**EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH**
CERN — SL

**CERN SL-99-074 HRF**

# THE VARIABLE POWER COUPLER FOR THE LHC SUPERCONDUCTING CAVITY

**H.P. Kindermann and M. Stirbet**

## Abstract

Variable input couplers, providing a remotely controlled change of external Q by an order of magnitude under power, are required for the 400 MHz LHC superconducting cavities. These couplers must handle a forward power of 120 kW average and 180 kW pulsed with a large variety of load conditions up to full reflection. A summary of the LHC prototype coupler design (using d.c. bias on the main coupler transmission line to suppress multipactor) and of the RF power tests on a normal conducting test cavity will be given. The same couplers now have been RF power tested on a prototype superconducting LHC bi-module. During both of these RF tests, multipactor events have also been observed in the variable coupler part - outside the main coupler line - which cannot be suppressed by the actual d.c. bias. An improved design with a second d.c. bias will therefore be implemented. Nevertheless, after the usual RF conditioning, these prototype couplers have successfully passed all RF tests at power levels well above the LHC requirements.

*Presented at 9th Workshop on RF Superconductivity,*
*Santa Fe, USA, 1-5 November 1999*

Geneva, Switzerland
November 1999

# THE VARIABLE POWER COUPLER FOR THE LHC SUPERCONDUCTING CAVITY

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*Abstract*

Variable input couplers, providing a remotely controlled change of external Q by an order of magnitude under power, are required for the 400 MHz LHC superconducting cavities. These couplers must handle a forward power of 120 kW average and 180 kW pulsed with a large variety of load conditions up to full reflection. A summary of the LHC prototype coupler design (using d.c. bias on the main coupler transmission line to suppress multipactor) and of the RF power tests on a normal conducting test cavity will be given. The same couplers now have been RF power tested on a prototype superconducting LHC bi-module. During both of these RF tests, multipactor events have also been observed in the variable coupler part - outside the main coupler line - which cannot be suppressed by the actual d.c. bias. An improved design with a second d.c. bias will therefore be implemented. Nevertheless, after the usual RF conditioning, these prototype couplers have successfully passed all RF tests at power levels well above the LHC requirements.

## 1 INTRODUCTION

The LHC variable coupler is an upgraded version of the LEP2 fixed coupler (288 couplers in operation).

The general layout and some improvements to the LEP2 coupler have already been described in detail [1], [2], [3], [4]. The principle of the LHC variable coupler has been mentioned in [3]. A summary of the layout, technical problems and the first results of RF power measurements made with the two LHC power coupler prototypes on a NC (normal conducting) test cavity has been presented in [5]. More details concerning these aspects will be described in this paper.

The same variable couplers have since been prepared for SC (superconducting) cavities and successfully tested on the SC LHC prototype bi-module. However, the RF measurements made on both the NC and SC cavity revealed the existence of a multipactor, which might be dangerous during operation as it can appear at any forward power level above 1 kW and cannot be suppressed with the d.c. bias on the existing coupler. An improved design is therefore being implemented on one of the LHC couplers.

## 2 POWER REQUIREMENTS

A variable power coupler is needed for the LHC to optimise the different modes of operation for the SC cavities at injection, acceleration and storage. These couplers must provide a remotely controlled change of external Q by an order of magnitude under power. During hadron acceleration an RF power of only 32 kW CW at 400 MHz is delivered to the beam.

However, to compensate for beam loading effects, forward power levels of 120 kW CW and 180 kW pulsed (for about 50 ms) are required. Since practically all forward power is reflected, the couplers are exposed to equivalent power levels of 480 kW CW and 720 kW pulsed.

## 3 VARIABLE COUPLER DESIGN

The coupler cross section is shown in Fig. 1.

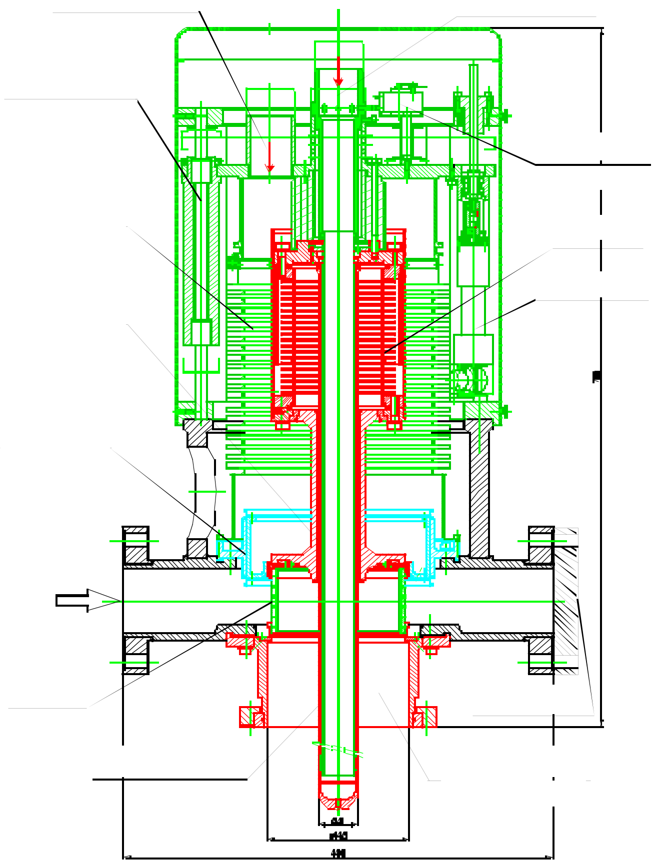

Figure 1: Cross section of the LHC variable coupler

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The RF power enters a waveguide port and passes through a cylindrical ceramic window into a 75 Ω coaxial line coupling to the cavity. Solid copper rings (instead of Kovar® ferrules) are brazed on the edges of the ceramic to ensure better thermal conductivity and reduced RF power losses. To diminish multipactor a thin layer of titanium is sputtered onto the vacuum side of the ceramic. A reduced height waveguide directly matches to the coaxial line and thus avoids the "doorknob" device. A d.c. bias voltage of 3 kV is applied to the antenna (inner conductor of the 75 Ω coaxial line), in order to suppress multipactor during operation. To insulate the high voltage from ground a coaxial capacitor is mounted in the waveguide. This coaxial version has been developed and used at CERN for tetrode amplifiers operating at 10 kV for many years. It also ensures reliable operation for the LEP2 couplers.

Two forced air-cooling systems are provided: one for the antenna and the other one for the ceramic and other components of the coupler. Helium gas at 4.5 °K is used to cool down the outer-conductor (double-walled copper plated stainless steel) of the 75 Ω coaxial line.

The position of the antenna is monitored via a linear potentiometer.

To control coupler conditioning and permit safe operation a UHV gauge, an electron pick-up antenna, optical arc detectors, temperature probes and air pressure sensors are used. RF screening and HV protection are provided by bellows in air.

Modified ConFlat® vacuum seals are used for both good RF contacts and UHV joints. On the variable part Helicoflex® seals are preferred.

A photo of the couplers mounted on a bi-module is presented in Fig.2.

## 4 RF POWER TESTS ON A NC CAVITY

Two prototype LHC couplers have been manufactured, assembled and vacuum tested. Low RF power measurements have been performed to verify and optimise the matching between the waveguide and the coaxial part at different antenna positions (matching better than 28 dB).

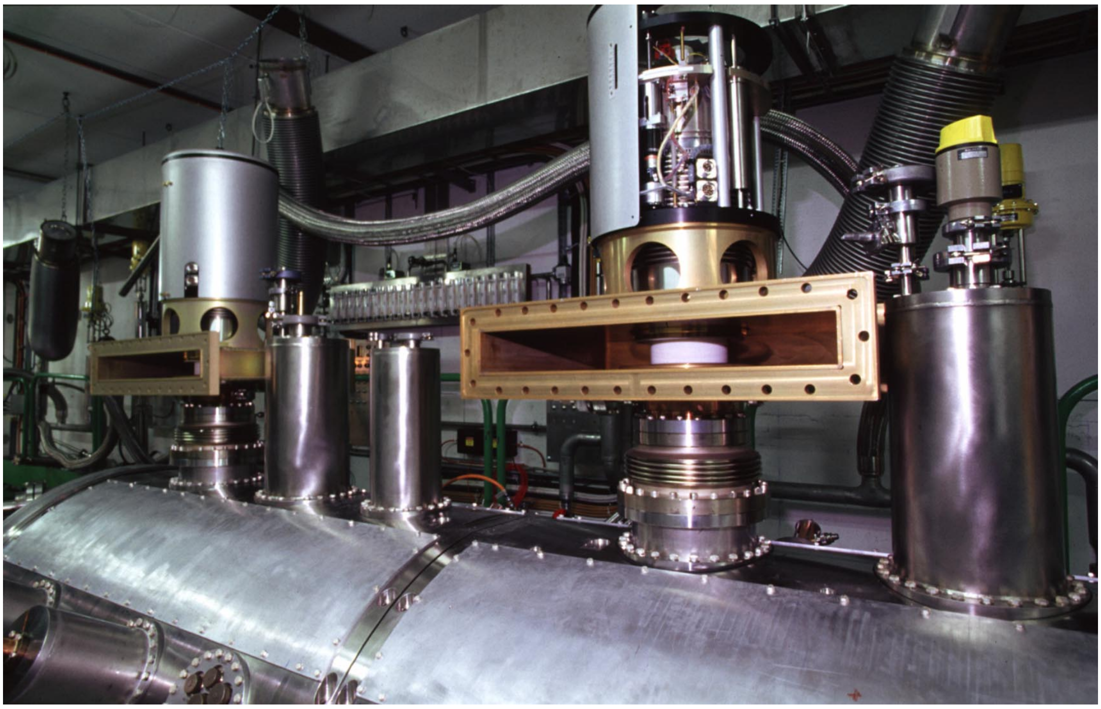

Figure 2: LHC variable couplers on a SC bi-module.

The change in coupling is made by an axial movement of the antenna (60 mm stroke), making use of bellows of about $\lambda/4$ length. A second low impedance $\lambda/4$ line transforms the current in the bellows to low values, thus avoiding copper plating of this stainless steel part.

The antenna movement is made with a high precision driving device using linear bearings, satellite rollers screw and a d.c. motor with gearbox and electromagnetic brake.

The two couplers have been mounted on a 400 MHz copper test cavity to do high RF power tests at room temperature.

The coupler design allows horizontal mounting and operation, even though on the LHC cavity the couplers will work in the vertical position. A 500 kW klystron [6] has been connected to the input coupler via a circulator.

The output coupler has been terminated with either a 1 MW waveguide load or an adjustable short-circuit.

Our standard RF conditioning procedure has been applied :

- Use of a fast analogue loop controlling the RF power as function of vacuum pressure (better than $5\ 10^{-7}$ mbar).
- RF pulsing with different pulse duration and duty cycles.
- CW RF power ramping.

Under matched conditions, strong multipactor has been observed at power levels of less than 15 kW.

In contrast to the usual multipactor on the main coaxial line, vacuum pressure rise has been observed without detecting electrons at the electron pick-up antenna. This multipactor could not be suppressed by the d.c. bias. Therefore we suspected that it occurs in the low impedance $\lambda/4$ line where the inner and the outer conductor are at the same d.c. potential.

After crossing this low power multipactor, the couplers have been conditioned up to 500 kW CW, passing several intermediate multipactor levels which could all be suppressed by the 3 kV d.c. bias. Long term RF power tests have been performed in travelling wave : at 400 kW for more than 150 hours and at 500 kW (maximum klystron power) for about 50 hours.

To test the power capabilities of the LHC couplers for pulsed operation at full reflection, the output coupler was terminated with an adjustable short-circuit.

Conditioning at any phase and any coupling has been achieved up to the maximum klystron power, crossing additional multipactor levels. Up to 500 kW forward power (2 MW equivalent peak power) has been reached with pulses of 50 ms duration and of 10% duty cycle.

After these tests the couplers have been disassembled and visually examined. No traces of damage could be found on the surfaces exposed to RF, only slight colour changes in some regions of the antenna have been observed, especially near the end of the low impedance $\lambda/4$-line, supposed to be due to the above mentioned multipactor.

## 5 RF POWER TESTS ON A SC CAVITY

The components of the coupler exposed to high vacuum have been carefully rinsed (high water pressure and alcohol) then dried under vacuum and assembled in a clean room class 100. The couplers were put again on the NC test cavity and RF conditioned up to 250 kW forward power CW under matched conditions, and pulsed under full reflection for different phases and antenna positions.

During RF conditioning the multipactor in the low impedance $\lambda/4$-line appeared again, but the conditioning process was faster (under matched conditions, up to 30 kW in only 6 hours instead of 18 hours).

The conditioned couplers were then stored under nitrogen before being installed on the SC cavity.

After cooling down the SC cavity, the external Q factor of both couplers was measured for different antenna positions. A variation of more than one order of magnitude has been achieved as is illustrated in Fig. 3.

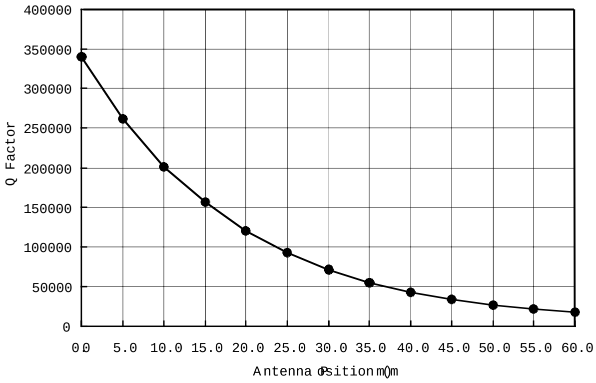


Figure 3: External Q as function of the antenna position.

Each coupler was RF conditioned using our standard procedure starting with loose coupling. The multipactor in the low impedance $\lambda/4$-line (strong vacuum bursts without electron activity at the electron pick-up) has again been observed.

This multipactor was conditioned in several hours and then it was possible to reach the forward power required for the maximum cavity voltage of 2.5 MV (Fig. 4.).

Changing to stronger coupling (by moving the antenna in steps of 5 mm) required for RF conditioning of the multipactor in the low impedance $\lambda/4$-line (several minutes) as well as for other multipactor levels (about one hour) up to 300 kW forward power.

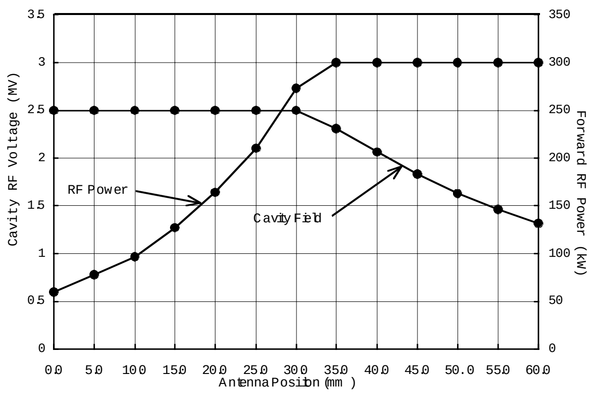


Figure 4: Forward RF power and cavity RF voltage.

The 300 kW CW power level has been maintained for several hours. Higher power levels were not possible due to the terminating load of the circulator. RF conditioning of the couplers has also been made with a detuned cavity, to shift the maximum of the RF standing wave voltage (responsible for multipactor) along the coaxial line.

## 6 IMPROVEMENTS

Technical problems occurred during the different treatments to some of the ceramic windows (out-baking at 200 °C, titanium coating and e.b. welding). Vacuum leaks also developed in the low impedance λ/4 line during out-baking of the coupler.

Solutions have been found:

- Improved brazing procedure and modified copper rings.
- Titanium coating with improved electrodes to ensure a more homogeneous field distribution.
- e.b. welding with adequate screening to avoid local overheating.
- Forged copper for the λ/4 line.

The multipactor in the low impedance λ/4-line could happen at any forward power level above 1 kW depending on the reflection factor of the cavity. To increase the reliability of the LHC coupler during operation this multipactor should be suppressed and a second d.c. bias will therefore be implemented, as shown in Fig. 5. The second capacitor is placed between the flange of the low impedance λ/4 line and one of the bellows, at the region where the RF current is minimum.

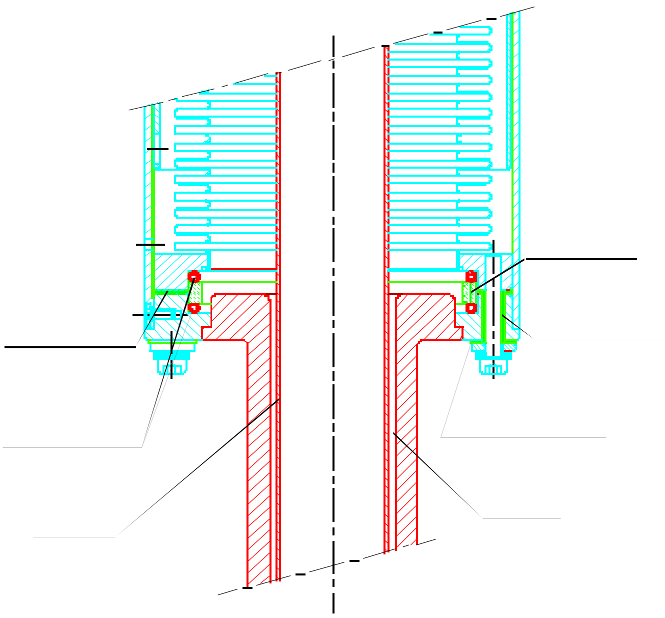

Figure 5: D.c. bias for the low impedance λ/4 line.

As the RF voltage generating multipactor in this region is quite small below 15 kW travelling wave on the main line, a d.c. voltage of about 200 V will be enough to suppress this multipactor. The capacitor consists of a ceramic ring on the vacuum side and of radiation and temperature resistant insulating disk, washers and tubes on the air side. This assembly has already been tested for electrical, temperature and vacuum performances.

## 7 CONCLUSION

Two prototype variable power couplers for the LHC superconducting cavity have been manufactured.

Solutions to the technical problems that occurred during manufacturing have been found. To suppress multipactor in a region where the main d.c. bias is not effective, a second d.c. bias system has been designed and is being mounted now on one of the prototype LHC couplers.

After the usual RF conditioning, the prototype couplers have successfully passed all RF tests at power levels well above the LHC requirements.

## 8 ACKNOWLEDGEMENTS

The authors wish to thank all the persons who participated in getting the new LHC coupler prototypes manufactured and the 400 MHz test set-ups completed. We are especially grateful to E. Haebel for active participation in LHC coupler and test cavity design, E. Chiaveri for providing the single cell 400 MHz copper test cavity, J. Genest for its mechanical design and also for supplying the helium cooled outer conductors, R. Gueissaz for mechanical design and follow up of the coupler manufacturing, M. Candolfi and G. Pistolato for the assembly of the couplers, N. Hilleret, M. Jimenez and G. Mathis for the bake-out procedures and vacuum systems, H. Frischholz for providing the 400 MHz RF power plant, B. Lambert, M. Prax, P. Martinez Yanez and S. Grillot for the careful installation of the test set-up, E. Montesinos for providing the electronic drive system for the antenna movement and R. Losito for his assistance during tests on the superconducting bi-module.

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