THE TESLA HIGH POWER COUPLER PROGRAM AT ORSAY

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Abstract

Within the general TESLA collaboration the Laboratoire de l'Accélérateur Linéaire has the responsibility for the development of high power input couplers for the super-conducting cavities. To this end we have assembled the required infra-structure necessary for the preparation, conditioning and tests of proto-type couplers. This infra-structure will be described along with brief results of the first proto-type tests.

INTRODUCTION

Super-conducting (SC) RF activities at LAL-Orsay are centred on the development of RF input couplers for the cavities of the TESLA linear collider study. This program of work is performed in the framework of a DESY/LAL collaboration. At the time of writing, four different versions of power couplers have been tested at the TESLA Test Facility (TTF) in DESY-Hamburg (three designed by DESY and one from the Fermi National Accelerator Laboratory) [1,2]. The latest DESY design, the so-called TTF-III coupler, appears to be capable of handling the required power for the present parameters of the 500 GeV stage of the TESLA project. However, improvements to the design may still be possible. In particular it is hoped that further development work at Orsay may result in enhanced performance and cost reductions.

INFRA-STRUCTURE

All coupler tests at Orsay are performed at room temperature due to the absence of cryogenic facilities. Nevertheless, it was anticipated that couplers conditioned at Orsay might eventually be mounted on modules containing SC cavities at DESY (see below). As the cold part of the coupler is an integral part of the cavity vacuum it is necessary to treat and prepare the couplers to the same degree of cleanliness as the cavities in order not to limit the cavity performance. Thus it was deemed necessary to have class 10 clean room facilities for coupler assembly. In addition it was decided that we would build a vacuum furnace allowing bake-out of the coupler parts before assembly.

The Clean Room

The clean room consists of a 27 m^2 zone of class 1000 and a 13 m^2 zone of class 10. The class 1000 area includes an ultra-sonic bath in which the couplers are cleaned using ultra-pure (UP) water. The UP water is produced using a commercial system which provides 200 litres per day (electrical resistivity = 18 MΩ.cm), filtered to remove all particulates above 0.22 µm in size. The ultra-sonic bath allows cleaning with up to 8 kW of power at 40 kHz. The class 10 area is used to assemble the cold parts of the coupler to their RF test bench. The couplers enter directly into the class 10 area from being baked out in the furnace. Once assembled, the couplers are leak checked in the clean room before exiting through an ante-chamber into the RF test area. The leak test is performed using a helium detector positioned outside the clean room. The helium gas and leak detector cables traverse the clean room wall via a special feed-through.

The RF Power Source

The modulator and klystron (THALES type TH 2104C) are provided by DESY. The modulator was delivered to Orsay in June of 2002 and, following connections to, and tests with, ancillary equipment was ready to produce RF power in November of that year. All auxiliary equipment control racks have been built at LAL. The source provides output pulses of up to 5 MW for 2 ms at 10 Hz repetition rate. The power is fed to the coupler via an RF wave-guide distribution system which includes directional wave-guide couplers for measurements of incident, reflected and transmitted power. A four port differential phase-shift circulator protects the klystron in case of excessive reflected power. The data acquisition system records the levels of the above mentioned RF powers, the vacuum level during each pulse and the signals from electron "pick-ups" in both the warm and cold coupler parts. The reflected power, transmitted power, electron signal, coupler temperature and vacuum levels are all used as interlocks to the RF system.

The Vacuum Furnace

Experience at DESY has shown that, to reduce conditioning times, the cold coupler parts should be baked out to 400 °C. In order to do this we have had an furnace built in industry corresponding to our specification. The furnace is cylindrical in form and is designed to have a uniform temperature over a length of 60 cm and a diameter of 25 cm, sufficient to contain either the warm or cold coupler parts (see Fig 1). The pressure obtained during coupler bake-out at 400 °C is < 10^{-6} mbar. Both end flanges of the oven can be opened which allows parts to be introduced/extracted either in the laboratory area or in the clean room area. The latter possibility is particularly attractive from the point of view of coupler preparation as, once baked, the coupler can be assembled without having been exposed to 'ordinary' air. The only disadvantage of this furnace is the rather long time (~ 10 hours) necessary to reach the operating temperature and even longer time (~ 15 hours) to cool down despite the use of a forced air cooling system. The result is that one can only envisage to bake one part per day.

Figure 1: The vacuum furnace connected to the wall of the class 10 clean room area.

The TTF-IV Proto-type Coupler

The TTF-IV coupler was proposed by B. Dwersteg (DESY) as a candidate input coupler for the TESLA "super-structure". This structure was suggested in order to increase the fill-factor of the TESLA linac and to simplify the RF distribution system [3]. It consists of four seven-cell cavities fed by a single input coupler. In order to reach the TESLA 500 specifications such a coupler would have to be capable of transmitting > 700 kW of RF power, roughly three times the specification of the TTF-III coupler [4]. A schematic of the coupler is shown in Fig. 2. It has many features of the TTF-III coupler. It employs two cylindrical ceramic windows, a "warm" window in the wave-guide to co-axial interface and a "cold" window which would seal the cavity after assembly in a clean room. The windows have received a nominal 10 nm coating of titanium-nitride on their vacuum surfaces at DESY in order to reduce their secondary electron emission coefficient. The end faces of the ceramics are brazed to copper collars which in turn are brazed to the warm and cold coupler parts (Fig. 3). These parts are mainly fabricated from stainless steel with the RF surfaces receiving a copper coating of a few electrical skin depths (~ 15 µm for the warm part and 5 µm for the cold part). The central antenna of the cold part is fabricated from bulk copper. It was decided that the central antenna would be "fixed" i.e. there is no possibility to adjust the coupling to a cavity. This avoids the need for a bellow in the cold part. An insulating ceramic, under air, allows one the possibility of applying a DC bias voltage to the central antenna as an anti-multipactor measure. The principal difference with the TTF-IV coupler is the co-axial diameter. With the aim of increasing the power handling capability and of pushing the expected multipactor levels to higher powers, the coupler has an outside diameter of 80 mm.

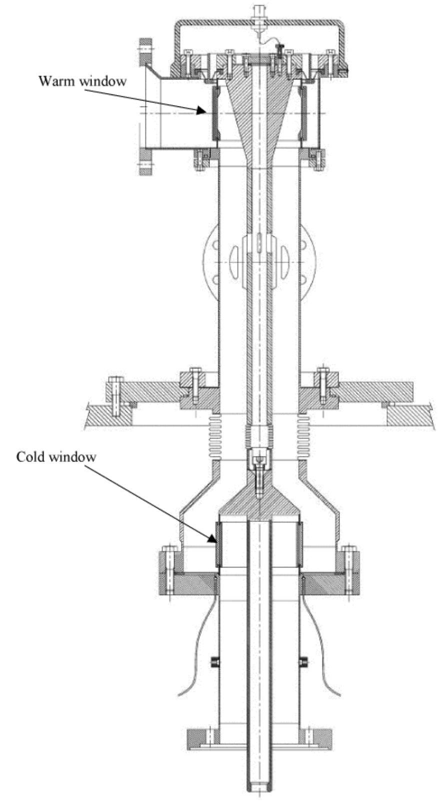

Figure 2: Schematic drawing of the TTF-IV coupler.

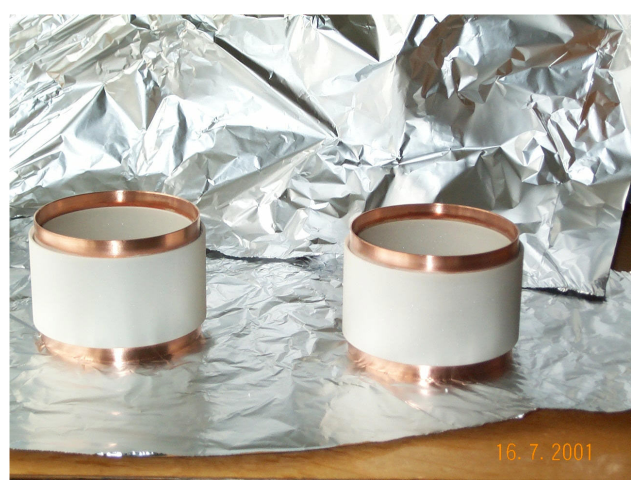

Figure3: TTF-IV coupler ceramic windows brazed to their copper collars.

The impedance for both the warm and cold parts of the coupler is 70 Ω. Five such proto-types have been built to date (see Fig. 4). Two were built in industry and another three from parts machined in our own workshop (wave-guide to co-axial interface, warm coupler part, cold coupler part). The final welding and brazing operations on these parts were done in industry. The principal difficulty in fabrication has been to reliably obtain leak tight copper-ceramic and copper-stainless steel brazes.

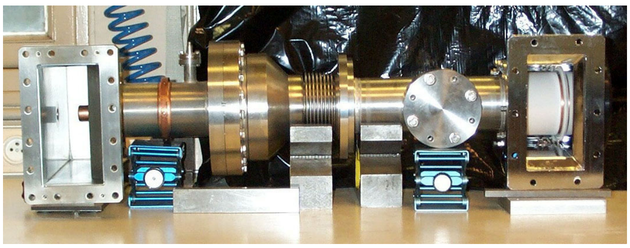

Figure 4: TTF-IV coupler attached to wave-guide test box. The warm window is to the right of the photograph.

Low power measurements of a warm coupler part, attached in turn to two different cold parts, are shown in figure three. The measurements are made by mounting the coupler on a wave-guide 'box' terminated in a matched load. As the central antenna is fixed the wave-guide box is designed with a connecting flange which should provide a good RF match between coupler and wave-guide (this is calculated using the commercial code HFSS).

The results of the low power measurements show a minimum of 17 dB in the return loss (RL) around 1285 MHz. At 1300 MHz the RL is only 14 dB (Fig. 5). Calculations performed at DESY using commercial simulation codes predict a minimum in the RL at 1300 MHz and with a value exceeding 20 dB [5].

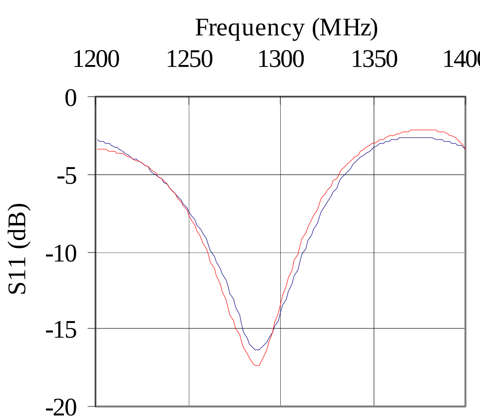

Figure 5: Measured reflection coefficient at low power on two different TTF-IV couplers.

The first high power tests of the TTF-IV coupler started in summer of 2003 (Fig. 6). At the time of writing, two couplers have been tested. The maximum power achieved is ~ 190 kW, limited by breakdown around the air side of the wave-guide to co-axial transition. Visible signs of the breakdown are clear on the ceramic side facing the direction of incoming RF power. The cause of this breakdown is currently under investigation.

Figure 6: TTF-IV coupler being assembled on the high power test bench.

TTF-III COUPLER PRODUCTION

In addition to the development of proto-type couplers we plan to condition a series of 30 TTF-III type couplers, purchased by DESY, some of which will be used on future modules of TTF. With the experience they have gained to date on these couplers the DESY group have suggested some minor but important improvements with respect to previous TTF-III couplers. After preparing a detailed set of fabrication drawings for this new series and organising a competitive call for tenders we are now overseeing their production in industry. We are presently at the stage of controlled reception of some of these couplers (twelve have been delivered to date and the others should be at Orsay before spring 2004). A special test bench has been devised using an endoscope coupled to a CCD camera to observe the weld and braze joints on the inner surface of the outer co-axial line without scratching the copper coated surface (Fig. 7). Figure 8 shows components from the batch of 30 couplers. It is hoped that the use of our dedicated test stand along with such a large series of couplers will provide useful statistical data on the conditioning times necessary for these couplers.

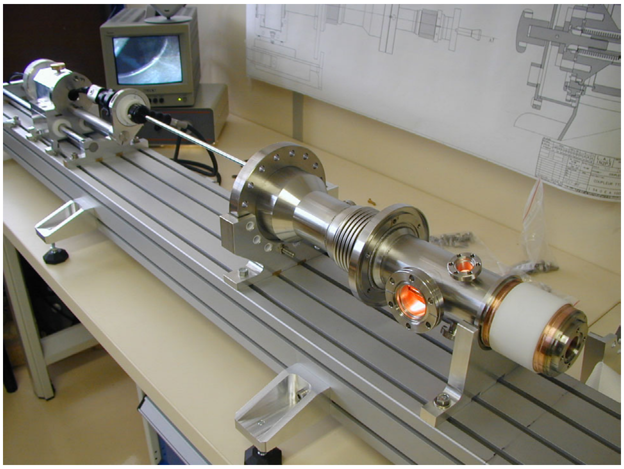

Figure 7: Reception test of a TTF-III Coupler.

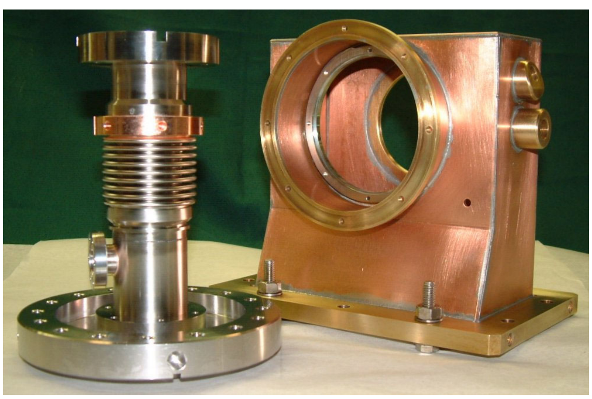

Figure 8: Machined parts from the series production of TTF-III couplers (left: cold outer line; right: WG interface).

PERSPECTIVES

We are currently performing simulations and investigations to understand the limitations in the performance of the TTF-IV couplers. Following RF simulations we plan to build others after incorporating modifications to the wave-guide interface. In addition new prototypes, intermediate in diameter to TTF-III and TTF-IV, are being designed and will be ordered in the coming months. Some "proto-type" TTF-III couplers will be built in industry employing alternative fabrication techniques which may tend in the direction of reduced costs. A sub-set of the series of 30 TTF-III couplers will be used for conditioning studies, an activity which will occupy a considerable part of our time in 2004.

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