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WANL-TME-712

March 6, 1964

TEST SERIES A 7
EXPERIMENTAL DETERMINATION
OF THE PRESSURE LOSS COEFFICIENT
FOR THE PRODUCTION TIE ROD CENTERING BUSHING
(Title Unclassified)

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By

Henry J. Fix

Fluid Flow Laboratory

SPECIAL REREVIEW FINAL DETERMINATION	Reviewer	Class.	Date
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Manager, Fluid Flow Laboratory

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INTRODUCTION

The purpose of this memo is to summarize the results of tests on a production-type tie rod centering bushing. The areas which were investigated were:

1. The variation in pressure loss coefficient as a function of Reynolds number when approached by various test conditions.
2. The effect of centering bushing leakage paths on the pressure loss coefficient.
3. The effect of tie rod diameter on the pressure loss coefficient.

Tests were conducted on a production-type centering bushing using hydrogen gas at inlet pressures of 670 and 330 psig and at ambient and cryogenic temperature. Tie rods having diameters of 0.110 inches and 0.122 inches were tested at the above conditions with the centering bushing leakage paths sealed and unsealed.

TEST APPARATUS AND INSTRUMENTATION

The flow loop is shown in Figure 1. Hydrogen gas passes through the pressure reducing valve, through the heat exchanger and a copper coil immersed in a dewar of liquid nitrogen and into the inlet plenum of the test fixture. The entire test fixture* is immersed in liquid nitrogen in a dewar to obtain isothermal conditions of operation. For ambient tests, the dewars remain empty.

*

NOTE: The test fixture was constructed according to Drawing NT700708.

From the inlet plenum of the test fixture, Figure 2, the gas passes through the centering bushing assembly, Figure 3. The four possible flow paths through the centering bushing assembly are:

- 1) Through the four (4) orifices (orifice flow)
- 2) Through the split in the split bushing (leakage flow)
- 3) Through the annulus formed by the tie rod and the bushing (leakage flow)
- 4) Around the edge where the split bushing insert fits into the centering bushing (leakage flow).

The centering bushing is glued to the test fixture and for the "sealed" tests all leakage paths are sealed with "Duce" cement, while for the "unsealed" tests the leakage paths remain open. The flow from the bushing assembly exhausts into a simulated tie rod annulus, passes down the annulus from which it flows into the outlet plenum, and then through the heat exchanger, a flow control valve, a sonic flow measuring orifice and exhausts to atmosphere. Pressure taps were located and the pressure measured in the inlet plenum and in the annulus at a point one-inch downstream of the centerlines of the orifices. The pressure differential between the two points was measured by 0-20, 0-50, 0-100 and 0-200 psi differential pressure gauges. Flow rates and inlet plenum temperatures were recorded. Pertinent dimensions of the tie rod centering bushing assembly are shown in Figure 4.

The flow rate through the fixture was measured to within $\pm 0.5\%$ maximum error. Inlet plenum pressure was measured to within $\pm 1.5\%$ maximum error for the 670 psig tests and to within $\pm 3\%$ maximum error for 330 psig tests. Temperatures were measured to within $\pm 1^\circ$ maximum error. For differential pressures between 200 and 10 psid the maximum error in measured pressure differential is 1 to 2% and between 10 and 5 psid the maximum error in measured pressure differential is between 2 and 4%. The above measurements would yield the following maximum possible error in loss coefficient

Inlet Pressure	Pressure differential	Maximum error in Loss Coefficient
660 psig	10 to 200 psi	5.5 to 4.5%
330 psig	10 to 200 psi	7 to 6%
660 psig	5 to 10 psi	7.5 to 5.5%
330 psig	5 to 10 psi	9 to 7%

METHOD OF OBTAINING RESULTS

Data obtained from the tests was reduced to flow rates, pressure loss coefficients and Reynolds number by means of a computer program. Tabulated hydrogen properties are introduced into the program to obtain density and viscosity. Values obtained from the tests are presented in Table I. Calculations of pressure loss coefficients and Reynolds numbers were based on the inlet plenum conditions.

Pressure Loss Coefficient

$$C = \frac{2 \pi^2 \rho g \Delta P d^4 N^2}{16 W^2}$$

where

C = pressure loss coefficient (dimensionless)

ρ = density (lb/cu ft) evaluated at inlet pressure (PIN)
and inlet temperature (TIN)

g = gravitational constant (ft/sec²)

ΔP = static pressure drop (DP) (lb/sq ft) across the bushing
assembly

d = orifice diameter (ft)

W = mass rate of flow (FLOW) (lb/sec)

N = number of orifices = 4

Reynolds Number

The Reynolds number is defined as:

$$Re = \frac{4 W}{\pi N \mu d}$$

where

Re = Reynolds number (RE) (dimensionless)

μ = Viscosity (lb/ft sec) evaluated at inlet pressure (PIN)
and inlet temperature (TIN)

DISCUSSION

Figures 5 thru 8 inclusive, present the data obtained from the tests and which is tabulated in Table I.

In general, the loss coefficient for a particular set of test conditions is found to decrease with increasing Reynolds number, then remain constant over a range and then increase with increasing Reynolds number. The decrease in loss coefficient with increasing Reynolds number for a particular set of test conditions is thought to be due to boundary layer development in the vicinity of the orifice which would result in less friction. The increase in loss coefficient for increasing Reynolds number is thought to be due to compressibility effects due to high pressure drops (Mach number) and turning losses at the high flow rates.

The loss coefficient for both the 0.110 and 0.122 diameter tie rod tests (Figures 5 and 6) is found to decrease from a nominal value of 1.8 for the sealed cases to 1.4 for the unsealed cases. This decrease due to leakage is as would be expected since the net effect of the leakage areas is a lower pressure drop for a given total mass flow rate.

The average loss coefficient for the sealed cases is constant over the range of Reynolds numbers investigated. However, for the unsealed cases the average loss coefficient increases over the range of Reynolds numbers investigated. It is felt that the individual loss coefficient for the leakage paths must increase with Reynolds number causing a net increase in pressure drop, and total loss coefficient. Varying the tie rod diameter was found to have no appreciable effect on the pressure loss coefficient for the tie rod

sizes considered. Figures 7 and 8 present flow rate pressure drop curves for the 0.110 and 0.122 inch diameter tie rods for various test conditions for both the sealed and unsealed cases. The effect of changing the test conditions, i.e., pressure and temperature, is as would be expected, namely that for a given pressure drop as the density increases, the total mass flow rate increases.

For a given set of test conditions, and a given pressure drop across the assembly, the flow rate is approximately the same for both the 0.110 and 0.122 inch diameter tie rods. The only exception is the cryogenic tests at 685 psia inlet pressure and this difference in flow rate is due to the difference in temperature for the various tests. For the sealed case, the temperature for the 0.110 inch diameter tie rod test was greater than the temperature for the case of the 0.122 inch diameter tie rod. This would result in a lower fluid density for the 0.110 inch diameter tie rod test and, therefore, for the same pressure drop a lower flow rate than for the 0.122 inch diameter tie rod. A similar reasoning applies to the unsealed case.

CONCLUSIONS

1. For similar leakage paths varying the tie rod diameter from 0.110 to 0.122 inch diameter has no effect on the flow rate pressure drop characteristics.
2. The nominal pressure loss coefficient based on orifice flow area for the 0.110 and 0.122 inch diameter tie rods for the unsealed case was found to 1.4.
3. The nominal pressure loss coefficient based on orifice flow area for the 0.110 and 0.122 inch diameter tie rods for the sealed case was found to 1.8.
4. Loss coefficient is found to be relatively independent of Reynolds number and dependent on Mach number.

Figure 1
 Small Scale Basic Flow System

Figure 2
Tie Rod Centering Bushing Test Fixture

Figure 3
Tie Rod Centering Bushing and Associated Components

* NOTE: APPLIES TO 0.122 IN. DIA. TIE ROD TESTS.

Figure 4
 Tie Rod Centering Bushing and Associated Components

Figure 5
 Loss Coefficient versus Reynolds Number
 for the 0.110 inch diameter Tie Rod

Figure 6

Loss Coefficient versus Reynolds Number
 for the 0.122 inch diameter Tie Rod

Figure 7
 Flow Rate versus Pressure Drop
 for the 0.110 inch diameter Tie Rod

Figure 8
 Flow Rate versus Pressure Drop
 for the 0.122 inch diameter Tie Rod

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TIE ROD CENTERING BUSHING

TEST NUMBER 40

ORIFICE DIAMETER IN INCHES = 0.0333

DIAMETER OF TIE ROD IN INCHES = 0.110

LEAKAGE PATHS SEALED

BAROMETRIC PRESSURE IN PSIA = 14.55

GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
684.55	158.10	18.00	6.470E-03	1.93	2.729E 05
684.55	157.10	21.00	7.043E-03	1.91	2.982E 05
684.55	158.10	24.30	7.746E-03	1.81	3.268E 05
684.55	158.10	25.50	7.967E-03	1.80	3.361E 05
684.55	158.10	27.20	8.111E-03	1.85	3.422E 05
684.55	158.10	30.20	8.557E-03	1.85	3.610E 05
684.55	158.10	32.00	8.921E-03	1.80	3.764E 05
684.55	158.10	36.50	9.418E-03	1.84	3.973E 05
684.55	157.10	39.50	9.843E-03	1.84	4.168E 05
684.55	157.10	45.00	1.050E-02	1.84	4.446E 05
684.55	157.10	50.50	1.119E-02	1.82	4.739E 05
684.55	156.10	53.00	1.151E-02	1.82	4.892E 05
684.55	157.10	56.10	1.172E-02	1.84	4.963E 05
684.55	157.10	60.50	1.213E-02	1.86	5.135E 05
684.55	157.10	65.90	1.262E-02	1.87	5.342E 05
684.55	157.10	69.90	1.303E-02	1.86	5.517E 05
684.55	156.10	76.50	1.353E-02	1.90	5.751E 05
684.55	156.10	78.00	1.365E-02	1.90	5.803E 05
684.55	154.50	84.10	1.430E-02	1.89	6.116E 05
684.55	153.60	93.00	1.506E-02	1.90	6.462E 05

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TIE ROD CENTERING BUSHING
TEST NUMBER 41
ORIFICE DIAMETER IN INCHES = 0.0333
DIAMETER OF TIE ROD IN INCHES = 0.110
LEAKAGE PATHS SEALED
BAROMETRIC PRESSURE IN PSIA = 14.55
GASEOUS HYDROGEN

PIN PSIA	TIN (K)	DP PSI	FLOW LB/SEC	C	RE
344.55	162.30	9.00	3.115E-03	2.03	1.354E 05
345.55	162.30	10.00	3.350E-03	1.96	1.456E 05
345.55	161.30	11.40	3.592E-03	1.95	1.568E 05
344.55	161.30	14.00	4.002E-03	1.93	1.747E 05
344.55	160.20	14.00	3.965E-03	1.98	1.740E 05
344.55	159.10	16.20	4.287E-03	1.97	1.891E 05
344.55	158.10	19.00	4.704E-03	1.94	2.084E 05
344.55	158.10	22.00	5.152E-03	1.87	2.283E 05
344.55	158.10	24.80	5.447E-03	1.88	2.413E 05
344.55	158.10	26.20	5.684E-03	1.83	2.518E 05
344.55	157.10	27.80	5.941E-03	1.79	2.644E 05
344.55	158.10	29.60	6.040E-03	1.83	2.676E 05
344.55	157.10	30.10	6.059E-03	1.86	2.697E 05
344.55	157.10	31.60	6.322E-03	1.79	2.814E 05
344.55	158.10	32.00	6.273E-03	1.83	2.779E 05
344.55	157.10	34.20	6.585E-03	1.79	2.931E 05
344.55	158.10	36.00	6.669E-03	1.82	2.955E 05

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TIE ROD CENTERING BUSHING

TEST NUMBER 38

ORIFICE DIAMETER IN INCHES = 0.0333

DIAMETER OF TIE ROD IN INCHES = 0.110

LEAKAGE PATHS SEALED

BAROMETRIC PRESSURE IN PSIA = 14.43

GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	KE
683.43	503.10	11.50	2.898E-03	1.84	5.722E 04
684.43	503.10	17.50	3.604E-03	1.81	7.116E 04
684.43	503.10	21.90	4.063E-03	1.79	8.021E 04
684.43	503.10	24.20	4.261E-03	1.80	8.513E 04
684.43	503.10	30.10	4.695E-03	1.84	9.269E 04
685.43	503.10	34.00	4.967E-03	1.86	9.807E 04
684.43	503.10	38.20	5.265E-03	1.86	1.039E 05
684.43	503.10	40.00	5.373E-03	1.87	1.041E 05
684.43	503.10	49.00	5.934E-03	1.87	1.172E 05
684.43	503.10	50.00	5.968E-03	1.89	1.173E 05
685.43	503.10	59.20	6.479E-03	1.90	1.279E 05
684.43	503.10	59.80	6.479E-03	1.92	1.279E 05
684.43	503.10	69.00	6.937E-03	1.93	1.370E 05
684.43	503.10	72.00	7.111E-03	1.92	1.404E 05
684.43	503.10	77.00	7.334E-03	1.93	1.448E 05
684.43	503.10	87.20	7.755E-03	1.95	1.531E 05
684.43	503.10	87.90	7.718E-03	1.99	1.524E 05
684.43	503.10	96.20	8.102E-03	1.97	1.600E 05
684.43	503.10	98.00	8.102E-03	2.01	1.600E 05

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TIE ROD CENTERING BUSHING

TEST NUMBER 7

ORIFICE DIAMETER IN INCHES = 0.0333

DIAMETER OF TIE ROD IN INCHES = 0.110

LEAKAGE PATHS SEALED

BAROMETRIC PRESSURE IN PSIA = 14.53

GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
344.53	538.60	11.10	1.944E-03	1.89	3.685E 04
344.53	538.10	16.10	2.386E-03	1.82	4.525E 04
344.53	537.60	20.50	2.697E-03	1.82	5.117E 04
344.53	538.10	27.00	3.044E-03	1.88	5.773E 04
344.53	538.10	31.00	3.344E-03	1.78	6.341E 04
344.53	538.10	40.30	3.776E-03	1.82	7.162E 04
344.53	538.10	45.70	4.004E-03	1.83	7.594E 04
344.53	538.10	49.70	4.112E-03	1.89	7.799E 04
344.53	538.10	54.80	4.316E-03	1.89	8.185E 04
344.53	537.60	60.80	4.508E-03	1.93	8.554E 04
344.53	538.10	65.50	4.674E-03	1.93	8.864E 04
344.53	536.60	70.00	4.782E-03	1.98	9.085E 04
344.53	538.10	75.20	4.937E-03	1.99	9.364E 04
344.53	537.10	80.00	5.035E-03	2.03	9.560E 04
344.53	538.10	84.90	5.157E-03	2.05	9.781E 04
344.53	537.10	92.00	5.339E-03	2.08	1.014E 05

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TIE ROD CENTERING BUSHING

TEST NUMBER 28

ORIFICE DIAMETER IN INCHES = 0.0333

DIAMETER OF TIE ROD IN INCHES = 0.110

LEAKAGE PATHS UNSEALED

BAROMETRIC PRESSURE IN PSIA = 14.49

GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
684.49	156.10	16.00	6.853E-03	1.55	2.912E 05
685.49	153.80	19.90	7.685E-03	1.56	3.293E 05
684.49	152.00	24.50	8.727E-03	1.51	3.766E 05
684.49	152.00	31.00	9.859E-03	1.50	4.254E 05
684.49	150.60	36.50	1.067E-02	1.52	4.629E 05
683.49	149.60	41.00	1.133E-02	1.53	4.934E 05
684.49	150.60	48.00	1.234E-02	1.50	5.350E 05
684.49	150.60	56.00	1.330E-02	1.50	5.769E 05
684.49	152.00	62.50	1.406E-02	1.48	6.068E 05
684.49	152.00	68.00	1.459E-02	1.50	6.294E 05
684.49	152.00	72.50	1.510E-02	1.49	6.516E 05
684.49	152.00	80.00	1.587E-02	1.49	6.848E 05
684.49	152.00	88.50	1.631E-02	1.56	7.037E 05
684.49	149.60	98.00	1.698E-02	1.63	7.393E 05

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TIE ROD CENTERING BUSHING

TEST NUMBER 46

ORIFICE DIAMETER IN INCHES = 0.0333

DIAMETER OF TIE ROD IN INCHES = 0.110

LEAKAGE PATHS UNSEALED

BAROMETRIC PRESSURE IN PSIA = 14.45

GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
344.45	142.40	5.30	2.884E-03	1.62	1.378E 05
344.45	142.40	5.50	2.966E-03	1.59	1.417E 05
344.45	142.40	6.60	3.259E-03	1.58	1.556E 05
345.45	142.40	7.50	3.428E-03	1.63	1.637E 05
344.45	142.40	8.50	3.701E-03	1.58	1.768E 05
344.45	142.40	9.90	3.975E-03	1.59	1.899E 05
344.45	141.10	10.00	4.127E-03	1.51	1.984E 05
345.45	142.40	12.00	4.486E-03	1.52	2.142E 05
344.45	141.10	13.20	4.742E-03	1.51	2.280E 05
344.45	141.10	14.80	4.966E-03	1.54	2.388E 05
344.45	141.10	15.20	5.107E-03	1.50	2.455E 05
344.45	142.40	17.00	5.344E-03	1.51	2.552E 05
344.45	141.10	17.80	5.534E-03	1.49	2.661E 05
344.45	141.10	18.90	5.749E-03	1.47	2.764E 05
344.45	141.10	20.80	6.054E-03	1.46	2.911E 05
344.45	141.10	22.20	6.301E-03	1.44	3.029E 05
344.45	142.40	26.00	6.818E-03	1.42	3.256E 05

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TIE ROD CENTERING BUSHING

TEST NUMBER 67

ORIFICE DIAMETER IN INCHES = 0.0333

DIAMETER OF TIE ROD IN INCHES = 0.110

LEAKAGE PATHS UNSEALED

BAROMETRIC PRESSURE IN PSIA = 14.35

GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
684.35	506.10	5.80	2.417E-03	1.33	4.755E 04
684.35	506.10	10.70	3.306E-03	1.31	6.507E 04
683.35	506.10	13.90	3.746E-03	1.32	7.369E 04
684.35	505.60	16.40	4.094E-03	1.31	8.058E 04
685.35	506.10	17.20	4.177E-03	1.32	8.215E 04
683.35	505.60	19.80	4.479E-03	1.32	8.815E 04
684.35	506.60	21.20	4.557E-03	1.37	8.957E 04
683.35	507.00	26.10	5.048E-03	1.37	9.917E 04
684.35	507.40	29.50	5.451E-03	1.33	1.070E 05
684.35	507.40	36.70	5.968E-03	1.38	1.172E 05
684.35	507.40	42.00	6.411E-03	1.36	1.259E 05
683.35	507.80	46.50	6.741E-03	1.36	1.323E 05
684.35	508.40	52.00	7.184E-03	1.34	1.409E 05
684.35	508.40	57.50	7.532E-03	1.35	1.477E 05
684.35	508.40	63.50	7.921E-03	1.35	1.554E 05
684.35	508.80	74.30	8.471E-03	1.38	1.661E 05
683.35	508.40	84.00	8.987E-03	1.38	1.763E 05
683.35	508.40	88.70	9.208E-03	1.39	1.806E 05
684.35	508.40	95.50	9.478E-03	1.42	1.859E 05

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TIE ROD CENTERING BUSHING
TEST NUMBER 68
ORIFICE DIAMETER IN INCHES = 0.0333
DIAMETER OF TIE ROD IN INCHES = 0.110
LEAKAGE PATHS UNSEALED
BAROMETRIC PRESSURE IN PSIA = 14.33
GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
344.33	506.10	6.40	1.789E-03	1.37	3.529E 04
345.33	506.10	8.50	2.061E-03	1.37	4.066E 04
345.33	506.10	10.30	2.284E-03	1.35	4.505E 04
344.33	506.60	12.40	2.494E-03	1.36	4.917E 04
344.33	507.00	14.30	2.666E-03	1.37	5.253E 04
345.33	507.00	16.10	2.839E-03	1.37	5.594E 04
345.33	506.60	18.80	3.025E-03	1.41	5.963E 04
343.33	507.00	21.50	3.210E-03	1.42	6.325E 04
344.33	507.00	24.60	3.408E-03	1.44	6.715E 04
344.33	507.00	26.70	3.581E-03	1.42	7.056E 04
344.33	507.00	30.40	3.777E-03	1.45	7.442E 04
344.33	507.00	33.40	3.963E-03	1.45	7.807E 04
344.33	506.60	38.50	4.259E-03	1.45	8.396E 04
344.33	506.60	42.10	4.407E-03	1.48	8.688E 04
344.33	506.60	47.00	4.630E-03	1.50	9.127E 04
344.33	506.60	49.00	4.764E-03	1.47	9.391E 04
344.33	506.60	53.00	4.925E-03	1.49	9.707E 04
344.33	506.60	56.00	5.083E-03	1.48	1.002E 05
344.33	506.60	58.50	5.157E-03	1.50	1.017E 05
344.33	506.10	63.00	5.342E-03	1.51	1.054E 05
344.33	507.00	67.50	5.466E-03	1.54	1.077E 05

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TIE ROD CENTERING BUSHING

TEST NUMBER 18

ORIFICE DIAMETER IN INCHES = 0.0333

DIAMETER OF TIE ROD IN INCHES = 0.122

LEAKAGE PATHS SEALED

BAROMETRIC PRESSURE IN PSIA = 14.36

GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
684.36	158.10	7.50	4.402E-03	1.73	1.857E 05
684.36	152.60	8.60	4.729E-03	1.80	2.036E 05
684.36	156.10	11.20	5.396E-03	1.75	2.293E 05
684.36	156.10	17.10	6.741E-03	1.71	2.865E 05
684.36	154.50	23.20	7.829E-03	1.74	3.347E 05
685.36	154.50	24.00	7.913E-03	1.77	3.383E 05
684.36	152.60	31.30	9.099E-03	1.77	3.917E 05
694.36	152.60	37.50	1.001E-02	1.77	4.301E 05
684.36	152.60	42.50	1.057E-02	1.78	4.551E 05
694.36	152.60	47.00	1.118E-02	1.78	4.806E 05
684.36	149.60	54.00	1.204E-02	1.78	5.241E 05
683.36	152.60	58.00	1.245E-02	1.74	5.363E 05
683.36	149.60	64.00	1.295E-02	1.82	5.638E 05
684.36	149.60	67.00	1.338E-02	1.79	5.824E 05
684.36	149.60	74.50	1.395E-02	1.83	6.074E 05
684.36	149.60	80.10	1.453E-02	1.82	6.325E 05
684.36	149.60	86.00	1.491E-02	1.85	6.493E 05
684.36	149.60	95.00	1.550E-02	1.89	6.748E 05
684.36	149.60	97.00	1.578E-02	1.86	6.871E 05

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TIE ROD CENTERING BUSHING
TEST NUMBER 17
ORIFICE DIAMETER IN INCHES = 0.0333
DIAMETER OF TIE ROD IN INCHES = 0.122
LEAKAGE PATHS SEALED
BAROMETRIC PRESSURE IN PSIA = 14.36
GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
344.36	177.10	6.60	2.678E-03	1.83	1.092E 05
344.36	176.40	6.80	2.769E-03	1.77	1.133E 05
344.36	174.20	9.90	3.383E-03	1.75	1.397E 05
344.36	173.40	10.80	3.481E-03	1.81	1.442E 05
344.36	172.40	14.60	4.130E-03	1.75	1.718E 05
344.36	169.60	20.90	4.891E-03	1.82	2.059E 05
345.36	169.60	25.10	5.448E-03	1.77	2.293E 05
344.36	166.60	25.70	5.486E-03	1.81	2.340E 05
343.36	166.60	31.30	6.049E-03	1.81	2.580E 05
344.36	169.60	33.90	6.313E-03	1.77	2.658E 05
344.36	166.60	34.60	6.416E-03	1.79	2.736E 05
344.36	169.60	37.00	6.569E-03	1.79	2.765E 05
344.36	166.60	37.20	6.643E-03	1.79	2.833E 05
344.36	166.60	38.50	6.744E-03	1.80	2.876E 05
344.36	169.60	39.80	6.788E-03	1.80	2.858E 05
345.36	166.60	40.20	6.910E-03	1.79	2.947E 05
344.36	166.60	41.90	6.985E-03	1.82	2.979E 05

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TIE ROD CENTERING BUSHING

TEST NUMBER 15

ORIFICE DIAMETER IN INCHES = 0.0333

DIAMETER OF TIE ROD IN INCHES = 0.122

LEAKAGE PATHS SEALED

BAROMETRIC PRESSURE IN PSIA = 14.37

GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
683.37	506.10	11.20	2.841E-03	1.86	5.588E 04
684.37	506.60	13.00	3.048E-03	1.87	5.992E 04
684.37	506.10	14.60	3.301E-03	1.79	6.493E 04
684.37	507.00	16.40	3.483E-03	1.81	6.843E 04
684.37	506.10	26.10	4.317E-03	1.88	8.491E 04
684.37	507.60	29.90	4.645E-03	1.85	9.119E 04
684.37	506.10	33.70	4.923E-03	1.86	9.684E 04
684.37	506.10	39.10	5.310E-03	1.86	1.044E 05
684.37	506.60	44.00	5.648E-03	1.85	1.110E 05
684.37	505.10	45.80	5.746E-03	1.86	1.132E 05
684.37	505.10	50.00	6.068E-03	1.82	1.195E 05
684.37	504.70	56.50	6.483E-03	1.81	1.277E 05
684.37	505.60	63.00	6.737E-03	1.86	1.326E 05
684.37	507.60	64.00	6.810E-03	1.84	1.337E 05
684.37	505.60	71.00	7.096E-03	1.89	1.397E 05
684.37	507.00	78.50	7.459E-03	1.89	1.466E 05
684.37	505.60	80.00	7.493E-03	1.91	1.475E 05
684.37	506.10	88.00	7.820E-03	1.93	1.538E 05
684.37	507.60	94.00	8.047E-03	1.94	1.580E 05
684.37	505.60	95.00	8.109E-03	1.94	1.596E 05

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TIE ROD CENTERING BUSHING

TEST NUMBER 16

ORIFICE DIAMETER IN INCHES = 0.0333

DIAMETER OF TIE ROD IN INCHES = 0.122

LEAKAGE PATHS SEALED

BAROMETRIC PRESSURE IN PSIA = 14.37

GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
344.37	508.00	9.40	1.862E-03	1.85	3.665E 04
344.37	508.00	14.00	2.247E-03	1.89	4.421E 04
345.37	507.60	19.20	2.678E-03	1.83	5.272E 04
344.37	508.00	19.40	2.642E-03	1.89	5.199E 04
344.37	508.00	26.60	3.048E-03	1.95	5.999E 04
344.37	508.00	34.50	3.481E-03	1.94	6.849E 04
344.37	507.60	45.60	3.903E-03	2.04	7.684E 04
344.37	508.00	48.00	4.012E-03	2.03	7.895E 04
344.37	507.60	54.00	4.238E-03	2.05	8.344E 04
345.37	508.00	59.20	4.444E-03	2.05	8.746E 04
344.37	507.60	66.00	4.597E-03	2.13	9.050E 04
344.37	508.60	72.00	4.769E-03	2.15	9.376E 04
344.37	508.00	77.50	4.918E-03	2.18	9.678E 04
344.37	508.00	79.90	5.003E-03	2.17	9.846E 04
344.37	507.00	85.00	5.046E-03	2.28	9.942E 04
344.37	508.60	86.00	5.115E-03	2.24	1.006E 05
344.37	507.00	90.00	5.171E-03	2.30	1.019E 05
344.37	508.00	94.00	5.300E-03	2.28	1.043E 05
344.37	506.60	96.00	5.343E-03	2.30	1.053E 05

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TIE ROD CENTERING BUSHING

TEST NUMBER 53

ORIFICE DIAMETER IN INCHES = 0.0333

DIAMETER OF TIE ROD IN INCHES = 0.122

LEAKAGE PATHS UNSEALED

BAROMETRIC PRESSURE IN PSIA = 14.55

GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
684.55	162.30	10.20	4.963E-03	1.80	2.061E 05
684.55	162.30	12.20	5.729E-03	1.61	2.380E 05
684.55	162.30	14.50	6.416E-03	1.53	2.665E 05
683.55	159.10	23.50	8.311E-03	1.51	3.494E 05
684.55	162.30	15.20	6.675E-03	1.48	2.773E 05
684.55	158.10	28.20	9.120E-03	1.52	3.847E 05
684.55	158.10	34.30	1.005E-02	1.52	4.241E 05
684.55	158.10	37.20	1.044E-02	1.53	4.406E 05
685.55	158.10	39.20	1.079E-02	1.51	4.549E 05
684.55	158.10	44.10	1.144E-02	1.51	4.826E 05
684.55	157.10	50.10	1.210E-02	1.54	5.124E 05
684.55	158.10	50.90	1.227E-02	1.51	5.176E 05
684.55	156.20	58.10	1.304E-02	1.55	5.539E 05
684.55	157.10	61.70	1.351E-02	1.52	5.722E 05
684.55	154.80	66.20	1.389E-02	1.58	5.932E 05
684.55	154.10	74.00	1.457E-02	1.61	6.240E 05
684.55	158.10	74.20	1.454E-02	1.57	6.135E 05
684.55	154.10	83.00	1.538E-02	1.62	6.585E 05
684.55	154.10	88.00	1.578E-02	1.63	6.757E 05

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TIE ROD CENTERING BUSHING

TEST NUMBER 66

ORIFICE DIAMETER IN INCHES = 0.0333

DIAMETER OF TIE ROD IN INCHES = 0.122

LEAKAGE PATHS UNSEALED

BAROMETRIC PRESSURE IN PSIA = 14.51

GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
344.51	161.50	5.50	2.895E-03	1.44	1.263E 05
344.51	161.50	6.40	3.140E-03	1.43	1.370E 05
345.51	160.40	7.70	3.424E-03	1.46	1.501E 05
344.51	158.10	8.70	3.717E-03	1.42	1.647E 05
345.51	161.50	8.90	3.776E-03	1.38	1.647E 05
344.51	161.50	10.20	3.996E-03	1.41	1.743E 05
345.51	159.10	10.80	4.260E-03	1.34	1.878E 05
344.51	159.10	11.40	4.307E-03	1.38	1.899E 05
344.51	159.10	13.80	4.759E-03	1.36	2.099E 05
345.51	158.10	14.00	4.794E-03	1.38	2.124E 05
345.51	159.10	15.00	5.069E-03	1.31	2.235E 05
343.51	159.10	17.70	5.509E-03	1.30	2.430E 05
345.51	155.10	18.30	5.600E-03	1.35	2.515E 05
345.51	157.20	21.40	6.101E-03	1.31	2.714E 05
345.51	155.10	22.90	6.233E-03	1.36	2.800E 05
345.51	157.20	23.00	6.227E-03	1.35	2.770E 05
344.51	157.20	25.40	6.464E-03	1.38	2.876E 05
344.51	154.10	25.80	6.621E-03	1.36	2.988E 05
344.51	158.10	27.20	6.729E-03	1.35	2.981E 05
344.51	158.10	29.20	6.865E-03	1.40	3.042E 05

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TIE ROD CENTERING BUSHING

TEST NUMBER 11

ORIFICE DIAMETER IN INCHES = 0.0333

DIAMETER OF TIE ROD IN INCHES = 0.122

LEAKAGE PATHS UNSEALED

BAROMETRIC PRESSURE IN PSIA = 14.42

GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
684.42	519.10	11.10	3.361E-03	1.28	6.505E 04
684.42	519.10	14.20	3.789E-03	1.29	7.334E 04
683.42	519.10	20.00	4.425E-03	1.33	8.564E 04
684.42	519.10	25.30	5.012E-03	1.32	9.700E 04
684.42	520.10	30.00	5.452E-03	1.32	1.054E 05
684.42	519.10	32.20	5.623E-03	1.33	1.088E 05
684.42	520.10	34.20	5.794E-03	1.33	1.120E 05
684.42	519.10	40.00	6.271E-03	1.33	1.214E 05
684.42	520.10	40.60	6.320E-03	1.33	1.222E 05
684.42	520.10	47.20	6.834E-03	1.32	1.321E 05
684.42	520.10	51.00	7.115E-03	1.31	1.375E 05
684.42	520.10	59.00	7.641E-03	1.32	1.477E 05
684.42	519.10	62.00	7.824E-03	1.32	1.514E 05
684.42	520.10	71.00	8.301E-03	1.34	1.605E 05
684.42	520.10	78.00	8.680E-03	1.35	1.678E 05
684.42	519.10	78.00	8.754E-03	1.33	1.694E 05
684.42	520.10	88.00	9.169E-03	1.36	1.773E 05
684.42	521.10	96.00	9.567E-03	1.37	1.847E 05
683.42	519.10	96.50	9.524E-03	1.39	1.843E 05

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TIE ROD CENTERING BUSHING

TEST NUMBER 65

ORIFICE DIAMETER IN INCHES = 0.0333

DIAMETER OF TIE ROD IN INCHES = 0.122

LEAKAGE PATHS UNSEALED

BAROMETRIC PRESSURE IN PSIA = 14.42

GASEOUS HYDROGEN

PIN PSIA	TIN (R)	DP PSI	FLOW LB/SEC	C	RE
343.42	497.20	10.00	2.332E-03	1.28	4.652E 04
344.42	497.20	13.90	2.694E-03	1.33	5.376E 04
344.42	497.20	14.00	2.797E-03	1.25	5.580E 04
345.42	498.40	17.50	3.096E-03	1.27	6.167E 04
344.42	496.80	19.20	3.186E-03	1.32	6.360E 04
343.42	498.40	22.00	3.420E-03	1.30	6.814E 04
343.42	496.80	23.40	3.475E-03	1.35	6.936E 04
344.42	498.40	26.80	3.784E-03	1.30	7.538E 04
344.42	496.80	30.00	3.939E-03	1.35	7.863E 04
345.42	497.20	33.50	4.210E-03	1.32	8.400E 04
345.42	496.80	35.50	4.228E-03	1.39	8.439E 04
345.42	496.80	38.90	4.414E-03	1.39	8.812E 04
344.42	495.40	40.50	4.582E-03	1.35	9.162E 04
344.42	497.20	46.00	4.791E-03	1.39	9.558E 04
344.42	495.40	46.50	4.871E-03	1.37	9.740E 04
344.42	496.40	52.50	5.097E-03	1.41	1.018E 05
346.42	497.20	53.50	5.178E-03	1.40	1.033E 05
346.42	496.80	58.10	5.378E-03	1.41	1.074E 05
342.42	495.80	59.00	5.358E-03	1.43	1.071E 05
345.42	496.40	65.00	5.606E-03	1.45	1.120E 05
343.42	495.40	69.90	5.847E-03	1.42	1.169E 05
345.42	496.40	70.10	5.820E-03	1.45	1.162E 05

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