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# ECT Evaluation on Fretting Wear of Steam Generators in NPPs

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## ABSTRACT

It has been experienced that the fretting wear rate of CE-typed steam generator(SG) is usually higher than that of other models in domestic NPPs. The anti-vibration structure(AVS) of this model consisted of bat wings(BW), vertical strips(VS), and horizontal strips(HS) in the upper bundle region where there are no tube support plates(TSP). Wear location in this model is generally confined within the upper region of the stay cylinder where flow velocity and operation temperature are relatively high. It is necessary, therefore, to investigate the alignment condition between tube and AVS at the wear location and to understand completely the structural factors in the process of fretting wear of this SG model. An eddy current test(ECT) method using MRPC(motorized rotating pancake coil) with low frequency that makes it possible to interpret simultaneously the contacted or aligned condition between tube and AVS at the wear area was introduced in this study. ECT evaluation on the behavior and the structural factors of fretting wear of SG tubes using this method was performed for 35 wear tubes of two plants having the same SG model. From this ECT signal evaluation, it was found for all the 35 tubes that the alignment condition of every tube and AVS strip at the wear location was not normal, in other words, the alignment between the two structures was slightly distorted so that the gap between the two structures did not maintain a constant distance. This abnormal alignment condition resulted in an appearance of an inclined wear surface for most of the wear tubes. Therefore, it can be concluded that the main cause of fretting wear in this SG model is high local stress acting against the tube surface at the edge of the AVS strip under flow-induced vibration.

**KEY WORDS :** fretting wear, steam generator tube, anti-vibration structure, eddy current test, MRPC C-scan, PWR, alignment condition, edge effect, high local stress.

## INTRODUCTION

It is well known that the occurrence of fretting wear of the SG tubes in nuclear power plants is mainly caused by the repetitive impact and the sliding motion between the tube surface and AVS under flow-induced vibration. Fretting wear of a SG tube is an inevitable degradation mode for all of the SG models in PWRs, but the wear rate and appearance could be varied with the characteristics of the arrangement between the tube and AVS in each model.

It has been experienced that fretting wear rate of CE-typed SGs is usually higher than that of other models in domestic NPPs. AVS of this model consisted of BW, VS, and HS in the upper bundle region where there are no tube support plates[1]. As shown in Fig. 1, wear location in this model is generally confined within the area of the tube row No.‘s 22 to 40 where flow velocity and operation temperature are relatively high[2].

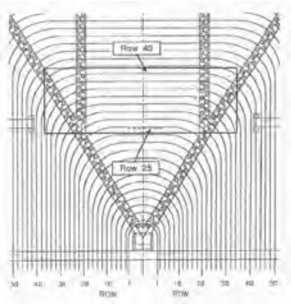

Fig. 1 Potential area of tube wear

Evaluation on SG tube wear is generally limited to tube itself using eddy current test data, and wear tubes having above 40% of wear depth are plugged. However, an investigation into the relationship between wear and the alignment condition of both the tube and AVS as well as the wear of the tube surface is required to understand the structural factors in the process of fretting wear of this SG model.

An eddy current test method using MRPC with low frequency that makes it possible to interpret simultaneously the contacted or aligned condition between the tube and AVS at the wear area was introduced in this study. ECT evaluation on the behavior and the structural factors of fretting wear of SG tubes using this method was performed for 35 tubes(44 wear events) from two plants A and B having the same SG model. ECT signal analysis is carried out using 1st-ISI data for plant A and 5th-ISI data for plant B.

## DESIGN OF AVS COMPONENTS

In order to understand completely the fretting wear of this SG model, it is necessary to describe briefly the structural characteristic of AVS. Fig. 2 is a schematic of AVS components. AVS components are consisted of BW, VS, and HS and are positioned at the upper tube bundle of the SG where there are no TSP. As shown in Fig. 2-(a), BWs are designed as a V-shaped wing, and each one of the two BWs is located along the center line of the tube bent part both in the hot- and cold-leg side. 4 VSs are connected vertically with the BWs. Fig. 2-(b) is a schematic of the construction between the VS and HS, and shows the tube arrangement in this structure. Each strip of BW and VS are designed to have two lines of parallel hole with the longitudinal direction of strip, thus narrow strip side(N-side) and wide strip side(W-side) are formed around each hole as shown in Fig. 3.

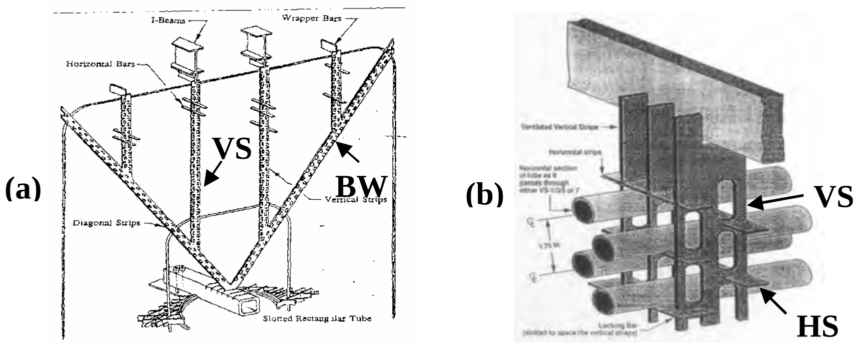


Fig. 2 Schematic of anti-vibration structures. ; (a) BW and VS, (b) VS and HS

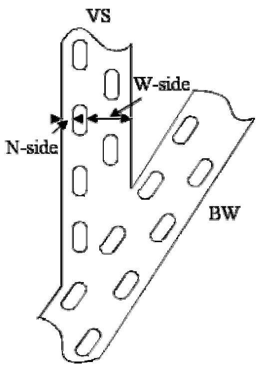


Fig. 3 Structure of bat wing and vertical strips.

## CHARACTERISTIC OF WEAR APPEARANCE

As shown in Fig. 4 to 6, one set of the two MRPC C-scan displays in each ECT evaluation result for every wear tube is primarily presented, of which the upper C-scan display indicates the wear signal itself of the tube surface and the lower one shows the signal of the adjacent AVS strip to the tube. The signal amplitude in the upper C-scan display represents the relative wear depth of the tube surface, while the difference in amplitude of the lower C-scan display indicates the alignment condition between tube surface and AVS strip. That is, high amplitude in the lower C-scan display means a close contact between two components, on the contrary, low amplitude indicates that the gap distance between the two components is maintained relatively well. The sink part of the amplitude in each lower C-scan corresponds to the position of holes within the AVS strip of Fig. 3. Signal analysis using this data gives us basic information about the alignment condition between the two components and the degree of the proximity of the AVS to the surface of the wear tube. From this investigation, characteristic of wear appearance can be classified into the following groups.

### One–sided wear

One-sided wear means the occurrence of wear at one side of the tube surface facing the adjacent AVS strip. Fig. 4 shows the typical one-sided wear of the tube surface. Most of the wear appearance of plant A operated for 1 cycle have one-sided wear characteristic. Fig. 4-(a) is a case of severe wear having 49% of wear depth and represents wear occurrence at the contact point between n-side of the AVS strip and tube surface. In this figure, it can be found that the signal amplitude at n-side of the AVS corresponding to the tube wear area is very high and amplitude decreases gradually to the w-side of the AVS strip. This means that the two components are not parallell with each other, that is, they are contacted closely at the n-side of the AVS or the n-side edge of the AVS strip is penetrated deeply into the tube surface. Fig. 4-(b) is also a one-sided wear, but there is a difference in appearance from Fig. 4-(a). It can be seen in this figure that there is no wear at the opposite side to the wear surface in spite of a high amplitude of the AVS strip at this side. In this case, a uniform height of high amplitude at this side indicates that the tube and AVS strip have good parallell alignment although they might be contacted closely with each other, therefore, wear due to the inclined alignment between the two components did not occur under this condition.

From these results, the following important information can be obtained.

i) A slight distortion between the tube and AVS strip affects directly the wear of tube surface,

ii) This abnomal arrangement of the two components results in local high stress at a contact point between the edge of the AVS strip and tube surface and a rapid wear under the FIV condition.

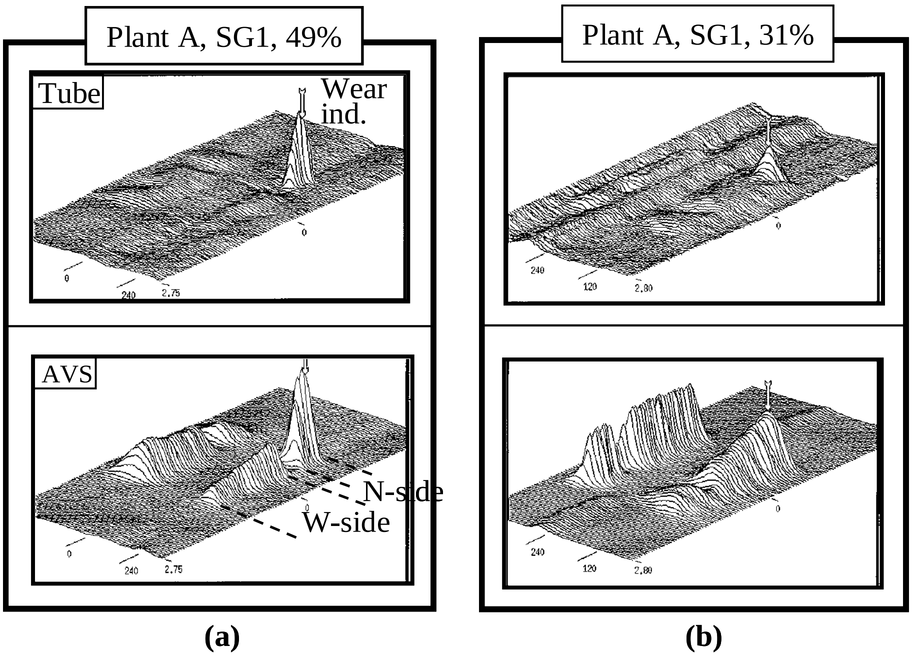


Fig. 4 MRPC C-scan data of one-sided wear.

**Two–sided wear**

From the above results, occurrence of two-sided wear can be expected for longer operation conditions. Fig. 5 are examples of two-sided wear appearance of the tube surface for plant B after 5 cycles of operation. It can be found in these figures that two-sided wear occurred at both opposite sides of one tube contacting tangentially with two AVS strips. This result can also be explained by a signal analysis of the inclined alignment between the two components as mentiond above.

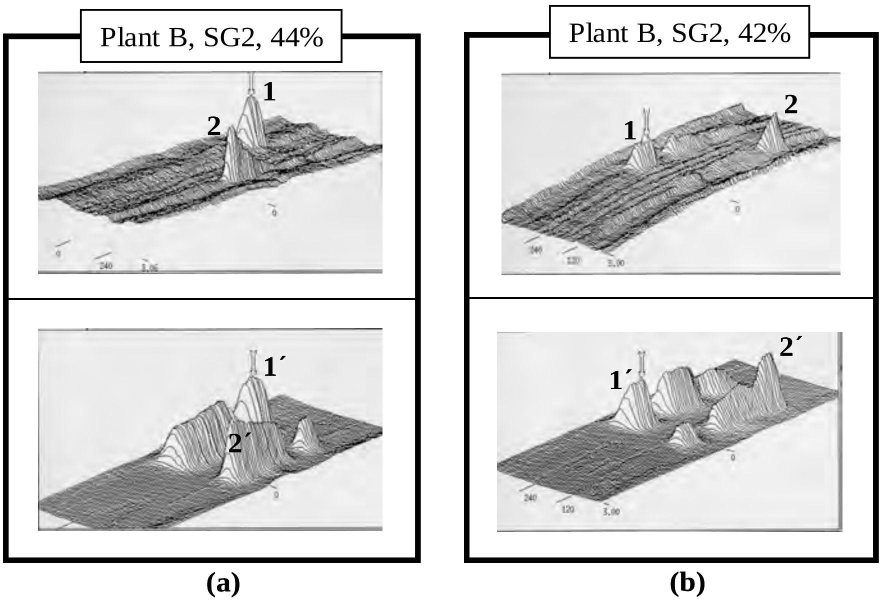


Fig. 5 MRPC C-scan data of two-sided wear.

**Two–stepped wear**

Fig. 6 represents two-stepped wear appearance. It can be seen that two wear indications on the same surface of the tube are shown in the upper C-scan displays of each figure. This wear appearance could have taken place due to the special geometrical structure of the AVS strip. As shown in Fig. 7, primary wear is initiated at the contact point between the edge of the AVS strip and tube surface under the abnormal alignment condition of the two components. After primary wear begins to continuously proceeded in the direction of tube wall, a new contact - the second contact - is formed at the point between the inner edge of the AVS hole and tube surface, thus, secondary wear is produced.

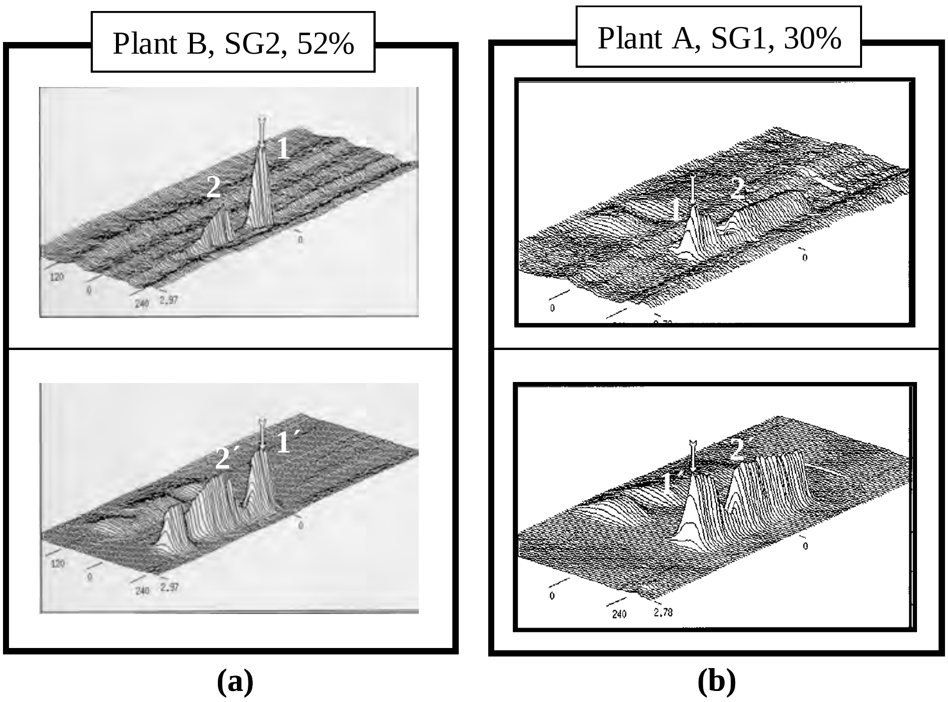


Fig. 6 MRPC C-scan data of two-stepped wear.

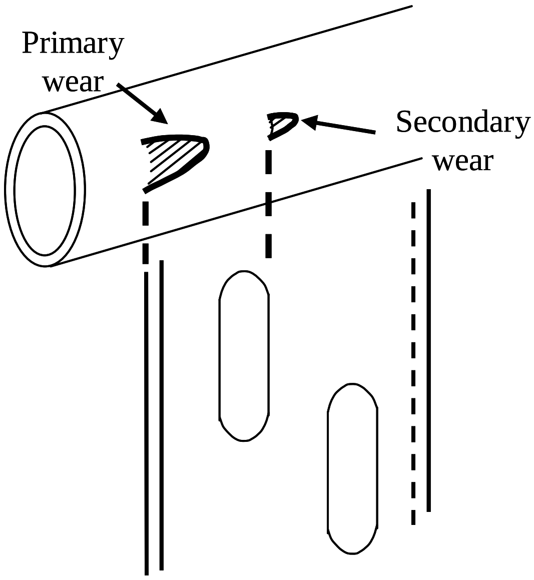


Fig. 7 Two-stepped wear due to geometrical structure between tube and AVS.

## SUMMARY

From this study, it was found for all of the 35 wear tubes that the alignment condition of every tube and AVS strip at the wear location was not normal, in other words, the alignment between the two structures was slightly distorted so that the gap between the two structures did not maintain a constant distance. This abnormal alignment condition resulted in the appearance of an inclined wear surface for most of the wear tubes. Therefore, it can be concluded that the main cause of fretting wear in this SG model is high local stress acting against the tube surface at the edge of the AVS strip under flow-induced vibration. Some other important features in the fretting wear of this SG model can be drawn. Wear surface appearance of a tube can be classified into one-sided, two-sided, and two-stepped wear. Most wear appearances, in the case of 1 cycle operation, showed one-sided wear surface of the tube. However, for the longer operation of 5 cycles, two-sided wear also occurred at both opposite sides of one tube contacting tangentially with the AVS strips. In addition to this feature, it was confirmed that two-stepped wear surfaces were formed along the longitudinal direction of a tube due to the special geometrical structure of the AVS strip.

As for all of the results described above, it should be noted that there are no support structures to suppress the horizontal motion of the upper bundle in the region of no TSPs, and the distances between the TSPs in the region of the upper bundle are too long to suppress the vibratory motion at the contacting areas between the BWs and bent part of the tube[3]. These are important structural factors affecting the wear behavior of this SG model, that is, fretting wear of this SG model can be characterized as the combination of structural factors and the edge effect of high local stress acting on the tube surface due to the abnormal alignment between the tube and AVS strips.

## ACKNOWLEDGEMENTS

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