995.

II. Brief History of Radial Bearing Runner Symptoms

The 64-m antenna at DSS 14 was completed in 1966. The preload between each truck (an assembly of two wheels) and the track was set at 1,468,500 N. The following observations and changes were made in the years noted:

1968

The wear strips displayed a constantly changing wheel contact pattern.

1975 July

The wear strip contact pattern suggested areas of localized stiffness behind the runner. The pattern suggested that the alignment bolts were firm and were supporting the radial loads. Further investigation showed deterioration of the contact between the runner and the grout. The truck preload was reduced to 979,000 N.

1976 July

The gap between runner and grout had increased so that 0.50-mm feeler gage could be inserted to a depth of 150 mm.

1976 November

The gap between runner and grout had increased to 1.00 mm, and bolts holding the wear strips to the runner were starting to break.

1976 December

The wear strip bearing surface was not vertical but was sloped inward and upward by 0.24 degrees.

III. Ascertainment of the Cause of Runner Displacement

In 1977 a section of grout was cored out so that the inside of the runner could be seen. A large amount of scale was present, especially at the bottom where its thickness was 2 mm or more (see Fig. 2). It was then definite that the corrosion was caused by moisture coming into contact with the runner/EMBECO grout interface. The conical shape of the runner was judged to be due to the graduation of corrosion, varying from a very small amount at the top to an appreciable amount at the bottom. It was impossible to know what change had occurred in the runner radius, since original dimensions were not known more precisely than were given by dimensional tolerances. It could only be assumed that the conical shape of the runner was caused primarily by an outward radial displacement of its lower edge equal to the product of the measured slope and runner height. An analysis of the runner was made to determine its hoop force corresponding to the estimated amount of radial displacement. Then an estimate of the joint pin shear stresses, corresponding to this hoop force, was made. When the shear pin stress was compared to what was believed to be the breaking stress, it was judged that the margin of safety was too low. It was believed also that the corrosion on the back side of the runner would cease if oxygen were excluded from the region. Therefore the decision was made to strengthen the runner by welding the joints and to exclude oxygen by filling all voids with an epoxy cement and sealing the upper and lower edges of the runner with an appropriate substance (see Fig. 3).

IV. Action Taken to Stop Corrosion and Restore Runner Strength

In 1977 the runner joints at DSS 14 were welded in sequence according to the following procedure:

- (1) All wear strips were removed. This increased the load

on the joint shear pins by an estimated amount of from 2 to 5%.

- (2) A weld was placed along the mitered edge of the joint so that a penetration of 26 mm was obtained. This produced an additional shear area of approximately 0.030 m^2 . The combined shear area of the five shear pins was 0.0057 m^2 .
- (3) Approximately 0.152 m was torch-cut off the end of the runner segment. In so doing one shear pin was sacrificed. The cut end was then welded to its mating runner segment across the 0.114-m thickness of the runner. The additional weld area was approximately 0.006 m^2 .
- (4) Step 3 was repeated at the joint's other end, thereby sacrificing another shear pin.
- (5) Weld material was added alternately to the top and bottom end welds until the spaces occupied by the cut off parts were filled. The total weld area per joint was approximately 0.062 m^2 .
- (6) The outer surface of the runner at the joint was ground smooth and the wear strips replaced. Holes in the wear strips had to be enlarged in order to replace the holding bolts.

It had been decided to fill the voids behind the runner with a special epoxy resin which had been developed for filling cracks and voids in earthquake-damaged concrete structures. Since there existed a finite gap between the grout and upper edge of runner, the epoxy could enter at the gap and by elevation head pressure be made to fill all the voids, provided that a temporary seal was established at the lower edge of the runner. The epoxy filling was accomplished in 1978. The exothermic action of this particular epoxy reduces the initial viscosity enormously so that it is capable of entering hairline cracks. For this reason it may be assumed that the voids were filled. The subsequent application of a sealing paint to the outside insures that oxygen is excluded from the runner grout interface.

V. Measurement of Runner Residual Stresses

Although it was believed that welding the runner joints and filling the grout voids would prevent further distortion, it was deemed prudent to prove that such would be true. This was done, first, by measuring the total stress at several critical places in the vicinity of welded joints, and second, by installing a reference ring from which any additional distortion could be measured. Both of these procedures were carried out in the summer of 1979.

The total stresses were measured by the proprietary process developed by R. G. Sturm (Ref. 1). The method consists of making a very shallow indentation in a highly polished spot of the surface where the measurement is to be made. The indentation (0.25 to 1.0 mm in diameter and less than 0.10 mm deep) is made with a conical indenter under a precisely controlled load. If stress exists at the polished surface, the edge of the indentation will be elliptical rather than circular. The ratio of the major-to-minor diameter is a function of the total stress at the surface. By indenting a calibration bar made of the same material and subjected to a known bending stress, a good estimate of the stress in the subject material can be calculated.

Polished spots were prepared at 21 places, most of which were near the welded joints. Two of the spots were inadvertently placed on the weld material and spurious results obtained. The location of the spots and the calculated stresses are listed in Ref. 2. Of the 19 measurements considered valid, the highest and lowest tensile stresses were 8292 (10^4) and 429 (10^4) N/m². The highest and lowest compressive stresses were 7055 (10^4) and 1951 (10^4) N/m². Since the minimum tensile yield stress of the material is 24830 (10^4) N/m², the measured residual stresses are considered to be sufficiently low. If a hoop stress is calculated for the lower edge of the runner, based upon a radial displacement of 1.9 mm, which corresponds to the average of measured slopes, the value of 8480 (10^4) N/m² is obtained. This calculation for the hoop stress, σ_H , is from the expression:

$$\sigma_H = \frac{\Delta R}{R} E \quad (1)$$

where ΔR is the change in radius, R is the mean radius of the runner, and E is the elastic modulus.

Since the upper edge of the runner has moved outward by a small amount compared to that of the lower edge, the estimate for the average hoop stress is half of that estimated for the lower edge, namely 4240 (10^4) N/m². The average shear stress, τ_{AV} , on the joint plane, which is at 25° to the edge of the runner, would be:

$$\tau_{AV} = \sigma_{AV} (\sin 25^\circ) \cos 25^\circ = 0.383 \sigma_{AV} \quad (2)$$

if the weld covered the entire joint area. Since the weld area is only 47% of the entire area, the average weld shear stress is estimated to be:

$$\tau_{AV} = \frac{0.383}{0.47} \sigma_{AV} = 0.814 \sigma_{AV} \quad (3)$$

Taking the average hoop stress as 4240 (10^4) N/m², the average shear stress at the weld is 3455 (10^4) N/m², which

may be compared to the minimum shear yield of the material of 12415 (10^4) N/m².

The foregoing calculations indicate that there are no excessive stresses in the runner as it now exists after having its joints welded. The measured surface stresses substantiate this conclusion.

VI. Reference Ring

The cross section of the reference ring and its relationship to the radial bearing runner is shown in Fig. 4. Also shown in this figure is the fixture which measures changes in the horizontal distance between the reference ring and runner. The details of these parts can be obtained from JPL drawing 9470753.

The cross section of the reference ring is approximately 63 mm wide and 39 mm high. Its inside radius is 4.13 m, which is approximately 0.42 m less than the radius of the runner wear strip. Any temperature expansion errors will be proportional to 0.42 m and not to the absolute radius, which is more than 10 times as much. Since the temperature difference between the fixture and runner structure is not likely to exceed 3°C and since their expansion coefficients are virtually the same, a measurement error of only 0.014 mm is calculated by forming the product of the distance, temperature difference, and expansion coefficient, namely the product, 420(3)(11) 10^{-6} = 0.014 mm. This is a trivial amount compared to the radial displacements which have already occurred, such as 1.9 mm at the lower edge of the runner. However, the sensitivity and accuracy of the measurement system is capable of detecting displacements smaller than 0.014 mm.

The reference ring was made in eight equal circular arc pieces. It was machined on a very accurate vertical boring mill. The final cuts were made after the rough machined parts had been stress relieved. Upon being unclamped from the machine, very little distortion from the circular shape occurred. Locating pads for the ring segments are shown in Fig. 5. The pads were located from a circle of bench marks near the radial bearing runner. The pads were leveled to a common plane by using push-pull screws and surveying techniques. Then the pads were grouted against the concrete foundation with epoxy resin. The pads are within 0.25 mm of a common level plane. The radial buttons, against which the inside edge of the reference ring bears, were located with a precision measuring bar pivoted at the center of the instrument tower. The bar passed through holes in the tower wall which were on the same radial lines as the mounting pads. After being located and checked, the buttons were doweled to the pads. The reference ring segments were placed on the pads and held securely with dogs and screws. Thus the inner edge of the reference ring was circular

as placed. When it was placed, there was a preload on the radial bearing trucks of approximately 890,000 N. A deflection analysis of the concrete structure composed of the ring portion and the disk portion shows a radial inward deflection of 0.061 mm at the trucks and an outward deflection of 0.058 mm midway between the trucks. This should be considered in calculating the circularity of the radial bearing runner.

The position of the radial bearing wear strip with respect to the reference ring may be seen in Fig. 4. The fixture which measures the horizontal distance from the inside of the reference ring to the outside of the wear strip appears to be two bars forming a right angle. The end of the horizontal bar contains oval-headed setscrews which bear against the top and inside surfaces of the reference ring. The vertical bar contains two linear displacement transducers spaced 254 mm apart. The setscrews shown near the end of the horizontal bar are actually two pairs of screws spaced approximately 0.50 m apart in the direction perpendicular to the plane of the figure. Halfway between the transducers on the vertical bar is a single setscrew. This arrangement allows the fixture to hang in a stable, statically determinate position. The transducer zero values are obtained through the use of a reference gage fixture, which is a welded steel structure duplicating a short section of the radial bearing wear strip and reference ring. The procedure essentially is as follows:

- (1) The reference gage fixture is leveled by adjusting set screws on its three supporting feet. A precision machinist level is used to detect the level position (see Fig. 6).
- (2) The fixture containing the transducers (hereinafter called the tool) is hung onto the reference gage fixture (see Fig. 7).
- (3) The precision level is placed on the horizontal leg of the tool and the adjusting screw between the transducers is turned until the level reads zero. The transducers are moved axially until they both read zero.
- (4) The tool is hung on the reference ring and slid circumferentially a small amount until it touches one of many locating pins in the reference ring. These pins establish the exact azimuth angles at which the measurements will always be made.
- (5) The precision level is placed on the horizontal leg of the tool and the adjusting screw turned until the level indicates zero. The transducers are read and recorded.

The particular machinist level used has a sensitivity of 0.000042 radians per division. With care, estimates of half divisions can be made. A consideration of the configuration of Fig. 5 shows that the relationship between the transducer displacement δ and the angular level error ϵ_θ is approximately:

$$\delta = 430 \epsilon_\theta \quad (4)$$

where δ is in millimeters.

$$\text{Taking } \epsilon_\theta \text{ as } \frac{0.000042}{2} = 0.000021 \text{ gives}$$

$$\delta = 430 (0.000021) = 0.0090 \text{ mm} \quad (5)$$

Experience indicates that if a reading is carefully made and the tool removed, replaced, leveled, and read again, the transducer readings can be repeated to within 0.009 mm. The slightest amount of surface damage, foreign particle inclusion, or change in level temperature can increase the transducer error considerably. Using the tool with the amount of care that is practical, the repeatability error of the transducers is approximately 0.025 mm.

The first measurements of the runner with respect to the reference ring were made in October 1979. In Table 1 some of these are compared to the latest ones made in May 1981. Complete records are available from Section 355.

Detailed instructions for the use of the above described instrumentation can be obtained from JPL Section 355 personnel.

VII. Radial Bearing Runner Condition at DSS 43 and DSS 63

A reference ring was installed at DSS 63 in January 1981. The general condition of the runner was good, in that there were no gaps between it and the grout. Initial measurements were taken and periodic measurements will be made.

A reference ring was installed at DSS 43 in March 1981. Near the preloaded trucks the gap between runner and grout was near zero, but gradually increased to 1.30, 0.65, and 0.63 mm at the three midpoints between trucks. Circumferential walking of the runner had been observed. Also, cracks and spalled off pieces of concrete had occurred below the runner in the vicinity of a joint.

The walking action can be explained by the fact that the periphery of the inside of the runner is greater than the periphery of the grout. The preloaded wheels force the runner against the grout, producing a rolling action which causes the runner to advance in one turn by the amount of $2\pi h$, where h is the average gap. Taking h as 0.43 mm, the advance in one turn would be approximately 2.7 mm. Because of various asymmetries, reverse motion would not exactly cancel the circumferential displacement, thus allowing a possible net displacement greater than 2.7 mm.

The reason why a gap between runner and grout has developed at DSS 43 and not at DSS 63 is not now known. The age of the two antennas is approximately the same. It is considered that a shrinkage of 0.43 mm over the grout thickness of 76 mm is very large for the dry pack type of portland cement grout used. A stress analysis indicates that the runner alignment bolts could support the runner against the wheel preload. If the grout had shrunk, there should be a gap at the wheel position where the runner would be supported by the alignment bolts. Rather it is more likely that the entire concrete pedestal structure has shrunk radially by the amount of 0.43 mm over the radial distance of 4340 mm. The reason why the DSS 43 pedestal might have shrunk and the DSS 63 pedestal remained dimensionally stable may involve the chemical properties of the different aggregates used.

Table 2 shows a comparison of measurements made at DSS 43.

VIII. Design of Replacement Radial Bearing

It was decided to procure one or more new radial bearings to replace existing ones in case repairs on the present one are not successful. If repairs appear to be successful, the new one would serve as a spare and its existence would substantially shorten the bearing replacement time if such became necessary.

A replacement runner cannot be installed as were the original ones, because most of the antenna was constructed after the runner was installed as a complete ring. Therefore, the design of the replacement runner must be different. If the runner is made in four segments, as was done with the original runners, and its height reduced from 508 to 445 mm, each segment can be slid under the alidade base structure and then lifted up to its proper position on the pedestal. The four segments would be joined by close fitting bolts at mitered joints. Then the assembled ring would be aligned to the reference ring and grouted into place. The joint design is depicted in Fig. 8 and the details are shown on JPL drawing 9474446. The joint is mitered and uses eight special bolts, having precision-ground sections of 38-mm diameter which serve as shear pins. This is to be compared to the original design which employed five shrunk-in pins of the same diameter. The installation of a new runner would consist of the following steps:

- (1) Remove the old wear strips.
- (2) Torch-cut the old runner into sufficiently small lengths for removal.
- (3) Chip off old grout and renovate alignment bolts. If old bolts cannot be turned in the anchor nuts, they must

be torch-cut off and oversized holes tapped in the anchor nuts.

- (4) Bring in the four segments of the new runner and assemble into one ring by installing the 32 special bolts, nuts and lock plates.
- (5) Align the new runner assembly to the reference ring.
- (6) Grout the runner in place.
- (7) Install the new wear strips.

IX. Recommended Repairs

The repair of the DSS 14 runner has been described above. The bearing surface is now conical instead of cylindrical and the wheel preload has not been restored to its original value because of the reduced contact area between the wear strip and wheel. It is proposed that the wheel assemblies be tilted to conform to the average slope of the conical surface of the wear strip. This can be done easily by shimming the wheel bearing housings and taking advantage of the self-aligning characteristics of the spherical roller bearings now in use. If the contact areas in the worst places are sufficiently improved to allow restoration of the original preload, and the tendency of the wheel to run off the track is not excessively increased, then this would seem to represent a satisfactory solution. If these conditions are not met, the new bearing should be installed.

At DSS 43 the gap could be filled with the same type of epoxy resin used at DSS 14. With the wheel preload removed, the circularity of the wear strip surface would be measured and calculated with respect to the reference ring. If the calculated circularity required improvement, it may be possible to achieve it by driving wedges between the runner and grout. Then the epoxy could be applied as it was at DSS 14.

The adherence of the epoxy to runner will probably reduce the tendency for the runner to walk circumferentially. If walking persisted, keys could be inserted by coring out the grout at four equally spaced places and inserting a vertical key containing several tapped holes of 25-mm diameter. Matching holes would be bored and counterbored in the runner and the keys attached to the inside of the runner with bolts. Grout would then be put around the keys. The keys and grout should be designed to withstand a shear force equal to the product of the wheel preload and the coefficient of friction between the runner and grout.

So far the DSS 63 azimuth bearing is without any of the above described defects. However, periodic measurements will be made with respect to its reference ring.

References

1. Sturm, R. G., "Total Stress Gage, a Method and a Device for Determining Total Stress by Allowing the Material to Indicate Nondestructively the Stress Within It," Technical Note TN-001, Sturm-Stress, Inc., November 1970.
2. Liaw, B. D., Lock, R., Jr., and Sturm, A., "Total Stress Measurement in the DSS 14 64-m Antenna Bearing Ring," prepared under JPL contract (Purchase Order U-698621), July 1979.

Table 1. Radial bearing measurements at DSS 14

Date	Azimuth angle station, deg	Transducer measurements, distance from vertical reference, mm		Slope from vertical, deg	Mean slope from vertical, average of slopes at 15 azimuth stations, deg
		Top	Bottom		
10-01-79	350	-0.06096	1.4734	0.3461 max.	0.3014
	200	-0.18491	0.8948	0.2436 min.	
11-09-79	350	-0.07620	1.4486	0.3439 max.	0.3021
	200	-0.17348	0.8936	0.2407 min.	
2-2-80	350	-0.09169	1.4491	0.3476 max.	0.3023
	200	-0.13868	0.9548	0.2466 min.	
4-7-80	350	-0.08890	1.4376	0.3443 max.	0.3023
	200	-0.14783	0.9256	0.2421 min.	
7-1-80	350	-0.04775	1.5006	0.3493 max.	0.3030
	200	-0.06071	0.9749	0.2336 min.	
10-25-80	350	-0.02108	1.5400	0.3521 max.	0.3076
	200	0.01270	1.0587	0.2359 min.	
5-10-81	350	-0.05131	1.5265	0.3559 max.	0.3080
	200	0.01270	1.0571	0.2350 min.	

Table 2. Radial bearing measurements at DSS 43

Date	Azimuth angle station, deg	Transducer measurements, distance from vertical reference, mm		Slope from vertical, deg	Mean slope from vertical, average of slopes at 15 azimuth stations, deg
		Top	Bottom		
4-7-81	75	-0.18313	0.24232	0.09597 max.	0.0000618
	330	-1.31293	-1.44272	-0.02928 min.	
7-10-81	75	0.44653	0.82448	0.085256 max.	0.0000544
	330	-0.89510	-1.02591	-0.029507 min.	

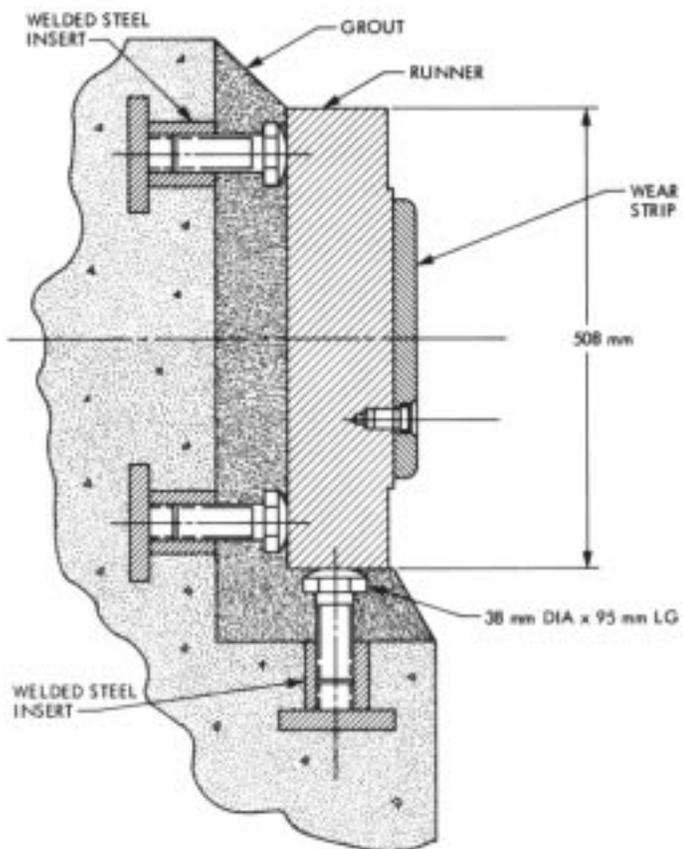


Fig. 1. Cross section of runner showing alignment bolts and grout

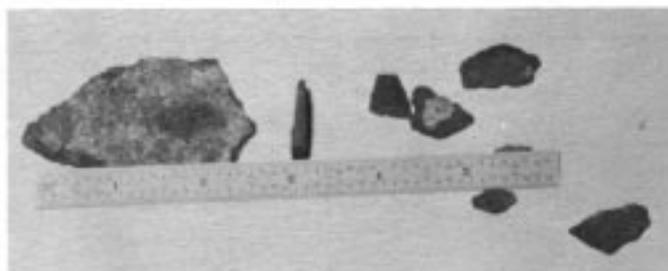


Fig. 2. Scale removed from runner at grout interface, DSS 14

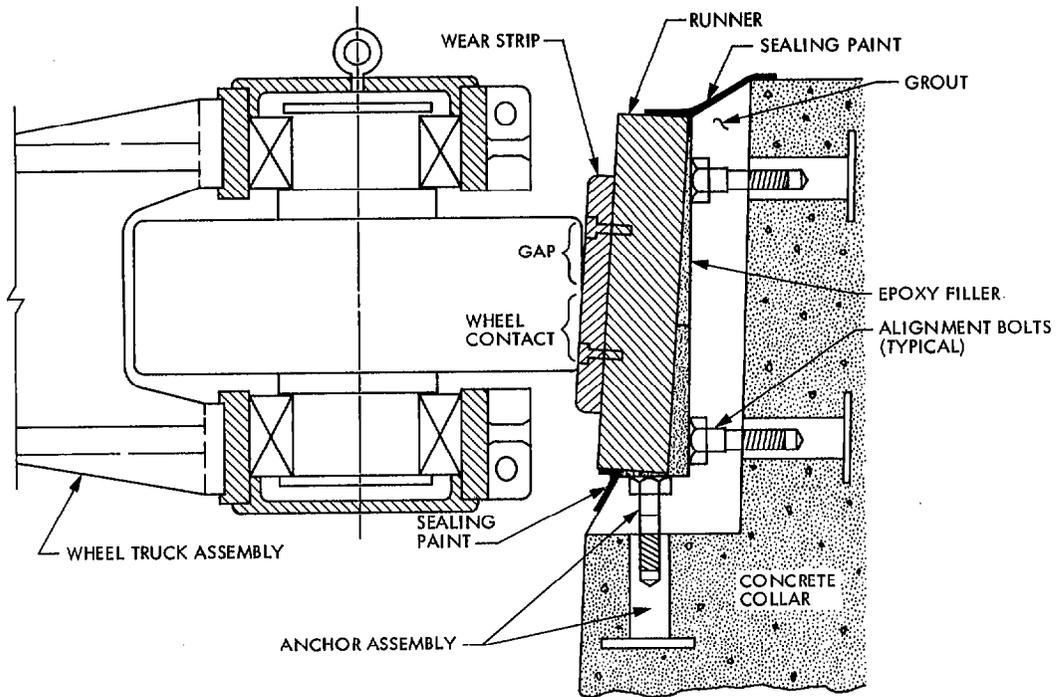


Fig. 3. Distorted runner at DSS 14; voids filled with epoxy resin

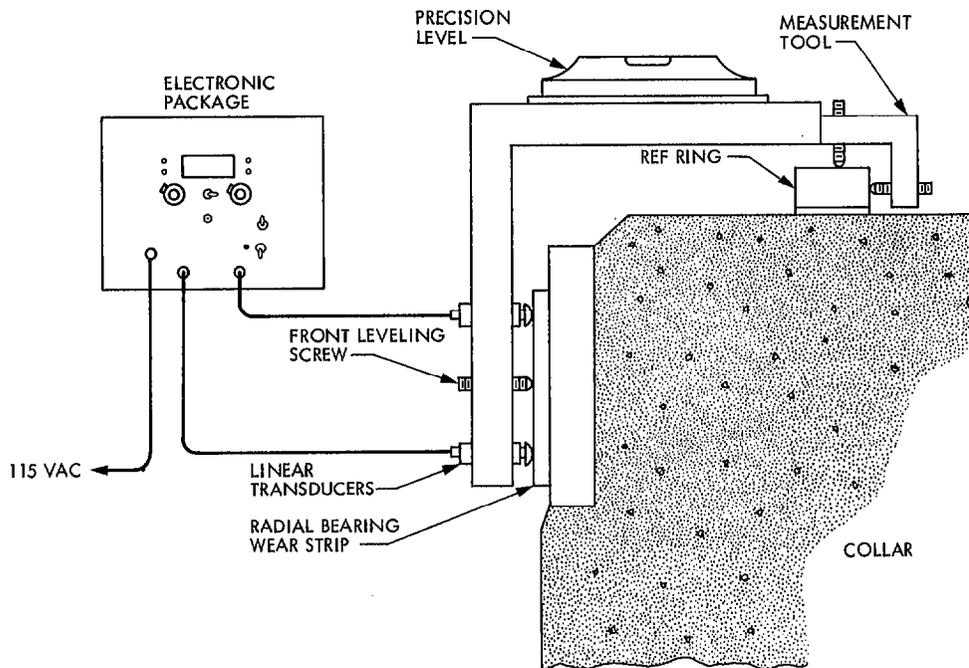


Fig. 4. Reference ring and its relationship to wear strip

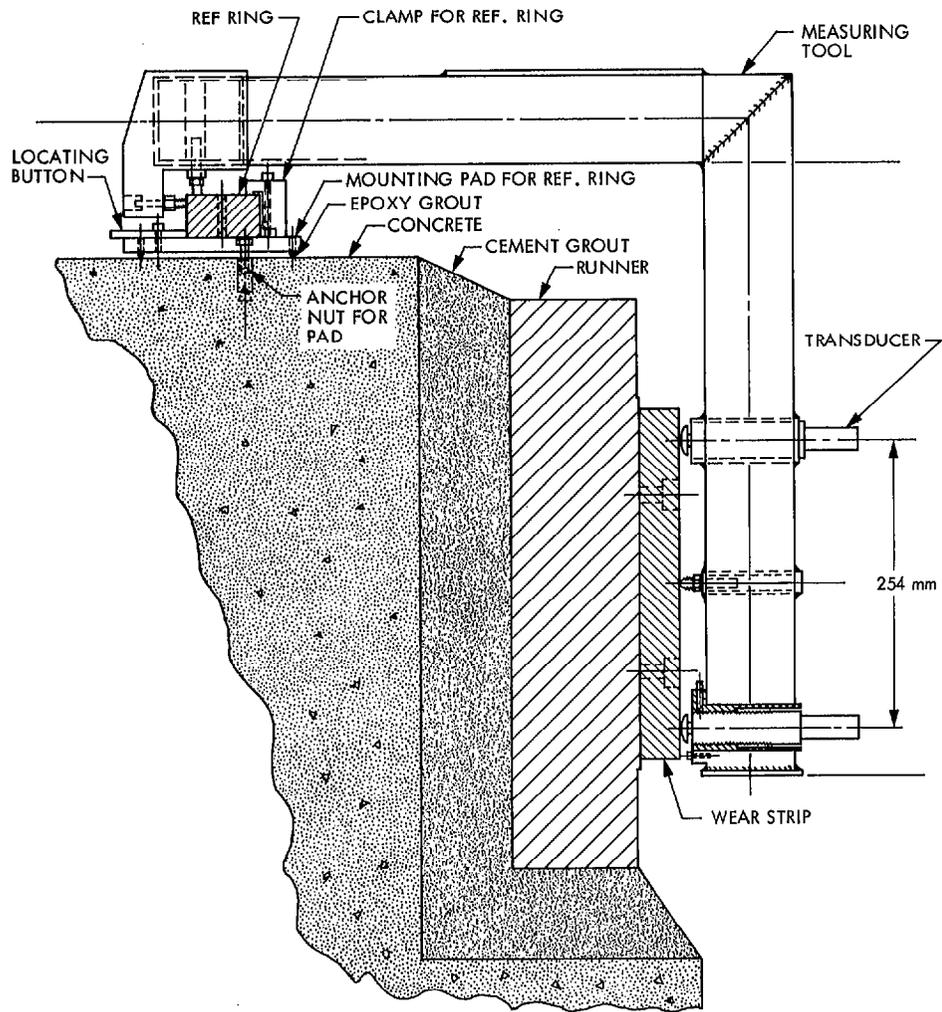


Fig. 5. Reference ring location and attachment

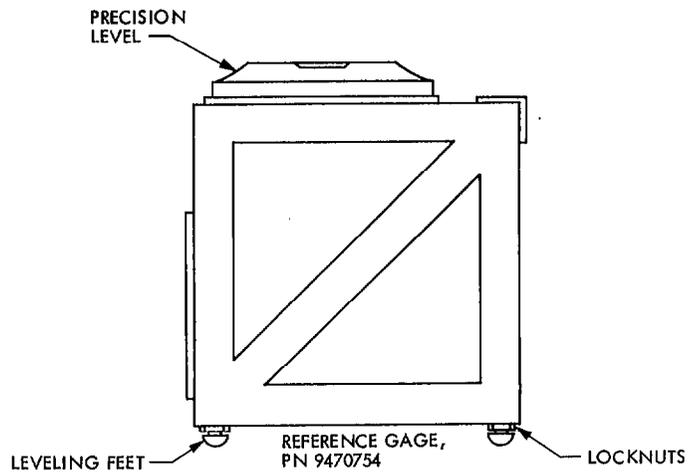


Fig. 6. Reference gage zeroing fixture

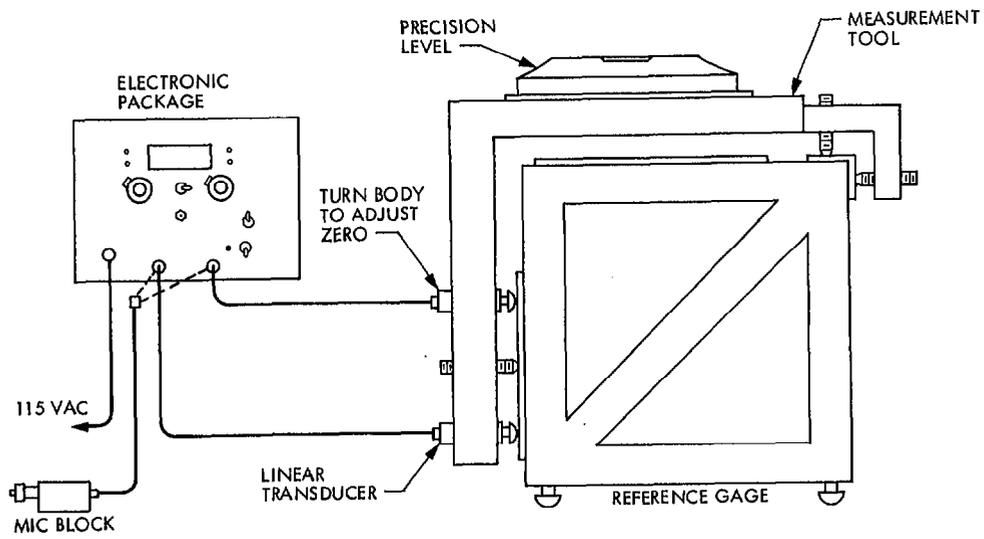


Fig. 7. Measuring tool on reference gage zeroing fixture

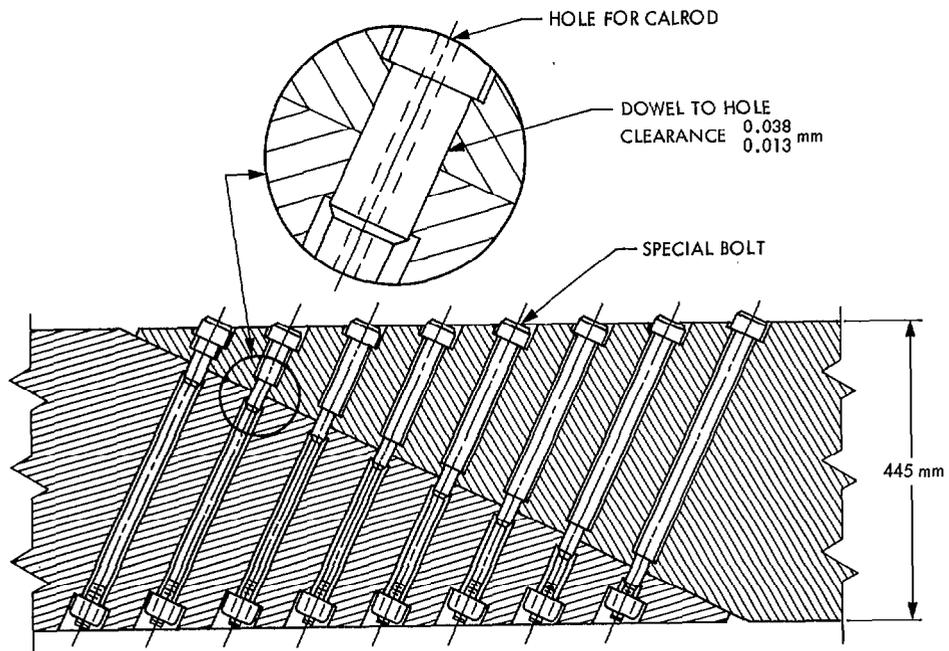


Fig. 8. Joint design for spare radial bearing runner