Evaluation of the Fluid Force in the Main Feed Water Control Valve for APWRs

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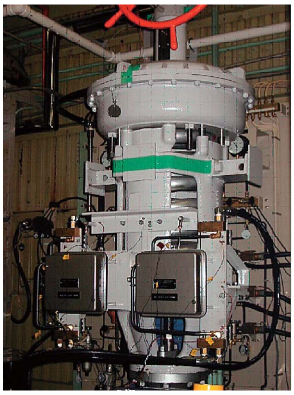

1. Introduction

In pressurized water reactor (PWR) power plants, the main feed water control valve plays an important role in controlling the water level in the steam generator by regulating the feed water (flowing to the steam generator) (**Fig. 1**).

Mitsubishi Heavy Industries, Ltd. (MHI) is now in the process of designing an advanced pressurized water reactor (APWR), which puts out about 40% more power than a conventional PWR of comparable size. Since the increase in reactor output also causes feed water flow to grow by roughly 40%, it follows that the fluid force acting on the plug of the main feed water control valve rises considerably. Fluid force acting on the valve plug in a vertical direction affects the valve operation. Therefore, it is necessary to ascertain that the main feed water control valve, even when exposed to such increment in fluid force, will be capable of controlling the steam generator water level stably in response to the command signal. In the absence of any widely known experiences that have enabled a quantitative assessment as to how the feed water valve's controlling performance is influenced by the fluid force to which it is subjected, we have carried out a flow test to determine the amount of force that works on the plug of the main feed water control valve and run a computer simulation considering the fluid force to evaluate the valve's controlling capability.

2. Construction of the main feed water control valve

Fig. 2 is a conceptual illustration of the main feed water control valve. This is an air-operated valve which accomplishes water flow control by vertically moving the plug (connected to the actuator via the stem). Because a pressure distribution is formed around the plug by fluid flow, a load (fluid force) is imposed on the plug. If the amount of fluid force which vertically acts on the plug is significant compared with that of the force delivered by the actuator, the valve's ability to control fluid flow can be adversely affected.

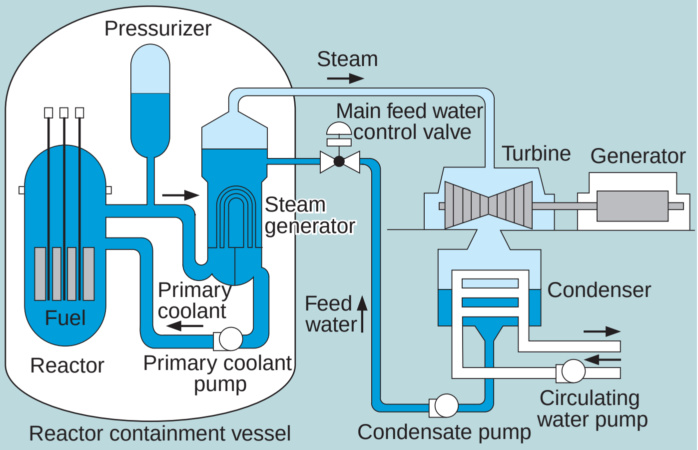

Fig. 1 Schematic diagram of PWR power plant

3. Flow test

3.1 Test setup

A flow test was conducted in order to grasp the amount of fluid force that vertically acts on the plug. Used as a test specimen was a 1/3 scale model, which was exactly analogous to a production model in terms of the internal flow pass contour. Fluid force measurements were taken by means of a strain gage. An external view of the test setup is given in **Fig. 3**.

3.2 Test conditions

The flow test was performed at room temperature. Flow velocity was made equal to that found in actual installations so that the stress and strain imposed by fluid force on the plug would become identical with those found on-stream, except for the influence of fluid density.

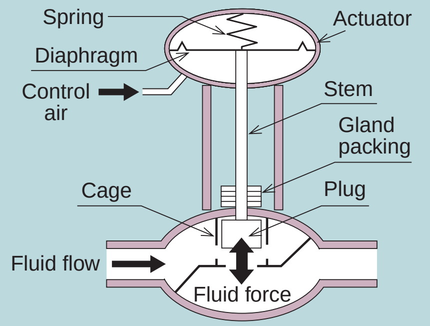

Fig. 2 Main feed water control valve concept

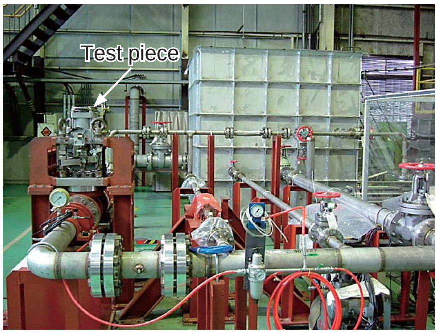

Fig. 3 External view of test setup

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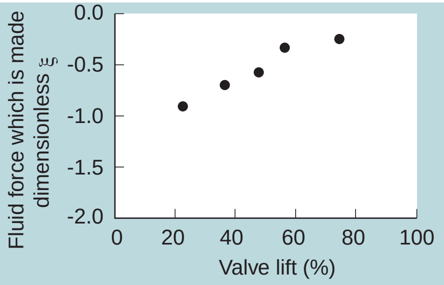

Fig. 4 Fluid force coefficient
Value obtained by making fluid force, which has been obtained from a flow test, dimensionless by dynamic pressure and representative area

On the other hand, there were no specific efforts to ensure inlet pressure matched that observed on-line, because it had no impact on the flow situation inside the valve. The Reynolds number during the flow test was lower compared with that observed in actual units, but the flow situation within the valve was considered almost the same as that noted in real installations, because it was well within the turbulence range.

3.3 Test Result

Fluid force can be calculated from the strain in the stem, which has been determined through the flow test, using equation (1): $F_{fluid} = S_{stem} \times \sigma = S_{stem} \times E\varepsilon$

Where:

F_{fluid}: fluid force

S_{stem}: cross-sectional stem area

σ : stress developed in the stem

E: modulus of longitudinal elasticity

ε : strain

Since fluid force is in proportion to dynamic pressure and the area on which it works, it can be made dimensionless by dynamic pressure and its working area into equation (2):

$$\zeta = \frac{F_{fluid}}{\frac{1}{2}\rho v^2 A}$$

Where:

ζ : fluid force which is made dimensionless (hereinafter referred to as fluid force coefficient)

ρ : fluid density

v: representative velocity

A: representative area

In a range where the Reynolds number is adequately high, the flow situation within the valve stays roughly identical, irrespective of the Reynolds number. Thus, the fluid force coefficient remains virtually constant, regardless of such conditions as fluid velocity or scale. **Fig. 4** shows the relationship between the fluid force coefficient and the valve lift that were determined by the test. A negative fluid force coefficient indicates that fluid force is acting in a downward direction. Representative velocity was taken as mean fluid velocity across an orifice and representative area, the area of the orifice's opening.

4. Assessment of controlling performance

4.1 Simulation model

In order to verify the controlling ability of the main feed water control valve, a computer simulation was conducted by incorporating a model embodying the main feed water control valve itself into that representing the entire plant. Note that the model of the main feed water control valve was formulated to contain an equation of motion based on the plug being the material point. This means that the fluid force in actual installations, which had been computed from the fluid force coefficient obtained from the test, is factored in as an external force.

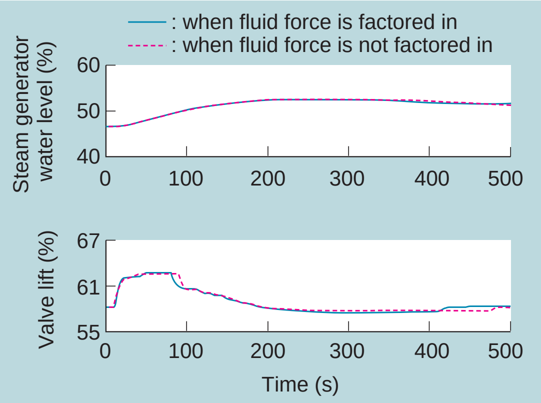

Fig. 5 Examples of behaviors of the steam generator water level and main feed water control valve lift, found at a given change in operating conditions

4.2 Simulation results

The simulation revealed that the main feed water control valve would be able to control the steam generator water level reliably under varying transient conditions encountered during operation. As an example, **Fig. 5** shows the behaviors of the steam generator water level and the main feed water control valve lift, noted at given change in operating conditions. For reference, the figure also illustrates the behaviors they would exhibit if fluid force were not factored in. It has been affirmed that there is some difference in the behavior of the main feed water control valve, depending on whether or not fluid force is involved, but the steam generator water level remains barely affected.

5. Conclusion

In PWR or APWR, the main feed water control valve plays a key role in regulating the steam generator water level. Hence, we assessed its performance taking fluid force into account and determined that it can achieve stable control of the generator water level.


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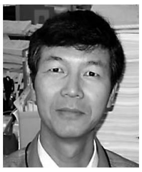
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