STUDY ON FAULT SCENARIOS OF COAXIAL TYPE HOM COUPLERS IN SRF CAVITIES*

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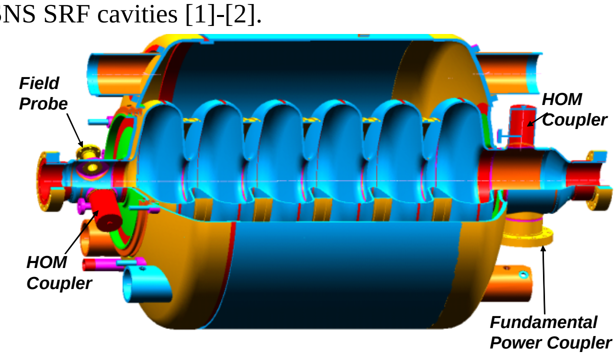
Abstract

Coaxial type couplers are adopted in many superconducting radio-frequency (SRF) cavities to suppress higher order modes for beam dynamics and cryogenic loads issues. HERA (Hadron-Electron Ring Accelerator) and TTF (Tesla Test Facility) are equipped with this type of HOM couplers and showed successful performances. It is, however, under suspicion that a limitation or a fault could be initiated from this type of coupler at certain unwanted combinations between cavity conditions and engineering designs of the coupler. Possible scenarios that could result in faults are under investigations and are summarized in this paper based on observations in the SNS (Spallation Neutron Source) SRF cavities.

INTRODUCTION

The Spallation Neutron Source (SNS) uses two types of superconducting cavities to accelerate the H^- beam from 185 MeV to 1000 MeV. 33 six-cell pi-mode elliptical cavities with a geometrical β=0.61, followed by 48 six-cell pi-mode elliptical cavities with a geometrical β=0.81 are used. The SNS beam has a time structure. Micro-bunches are separated by about 2.5 ns which corresponds to 402.5 MHz. A midi-pulse is composed of about 260 micro bunches and there's about 300-ns gap for the injection to the accumulator ring. The midi-pulse period corresponds to the ring revolution time. About 1000 midi-pulses build up one macro pulse whose repetition rate is 60 Hz. Each time structure generates resonance (beam power spectral line) or anti-resonance. If any HOM mode hits a resonance, the induced power could be large enough to make cavity quenching. The probability that any cavity HOM frequency will fall on a significant beam power spectral line at any instant in time is, however, estimated to be very small. Many factors can cause HOM frequencies to move around with time. To have a reliable accelerator, coaxial type HOM couplers are adopted in SNS SRF cavities [1]-[2].



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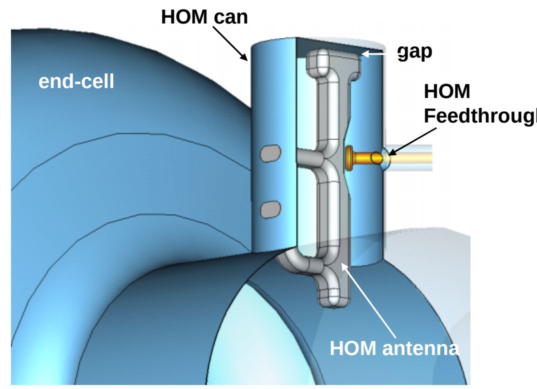
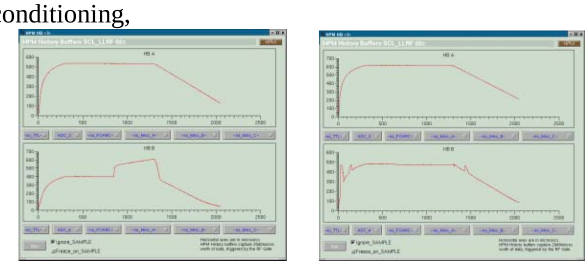


Figure 1: SNS SRF cavity assembly and HOM coupler.

Schematics of the SNS SRF cavity assembly and HOM coupler are shown in Fig. 1. The HOM coupler is composed of the coupling loop (inductance), the gap between the HOM antenna and the HOM can (capacitance), and the HOM feedthrough for power extraction through the capacitive coupling. The coaxial type HOM coupler is a tunable notch-filter that is designed to reject the fundamental mode frequency by adjusting the gap. During the operation of SNS SRF cavities, some cavities are showing abnormal signals through the HOM feedthrough. In this paper, faults scenarios analogized from observed data and simulations are introduced.

OBSERVATIONS

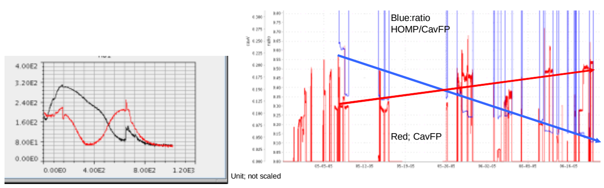
Some examples we observed during the operation are introduced in this section. Fig. 2 shows signals from HOM feedthrough while operating RF only. The vertical axes are in logarithmic scale, so the top ones are normal cavity fields coupled to HOM couplers at the field probe side. The bottom ones clearly show that abnormal signals are added on the normal cavity field that comes with vacuum excursion. In this specific case those abnormal signals at lower gradients disappeared after careful conditioning,



(a) (b)

Figure 2: Abnormal waveforms through HOM feedthrough running RF only without beam (electron loading). (a) at 3.5 MV/m, (b) at 6 MV/m.

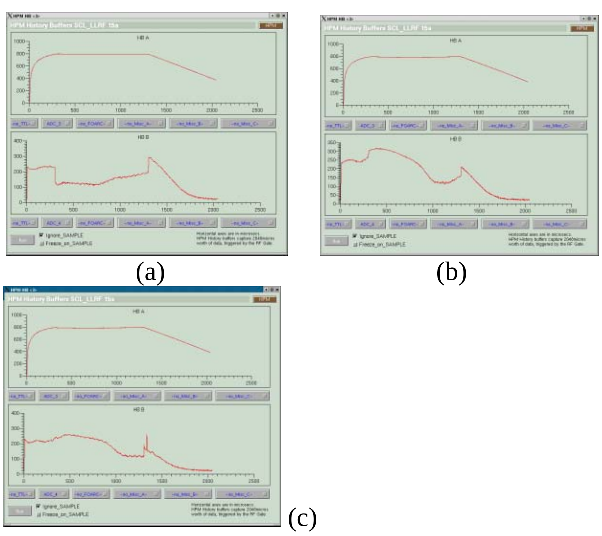
In some cavities, changes of signals were observed in both amplitudes and waveforms. Fig. 3 (a) is comparisons of signals from HOM couplers that are 3 months apart and Fig. 3 (b) is plots of ratio between signals from HOM coupler and field probe signals for about 45 days.



(a) (b)

Figure 3: Change of waveform through HOM feedthrough at the same operating gradient (long term changes).

Repetition rate dependent signals from HOM couplers are observed in some other cavities as shown in Fig. 4. The waveforms are changing immediately after repetition rate is changed (from (a) to (b)), which is much faster than the thermal time constant. The waveform kept changing slightly and about 20 minutes later sharp spikes were observed with large vacuum excursions, which can be seen in Fig. 4 (c) at the end of RF pulse.



(a) (b) (c)

Figure 4: Repetition rate dependent waveforms through HOM coupler. (a) waveform at 1 to 5Hz, (b) waveform at 30 Hz, and (c) waveform at 30 Hz 20 min. after the repetition rate is set to 30 Hz.

PHYSICAL CONDITIONS AT AROUND HOM COUPLER

Thermal issues related with a material of feedthrough and a cooling scheme are know to be a limitation especially in CW operation and there are advanced designs to enhance those aspects [3]-[4]. While commissioning and operation of SNS SCL, however, changes of HOM signals and abnormal signals that are believed to be electron loadings are observed from some cavities even at 10-Hz operation and 1.3 % duty or lower. In order to understand the causes for these anomalies, physical conditions at around HOM couplers are examined.

Electromagnetic Field

The stray field strengths are estimated with the MWS modeling. The surface magnetic field on the surface of the HOM feedthrough is about 3.5 mT that will induce about 200-mW surface dissipation at 8 % duty and the nominal field operation. The MWS modeling and surface magnetic field distribution are shown in Fig. 5.

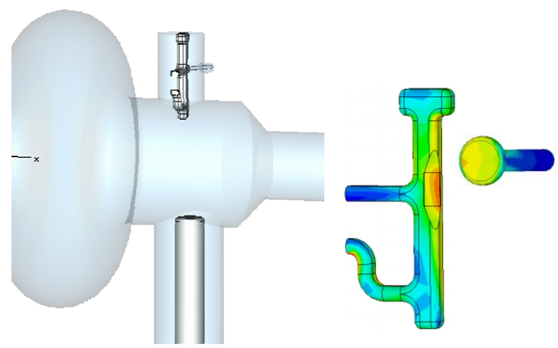


Figure 5: MWS modeling and magnetic field distributions at HOM antenna and feedthrough from stray field coupling of cavity fundamental mode frequency.

Electric field patterns of the HOM antenna and the inner conductor of the fundamental power coupler are shown in Fig. 6. At both ends of the HOM antenna has peak electric field, which is the characteristics of coaxial type notch filter. The peak amplitudes are estimated to be about 12 MV/m and 6 MV/m at the HOM antenna and the tip of inner conductor respectively.

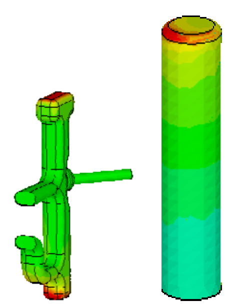


Figure 6: Electric field distributions at HOM coupler feedthrough and inner conductor of fundamental power coupler from stray field coupling of cavity fundamental mode frequency.

Electron Loadings

Electron activities at around HOM coupler would partially or completely destroy the electromagnetic standing wave patterns and eventually could results in HOM coupler degradation and/or failure.

The gap distance between the HOM antenna and the tuning plate of HOM coupler is about 0.5 mm. Conditions for resonant and/or non-resonant multipacting could be formed at around this gap.

Operating gradients of SNS cavities are higher than their field emission thresholds. Radiation pattern is following the cavity field in majority of cavities as shown in Fig. 7 (a).

One interesting observation is that radiation patterns from some cavities do not show cavity field shape. It has spikes at the end of RF pulses and/or during the cavity filling as shown in Fig. 7 (b) and (c). At those moments when radiation waveforms are showing spikes, the power flowing through the fundamental power coupler has full standing wave pattern, and at the same moments we observed spikes from signals of HOM couplers in some cavities. The most affecting region with the traveling wave contents is the tip of the inner conductor. One explanation of this observation is that multipacting starts at the tip of fundamental power coupler when the full traveling wave happens and emitted electrons are accelerated to around HOM coupler.

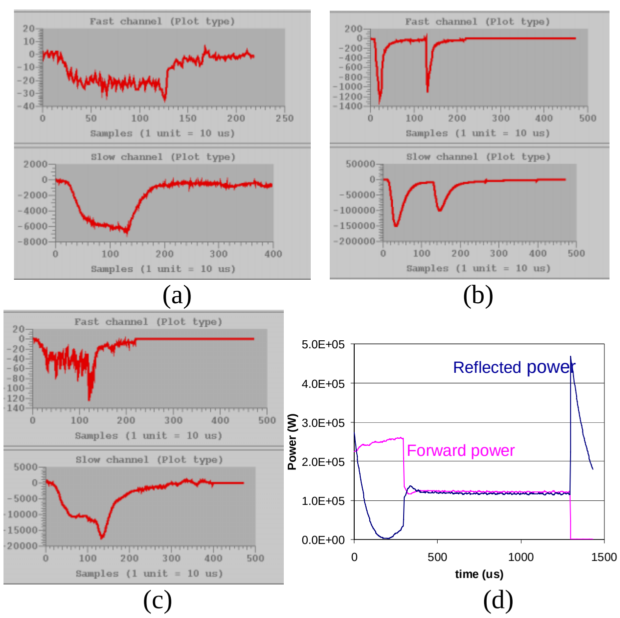


Figure 7: Radiation patterns from cavity. (a) cavity field type, (b) full traveling wave type, (c) combined type and (d) waveforms of forward and reflected power in closed loop.

Notching Characteristics

The external Q's of HOM couplers show scattered distributions ranging from 10^{10} to 10^{14}. Low power measurements are done to check notching characteristics, which comes up with little correlations between Q's and distance from notching frequency.

Other Uncertainties

Other uncertainties could lead to worse situations at around HOM couplers such as field tilt, local vacuum, mechanical uncertainty, and surface condition/cleanness.

DISCUSSIONS

About 15 % of installed cavities in the SNS SCL are showing abnormal signals through HOM feedthroughs. Observations and physical conditions at around HOM couplers described in previous sections imply that HOM coupler failures and/or degradations seem to be a result from electron activities originated by combinations of multiple causes. Multipacting in the HOM coupler, electron loadings from field emission, or dark current from the inner conductor tip of fundamental power coupler could place at HOM couplers. Thermal effects are also observed. Other investigations are under progress to verify further operability. For example, preliminary results measured with real time spectrum analyzer show dependencies of repetition rate (Fig. 8).

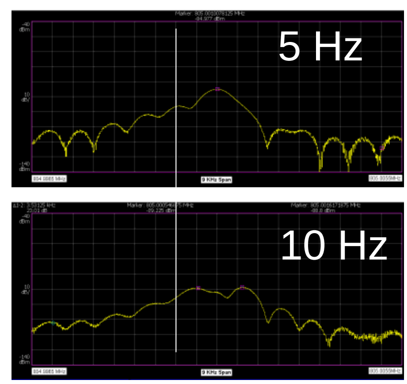


Figure 8: spectrum analyzer measurement of signals from HOM feedthrough with RF only at 5 and 10 Hz. The vertical line corresponds to the resonance frequency of the cavity tested.

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