STATUS OF RF POWER COUPLERS FOR SUPERCONDUCTING CAVITIES AT CERN

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Abstract

For LEP2 fixed RF power couplers of the open-ended coaxial line type with d.c. bias are used. The nominal power under matched conditions is about 120 kW at 352 MHz. However, to avoid ponderomotive instabilities [1], the cavities may not be detuned, i.e. the reactive beam loading cannot be compensated. The coupler is therefore exposed to standing waves with an equivalent power (travelling-wave (TW) producing the same field as the peak fields on the coupler line) of more than 200 kW. The final design of these couplers, their conditioning sequence and their actual performance are presented.

For LHC a motor-driven mobile coupler is required to change the external cavity Q by a factor of four between beam injection and storage. During injection the forward power levels at 400 MHz are about 120 kW CW (for approximately 20 minutes) and 180 kW peak (for several milliseconds). Since practically all this RF power is reflected the equivalent travelling power is 480 kW and 720 kW, respectively. These couplers will be also provided with d.c. bias to suppress multipacting and "deconditioning".

1 LEP2 POWER COUPLER

Technical details concerning the LEP2 power coupler have already been published [2], [3] and will not be repeated here. However, some details will be mentioned again when necessary for a comprehensive description.

1.1 General Description of the Coupler Design

The design of the LEP2 power coupler is shown in Figure 1. The coupler consists of five room temperature functional parts: a waveguide input, a "doorknob" waveguide-coaxial transition, a cylindrical ceramic window, an air cooled inner conductor (antenna, coupling electrically to the cavity) and an outer conductor equipped with an electron pick-up and a port for a vacuum gauge. An "extension" prolongs the outer conductor via a flange connection into the cryostat down to the cavity RF input port. Modified Conflat® vacuum seals are used to provide at the same time good RF contact and UHV joint.

D.c. bias of 2.5 kV is applied to suppress multipactor due to "deconditioning". To separate the HV potential of the antenna from the waveguide a coaxial capacitor is mounted into the RF current path of the "doorknob". To use existing components its inner cylinder had to be insulated also from the waveguide by a copper plated Kapton® disk which is only exposed to the small RF current generated by the leakage through the main capacitor.

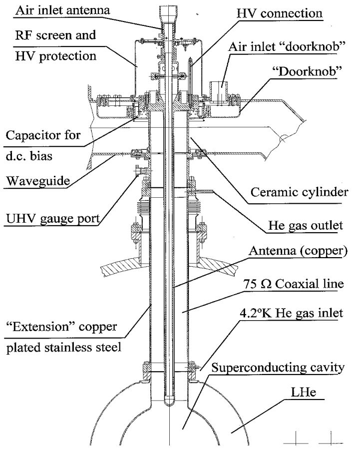

Figure: 1 Design of the 75 Ω fixed coupler for LEP2

Two independent air cooling circuits are used to cool the antenna and the "doorknob"-capacitor-ceramic assembly. The required air pressure for the antenna cooling is relatively high (> 700 mm water column) to permit an air flow of more than 0.5 m^3/minute, necessary to provide good heat transfer by convection and low temperature increase of the cooling air. At 120 kW travelling wave power the temperature increase at the antenna tip is less than 10°C.

Figure 2 shows the couplers mounted on the module and their connection to the waveguide.

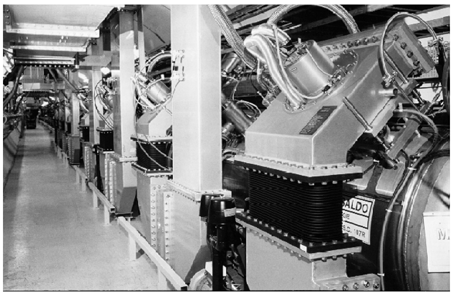

Figure: 2 Couplers mounted on LEP2 modules

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[1] *on leave from Inst. of Atomic Physics, Bucharest, Romania*

[2] *on leave from Budker Institute of Nuclear Physics, Novosibirsk, Russia*

1.2 Assembly of Outer Conductor, Antenna and Ceramic Cylinder

The copper antenna (inner conductor of the 75 Ω coaxial line) is electron beam welded to its copper body. The outer conductor is also made from copper. Stainless steel flanges are brazed onto it. Copper plated stainless steel rings are brazed to both the antenna body and the outer conductor. The ceramic cylinder is equipped with copper plated Kovar® ferrules. Copper plating of the Kovar® parts is very important, since due to the high permeability (small skin depth) and high resistivity the RF losses are extremely high. At the end of these rings and ferrules a band of about 3 mm is kept free of copper to allow for TIG welding of the ceramic window between the antenna body and the outer conductor.

The ceramic window undergoes a thermal cycling (twice 250°C with a ramping of 30°C/hour) and is then titanium coated (d.c. resistance after coating 10-20 MΩ in vacuum) to reduce the risk of multipactor.

The three components are carefully cleaned before pre-assembly (in a clean room) for welding: the outer conductor and antenna body by high pressure water (100 bar), the window by lower pressure alcohol (3 bar) and the antenna with a clean room cloth. After assembly the coupler is closed with a metallic cover and filled with argon gas at a slight over-pressure which is maintained during transportation to the TIG welding workshop to prevent dust penetration.

1.3 "Extension" (Helium Gas cooled Outer Conductor)

The stainless steel (316 LN) outer conductor of the 75 Ω coaxial line penetrating into the cryostat is double walled to allow for cooling by cold helium gas. The inner cylinder is machined from a forged piece to avoid the risk of damage of TIG welding or brazing seams exposed to RF power, machine vacuum and liquid helium temperature. The outer cylinder and bellows are assembled by TIG welding. The "extension" is then heat treated at 950°C for two hours (ramping rate of 300°C/hour) to release mechanical stresses. To decrease RF losses the inner cylinder is copper plated by sputtering with a thickness of ~10 μm. An intermediate layer of sputtered titanium (~0.5 μm) is needed to increase the adherence of the copper. Before RF conditioning starts the inside cylinder is wiped with a clean room cloth and closed with metallic covers and seals.

1.4 "Doorknob" and Capacitor for d.c. Bias

The "doorknob" is made from aluminium with an "alodine" surface treatment to avoid oxidation and corrosion. Good contact with the RF contact fingers of the d.c. bias capacitor is achieved by local gold plating of this area. The capacitor is made of an inner aluminium cylinder and an outer brass cylinder.

Five layers of 50 μm Kapton® foil are wrapped around the inner cylinder. The outer cylinder is heated to 180°C and then shrunk onto this assembly. Plastic (PPO) rings are mounted on both sides of the capacitor to avoid mechanical damage of the Kapton® foils due to flapping in the flow of cooling air. The capacitor is connected to the "doorknob" via gold plated sliding contacts and can be replaced without breaking the vacuum or demounting the waveguide system.

The chosen diameter of the capacitor avoids circumferencial resonances in the Kapton® line at the fundamental frequency and at the 2nd and 3rd harmonics.

1.5 Conditioning Sequence

Each coupler is pre-conditioned to clean the surfaces exposed to RF and vacuum and to provide a high power RF test prior to installation on the module. Two couplers are mounted on a warm single cell copper cavity (with an external Q much lower than Q_0 so that the cavity dissipation remains small). The output coupler is connected to a high power RF load permitting TW operation.

Bake-out of the ceramic window at 200°C and of the "extension" and the antenna at 150°C is performed under vacuum for 24 hours (ramping time 12 hours). Argon atmosphere is provided to the external copper surfaces near to the ceramic to avoid oxidation.

RF power conditioning starts in a pulsed mode (pulse length 1-10 msec and repetition rate 200-50 msec) trying to limit the pressure rise to about $2\ 10^{-7}$ Torr. Here the use of a fast analogue vacuum loop (permitting immediate reduction of the RF power in case of a vacuum pressure burst and automatic increase of the power when the vacuum improves) is essential for rapid and safe progress. After several hours of pulsing it is possible to reach 250 kW but multipacting discharges are still present and RF processing continues in cycling the power with different ramping rates (controlled by a computer program in addition to the loop). A test at an RF power of 150 kW CW for several hours is again followed by cycling to reduce residual random multipacting activities. During this operation d.c. bias efficiency in suppressing such events is also tested. With these procedures two couplers are conditioned up to 250 kW in about three days.

After RF processing is completed couplers are stored under nitrogen atmosphere until they are mounted on a module in a clean room.

1.6 Coupler Performance

A superconducting test cavity has been equipped with a fixed 75 Ω input coupler and a mobile 50 Ω output coupler, connected to a high power RF load. By changing the output coupling and the cavity tuning the input coupler can be tested under matched conditions or with any reflection factor and phase up to full reflection.

Under matched conditions a TW power of more than 200 kW CW has been reached, only limited by the onset of field emission in the cavity with the concomitant heat dissipation and high levels of ionising radiation. With the detuned cavity "equivalent" power levels of more than 450 kW have been obtained in standing wave conditions up to full reflection.

The couplers are exposed to air during their installation on the module, thus enabling adsorption of gas molecules, especially on the ceramic. After cooling down the modules very time consuming re-conditioning was necessary, since the gas was released from the RF heated ceramic [2] and condensed on the cold surface of the extension (resulting in an increased secondary electron emission). Conditioning of the cold modules is necessary to permit safe operation with d.c. bias. By *in situ* bake-out of the ceramic RF window at 200°C for 24 hours prior to cooling down the module, the conditioning time could be reduced by about one order of magnitude.

By applying after re-conditioning a d.c. bias of 2.5 kV safe operation is achieved, the multipacting events being completely suppressed for all operating conditions.

2 LHC POWER COUPLER

The layout of the LHC coupler (see Figure 3) is based to a large extent on the LEP2 coupler design: waveguide-coaxial transition, cylindrical ceramic window, 75 Ω coaxial line, air cooled inner conductor (antenna), helium gas cooled "extension", cylindrical capacitor for d.c. bias. However, the outer and inner diameters of the coaxial line are increased from 103 to 145 mm and from 30 to 41 mm, respectively. The multipactor levels and RF power losses are thus adapted to the higher power needs and forced air cooling of the antenna is simplified. The ceramic cylinder of the window is equipped with copper rings replacing the copper plated Kovar® ferrules.

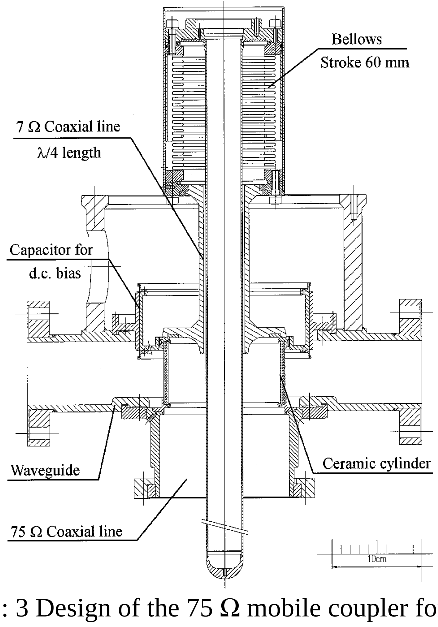

Figure: 3 Design of the 75 Ω mobile coupler for LHC

The waveguide height is reduced to permit a waveguide coaxial transition without a "doorknob". A λ/4 waveguide section provides the transformation to the standard half height LEP2 waveguide. The coaxial d.c. bias capacitor is mounted directly on the waveguide and the ceramic window, avoiding the second isolation between the capacitor and the waveguide.

For the mobile part, two versions have been investigated, one with RF choke (sliding RF contacts at minimum current) and a second with bellows, both outside the main coaxial line. The bellows version has been retained since it reduces the risk of metallic particles falling down to the cavity. The bellows/antenna coaxial line has a variable length of λ/4 ± 30 mm and is short-circuited at its end. The connection to the 75 Ω main line is made by a low impedance λ/4 coaxial line. The characteristic impedance jump between the bellows line and the connection line is about a factor of 7. The maximum current at the short-circuited end of the bellows is there-fore 1/7 of the current at the input to the connecting line. The power losses are thus reduced sufficiently to permit use of stainless steel bellows without copper plating.

A prototype of this LHC coupler design is under construction.

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