Rockwell International
Atomics International Division

SUPPORTING DOCUMENT

NUMBER	REV LTR/CHG NO.
N266TI000003	SEE SUMMARY OF CHG

DOCUMENT TYPE: Technical Information

KEY NOUNS: Inducer Pump

MASTER

ORIGINAL ISSUE DATE: April 20, 1978

GO NO.	S/A NO.	PAGE 1 OF TOTAL PAGES 17
09280	23000	REL. DATE 4-21-78 BK

PROGRAM TITLE: Intermediate- Size Inducer Pump

DOCUMENT TITLE: Recirculating Flow Analyses of Intermediate Size Inducer Pump (ISIP)

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IR&D PROGRAM? YES ☐ NO ☒ IF YES, ENTER TPA NO.____

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SECURITY CLASSIFICATION

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ABSTRACT

DOE/SF/76026--T25

Enclosed is a report which documents the recirculation flow analyses for the Intermediate-Size Inducer Pump (ISIP), from which the primary flowrates through the pump were obtained. The front and rear impeller labyrinth seals, which incorperate stepped pockets with slanted and rounded ribs were checked. These seal design features should minimize the impeller labyrinth seal leakages and also provide excellent shutoff head characteristics.

AT03-76SF76026

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DISCLAIMER

Recirculating Flow Analyses of Intermediate Size Inducer Pump (ISIP)

Refs: (1) AI Drawing, "Intermediate-Size Inducer Pump Layout, ISIP," Drawing N266R000015, Issue 1, March 16, 1978

(2) Allen, H. G., "Hydraulics Design Report FFTF Primary Pump," Engr. Memo 4476, Westinghouse Electric Corporation, Electro-Mechanical Div., Cheswick, Pennsylvania, January 15, 1973

(3) Crane, "Flow of Fluids Through Valves, Fittings, and Pipe," Technical Paper 410, Crane Company, New York, N.Y., 1976

(4) Internal Letter, "Pump Impeller Labyrinth Seal Study," DDR-712-3012, Isaacson, J., Rocketdyne Division, Rockwell International, Canoga Park, California, December 4, 1957

(5) Crewdson, E., "Water-Ring Self-Primary Pumps," Vol. 170, No. 13, Institution of Mechanical Engineers, Westminster, South Wales, 1956

INTRODUCTION

Recirculating flows of the ISIP were analyzed, and the calculations are shown in Appendix A. Secondary flow paths were first obtained before the primary flow rates through the pump were obtained. Analyses were also conducted to check the impeller labyrinth seal design and the drain and vent hole leakages.

SUMMARY

Recirculation flow rates were obtained and are shown in Figures 1 and 2. From these recirculation flows, the primary flow rates through the pump were obtained and are also shown in Figures 1 and 2.

The impeller labyrinth seal design incorporates good design features which are stepped pockets with slanted and rounded ribs. These features are especially helpful in minimizing the leakage flows for this large clearance seal application.

DISCUSSION

The ISIP layout drawing (Reference 1) was used to determine the various recirculation flow paths through the pump. Recirculation flows which remained the same from the previous pump design were obtained from Reference 2 and are shown in Figure 1.

Secondary flow paths were first obtained and are summarized below:

1. Q_1, leakage between suction nozzle outlet cone and inlet to suction elbow = 160 gpm.
2. Q_2, leakage through inlet static seal = 85 gpm.
3. Q_3, flow through drive shaft = 50 gpm.
4. Q_4, leakage through front impeller labyrinth seal = 648 gpm.
5. Q_5, leakage through rear impeller labyrinth seal = 569 gpm.
6. Q_6, flow through hydrostatic bearing = 200 gpm.
7. Q_7, leakage through the diffuser and radial bearing housing = 131 gpm.
8. Q_8, leakage through discharge bellows static seal = 10 gpm.
9. Q_9, leakage through impeller return holes = 669 gpm.

These recirculation flow calculations are shown in the appendix, and the flows are shown in Figures 1 and 2. Friction factors used were obtained from Crane (Reference 3).

Impeller labyrinth seal leakage rates were checked using previous Rocketdyne empirical data (Reference 4) and results obtained from E. Jackson (addendum to Reference 5). The seal flow coefficient obtained for both front and rear labyrinth seals was 0.428 which is realistic for the present design. These labyrinth seal designs incorporate the step configuration from Reference 4 and the slanted rounded backs of the ribs from Reference 5. These features should minimize these leakages and also provide excellent shutoff head characteristics.

The shaft extension does not affect the flow rate through the drive shaft. Only a small decrease (less than 1/2 gpm), which includes the vent/drain holes contribution, is realized and was neglected for this analysis.

From this recirculation flow analysis, the following primary flow rates through the pump were obtained:

1. Q disch., discharge flow rate = 14,500 gpm.
2. Q inlet, inlet flow rate = 14,500 gpm.
3. Q suct. el., suction elbow flow rate = 14,660 gpm.
4. Q ind., flow through inducer = 14,695 gpm.
5. Q imp., flow through impeller = 15,997 gpm.
6. Q trans. diff., flow through transition diffuser = 14,780 gpm.
7. Q exist. diff., flow through existing diffuser = 14,841 gpm.

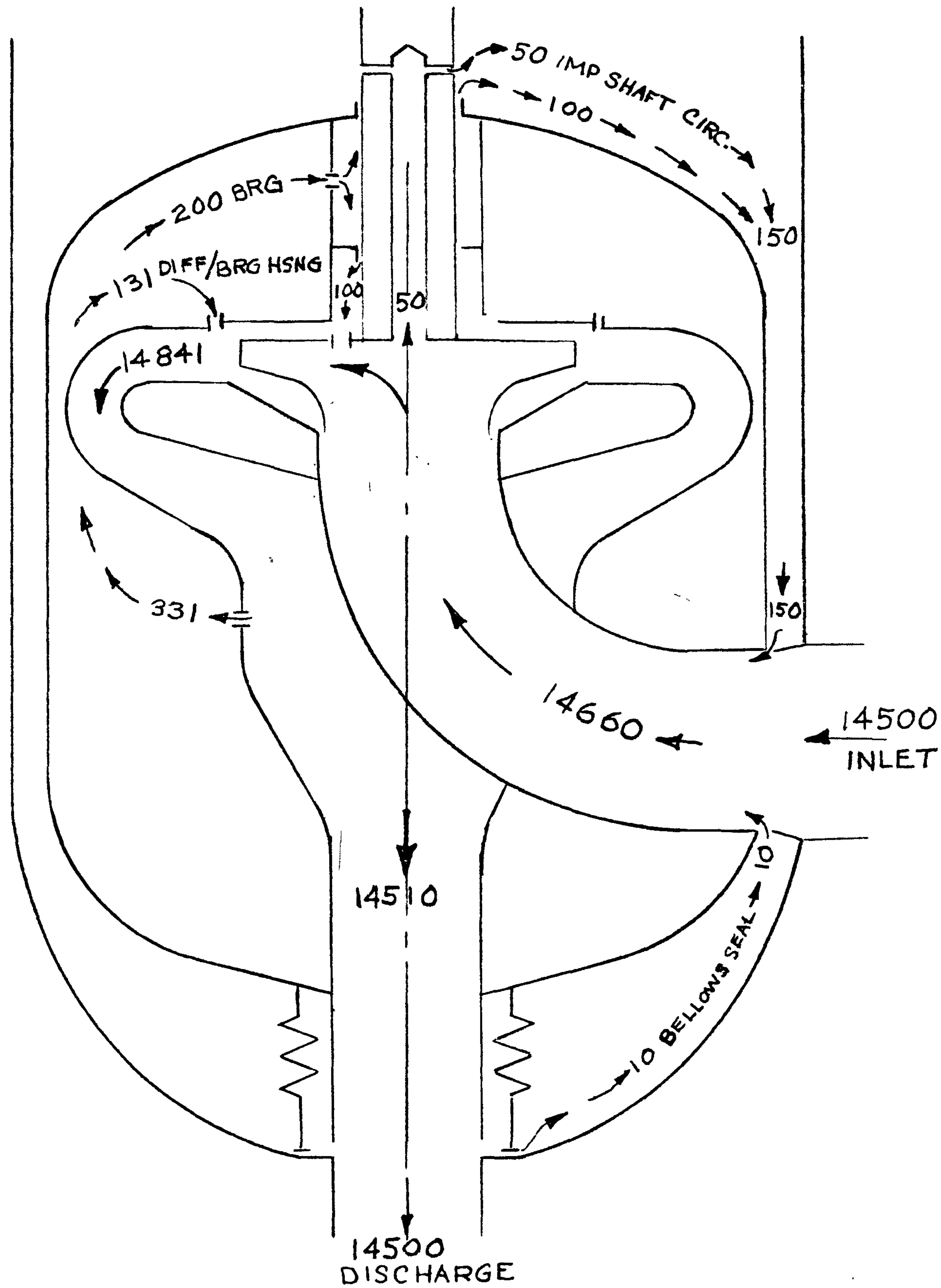

FIG. 1 WEMD RECIRCULATION FLOWS

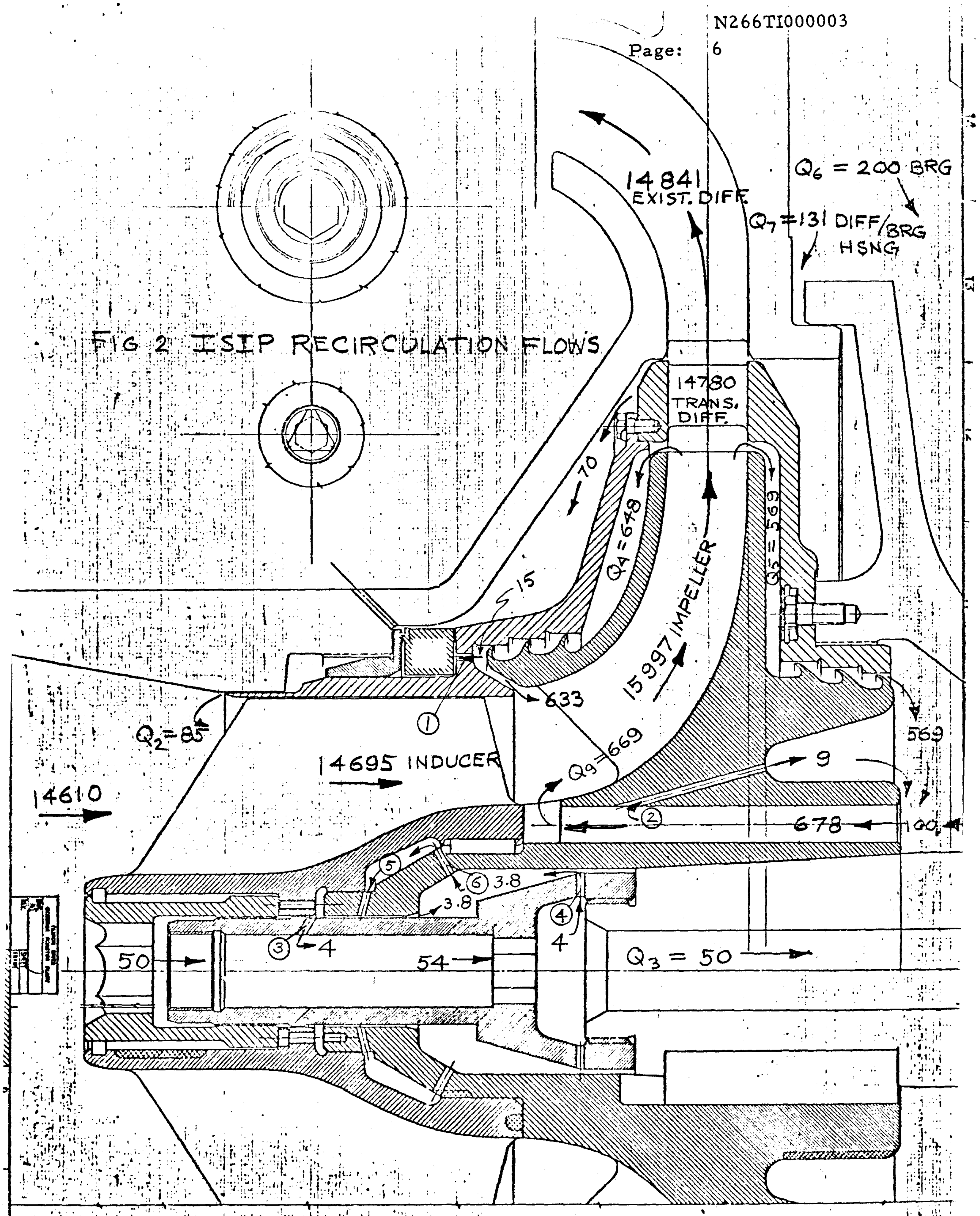
FIG 2 ISIP RECIRCULATION FLOWS
14841 EXIST. DIFF.
Q6 = 200 BRG
Q7 = 131 DIFF/BRG HSNG
14780 TRANS. DIFF.
70
Q4 = 648
Q5 = 569
15997 IMPELLER
15
633
1
Q2 = 85
14695 INDUCER
Q9 = 669
569
9
2
14610
678
100
5
6 3.8
3.8
4
3
4
50
54
Q3 = 50

I. THIS FLOW ANALYSES INCLUDES: 1) SECONDARY & PRIMARY FLOWS, 2) LABYRINTH SEAL, DRAIN, & VENT HOLE FLOWS.

A. THE SECONDARY FLOW PATHS ARE DEFINED AS FOLLOWS:

1. Q_1 LEAKAGE BETWEEN SUCTION NOZZLE OUTLET CONE AND INLET TO SUCTION ELBOW.
2. Q_2 LEAKAGE THROUGH INLET STATIC SEAL.
3. Q_3 FLOW THROUGH DRIVE SHAFT.
4. Q_4 LEAKAGE THROUGH FRONT IMPELLER LABYRINTH SEAL.
5. Q_5 LEAKAGE THROUGH REAR IMPELLER LABYRINTH SEAL.
6. Q_6 FLOW THROUGH HYDROSTATIC BEARING.
7. Q_7 LEAKAGE THROUGH THE DIFFUSER AND RADIAL BEARING HOUSING.
8. Q_8 LEAKAGE THROUGH DISCHARGE BELLOWS STATIC SEAL.
9. Q_9 LEAKAGE THROUGH IMPELLER RETURN HOLES.

B. FROM THESE DEFINITIONS, THE FOLLOWING PRIMARY FLOWRATES ARE OBTAINED:

1. $Q_{DISCH.}$ = DISCHARGE FLOWRATE
   = 14,500 GPM
2. Q_{INLET} = SUCTION NOZZLE FLOWRATE
   $= Q_{DISCH.} = 14,500$ GPM
3. $Q_{SUCT.\ EL.}$ = SUCTION ELBOW FLOWRATE
   $= Q_{INLET} + Q_1$
   $= Q_{INLET} + Q_3 + \frac{1}{2} Q_6 + Q_8$
4. $Q_{IND.}$ = FLOW THROUGH INDUCER
   $= Q_{SUCT.\ EL.} + Q_2 - Q_3$
5. $Q_{IMP.}$ = FLOW THROUGH IMPELLER
   $= Q_{IND} + Q_9 + Q_4 - 15$ GPM

6. $Q_{TRANS. DIFF.}$ = FLOW THROUGH TRANSITION DIFFUSSER
$= Q_{IMP} - Q_4 - Q_5$

7. $Q_{EXIST. DIFF.}$ = FLOW THROUGH EXISTING DIFFUSSER
$= Q_{TRANS. DIFF.} + Q_7 - Q_2 + 15\ GPM$

8. $Q_{DISCH.}$ $= Q_{EXIST. DIFF.} - Q_6 - Q_7 - Q_8$
= 14,500 GPM.

C. THIS SECONDARY FLOW ANALYSES ARE AS FOLLOWS:

1. Q_6 HYDROSTATIC BEARING
SAME AS WEMD REPORT (REF. 2)
Q_6 = 200 GPM ←

2. Q_7 DIFFUSER AND RADIAL BEARING HOUSING
SAME AS WEMD REPORT (REF. 2)
Q_7 = 131 GPM ←

3. Q_8 DISCHARGE BELLOWS STATIC SEAL
SAME AS WEMD REPORT (REF. 2)
Q_8 = 10 GPM ←

4. Q_4 FRONT IMPELLER LABYRINTH SEAL
FROM ROCKETDYNE DIV., ROCKWELL INT.
6633 CANOGA AVE, CANOGA PK., CA.
Q_4 = 648 GPM ←

5. Q_5 REAR IMPELLER LABYRINTH SEAL
FROM ROCKETDYNE DIV., ROCKWELL INT.
6633 CANOGA AVE, CANOGA PK, CA.
Q_5 = 569 GPM ←

6. Q_2 INLET STATIC SEAL
GIVEN: MEAN SEAL DIA. = 23.2 IN.
FACE WIDTH = $\frac{1}{8}$ IN
CLEARANCE = 0 TO 3 MILS, SAY 1.5 MILS
PER SEAL:
AREA = π (MEAN DIA) CLEARANCE
$= \pi (23.2)(.0015) = 0.109\ IN^2$

LET: HEAD LOSS (H_2) THROUGH GAP EQUAL TO:

$$H_2 = 1.5 \frac{V^2}{2g} + f \frac{L}{D} \frac{V^2}{2g}$$

WHERE: V = VEL THROUGH GAP

f = FRICTION FACTOR

= 0.037 FOR VERY SMALL CLEARANCES

L = LENGTH

$= \frac{1}{8}$ IN.

D = EQUIVALENT DIA

= TWICE THE CLEARANCE

= 2 (0.0015) = 0.003 IN.

g = ACCELERATION DUE TO GRAVITY

= 32.174 FT/SEC

SUBSTITUTING:

$$H_2 = 1.5 \frac{V^2}{2g} + \frac{.037\left(\frac{1}{8}\right)}{(.003)} \frac{V^2}{2g}$$

SOLVING FOR V:

$$V = \left(\frac{2g\ H_2}{3.04}\right)^{\frac{1}{2}}$$

LET: H_2 = 500 FT (MAX.)

$$V = \left(\frac{2\ g\ 500}{3.04}\right)^{\frac{1}{2}} = 103 \text{ FT/SEC}$$

$$V = \frac{Q\ 144}{A\ 448.83}$$

WHERE:

Q = FLOWRATE THROUGH SEAL

A = AVE. LEAKAGE AREA = 0.109 $IN.^2$

$$\therefore Q = \frac{VA\ 448.83}{144} = \frac{103}{144}(0.109)\ 448.83$$

= 35 GPM

FOR BOTH FACES:

Q = 2 (35) = 70 GPM

ADDITIONAL LEAKAGE THROUGH THE 2 EA $\frac{1}{4}$ IN. DRAIN HOLES MUST BE ACCOUNTED FOR

$\Delta P = 35.8 - 15.1 = 20.7$ PSID

$A = \frac{2\pi}{4(144)} \left(\frac{1}{4}\right)^2 = 0.000682 \text{ FT}^2$

$\text{HEAD LOSS} = 1.5 \frac{V^2}{2g} + f \frac{L}{D} \frac{V^2}{2g}$

LET: $f = 0.037$

$\therefore V = \left(\frac{2g\,\Delta H}{1.587}\right)^{\frac{1}{2}} = \left(\frac{2g\,(20.7)}{(1.587)} \frac{144}{\rho}\right)^{\frac{1}{2}}$

WHERE: ρ = DENSITY
= 50.971 LB/FT³

$\therefore V = 48.7$ FT/SEC

AND $Q = VA\,488.83 = 48.7(0.000682)\,448.83$
= 14.9 GPM, SAY 15 GPM

$\therefore$ TOTAL INLET STATIC SEAL LEAKAGE IS:
$Q_2 = 70 + 15 = 85$ GPM

CHECK ON REYNOLD'S NO. (Re)

$Re = \frac{\rho V d}{\mu}$

WHERE: d = DIA., FT
μ = VISCOSITY
= 0.5221 LB/FT HR

SUBSTITUTING:

$Re = \frac{50.971(48.7)\frac{.25}{12}(3600)}{0.5221} = 3.5 \times 10^5$

LET: $\frac{e}{d} = \frac{0.0001}{\frac{1}{4}} = 0.0004$

FROM CRANE (REF. 3)
$f = 0.0173$

$\therefore \Delta H = 1.5 \frac{V^2}{2g} + (0.0173) \frac{.59}{\frac{1}{4}} \frac{V^2}{2g}$

$V = \left(\frac{2g\,\Delta H}{1.54}\right)^{\frac{1}{2}} = \left(\frac{2g\,(20.7)}{1.54} \frac{144}{50.971}\right)^{\frac{1}{2}} = 49.4$ FT/SEC

$Q = 49.4(0.000682)\,448.83 = 15$ GPM

$\therefore Q_2 = 70 + 15 = \underline{85 \text{ GPM}}$ ←

7. Q_3 DRIVE SHAFT

FROM THE WEMD REPORT (REF. 2)

$Q_3 = 49.8$ GPM

BECAUSE THE ISIP DESIGN HAS AN ADDITIONAL SHAFT EXTENSION, THE ADDITIONAL PRESSURE LOSS AND ACCOMPANYING DECREASE IN FLOWRATE WAS CHECKED AS FOLLOWS:

LET: $d = 1.95$ IN. (DISTANCE ACROSS FLATS)

$$\therefore A = \frac{\pi}{4(144)}(1.95)^2 = 0.0207 \text{ FT}^2$$

LET: $Q = 49.8$ GPM

$$\therefore V = \frac{Q}{A\,448.83} = \frac{49.8}{(0.0207)\,448.83}$$

$$= 5.36 \text{ FT/SEC}$$

$$Re = \frac{50.971(5.36)\frac{1.95}{12}(3600)}{0.5221}$$

$$= 3.07 \times 10^5$$

$$\frac{e}{d} \doteq \frac{0.001}{1.95} = 0.0005$$

FROM CRANE

$$f = 0.0182$$

$$\Delta H = 1.5\frac{(5.36)^2}{2g} + \frac{0.0182(13.9)(5.36)^2}{1.95(2g)}$$

$$= 0.73 \text{ FT}$$

$$Q = K\sqrt{\Delta H}, \text{ OR: } K = \frac{Q}{\sqrt{\Delta H}}$$

FROM WEMD (REF. 2)

$$K = \frac{49.8}{\sqrt{49.84}} = 7.054$$

$$\therefore Q_3 = 7.054\sqrt{49.84 - .73} = 49.44 \text{ GPM}$$

DECREASE IN FLOW = 49.8 − 49.44

= 0.36 GPM (NEGLIGIBLE)

$\therefore$ LET Q_3 = **50 GPM** ←

8. Q_1 SUCTION NOZZLE OUTLET CONE AND INLET TO SUCTION ELBOW

$$Q_1 = Q_3 + \frac{1}{2} Q_6 + Q_8$$
$$= 50 + \frac{1}{2}(200) + 10$$
$$= 160 \text{ GPM}$$

9. Q_9 IMPELLER RETURN HOLES

$$Q_9 = Q_5 + \frac{1}{2} Q_6$$
$$= 569 + \frac{1}{2}(200)$$
$$= 669 \text{ GPM}$$

D. IMPELLER LABYRINTH SEAL CHECK

FROM ROCKETDYNE DIV., ROCKWELL INT.

$Q_4 = 648$ GPM

$Q_5 = 569$ GPM

ΔP_4 = DELTA PRESSURE (STATIC) ACROSS FRONT LABYRINTH SEAL
$= 129.7 - 35.8 = 93.8$ PSID

ΔP_5 = DELTA PRESSURE (STATIC) ACROSS REAR LABYRINTH SEAL
$= 126.9 - 39.7 = 87.2$ PSID

FRONT SEAL AVE. DIA. = 22.5 IN.

REAR SEAL AVE. DIA. = 20.45 IN.

DIAMETRAL CL. = 0.100 TO 0.110 IN.

AVE. DIAMETRAL CL = 0.105 IN.

FRONT CASING DIA. = 22.5 + 0.105 = 22.605 IN.

REAR CASING DIA. = 20.45 + 0.105 = 20.555 IN.

$$\text{FRONT SEAL CL. AREA} = (22.605^2 - 22.5^2)\frac{\pi}{4(144)}$$
$$= 0.02583 \text{ FT}^2$$

$$\text{REAR SEAL CL. AREA} = (20.605^2 - 22.5^2)\frac{\pi}{4(144)}$$
$$= 0.02348 \text{ FT}^2$$

FLOW IN $FT^3/SEC = KA(2g\Delta H)^{1/2}$

OR $K = \dfrac{Q}{A(2g\Delta H)^{1/2}} \dfrac{1}{448.83}$

$\Delta H = \Delta P\left(\dfrac{144}{50.971}\right)$

WHERE : K = SEAL FLOW COEFFICIENT

$\therefore$ K FOR FRONT SEAL $= \dfrac{648}{0.02583\left(2g(93.9)\dfrac{144}{50.971}\right)^{\frac{1}{2}}} \dfrac{1}{448.83}$

$= 0.428$

K FOR REAR SEAL $= \dfrac{569}{0.02348\left(2g(87.2)\dfrac{144}{50.971}\right)^{\frac{1}{2}}} \dfrac{1}{448.83}$

$= 0.428$

$Re = \dfrac{d_h V \rho}{\mu}$

WHERE: $d_h = \dfrac{4\ (CL\ AREA)}{WETTED\ PERIMETER}$, FT

$V = \dfrac{Q_L}{A(448.83)}$, FT/SEC

μ = VISCOSITY

= 0.5221 LB/FT HR

FRONT SEAL WETTED PERIMETER $= \dfrac{\pi}{12}(22.605 + 22.5)$

$= 11.81$ FT

REAR SEAL WETTED PERIMETER $= \dfrac{\pi}{12}(20.555 + 20.45)$

$= 10.74$ FT

$\therefore$ FRONT SEAL $Re = \dfrac{\dfrac{4(0.02583)\ 648}{11.81\ (0.02583)448.83}(50.971)}{0.5221\dfrac{1}{3600}}$

$\doteq 1.72 \times 10^5$

REAR SEAL $Re = \dfrac{4(569)(50.971)(3600)}{10.74(448.83)(0.5221)} = 1.66 \times 10^5$

THE K VALUES FOR BOTH SEALS ARE OF REALISTIC VALUES BASED ON PREVIOUS ROCKETDYNE DATA (REF. 4) AND FROM THE RESULTS OF E.A. JACKSON (ADDENDUM OF REF. 5).

THE LABYRINTH SEAL CONFIGURATION INCORPERATES FEATURES FROM BOTH REFERENCES, NAMELY:

1. STEP CONFIGURATION FROM REF. 4.
2. ROUNDED BACKS OF SLOPED RIBS FROM REF. 5

THE STEP CONFIGURATION RESULTS IN LOW LEAKAGE FLOWS COMPARED TO NON-STEPPED CONFIGURATIONS (REF 4).

THE ROUNDED BACK ALSO RESULTS IN LOW LEAKAGE FLOWS, ESPECIALLY FOR SEALS WITH LARGE CLEARANCES (AS IN OUR DESIGN). THIS ROUNDED BACK DESIGN ALSO PROVIDES FOR EXCELLENT SHUT-OFF HEAD CHARACTERISTICS WHERE HIGH PUMPHEAD IS MAINTAINED, (REF. 5).

E. DRAIN AND VENT HOLE CHECK

VARIOUS DRAIN AND VENT HOLES LOCATED MAY ALLOW LEAKAGE FLOWS WITHIN THE PUMP. THESE HOLES ARE IDENTIFIED BY CIRCLED NUMBERS (SEE FIG. 2)

(1) INDUCER AND IMPELLER (FRONT SHROUD) HOUSING DRAIN HOLES = 15 GPM (SEE PG A4)

(2) IMPELLER DRAIN HOLES (2 EA, $\frac{1}{4}$ IN DIA.)

$$\Delta H = \frac{U_2^2 - U_1^2}{2g}$$

$$U_2 = \frac{\pi D_2 N}{720} = \frac{\pi (13.8) 1110}{720} = 66.8 \text{ FT/SEC}$$

$$U_1 = \frac{\pi D_1 N}{720} = \frac{\pi (11.2) 1110}{720} = 54.2 \text{ FT/SEC}$$

$$\Delta H = \frac{66.8^2 - 54.2^2}{2g} = 23.6 \text{ FT}$$

$$\Delta H = \frac{1.5 V^2}{2g} + f \frac{L}{D} \frac{V^2}{2g}$$

$$= \frac{1.5 V^2}{2g} + 0.0173 \frac{(4.8)}{0.25} \frac{V^2}{2g}$$

$$V = \left(\frac{2g \Delta H}{1.83}\right)^{\frac{1}{2}} = \left(\frac{2g (23.6)}{1.83}\right)^{\frac{1}{2}} = 28.8 \text{ FT/SEC}$$

$$Q = VA\, 448.83 = 28.8(0.000682)448.83$$

$$= 9 \text{ GPM.}$$

③ DRAIN HOLES IN SHAFT EXTENSION (2 EA., $\frac{1}{4}$ IN. DIA.)

$$U_2 = \frac{\pi}{720}(3.6)\,1110 = 17.4 \text{ FT/SEC}$$

$$U_1 = \frac{\pi}{720}(2.4)\,1110 = 11.6 \text{ FT/SEC}$$

$$\Delta H = \frac{17.4^2 - 11.6^2}{2g} = 2.6 \text{ FT}$$

④ VENT HOLES IN SHAFT EXTENSION (2 EA, $\frac{1}{4}$ IN. DIA.)

$$U_2 = \frac{\pi(6.6)\,1110}{720} = 32 \text{ FT/SEC}$$

$$U_1 = \frac{\pi(5.0)\,1110}{720} = 24.2 \text{ FT/SEC}$$

$$\Delta H = \frac{32^2 - 24.2^2}{2g} = 6.8 \text{ FT}$$

⑤ DRAIN HOLES IN IMPELLER HUB (2 EA., $\frac{1}{4}$ IN. DIA.)

$$U_2 = \frac{\pi(5.3)\,1110}{720} = 25.8 \text{ FT/SEC}$$

$$U_1 = \frac{\pi(3.7)\,1110}{720} = 17.9 \text{ FT/SEC}$$

$$\Delta H = \frac{25.8^2 - 17.9^2}{2g} = 5.4 \text{ FT}$$

⑥ VENT HOLES IN IMPELLER HUB (2 EA, $\frac{1}{4}$ IN. DIA.)

$$U_2 = \frac{\pi(8.2)\,1110}{720} = 39.7 \text{ FT/SEC}$$

$$U_1 = \frac{\pi(6.5)\,1110}{720} = 31.5 \text{ FT/SEC}$$

$$\Delta H = \frac{39.7^2 - 31.5^2}{2g} = 9.1 \text{ FT}$$

REFERING TO FIG. 2 ΔH ③ IS ACTING AGAINST ΔH ④ AND ΔH ⑤ IS ACTING AGAINST ΔH ⑥.

∴ ΔH ④ − ΔH ③ = 6.8 − 2.6 = 4.2 FT

ΔH ⑥ − ΔH ⑤ = 9.1 − 5.4 = 3.7 FT

AND $\Delta H ④ = 1.5\frac{V^2}{2g} + 0.0173\left(\frac{.75}{.25}\right)\frac{V^2}{2g} = 4.2$ FT

$$V ④ = \left(\frac{2g(4.2)}{1.55}\right)^{\frac{1}{2}} = 13.2 \text{ FT/SEC}$$

$$Q ④ = 13.2\,(0.000682)\,448.83 = 4 \text{ GPM}$$

$$\Delta H\,6 = 1.5\frac{V^2}{2g} + 0.0173\frac{(.98)}{.25}\frac{V^2}{2g} = 3.7\,FT$$

$$V\,6 = \left(\frac{2g(3.7)}{1.568}\right)^{\frac{1}{2}} = 12.3\ FT/SEC$$

$$Q\,6 = 12.3(0.000682)\,448.83 = 3.8\ GPM$$

∴ RECIRCULATION FLOWS ARE:

$Q_3 = 4\ GPM$

$Q_4 = 4\ GPM$

$Q_5 = 3.8\ GPM$

$Q_6 = 3.8\ GPM$

SEE FIG. 2 FOR FLOW DIRECTION

BECAUSE AN ADDITIONAL 4 GPM FLOWS THROUGH THE SHAFT EXTENSION, Q_3 FLOWRATE IS CHECKED.

F. CHECK OF Q_3 FLOW THROUGH DRIVE SHAFT

LET: $Q' = 49.8 + 4 = 53.8\ GPM$

$$V' = \frac{53.8}{0.0207(448.83)} = 5.79\ FT/SEC$$

$$Re = \frac{50.971(5.79)\frac{1.95}{12}(3600)}{0.5221} = 3.3 \times 10^5$$

FROM CRANE, $f = 0.0182$

$$\Delta H = 1.5\frac{(5.79)^2}{2g} + \frac{0.0182(13.9)(5.79)^2}{1.95(2g)}$$

$$= 0.85\ FT$$

∴ $K = 7.054$ (SEE PG. A5)

∴ $Q = 7.054\sqrt{49.84 - .85} = 49.37\ GPM$

DECREASE IN FLOW $= 49.84 - 49.37$

$= 0.47\ GPM$ (NEGLIGIBLE)

∴ LET: $Q_3 = \underline{\underline{50\ GPM}}$ ←

G. PRIMARY FLOWRATES THROUGH PUMP

FROM PARA B, PAGES A1 AND A2, THE FOLLOWING FLOWRATES ARE OBTAINED:

1. $Q_{DISCH} = 14,500$ GPM
2. $Q_{INLET} = 14,500$ GPM
3. $Q_{SUCT.\ EL.} = Q_{INLET} + Q_1$
   $= 14,500 + 160 = 14,660$ GPM
4. $Q_{IND.} = Q_{SUCT.\ EL.} + Q_2 - Q_3$
   $= 14,660 + 85 - 50$
   $= 14,695$ GPM
5. $Q_{IMP.} = Q_{IND} + Q_9 + Q_4 - 15$
   $= 14695 + 669 + 648 - 15$
   $= 15,997$ GPM
6. $Q_{TRANS\ DIFF.} = Q_{IMP} - Q_4 - Q_5$
   $= 15,997 - 648 - 569$
   $= 14,780$ GPM
7. $Q_{EXIST.\ DIFF.} = Q_{TRANS\ DIFF} + Q_7 - Q_2 + 15$
   $= 14,780 + 131 - 85 + 15$
   $= 14,841$ GPM
8. $Q_{DISCH} = Q_{EXIST.\ DIFF.} - Q_6 - Q_7 - Q_8$
   $= 14,841 - 200 - 131 - 10$
   $= 14,500$ GPM