Library #12

MASTER

Astronuclear

WANL-TMI-1201

August 10, 1964

AN EXPERIMENTAL DETERMINATION
of the
VARIATION IN FLOW PARAMETERS
for
CROWNED AND STRAIGHT SPLINE COUPLINGS

by

William L. Jacob
Fluid Flow Laboratory
Experimental Engineering

Approved By:

Henry J. Fix, Supervisor
Fluid Flow Laboratory

INFORMATION CATEGORY

UNCLASSIFIED

8/14/64
Authorized Classifier Date

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SUMMARY

Tests were conducted in the Fluid Flow Laboratory to determine the difference in flow-pressure drop characteristics between straight spline and crowned spline couplings. The purpose of the test was to provide a means of correlating the test results obtained from tests on the control drum drive shaft model with the coupling in the reactors. The couplings tested were models of the actuator end control drum drive shaft coupling. They were machined according to Drawing No. 976D098, Revision D, with the exception that one of the models was machined with straight splines rather than crowned.

The test results showed that the ratio of straight spline loss coefficient to crowned spline loss coefficient is 1.16, the straight spline loss parameter (loss coefficient divided by area squared) is 265, the crowned spline loss parameter is 375, and that the ratio of straight spline loss parameter to crowned spline loss parameter is 0.705. The flow area of the crowned spline was less than that of the straight spline at the minimum cross section of the spline. The area ratio was 1.279 straight to crowned.

TEST SET-UP

The test fixture, Figure 1, for the straight splined tests consisted of hardware from the experimental work performed on the control drum drive shaft model. The test fixture for the crowned spline was identical to the straight spline hardware except the crown spline drive shaft replaced the straight splined shaft. All of the flow passages in the test hardware were plugged except those passages admitting air through the drive shaft for discharge out of the actuator end coupling.

Air enters the drive shaft through a plenum and the dome end bearing shaft, from here it discharges out through the actuator end drive shaft splines and passes through a calibrated flow nozzle built to ASME specifications.

CALCULATIONS

The experimental data was reduced with the use of a FORTRAN computer program and is presented in Appendix A. The calculations used in the program are as follows:

Flow

For a general reversible adiabatic flow nozzle the equation for flow rate is

$$W = C A_N \left[2g \rho_N \left(p_1 - p_2 \right) \left(\frac{k}{k-1} \right) \left(\frac{r^{2/k}}{1 - \beta^4 r^{2/k}} \right) \left(\frac{1-r^{k/k}}{1-r} \right) \right]^{1/2}$$

where

W = flow rate (lb_m/sec)

C = flow coefficient for nozzle (dimensionless)

A_N = flow area of nozzle (in.²)

g = gravitational constant (in./sec²)

ρ_N = density of fluid evaluated at upstream conditions using the Perfect Gas Law (lb_m/in.³)

p_1 = upstream nozzle pressure (psia)

p_2 = downstream nozzle pressure (psia)

k = specific heat ratio (dimensionless)

r = ratio of the absolute downstream to the absolute upstream pressure (p_2/p_1)

λ = ratio of the nozzle throat diameter to the upstream pipe diameter

Loss Parameter

The loss parameter is calculated instead of loss coefficient since the flow area is difficult to determine accurately. Loss parameter is defined as the loss coefficient divided area squared.

$$LP = \frac{2g_L \Delta P}{W^2}$$

where

LP = loss parameter (in.^{-4})

ΔP = pressure drop across the coupling (lb/in.^2)

ρ = density at inlet to coupling (lb/in.^3)

Loss Coefficient Ratio

Although the loss coefficient was not calculated, a representative ratio of the straight spline to crowned spline loss coefficient was determined.

Castings were made of one of the straight spline teeth, one of the crowned spline teeth, and one of the splined coupling teeth. These castings were employed so that a geometric flow area for a straight spline tooth and a crowned spline tooth could be determined. The straight spline tooth and crowned spline tooth flow area can then be ratioed with respect to each other, squared, and then multiplied by the ratio of the loss parameters yielding a loss coefficient ratio.

$$\frac{A_s^2}{A_c^2} = A_R$$

where

A_s = straight spline tooth flow area (in.²)

A_c = crowned spline tooth flow area (in.²)

A_R = squared area ratio of straight to crowned splines

and

$$\frac{LP_S}{LP_C} = LP_R$$

where

LP_S = loss parameter ratio of straight splines

LP_C = loss parameter ratio of crowned splines

LP_R = loss parameter ratio of straight to crowned splines

finally

$$C_{LR} = A_R LP_R$$

where

C_{LR} = ratio of the straight spline and crowned spline loss
coefficient

Reynolds Number

The Reynolds number is that of the flow through the central hole of the dome end bearing shaft.

$$N_{Re} = \frac{W d}{\mu A}$$

where

N_{Re} = Reynolds number

d = diameter of central hole of dome end bearing shaft
(0.505 in.)

μ = viscosity $\left(\frac{\text{lb}_m}{\text{in.-sec}} \right)$

A = area based on d (in.²)

DISCUSSION OF RESULTS

The results of the experiments showed that the ratio of straight spline to crowned spline loss coefficient is 1.16. The straight spline has higher losses than the crowned spline since the flow transition into the minimum flow area is more sudden than that of the crowned spline. It can be seen from the data (Figure 2) that the loss parameter ratio is 0.705. The flow area ratio of the straight spline tooth coupling assembly to the crowned spline tooth coupling assembly was found to be 1.279.

The straight shaft spline was moved axially within the splined coupling so that the effect of increasing the gap between the end of the shaft and the coupling from 0.5-inch to 0.75-inch could be observed. This axial

dimension change retained the male splines wholly within the female coupling splines. The loss parameter increased about 2% as a result of the change in position.

The splined drive shaft was butted up against the female splined coupling resulting in a very high loss parameter (2000) due to high pressure drops and very low flow area. The controlling area is now the gap between the end of the drive shaft and the coupling instead of the splines, and the exact gap dimension was indeterminate.

CONCLUSION

The loss coefficient ratio of straight to crown splines is 1.16 and can be used with the air data obtained for the coupling on the control drum drive shaft model to predict performance of the coupling in the reactor.

Figure 1

Section View of the Actuator End of the Drive Shaft and Coupling

Figure 2

Loss Parameter vs Reynolds Number For Crowned and Straight Splines

APPENDIX A

FORTTRAN COMPUTER PROGRAM DATA CALCULATIONSDescription of Headers Used In Output

<u>HEADER</u>	<u>DESCRIPTION</u>
P19	Used in loss coefficient density calculation Pressure tap located in drive shaft upstream of spline
DP(19-16)	Pressure drop across splines. From location 19 to 16 in Figure 1
TEMP	Air temperature across splines
CLDASQ	Loss parameter (loss coefficient divided by area squared)
FLOW	Air flow rate through splines
Reynolds No. LOC. 10	Reynolds number through the central hole of the Dome End Bearing Shaft

DRIVE SHAFT SPLINE AIR FLOW TESTS

RUN DATE. MAY 11, 1964

CROWNED SPLINES

THE GAP BETWEEN THE SHAFT AND THE COUPLING IS ONE - HALF INCH

THE LOSS PARAMETER IS CALCULATED FOR STATION 19 TO 16

	P19 PSIA	DP(19-16) PSID	TEMP DEG R	CLDASQ INCH-4	FLOW LB/SEC	REYNOLDS NO LOC 10
1	131.90	0.2419E 01	532.5	0.3716E 03	0.4412E-01	0.9103E 04
2	132.70	0.4519E 01	532.5	0.3685E 03	0.6075E-01	0.1253E 05
3	132.50	0.6901E 01	532.5	0.3760E 03	0.7425E-01	0.1532E 05
4	132.30	0.9603E 01	532.5	0.3915E 03	0.8577E-01	0.1770E 05
5	136.40	0.1169E 02	532.0	0.4036E 03	0.9470E-01	0.1955E 05
6	130.40	0.1558E 02	532.0	0.4177E 03	0.1051E-00	0.2169E 05
7	137.10	0.1675E 02	531.5	0.4148E 03	0.1121E-00	0.2316E 05
8	137.00	0.2048E 02	531.0	0.4439E 03	0.1199E-00	0.2478E 05
9	133.90	0.2402E 02	531.0	0.4592E 03	0.1262E-00	0.2609E 05

APPENDIX A (Continued)

DRIVE SHAFT SPLINE AIR FLOW TESTS

RUN DATE MAY 12, 1964

STRAIGHT SPLINES

THE GAP BETWEEN THE SHAFT AND THE COUPLING WAS ONE HALF INCH.

THE LOSS PARAMETER IS CALCULATED FOR STATION 19 TO 16

	P19 PSIA	DP(19-16) PSID	TEMP DEG R	CLDASQ INCH-4	FLOW LB/SEC	REYNOLDS NO LOC 10
1	34.02	0.1744E 01	530.0	0.7286E 02	0.4307E-01	0.8913E 04
2	133.32	0.3667E 01	530.0	0.2843E 03	0.6258E-01	0.1295E 05
3	133.12	0.5231E 01	530.0	0.2857E 03	0.7451E-01	0.1542E 05
4	132.92	0.6950E 01	530.0	0.2884E 03	0.8542E-01	0.1768E 05
5	133.32	0.8743E 01	530.0	0.2869E 03	0.9621E-01	0.1991E 05
6	134.92	0.1051E 02	529.0	0.2953E 03	0.1047E-00	0.2170E 05
7	134.92	0.1243E 02	529.0	0.3035E 03	0.1123E-00	0.2327E 05
8	134.82	0.1466E 02	528.0	0.3145E 03	0.1199E-00	0.2488E 05
9	133.32	0.1617E 02	528.0	0.3081E 03	0.1265E-00	0.2625E 05
10	134.32	0.1856E 02	527.0	0.3205E 03	0.1335E-00	0.2773E 05
11	134.12	0.2080E 02	527.0	0.3278E 03	0.1396E-00	0.2902E 05
12	133.82	0.2344E 02	527.0	0.3393E 03	0.1455E-00	0.3024E 05

APPENDIX A (Continued)

WAMU-TME-1201

DRIVE SHAFT SPLINE AIR FLOW TESTS

RUN DATE MAY 15, 1964

STRAIGHT SPLINES

THE GAP BETWEEN THE SHAFT AND THE COUPLING WAS ONE HALF INCH.

THE LOSS PARAMETER IS CALCULATED FOR STATION 19 TO 16

	P19 PSIA	DP(19-16) PSID	TEMP DEG R	CLDASQ INCH-4	FLOW LB/SEC	REYNOLDS NO LOC 10
1	131.00	0.1670E 01	533.0	0.2658E 03	0.4318E-01	0.8902E 04
2	133.50	0.3301E 01	533.0	0.2658E 03	0.6128E-01	0.1263E 05
3	133.20	0.5042E 01	533.0	0.2637E 03	0.7596E-01	0.1566E 05
4	131.00	0.6582E 01	532.0	0.2656E 03	0.8584E-01	0.1772E 05
5	134.00	0.8117E 01	533.0	0.2690E 03	0.9570E-01	0.1973E 05
6	136.51	0.9308E 01	532.0	0.2655E 03	0.1042E-00	0.2152E 05
7	136.71	0.1124E 02	532.5	0.2745E 03	0.1126E-00	0.2324E 05
8	133.51	0.1326E 02	532.5	0.2796E 03	0.1198E-00	0.2472E 05
9	135.51	0.1428E 02	532.5	0.2714E 03	0.1272E-00	0.2623E 05
10	136.51	0.1611E 02	532.0	0.2788E 03	0.1338E-00	0.2762E 05
11	136.71	0.1867E 02	531.5	0.2931E 03	0.1406E-00	0.2905E 05
12	134.01	0.2063E 02	531.5	0.2952E 03	0.1459E-00	0.3013E 05
13	131.21	0.2323E 02	531.0	0.3027E 03	0.1513E-00	0.3128E 05

APPENDIX A (Continued)

DRIVE SHAFT SPLINE AIR FLOW TESTS

RUN DATE MAY 18, 1964

STRAIGHT SPLINES

THE GAP BETWEEN THE SHAFT AND THE COUPLING WAS THREE QUARTERS OF AN INCH
THE LOSS PARAMETER IS CALCULATED FOR STATION 19 TO 16

	P19 PSIA	DP(19-16) PSID	TEMP DEG R	CLDASQ INCH-4	FLOW LB/SEC	REYNOLDS NO LOC 10
1	137.02	0.1609E 01	538.0	0.2671E 03	0.4304E-01	0.8816E 04
2	137.02	0.3291E 01	537.0	0.2745E 03	0.6077E-01	0.1246E 05
3	132.52	0.4986E 01	537.0	0.2693E 03	0.7427E-01	0.1523E 05
4	136.72	0.6484E 01	536.0	0.2744E 03	0.8530E-01	0.1752E 05
5	133.02	0.8338E 01	536.0	0.2743E 03	0.9543E-01	0.1960E 05
6	135.02	0.9664E 01	536.0	0.2713E 03	0.1041E-00	0.2138E 05
7	135.02	0.1167E 02	536.0	0.2788E 03	0.1128E-00	0.2317E 05
8	135.02	0.1375E 02	535.0	0.2893E 03	0.1204E-00	0.2475E 05
9	131.72	0.1582E 02	535.0	0.2920E 03	0.1269E-00	0.2609E 05
10	135.32	0.1716E 02	535.0	0.2947E 03	0.1333E-00	0.2742E 05
11	134.52	0.1881E 02	535.0	0.2903E 03	0.1403E-00	0.2884E 05
12	135.72	0.2070E 02	535.0	0.2971E 03	0.1461E-00	0.3004E 05
13	135.52	0.2274E 02	534.0	0.3055E 03	0.1510E-00	0.3110E 05
14	135.52	0.2368E 02	534.0	0.3100E 03	0.1530E-00	0.3150E 05

APPENDIX A (Continued)

DRIVE SHAFT SPLINE AIR FLOW TESTS

RUN DATE. MAY 6, 1964

CROWNED SPLINES

THE SHAFT WAS BUTTED UP AGAINST THE COUPLING

THE LOSS PARAMETER IS CALCULATED FOR STATION 19 TO 16

	P19 PSIA	DP(19-16) PSID	TEMP DEG R	CLDASQ INCH-4	FLOW LB/SEC	REYNOLDS N ² LOC 10
1	134.43	0.2886E 01	543.5	0.2359E 04	0.1911E-01	0.3887E 04
2	133.43	0.5575E 01	543.0	0.2133E 04	0.2785E-01	0.5668E 04
3	132.43	0.8338E 01	542.0	0.2156E 04	0.3378E-01	0.6883E 04
4	131.43	0.8792E 01	541.0	0.2013E 04	0.3580E-01	0.7304E 04
5	134.63	0.1186E 02	540.5	0.1948E 04	0.4279E-01	0.8737E 04
6	134.93	0.1431E 02	539.5	0.1965E 04	0.4689E-01	0.9587E 04
7	134.93	0.1766E 02	539.5	0.1975E 04	0.5196E-01	0.1062E 05
8	135.13	0.1984E 02	537.5	0.2018E 04	0.5464E-01	0.1120E 05
9	134.63	0.2231E 02	537.5	0.2043E 04	0.5747E-01	0.1178E 05
10	133.93	0.2449E 02	537.5	0.2087E 04	0.5941E-01	0.1218E 05

APPENDIX A (Continued)

DRIVE SHAFT SPLINE AIR FLOW TESTS

RUN DATE MAY 12, 1964

STRAIGHT SPLINES

THE SHAFT WAS BUTTED UP AGAINST THE COUPLING

THE LOSS PARAMETER IS CALCULATED FOR STATION 19 TO 16

	P19	DP(19-16)	TEMP	CLDASQ	FLOW	REYNOLDS NO
	PSIA	PSID	DEG R	INCH-4	LB/SEC	LOC 10
1	136.93	0.2849E 01	533.0	0.6178E 03	0.3782E-01	0.7797E 04
2	133.83	0.5612E 01	532.0	0.6065E 03	0.5301E-01	0.1094E 05
3	133.83	0.8228E 01	532.0	0.5859E 03	0.6531E-01	0.1348E 05
4	134.83	0.1091E 02	532.0	0.5987E 03	0.7467E-01	0.1541E 05
5	134.83	0.1390E 02	532.0	0.6227E 03	0.8265E-01	0.1706E 05
6	132.83	0.1709E 02	532.0	0.6346E 03	0.9011E-01	0.1860E 05
7	135.03	0.1962E 02	531.5	0.6271E 03	0.9797E-01	0.2024E 05
8	136.33	0.2302E 02	531.0	0.6586E 03	0.1041E-00	0.2152E 05
9	133.03	0.2408E 02	530.5	0.6510E 03	0.1058E-00	0.2189E 05

APPENDIX A (Continued)