Low Friction Sensor Cable for SMART Steam Generator In-Service Inspection

Yun Hang Choung [a*], DongOk Kim[a], Jin Seok Park [a], Won Jae Lee [a]
[a]*Korea Atomic Energy Research Institute, SMART Development Dept.*
1045 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Republic of Korea
[*]*Corresponding author: cyh@kaeri.re.kr*

1. Introduction

The integral reactor, SMART, has 8 identical Steam Generator (SG) units, which are located in the annulus formed by the reactor pressure vessel and core support barrel. Each SG unit is of once-through design, with a number of helically coiled tubes as shown in Fig. 1.

In the inspection of SG tube in Nuclear Power Plant (NPP), the Eddy Current Testing (ECT) probe plays an important role in detecting tube defects.

The helical type tubes adopted for SMART SG may have totally different figure from that of U-tubes which are used in typical NPP. Generally, the helical tube is difficult to inspect using a commercial ECT sensor because the friction force is exponentially increased as an inserted cable length, thus a new type of ECT sensor is needed for inspection integrity of SG tube in SMART.

Low friction sensor cable makes it possible to meet demands for finding small defects in helical coil type steam generator tube inspection.

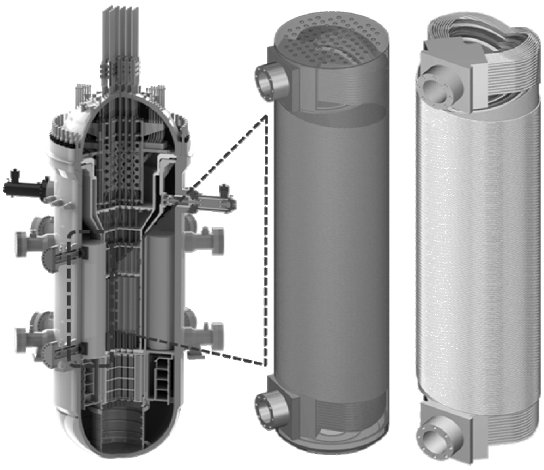


Fig. 1 SMART SG Design

This paper carried out a study on insertion ability of the sensor cable for the helically coiled tubes, including cable friction characteristics, to inspect of such tubes during SG In-Service Inspection (ISI).

2. SMART SG ISI Method

2.1 SG ISI Test Method

The SMART SG tubes are made of Alloy 690. The outer diameter is 17mm and the thickness is 2.5mm. The feature of SMART SG tube is helical type with around 600mm of innermost diameter and the tube full length is about 35m.

For SG ISI, the ECT sensor is inserted into the each SG tube, and it is the most difficult for the innermost one to be inserted into a tube as shown in Fig.2.

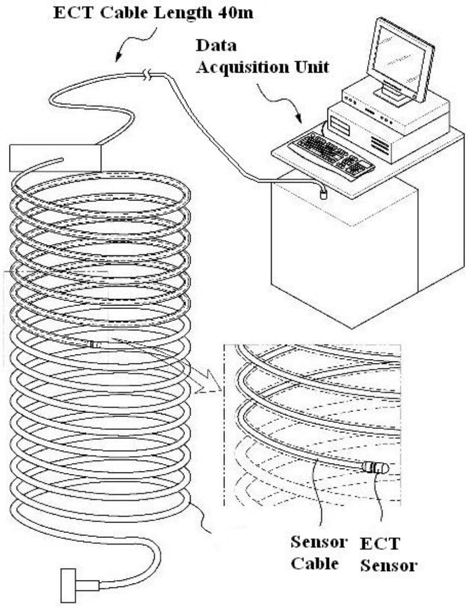


Fig. 2 SG ISI Test Method

2.2 Cable Insertion Test

When the commercial ECT sensor is inserted into a helical tube, the insertion force and the possible insertion length are as shown in Fig. 3. As the inserted cable length is increased, the insertion force is also exponentially increased.

As a result, a commercial sensor cable could be inserted about 10m by normal human power. It means a commercial sensor cable type is not appropriate for inspection of long length with helical type tube such as SMART SG tube.

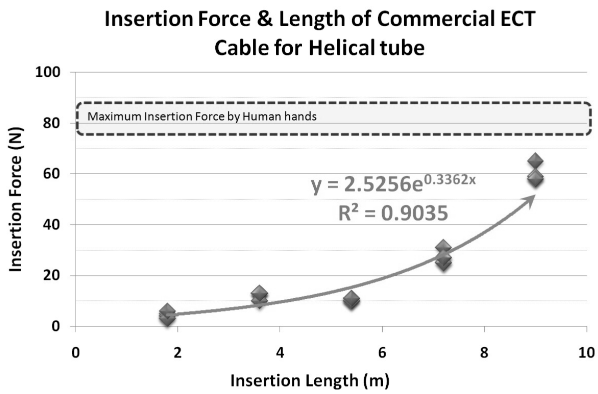


Fig. 3 Insertion force analysis for helical tube

3. Development of low friction sensor cable

The insertion force of the sensor cable should be decreased in order to perform an inspection for the full length of the SG tube. For decreasing the insertion force of the sensor cable, generally it could be used a method of reducing friction force by improving cable protection hose material or its shape

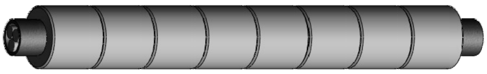
This section describes some of the design concepts for low friction sensor cable and friction test results.

3.1 Low friction Sensor Cable Design Concept

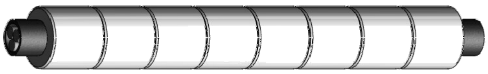
For the test of the method, this paper suggested two different types of cable protection hose concept as shown in Table I and Fig. 4, and measured coefficient of friction for the specimen of the cable concepts

Table I: Development cable concept specification

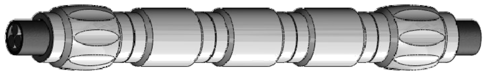
Test Tube	Acrylic Tube	Straight Tube
	Alloy600 Tube	Straight Tube
Test Specimen (Length 80mm)	(1) Nylon 6 (Commercial cable)	Sensor original material, Cylinder type O.D. Ø10.5mm
	(2) Teflon	Low friction material, Cylinder type O.D. Ø10.5mm
	(3) Teflon Shape	Low friction material, Low contact shape, O.D. Ø11.5mm



(1) Material: Nylon 6 / Cylinder Type



(2) Material: Teflon / Cylinder Type



(3) Material: Teflon / Low Contact Shape

Fig. 4 Development Cable IDEA Concept

3.2 Concept Cable Friction Test

The cable friction test is performed for calculating the friction coefficient using test apparatus as shown in Fig. 5. In the measuring friction, friction coefficient can be calculated by measuring the angle of friction for each cable specimen which is short length (80mm) cable samples. Thus, the friction coefficient of cable can be calculated as below,

$$W\sin\theta = \mu_s W\cos\theta,\quad \mu_s = \frac{W\sin\theta}{W\cos\theta},\quad \mu_s = \tan\theta,$$

$$\therefore \mu_s = \tan\theta = \frac{Height}{Length} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where, μ_s = Friction coefficient
$\boldsymbol{\theta}$ = Angle of friction (°)
H = Height as a gradient of test tube (mm)
L = Length to hinge (mm)

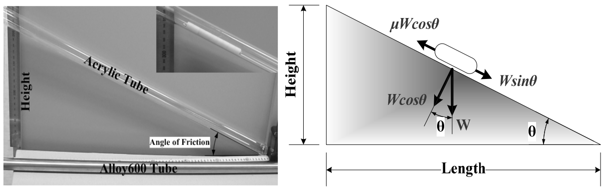


Fig. 5 Test method for measuring the friction coefficient

3.3 Friction Test Result

Fig. 6 shows the measured friction coefficient for each cable concept. The result is a bit different depending on test tubes (Acrylic / Alloy 600); however, it shows a reduction of friction of about 40% totally according to the change of cable protection hose material.

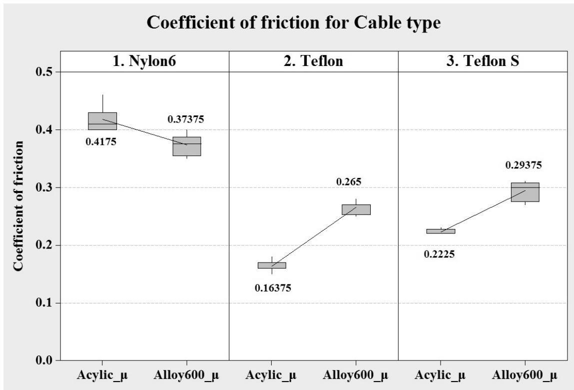


Fig. 6 Friction coefficient for concept cable specimens

4. Conclusions

In this paper, the cable friction tests are performed for a commercial cable and low friction sensor cable concept. The results of friction test show that the suggested concept cables improve the insertion ability as below,

1) Cable protection hose of low friction material
→ Improved insertion ability about 40% than commercial cable
2) Cable protection hose of low contact shape
→ No effect of improving the insertion ability.

According to the results, it is probably not suitable for inspecting SMART SG helical tubes to use the sliding friction type cable, although the insertion ability is improved

Consequently, for the inspection of SMART SG tube, it is necessary to apply another method which reduces friction force such as converting sliding friction into rolling friction. This will be reported in a separate article.

Acknowledgements

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