WARMING RATE REDUCTION OF THE SARAF RF COUPLERS BY APPLICATION OF A HIGH VOLTAGE DC BIAS

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Abstract

Warming up of the coupler region of the SARAF Half Wave Resonator (HWR) cavities was one of the main limiting factors for long operation at high RF field values. The warming effect is, most likely, associated with multipacting in the coupler region. We have tried to suppress the multipacting discharge in the couplers by application a DC bias to their inner conductors. A bias-T, element that conducts up to 4 kW of 176 MHz RF power and provides DC insulation of the coupler inner conductor, was designed and built for this purpose. First on-line operation showed that the DC bias indeed reduces dramatically the warming rates of most of the cavities by an order of magnitude. Today, coupler warming is no longer the main factor hindering accelerator operation.

THE RF COUPLERS WARMING

During operation of the superconducting 176 MHz HWR cavities in the SARAF Prototype Superconducting Module (PSM) [1], the capacitive RF couplers were warming up. Cooling copper strip lines between the couplers cold windows and the 50 K thermal shield proved not to be adequate [2]. Thus, we were compelled to reduce the field in the 2nd, 3rd and 6th cavities in order to keep the external coupler's temperature below 120 K during long operation (Fig.1). It is noteworthy that only moderate warming is observed at the 5th cavity coupler.

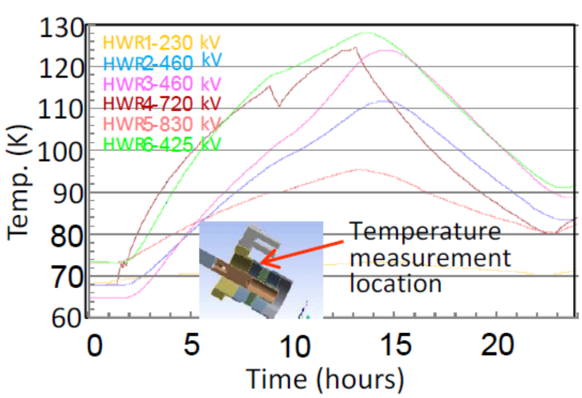

Figure 1: The couplers temperatures during operation of a 1 mA 3.6 MeV proton beam. The cavities voltages are indicated. The location where the temperature is measured is shown in the insert.

It is also worth to note that the warming rates varied on a daily basis. The coupler temperatures taken during two weeks of daily operation are shown in Fig. 2. Two different accelerator setups, involving operation of six and three cavities, were used during this period [3]. This daily variation of the warming rates prompted us to conclude that the origin of the problem is multipacting.

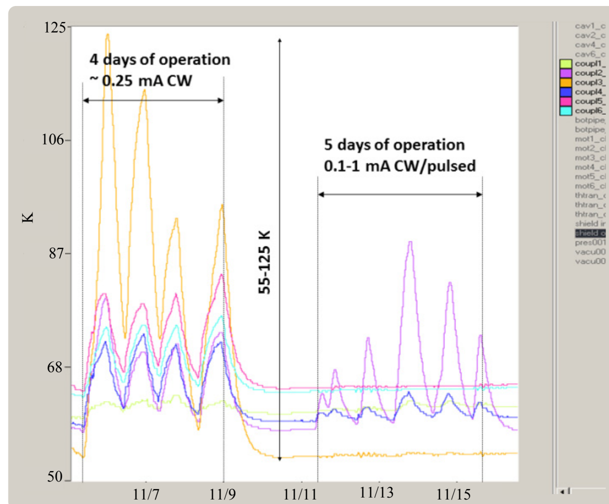

Figure 2: Daily variation of the warming rates during operation at the same field values. The couplers warmed up during day time operation and cooled overnight.

It is known from the literature [4, 5] that application of a DC bias to the coupler inner conductor should suppress multipacting discharge. We therefore decided to test this idea at the SARAF couplers.

DEVELOPMENT OF A BIAS-T

A three port network bias-T adaptor was designed and built in order to apply a high voltage DC bias on the inner conductor without disturbing other components, such as the RF amplifiers.

Conceptually, the bias-T can be viewed as a simple network which includes: 1. an ideal capacitor that allows AC current through but blocks the DC bias and 2. an ideal inductor that blocks AC but allows DC (Fig. 3). The low frequency port is used to set the bias; the high frequency port passes the radio frequency signals but blocks the DC bias.

The combined port is connected to the coupler.

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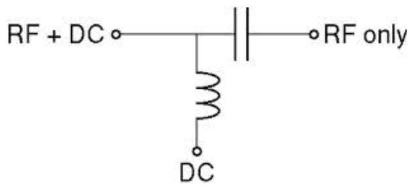

Figure 3: Bias-T basic scheme.

A bias-T adaptor is generally a simple device. However, the special requirements in the case of the SARAF couplers (high RF power (4kW), high DC voltage (1kV)) led to significant efforts dedicated to development of the device.

The impedance of the capacitor (X_C) is chosen to be much less than $Z_0 = 50\Omega$ (characteristic impedance of the transmission line) and the impedance of the inductor (X_L) is chosen to be much greater than Z_0.

$$|X_C| = \frac{1}{\omega C} = \frac{1}{2\pi f C} \ll Z_0$$

$$|X_L| = \omega L = 2\pi f L \gg Z_0$$

The capacitors and the coil are required to meet high current requirements since the maximum power (4kW) passes through the bias-T and generates a maximum current of 9 A. It is especially important that the inductor be rated for the necessary current and should optimally have a minimum self-resonant frequency much higher than 176 MHz.

Several bias-T prototypes were built and tested. The electrical diagram of the final version is given in Fig. 4. The following components were selected: C1-C4, 0.39μF multi-layer RF capacitors (ATC100E391); L1, a 0.5 μH inductor single-layer coil, handmade of 2 mm copper wire; and C5, a 10 nF capacitor, used for insulation of the DC supply.

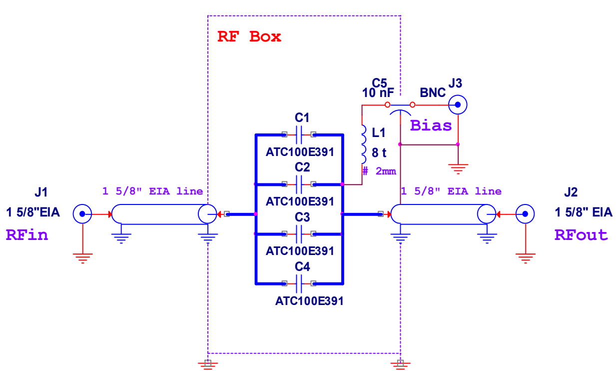

Figure 4: Electrical diagram of the final version of a 4 kW bias-T adaptor.

The final bias-T version (Fig. 5, left) consists of a square copper box welded to a 1 5/8" copper tube. The square shape was chosen to prevent electrical breakdown. 1 5/8" RF flange coaxial male connectors are installed on the tube ends. The two opposite sides of the box can be removed for access to the inner parts. Several holes are drilled in the box sides for air ventilation. The inner conductor consists of two copper tubes isolated by a Teflon insulator. The electrical connection between the two tubes is done by the four C1-C4 capacitors. A DC bias is applied via the L1 inductor and the C5 capacitor, connected to a BNC connector that is installed on the box side.

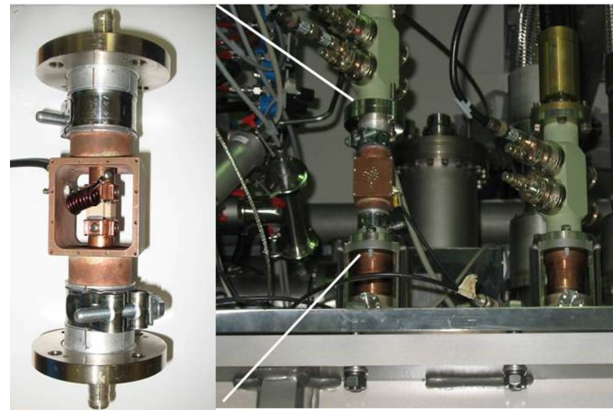

Figure 5: Left. The final version of the bias-T adaptor. Right. The adaptor installed on the PSM top.

All the bias-T adaptors were tested during a few hours with a 4 kW RF amplifier on a 50 ohm dummy load resistor (without DC). The results of the off-line tests were satisfactory. No any sign of burning or significant heating were observed. The main characteristics of the bias-T adaptor are shown in the table below.

Table 1. The main characteristic of the bias-T adaptors.

Isolation	60 dB
Insertion Loss	0.1 dB
VSWR	1.1
Maximum DC Voltage	1000 V
Maximum AC Current	12A
Maximum tested RF power	4 kW

Six bias-T units for the six HWRs were installed adjacent to the room temperature coupler windows on the PSM top lead (Fig. 5, right). High voltage from a programmable Spellman HV power supply was distributed to all bias-T units.

FIRST ON-LINE TESTS

Performance of the bias-T was tested in a limited range during beam experiments. For example, the effect of a 1 kV bias application during a 2 MeV, 1.5 mA proton experiment [6] is shown in Fig. 6. In this low energy experiment only three cavities were operational and only two of them (HWR2 and HWR4) had significant fields. Dramatic reduction in warming up rate is observed. The effect is especially strong for coupler #2. Previous tests with a prototype [3] demonstrated that the polarity of the DC bias has no significance.

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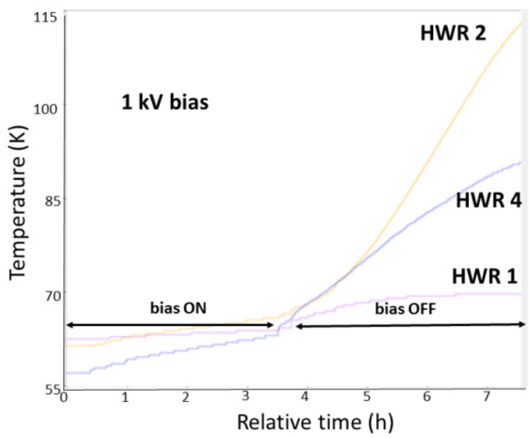

Figure 6: The effect of applying 1 kV bias on the 2nd and 4th cavities.

In another experiment, with a 5.6 MeV low current deuteron beam, the third and fifth cavities were operated as well. It is interesting to observe that the HWR5 coupler is basically non-sensitive to the DC bias application while, for example, the warming rate in the HWR3 coupler was reduced by an order of magnitude (Fig. 7). As was mentioned earlier HWR5 exhibited moderated warming up rates (Fig. 1). It is possible that HWR5 does not suffer from multipacting. Disassembling and examining of the couplers may lead to better understanding of this behaviour.

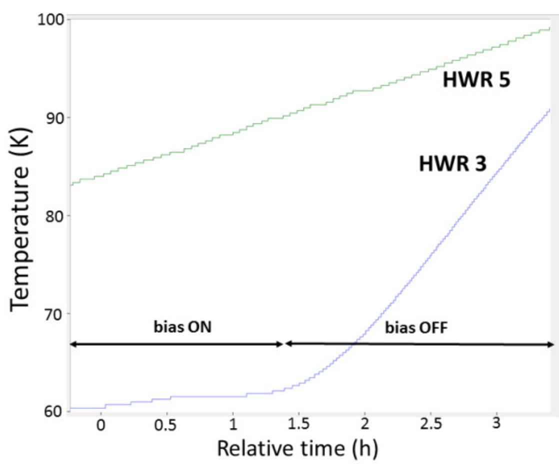

Figure 7: Non-sensitivity of the 5th cavity to DC bias application. The strong effect in the 3d cavity is shown for comparison.

SUMMARY

4 kW bias-T adaptors were designed, built and tested at SARAF in order to reduce the warming of the RF couplers. Reduction of the warming up rates by DC bias is expected due to offsetting of the multipacting process. The first on-line experiments showed that the DC bias indeed reduces dramatically the warming rates of most of the cavities. The coupler of the fifth cavity exhibited a moderate warming rate originally, and was not affected by the bias application. It is possible that its warming up is due to another mechanism.

Higher DC voltage will be tested in the future for further improvement of the multipacting suppression effect. In parallel, we consider improving the coupler cooling by introducing much thicker copper strips between the thermal shield and the couplers bodies. More sophisticated proposals for cooling improvement are also considered [2].

From the beam operation point of view, coupler warming is no longer the main factor hindering accelerator operation. The next main challenge for the SARAF linac team will be the reduction of the HWR cavities sensitivity to mechanical disturbances [7, 8].

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