Transactions of the 15th International Conference on
Structural Mechanics in Reactor Technology (SMiRT-15)
Seoul, Korea, August 15-20, 1999

Fatigue Analysis of Modified Main Steam Isolation Valve for Yonggwang Nuclear Units 1 & 2

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ABSTRACT

In April 1993, Kori Unit 4 that is the same type of nuclear power Yonggwang Units 1&2 had experienced unplanned shutdown caused by closing of MSIV during normal operation. The result of inspection to MSIV showed that the direct cause of the valve closing was a break of the valve stem. To prevent this problem for Yonggwang Units 1&2, the design in valve was modified from the thermal shrink assembly to the integral form assembly with smooth rounding shape. In this study, a fatigue analysis was performed to assure the integrity of the modified MSIV.

The scope is composed of the stress analysis, the material strength evaluation, the estimation of fatigue limit, the generation of S-N curve, and the lifetime evaluation of the modified MSIV. The result indicated that the fatigue life of the MSIV for Yonggwang Units 1&2 exceeded the design life(40 years).

1. INTRODUCTION

Main steam system(MSS) for Yonggwang Units 1&2 is convey Steam from the steam generators to the high pressure turbine for power generation(See Fig.1). MSS consists of the main steam piping, main steam isolation valves, main steam safety valves, power operated relief valves, etc. The main steam piping is designed for 1185psig and 600°F. Three 32-inch nominal size MSIVs(See Fig.2) are provided, one in each main steam line penetrating the containment. In April 1993, Kori Unit 4 that is the same type of nuclear power plant as Yonggwang Units 1&2 has experienced unplanned shutdown caused by closing of MSIV during normal operation. The result of inspection to MSIV showed that the direct cause of MSIV closing was a break of the valve stem(See Ref.1). D.Y.chung had studied " the fatigue lifetime evaluation of MSIV for Kori NPP Unit 4" related to this problem(See Ref.2). To prevent this problem for Yonggwang Units 1&2, the design in valves stem was modified. In this paper we perform the fatigue analysis based on the modified MSIV stem. The purpose of this study is to confirm the integrity of the modified MSIV stem for design lifetime.

2. THE DAMAGE MECHANISM OF MSIV STEM AND DESIGN MODIFICATION

2.1 The Crack Initiation

The MSIV are tested prior to start-up operation and during each refueling shutdown. Closure times under no-flow and no- load conditions are verified at five seconds or less. As those tests have continuously performed, so the crack at MSIV stem may be initiated by impact load. Also, it can be not excluded that the crack initiation is resulted from the manufacturing defect at MSIV stem (See Fig.2)

2.2 The Crack Growth And Rupture

The back seat ring for the original MSIV is assembled by thermal shrinkage on the lower part of MSIV stem (small diameter) beneath the upper part of MSIV stem (large diameter). When the working loads are forced on MSIV stem during the normal operation, there is the notch at the interface surface between the upper part of MSIV stem and the back seat ring)(See Fig.4). Thus, the growth of crack at this notch is progressed slowly by fatigue and finally MSIV stem had been ruptured abruptly.

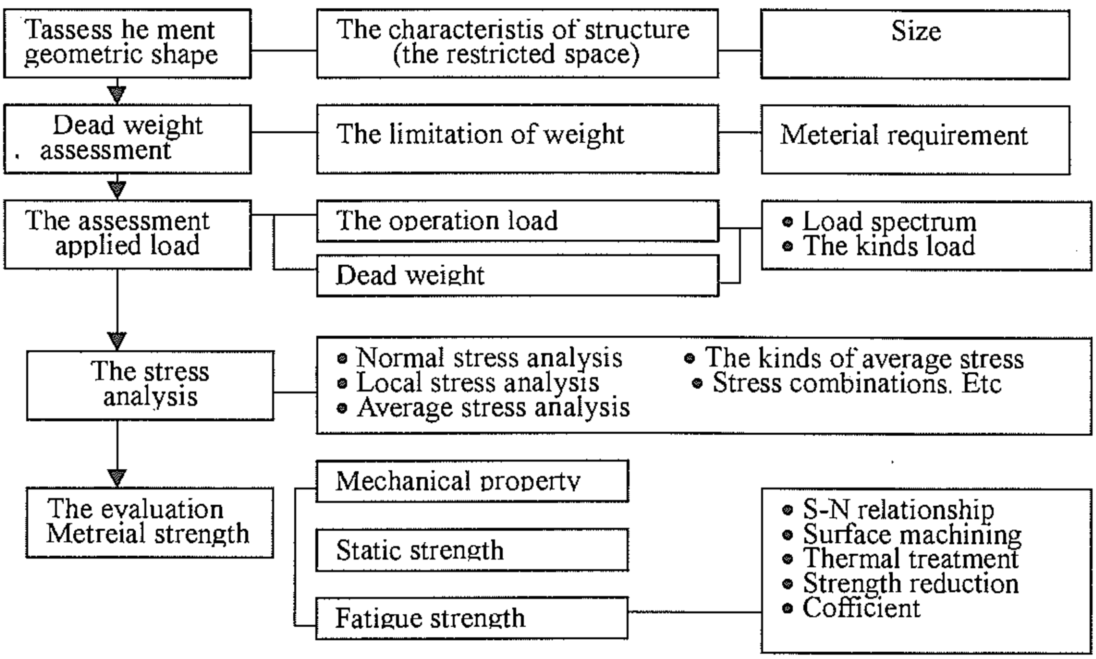
2.3 Design Modification(Countmeasure)

There are notches in the general structures. The original MSIV stem has the notch of knife type at the interface surface between back seat ring and the upper part of stem during the plant operation. To prevent this problem for Yonggwang Units 1 & 2, the design in valve was modified from the thermal shrink assembly to the integral form assembly with smooth rounding shape(See Fig .3). This kind of design change makes the stress concentration decreased.

3. FATIGUE ANALYSIS OF THE MODIFIED MSIV

3.1 Fatigue Analysis Process(See Table 1)

Table 1. Fatigue analysis process



3.2 Mechanical Property And The Structure Of MSIV

3.2.1 Mechanical Property

	Tensile strength(ksi)	Elongation ratio(%)	Hardness(HRC)
A-554 standards	Above102	Above13	Above31
CMTR	193(1333Mpa)	17	35(388BHN)

3.2.2 Structure(See Fig.1)

3.3 The Stress Analysis

The loads acted on MSIV Stem consist of the valve open force(tensile stress), the dead weight of valve stem and disc(tensile stress), the steam pressure force (compressure stress), the bending force by the fluid flow at 90%, the vibration load and impact load by the fast closing of MSIV. The mean stress is the combination of the tensile stress and the compressive stress, and the variation stress is related to the vibration load. The impact load has a little effect on fatigue crack growth, but is only related to the crack initiation. Thus we don't consider this load in the process of fatigue analysis.

3.3.1 The Mean Stress

We calculated the applied load(stress) at 90% power and 100% power (See ref.2). Each stress is summarized at the table 2

Table 2 . The applied stresses Unit : Mpa

Operation power	Valve operation force	Dead weight	Bending force	Stress pressure force	Mean stress
90%	92.72	1.1	333.5	6.3	420
100%	154.5	1.1	0	6.3	149.4

Also, we can calculate the mean stress as using equation (1).

$$Sm = So + Sd = Sb - Sp \qquad (1)$$

Where Sm : average stress, So : valve open force(stress), Sd : dead weight(stress), Sb : bending force(stress), and Sp : steam pressure force(stress)
The calculated result is arranged at the Table 2.

3.3.2 The Vibration Stress(Force)

When there is the geometric discontinuity in flow field which is the same type of the cavity, the flow of fluid is separated. The flow separation makes a self-sustaining oscillation occurred near the geometric discontinuity. The cause of excessive vibration of MSIV in the Yonggwang nuclear power plant #1 & 2 is presummed to the self-sustaining oscillation. In the experiments of self-sustaining oscillation, the Strouhal No. can be written as the function of the length(L) to the depth(w) of the cavity. If the ratio number(L/W) is 3.6, the

Strouhal No. is 1.1 for Yongwang Units 1&2(See Ref.2). Also the dimensionless Strouhal No. is the function of the fluid speed and cavity length and the fluctuating pressure frequency of fluid flow.
The calculated frequency value(270Hz) during power operation is approximately similiar to the frequency value(250Hz) of "pipe vibrations analysis of the load follow reseach report for Kori #3,4 & YGN #1,2".
The highest vibration is 12 μm at 100% and is 18 μm at 90%(The vibration value of Kori NPP #4 is similiar to Yonggwang NPP #1,2). We can convert the displacement of vibration to the acceleration
Also, we can represent the vibration force as following

Power	Vibration force	Vibration stress
90%	0.0223MN	4.13Mpa
100%	0.0184MN	3.41Mpa

3.4 The Standard Fatigue Limit(S_f)

When the bending force is acted on the notchless and highly polished steel, fatigue limit can be calculated based on the ultimate strength and hardness as the following

$Sf = 0.5Su$ for $Su \leq 1400MPa$ (2)

$Sf = 700$ MPa for $Su \geq 1400MPa$

Since the ultimate strength of the valve stem is 1333MPa, The fatigue limit is 666.5MPa

$Sf = 1.75$ BHN MPa for $BHN \leq 400$ (3)

$Sf = 700$ MPa for $BHN \geq 400$

If the hardness(BHN) of the valve stem is 333, the fatigue limit shall be 679MPa. Therefore, the standard fatigue limit could be observed to be 666.6MPa in the Yonggwang NPP Units 1&2

3.5 Correction Of The Fatigue Standard Limit (S_f')

Generally, fatigue limit is dependent on the size effect, the kind of loads, the corrosive surroundings, the mean stress, and the notch, etc. Therefore, fatigue limit should be revised by these parameters

$S_f' = (S_f \times C_s \times C_l \times C_d) / K_f$ (4)

3.5.1 The Surface Machining Effect(Cs)

In considering the fact that fatigue breaks happens mainly in the surface, the surface condition is an important design factor in the structure being worked with the repeated load. The modified MSIV stem is commercial polished and the surface factor is 0.85(See Fig.6).

3.5.2 The Size Effects Of The Specimen(C_d)

In general, The large specimens have the large bulk, and contains more the defects on surface or in the inside than the small ones. The factor of specimen size effects is calculated as follows.

$C_d = 1.0$: $d \leq 8mm$ (5)

$C_d = 1.189d^{-0.097}$: 8mm $\leq$ d $\leq$ 250mm

Since the diameter of the MSIV stem is 83mm, the C_d is estimated to 0.77.

3.5.3 The Load Effects(C_l)

The S- N curve is made under the rolling and bending loads. According to the result of the experiment, the limit fatigue of the axial load is 15% smaller than that of the rolling and bending force and the torsion factor C_l is known to 0.577. Although the MSIV is mostly working to be under axial forces, the bending force is also added to the MSIV at 90%. So the C_l is calculated to 0.85.

3.5.4 Notch Effects

In the fatigue analysis of the structure, the notch effect is a primary factor. There is necessarily the notch in most of structure. Considering the notch effect, we can use the stress concentration factor(K_t) and the fatigue notch factor(K_f). First, we consider the section B-B between the back seat ring and the lower stem (dia : 83mm)(See Fig.5). The back seat ring of the modified MSIV(dia : 114.5mm) is stepped at the screw part of stem (dia : 83mm)with the smooth rounding shape (radius : 4mm). We can find the stress concentration factor(K_t) at notch factor diagram when the D/d(114.5/83) and d/r(83/4) are given. K_t is read by 2.22. To evaluate how the actual notch has an effect on the fatigue, it is need to use the fatigue notch factor(K_f). K_f is dependent on the material type. K_f is calculated by using equation (6) for the modified MSIV stem and K_f is equal to 2.2.

$$K_f = 1+(K_t-1)/(1+a/r) \qquad (6)$$

Where a is 0.0635mm and r is 4mm.

Second, we review the section A-A between the back seat ring and the upper stem(dia : 10mm)(See Fig.5). The stress concentration coefficient(Kt) is determined by D/d(114.5/101.6 =1.13) and r/d(4.6/19.6=0.14) and Kt is 2.0. Also, K_f is calculated by using equation (6) and is equal to 1.968

3.5.5 Temperature Effects

If the main steam temperature is about 300℃ in steel pipe, the temperature effect could be neglected(See Ref. 3).

3.5.6 The Correction Of fatigue Limit

The limit fatigue of the standard MSIV specimen was given to 666.5 MPa. If it is considered the various correction factor, fatigue limit is corrected by using the equation(4).

1) Stem section B-B (See Fig.5)

S_f' =(666.5/2.2)×(0.85×0.85×0.77)Mpa=168.54MPa

2) Stem section A-A (See Fig.5)

S_f'=(666.5/1.968)×(0.85×0.85×0.77)Mpa=186.7MPa

3.6 Generation Of The S-N Curve

Considering the limit fatigue(666.5MPa) inferred from the tensile strength and the fracture strength(σ_f') which is tested in one cycle operation, we can obtain the S-N curve for the un-notched smooth specimen. But we should correct the S-N curve for a given material considering the notch effect/ the surface maching / working loads / the mean stress, etc.

The material contant σ_f' is generally obtained by carrying out experiments, but we can obtain it by the following method. Extending the straight line which connect one point(0.9Su, N=10^3) with other point(S_f = 666MPa, N= 10^6) , σ_f' is obtained at N=1

Considering the mean stress and the elastic area only, Marson's Slope curve is revised to Basquin's Equation as the following.

$Sa = (\sigma_f' - Sm)(2N_f')^b$ (7)

Sa : the variation stress, σ_f' : the true fracture stress(1200.23MPa ; See Ref.6),

b : - 0.142 for stem section B-B, -0.1347 for stem section A-A

Therefore, the modified S - N curve is shown in Fig 7

3.7 The Life-Time Of The Modified MSIV Stem

We can predict the lifetime of the modified MSIV stem using the equation(7).

$3.41=(1200.23\text{MPa}-149.4)(2N_f)^b$ (7)′

Solving the equation (7)′, we obtain $2N_f=1.75\times10^{11}$cycle for stem section B-B and $2N_f=1.85\times10^{11}$cycle for stem section A-A each other.

This fatigue life time is exceeded the design life time(32 EFPY)

4. CONCLUSION

The crack at the notch part between the back seat ring and the upper part of stem which is structually weakened is initiated by impact load at closing of valve and by the defect of the manufacturing process. The crack is grown slowly by fatigue and MSIV stem is broken abruptly by the external force. To present this problem, MSIV stem for Yonggwang NPP#1,2 was modified to integral form assembly with smooth round shape. Fatigue analysis was performed to assure the integrity of the modified MSIV according to fatigue analysis process. The result indicated that fatigue life time of the modified MSIV for Yonggwang is longer than design life time.

5. REFERENCES

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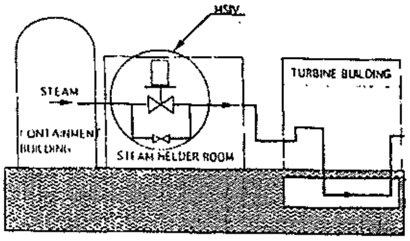

Fig1. Main steam piping and MSIV

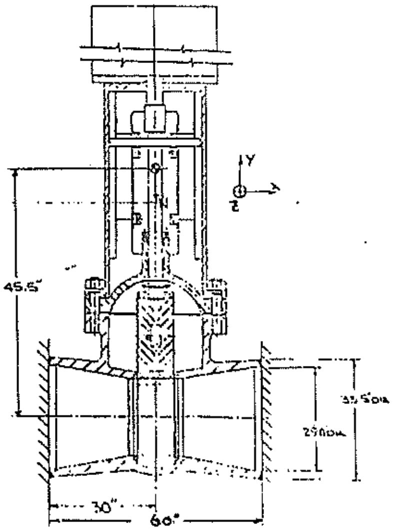

Fig2. Main steam Isolation valve

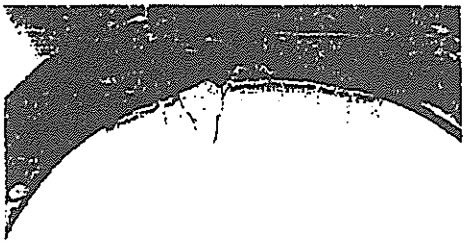

Fig3. The rupture surface of MSIV steam

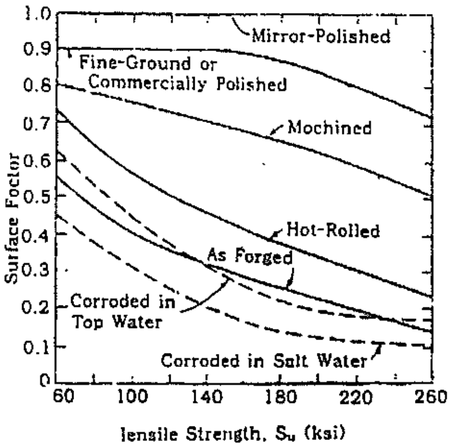

Fig6. The surface maching coefficient

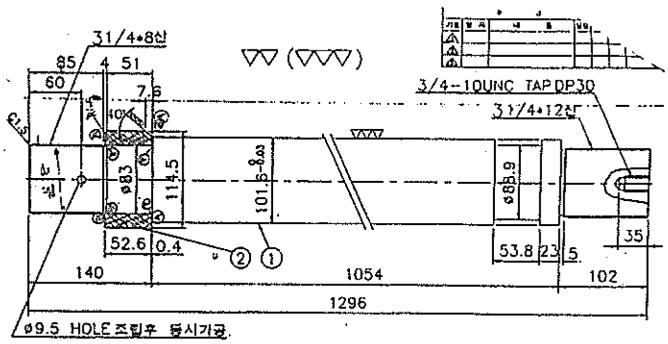

Fig4. The original MSIV stem

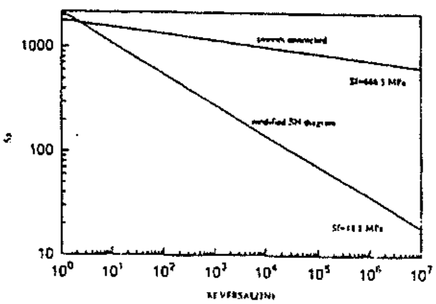

Fig7. Modified S-N curve

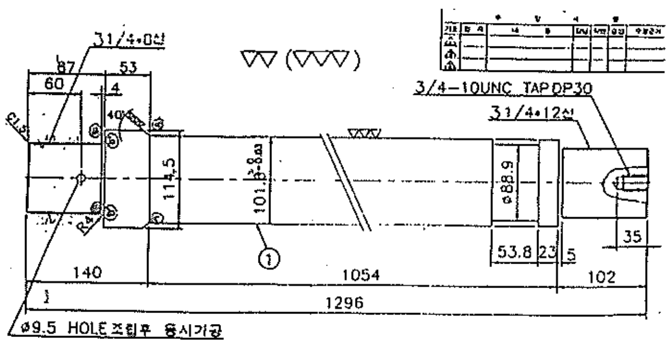

Fig5. The modified MSIV stem