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WAPD-PWR-RD-670

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Subject: VARIABLE FLOW RESISTANCE WITH ADJUSTABLE
MULTI-PENETRATION ORIFICE PLATES IN SERIES

Ref: WAPD-PWR-RD-622, PWR Core 2 Development Test Program

Dear Sir:

Transmitted for your information are the results of hydraulic studies of a variable flow resistance orificing scheme now being considered for PWR Core 2. This test, proposed in the above referenced document, is listed as Test FAH-7. The results of the study show that the scheme is feasible from the hydraulic standpoint for Core 2. Future studies which are now under consideration will be directed toward investigating the mechanical feasibility of the scheme.

Very truly yours,

J. Sherman, Manager
PWR Core 2 Design Section

FAGrochowski/jr
Encl - WAPD-PWR-(RD2)-266

Transmitted by RD Contrella

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VARIABLE FLOW RESISTANCE WITH ADJUSTABLE MULTI-PENETRATION ORIFICE PLATES IN SERIES

Frank A. Grochowski

INTRODUCTION

In nuclear reactor design, because of the uneven radial power distribution, it is desirable to regulate the amount of coolant passing through individual fuel assemblies. Also, because the radial power distribution varies during the reactor lifetime, it is desirable to re-adjust the flow rate in individual assemblies at pre-selected times during the life of the reactor. This is especially true in PWR, a seed and blanket type core, in which the power density of the highly enriched U-235 seed is considerably higher than that of the natural uranium blanket. Also, in PWR there is a power shift from the seed to the blanket due to fuel depletion of the seed and production of plutonium in the blanket. To regulate the flow rate to individual fuel assemblies according to their heat generation rates requires the addition of flow resistance to certain assemblies. In the case of PWR, the required flow rate through the high power density seed dictates the pressure differential across the core; to regulate or reduce the flow rate through the parallel flow blanket fuel assemblies to their requirements necessitates the addition of flow resistance. The resistance which must be added to the blanket assemblies is very high, in excess of 30 psi. In Core 1 initial consideration was given to a single hole orifice; however, to achieve the resistance required, excessively high water velocities resulted, thus presenting erosion problems. This led to the selection of multi-hole orifices in series, in which the holes of successive plates are misaligned to increase the flow resistance at relatively low water velocities. Figure 1 shows the orificing scheme used in the first PWR core.

With this scheme, however, the resistance is fixed and can only be changed by inserting a new unit with a different hole size. As previously stated, the radial power distribution varies during core life. Early in the life of the PWR core, the ratio between the seed and blanket power is nearly 45:55, respectively. During core life there is a power shift to the blanket and the ratio changes to about 35:65. This power shift is due to seed fuel depletion and the production of plutonium from fissioning of U-238 in the blanket. Because of this power shift, it would be desirable to redistribute reactor core flow during core life; that is, increase blanket and decrease seed flow. A method of achieving the desired variation in flow resistance is to use the multi-hole orifices in series, as used in the first PWR core, but provide means by which alternate plates can be rotated to change the hole alignment of successive plates, thus changing the resistance to coolant flow. This orificing scheme would permit the selection of the orifice plate design prior to finalization of the flow requirements, since it would not be necessary to change the penetration size to change the resistance to flow.

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001

Figure 1

PWR Core 1 Orificing Scheme

The orificing scheme tested, for which data is presented in this report, is shown in Figures 2 and 3. It consists of three multi-hole or multi-slot orifice plates in series, in which the center plate can be rotated to give the desired misalignment of openings in the plates. The range of orifice area ratio chosen for test was between 0.09 and 0.40, since this is the range in which the maximum resistance to flow will occur. Two different spacings (0.160 in. and 0.347 in.) between plates were tested.

This test was run in Loop #49 at the Clairton Site. Loop #49 is a low pressure, low temperature loop. Flow rates were sufficiently high to give Reynolds number through the test unit up to 3.5×10^5 . This Reynolds number is well above the region where viscous forces become negligible, and the flow resistance coefficient remains essentially constant with increasing Reynolds number. The Reynolds number for flow through the prototype orifices will also be in this region.

SUMMARY AND CONCLUSIONS

Full-scale water flow tests were performed to determine the feasibility of a variable resistance orificing scheme for PWR Core 2. A low temperature, low pressure loop was used, and three, two, and one multi-hole and multi-slot orifice plates in series were tested. For the three and two plates in series, the range in flow resistance was determined for the condition where all penetrations were aligned to the condition of maximum misalignment. Flow characteristics of a single multi-hole and multi-slot plate were also studied.

Tests performed on the multi-hole and multi-slot orifices in series showed that a considerable range of flow resistance could be obtained when the alignment of penetrations is varied. For the area ratio, which gave the largest resistance to flow, the results showed a range in pressure loss coefficient of about 1 to 6 in the case of three multi-hole plates and about 1 to 4 for three multi-slot plates. For the multi-hole geometry tested, the increase in flow resistance with angular misalignment was very high and occurred over an angular rotation of the center plate of 15° . To spread out this increase of resistance over a larger angle of rotation of the center plate using the multi-hole configuration is not possible; therefore, consideration was shifted to narrow angular slots. Employing angular slots allowed greater freedom in the choice of the range of angular rotation to go from the minimum to the maximum flow resistance conditions. The resistance coefficient variation of 1 to 4 stated above occurred linearly over an angular rotation of the center plate of 30° . For this reason the angular slot configuration will be considered for further study for application in PWR Core 2. (Since its hydraulic feasibility has been proven, it is planned to continue this study from the mechanical standpoint to verify its mechanical feasibility. Also, further hydraulic tests will be performed, since the prototype configuration is different, and also because it will be necessary to use more than three plates in the prototype, in order to achieve the required flow resistance at reasonable flow velocities. Future studies will therefore be concerned with not only three, but five plates in series.)

783 003
~~783 002~~

VARIABLE PRESSURE DROP ORIFICE TEST UNIT

Figure 2

Figure 3

Variable Pressure Drop Orifice Test Unit Disassembled

783 005

~~783 003~~

TEST SET-UP AND LOOP DESCRIPTION

Figures 4 and 5 show a schematic and photograph of Loop #49 at the Clairton Site, which was used in these studies. In the test section of the loop, two 4 in. parallel legs, in addition to the 10 in. main piping, is provided. This permits considerable flexibility in setting up and running several tests. As shown in the sketch, the variable resistance orifice test unit was placed in the outside leg of the loop test section. The outside leg and also the inside leg contains a flow regulating valve and flow meter (orifice). During testing the valves in the inside leg and main piping are closed, so that all the loop flow was through the test unit. This allowed the measurement of the flow rate by an orifice in the 4 in. line, and also by an orifice in the 12 in. main piping. This gave a continuous check on the measurement of flow. In addition, an orifice in the inside leg of the test section was calibrated by the weighing technique and was used periodically to check the other two orifices in the loop. The temperature of the loop was controlled by regulating the flow rate through the surge tank near the inlet to the pump. To measure the pressure differential across the test unit and flow meters, 100 in. well type Meriam manometers were used.

The test unit shown in Figure 2 consists of three orifice plates (0.1875 in. thick), two stationary and one adjustable; a housing which also acts as a flow conduit; end caps which join the main piping of the 4 in. leg; a support spider to give axial support with the housing; and a guide pin and angular adjustment points to provide a positioning device for the adjustable orifice plate. For the plates with round holes, angular positions 0°, 7 1/2°, 15°, and 22 1/2° were used. Zero degrees in this case is the configuration where all holes are aligned. For the angular slots, the range was extended to 30°, making 5 instead of four, as used with plates having round holes.

For each position, three test runs were made, and the manometers were bled and the zero checked before and after each run. For each run, readings were taken at intervals from a low flow rate to a rate at which the capacity of the 100 in. mercury differential manometers was reached.

The pressure loss coefficients presented in this report are the average of the three runs and are based on the velocity through the test unit orifices.

DISCUSSION OF RESULTS

The flow resistance coefficients were obtained from the test data by the following procedure.

$$\Delta P = \frac{K V_o^2}{2g} \quad \text{or} \quad K = \frac{\Delta P \cdot 2g}{V_o^2}$$

SKETCH SHEET
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Figure 5

Loop No. 49, Clairton Site

Now:

$$V_4 A_4 = C_D A_4 \sqrt{2gh}$$

from continuity, $V_4 A_4 = V_O A_O$.

Therefore,

$$V_O^2 = C_D^2 \left(\frac{A_4}{A_O} \right)^2 2gh$$

and so,

$$K = \frac{\Delta P \ 2g}{C_D^2 \left(\frac{A_4}{A_O} \right)^2 2gh}$$

or,

$$K = C_1 \frac{\Delta P}{h}$$

$$\text{where } C_1 = \frac{1}{C_D^2 \left(\frac{A_4}{A_O} \right)^2}$$

Where:

ΔP = Pressure differential across test unit

K = Flow resistance coefficient

V_O = Velocity through multi-penetration orifices

A_O = Flow area of multi-penetration orifices

V_4 = Velocity through flow metering orifice in 4 in. line

A_4 = Flow area of flow metering orifice in 4 in. line

h = Pressure differential across flow metering orifice

C_D = Discharge coefficient of flow metering orifice

g = Acceleration of gravity

Curves 1 through 4 give the results of tests using three and two multi-hole plates in series for two different spacings between plates. In general, the resistance coefficient increases for the first three angular positions of the center plate. Between the third and fourth positions, however, the resistance coefficient did not change appreciably. This can

3 - 0.160 SPACING
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CURVE NO. 1

VARIABLE RESISTANCE ORIFICE
THREE MULTIHOLE PLATES IN SERIES
0.160" SPACING BETWEEN PLATES
NO. OF HOLES = 24

	HOLE SIZE	AREA RATIO
○	1/2 IN	0.392
□	3/8 IN	0.221
△	1/4 IN	0.0988

783

008
10

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1/2
3/8
1/4

2 - 0.160

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CURVE NO.

2

VARIABLE RESISTANCE ORIFICE
TWO MULTIHOLE PLATES IN SERIES
0.160" SPACING BETWEEN PLATES
NO. OF HOLES = 24

783

789 11

SIGNATURE

Frank A. Grochowski

8/27/58

2

○ 1/2
□ 3/8
△ 1/4

3 - 0.247

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CURVE NO.

3

VARIABLE RESISTANCE ORIFICE
THREE MULTIHOLE PLATES IN SERIES
0.347" SPACING BETWEEN PLATES
NO. OF HOLES = 24

○ 1/2
□ 3/8
△ 1/4

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2 PLATES 0.347" SPACING

CURVE NO. 4

VARIABLE RESISTANCE ORIFICE
Two MULTIHOLE PLATES IN SERIES
0.347" SPACING BETWEEN PLATES
NO. OF HOLES = 24

SIGNATURE Frank A. Grochowski DATE 8/27/58 CURVE NO. 4

be explained by Figure 6. The sketch shows the view seen by looking normal to the three plates. In the zero degree position, all holes are aligned, and therefore the holes are shown clear. With the center plate in the $7\frac{1}{2}^\circ$, 15° , and $22\frac{1}{2}^\circ$ position, the shaded portion shows the blockage caused by the misalignment of the center plate. It can be seen that the blockage increases considerably when the center plate is rotated from the 0° to 15° position; however, between the 15° and $22\frac{1}{2}^\circ$ positions, the change in blockage is not significant. For this reason, there is a relatively small change in the resistance coefficient between the 15° and $22\frac{1}{2}^\circ$ positions. Also, because of the uncertainty of the change in flow resistance between these two points, that portion of the curve has been indicated with a broken line.

Curve 5 gives the results for one orifice plate with three different area ratios. As shown by the curve, the area ratio at which the maximum resistance occurs was covered by the test.

Because of the rapid change in flow resistance with small angular rotation of the center multi-hole plate, and because of the ineffectiveness of the last $7\frac{1}{2}^\circ$ rotation from 15 to $22\frac{1}{2}^\circ$, this type of multi-penetration plate was not desirable. The objective was to obtain a uniform or linear resistance variation with misalignment of penetrations and to have the range occur over a larger angle. These objectives led to the angular slot design. Curves 6 to 9 give the results for the multi-slot design. As can be seen in the curves, the resistance coefficient varies linearly with angular position of the center plate and the range of angular rotation was extended to 30° . Figure 7, which is similar to Figure 6 for the multi-hole plates, shows the linear increase in blockage with angular misalignment, and therefore explains the linearity of the resistance coefficient with angular misalignment.

The curves of resistance coefficient versus Reynolds number, which are usually given in reports of this type, have not been included because of the large number of curves which would be required. However, a Reynolds number of flow through the orifices up to 3.5×10^5 was achieved and the curves were essentially flat. In prototype design, velocities through the orifices will be sufficiently high so that the Reynolds number for flow will be beyond the region where the coefficient varies with Reynolds number.

Tables I and II give the result of the study in tabulated form.

ACKNOWLEDGMENTS

This work was performed by the Engineering and Analysis Section of CTA, and their aid and cooperation in conducting this study is gratefully appreciated.

0°

7 1/2°

15°

22 1/2°

FIG. 6
POSITION & BLOCKAGE
MULTIHOLE ORIFICES IN
SERIES

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CURVE NO.

5

3 - 0.160
0 3/16 □ 1/8 SLOTS

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CURVE NO. 6

VARIABLE RESISTANCE ORIFICE
THREE MULTISLOT PLATES IN SERIES
0.160 IN SPACING BETWEEN PLATES
No. OF SLOTS = 36

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FORM 17691

2 - 0.160

WESTINGHOUSE ELECTRIC CORPORATION

3/16 1/8 Slots

CURVE NO. 7

VARIABLE RESISTANCE ORIFICE
TWO MULTISLOT PLATES IN SERIES
0.160 IN SPACING BETWEEN PLATES

	SLOT SIZE	AREA RATIO
○	3/16	0.393
□	1/8	0.267

3-0.247

3/16 1/8 slots

8

VARIABLE RESISTANCE ORIFICE
THREE MULTISLOT PLATES IN SERIES
0.247" SPACING BETWEEN PLATES
NO. OF SLOTS = 36

	<u>SLOT SIZE</u>	<u>AREA RATIO</u>
○	3/16" IN	0.393
□	1/8" IN	0.267

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8

9

VARIABLE RESISTANCE ORIFICE
TWO MULTISLOT PLATES IN SERIES
0.347" SPACING BETWEEN PLATES
NO. OF SLOTS = 36

0°

7 1/2°

15°

22 1/2°

30°

FIG. 7
POSITION & BLOCKAGE
MULTI-SLOT ORIFICES IN SERIES

TABLE I
VARIABLE RESISTANCE ORIFICING SCHEME

Multi-Hole Orifice Plates

Hole Dia.	No. of Plates	Spacing	0	$7\frac{1}{2}$	15	$22\frac{1}{2}$	Spacing	0	$7\frac{1}{2}$	15	$22\frac{1}{2}$	Area Ratio
1/2	3	0.160	1.045	2.538	3.937	4.12	0.347	1.332	2.445	3.474	3.791	0.393
1/2	2	0.160	1.115	2.230	2.663	2.585	0.347	1.187	2.064	2.524	2.592	0.393
1/2	1	-----	1.207	-----	-----	-----	-----	-----	-----	-----	-----	0.393
3/8	3	0.160	1.238	3.368	5.835	5.820	0.347	1.614	3.691	5.111	5.435	0.221
3/8	2	0.160	1.205	2.889	3.553	3.426	0.347	1.460	2.665	3.432	3.666	0.221
3/8	1	-----	1.533	-----	-----	-----	-----	-----	-----	-----	-----	0.221
1/4	3	0.160	1.541	4.135	5.366	5.364	0.347	2.022	4.10	4.96	5.11	0.0988
1/4	2	0.160	1.336	2.755	3.324	3.254	0.347	1.582	2.880	3.148	3.330	0.0988
1/4	1	-----	1.509	-----	-----	-----	-----	-----	-----	-----	-----	0.0988

TABLE II
VARIABLE RESISTANCE ORIFICING SCHEME

Multi-Slot Orifice Plates

Slot Width	No. of Plates	Spacing	0°	7½°	15°	22½°	30°	Spacing	0°	7½°	15°	22½°	30°	Area Ratio
3/16	3	0.160	0.966	1.529	2.235	3.057	3.61	0.347	1.36	1.69	2.13	2.62	2.88	0.393
3/16	2	0.160	0.876	1.35	1.76	2.06	2.45	0.347	1.10	1.39	1.64	1.83	1.93	0.393
3/16	1	-----	0.919	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.393
1/8	3	0.160	1.15	1.77	2.56	3.44	4.15	0.347	1.58	2.08	2.66	3.21	3.49	0.267
1/8	2	0.160	1.04	1.42	1.91	2.22	2.59	0.347	1.25	1.51	1.87	2.09	2.26	0.267
1/8	1	-----	0.979	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.267