Dynamic Analysis of Mineral Insulated Cable Depending on the Routing Shapes

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1. Introduction

HJTC (Heated Junction Thermocouple) Mineral Insulated (MI) cables are located immediately above the reactor vessel closure head (RVCH) instrument nozzles and routed to the Refueling Disconnect Panel (RDP) attached to the Integrated Head Assembly (IHA). The HJTC MI cables classified into class 1E (safety-related electric) equipment shall remain functional when subjected to applicable service conditions including design basis events (DBE). The functions can be demonstrated and verified in accordance with IEEE 323 [1].

In accordance with the Sec.6.3.1.3 of IEEE 323, the installation routing of the HJTC MI cables for EQ (Equipment Qualification) shall simulate the actual routing shapes. When the routing shapes of the HJTC MI cables installed in the field, however, are severely different from those of EQ test due to the bendable characteristic of the cable, the dynamic responses of the cable can remarkably be changed beyond the EQ results. So it is needed to confirm the installation shapes of the HJTC MI cables having various routing by analysis.

This paper analyzes how much the dynamic characteristic of the HJTC MI cable can be changed depending on the routing shapes. A representative cable is analyzed and the results are compared with those of various routing cases.

2. The HJTC MI Cable Materials and Assumption

The HJTC MI cables installed above the RVCH are exposed to harsh environments. Therefore, the HJTC MI cables having five (5) conductors are protected by the sheath which is made of Stainless Steel and filled with mineral insulation material such as SiO_2 inside.

The dynamic response of the MI cable is found to have linear behavior within small-elastic strains because of the stainless steel. The HJTC MI cable in this paper is assumed to exhibit linear elastic behavior under the loads during the normal operation.

The effects of plasticity are incorporated into the model by applying a reduced modulus of elasticity (E) to the top and bottom finite elements of the sensor tail [2]. The reduced E, 272ksi (1.88Gpa), is equal to the fully plastic (minimum) slope of the Stainless Steel stress strain curve [3].

3. Methods and Results

The analysis model of the HJTC MI cable for the research is one of the cables installed in the outermost location and the longest projected displacement. To clarify the tri-axial response from various cases, the HJTC MI cable models are simplified on a two-dimensional plane.

3.1 Possible Routing shapes of the HJTC MI Cable

Considering the cable support location, the connector location and the separation requirement between adjacent cables, cable routing cases are selected as shown in Figure 1;

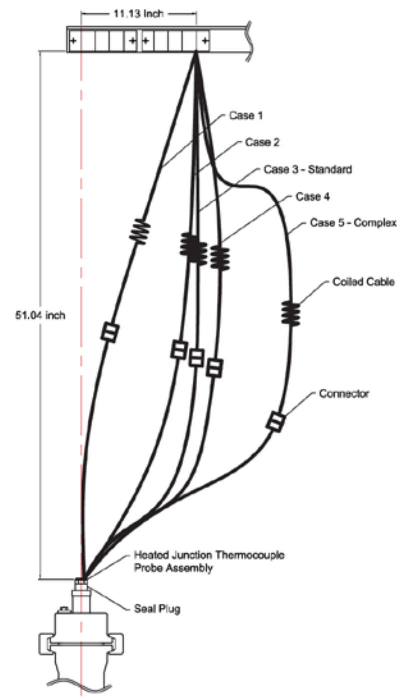

Fig. 1. Cases of the HJTC MI Cable routing shape

Case 1: Negative small curvature
Case 2: Positive small curvature
Case 3: Standard described in the routing drawing
Case 4: Positive large curvature
Case 5: Complex having excessive convex curvature

The HJTC MI cable routing shape of cases 1 through 4 can be considered in selecting a representative cable for the EQ test so that the cables in the field are able to be routed in shape of those cases. On the other hand, the cable routing shape of case 5 has excessive convex curvatures, which have not been generally considered in EQ tests.

3.2 Dynamic Analysis

Finite element models were built for the routing cases using beam elements of ANSYS. The connection between the seal plug of the HJTC probe assembly and the sensor lead cable is welded so that six (6) degrees of freedom are fixed at the bottom of the MI cables. The HJTC MI cable support restricts the movement of cables with a clamp assembly. Therefore the top of the HJTC MI cable model is also fixed in six (6) degrees of freedom. The overall structure can be seen as a flexible beam with both ends fixed.

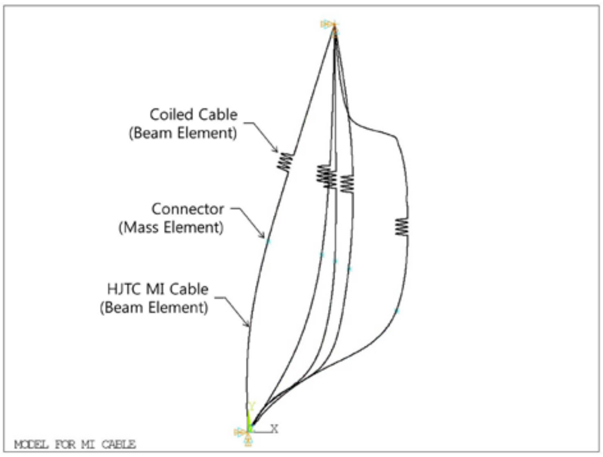

Fig. 2. Analysis Model of the cases

To compare the responses of the routing cases, the transfer functions at the connector areas were calculated because the connector is the most critical in terms of dynamic tests.

3.3 Analysis Result

Figures 3 through 5 show the analysis result. While cases 1 through 4 show the maximum response below 8 Hz, case 5 has the maximum response at approximately 50 Hz in X direction.

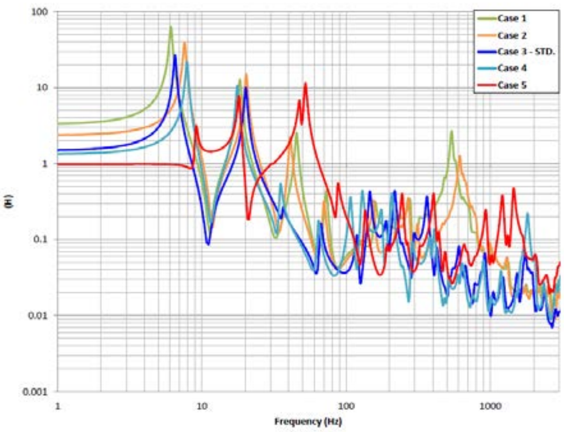

Fig. 3. Transfer functions at connector in X direction

As shown in Figure 4, no particularly different responses of case 5 are observed in vertical direction.

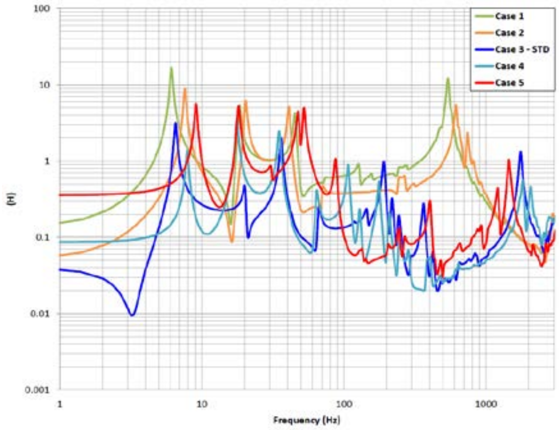

Fig. 4. Transfer functions at connector in Y direction

There is a marked contrast between case 5 and the other cases in Figure 4. It may be caused that the cable length of case 5 is longer than that of the other cases.

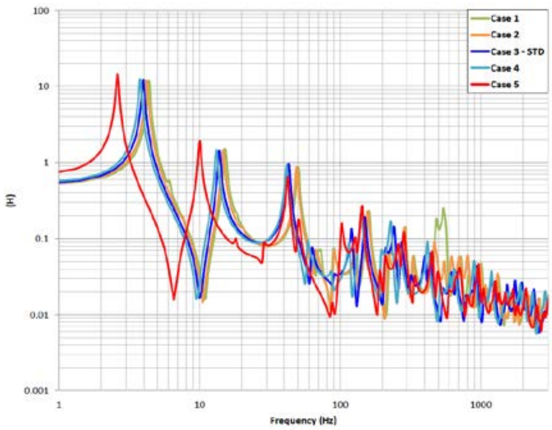

Fig. 5. Transfer functions at connector in Z direction

In the analysis, case 5 shows different dynamic characteristics in X and Z direction. The trend is that the greater the excessive convex curvature of the HJTC MI cable has, the higher the resonant frequency becomes in X direction and the lower the resonance frequency becomes in Z direction.

4. Conclusion

Up to now we have looked at that the responses at the connector are shown to be different depending on the routing shapes of the HJTC MI cable. The EQ is important to certify the design life of the HJTC MI cable. But no less significant than the successive EQ is the correspondence between the routing shapes of the cables in the EQ and in the field.

So, it is recommended that the equipment supplier shall choose the representative test cable for the EQ with the evaluation data about the various routing shapes of the HJTC MI cable and the field workers shall be fully aware of the installation guidelines before installing the cable. Moreover, at present, there is no systematic procedure to confirm whether or not the HJTC MI cable installed on the site appropriately reflecting the results of EQ test. Therefore, it is required to establish the provision for performing objective assessment in the near future.

REFERENCES

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