The Design Concept of a Steam Generator Cassette Mock-Up for ISI of Helical Tubes in SMART Steam Generator

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1. Introduction

The SMART reactor steam generator is composed of 8 Steam Generator Cassettes (SGC) and each the SGC has a once-through-type, helical-coil-tube bundle structure using INCONEL alloy 690 tubes. The SGC installed in reactor vessel is a kind of heat exchanger made of INCONEL alloy 690 tubes.

This paper introduces the design concepts of an SGC mock-up for the test probe insertion ability of In-Service Inspection (ISI). The backgrounds of selected tube material, size and tube composition are described.

2. SMART SGC mock-up tubes

In this section, some of the tube materials and the manufacturing specifications for the SGC mock-up are described.

2.1 Tube Materials

The SMART reactor SGC mock-up is a much more similar design to the real steam generator, therefore it is used to the same material which is INCONEL alloy 690 to simulate the mechanical properties of the real SGC tubes.

The material Alloy 690 belongs to ASME Spec. SB-163, UNS N06690, and it can be thermally treated to increase stress-corrosion-cracking (SCC) resistance.

Thermal treatment (TT) producing semicontinuous intergranular carbide was reported to be beneficial to SCC resistance in primary water[2]. Therefore, alloy 690TT is being used as a steam generator tubing for new and replaced steam generators in nuclear power plants. For life prediction and timely maintenance of a nuclear power plant, it is very important to identify the effect of environmental and mechanical parameters on the SCC process

The alloy 690 material chemical compositions are shown in Table I (ASME SB-163), and physical properties are shown in Table II.

Table I: Material Chemical Composition (%)

Nickel-chromium-iron alloy UNS N06690							
Ni	Cr	Fe	C	Si	Mn	S	Cu
58.0 (min.)	27 ~ 31	7 ~ 11	0.05 (max.)	0.5 (max.)	0.5 (max.)	0.015 (max.)	0.5 (max.)

Table II: Material Physical Properties[1)]

Contents	Unit	Value
Density	kg/m^3	8190
Melting Range	℃	1343 ~ 1377
Specific Heat	J/kg-℃	450
Electrical Resistivity	μΩ-m	1.148
Permeability @ 15.9kA/m		1.001
Young's Modulus	GPa	211
Poisson's Ratio		0.289

1) The Data from "Special Metal_INCONEL alloy 690, Material properties"

2.2 Tube Manufacturing Specifications

A real SG tube has a nuclear grade (high temperature, high pressure, radiation environments) treatment, therefore the specifications are quite strict compared to others such as restriction of chemical composition and thermal treatment, etc.

Added to the restrictions and thermal treatments are the increased prices of the tubes. However an SGC mock-up is used to perform an ISI test at room temperature and atmospheric environments, so it could be used to lower grade treatments (not necessary TT process in SGC mock-up), as shown in Table III.

Table III: SGC Mock-Up Tube Specifications

Contents		Unit	Value
0.2% Yield strength @20℃		MPa	276 (min.)
Tensile strength @20℃		MPa	586 (min.)
Oxides and Sulphides Ti-Carbonitrides			Non-restriction
Grain Size(ASTM No.)			5≤ X ≤ 8
Final bright annealing		℃	1070, 2 minutes ≤
Tensile test prior straightening		MPa	272
Tensile test after straightening		MPa	272
Long time thermal treatment		℃	Non-restriction
Intergranular corrosion test			Non-restriction
Surface roughness	Internal	μm	0.5 (max.)
	External	μm	1.0 (max.)

3. The Design Concept for a SMART SGC Mock-Up

In this section, some of the design concepts for the SGC mock-up are described.

3.1 SGC Mock-Up Sizing & Tube Composition

The SGC Mock-up design is much more simple structure than the real SGC structure. It consists of 6

rows which correspond to 1, 2, 9, 10, 16, and 17-row in the real SGC. The innermost tubes are 1 and 2-row and the outermost tubes are 16 and 17-row. Each row in the SGC mock-up has 3 tubes.

A test campaign to confirm the ISI test probe insertion ability on once-through-type long length helical coil tube was successfully carried out. It checked the repeatability and reproducibility of the test probe insertion test at a selected 3-bend radius.

Currently, the SMART SGC mock-up sizing (one cassette of eight) is as follows:

Number of helical rows : 6
Tube bending method :
3 rows in clockwise (#1, #9, #16)
3 rows in counterclockwise (#2, #10, #17)
Number of tubes per row : 3ea
Tubes number (Total) : 18ea
SGC Mock-up external diameter : about 1,300mm
SGC Mock-up overall height : about 1,600mm

The current design concept of the SMART SGC mock-up is shown in Fig 1.

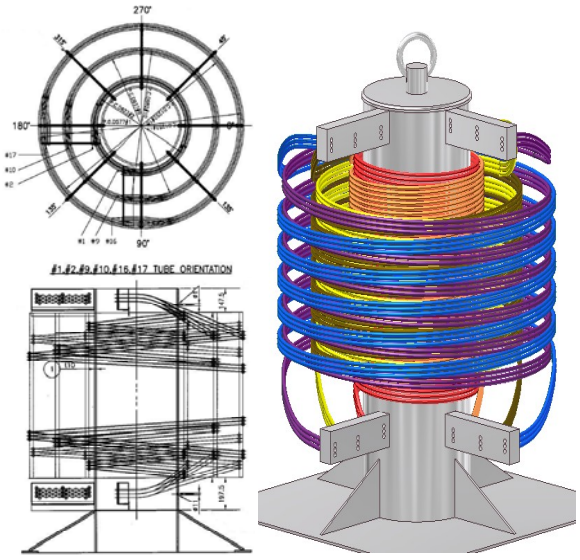

Fig. 1. SMART SGC mock-up concept design (overall)

3.2 SMART SGC In-Service Inspection: Preliminary Studies

In-Service Inspection (ISI) of the SMART SG tubing is a complex operation, owing to the severe technical specifications regarding flaw detection / sizing, the high inspection speed, and the unfavorable characteristics of the tubes, such as their long length, tortuous geometry (helical tubes with orthogonal bends), and associated friction.

The test probe insertion ability detects at 3 points of the external tube (one of three, the largest radius, #17), which are the upper, middle, and lower locations of the selected tube. The ISI test using the SGC mock-up is shown schematically in Figure 2.

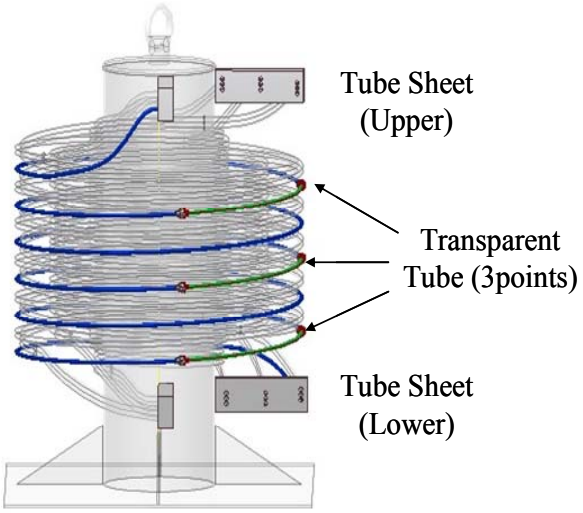

Fig. 2. SGC ISI detection point at the SGC mock-up

4. Conclusions

The Design concept of the SGC mock-up for ISI test of helical tubes is described. The differences of material specifications between the SGC mock-up tubes and the real SG tubes are explained. In a near future, an eddy current test probe is inserted in the helical tubes of the SGC mock-up for verifying the probe insertion ability.

REFERENCES

[1] L. Cinotti, C. V. Lombardi, L. E. Conway, Steam Generator of the International Reactor Innovative and Secure, Proceedings of ICONE10, Arlington, VA, April 14-18, 2002
[2] Was, G. S. and Lian, K., "Role of Carbides in Stress Corrosion Cracking of Alloy 600 and Controlled Purity Ni-16%Cr, 9%Fe in Primary Water at 360℃", Met. Trans. A Vol. 23A No.4, 1992, pp. 675-688.