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DISCLAIMER

STUDY OF THE RHIC BPM SMA CONNECTOR FAILURE PROBLEM*

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Abstract

About 730 BPMs are mounted on the RHIC CQS and Triplet super-conducting magnets. Semi-rigid coaxial cables are used to bring the electrical signal from the BPM feedthroughs to the outside flanges, at the ambient temperature. Every year around 10 cables will lose their signals during the operation. The connection usually failed at the warm end of the cable. The problems were either the solder joint failed or the center conductor retracted out of the SMA connector. Finite element analyses were performed to understand the failure mechanism of the solder joint. The results showed that (1) The SMA center conductor can separate from the mating connector due to the thermal retraction. (2) The maximum thermal stress at the warm end solder joint can exceed the material strength of the Pb37/Sn63 solder material and (3) The magnet ramping frequency (~10 Hz), during the machine startup, can possibly resonant the coaxial cable and damage the solder joints, especially when a fracture is initiated. Test results confirmed that by using the silver bearing solder material (a higher strength material) and by crimping the cable at the locations close to the SMA connector (to prevent the center conductor from retracting) can effectively resolve the connector failure problem.

INTRODUCTION

In RHIC, the maximum beam intensity inside the Beam Position Monitor (BPM) cable has 1×10^{11} charges per bunch with 60 bunches in the ring. The bunch spacing is 213 ns and the bunch length is 0.6 ns [1]. About 730 cryogenic BPMs are mounted on the CQS and the Triplet super-conducting magnets. Fifty ohms semi-rigid coaxial cables (see Fig. 1) [2] are used to bring the signal from the BPM feedthroughs (at 4 K) to the outside flanges at the ambient temperature.

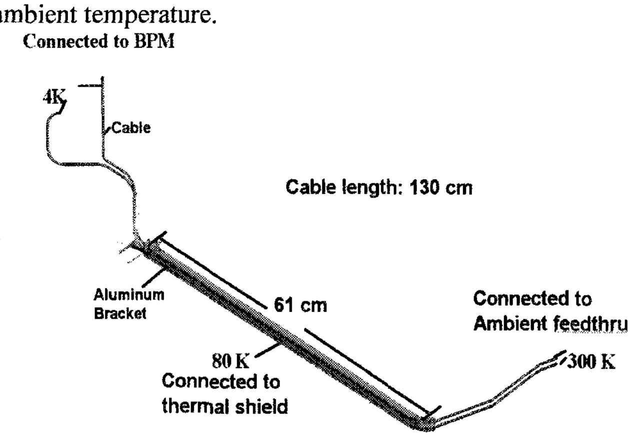

Fig 1: The BPM cable

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The outer jacket of the cable is a .141" OD x .010" wall stainless steel tubing and the center conductor is a .035" diameter copper wire. The dielectric material is made of Tefzel. The SMA connectors (see Fig. 2), which were soldered (using Sn63/Pb37 solder material) to the outer jacket of the cable at both ends, are made of stainless steel with the inner housing surface gold plated. In practice, two signal cables are bundled together using a box shape aluminum bracket (.75" x .375"x .125" thick) and are maintained at 80K at the location attached to the thermal shield.

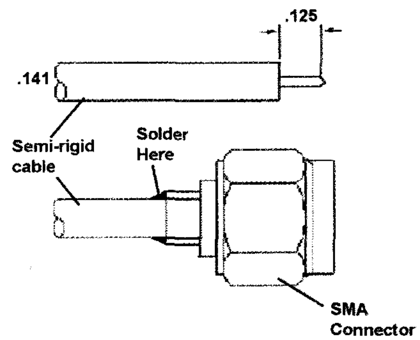

Fig 2: The solder joint between the cable and the SMA connector

Every year around 10 cables would lose their signals during the operation. The connection usually fails at the warm end of the cable. Previous observations showed that either the solder joint failed, which could separate the cable from the SMA connector, or the center conductor could retract out of the SMA connector. The purpose of this paper is to understand the failure mechanism of the warm end cable connection and to come up with methods to resolve the problem through finite element analysis and laboratory testing.

SYSTEM ANALYSIS

Rigorous analyses (using 3D finite elements in ANSYS), including thermal, structural, and modal analysis, had been performed to understand the failure mechanism of the warm end solder joint. The analyzed system (see Fig. 1) included two cables, one aluminum bracket and four SMA connectors. The SMA connectors were soldered onto the cable at both ends. The solder joint included a conical and a cylindrical shape solder region (see Fig.2). The boundary conditions were 4K at the cold end, 80 K at the middle of the aluminum bracket, and 300 K at the warm end. Joule heating in the center conductor was based on a maximum current of 150 mA. Heat transfer through radiation and convection were neglected in the analysis. Cold end displacements, due to the cold mass contraction ($\delta_{axial} = 7.9 \times 10^{-4}$ in; $\delta_{radial} = 2.5 \times 10^{-5}$ in), were considered. Temperature dependent material properties [3, 4], including thermal conductivity, thermal expansion coefficient, Young's modulus, electrical resistivity, and heat generation, were used in the analysis (see Fig 3 and Fig 4).

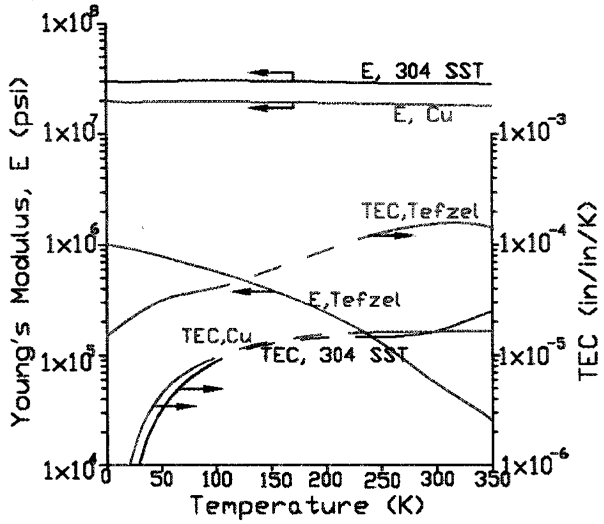

Fig.3: Mechanical properties of copper, stainless steel and Tefzel [3]

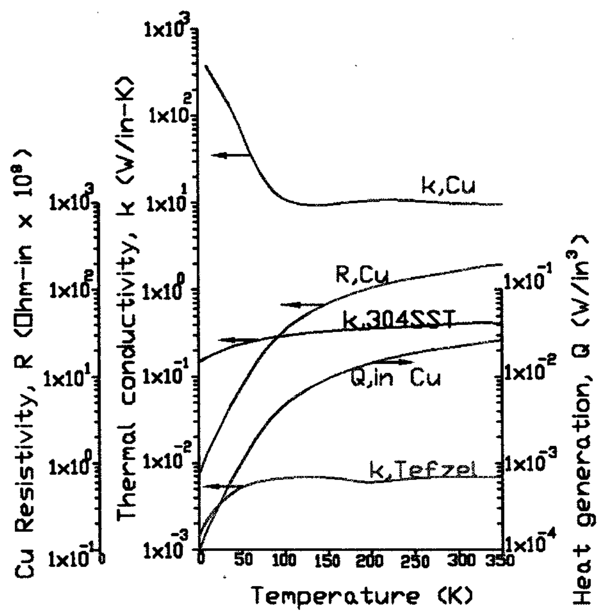

Fig.4: Electrical and thermal properties of the copper conductor [4]

Center Conductor Retraction Analysis

The calculated maximum center conductor retraction with respect to the cable outer jacket, assuming frictionless between the metal and the insulator material, was .035", which could cause a signal loss problem since the pin engagement in the mating connector is ~ .030".

Warm End Solder Joint Stress Analysis

Two different solder materials [5, 6], Pb37/Sn63 and Stay-Brite (tin/silver) (see Table 1), were compared in the analysis. Bi-linear hardening plasticity property was assumed to model the stress and strain relationship of these materials. In Table 1, Young's modulus and Tangent modulus are the slopes of the stress vs. strain curve in the elastic and the plastic zone respectively.

Table 1: Properties of two solder materials [5, 6]

Composition	**Pb37/Sn63**	**Stay-Brite**
Young's Modulus*	4.77 x 10^6 psi	6.58 x 10^6 psi
Tangent Modulus*	1661 psi	9098 psi
Tensile Strength, σ_u	7500 psi	14000 psi
Yielding Strength*, σ_y	6675 psi	11760 psi

*: Engineering estimation.

Assume that the solder material will fail when the maximum shearing stress equals that in the simple tension (or compression) specimen at ultimate tensile stress, mathematically, σ_1-σ_3 = +/-σ_u [7]. (This failure criterion will be validated in the following prototype testing.) The stress analysis results (see Table 2) showed that the solder joint would not exceed the material strength for both cases if soldered properly. However, if the solder material does not fill uniformly between the connector and the cable, the Pb37/Sn63 solder joint could fail.

Table 2: Maximum stress in the warm end solder joint

Solder Material	**Max. Stress Intensity* (1), psi**	**Max. Stress Intensity* (2), psi**
Pb37/Sn63	4430	7568
Saty-Brite	5099	11541

*: Stress Intensity=Maximum of the difference between two principal stresses
(1): Solder joint includes a cylindrical and a conical region.
(2): Solder joint without a cylindrical region (an extreme condition)

Modal Analysis

From the modal analysis, the three lowest natural frequencies of the system are shown in Table 3. Note that the fundamental frequency is close to the magnet ramping frequency of 10 Hz.

Table 3: Natural frequencies of the lowest three modes

Mode No.	**Frequency , Hz**
1	11.09
2	14.54
3	22.76

PROTOTYPE TESTING

Pull Tests of Solder Joints

Eight sample BPM cable/connector assemblies were pull-tested at room temperature to evaluate the strength of the solder joints. The test results and the preparation of each solder joint are shown in Fig 5. The results show that (1) Not all the factory solder joints had the same strength. The breaking loads varied from 70 lbf to 260 lbf. (2) Adding more solder material over the factory solder joint could improve the strength of the solder joint

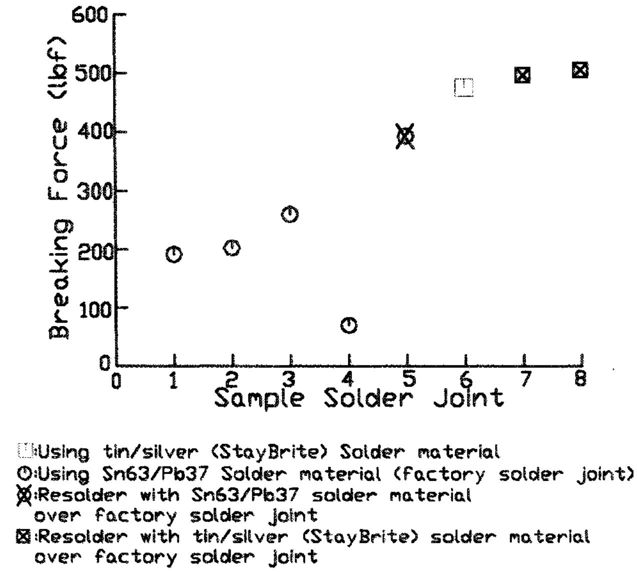

Fig 5: Pull tests of solder joints

Stress analyses (using ANSYS) were also performed on five tested samples to confirm the finite element model and the failure criterion. The analysis results (see Table 4) predicted that all the samples would fail but Sample #4, which could be due to defects in the solder joint.

Table 4: Calculated stresses in the solder joint

Sample	Solder material	Breaking load, lbf	Max. Stress Intensity*, psi
1	Pb37/Sn63	191	7580
2	Pb37/Sn63	202	7585
3	Pb37/Sn63	260	8082
4	Pb37/Sn63	70	6051
6	Stay-Brite	476	15101

*: Stress Intensity=Maximum difference between two principal stresses

Cold Tests of BPM Cables

A BPM cable was submerged in a liquid nitrogen bath. The center conductor retracted over .030", as expected.

Two BPM cables were crimped at the locations near the SMA connectors and were thermal cycled between the liquid nitrogen and the room temperature eight times to evaluate the effectiveness of the crimping method on the prevention of the center conductor retraction. The results showed that the maximum pin retraction was within .01" (see Fig. 6), which is acceptable.

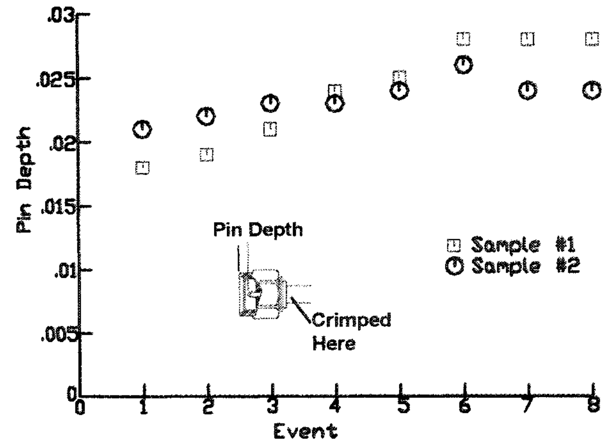

Fig.6: Cold test of two crimped cables

CONCLUSIONS

Based on the analyses and test results, the conclusions are as follow:

- Defect in the factory solder joint and the fatigue failure due to the vibration caused by the magnet ramping could be the reasons why some of the warm end solder joints failed.
- Replacing the tin/lead solder material with Stay-Brite (tin/silver) solder material can eliminate the SMA solder joint failure problem.
- Adding more solder material over the factory solder joints can also improve the strength of the solder joint.
- Crimping cable at the locations close to the SMA connectors can effectively resolve he conductor retraction problem.

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