TESLA MAIN COUPLER DEVELOPMENT AT DESY

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Abstract

TESLA is a superconducting linear collider with 500 GeV center of mass energy. Its superconducting 9 cell cavities will be operated at 1.3 GHz. A big variety of challenging boundary conditions, e.g.: 200 kW, 2 msec pulses, >1 MW cavity High Peak Power Processing at 1.3 GHz have to be met by the power rf input couplers. The complexity of the TESLA main coupler design led to two coupler development pograms. These are in progress since 1.5 years. One coupler development is performed at Fermilab [1,2]. In this paper the coupler development status at DESY is reported.

1. Introduction

The acceleration units of the TESLA linear collider will be cryostats of 12 m length.There will be 8 m of accelerating rf structure inside each cryomodule. This length consists of the active 1 m lengths of a string of 8 superconducting Niobium 9 cell cavities. These are driven in standing wave Pi-mode at 1.3 GHz. Each TESLA cavity has one main coupler which is a high rf pulse power transmission line between the outside WR650 room temperature waveguide system and the 1.8K cavity input port inside the cryostat.[3]

2. Coupler Performance Requirements

Normal operation power of the main coupler is transmission of 208 kW at 1.3 GHz, 10 pulses per second of 1.33 msec length which corresponds to 2.8 kW of average power. This is done to provide 25 MV/m of required acceleration gradient at a beam pulse current of 8 mA peak. Pulse time is distributed to 0.53 msec filling time and 0.8 msec beam on time.[4]
For *reprocessing* the superconducting cavity if necessary in case of performance degradation the coupler should also be capable of up to 1 MW pulse power transmission at reduced pulse length. (High Peak Power Processing [5])
During each rf pulse the cavity input impedance changes dynamically between open circuit, short circuit and match. Hence there is no defined static load for the coupler.
Two ceramic vacuum rf windows are necessary for the coupler. It needs a cold window very near the cavity because the cavity vacuum has to be closed at an early mounting stage already in the clean room. Thus an additional warm vacuum rf window at room temperature is unavoidable as well.
The *cryogenic aspect* of the coupler is to bridge between room temperature and cavity temperature of 1.8 K at low rf losses and low heat conduction. This requires a compromise between high electrical and low thermal conductivity over the distance between warm and cold end.

An unusual feature of the TESLA high power coupler is *mechanical flexibility* which allows up to 15 mm transverse motion of the 1.8 K end of the coupler with respect to the 300 K room temperature end. This is necessary to follow the shrinkage of the cavity string during cool down of the cryostat.
Also unusual for a high power coupler is *correction of cavity external Q* by length change of the capacitive antenna which couples to the electrical beam tube fields of the cavity. The external Q is to be 3E6. A correction of about a factor 10 around this value is thought to be necessary for compensation of cavity field flatness errors.

3. Design Status

3.1 General Characteristics

The DESY type main coupler (Fig.1) has *two parts* which are characterized by their cylindrical ceramic windows, one at 70 K level near the cavity, the second one at 300 K inside the waveguide to coax transition outside the cryostat. The cold window part of the coupler is mounted to the cavity already in the clean room as required. After insertion of the cavity string to the cryostat the warm coupler part has to be mounted via the cryostat flange from outside. It includes the 300K window and connects to the 70 K flange of the cold coupler part. This part needs a separate vacuum which will be pumped from outside the cryostat while the cold coupler part is connected to the cavity vacuum. Both parts of the coupler are coaxial with an outer conductor diameter of 40 mm. Total coupler length inside the cryostat is roughly 40 cm.
A reduced height waveguide matches the *WR650 waveguide to the 50 Ohm coax transition* under incorporation of the warm window as a UHV barrier towards the waveguide. Two stubs are inserted to the waveguide transition. They mainly compensate the short taper between full and reduced height waveguide. The coupler part outside the cryostat is very rigid and not sensitive against forces from the waveguide system. The warm ceramic window is mechanically decoupled by thin supporting copper collars and a weak area of the wider waveguide wall.
Two bellow sections in the inner and outer conductor of the warm coupler part inside the cryostat provide bends which allow *transverse motion* of the 1.8K coupler end by ±15mm if the cavity flange connection migrates thermally.
Inside the inner conductor there is an antenna tuning bar. Turning the tuning nut at the room temperature end of the bar moves the tuning bar and changes the capacitive antenna position by lengthening or shortening the cold inner conductor bellow. Thus the cavity *external Q change* is easily performed.
Combination of *low cryogenic losses and low rf losses* is realized by 0.5 mm stainless steel walls of the outer conductors with thin high conductivity copper coatings inside (between 10 μm and 20 μm). The inner conductor bellows of the warm part are made of hydroformed thin wall stainless steel. With proper copper coating their thermal impedance is high enough to allow the rest of the inner conductor to be copper. Copper is also used for the cold coupler part inner conductor in order to conduct its rf losses to the 70 K window which has a connection to the outer conductor. The cold bellow has a thick copper plating.
Temperature distribution and thermal power flow of the coupler are determined by the thermal intercept points at room temperature, 70K, 4.5K, 1.8K. The heat losses at the low temperature levels are are expected to be 6W, 0.6W, 0.06W at full rf load.

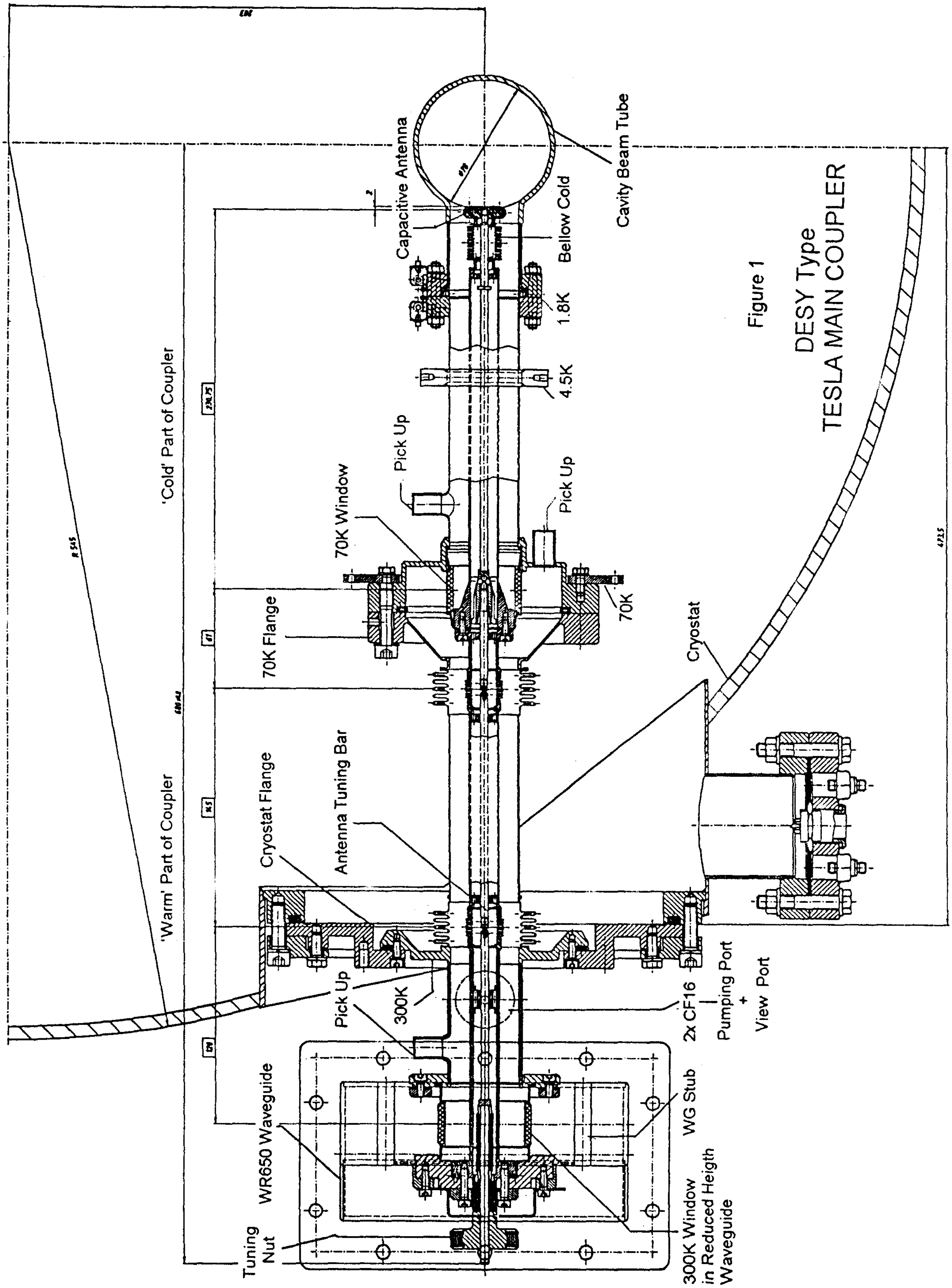

Figure 1

DESY Type
TESLA MAIN COUPLER

An additional feature of the coupler are ports for *diagnostic* instrumentation which serves to increase reliability of the device if connected to the interlock system. One vacuum port between waveguide and cryostat flange is thought for multiplier observation of light effects. Three capacitive pick up probes allow measuring of charged particles near the windows. Charged particles can indicate multipacting effects or plasma discharge before light comes up. It is very important for the coupler to prevent rf operation conditions which lead to multipacting or discharges inside the vacuum. The resulting pressure increase will cause material evaporation by rf plasma welding within a few μsec and thus lead to damage.

3.2 Technology and Fabrication

The coupler consists of three subgroups. One of those is the cold coupler part including the 70K window which is only one piece after assembly. A second piece is the inner conductor of the warm coupler part. The third piece is the warm outer conductor including the 300 K window.
These subgroups will be welded as far as possible with exception of the window connections and most bellow connections. Those will be brazed in an UHV furnace in maximally two steps at two different temperatures with two different braze alloys. One temperature is 820° C using CuAg eutectic braze for the first step. The other temperature is 500° C using $AuGe_{10}Cu_2$ braze. Critical copper coatings especially for the low temperature areas of the coupler will be done after brazing or before the 500° C braze. The ceramic windows will be provided with a Titanium antimultipactor coating on their vacuum side surfaces before brazing because it will be difficult to coat the windows after that. Brazing temperature for the window assemblies will be 820° C. High quality copper plating and final assembly of the manufactured parts by brazing will be done by two experienced industrial companies.

3.3 Technological Problems

There are still questions under study. One of those is influence of heat treatment on the conductivity of thin copper layers. This question comes up because the aim is first to plate the rf conducting surfaces with copper and afterwards to braze the coupler with eutectic braze. This is easiest to use and needs 820° C. Investigations of different copper platings and heat treatments have shown that very thin copper layers of only a few microns can degrade at this high temperature during brazing to RRR (residual electrical resistance ratio between 300K and 4K) values less than 2 which would be to low copper quality. The aim is to achieve a coating quality with a final RRR value of about 30. This is possible at brazing temperatures up to only 550° C with a different braze alloy.
A second question is the influence of heat treatment on the Ti antimultipactor coating which has a thickness of only a few nm. Actually tests of Ti coatings on ceramic surfaces and heat treatment of those are done at DESY. The influence of heat treatment is investigated at Hamburg University by Auger electron spectroscopy and XPS. Actual results say that the Ti stays at the ceramic surface but it is not clear what the chemical changes are. Most probably Ti forms a compound with Oxygen from the ceramic surface and Nitrogen. Both compounds are known to have very low secondary emission coefficients and prevent surface multipacting.

One of the questions which are still open is multipacting behaviour due to the coupler geometry. Under this aspect the rf field distributions especially of both windows have been studied under all possible operation conditions with the Hewlett Packard HFSS program (different phases at full reflection and travelling wave). In addition a multipactor research program has been started in summer 1993 at R. Nevalinna Institute, Helsinki.

4. Window Details

It should be mentioned that the position of the 70 K window is in the voltage standing wave minimum at the end of the rf pulses if there is no beam (high power conditioning). The 300 K window will be near the voltage maximum at that time. This inverts roughly at pulse beginning. Both windows have no enhanced field regions which means that the fields due to compensation techniques are not evidently higher than the unperturbed waveguide and coax fields. This is due to a very broadband design. Thus the window positions seem uncritical.
Also field concentration inside the ceramic is uncritical. The inside peak fields are about 3 MV/m at 1 MW full reflection. The breakdown field of the ceramic is 26 MV/m up to 43 MV/m. Fig.2 and Fig.3 show reflection of the windows vs frequency. Voltage reflection at 1.3 GHz is less than 1% in both cases.
The construction of window assembly is the same for both windows. They are connected to their environment by weak copper rings of 1 mm thickness and 1 cm height. The mechanical and thermal behaviour of this assembly have been tested thoroughly. Destructive mechanical force is at least 50 N/mm^2 stress at the copper to ceramic connection.
At tests with LN_2 the assembly proved to be absolutely thermal shock proof. No leak occurred at many tests.
Also the heat transfer capability of the 70 K window was tested because the inner conductor losses of about 4 W are cooled via this ceramic window. It was possible to transfer about 100W of thermal power without leak with the outer conductor connection of the ceramic cooled at 70 K.

5. Mounting Tool

Mounting of the coupler without a tool implicates danger of scratching the thin and weak copper layers of inner and outer conductor. The 'warm' coupler part is unstable as long as it is not fixed by the cryostat flange. A mounting tool has been constructed. It allows to assemble the 'warm' coupler parts to the cryostat without danger of damage and especially simplifies those situations where two persons would be needed for mounting.

6. High Power Test of 70 K Type Window

A 1.3 Ghz coaxial resonator of 3 half wavelenghts has been built with the 70K type window in the voltage standing wave maximum at the middle of the resonator. With two 400W rf amplifiers it was possible to excite a standing wave corresponding to a fully reflected travelling wave

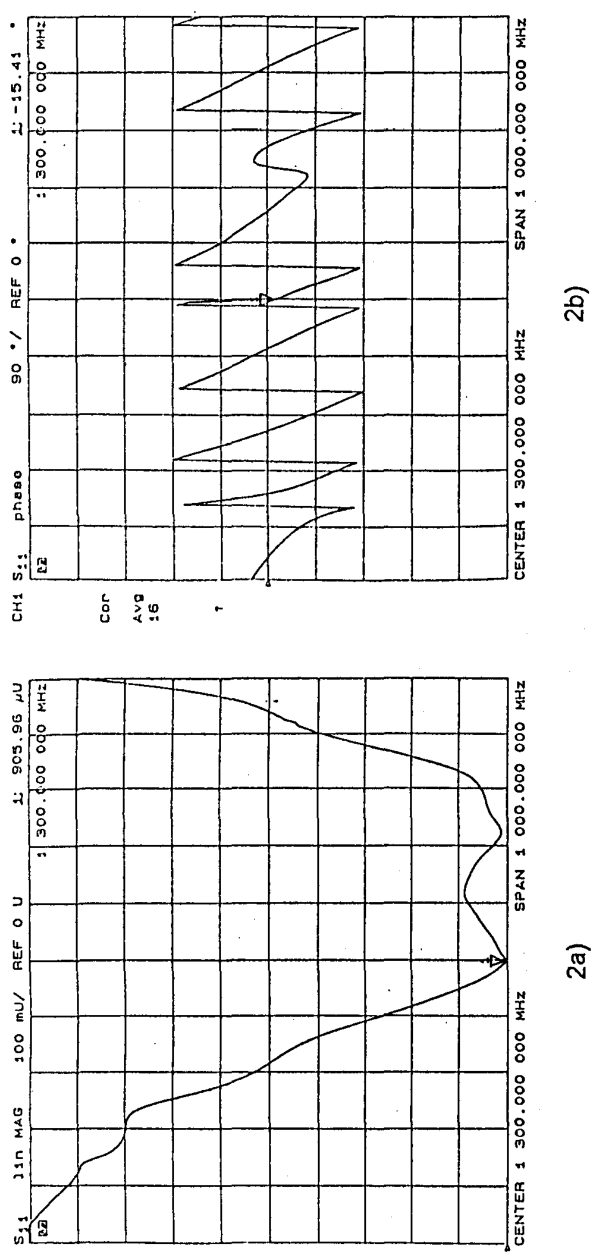

Figure 2

Reflection of 300K Window vs Frequency from measurement

a) Amplitude

b) Phase

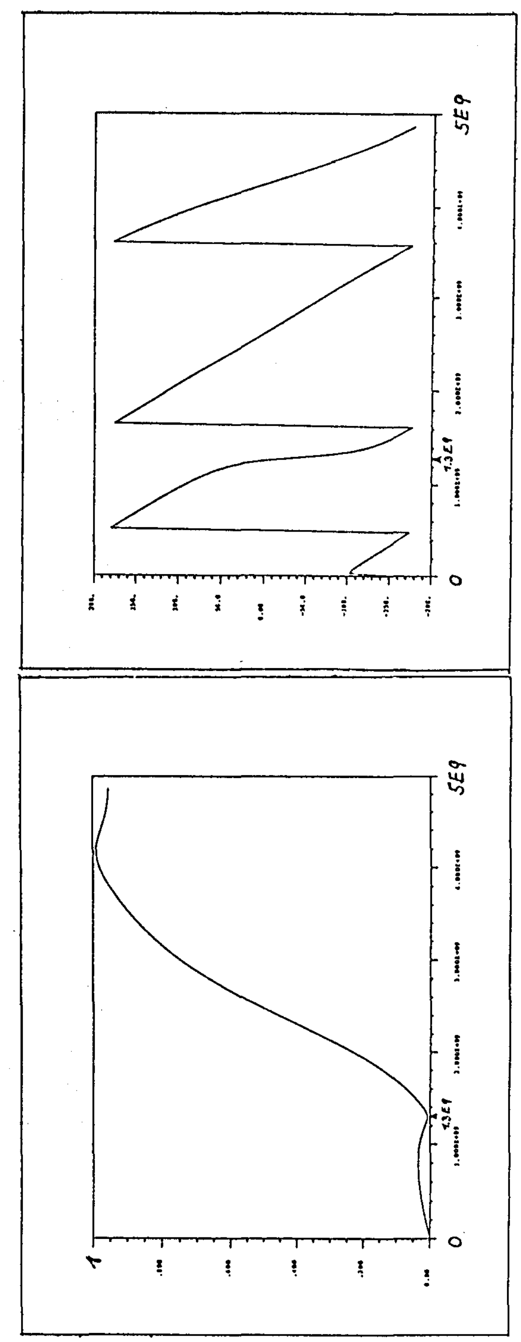

Figure 3

Reflection of 70K Window vs Frequency by computation

a) Amplitude

b) Phase

of 100 kW. Hence the achieved voltage at window position corresponds to 400 kW of travelling wave power.
An uncoated 70 K type window was tested up to this power at 2 msec pulses. The observed vacuum-, discharge- and light phenomena were eliminated by conditioning. No limitations were visible up to this power even with an uncoated window. Further tests with 800 W were not possible because one of two amplifiers was not available anymore.

7. Test Stand for Coupler Conditioning

High power couplers have to be conditioned. This is very difficult together with a superconducting cavity and might contaminate the cavity with the materials which are set free by the coupler during conditioning. For this reason a high power test stand has been constructed. The drawings are nearly finished. Materials are already ordered.
Mainly the test stand connects two couplers by a piece of waveguide inside a cryostat at liquid Nitrogen temperature and allows transfer of high rf power via both couplers to an external absorber.
An rf test model of the connecting waveguide with coupler input antenna models was designed by MAFIA computations. Successful measurements were done at a low power laboratory model.

8. Concluding Remarks

Design work of TESLA main coupler prototype at DESY is finished. A complete set of detailed drawings for fabrication exists. Three couplers are ordered. The demanding list of performance requirements led to a complex design which seems to solve the tasks. An optimization of the design, elimination or solution of open technological questions as well as an optimization of a fabrication procedure should be next steps. However first of all it is important to gain high power rf operation experience with prototypes.

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