RF power tests of LEP2 main couplers on a single cell superconducting cavity

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Abstract

To determine the power capability of the input couplers for the LEP2 superconducting (SC) cavities a new test set-up has been built. The new set-up permits tests at high RF power levels under realistic conditions (cooled-down SC cavity). The couplers have been exposed to high RF power in matched and unmatched CW conditions as well as in pulsed operation. Power levels of more than 500 kW CW have been reached.

1. INTRODUCTION

For LEP2, the nominal RF power per SC cavity at full beam current (under matched conditions) is 120 kW at 352 MHz. However, in reality, even at full beam current, the input coupler may be exposed to standing waves, since in order to avoid ponderomotive instabilities the cavities may not be detuned [1], i.e. the reactive beam loading will not be compensated. The equivalent power (travelling-wave power producing the same field as the peak field on the coupler line) will therefore increase to more than 200 kW. In order to determine the power capability of the coupler, tests at higher RF power have been envisaged. However, on our original test set-up (four-cell LEP2 type cavity) power levels of more than 300 kW CW under matched conditions could not be reached. This was due to relatively high radiation levels and limitations of coaxial RF components (elbows, RF terminating load) and of the cryogenic system. Therefore, a new experimental set-up has been implemented with a single cell cavity permitting even higher RF power tests to be performed in CW as well as in pulsed conditions.

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2. LAYOUT OF THE LEP2 COUPLERS

Details of the coupler design have already been described earlier [2,3]. Therefore, only a short summary of the main topics will be repeated here:

Fixed couplers of the open-ended coaxial line type with DC bias are used (see Figure 1). They consist of five room temperature functional parts: a wave-guide input, a "doorknob" waveguide-coaxial transition, a cylindrical ceramic window, an air cooled inner conductor (also called antenna, which couples to the cavity), and an outer conductor equipped with

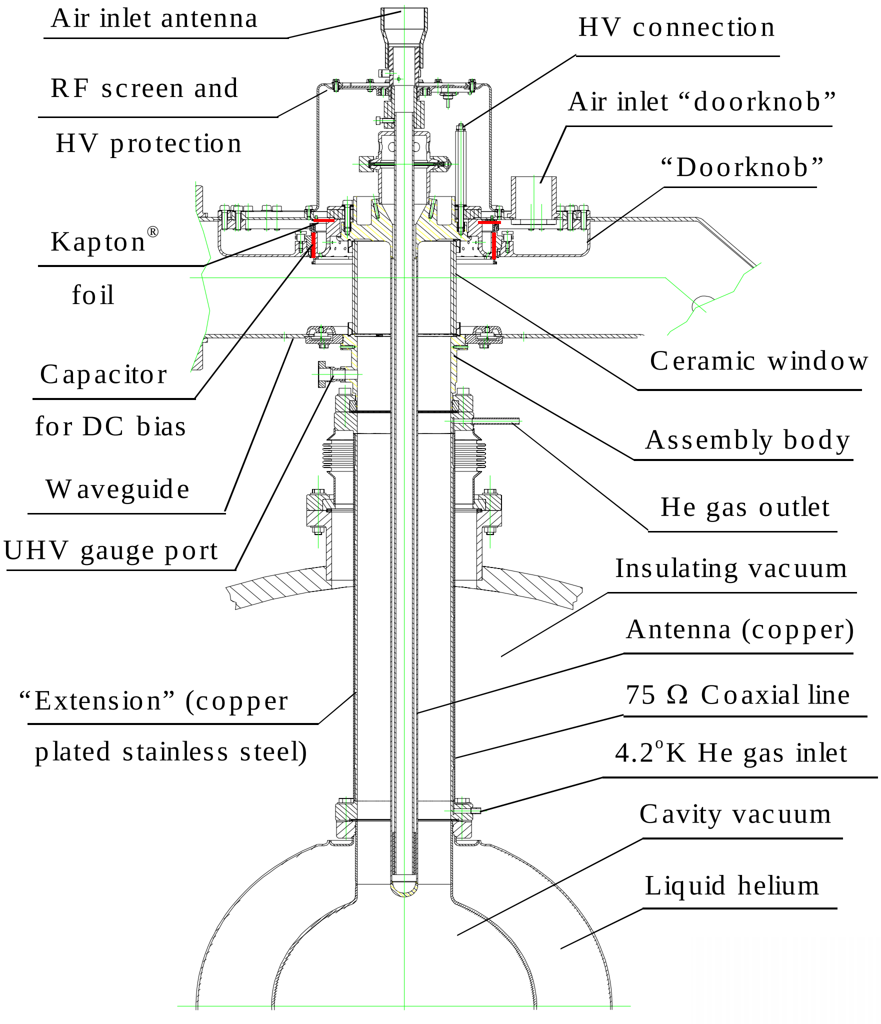


Figure 1 Layout of the 75 Ω fixed coupler for LEP2

an electron pick-up and a port for the vacuum gauge. A helium gas cooled "extension" prolongs the outer conductor via a flange connection into the cryostat down to the cavity port. Modified ConFlat® vacuum seals are used to permit at the same time good RF contacts and UHV joint. DC bias of 2.5 kV is applied to the inner conductor in order to suppress multipactor and reduce "deconditioning". A coaxial capacitor mounted into the "doorknob" (high RF current) separates the HV potential of the antenna from the "doorknob". An additional capacitor (disk of copper plated Kapton® foil) is placed between the base of the antenna and the waveguide (low RF current).

3. RF POWER TEST SET-UP

The new experimental set-up consists of a single cell superconducting cavity equipped with two 75 Ω fixed couplers. Details are shown in Figure 2.

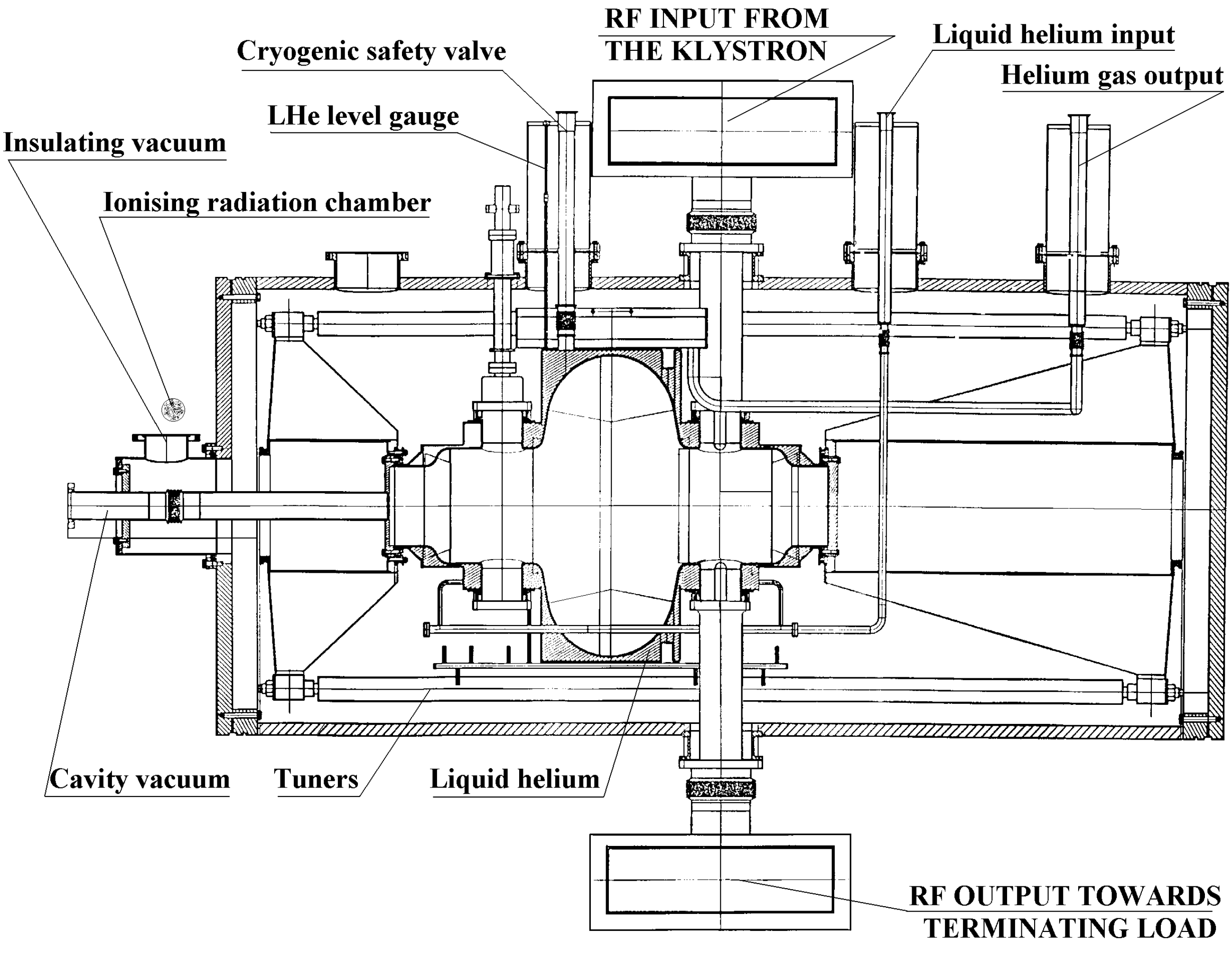


Figure 2 Single cell cavity with input and output coupler

The input coupler is connected via WR 2300 waveguides (half and full height sections) to the klystron. The output coupler feeds a 1 MW terminating waveguide load. The antenna length of the couplers has been increased by ~10 mm in order to decrease the external Q of the cavity ($Q_{ext} \cong 10^6$ per coupler), thus lowering the ionising radiation background due to the cavity field. Since both couplers produce the same external Q, practically all forward RF power under CW conditions is transferred into the load.
To monitor continuously the radiation background, two ionising radiation chambers have been installed on both sides of the cavity. By using a single cell superconducting cavity (instead of the previously used four-cell cavity) less cryogenic power is required and also the ionising radiation levels are reduced. Indeed, the measured radiation levels at 300 kW have been diminished by almost three orders of magnitude compared to the four-cell cavity.

4. RF CONDITIONING OF THE COUPLERS

The ceramic windows of the couplers were baked out under vacuum for 24 hours at 200^{o}C on the test cavity. This procedure facilitates efficiently the conditioning of the couplers [4]. Then the cavity was cooled down to liquid helium temperature and our standard RF conditioning procedure applied: first RF pulsing (the “extensions” not being cooled down), second cycling the RF power (controlled by computer and an analog feedback loop, adjusting the RF power as function of the vacuum level) with the “extensions” now being cooled by helium gas. At about 375 kW a strong vacuum activity with frequent RF switch-offs prevented further RF power increase for several days. Only by applying a DC bias of 2.5 kV to the antenna of the coupler could this difficult multipactor level be passed. After that, more than 500 kW were reached without vacuum activity. Operation with DC bias was then used for all CW or pulsed tests at high RF power.

5. HIGH RF POWER TESTS

5.1 CW Operation

The cavity field as function of the CW forward power is shown in Figure 3. The field increase is not exactly proportional to the square root of the power. This can be explained by the thermal expansion of the coupler antenna (the present air cooling is not designed for these high power levels), resulting in a stronger coupling (lower external Q) at higher power levels. But also changes in the input VSWR of the terminating load or in the helium pressure in the cryostat are affecting the cavity field. More detailed measurements would be required to analyse the influence of these different factors.

A long-term test at 445 kW CW has been performed for about 48 hours. During this run the field in the cavity was 7.4 MV/m with a coupler vacuum of about 5 10^{-10} Torr and a temperature near to the RF ceramic windows approaching 50 ^{o}C.

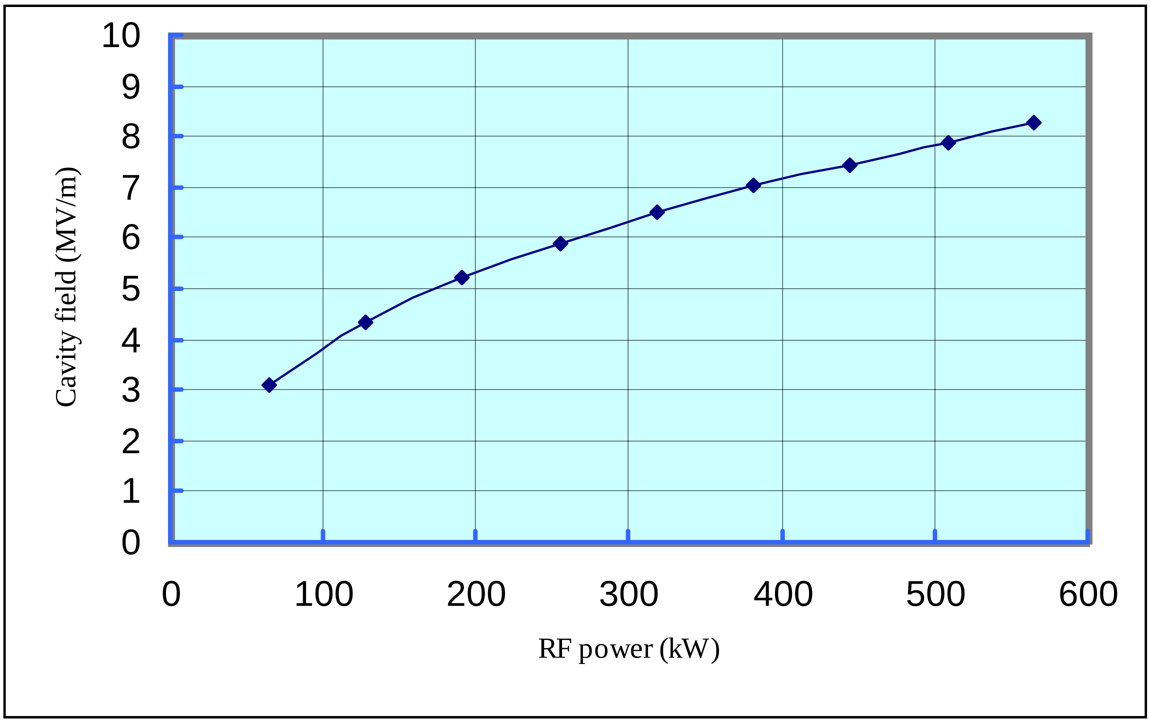
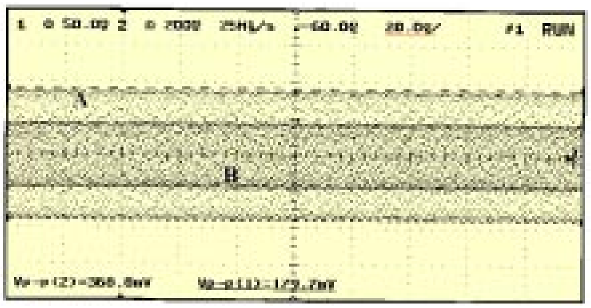


Figure 3 Cavity field versus RF power

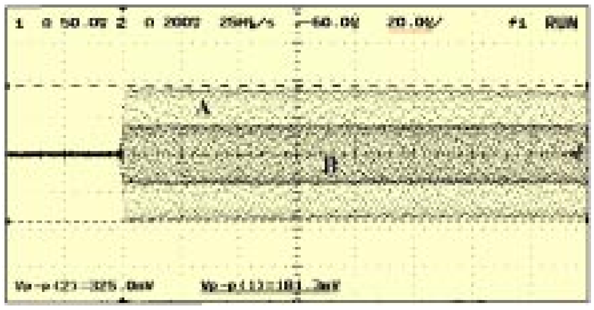
For more than two hours a constant RF power of 565 kW CW has been applied. During this time the field in the cavity reached 8.3 MV/m. The coupler vacuum went up from 1.5 10^{-10} Torr (without RF) to 1.1 10^{-9} Torr due to the increased temperature (63 ^{o}C measured at the RF ceramic windows) and subsequent outgassing. Ionising radiation readings were less than 20 rad/h. Higher power levels could not be reached with the present set-up due to limitations of the cryogenic system.
The RF power at high power levels was determined by calorimetric measurements on the waveguide terminating load.

5.2 Pulsed Operation

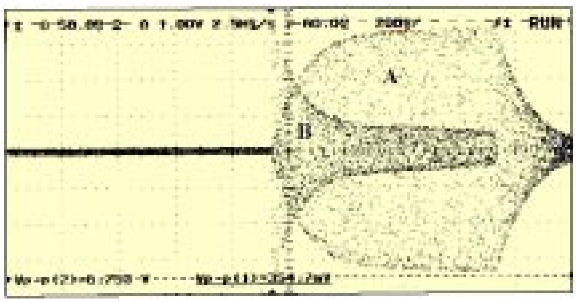
RF pulses with a duration of 800 μs and a rise time of less than 5 μs have been fed through the single cell superconducting cavity. Pulsed forward, reflected and klystron drive power as well as the cavity field were recorded with a fast digital oscilloscope. Figure 4 illustrates the results. The picture showing the CW measurements at 565 kW has been used for calibration of the forward power in pulsed mode.



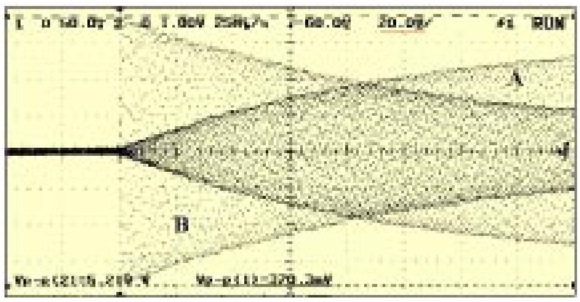
565 kW CW RF power
A - Forward power at the input coupler
B - Klystron drive power
Time scale 20 μs / div



Pulsed RF power
A - Forward power at the input coupler
B - Klystron drive power
Time scale 20 μs / div



Pulsed RF power
A - Cavity field
B - Reflected RF power
Time scale 200 μs / div



Pulsed RF power
A - Cavity field
B - Reflected RF power
Time scale 20 μs / div

Figure 4 High RF power pulsed operation

A forward power of 575 kW has been reached on the input coupler with a corresponding peak equivalent power of more than 2 MW at the start of the pulse. The maximum cavity field measured in pulsed operation was 8.7 MV/m.

5.3 Operation with Detuned Cavity

The single cell superconducting cavity could be detuned under stable CW operating conditions at a forward RF power of 380 kW up to ±40^{o} (between forward and cavity voltage) resulting in a reflection coefficient of more than 0.6. The equivalent peak power on the input coupler corresponding to this reflection coefficient was higher than 1 MW.
The cavity field measured with detuned cavity was between 6.3 and 7 MV/m. Further dephasing at this forward power level was not possible due to cavity field instabilities.

6. VISUAL INSPECTION AFTER THE HIGH POWER TESTS

After performing these high RF power tests a visual inspection of the RF components of the coupler was made. No traces of arcing or overheating have been found on:

- the external surfaces exposed to RF (waveguides, doorknobs, capacitors for DC bias, ceramic windows, etc.)
- the coupler antennae, the copper plated extensions or the vacuum seals
- the superconducting cavity coupler ports.

Concerning the vacuum side of the ceramic windows, no traces of arcing have been found on the output coupler. On the input coupler one dark spot of yet unidentified origin (with a diameter of about 5 mm) on the border of the ceramic in contact with the assembly body has been noticed. To determine the nature of this spot the RF ceramic window would have to be cut and analysed. However, since during the long-term high RF power tests no signs of vacuum problem or overheating occurred, we intend to continue with additional tests in the same experimental set-up.

7. CONCLUSION

With the new experimental test set-up, using a single cell superconducting cavity, an RF power of more than 500 kW in CW and pulsed operating conditions has been transferred from the input to the output coupler via the cavity. The input coupler has been exposed to more than 1 MW equivalent power under CW operation with a detuned cavity. In pulsed operation, at the beginning of cavity filling the equivalent peak RF power on the input coupler was higher than 2 MW.

Acknowledgments

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