HIGH POWER COUPLER FOR THE TESLA TEST FACILITY

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Abstract

The TeV Energy Superconducting Linear Accelerator (TESLA) requires as one of its components an RF input coupler. It transfers 1.3 GHz power from the RF distribution system to the superconducting 9-cell cavity. Three different coaxial couplers were produced and operated in the TESLA Test Facility (TTF), a new design for a superstructure cavity is on the way. We report about the design criteria and tests. The processing and operation of the couplers in the TTF will be discussed.

1 INTRODUCTION

TESLA [1] requires, as one of its critical components, a high-power RF input coupler. The input coupler transfers the RF power from the RF distribution system to the superconducting 9-cell cavity. In the frame of the TESLA collaboration we have designed 4 types of coaxial couplers. Three coupler types are built, tested and under operation in the TTF (TESLA Test Facility) linac [2]. A fourth type is under construction. In many tests on TTF, the couplers are working according to the specified values.

A new cavity design, the so-called superstructure, requires only one coupler for four 7-cell cavities [3]. It has to transfer three times as much power. For this coupler the RF simulations are almost done and the mechanical design work has started.

Table 1: Specification of the high power coupler for TTF and TESLA

	TTF	TESLA, 9-cell first / Upgrade	TESLA super-structure first/ upgrade
Peak beam power incl. control margin#	250 kW	250 kW / 500 kW	845 kW / 1690 kW
Repetition rate/pulse length	10 Hz/1.3 ms	5 Hz/1.3 ms	5 Hz/1.3 ms
Coupling	Adjustable $Q_{ext}=10^6$ - 10^7	Fixed Q_{ext} =3 x 10^6	Fixed Q_{ext} =2.5 x 10^6
Longitudinal cavity movement	15 mm	1.5 mm	1.5 mm

#25 % for control margin [4]

2 THE COUPLER DESIGN

There are different design criteria for the TTF and TESLA input coupler. Some of the requirements also changed due to new cavity and cryostat designs. In Table 1 is shown that the main difference between TTF and TESLA is the need to double the power for TESLA due to the upgrade. In regard to mechanics the main difference is the adjustable vs. fixed coupling and the needed flexibility of 15 mm for TTF and only 1.5 mm for TESLA for cavity movement during cool down.

The general design parameters for all three machines are shown in Table2. In addition to the normal operation it is foreseen to apply High Power Processing (HPP) [5] to the cavity in order to cure field emission if the performance of the cavity has degraded.

Table 2: General design parameters of the high power coupler for TTF and TESLA

Frequency	1.3 GHz
standard pulse length	500 µs rise time and 800 µs flat top with beam
Power for HPP	1 MW at reduced pulse length (≤500 µs at 1 Hz repetition rate)
Safety	Two windows (protection of the cavity during assembly and against window failures)
Diagnostic	Sufficient for safety and monitoring

2.1 *Multipacting in High Power Couplers*

It is a well-known fact that multipacting (MP) in high power couplers can cause loss of the cavity field and might break the ceramic windows. In the frame of a joint project with DESY and the Rolf Nevanlinna Institute the influence of a bias voltage on the inner coax conductor is numerically studied [6]. At the LEP superconducting cavities the DC biasing voltage turned out to be an effective method to suppress MP in coaxial lines [7]. Given scaling laws for the multipacting bands in coaxial lines show that a bigger diameter and higher impedance push the MP bands to higher power level. It is shown that

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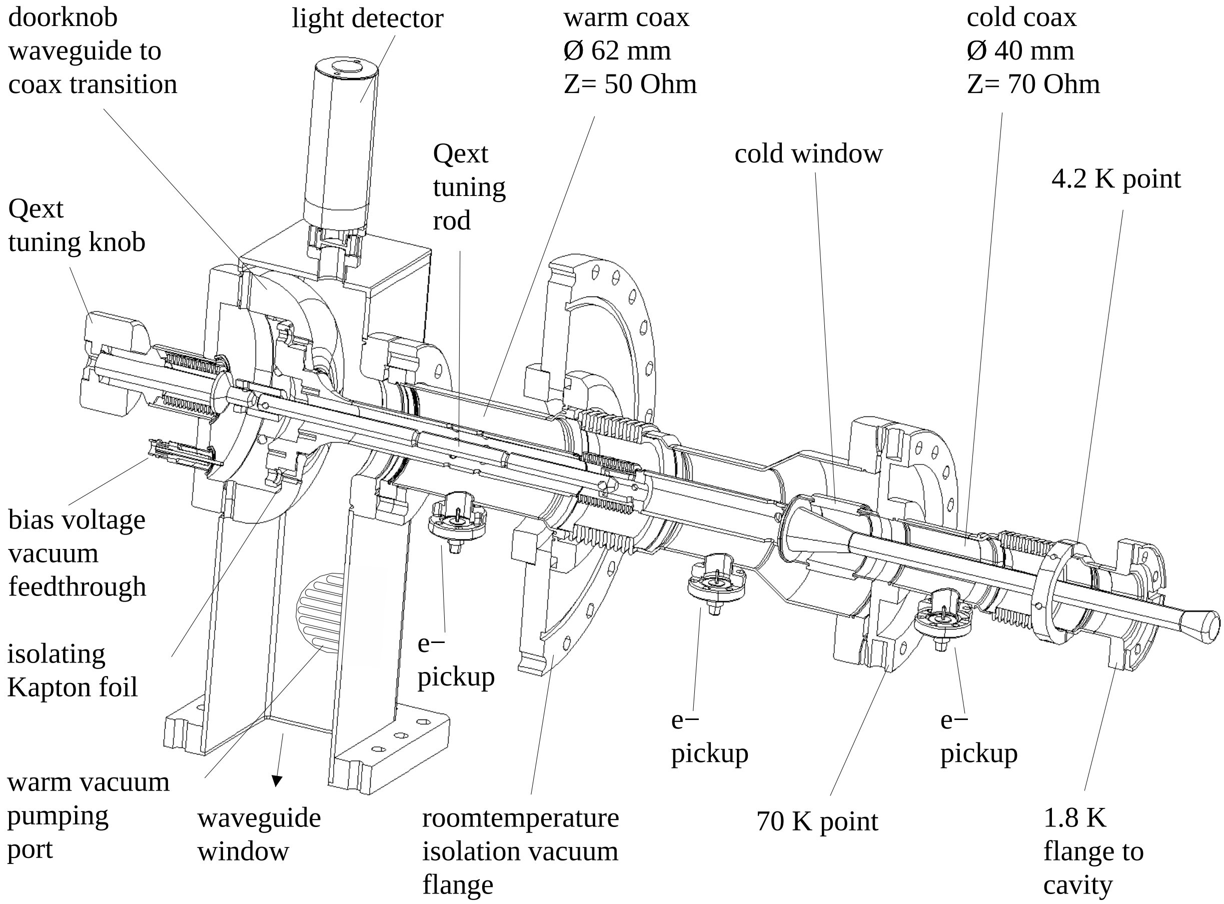

Fig. 1 The TTF2 coupler design has a wave guide window. The insulating Kapton foil is in the vacuum.

an increase of the diameter goes with fourth power while the impedance scales linearly.

2.2 The Different Couplers for TTF

The first 15 couplers were designed and produced by the TESLA collaborator Fermilab. A description is given in [8]. There is also an early DESY design [9].

In Fig. 1 the TTF2 coupler is shown. It has an electrically coupling antenna rigidly connected to the cylindrical cold window. The warm wave guide window is not shown. For Q_{ext} tuning the cold window together with the antenna can be moved axially by a tuning rod connected to a thread knob at the airside of the doorknob. The inner coax conductor is isolated against the doorknob by a metallised Kapton foil forming a capacitance. This allows biasing the inner conductor with a DC voltage. The cross section of the pumping port is substantially increased (now 35 mm diameter) compared to the earlier designs. We have built 20 TTF2 couplers. All couplers are tested, preconditioned and eight are in operation in the third TTF accelerating module.

The TTF3 coupler consists of the same cold window design as TTF2 and is compatible with it (Fig. 2). Unlike TTF2 it has a cylindrical warm window in the half height wave guide to coax transition. The Kapton foil is not in the vacuum in order to avoid outgassing. The wave guide is on air so that the surfaces in the warm vacuum are reduced.

On both couplers the warm and cold coax have impedance of 50 Ohm (diameter 62 mm) and 70 Ohm (diameter 40 mm) respectively.

All couplers have detectors for e^- in the warm and cold coaxial line and a light detector on the vacuum side of the room temperature window. There is also a spark detector and an infrared temperature measurement on the airside of the room temperature window.

3 TEST RESULTS AND OPERATION

3.1 Test Procedure and Processing

All couplers are tested and preconditioned on a teststand at room temperature. Two couplers are mounted with their antennas to a half height waveguide transition. Prior to the test the whole assembly is baked out at 200 C and 24 h for outgassing. After cooling to room temperature the

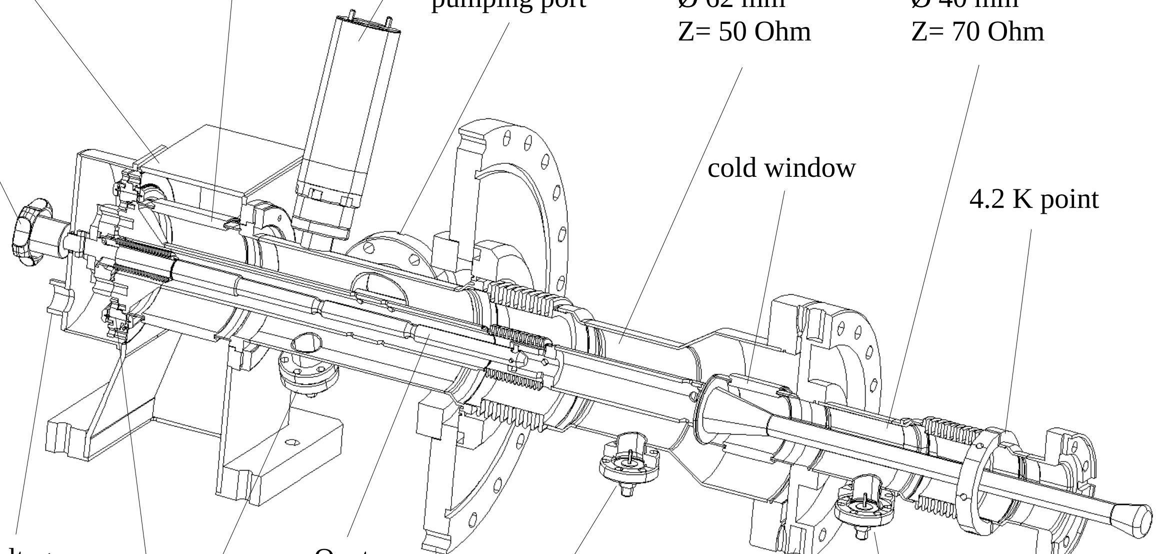

Fig. 2 The TTF3 input coupler design with a cylindrical window in the wave guide to coax transition. The Kapton isolation is not in the vacuum.

pressure is in the 10^{-10} mbar range. The dominating partial pressure is hydrogen followed by the masses 28 (C0) and 18 (H_2O).

The processing is usually done with travelling waves. The power is cycled from low to high values, starting with short pulses (20 µs, 1 Hz). After reaching the specified power value the pulse length is doubled and the power rise starts again at low power. After the full pulse length of 1.3 ms is reached the power is cycled between zero and 1 MW. The rate of the power increase is limited by the different thresholds set for the coupler vacuum, the light in the coupler and the charged particle activities measured at the e^- pick ups. There is also a hardware interlock system, which reacts on high reading from the sensors of vacuum, light, electrons or ceramic temperatures.

At the first power rise there are typically no activities in the coupler up to a power level of 50 - 60 kW. At this power level an initial vacuum activity is observed in most cases. As a result, new conditioning starting at 10 kW is necessary. The first power rise at 20 µs takes normally about 3 days whereas the following processing at longer pulse length is finished in much shorter time. Finally the transferred power can be cycled with almost no measurable activities in the coupler. All 38 couplers tested so far reached the design values of 1 MW at 500 µs and 250 kW at 1.3 ms. One pair of the TTF2 coupler was successfully tested up to 1.6 MW at full pulse length of 1.3 ms. The dependency of the remaining multipacting activities in the coaxial part of the coupler on the value of the bias voltage is shown in Fig. 3. A bias voltage of +2500 V on the inner conductor of the coupler is chosen for multipacting-free operation.

3.2 Operating the Coupler on a Cavity

The cavities are tested in a horizontal test cryostat (CHECHIA) [2], equipped with all auxiliary components like high power coupler, helium vessel, tuning system and higher order mode coupler. Prior to the cool down of the system the coupler is usually processed under full reflection up to the design values (see section 3.1). During cooldown to the cryogenic temperature the RF power is cycled over the full power range.

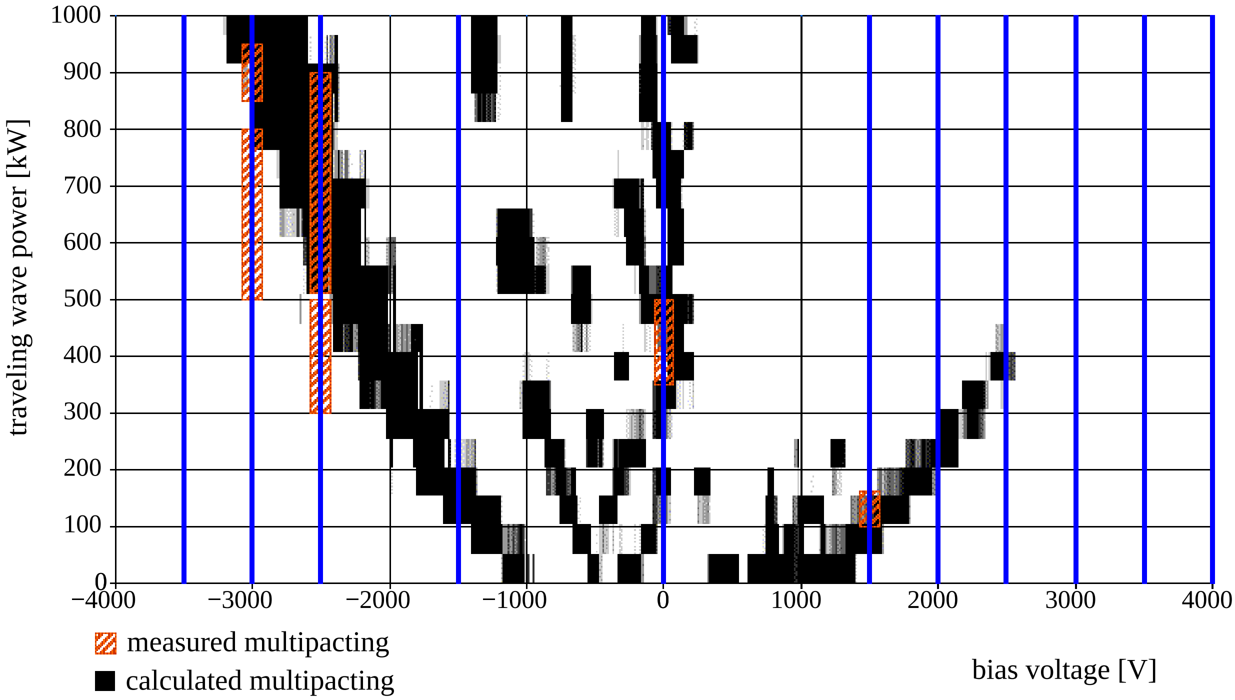

Fig. 3 The plot of the calculated multipacting bands in a coaxial line (d = 62 mm, Z = 50 Ohm) as a function of the incident power (vertical axis) and the DC biasing voltage (horizontal axis). The red areas are the measured activities (e^- pick up) in the warm coax of the TTF2 coupler. The measurement agree reasonable with the predicted multipacting activities.

Due to the tight time schedule, the cooldown often was started at the same time as the RF processing. The needed processing time was much shorter in these cases, but we are afraid that desorbed gas might be collected at the cavity's and the coupler's cold surfaces and will cause problems later.

At an operating temperature of 2.0 K the cavity is tuned to the resonance frequency and a second processing of coupler plus cavity takes place beginning at short pulses. At this time the cavity is driven to very high gradients with short pulses (≤ 500 µs) in order to process the field emission of the cavity [5]. During this HPP fields up to E_{acc} = 40 MV/m for about 10 µs could be established (RF pulse length ≤ 500 µs at P = 800 kW). At the following standard pulse measurements of the cavity gradient vs. the cryogenic losses the coupler never limited the cavity performances up to E_{acc} = 30 MV/m, (P = 325 kW, 10 Hz repetition rate, 1.3 ms pulse length).

3.3 *Operation in the Module*

At the module, the vacuum of all eight couplers is pumped by a common pumping line with one common pressure gauge. The RF wave guide distribution connects one 5 MW klystron to 16 couplers, so the maximum available power per coupler is 250 kW. Connecting only one module (8 couplers) to the klystron gives us a maximum power of P = 500 kW per coupler during the processing. All eight couplers were processed at the same time taking the same procedure as in the horizontal test cryostat. In this procedure it happens that one coupler with a performance limit limits all the others. In spite of this limitation, experience shows that parallel processing of all eight couplers saves time compared to individual processing.

During HPP only one cavity is on resonance at a time. Individual cavities could be operated up to 30 MV/m with no beam current; this corresponds to a forward power of 325 kW at 500 µs rise time and 800 µs flat top.

The third module equipped with TTF2 couplers is operated routinely at P = 185 kW at 10 Hz repetition rate. At the standard pulse this corresponds to an average gradient of Eacc = 22.8 MV/m.

4 FUTURE DEVELOPMENTS

4.1 *Argon Processing*

For big numbers of couplers in a linac, long processing times would be a problem. To shorten the processing procedure tests with soft RF discharge in argon at a pressure near the Paschen curve minimum were done [10]. After pumping and baking of the coupler test stand the coupler vacuum was filled with argon up to a pressure of 10 mbar. Instead of a load, a long (50 m) waveguide with a short was connected to the teststand output. Sweeping the klystron frequency allows shifting the standing wave phase distribution and at the same time the discharge region. The argon processing was done at a power P≤5 kW and a pulse length of 20 µs for 1 h. Then the argon was pumped out and replaced by new clean argon. After a second hour processing the argon was pumped out and the usual processing procedure at travelling wave was carried out. The time needed for the first power rise at 20 µs pulse length was only 16 h compared to more than 3 days under normal conditions.

4.2 Coupler for the Superstructure

The first test of the superstructure will be done with a TTF3 coupler. The model calculations for a new coupler with a 60 mm diameter on the cold coax are finished and the mechanical design work has started. Several model calculations for waveguide couplers are done so far [11].

5 CONCLUSION

All 38 couplers fabricated until now meet the requirements and were able to transfer 250 kW RF power at a pulse length of 1.3 ms and 10 Hz repetition rate. All four types of couplers were operated successfully in the linac. During HPP of the cavities in the linac 400 kW per coupler were applied to the cavities at a pulse length of ≤500 µs. Routine operation was done at P = 185 kW, 10 Hz and standard pulse.

Processing of couplers still takes too long. It is shown that argon processing can shorten this time significantly. More investigations are necessary to use the procedure also on the couplers in the modules.

Two TTF2 couplers are operated on the teststand up to 1.6 MW at 1.3 ms pulse length. For the first superstructure test we plan to take TTF2 or TTF3 couplers. For the future there is a mechanical design with 80 mm diameter cold coax on the way.

6 ACKNOWLEDGEMENT

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7 REFERENCES

[1] R. Brinkmann, G. Materlik, J. Rossbach, A. Wagner (Editors), "CONCEPTUAL DESIGN OF A 500 GeV e+e- LINEAR COLLIDER WITH INTEGRATED X-RAY LASER FACILITY", DESY 1997-048/ECFA 1997-182 (1997)

[2] D.A. Edwards, "TESLA Test Facility Linac Design Report", TESLA Report 95-01 (1995)

[3] J. Sekutowicz et al., "Nb PROTOTYPE OF THE SUPERSTRUCTURE FOR THE TESLA LINEAR COLLIDER", this workshop

[4] S. Simrock, private communication

[5] J. Graber, PhD Thesis, Cornell University (1993)

[6] E. Somersalo et al, "Analysis of Multipacting in Coaxial Lines", Proc. of the PAC95 (1995), p 1500

[7] H. P. Kindermann, M. Stirbet, "The Variable Power Coupler for the LHC Superconducting Cavities", this workshop

[8] M. Champion, "Design, Performance and Production of the Fermilab TESLA RF Input Couplers", Proc. of the LINAC 96

[9] B. Dwersteg, "Mechanical Concept of TESLA Main Coupler Development at DESY", TESLA Report 93-15 (1993)

[10] A. Zavadtsev et al, to be published as TESLA Report in 2000

[11] J. Boster et al, "TESLA Waveguide Coupler", Coupler Workshop at DESY, TESLA Report 99-10 (May 1999)

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