COAXIAL COUPLING SCHEME FOR TESLA/ILC-TYPE CAVITIES

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Abstract

This paper reports about our efforts to develop a flangeable coaxial coupler for both HOM and fundamental coupling for 9-cell TESLA/ILC cavities. The cavities were designed in early 90`s for pulsed operation with a low duty factor, less than 1 %. The proposed design of the coupler has been done in a way, that the magnetic flux B at the flange connection is minimized and only a magnetic flux of <3 mT would be present at the accelerating field of 34 MV/m (~150 mT in the cavity). Even though we achieved reasonably high Q-values at low field, the cavity/coupler combination was limited in the cw mode to ~7 MV/m, where a thermally initiated degradation occurred. After we have improved the cooling conditions the modified prototype performed well up to 9 MV/m in cw mode. This paper reports about modelling and test results in continuous wave (cw) and low duty factor pulsed mode, which is closer to the TESLA/ILC operation conditions.

INTRODUCTION

Motivation

Our motivation to develop the coaxial coupling (CC) scheme (Fig. 1) for HOM and FM has been discussed comprehensively in [1, 2]. Here, we recall some arguments. The CC scheme has the following advantages as compares to the standard TESLA coupling:

- Field asymmetries and kicks from all couplers are small.
- The distance between two cavities is shorter.
- The body of the cavity stays cylindrically symmetric, which enables its fabrication by hydro-forming as a seamless device.
- The interior of the coupling device and the cavities can be better cleaned before the final assembly.
- The CC scheme provides for good damping of HOMs and for easy matching of the fundamental mode coupler.

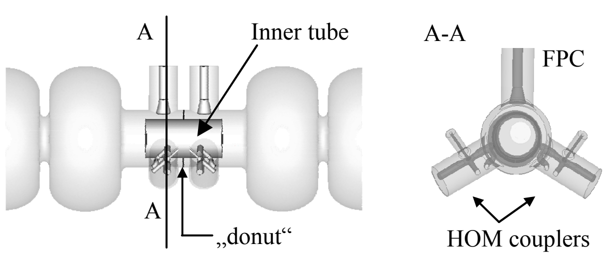

Figure 1: FPC and HOM couplers in two mirrored coaxial coupling devices placed between two cavities (left) and cross-section of the coupling device (right).

Test Results

The cryogenic test results of the prototype shown in Figure 2, and improvements in the scheme are discussed in [3]. Figure 3 summarizes results of the cw tests for the CC scheme with single crystal gasket and improved cooling by initially drilling radial channels every 30°, then every 15° into the shorting plate. The achieved maximum accelerating field, Eacc = 9 MV/m, for the prototype with improved cooling, seemed to us limited by heating of the inner tube.

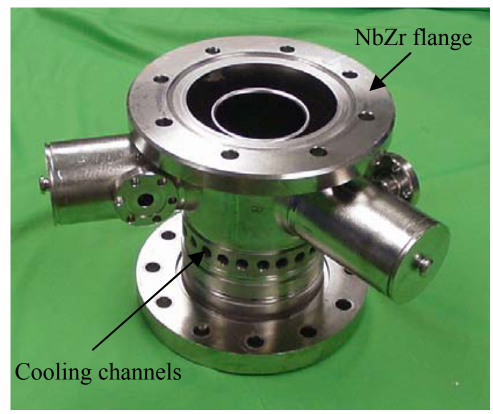

Figure 2: Prototype of the coaxial coupling.

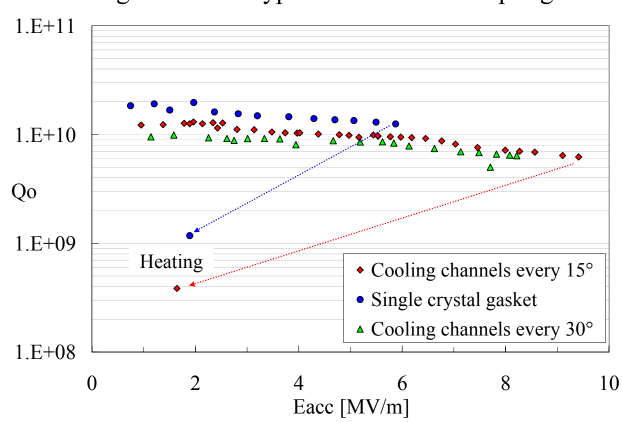

Figure 3: Results with single crystal gaskets and improved cooling.

The prototype was recently detached from the test cavity for an additional cleaning and sharpening of conflat knifes of the NbZr flange. The hardness of NbZr alloy used for flanges was lower than specified by the vendor and the conflat knifes, usually after few assemblies, must be re-sharpened to avoid vacuum leaks. Unfortunately, the test result after that cleaning was not satisfactory. The CC prototype reached only Eacc of 7.5 MV/m. At that field the intrinsic Q degraded by one order of magnitude. The result is displayed in Figure 4. In addition to the inner tube heating, we suspect that the

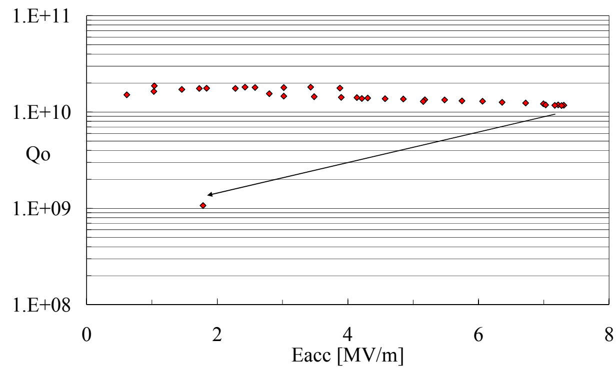

Figure 4: Test result after re-cleaning of the CC prototype.

superconducting connection may contribute to the poor performance of the prototype, however magnetic flux at its location does not exceeds 2.8 mT at Eacc=34 MV/m. At the end of that cw testing, we have tried for the first time the pulse mode with duty factor of 20%. In that mode the prototype could reach 11.4 MV/m. The field was determined by the strength of pickup probe signal. The intrinsic Q value could not be measured with the electronics we used for that test. It will be modified for coming tests to enable the evaluation of intrinsic Q.

MODELING

For the thermal modeling of the assembly we compute the magnetic field along its metal wall. The contour of magnetic field and its value along the Nb wall for Eacc = 34 MV/m are shown in Figure 5 and 6 respectively.

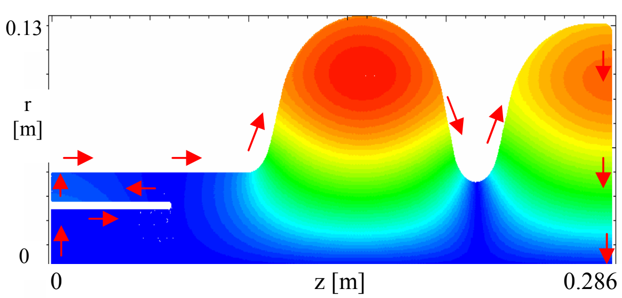

Figure 5: Contour of the magnetic field at 34 MV/m. The maximum H field (red color, in the mid of full cell) is 125 kA/m. The field flatness for that modeling was ~95%.

The red arrows in Figure 5 show the metallic wall coordinate (s); in Figure 6 the surface field is plotted along this contour. At the wall, the maximum H field is 115 kA/m. In the computer modeling, the density of the dissipation in the metal was adjusted with respect to its current surface resistance, assuming that the magnetic field stays unchanged. The dependence of niobium surface resistance on temperature has been modeled accordingly to the BCS theory with the assumption that the residual resistance is 14 nΩ, which was experimentally measured for clean Nb surface. We did not model any presence of surface contamination with non superconducting particulates. The modeling was

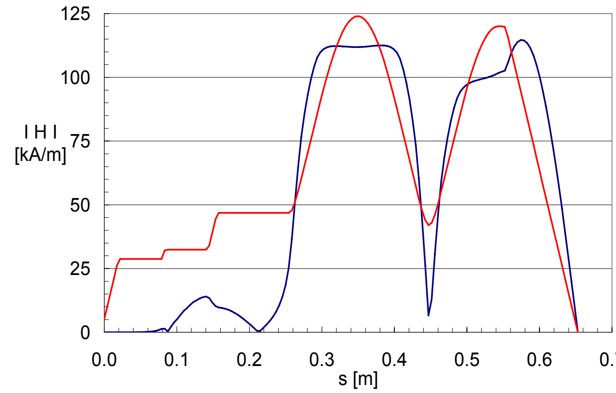

Figure 6: Magnetic field (blue line) at 34 MV/m along the metal wall (red line). The maximum H field on the wall is 115 kA/m.

performed iteratively until the temperature distribution was stable. At first, the computer simulation was done for continuous wave (cw) mode and the accelerating field range from 7 MV/m to 25 MV/m. In the second step, the modeling was repeated for higher fields up to 34 MV/m in the pulse mode with a duty factor of 1%, which is close to the ILC nominal operation conditions.

Modeling Results for CW case

For the cw modeling, we assumed that the outer wall is immersed in a 2K superfluid helium bath, similarly to the situation in all performed vertical tests. Niobium wall temperature maps as function of the stored energy (and accelerating gradient) have been calculated to estimate the threshold for quench. A typical temperature profile in the coaxial coupler part of the whole assembly is shown in Figure 7. In all modeled cases the highest temperature was observed at the tip of the inner tube. Table 1 summarizes the modeling results for the cw (static) case. At accelerating gradients higher than 25 MV/m the temperature rose above the niobium critical temperature of 9.2 K, indicating quenching in the coaxial coupler. The computed cw threshold for stable operation is much higher than the best measured value of 9 MV/m. This indicates that either the Nb surface preparation or/and superconducting junction needs further improvements.

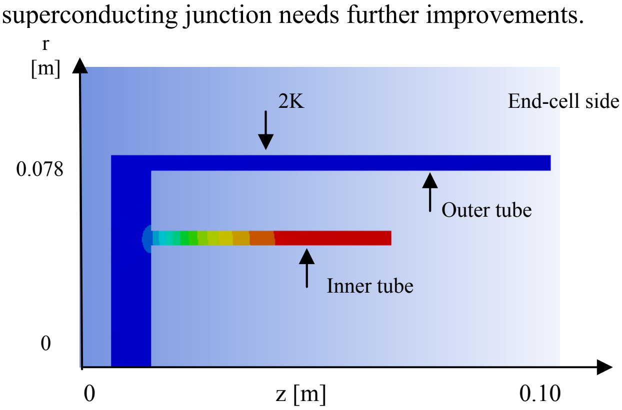

Figure 7: ANSYS modeling of the temperature map. Red color indicates the highest temperature.

Table 1: Maximum T vs. stored energy W (and Eacc)

W	J	1	3	6	10	12	13.5	14
Eacc	MV/m	6.8	11.8	16.7	21.5	23.6	25.0	25.4
T	K	2.027	2.085	2.186	2.380	2.553	2.977	> 9.2

Modeling Result for Pulse Operation

The pulse modeling is very time consuming and it will be automated for future simulations. For 25 Joule of stored energy, which corresponds to 34 MV/m, we performed simplified computer modeling overestimating dissipation in the superconducting wall in the coaxial coupler part. For that case, we have assumed a dissipation of 0.3 mW/cm^2 distributed uniformly on the whole CC superconducting surface. This dissipation value shall be observed only at the inner tube close to the donut, where the magnetic field amplitude is doubled due to reflection forming the standing wave. The assumed Nb surface resistance was equal to that at 2 K in the previous cw modeling. The length of the RF-pulse was fixed to 2 ms and the RF off time was 198 ms. This pulse time structure exceeds by 54 % the duty factor of ILC, for which RF-pulse length will be 1.3 ms. Even though, we overestimated both the heat load and duty factor, the maximum temperature, which was as before at the tip of inner coaxial tube, tended to stabilize after few seconds of operation. The modeling result is shown in Figure 8, where the temperature rise at the inner coax tip is plotted vs. time. The final temperature rise did not exceed 0.1 K, which should guarantee stable operation of the coupling device for the ILC gradient.

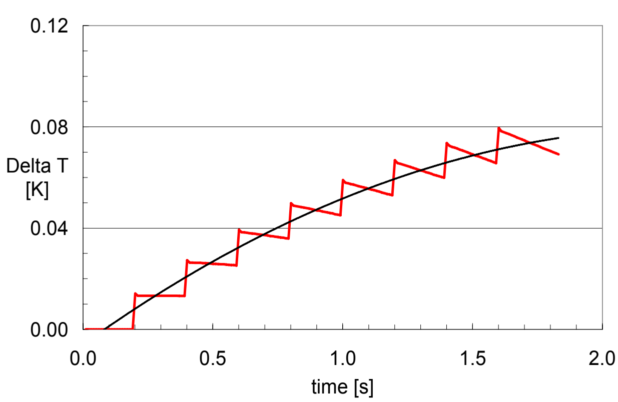

Figure 8: ANSYS modeling of the temperature (red) and trend line (black) for pulse operation.

FINAL REMARKS

The modeling of heat loads demonstrates that the coaxial coupling scheme should operate both in the cw and pulse mode, at much higher gradients than those achieved experimentally. It seems obvious that before going to more complicated technically construction with a better cooling, e.g. double-wall of inner tube, we should attempt to improve the surface quality of the CC device and/or the performance of the superconducting junction. As the modeling results showed, the cooling of the inner tube should not yet limit the achievable gradients in the tested assembly.

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