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FARE Device Operational Characteristics of Remote Controlled Fuelling Machine at Wolsong NPP

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Abstract

There are 4 CANDU6 type reactors operating at Wolsong site. For fuelling operation of certain fuel channels (with flow less than 21.5 kg/s) a FARE (Flow Assist Ram Extension) device is used. During the refuelling operation, two remote controlled F/Ms (Fuelling Machines) are attached to a designated fuel channel and carry out refuelling job. The upstream F/M inserts new fuel bundles into the fuel channel while the downstream F/M discharges spent fuel bundles. In order to assist fuelling operation of channels that has lower coolant flow rate, the FARE device is used instead of F/M C-ram to push the fuel bundle string. The FARE device is essentially a flow restricting element that produces enough drag force to push the fuel bundle string toward downstream F/M. Channels that require the use of FARE device for refuelling are located along the outside perimeter of reactor. This paper presents the FARE device design feature, steady state hydraulic and operational characteristics and behavior of the device when coupled with fuel bundle string during fuelling operation. The study showed that the steady state performance of FARE device meets the design objective that was confirmed by downstream F/M C-ram force to be positive.

Key Words : CANDU fuel handling system, flow restrictive device, flow control device, movable orifice, on-power refuelling device

1. Introduction

Currently there are 4 CANDU6 reactor units that are in operation at Wolsong site. It has been known some time that there are some anomalies during fuelling operation of selected channels that require FARE device for refuelling. An in-depth analysis on fuelling operation which focuses on the anomalies such as too much flow restriction during refuelling when FARE device is used is presented in reference 1. A fuelling method related matter such 8-bundle or 4-bundle shift refuelling scheme was presented in reference 2.

For CANDU reactors in general, two remote controlled F/Ms are required to carry out fuelling operation. Since CANDU reactors require on-power refuelling, fuelling operation is done on a daily basis. During fuelling operation, the F/Ms are clamped onto fuel channel upstream and downstream end fittings. The one clamped to the upstream end fitting inserts new fuel bundles while the other one clamped to the downstream end fitting discharges spent fuel bundles. During the fuelling operation no part of F/M components enters into the core region. The main reason is to prevent activation of F/M components by radiation so that maintenance and repair of F/M can be done routinely. The coolant flow rate for channels located in the center region is high enough that fuel bundles are float with coolant stream and move toward downstream F/M magazine, hence there is no need to use F/M ram to push fuel bundle string, reference 3. However coolant flow for channels located outside perimeter of reactor is not sufficient to produce drag force that is enough to push fuel bundles toward downstream F/M magazine. To assist fuelling operation in such cases, a flow restricting element called FARE (Flow Assist Ram Extension) device is used instead of F/M C-ram to push the fuel bundle string. The FARE device is discharged into storage bay same as spent fuel bundles prior to maintenance of F/M to prevent radiation dose to the maintenance personnel working on the machine.

The FARE device consists of three main parts; front part (fuel adapter and tube) that contacts with fuel bundle, middle part (ring orifice and spring, etc) that restricts channel coolant flow and rear part (casing, sleeve and stem, etc) that interfaces with F/M rams. The FARE device was initially developed for use in Pickering reactors (it was evolved into CANDU6 type reactor) for fuelling operation, reference 4. For Pickering reactors, the FARE device is used in channels with coolant flow rates ranging from the minimum of 15kg/s to 21.5 kg/s. Because the variation of flow rate is not big the FARE device was designed with fixed type ring orifice. The coolant flow restriction by the FARE device is tolerable for the flow range and does not pose a danger of over heating of fuel bundles. At the same time it produces big enough drag force that is necessary to push fuel bundle string. So a fixed type ring orifice was incorporated for Pickering FARE device.

On the other hand, the range of coolant flow rates for CANDU6 FARE device is from 9.5 kg/s to 21.5 kg/s, reference 5. Because of the big variation in flow rates, it is required to use several different fixed ring orifice type FARE devices to cope with the wide flow range. But it is not economical and mix up during operation may cause a danger of fuel overheat problem. Instead, movable ring orifice is used in the CANDU6 FARE device in that the ring orifice opens up flow area wider as flow rate increases and can cover whole range of flow condition.

The CANDU6 FARE device has been showing channel low flow phenomena when the FARE device is used for the refuelling of instrumented-channels (channels where flow meters are installed). It has been suspected and believed that the FARE device might restrict channel coolant flow too much. Since flow meters are installed only on some channels, other channels that are not instrumented may actually be in a low flow state during fuelling operation and initiated a program to investigate the problem. When the FARE device is inserted into the core flow region, the channel coolant flow decreases at the beginning due to increased flow restriction, however the flow rate increases as the spent fuel bundles are removed from the channel. Therefore, the channel flow is related to the number of fuel bundles in the core region as well as the presence of FARE device.

This paper describes the CANDU6 FARE device design features, hydraulic characteristics when FARE device is fully submerged in axial flow region of the core (a steady state hydraulic behavior), and operational characteristics when coupled with fuel bundle string. An analysis of transient hydraulic characteristics of FARE device is presented in reference 1 with recommended design improvements.

2. FARE Device Design Features

Figure 1 shows CANDU6 FARE device assembly and interface with F/M rams, reference 7. FARE device consists of three main parts; front part that contacts with fuel is fuel adapter, middle part that controls flow consists of ring orifice and spring, etc, and rear part that interfaces with F/M head consist of casing, sleeve, stem, etc. The zirconium tube makes the FARE device length to be approximately the same as 2 fuel bundles so that the FARE device can be handled by F/M head in a manner similar to fuel bundles and other components such as shield plug, channel closure and snout plug. The diameter of FARE device is also approximately the same as fuel bundle so that it is compatible with fuel channel pressure tube, end fitting liner tube and F/M magazine, see Figure 2.

The front face of fuel adapter contacts with fuel bundle end plate so it is designed to support fuel bundle properly by having 3 concentric support areas that mate to fuel bundle end plate. Next to fuel adapter is zirconium tube that has holes at each end of tube. The holes allow flow to go in and out of the tube. When the FARE device is out of core region the flow will go to the tube, and when the FARE device is fully into the core flow region the flow will go out of the tube. The other end of FARE device is connected to the middle part.

The middle part consist of tube adapter, ring, spring holder, pin and spring. The tube adapter body has 4 slots that allow flow goes into the adapter body inside. Pins through the tube adapter body slots connect the ring outside and spring holder inside. The spring holder is loaded by spring, so the slots are closed. However upon insertion of the FARE device into the core flow region, the ring moves by drag force and opens tube adapter body slots. As the flow increases the slot opening widens and the drag force on the ring maintains a rather flat response. The clearance between ring and channel pressure tube is critical and tightly designed to prevent too much bypass flow around the ring orifice. The outside surface of ring orifice is designed to have number of grooves to give more stable behavior in the turbulent flow.

The rear part consists of casing, sleeve, stem and spring. This is the part that interfaces with F/M rams. This part is similar to shield plug that is installed each end of the core to reduce radiation level outside of reactor and channel closure that is installed in the end fitting to seal the channel. So F/M can pickup and install these components with the same movement. It is note that F/M has 3 rams that are C-ram (hydraulic ram), B-ram and Latch-ram (mechanical ram). The interface dimension is importance to have compatibility with F/M rams. The sleeve is loaded by 4 springs.

When upstream F/M inserts FARE device, it uses C-ram to push the FARE device into the core region along with the fuel bundle string in front of it. The C-ram does not clamp to the FARE device by the insertion action because sleeve is loaded by spring. It just slides into the core without clamped to C-ram. Once it moves into the core flow region, the channel flow pushes the FARE device and fuel bundle string toward downstream F/M magazine.

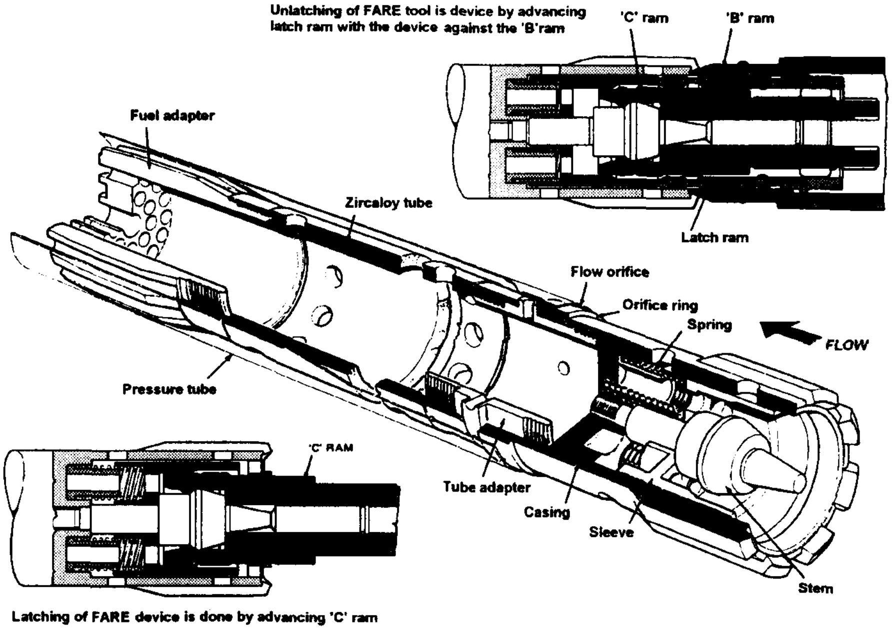


Fig. 1. FARE Device Assembly and Interface with F/M Rams

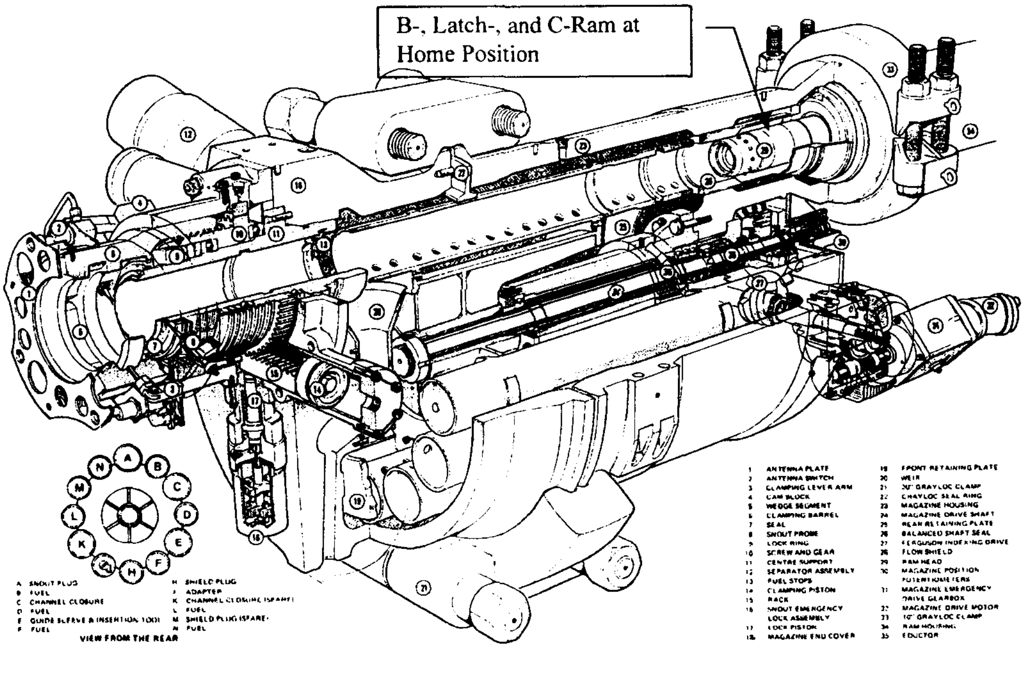
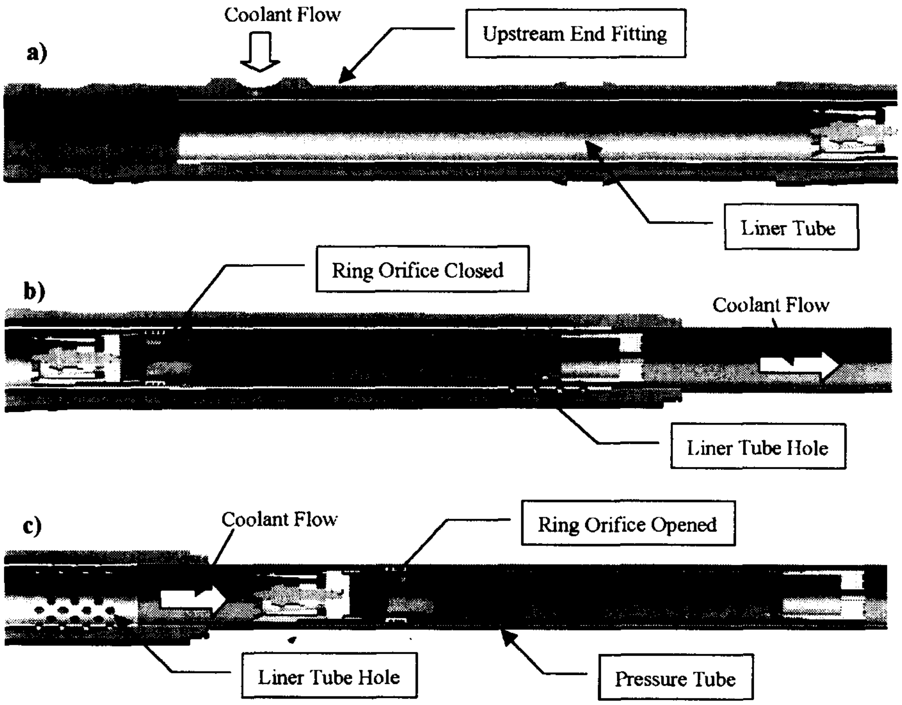


Fig. 2. F/M Head Magazine and Snout Assembly



a) Coolant flow at the upstream end fitting - coolant flows along the gap between the end fitting and liner tube
b) FARE Device at the liner tube hole-ring orifice closed
c) FARE Device inside the pressure tube - ring orifice opened

Fig. 3. FARE Device Insertion into Fuel Channel

After 8 spent fuel bundles are discharged from core, the downstream F/M pushes back the whole fuel bundle string and the FARE device back into core region and the FARE device gets out of the core to the upstream end fitting. The upstream F/M clamps to the FARE device by pushing C-ram forward while the FARE device is held in position by fuel string. The figure in the lower left corner of Figure 1 shows clamping of FARE device by F/M C-ram. Then the F/M C-ram withdraws back into home position with the FARE device at the tip of C-ram. It then releases and stores the FARE device in the F/M magazine by withdrawing C-ram while advancing Latch-ram. The figure in the upper right corner of Figure 1 shows unlatching of FARE device by Latch-ram at home position. Figure 2 shows F/M head magazine assembly and rams at home position. A detailed description of F/M Head can be found in reference 7.

Figure 3 shows the FARE device operation as it is inserted into a fuel channel. It does not show fuel bundles and F/M rams. Figure a) shows the upstream end fitting and liner tube. The coolant flows into the end fitting and along the gap between end fitting and liner tube. Figure b) shows the FARE device located at the liner tube hole and the ring orifice is still closed. The coolant flows into the bore of liner tube through the holes and into the core. Figure c) show the FARE device inserted fully into the core and the ring orifice is opened.

3. FARE Device Hydraulic Characteristics

Figure 4 shows the FARE device hydraulic characteristics based on test data obtained for H2O at 558°K, reference 5. As mentioned previous section, the ring orifice is closed at low flow condition due to orifice spring pre-load. From Figure 4, the ring orifice starts to open at flow around 8.5 ~ 10.8 kg/sec depending on the pressure tube inside diameter. Below this flow range, the FARE device shows a fundamental square low of flow characteristics in that the flow resistance is proportional to the square of mass flow rate for a given temperature. At this range virtually all flow passes through the gap between ring orifice and pressure tube. The pressure tube inside diameter is critical because it affects the gap between ring orifice O.D. and pressure tube I.D. As the gap becomes bigger, the effective pressure drop between up- and down-stream of ring orifice decreases. The effect of pressure tube inside diameter increase is clearly shown in Figure 4 as decreased pressure drop.

A similar plot is given in Figure 5 where the mass flow rate change is given. Note that it is plotted per kg/sec. As the temperature of fluid decreases, the flow resistance decreases too. For the same weight of fluid, the density of fluid at low temperature is higher than that at high temperature, and consequently, the fluid velocity at low temperature is lower and resulting in lower flow resistance.

Flow resistance occurs mostly at ring orifice section, other parts that contribute to the flow resistance is front part (casing, stem, etc) and rear part (zirconium tube, fuel adapter, etc). The geometry of these parts is fixed and has relatively big flow area; hence the effects on flow resistance are minor. However, during the insertion of the FARE device, Figure 3 b, when the FARE device is still out of core flow region, the effect of zirconium tube on flow resistance is critical, see reference 1. At this point the flow passage is limited to the gap between zirconium tube and liner tube, and more over the flow that are coming into the core through liner tube hole is directly blocked by zirconium tube. The behavior at this stage is under investigation.

As the flow increases, the drag force of ring orifice increases. When drag force is greater than ring orifice spring pre-load, the ring orifice slot opens. The FARE device shows the similar behavior for decreasing flow too. The ring orifice spring pre-load sets the minimum flow in which ring orifice starts to open and becomes complete close. A too low pre-load will cause early opening of ring orifice and won' t be able to produce enough drag force that can push fuel string forward. On the other hand too high pre-load will cause late opening of ring orifice and restrict flow too much and may cause heat up of fuel and produce unnecessary big drag force that may damage fuel bundle.

As the FARE device is moving into the core by F/M C-ram, the ring orifice section passes over liner tube hole region and uncovers the ring orifice slot. The amount of slot opening depends on the flow rate of the channel. As flow rate increases, the slot opening increases allowing more flow into the tube adapter and zirconium tube bore. The drag force and the ring orifice spring force balances all time. As flow increases slot opening increases, however, the slot will not open as much as flow increase. As slot open area increases the flow velocity will decrease around ring orifice section causing low flow resistance. This causes rather flat response in pressure drop versus flow rate as shown in Figure 4 and 5. This characteristic is the objective of the FARE device design, i.e. having flat hydraulic response for a given range of flow rate.

In Figure 4, and 5, the slot completely opens up at around 33 (kg/s). Although the FARE device is designed to be used channel flow of up to 21.5 kg/sec; an inadvertent insertion of the FARE

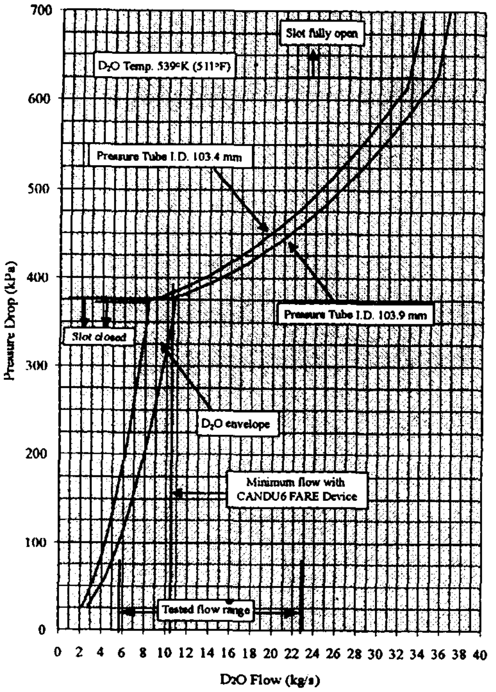


Fig. 4. FARE Device Hydraulic Characteristics-Effect of Pressure Tube

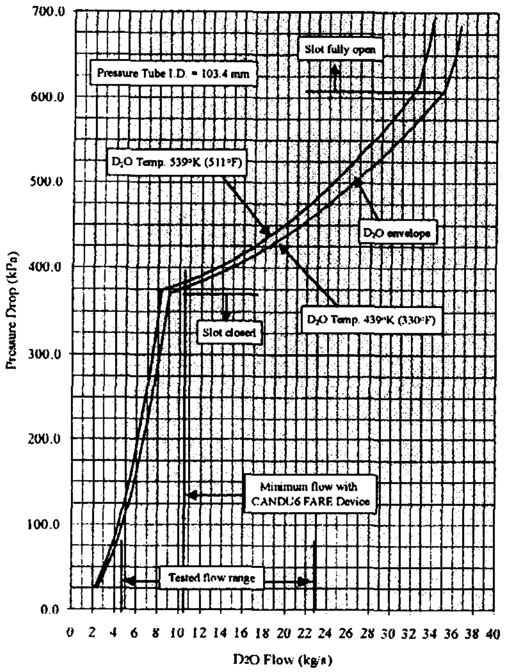


Fig. 5. FARE Device Hydraulic Characteristics-Effect of D₂O Temperature

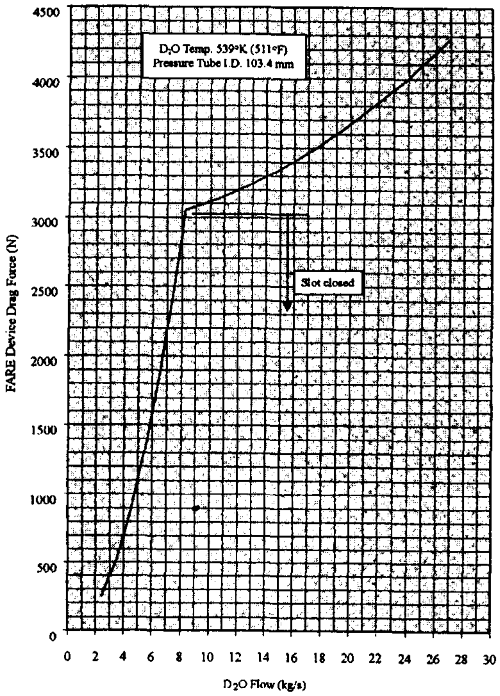


Fig. 6. FARE Device Hydraulic Drag Froces

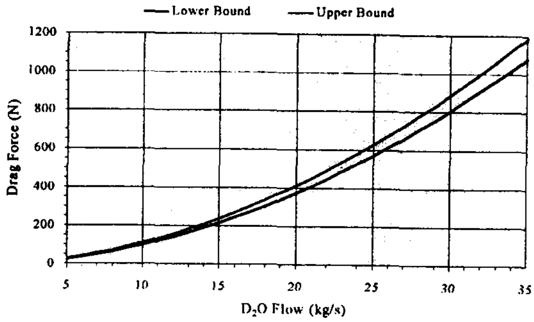


Fig. 7. Single Fuel Bundle Drag Froces

device into high flow channel should not cause a problem. So the operation range of up to around 33 (kg/s) is higher than it is necessary. After this flow range, the ring orifice slot opens completely and again shows square low pattern.

The hydraulic drag force of the FARE device is given in Figure 6. This was obtained from the pressure drop given in Figure 4. The weight of the FARE device is around 18(kg) when it is

Table 1. Total Number of Fuel Bundles in the Core and the Fuel String During FARE Fuelling Operation

Steps shown in Figure 9.	Number of fuel bundles in core	Number of fuel bundle in the string	Number of fuel bundle in the downstream end fitting
5	11+FARE	16+FARE	5
6	9+FARE	14+FARE	5
7	7+FARE	12+FARE	5
8*	5+FARE	10+FARE	5
9*	3+FARE	8+FARE	5
10*	1+FARE	6+FARE	5
11*	0+FARE/2	4+FARE	4 + FARE/2
12*	-FARE	4+FARE	4 + FARE

* Not shown in Figure 9.

submerged in D2O and the friction force between the FARE device and pressure tube is approximately 90(N). The dynamic friction coefficient between the FARE device and pressure tube in wet condition is found to be around 0.5.

4. Refuelling Operation with FARE Device

The purpose of FARE device is to make refuelling operation possible for low flow channels without restricting flow excessively. The validity of FARE device can only be justified when the FARE device together with whole fuel bundle string is considered. In this section, the total drag force of FARE device and fuel bundle string during fuelling operation is calculated based on the FARE device hydraulic drag force and fuel string drag force.

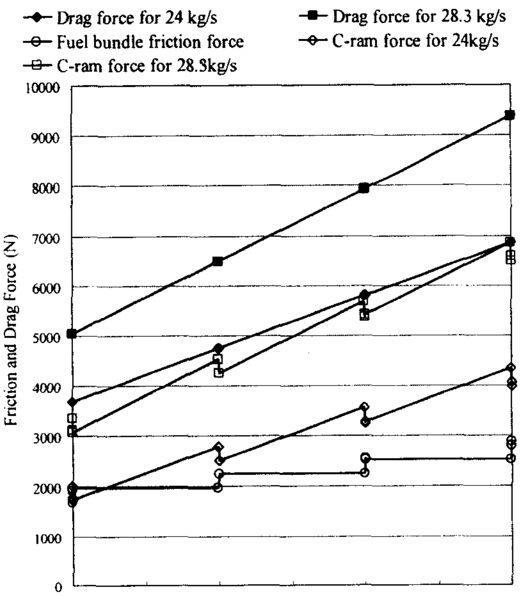


Fig. 8. Downstream F/M C-ram Force During FAF Fuelling

Before addressing the total drag force during fuelling operation, fuel string drag force for center channels is calculated to present as a reference value based on the experiment given in reference 3. The channel flow versus drag force of equivalent single fuel bundle is shown in Figure 7. From reference 3, the dynamic friction value of fuel bundle in D2O condition is conservatively 140(N), friction coefficient of 0.6, and the static friction for fuel bundle is conservatively 160(N) per bundle. The nominal value of coolant flow rate for center channel is 24 kg/s and the maximum is 28.3 kg/s. The calculation did not consider the flow increase due to reduced impedance as spent fuel bundles are removed from the core.

Figure 8 shows the fuel string drag force during FAF (flow assist fuelling method) fuelling. At the

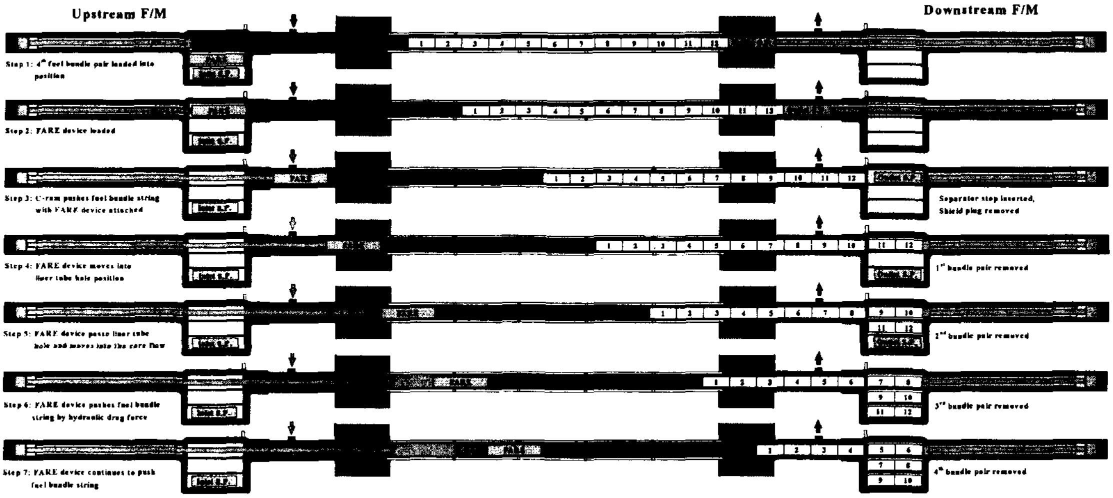


Fig. 9. Part of Fuelling Operation Using FARE Device

start of FAF fuelling, 13 fuel bundles are in the core and the fuel string length is 20 bundles. Using Figure 7, the fuel string force is found to be 6900(N) for 24 (kg/s) flow and 9400(N) for 28.3 (kg/s) flow. The total static friction force for the fuel string is 3200 (N) and the dynamic friction force is 2800 (N). At the end of FAF fuelling, 7 fuel bundles are in the core and the fuel string length is 12 bundles. The fuel string force is 3700(N) for 24 (kg/s) flow and 5050(N) for 28.3 (kg/s) flow. The total static friction force for the fuel string is 1920 (N) and the dynamic friction force is 1680 (N). The F/M inlet flow into the core is not considered in the calculation.

Figure 8 also shows the downstream F/M C-ram reaction forces during refuelling operation. The C-ram force is the net force of fuel string on C-ram and can be computed by subtracting fuel string drag force by the friction force of the fuel string. Because the static friction and dynamic friction force is different, it is shown as stare case plot.

A similar method is applied to compute the downstream F/M C-ram force for FARE fuelling operation. Table 1 shows the number of fuel bundles in the core flow and total fuel bundles in the fuel string. This table assumes that the FARE device moves all the way to the downstream liner tube hole. Figure 9 shows part of fuelling operation that is directly related to the FARE device movement. The steps after the final step shown in Figure 9 is recovering the FARE device by upstream F/M. The number of fuel bundles in core and in the fuel string for the steps 5,6 and 7 of Figure 9 is are listed in Table 1. A more detailed fuelling sequence related to the FARE device at reactor face refuelling operation is described in reference 1, while an overall fuelling sequence is described in reference 2.

Step 1 of Figure 9 shows a state in which 3 new fuel bundle pairs are already inserted and magazine tube containing another pair of new fuel bundles is rotated so that C-ram can push whole fuel bundle string. During the insertion of 3rd new fuel pair, the downstream shield plug must be repositioned by F/M to allow upstream F/M magazine rotation. At step 1, the upstream F/M C-ram pushes the whole fuel string just enough so that the magazine can rotate. In step 2, magazine rotates so that magazine tube containing the FARE device is in position. In step 3, downstream shield plug is removed from end fitting and stored in magazine tube. The downstream F/M separator holds the rest of fuel bundle string from getting into the magazine tube. In step 4, downstream F/M rotates magazine to receive spent fuel bundles, and upstream F/M C-ram pushes the FARE device into end shield region. The FARE device front tip is in the channel flow and starts to affect channel flow. In step 5, 1st spent fuel bundle pair is stored in the downstream F/M magazine, and the FARE device moves into core flow region completely and affect channel flow. The upstream F/M C-ram does not extend into core flow region. In steps 6 and 7, the FARE device alone pushes the whole fuel string. The downstream F/M stores 2nd and 3rd spent fuel bundle pairs and 4th spent fuel bundle pair moves in the magazine tube. In the following steps, downstream F/M will rotate F/M magazine so that it can reload shield plug in position. The upstream F/M C-ram picks up the FARE device when it is pushed back into upstream side end shield region.

As an example of downstream F/M C-ram force calculation, two cases are presented here, i.e. refuelling operation with the FARE device for channels with maximum flow and minimum flow.

Case 1. Minimum Channel Flow (nominal channel flow of 10.6 kg/s)

For the minimum flow channel that use FARE device the nominal channel flow is 10.6 (kg/s). The minimum channel flow during FARE refuelling is 10.1 (kg/s) and maximum channel flow is 11.01 (kg/s). The F/M inlet flow of about 1.89 (kg/s) should be added to the channel flow. Because channel flow rate changes according to channel flow impedance, flow at the beginning is lower than the flow at the end of FARE device push. Following calculation takes into account the F/M inlet flow as well as channel flow-change during refuelling operation.

At step 5 of Table 1: Channel Nominal Flow of 10.6 (kg/s)

This is the instance when the FARE device separated from C-ram and starts to push fuel bundle string. There are 11 fuel bundles and FARE device in core, 16 fuel bundles in the fuel bundle string, and 5 fuel bundles in downstream end fitting. Note that at step 5, the downstream F/M C-ram supports fuel bundle string and the FARE device and the upstream C-ram stops extending into core. Therefore, at the beginning of step 5, fuel string and the FARE device is in a pause state and the friction should be static friction. As soon as downstream C-ram starts to retract, the friction changes to dynamic friction.

Note also that downstream F/M inlet flow acts in an opposite direction of channel flow, so the drag force by the fuel bundles in the downstream end fitting acts in a backward direction. The upstream F/M inlet flow should be added to channel flow in the calculation of drag force of fuel bundle and FARE device.

1) Fuel and FARE Device Friction Force Calculation

- Fuel dynamic friction coefficient of 0.6 (from actual measurement):
  Static friction (μ: 0.68) = 16 (bundles) × 160(N) + 100 (N, FARE) = 2660(N).
  Dynamic friction (μ: 0.6) =16 (bundles) × 140(N) + 90 (N, FARE) = 2330(N).
- Fuel dynamic friction coefficient of 1.0 (conservative assumption):
  Static friction (μ: 1.08) = 16 (bundles) × 254(N) + 100 (N, FARE) = 4164(N).
  Dynamic friction (μ: 1.0) =16 (bundles) ×

233(N) + 90 (N, FARE) = 3818(N).

2) Fuel and FARE Device Drag Force Calculation

FARE device drag force = 3196 (N) at 11.99 (kg/s) of flow.

Fuel drag force = forward drag - back ward drag by F/M flow

11(bundles) (141.6(N) - 5(bundles) (4(N) = 1562(N) - 28 (N) = 1538 (N)

Total drag force = 1538 + 3196 (N) = 4734 (N)

3) Downstream F/M C-ram Force Calculation

D/S F/M C-ram force for static friction (μ=0.6) = 4734 - 2660 = 2074 (N)

D/S F/M C-ram force for dynamic friction (μ=0.6) = 4734 - 2330 = 2403 (N)

D/S F/M C-ram force for static friction (μ=1.0) = 4734 - 4164 = 570 (N)

D/S F/M C-ram force for dynamic friction (μ=1.0) = 4734 - 3818 = 915 (N)

A similar calculation should be done for other steps and the results are shown in Figure 10. For better results, calculation for points in between steps using interpolated channel flow rates are carried out and presented in Figure 10 below.

Case 2. Maximum Channel Flow (nominal channel flow of 21.8 kg/s) - Figure 11

For the maximum flow channel that use FARE device the nominal channel flow is 21.8 (kg/s). The minimum channel flow during FARE refuelling is 16.8 (kg/s) and maximum channel flow is 19.9 (kg/s). The F/M inlet flow of about 1.89 (kg/s) should be added to the channel flow. Following calculation for step 11 is similar to the

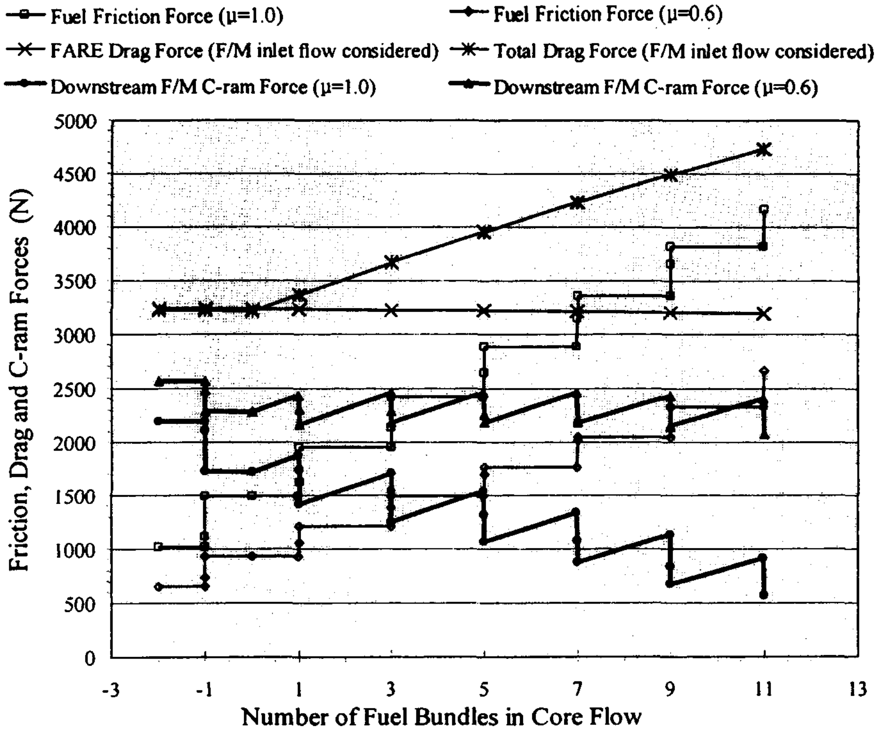


Fig. 10. Minimum Flow Channel Defuelling Forces(Normal Flow : 10.6kg/s)

one shown above.

At Step 11 of Table 1: Channel Nominal Flow 21.8 (kg/s)

This is the instance when FARE device moves toward downstream end fitting liner tube flow hole. The FARE device is half into the flow hole and all fuel bundles are out of core flow region. In normal refuelling operation this step does not occur, however, this operation is required if all fuel bundles are to be removed from channel. There are 4 fuel bundles in the end fitting and F/M snout region. No fuel bundle is in core, only a half of the FARE device is in core flow. The calculation is similar to the one given above, only the channel flow and number of fuel bundles in core and end fitting region are different. The core flow of 19.9(kg/s) is used in the following calculation.

1) Fuel and FARE Device Friction Force Calculation

- Fuel dynamic friction coefficient of 0.6 (from actual measurement):
  Static friction (μ: 0.68) = 4 (bundles) (160(N) + 100 (N, FARE) = 740(N).
  Dynamic friction (μ: 0.6) =4 (bundles) (140(N) + 90 (N, FARE) = 650(N).
- Fuel dynamic friction coefficient of 1.0 (conservative assumption):
  Static friction (μ: 1.08) = 4 (bundles) (254(N) + 100 (N, FARE) = 1116(N).
  Dynamic friction (μ: 1.0) =4 (bundles) (233(N) + 90 (N, FARE) = 1022(N).

2) Fuel and FARE Device Drag Force Calculation

FARE device drag force = 3813 (N) at 21.8 (kg/s) of flow.

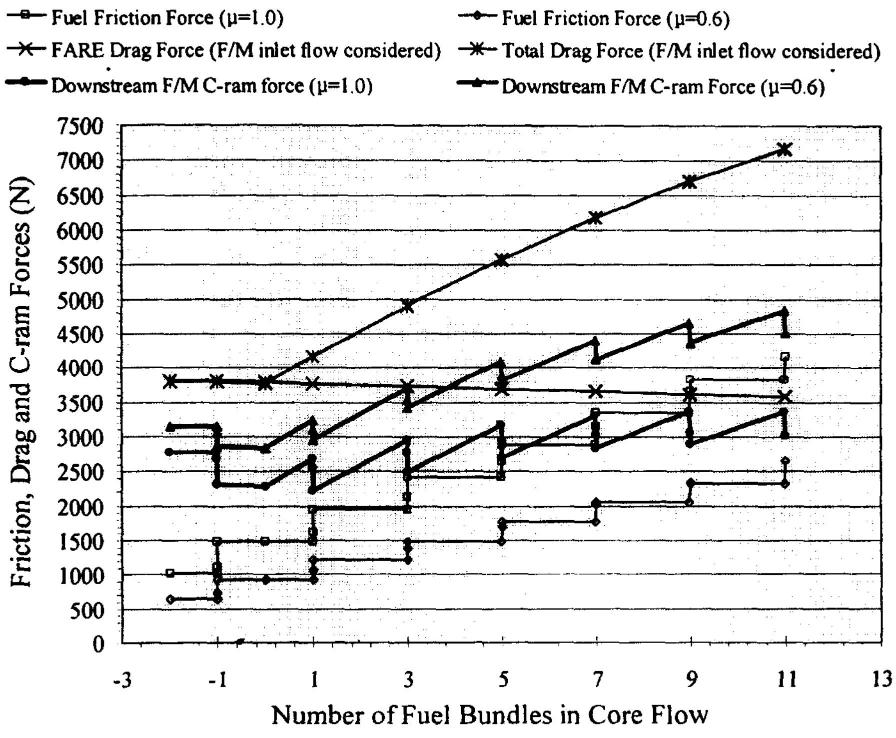


Fig. 11. Minimum Flow Channel Defuelling Forces(Normal Flow : 21.8kg/s)

Table 2. Summarized Downstream F/M C-ram Forces

Channel	Fuel bundle dynamic friction coefficient	Downstream F/M C-ram forces (N)		
		Maximum	Minimum	Minimum for 8 bundle shift
Minimum flow channel (10.6 kg/s)	$\mu=0.6$	2567	2074	2186
	$\mu=1.0$	2195	570	1070
Maximum flow channel (21.8 kg/s)	$\mu=0.6$	4516	2841	3813
	$\mu=1.0$	3012	2217	2697

Fuel drag force = forward drag - back ward drag by F/M flow

0 - 4(bundles) (4.18(N) = - 17 (N)

Total drag force = 3813 - 17 (N) = 3796 (N)

3) Downstream F/M C-ram Force Calculation

D/S F/M C-ram force for static friction ($\mu=0.6$) = 3796 - 740 = 3056 (N)

D/S F/M C-ram force for dynamic friction ($\mu=0.6$) = 3796 - 650 = 3146 (N)

D/S F/M C-ram force for static friction ($\mu=1.0$) = 3796 - 1116 = 2680 (N)

D/S F/M C-ram force for dynamic friction ($\mu=1.0$) = 3796 - 1022 = 2774 (N)

Figure 11 shows the calculation results.

Table 2 summarizes the maximum and minimum downstream F/M C-ram forces. It showed that the downstream F/M C-ram force is positive for all cases, including conservative estimates by considering friction coefficient of 1.0.

5. Conclusions and Further Considerations

In this paper investigated the hydraulic characteristics of FARE device and the performance of FARE device. The FARE device exerts big enough drag forces for all cases that the downstream F/M C-ram will feel a positive compression (570 N for conservative estimate). This means fuel bundles will move toward downstream F/M in any cases.

The investigation was based on steady state hydraulic test of The FARE device, and assumed that FARE device is completely submerged in the core flow. A further investigation for the transition period hydraulic characteristics of the FARE device is planed as next phase of research. It will include the measurement of flow rate change and drag force variation for transition interval when inserting the FARE device into the core flow region. Dimensional change is also planed to optimize the performance of the FARE device.

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