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A SIMPLE VARIABLE COUPLER FOR THE CRYOGENIC TEST OF SRF CAVITIES*

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Abstract

The cryogenic rf tests of superconducting radio-frequency (SRF) cavities in vertical cryostats is typically carried out using fixed-length antennae to couple rf power into the cavity and to probe the energy stored into the cavity. Although variable couplers have been designed, built and used in the past, they are often a complex, costly, not very reliable auxiliary component to the cavity test. In this contribution, we present the design and implementation of a simple variable rf antenna which has ~50 mm travel, allowing to obtain about four orders of magnitude variation in Q_{ext}-value. The motion of the antenna is driven by a motorized linear feedthrough outside of the cryostat. The antenna can easily be mounted on the most common type of cavity flanges.

INTRODUCTION

The preparation of a superconducting radio-frequency (SRF) cavity for measuring its performance at cryogenic temperatures typically involves assembly of at least two flanges onto two cavity ports. Each flange would have an rf feedthrough with a threaded pin onto which a copper or niobium cylindrical rod antenna is attached. One antenna is used to couple power into the cavity and the other is used to probe the amount of stored energy into the cavity. The length of each antenna is calibrated at room temperature to a desired Q_{ext}-value.

A drawback of this setup is that the cavity quality factor, Q_0, typically changes with increasing amplitude of the rf field, even by one order of magnitude in some cases. When the Q_0 value changes, the mismatch between the coupling antenna and the cavity result in large values of reflected power, which limits the maximum power that can be fed into the cavity, due to the power rating of the input cable and of the rf amplifier, and also results in larger measurement errors.

An input antenna with adjustable "in-situ" penetration into the cavity volume would allow overcoming those limitations, as a near critical coupling condition could be maintained throughout the cavity testing. The difficulty of realizing such setup is given by the need of mechanical movement of the antenna at cryogenic temperatures, which also poses the risk for movement of particulates that can land on the cavity surface and cause field emission. For these reasons, variable couplers are not commonly used during the performance test of SRF cavities in a vertical cryostat.

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Different type of variable couplers have been designed throughout the years at different laboratories. Some of them use a cryogenic stepper motor [1]. Some are designed to be mounted to a side-port [1, 2], others from a beamline port [3-5]. Some have the cavity stationary and the antenna moving [3], others have the antenna stationary and the cavity moving [4, 5].

In this contribution, we present the design of a variable coupler that is simple to fabricate, inexpensive, adaptable to different style flanges and it has been used with good results so far.

DESIGN AND IMPLEMENTATION

The movable section of the variable coupler is shown in Fig. 1. It consists of an N-type rf feedthrough, a stainless steel (SS) cage, a bellow and three SS sliding rods with threaded ends. The rods slide into precision-machined tubes made of Duratron T4301 PAI (Quadrant Engineering), press-fitted into the SS cage.

A long copper antenna is screwed onto the rf feedthrough, which is made in two pieces joined by a 0.5" long #0-80 threaded pin. A Teflon ring is used, to keep the antenna concentric with the outer conductor.

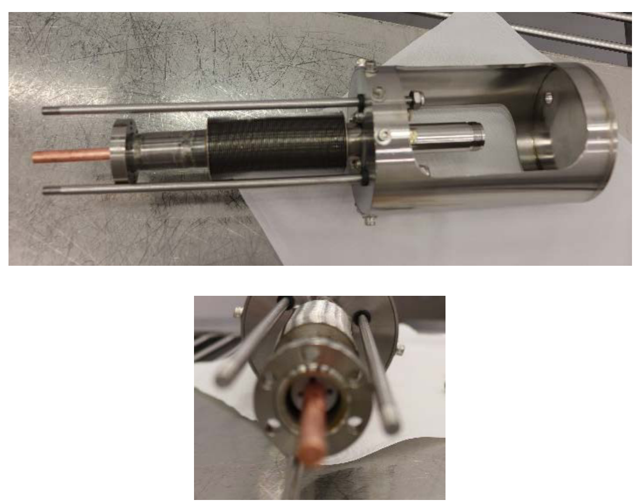

Figure 1: Movable portion of the variable coupler (top). The picture at the bottom shows a front view, with the Teflon ring that is between two copper rods.

The assembly shown in Fig. 1 can be mounted directly onto a flange, which has been modified with threaded mounting holes. Said flange can be the one that mounts directly to the cavity, or to another flange that can be as small as a 2.75" diameter Conflat style flange. This smaller flange is then mounted onto a larger flange to be bolted to the cavity. The latter configuration is shown in Fig. 2, in

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which the assembly of Fig. 1 is mounted onto a 2.75” Conflat flange, attached to a SS flange suitable for XFEL/LCLS-II-style beamline cavity flanges.

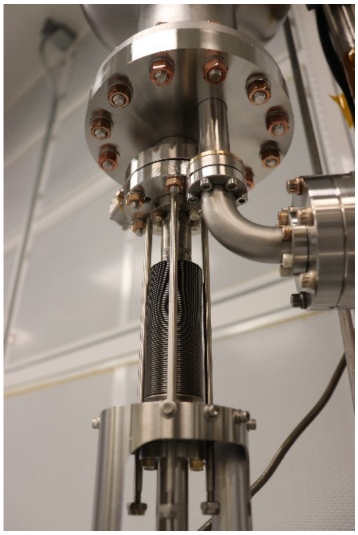

Figure 2: The movable coupler assembly is screwed on a 2.75” Conflat, screwed to a 6” diameter SS flange compatible with XFEL/LCLS-II beamline cavity flanges.

An aluminium bar is bolted to the SS cage and it is connected to another bar above the cavity with two aluminium rods. These bars are made of either brass or aluminium. The top bar has a threaded hole in the center, through which a 0.5” diameter threaded rod is attached. The threaded rod connects with a coupling nut to a longer threaded rod attached to the shaft of a linear motion feedthrough (part number 660006, MDC Vacuum) which is mounted on top of the test stand top-plate. Any type of NEMA 23 stepper motor with a motor driver and controller can be used to operate the linear actuator remotely. One configuration we used is with an integrated stepper motor (DMX-ETH-23, Arcus Technology) remotely controlled via Ethernet, using the software provided by the manufacturer.

The cavity is rigidly mounted to the frame of the test stand, using four long threaded rods that are part of the hardware to seal the top cavity flange. The linear motion of the feedthrough on the top plate translates directly into the linear motion of the antenna. A picture of the setup assembled on a 1.3 GHz single-cell cavity is shown in Fig. 3. Although the variable coupler can also be assembled on the top cavity flange, it is preferable to attach it to the bottom cavity flange to minimize the risk of any particulate falling into the cavity while moving the antenna.

A nice feature of the design is that the length of the antenna section protruding into the cavity can be set differently for different cavities to cover different range of Q_{ext}-values. It has been typically set to allow covering Q_{ext} in the range 10^8-10^{12} for the 1.3-1.5 GHz single-cell cavities for which the coupler has been used so far.

The total cost for the hardware and materials, including linear feedthrough and stepper motor was about $3,000.

Figure 3: Picture of the variable coupler attached to a 1.3 GHz single-cell cavity mounted onto a vertical test stand.

So far, the variable coupler described in this article has been used for thirteen tests of single-cell cavities. In one instance, the test was limited by field emission. In another instance, the length of the antenna was set incorrectly and a $Q_{ext} > 3\times10^9$ was beyond the travel range of the bellow.

During rf cavity testing, the coupler is moved until the reflected power is close to zero for each accelerating field value, corresponding to near critical coupling. In some tests, an rf power of up to ~200 W at 1.3 GHz was coupled into a single-cell cavity at 2 K using this variable coupler.

CONCLUSION

The variable input coupler described in this article has many features in terms of adaptability, cost, number of parts and ease of assembly that make it suitable for routine SRF cavity testing in a vertical cryostat. So far, its use has shown that it also has good reliability and low-risk for particulate contamination of the cavity.

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