The Root Cause of The Thermal Sleeve Loose In KSNP

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1. Introduction

The components or parts of nuclear power plants can be aggravated or damaged by various mechanisms. One of which is thermal sleeve(T/S) in SI nozzle loosened by Flow-Induced Vibration (FIV). Even the FIV can be categorized into Flow-Elastic Instability, Turbulent Excitation, Vortex shedding Vibration, Acoustic Resonance Vibration, Leakage Flow-Induced Vibration, etc, these mechanisms have their own specific features such as flow conditions, geometry layout, flow regime. Recently, T/S in the Safety Injection Nozzle of KSNP had been loosened. The cause of the loose T/S has not been identified yet. Therefore, a lot of relevant articles and documents, operating experiences, and data from KSNP thermal sleeves such as relevant geometry, thickness, change of thickness before and after explosion, and finally design and material change from Palo Verde to Youngkwang and Ulchin #5,6 had thoroughly been investigated to find out the root cause of the loose thermal sleeves. The root cause of the loose T/S may be the insufficient explosion force because the T/S design was changed by two times. One is the deepened groove and the other is material. However the amount of explosive and explosion method were same as the previous one. Even though the removal of T/S from the KSNP would not endanger NPP safety, it is worthy to identify the root cause of the loose T/S and its relevant mechanisms. Therefore in this study, a set of experiments had been performed to find out the related FIV mechanisms such as Leakage Flow-Induced Vibration.

2. The Root Cause of The Loose Thermal Sleeve

2.1 The Analysis of the design changes in KSNP #5,6

Since the T/S in YGN and UCN #3,4 were in solid supported state, it is worthy to check the design change between YGN #3,4 and #5,6. Through this scrutinized review process, a lot of things were found. One of them is the groove depth change from 2.48mm to 3.3mm. This deepened groove was recommended after the experience of the T/S loose of Palo Verde NPP #1,2,3. By the recommendation, T/S of the KSNP YGN #3, 4 and UCN #3,4 were designed and installed. There was no problem. However, in T/S of KSNP YGN #5,6 and UCN #5,6 with a deepened groove, In-690 instead of In-600 was used. All of the T/S except one was in trouble(loosened). From the basic knowledge of the solid mechanics and data from Doosan Heavy Industry, the explosion energy should be enhanced by 2.4 times of that of the original design for the groove depth and the material change(Since the strain energy is proportional to ε^2, the depth change from the 2.48mm to 3.3mm requires 1.7 times of explosion energy. Also the material change from In-600 to In-690 additionally needs about 1.4 times of explosion energy).

2.2 The Comparison of explosive energy between #3,4 and #5,6

As mentioned before the consequentive design change of groove depth and material totally needs(1.7 ∗ 1.4≒2.4) times of the explosion energy of initial design. However, the amount of explosive and the method of explosion were same as previous ones. The additional energy for the groove depth change could be covered by the margin of the explosion energy(30~70% margin). So the deepened groove helps to prevent the T/S from loosening. That is why T/S of YGN and UCN #3,4 are solid support state. Additional material change needs more explosion energy. However, the margin of the explosion energy may not be enough to cover additional explosion energy of 150%. That example cases would be KSNP YGN and UCN #5,6. Then why was T/S 1A, one of the T/S in KSNP YGN #5, so solid supported? That can statistically be explained as Figure 1. If the explosion energy is slightly not enough to the required energy of T/S support, a large portion of T/S are loose, though a few of them are solid supported(left). However if the explosion force is quite enough, the probability of the loosening is almost zero(right).

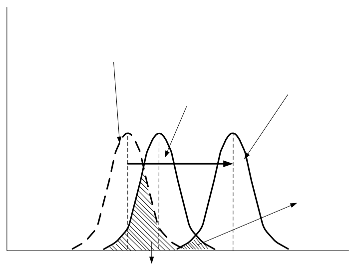

Figure 1. Probability of T/S support versus the explosion energy

2.3 Acceptance Criteria and Quality Control of T/S

As shown in the table the deviation of the measured value is quite so large that the acceptance criteria of the explosive expansion which is G–(D+2T)<0.005G should be carefully interpreted and re-established by statistical and experimental procedure. The margin in the criteria is not the allowance of the gap between the T/S and SI Nozzle but the tolerance of error of the manufacturing and measuring. Therefore the QC of the T/S and SI Nozzle manufacturing and installation should be strengthened to narrow the tolerance band. That can guarantee the reliability and solid support of the T/S. Also the thinning of T/S by the explosion(enlarging) should be considered. That means that T(thickness before explosion) should be replaced by t(thickness after explosion) when the acceptance criteria is applied. The t can be easily calculated by the theory of material conservation. This assertion was verfied by the comparison between the theoretical value and measured.

NPP	No	Nozzle I.D. (G)	T/S I.D. (D)	T/S Thickness (T)	Gap [G-(D+2T)]	State
YG #3	1A	311.67	303.48	4.50	-0.81	Supported
	1B	311.76	303.21	4.5	-0.45	〃
	2A	311.68	303.3	4.25	-0.21	〃
	2B	311.66	302.95	4.25	+0.21	〃
YG #4	1A	311.67	303.55	4.5	-0.88	〃
	1B	312.13	303.50	4.15	0.33	〃
	2A	312.18	303.50	4.31	0.06	〃
	2B	311.82	303.37	4.14	0.17	〃
YG #5	1A	311.68	303.10	4.39	-0.2	Removed
	1B	311.74	302.41	4.37	0.59	Loosened
	2A	311.76	302.40	4.44	0.48	〃
	2B	311.76	302.56	4.43	0.34	〃
YG #6	1A	311.66	302.69	4.44	0.09	〃
	1B	311.70	302.52	4.38	0.42	〃
	2A	311.66	302.60	4.44	0.18	〃
	2B	311.64	302.95	4.41	-0.13	〃

Table 1. The measured data of T/S in KSNP(YG # 3,4,5,6)

2.4 The Experiment Leakage Flow-Induced Vibration of T/S

As mentioned before, the supporting of T/S may not be sufficient. Therefore the flow force may interact with the T/S. The phenomena is known as FIV. There are lot of FIV mechanisms. So this experiment will be focused to find out the mechanism that causes T/S to loosen. The most probable mechanisms are Leakage Flow-Induced Vibration and Vortex Shedding Vibration. So, the first experiment was performed for LFIV. Generally, in the presence of very narrow flow channels surrounded by flexible structures, a phenomenon called Leakage Flow-Induced Vibration may occur. As shown in the Figure 2, Thermal Sleeve Test Facility simulated YGN and UCN # 5,6, consists of test section and test loop.

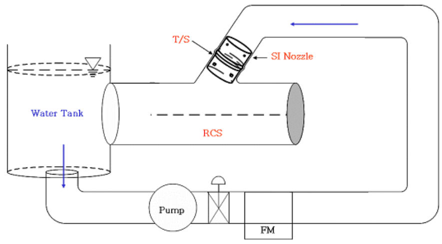

Figure 2. Test loop and test section

The test section, which was manufactured 3:1 in radius and 1:1 in length has three changeable different gaps. which are 0.05mm, 0.25mm, and 0.5mm, respectively. And Linear Laser Vibrometer(Bruel & Kjaer Type 8329) was utilized for monitoring the T/S vibration. The flow was varied up to 0.061m³/s which is equivalent to the velocity of 5m/s. The flow rate(velocity) is same as that of maximum of KSNP. The experiment results show that there was no any sign of vibration except the some signal fluctuations by pump operation(Table 2)

Gap	0.1mm	0.25mm	0.5mm
Vibration	X	X	X
Velocity	Noise	0.8μm/s	1.5μm/s
Leakage flow	None	small	large

Table 2. T/S vibration, velocity, leakage flow(full flow)

4. Conclusion

Through the thorough review of relevant document, data, and experiment, it was finally concluded follows. The T/S design was changed two times from the original one(Palo Verde). These design changes require more explosion energy(about more than 2 times). However, the amount of explosive and the explosion method were same as previous ones. Therefore, the explosion energy was not enough to solidly support the T/S. That resulted in the T/S susceptibility to the vibration of the weak force induced by flow. Also the faulty acceptance criteria and loose quality control practice prevent the loose contact thermal sleeve being from screened out. Finally to find out the flow force to cause the T/S loose, a set of LFIV experiment was preformed. The experiment result shows that LFIV may not be the root cause of the loose T/S.

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