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Design Improvement for Cavitation Induced Erosion at the Flow Control Valve in the Nuclear Service Cooling Water System

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1. Introduction

The function of nuclear service cooling water (NSCW) System is for supplying cooling water (sea water) to the Component Cooling Water Heat Exchangers, Essential Chillers and Emergency Diesel Generator Chillers. In the NSCW system, the flow control valve (FCV) is installed to prevent an overflow of the system. As metal loss damage (erosion) inside the FCV due to the cavitation and sea water corrosion occurred frequently, the material of valve disc was changed from AL-Bronze to Monel in 1996. After changing the material, the erosion by sea water corrosion was clearly improved. But the erosion induced by cavitation is still observed. Therefore, this study investigates the metal loss damage mechanisms in the FCV of NSCW system and proposes the design modification to mitigate the metal loss damage in the valve.

2. Cause of Metal Loss in Flow Control Valve

2.1 Nuclear Service Cooling Water System

System overflow is prevented by a FCV (18"), and an orifice is provided at the downstream of the heat exchanger to avoid cavitation due to excessive pressure drop through a FCV, and to meet the flow rate through each flow line. The FCV is of a butterfly type, which is commonly used for modulating in the opening angle range of 20° ~ 70°, because in general it has an equal percentage nature in this range as shown in Figure 1.

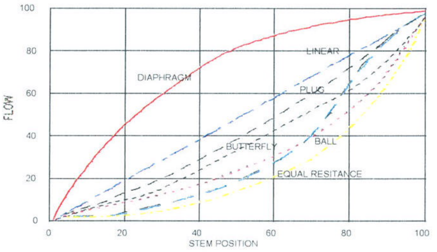

Fig. 1 Inherent flow characteristic curve of the valve

2.2 Cavitation by Pressure Drop

To calculate the pressure drop through the FCV, Flow series, a system sizing computer program, was used. The pressure loss charged by the FCV was calculated based on the conditions of low low water level(LLWL) and high high water level(HHWL), and it was evaluated to determine whether or not cavitation occurred at this pressure drop. The results are as shown below.

Table 1 Evaluation result of cavitation for LLWL

Flow rate of sea water (gpm)	Pump Head (ft)	Required Head of Valve (psi)	Cavitation	Valve opening angle
15,000	156.8	31.31	Yes	44°
18,000	146.5	16.42	Yes	55°
21,000	-	-	-	-

Table 2 Evaluation result of cavitation for HHWL

Flow rate of sea water (gpm)	Pump Head (ft)	Required Head of Valve (psi)	Cavitation	Valve opening angle
15,000	156.8	41.87	Yes	41°
18,000	146.5	26.98	Yes	51°
21,000	135.1	9.75	Yes	65°

The result above shows that cavitation occurs at the pressure drop where the valve should be charged, in a manner dependent on the sea water flow rate and sea water level.

2.3 Erosion by Turbulent Flow

Damage of the valve disc and the body shows typical erosion, and it has a uniform direction as shown in Figure 2.

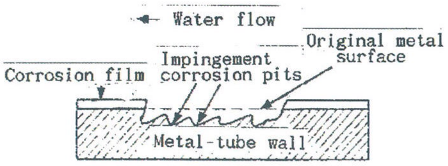

Fig. 2 Erosion due to flow velocity

This phenomenon is caused by the fact that wear occurs on the metal surface due to the serious turbulent flow of the fluid, and the flow velocity varies more rapidly as the FCV operates in a state of partial opening at around 65% during operation. It is assumed that the mixed coarse sand presents a more serious environmental factor in terms of the likelihood of erosion.

3. Design Improvement

3.1 Change of valve material

Although the present valve material, Monel, has superior corrosion resistance and relatively excellent erosion resistance against sea water, the erosion speed increases rapidly when solid particles such as sand are included in the fluid. To address this weakness, it is desirable to apply Super Stainless Steel (SR50A), which has excellent corrosion and erosion resistance, as the valve material. Components that affect erosion resistance are Cr, Mo and N. As SR50A includes 22～24% Cr, 6.0～6.8% Mo, and 0.21～0.32% N, it can be assumed to have much better excellent erosion resistance compared with Al-Bronze and 304 Stainless Steel. SR50A has excellent corrosion resistance against sea water to the same extent as Monel, and its mechanical characteristics are much more superior than those of Monel and Al-Bronze. (Refer to Table 3)

Table 3 Mechanical properties of SR50A, Monel and Al-Bronze

Description	SR50A (ASTM A743 CK35MN)	Monel (N04400)	Al-Bronze (ASME SB148 C95200)
Tensile strength (ksi)	min. 83	min. 70	min. 65
Yield strength (ksi)	min. 41	min. 25	min. 25
Hardness (HB)	-	-	min. 110
Elongation	min. 35%	min. 35%	min. 20%

3.2 Change in Valve and Orifice Sizes

The plan suggested is that the valve size be increased to 24" to mitigate the high velocity through the valve, while the required head be decreased so as not to generate cavitation at the valve, and the orifices installed at downstream of the heat exchanger and the cooler of each flow path additionally charge the reduced head. The pressure drop that the orifices should additionally charge based on the pressure loss appropriate to the suitable opening angle (65°) as reviewed above are as follows.

Table 4 Calculation result of Additional requested △P at orifice

Sea water level	Flow rate (gpm)	Flow control valve		Additional requested △P(psi) at orifice
		Requested △P(psi)	△P(psi) at opening angle 65°	
LLWL (54.33ft)	15,000	31.31	5.53	25.78
	18,000	16.42	7.97	8.45
	21,000	-	-	-
HHWL (79.75ft)	15,000	41.87	5.53	36.34
	18,000	26.98	7.97	19.01
	21,000	9.75	6.22	3.53

4. Conclusions

This study describes the reasons for valve damage and the plan to address these reasons by reviewing the design data of the NSCW System and the FCV, analyzing the operating condition, and evaluating to determine whether or not cavitation occurs at the pressure drop that the valve charges. The results indicate that it is desirable to replace valve material with SR50A, which can endure in sea water that includes coarse sands and which has excellent corrosion and erosion resistance, to increase the valve size to 24" from 18" to mitigate the high flow velocity, and finally to decrease △P of the valve by increasing △P that the orifice charges at the upstream of the valve.

References

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