BRUSH SEALS FOR CRYOGENIC APPLICATIONS

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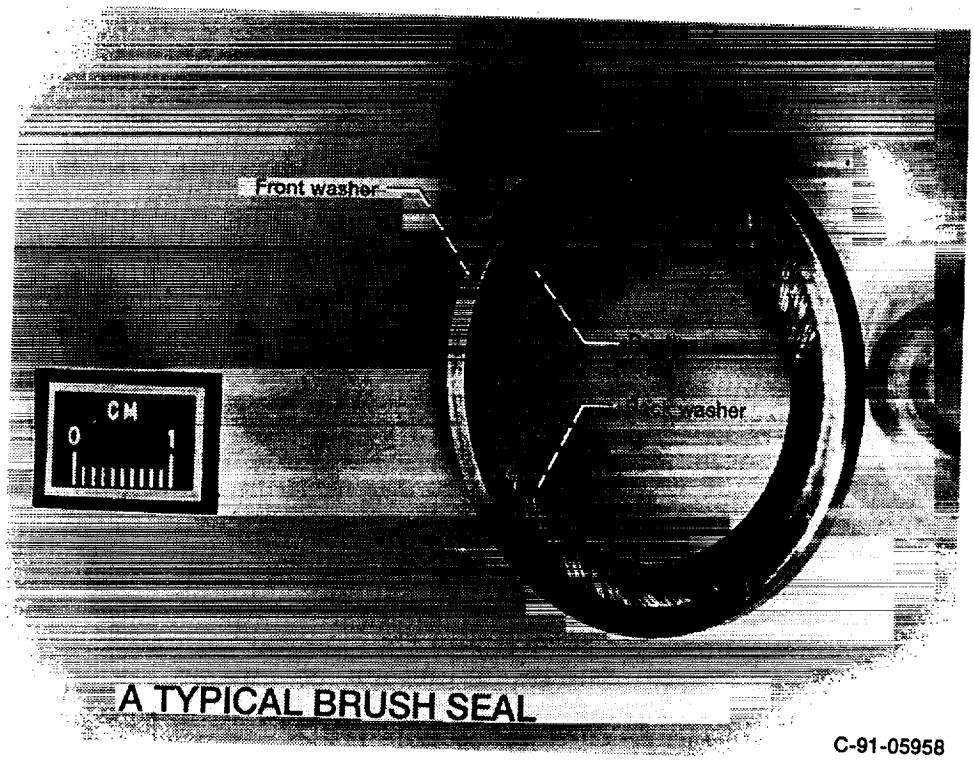


A TYPICAL BRUSH SEAL

C-91-05958

TEST PLAN

LN_2:
- CHECKOUT TESTER WITH FIXED CLEARANCE SEALS
- MEASURE LEAKAGE & WEAR PERFORMANCE OF
  - SINGLE BRUSH SEAL
  - 2 BRUSH SEALS FAR APART
  - 2 BRUSH SEALS CLOSE TOGETHER

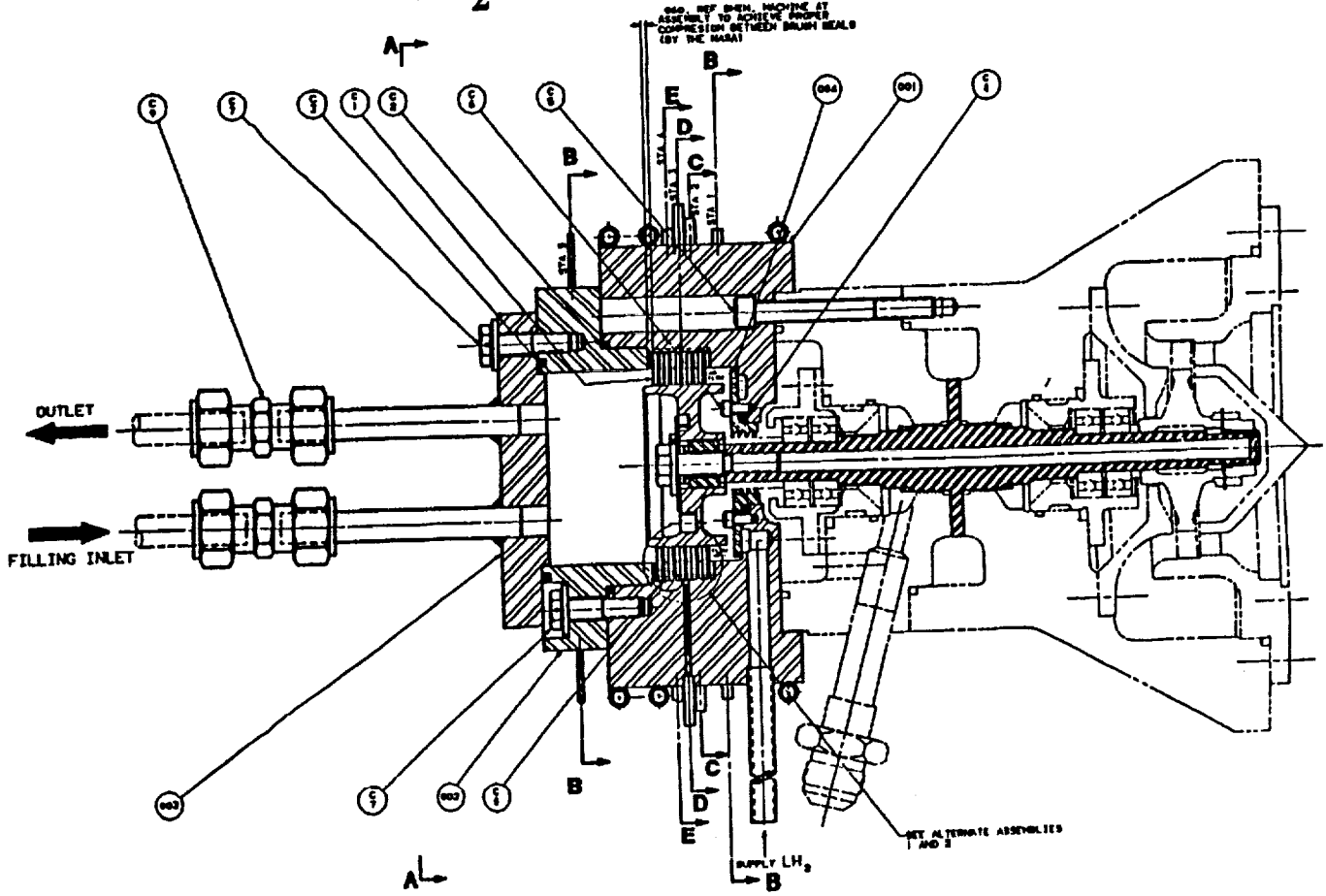
  up to 40,000 rpm
  Δp /seal 150 psi max

LH_2:
- MEASURE LEAKAGE & WEAR PERFORMANCE OF
  SINGLE BRUSH SEAL - UP TO 62,000 RPM (525 fps)
  5 BRUSHES TIGHTLY PACKED
- MEASURE LEAKAGE & WEAR OF BRUSH SEALS FOR 4 DIFFERENT MATERIALS AND 3 DIFFERENT INITIAL INTERFERENCES

BARE INCONEL	
OXIDE OF AL, MAGNESIA-ZIRCONIA OR ZIRCONIUM	0.0025 inches
CHROME CARBIDE	0.005 inches
SILVER	0.0075 inches

LN_2:
- MEASURE EFFECT OF FENCE HEIGHT, BRISTLE DIAMETER, PACKING DENSITY, DEPTH OF SPACES BETWEEN BRUSHES, BRISTLE MATERIALS, BRISTLE LENGTH AND ANGLE ON BRUSH SEAL PERFORMANCE

LH_2 BRUSH SEAL TESTER

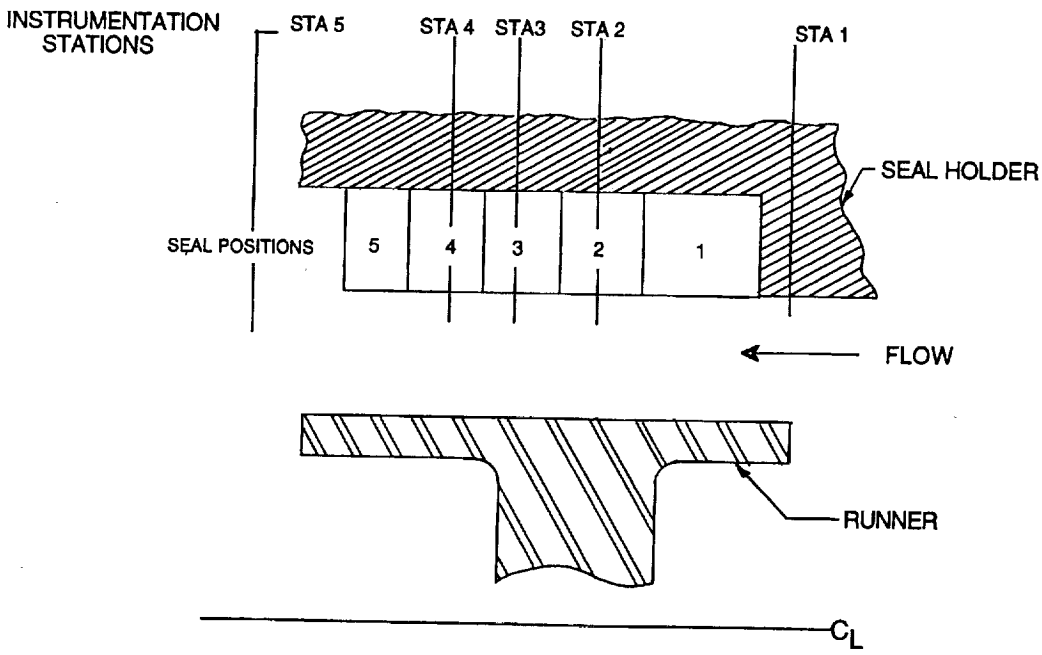


TESTER/FACILITY CAPABILITIES IN LN2

800 PSIG SUPPLY TO TEST SEAL

37,700 RPM AT 0 DELTA-P ACROSS SEAL

300 PSID ACROSS SEAL DURING ROTATION (LIMIT OF BALANCE PISTON)

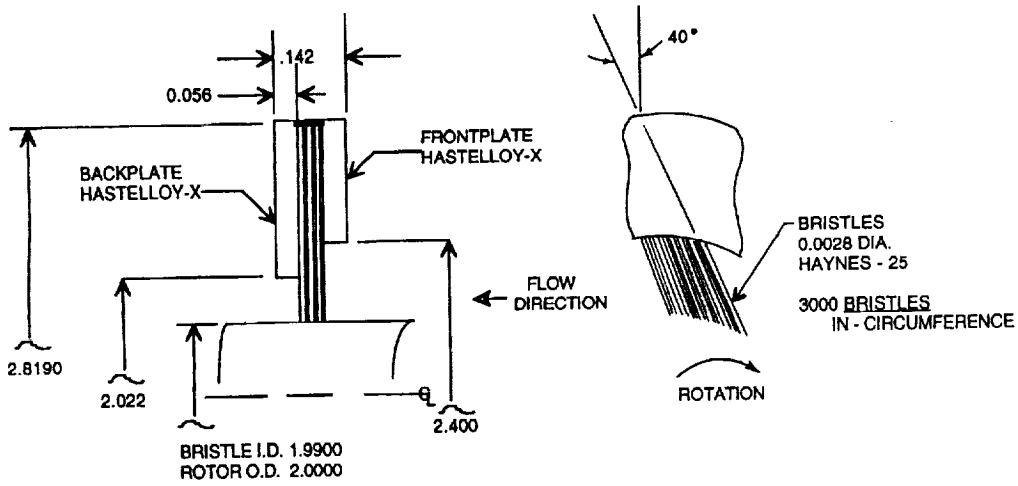


POSITIONS & STATIONS

CONFIGURATIONS TESTED IN LN2

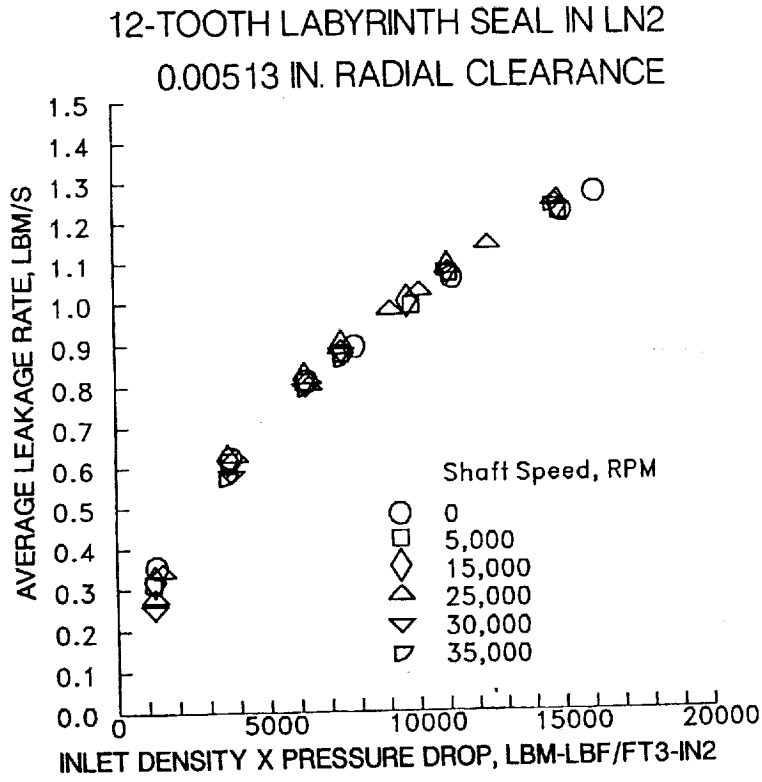
NO.	DESCRIPTION
1	12 TOOTH LABYRINTH SEAL (0.00513 IN. RADIAL CLEARANCE)
2	SINGLE BRUSH SEAL (POSITION 1)
3	TWO BRUSHES FAR APART (POSITIONS 2 & 5)
4	TWO BRUSHES TIGHTLY PACKED (POSITIONS 3 & 4)
5	THREE BRUSHES (POSITIONS 1, 3 & 5)
6	TWO BRUSHES (POSITIONS 2 & 5) - PRESSURE TAPS AT SPACER ID
7	THREE BRUSHES (POSITIONS 1, 3, 5) - PRESSURE TAPS AT SPACER ID
8	SINGLE BRUSH (POSITION 1) - BLOWOUT TEST

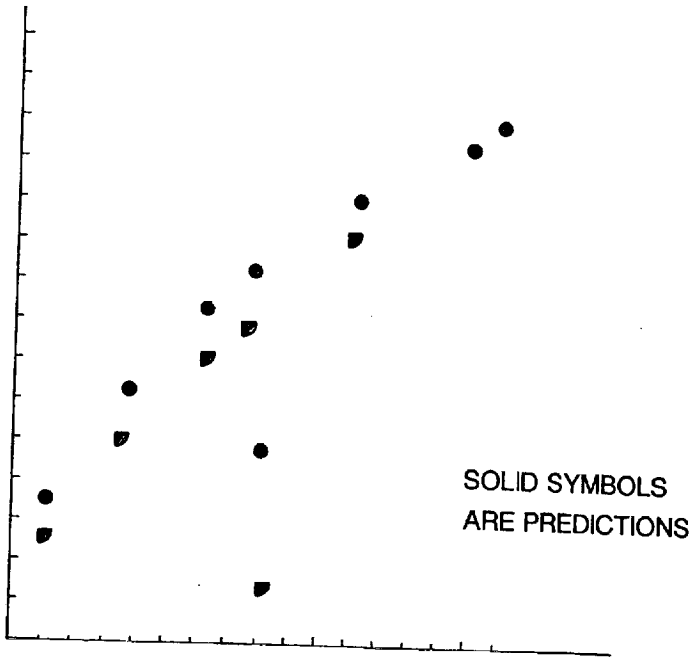
NOMINAL BRUSH GEOMETRY

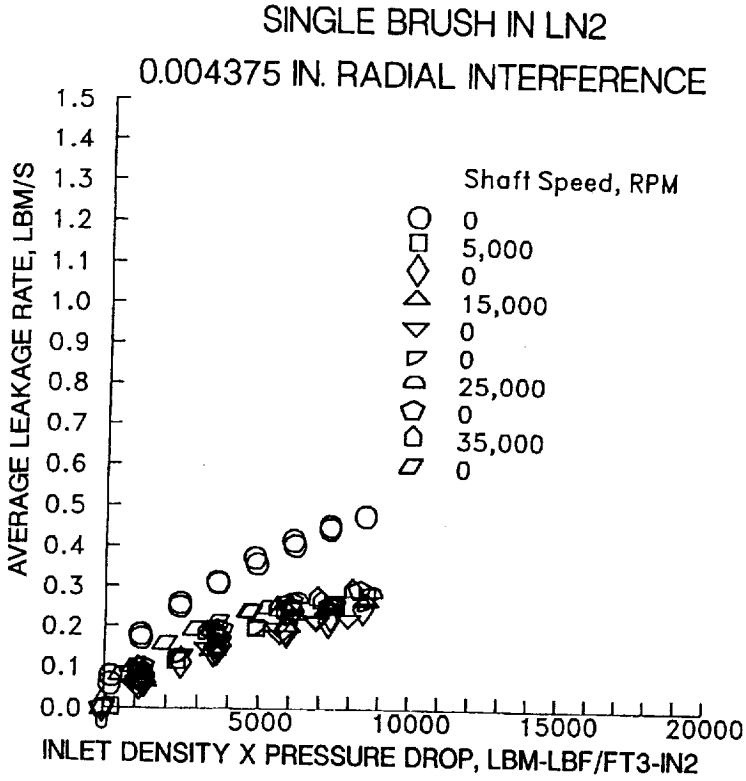


RADIAL INTERFERENCE	0.0050
RADIAL CLEARANCE BETWEEN BACKPLATE AND ROTOR	0.011
RADIAL DISTANCE BETWEEN BACKPLATE AND BRISTLE I.D'S	0.016
RADIAL DISTANCE BETWEEN FRONTPLATE AND BRISTLE I.D.'S	0.205

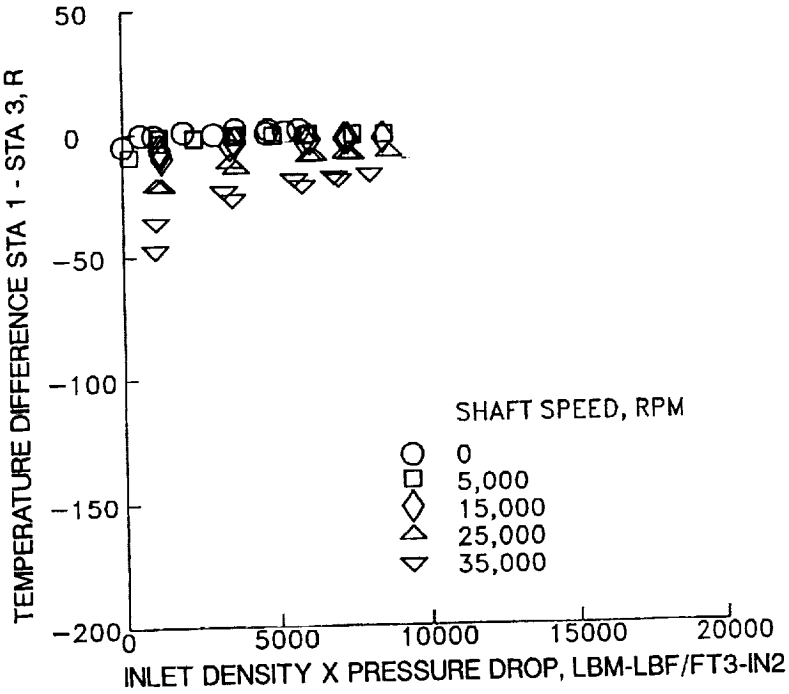
(NOT TO SCALE; ALL DIMENSIONS ARE INCHES)



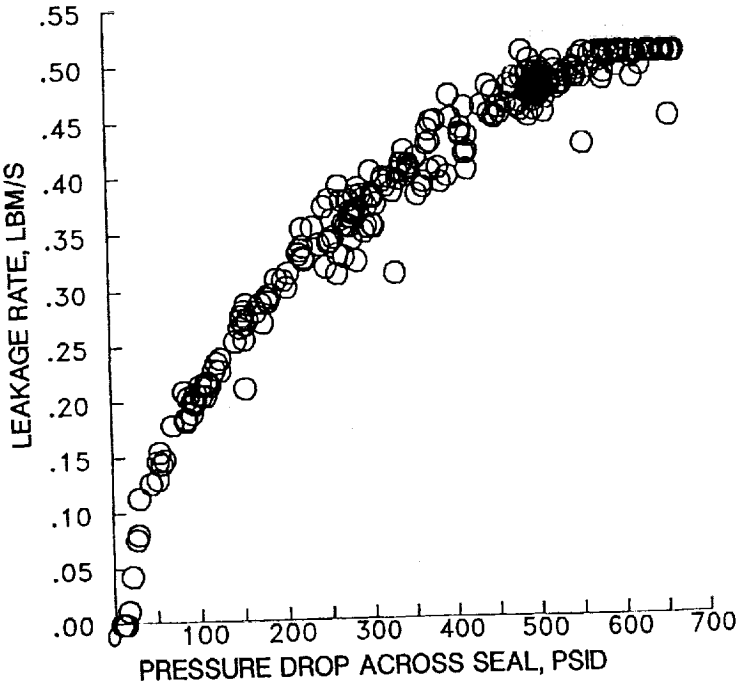

SOLID SYMBOLS
ARE PREDICTIONS

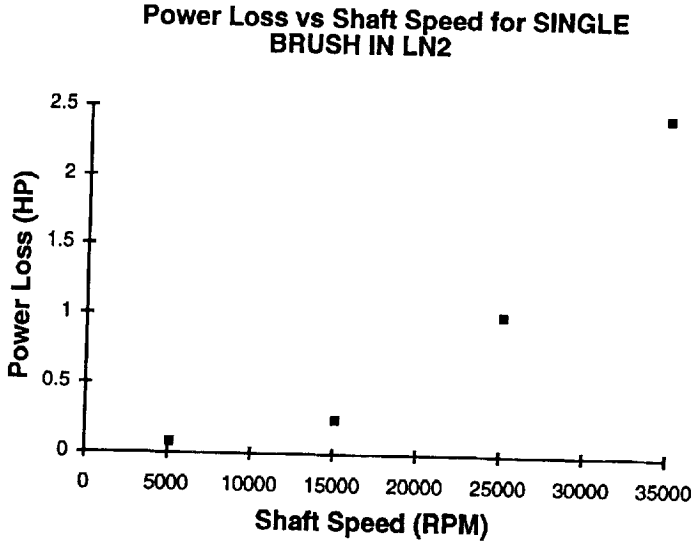

SINGLE BRUSH IN LN2
0.004375 IN. RADIAL INTERFERENCE
AVERAGE LEAKAGE RATE, LBM/S
INLET DENSITY X PRESSURE DROP, LBM-LBF/FT3-IN2
Shaft Speed, RPM
0
5,000
0
15,000
0
0
25,000
0
35,000
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
5000
10000
15000
20000

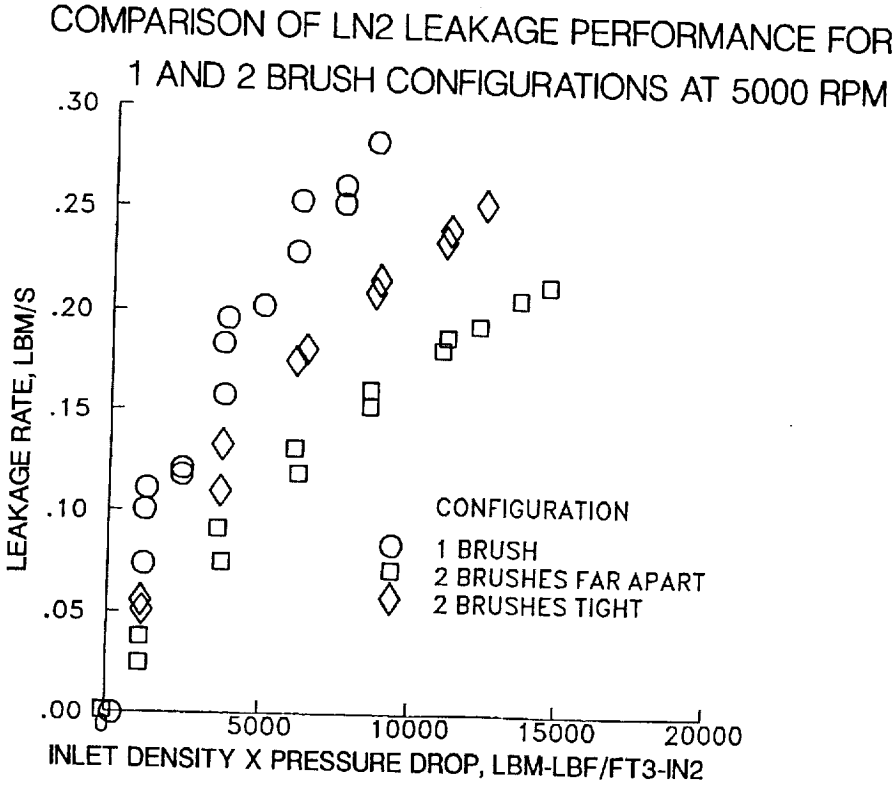
SPEED EFFECTS ON TEMPERATURE
FOR A SINGLE BRUSH IN LN2



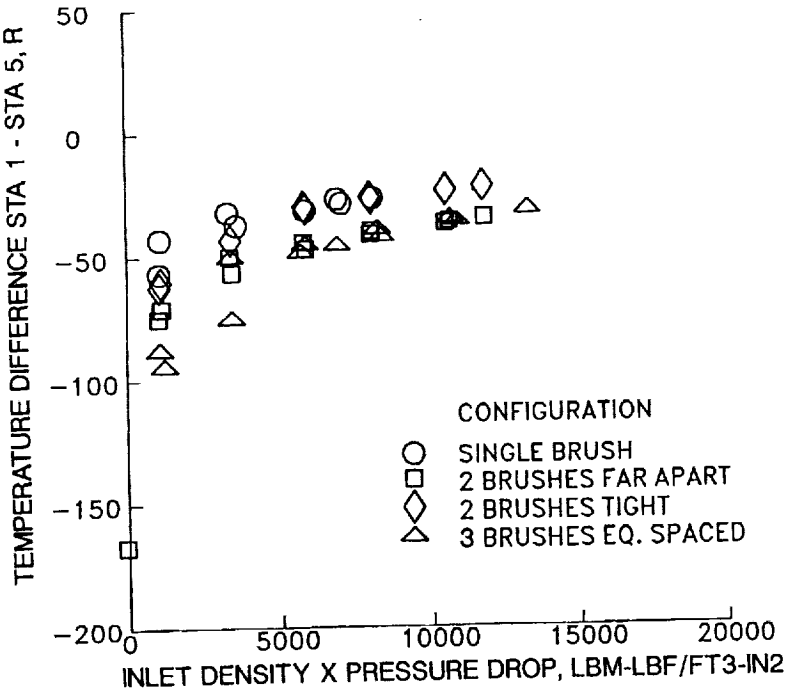
BLOWOUT TEST OF A SINGLE BRUSH IN LN2 AT ZERO RPM



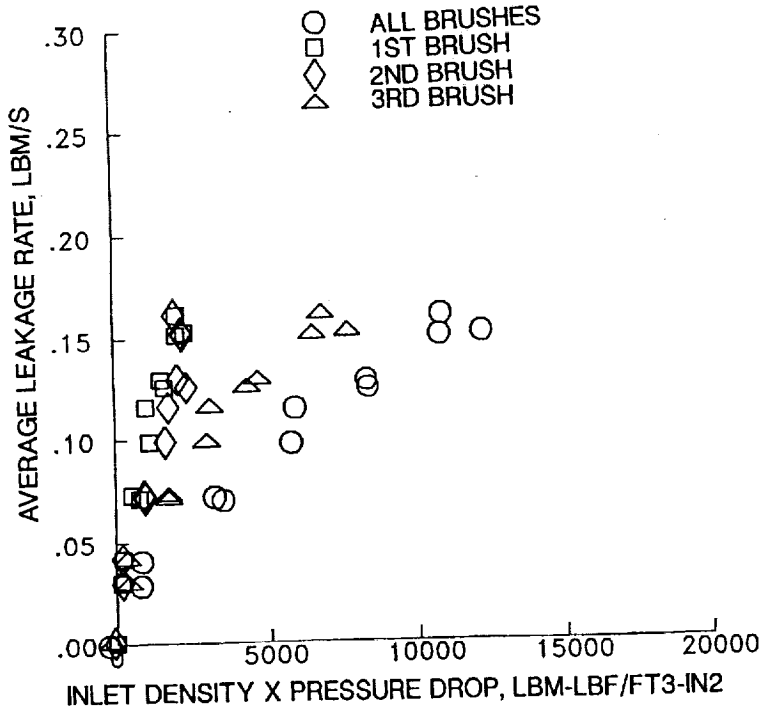

Power Loss vs Shaft Speed for SINGLE BRUSH IN LN2
Power Loss (HP)
2.5
2
1.5
1
0.5
0
0
5000
10000
15000
20000
25000
30000
35000
Shaft Speed (RPM)

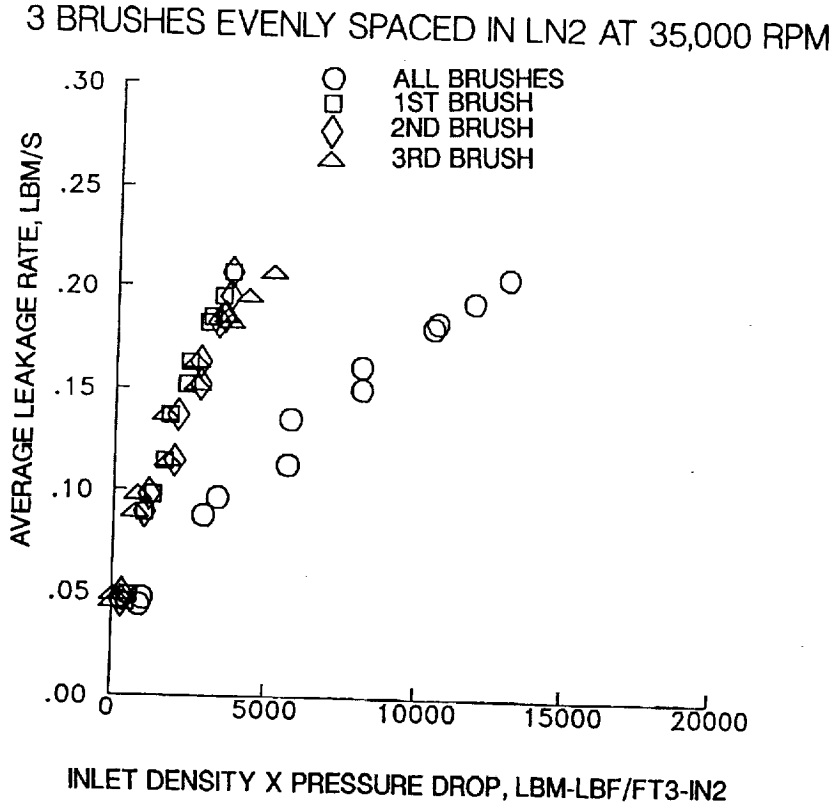

COMPARISON OF LN2 LEAKAGE PERFORMANCE FOR 1 AND 2 BRUSH CONFIGURATIONS AT 5000 RPM
LEAKAGE RATE, LBM/S
.30
.25
.20
.15
.10
.05
.00
0
5000
10000
15000
20000
INLET DENSITY X PRESSURE DROP, LBM-LBF/FT3-IN2
CONFIGURATION
1 BRUSH
2 BRUSHES FAR APART
2 BRUSHES TIGHT

STAGING EFFECTS ON TEMPERATURE
IN LN2 AT 35,000 RPM



3 BRUSHES EVENLY SPACED IN LN2 AT ZERO RPM





WEAR DATA

CONDITIONS:

INCONEL 718 ROTOR

HAYNES - 25 BRISTLES

SHAFT ROTORDYNAMICS VERY GOOD

- NOMINAL ROTOR ORBITS < 0.2 MILS IN DIAMETER
- MAXIMUM ORBIT WAS 1.0 MIL DIAMETER

MAXIMUM SHAFT SPEED: 35,000 RPM

MAXIMUM SURFACE VELOCITY: 305 FT/S

WEAR DATA

ROTOR:

PROFILOMETER TRACES ACROSS AXIAL LENGTH OF ROTOR TAKEN AT 4 LOCATIONS - 0, 90, 180, AND 270 DEGREES

MAXIMUM GROOVE DEPTH MEASURED: 0.0010 INCH

NOMINAL GROOVE DEPTH MEASURED: 0.00075 INCH

PLOT OF GROOVE AREA SHOWS AN INCREASE WITH TIME WITH A MAXIMUM VALUE OF 12,361 SQUARE MICRONS

4 -1/2 HOURS OF SHAFT ROTATION ACCUMULATED

WEAR DATA

BRUSHES:

SOME BRISTLE WEAR OCCURRED (1-3 MILS)

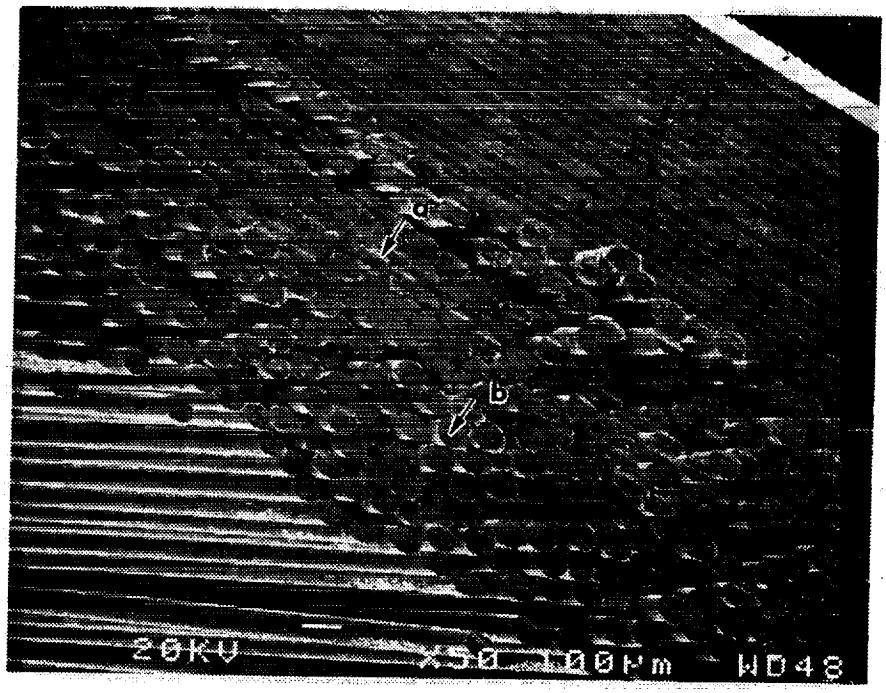
BRISTLE WEAR IS DIFFICULT TO QUANTIFY DUE TO UNCERTAINTY IN BRISTLE BORE I.D. MEASUREMENTS

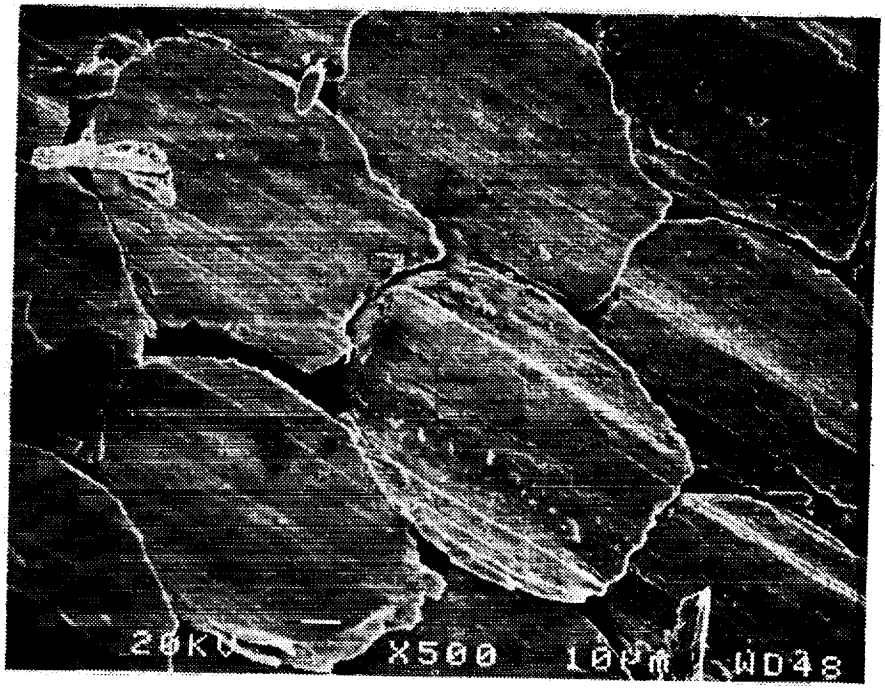
BORE I.D. CAN VARY BY 7.5 MILS

OPTICAL COMPARATOR USED

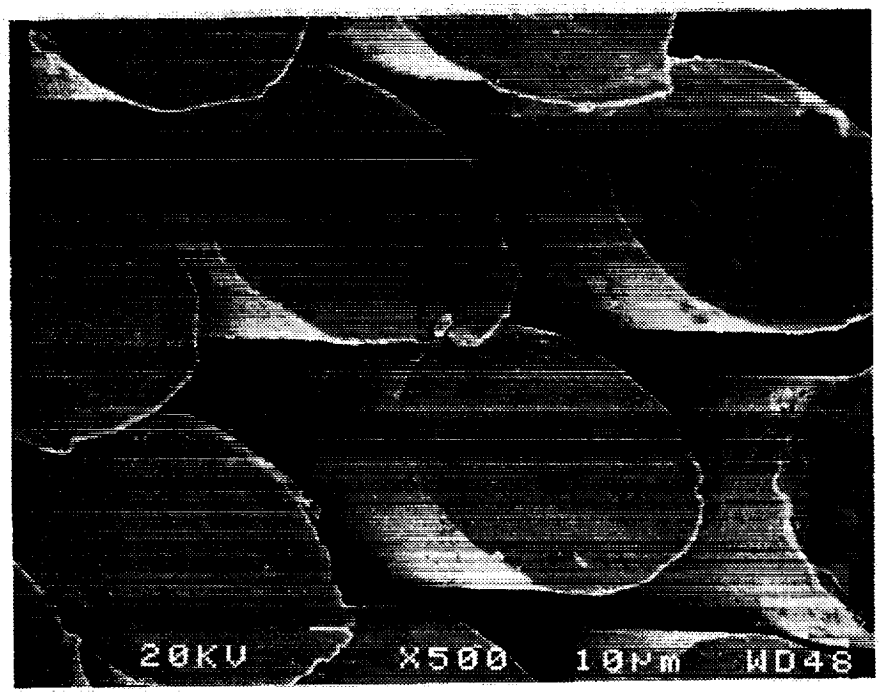
SOME MELTING OF BRISTLES DID OCCUR, THOUGH IT WAS MINIMAL.....APPROXIMATELY 10 BRISTLES

AFTER MELTING WAS FIRST OBSERVED, TEST CONDITIONS OF ROTATION WITH NO DELTA-P ACROSS THE SEAL WERE DISCONTINUED





Region A



Region B

SUMMARY OF LN2 BRUSH SEAL TEST RESULTS

- LEAKAGE FOR A SINGLE BRUSH SEAL WAS 2-3 TIMES LESS THAN FOR A 12-TOOTH LABYRINTH SEAL.
- THE MAXIMUM TEMPERATURE RISE FOR A SINGLE BRUSH SEAL WAS LESS THAN 50 R AND OCCURRED AT 25 PSID ACROSS THE SEAL AND 35,000 RPM. (THIS TEMPERATURE RISE WOULD BE GREATER AT 0 PSID).
- A STATIC BLOWOUT TEST DEMONSTRATED SEALING CAPABILITY UP TO 550 PSID. THE SEAL LIMIT WAS NOT OBTAINED.
- THE POWER LOSS FOR A SINGLE BRUSH AT 35,000 RPM AND 175 PSID WAS 2.45 HP.
- TWO BRUSHES FAR APART LEAK LESS THAN TWO BRUSHES TIGHT PACKED.
- ROTOR WEAR WAS ~ 0.00075 MILS AND BRISTLE WEAR WAS 1-3 MILS AFTER 4-1/2 HOURS.