IMPROVEMENTS TO POWER COUPLERS FOR THE LEP2 SUPERCONDUCTING CAVITIES

J. Tückmantel, C. Benvenuti, D. Bloess, D. Boussard, G. Geschonke, E. Haebel, N. Hilleret, S. Juras , H.P. Kindermann, J. Uythoven, C. Wyss, CERN, Geneva, Switzerland

M. Stirbet, Institute of Atomic Physics Bucharest, Romania

Abstract Power couplers for the 352 MHz LEP2 superconducting RF cavities have been plagued by vacuum and electron outbursts which are attributed to multipacting. Processing of these couplers has been a lengthy operation which was often needed again after high power running even if only for a relatively short time. We report here on recent progress made in improved production methods of coupler parts and special treatment of surfaces, as well as practical tests and simulations of geometrical coupler modifications.

I. INTRODUCTION

All couplers of the LEP 352 MHz superconducting cavities are located on the cut-off tubes to avoid ports on the cavity cells themselves. The first power coupler design used a homogeneous 50 Ω antenna line [1]. Based on this coupler an adjustable version was designed containing a $\lambda/4$ section of 25 Ω impedance which houses a choke construction [2].

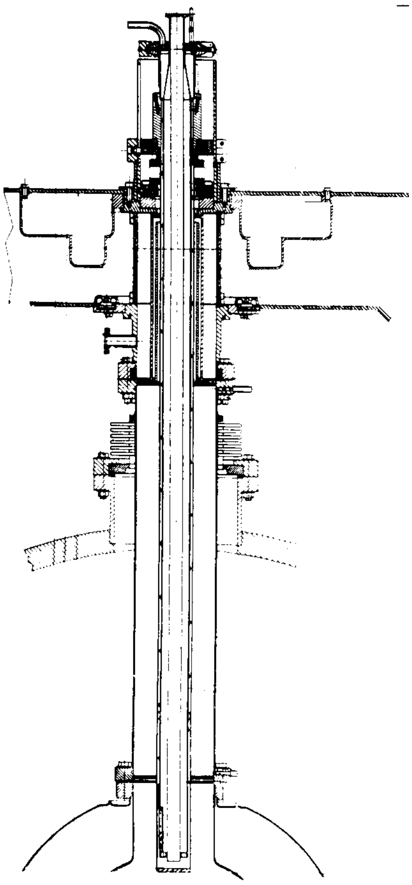

Fig.1 : The adjustable coupler

Keeping the RF-line outer diameter of 103 mm with the proven cylindrical window design as used for the LEP copper cavities (operated at up to 120 kW and being tested up to 180 kW [3]) allowed a sufficient safety margin at the original design value of 60 kW. However, specifications for field level and beam current were increased, swallowing all of this safety margin. It also has to be considered that due to the RF transformation via the 25 Ω choke the RF currents near the ceramic window are strongly increased.

During a surface test of a cavity (standing wave case) a leak developed linked with a burn-mark on the outer coaxial line. Subsequent tests with improved instrumentation (local vacuum gauges on the couplers, electron pick-ups, infrared camera) showed that in fact levels with vacuum and electron bursts could be observed when ramping the power. Static magnetic fields could influence the levels — but not suppress them — thus confirming that multipacting (MP) was the culprit.

One-side MP trajectories in coaxial lines had already been simulated [4], neglecting the magnetic field. In the power range used by us the influence of the magnetic field is small and with a simple BASIC program similar tracks with impacts only on the *outer* coaxial conductor in the 50 Ω part of the line were found at the E-field maxima of a standing wave where the magnetic field is exactly zero [5]. Note the scaling law: the RF power where the MP occurs is proportional to f^4. Furthermore two-side MP was detected on the 25 Ω line section of the adjustable coupler . Table 1 shows, in the range used, the most dangerous predicted and measured levels for the 50 Ω couplers. P_{SW} is the necessary incident power on the coupler in full reflection (sc. cavity without beam) producing the peak voltage V_{RF} in a 50 Ω line section. Use of a systematic scan procedure including the magnetic field [6] identified the same levels.

order	V_{RF} [kV]	P_{SW}(th) [kW]	P_{SW}(ex) [kW]
3	4.1	42	38-43
4	3.2	26	26-28
5	2.6	17	15-18

Table 1. One-side MP levels theoretical (th) [5] and experimental [ex] in 50 Ω line

II. COUPLER PROCESSING AND DECONDITIONING

Processing of the couplers (with the local coupler vacuum used to control the input power) proceeds in two stages In the first stage a pair of couplers is mounted on a resonant copper cavity with strong over-coupling. One coupler is used as input coupler. The second one as output coupler can be connected either to a matched load or an adjustable short circuit. Conditioning takes in general 4-5 days, starting manually to process the low levels, then using pulsed mode with pulse lengths between 10 μs and 50 ms and a duty cycle around 20 %. Finally ramping up and down under computer control in cycles of 2-5 minutes processes up to 200 kW.

A second processing is necessary on the cold cavities and generally done in parallel on the couplers of a whole module (four cavities in a common cryostat). Initial conditioning has to be repeated and again takes several days including pulsed power processing with peak fields in the cavities reaching 8 MV/m.

For couplers from the first production lot, running at nominal power on the cavities often for only a few minutes was sufficient, to erase the conditioning done before. A reconditioning period of typically several minutes was necessary to regain nominal field. Also, for a perfectly processed coupler, the well known levels reappeared after switching off the RF for several hours. These effects, called deconditioning, were attributed to gas getting trapped on the cold outer conductor.

III. CERAMIC WINDOW IMPROVEMENT

On some of the damaged couplers traces of arcing have been found on the brazing between ceramic cylinder and Kovar ferrule, on the RF contact between Kovar ferrule and copper part, or on the relatively thick titanium coating of the ceramic near to the RF contact (compared to the thin coating on the cylindrical part). It was also observed that during high power operation the windows were strongly heated near the Kovar ferrules

To avoid these problems the following modifications have been made: i) brazing completely penetrating through the Kovar-ceramic connection, ii) Kovar ferrules machined at the contact surface after brazing and welded to the coupler under pressure to improve the RF contact, iii) more homogeneous titanium coating of the whole ceramic cylinder with a DC resistance decreased from 500 MΩ to 10-20 MΩ, iv) copper plating of the Kovar ferrules to reduce RF losses, v) Improved air cooling around the ceramic cylinder and the ferrule. In fact, couplers equipped with the new windows no longer showed sensitive heating up to 200 kW travelling wave.

In order to permit even higher RF currents the simple pressed contact has been replaced by a spiral contact and tested successfully. But the assembly of this version is much more complicated and delicate.

However, even though the improved windows operated safely under these increased power levels, their use did not eliminate the deconditioning phenomenon and further steps to fight MP itself had to be undertaken.

IV. MEASURES AGAINST MULTIPACTING

Work was done in parallel in several areas and although tests have been done in the warm and cold state of the coupler, a full beam test is still pending.

A Choice of fixed coupler version

Movable couplers are attractive because i) they allow a measurement of the Q versus E curve of a cavity without having to break the cavity vacuum and ii) they can precisely match to a wide range of cavity voltages, beam intensities and stable phases. Unfortunately, due to the restricted space in the LEP tunnel, the choke necessary in the movable coupler had to be folded back into the coupler (25 Ω line). With this geometry two additional MP levels appear. The extra risk associated with these levels was felt to be unacceptable and the movable coupler version was abandoned for the series production. Note that coarse estimates of the cavity Q can be obtained by cryogenic methods and that imperfect matching essentially results in higher fields in the coupler. But even at 200 kW both types of couplers are operated far below any electric field breakdown limit [7].

B Improvement of the surface

As shown by the simulations, the MP takes place on the outer conductor. The corresponding line piece is double walled to allow He-gas cooling. The original work-piece, called ‘extension’, was produced from rolled and welded sheet-metal, the welding making it difficult to obtain a smooth surface. Therefore the new extensions are now produced — including vacuum flanges — from a single stainless steel forging thus avoiding welding or brazing in critical areas.

The inner surface of the extension has to be copper plated to reduce RF heating. The original fabrication used ‘standard’ galvanic deposition. To improve the quality of the surface avoiding possible traps for gas, two methods were tried in parallel. One uses a galvanic deposition with pulsed current showing a smoother surface; tests allowed faster MP processing in the warm state. The second deposits copper by sputtering [8]; test showed faster MP processing in the warm but a tedious one on the cold cavities. A version with improved gas cooling also showed good results on a cold cavity. Tests of a sputtered extension submitted to water rinsing are under way. Titanium coating of the extensions has also been tried, but was not successful.

Furthermore, an apparatus to measure the secondary emission coefficient between 1/10 and 2000 eV was constructed and used for measurements on copper and titanium layer specimen.

C. Change of antenna diameter

A geometrical modification [7] was done in changing the antenna line impedance. For impedances of 50 Ω and higher, the multipacting is 'running' only on the outer conductor. By reducing the inner conductor diameter and scaling the RF voltage proportionally to the line impedance one leaves the fieldmap in the outer coaxial region unchanged. This fact was used to transfer the MP levels to higher powers by reducing the standard antenna diameter of 44.8 mm (50 Ω) to 30 mm (75 Ω), thus shifting the levels up by 50% in power [7]. A further decrease of the diameter is not considered due to increased mechanical and thermal problems.

Measurements confirmed this approach: the same MP levels appeared, but at correspondingly higher power, thus giving more margin for operation. The RF currents near the ceramic window are also reduced, compared to the 50 Ω case, thus permitting the use of the simple pressed contact. All future couplers will be of the 75 Ω type.

D. Eccentric Coupler

Simulations [9] showed that with an eccentric antenna the MP tracks run around the outer conductor towards the wider gap. Tracks coming from the smaller gap are stopped after only a few impacts due to the changing conditions. It was hoped that tracks starting close to the wide gap would be concentrated on a small strip which would clean more easily.

A pair of such 75 Ω couplers with 4 mm eccentricity were built and tested on the warm stand. Their behaviour was not better than the average standard coupler. Due to the more complicated fabrication, the idea was abandoned.

E. Injection of Perturbing RF

To break the resonant kinematic conditions of MP, a perturbing RF voltage can be used. This was realised by adding power at an incorrelated frequency (noise band or single frequency). Since MP can rise in a short lap of time, the injected frequency has to be 'far' away from the fundamental one. An injection of about 2% RF power on a sideband at 200 kHz to 1 MHz frequency distance (klystron bandwidth limitation) was a sufficient perturbation to make (on the warm test stand) MP disappear and significantly reduce it on the cold cavities. Since the cavity bandwidth is below 200 Hz, the second signal does not perturb the cavity voltage

F. Electric DC bias

Perturbation with static magnetic fields had already been tested at an early stage. Influence on the levels had been observed but suppression could not be achieved.

The coaxial antenna geometry offers a relatively simple possibility to apply a DC bias voltage. It is trivial that a DC bias higher than the RF voltage will inhibit all return paths for electrons. Simulations [10] showed that depending on polarity about -1.5 kV or +2.5 kV with respect to ground would already be sufficient to obtain complete suppression up to 200 kW of travelling wave power (5.5 kV RF voltage). Experimentally it was found that with +2.5 kV MP is completely suppressed.

The main problem of this approach has been the capacitors which are needed to separate RF and DC paths. For a first proof of principle with a minimum of modifications, Mylar or Kapton foils were inserted between the doorknob and the waveguide. During the practical tests on the cold cavities these capacitors showed breakdowns with a rate unacceptable for machine operation. The suspicion is that the breakdowns are caused by sharp edges in the waveguide or by particles introduced in the capacitor during mounting in the open air as it is actually done. As an intermediate solution copper plated Kapton foils will be used. A better version is under development using a coaxial capacitor similar to those of the SPS tetrode amplifiers [11] and mounted in a clean room.

To permit DC bias the He gas cooling of the antenna has been replaced by forced air cooling.

V. CONCLUSION

The RF window has been improved to decrease the window temperature and to reduce the risk of breakdowns. Several approaches to suppress or reduce MP in the LEP2 power coupler have been examined. The choice of a higher antenna line impedance shifted MP levels up by 50% in power. Two perturbation methods have been worked out: Injection of about 2% power on a sideband several 100 kHz above the normal RF frequency and application of a DC bias voltage, achieving complete suppression. For the proof of principle a simplified construction has been used, the safe design for machine application is under way, to be followed by a large scale beam line test.

VI. REFERENCES

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