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A PROTOTYPE GAUGE FOR MEASURING
CONTOUR AND WALL THICKNESSES
OF HEMISPHERICAL PARTS

Research and Development
FABRICATION TECHNOLOGY GROUP

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SUBJECT DESCRIPTORS

Contour Measurements
Shells
Measuring Methods

**ROCKWELL INTERNATIONAL
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A PROTOTYPE GAUGE FOR MEASURING CONTOUR AND WALL THICKNESSES OF HEMISPHERICAL PARTS

Hendrik J. Aarts and John H. Robertson

Abstract. A prototype gauge (gage) was designed and fabricated using air bearings in a new configuration to provide less error and distortion during inspection of hemispherical parts. No wear occurs on the moving parts during operations and accuracy of alignment is maintained. The gauge will check outside radial distance, inside radial, and outside radial and wall, and inner radial and wall thicknesses of parts.

The gauge contains only four moving parts, which increases the measuring accuracy. A horizontal table rotates. A table mounted on the horizontal table at 45 degrees rotates through two transducers. All moving parts are mounted on hydrostatic gas bearings. Laser interferometric, air-bearing gauge heads are used to obtain the required data.

INTRODUCTION

A new concept of a gauge (gage) for inspecting hemispherical parts has been designed, built, and tested. The design eliminates cantilever of gravitational change errors during part inspection. The complete design layout is shown on Internal Drawing T-17750-E-1 A/4.

All rotary and linear motions use air bearings. Measurements are made with laser interferometry and linear air-bearing gauge heads. The hydrostatic gas bearings use an air pressure of 60 pounds per square inch gauge (psig). A gauge superstructure, upper air bearing, and 45-degree support are aligned to the lower air bearing to a common axis within 0.000010 inches. Maximum movement of the lower air bearing is 270° table rotation. [For SI (metric) use: 1 psi = 7 kilopascals (kPa), and 1 inch = 25.4 millimetres.]

Investigation of a hemispherical part is in any desired spiral path from equator to pole. Measurement information is obtained from two laser interferometric transducers using linear air bearings. The transducers use a Spectra Physics Model-120 helium and neon laser. Working range of each transducer is 1.5 inches.

The fringe voltage signals are amplified and converted to inches to be displayed on a digital readout. A punched paper tape contains the nominal inside diameter (ID) and outside diameter (OD) information in Binary Coded Decimal form. The tape is fed into a digital computer which calculates error information on ID, OD, and wall thickness. This information is converted to analog form and displayed simultaneously on a strip-chart recorder.

DISCUSSION

Gauge Design:

Figure 1 shows the complete gauge. The gauge design is an entirely different concept from existing sweep gauges presently in use. The design eliminates the use of trunnion bearings and cantilever arms of the conventional sweep gauges. Figures 2 and 3 show the horizontal hydrostatic bearing (x axis) which supports another hydrostatic bearing (y axis) at 45 degrees from horizontal. A collet to which the part attaches is inset into the 45° bearing. Since the bearings are independently driven, the part can be rotated around the x and y axes separately or together in an infinitely variable ratio of speeds. The rotary air bearings have four graphite pads on each supporting surface. A total of 24 pads are required. The Speer No. 8882 graphite is impregnated with duPont Lucite Acrylic Lacquer 326L and mixed with methylene

FIGURE 1. New Concept Gauge and Control Console.

18967-2

FIGURE 2. New Concept Gauge with Sensor Heads at Equator.

chloride to achieve an even air flow over the entire surface of the graphite pads (see Figure 4).

Laser Light Source:

A Spectra-Physics Model 120 gas laser, used with a Spectra-Physics Model 256 exciter, provides frequency-stable, 6328-angstrom ($\text{\AA}$) wavelength, monochromatic light to the optical interferometer.

Gauge Head:

The optical transducer gauge head is a small device consisting of an optical chamber approximately

cubical in shape, and having a cylindrical bearing housing with a shaft extending from one side. Two miniaturized preamplifiers are also attached to the optical chamber. The gauge head is approximately 3 inches long and about 1.5 inches wide through the chamber and preamplifiers (see Figure 5).

The laser beam enters the gauge head and passes into the interferometer. The beamsplitter of the interferometer divides the beam into two parts, which travel paths of unequal length. One part is reflected back from the mirror on the movable beryllium shaft. The reflected beams are combined in the beamsplitter and emitted as an interference

FIGURE 3. New Concept Gauge with Sensor Heads at Pole.

pattern composed of bright and dark bands, or fringes. The beryllium shaft moves in and out in response to variations in the contour of the part being inspected. The fringes progress across the photodetectors in a manner corresponding to the movement of the shaft.

Fringe motion is detected by the two photodetectors, which are adjacent to each other in the output beam. The electrical signals from the detectors go to the two small preamplifiers (Figure 6) on the gauge head, and thence from the preamplifiers via shielded cable into the bidirectional

digital counter. The counter converts the signals into a visual display of the fringe count.

Electronic Control System:

The Electronic Control System for interferometric information fringe detection and amplification eliminates all manual operations and calculations and replaces them with a few push-button operations (see *Inspection of Hemispherical Parts*, Page 9). Figure 7 is a flow diagram of the electronics system.

FIGURE 4. Radial Graphite Bearing Pads.

15288-1

FIGURE 5. Sectional View of Optical Transducer.

Legend
K = 1000 ohms.
V = Volts.

FIGURE 6. Preamplifier Circuit.

Capacity of Gauge:

The capacity of the gauge follows.

Inside Radial Distance	3.400 Minimum (inches)
Outside Radial Distance	5.150 Maximum (inches)

Gauge Operation:

A part to be inspected is placed, equator down, on the 45° turntable. A part is centered so it is

concentric to the *y* axis and the *x* and *y* axes intersect on plane *z*. Whether a part is rotated about the *x* axis (the vertical) or about the *y* axis (the pole) or both *x* and *y* axes, the attitude of a part with respect to the horizontal base remains the same. When a part is rotated 360° about the *x* axis, a circular path is traced (see Figure 8). When the part is rotated 360° about the *y* axis, a lateral band in a plane parallel to *z* is investigated (see Figure 9). A part rotated 360° about both *x* and *y* axes simultaneously will inspect a spiral path from equator to pole to equator (Figure 10).

When a part is rotated once about the *x* axis, while being rotated four times about the *y* axis, a two-spiral path from equator to pole and another two-spiral path from pole to equator will be traced.

FIGURE 7. Flow Diagram of Current Electronics System.

FIGURE 8. Circular Path, Equator to Pole to Equator.

FIGURE 9. Equatorial Path.

By varying the rotation speeds about these two axes, an infinite number of patterns on the surface of the part can be inspected.

Accuracy Tests of Gauge:

The probes of the transducers can be trammed in within 5 millionths of an inch within any fixed position. Linear travel can be adjusted to any desired tolerance. The two optical transducer styli aligned on a common axis within 0.0001 inches is adequate. Runout of the two rotary tables is within 10 millionths of an inch. Repeatability of the transducers is within 10 millionths of an inch.

Accuracy of the Gauge:

Chart comparisons of a stainless steel hemispherical part run on a Rotocon gauge at Rocky Flats Plant and the described prototype gauge show minor differences. The wall thickness throughout the total chart was within 100 millionths of an inch. The average of each band from each gauge was

FIGURE 10. Two-Spiral Path from Equator to Pole.

compared and the greatest difference was 300 millionths. Determination of which gauge is closer to the absolute true radial distance remains

FIGURE 11. Inspection Procedure for a Hemispherical Part.

a matter of opinion and cannot be determined without great expense.

Errors which may enter into the spherical measurement are the actual motions of the probing housings relative to spherical center. These may be caused by vibrations, creep, or thermal gradients in the machine structure. In general, they are proportional to machine size and a function of the material and geometry. A cantilever bridge system is not the best.

Inspection of Hemispherical Parts:

A. Preliminary operations—Supply air to air bearings on gauge and the air bearing transducers (55 psig). Stabilize laser by a 45-minute warm-up period.

B. Position and center a part, 3 buttons set the computer to receive part information.

1. Push the *read* button to feed the required tape to beginning of information.
2. Push *reset* button to clear logic storage devices.
3. Push *read* button again. Nominal values from a tape (see Introduction) are introduced into the computer.

C. To inspect a hemispherical part, 45 radial sweeps are made around the part in two-degree increments of latitude from the equator to the pole (Figure 11).

TABLE I. Data on Angular Movement of Rotary Table.

Part Degrees	Degrees	Minutes	Seconds
2	2	49	42.854
4	5	39	28.816
6	8	29	21.002
8	11	19	22.573
10	14	9	36.728
12	17	0	6.739
14	19	50	55.962
16	22	42	7.855
18	25	33	46.003
20	28	25	54.141
22	31	18	36.172
24	34	11	56.205
26	37	5	58.576
28	40	0	47.886
30	42	56	29.050
32	45	53	7.317
34	48	50	48.346
36	51	49	38.252
38	54	49	43.678
40	57	41	11.874
42	60	54	10.797
44	63	58	49.206
46	67	5	16.829
48	70	13	44.496
50	73	24	24.352
52	76	37	30.101
54	79	53	17.304
56	83	12	3.722
58	86	34	10.039
60	90	0	0.000
62	93	30	1.722
64	97	4	48.545
66	100	45	0.000
68	104	31	26.676
70	108	25	7.538
72	112	27	19.855
74	116	39	42.945
76	121	4	29.168
78	125	44	41.435
80	130	44	44.724
82	136	11	28.285
84	142	16	25.430
86	149	22	16.127
88	158	27	58.212
90	180	0	0.000

To arrive at the 2-degree increments of latitude, the following formula is required:

$$\cos a = 2 \cos (b - 1)$$

b = part theta angle

a = table index angle

Table I shows the angular movement of rotary table to arrive at the 2-degree increments on part using above formula.

RECOMMENDATIONS:

If another gauge is constructed for production uses, the following improvements should be made.

Height adjustment on the 45-degree rotary table is required for locating part to true position. Adjusting centerline of the two jets is time-consuming and critical in the present gauge. This can be corrected by a more convenient design of the 45-degree table. The two design changes above are imperative for any normal production use of this gauge. The motor drive to the 45-degree table needs a mechanical redesign. Gearing mechanism fails under load.

A more accurate rotating device for the lower air bearing (see Figure 1) such as an Inland Controls Rate Table System in conjunction with a holographic angular readout system would be desirable for operating speed. An optical readout system could also be used.

CONCLUSIONS

Although commercial suppliers have adequate gauges for purchase, the prime advantage of the prototype described relates to an inherent stability in the air bearings. The weight of parts will have negligible effects on accuracy. The feasibility of this new concept has been demonstrated with the prototype gauge and the design is applicable to a practical production system.