High Power Windows at DESY
Operation Experiences, Development Work on TTF Input Couplers

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Abstract

There are many different types of rf high power couplers operated in the various existing accelerators at DESY. However the main effort of coupler development is actually done at the TTF activity. Consequently this report concentrates on TTF input couplers.
The TESLA project needs for it's superconducting cavities input couplers with unusual features besides high performance and very high reliability. Reliability is a strict requirement because partial or complete exchange of a coupler after installation to a cryomodule might imply disassembling of more or less a whole module and danger of contamination to the cavities.
In reference to this both coupler types which were developed for the first TTF module are considered as prototypes. First experiences with these couplers and further development work will be reported here.

Introduction

The TESLA [1] rf power input coupler has to fulfill very demanding requirements. In so far it is a critical component. It's main specification features are :

pulsed operation at 1300 Mhz ,
210 kW peak power , 1.33 msec pulse length at 5 Hz repetition rate ,
800 μsec pulse flat top length at peak power with beam in the cavity ,
peak power capability of up to 1MW at
reduced pulse length and repetition rate (500 μsec , 1Hz) ,
tunability of Qext between 10^6 and 10^7 ,
transverse flexibility of up to 15 mm displacement of the cavity coupler port.

The external Q variation is needed to compensate for the scattering values of field flatness in the superconducting 9 cell structures. Transverse flexibility of up to 15 mm is needed to follow the coupler port displacement during cool down of the module. The peak power capability of 1 MW is needed for in situ high rf power processing of the cavities if one of those would degrade.
Two different prototypes of high rf power input couplers have been developed for the first TESLA module: one FNAL type TTF coupler (Figure 1) and one DESY type TTF coupler (Figure 2).

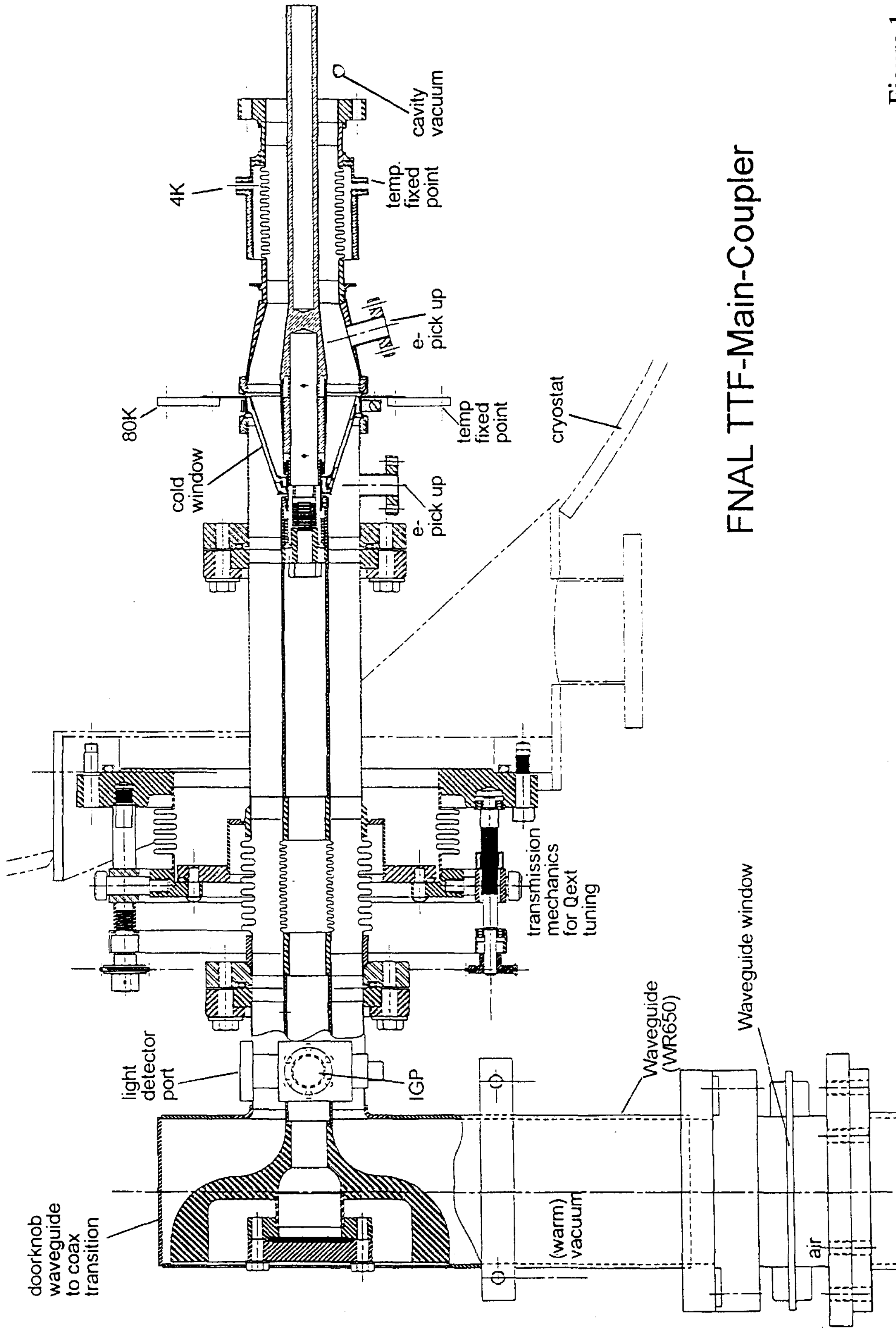

FNAL TTF-Main-Coupler
cavity vacuum
4K
temp. fixed point
e- pick up
80K
temp fixed point
cold window
e- pick up
cryostat
transmission mechanics for Qext tuning
Waveguide window
Waveguide (WR650)
light detector port
IGP
doorknob waveguide to coax transition
(warm) vacuum
air

Figure 1

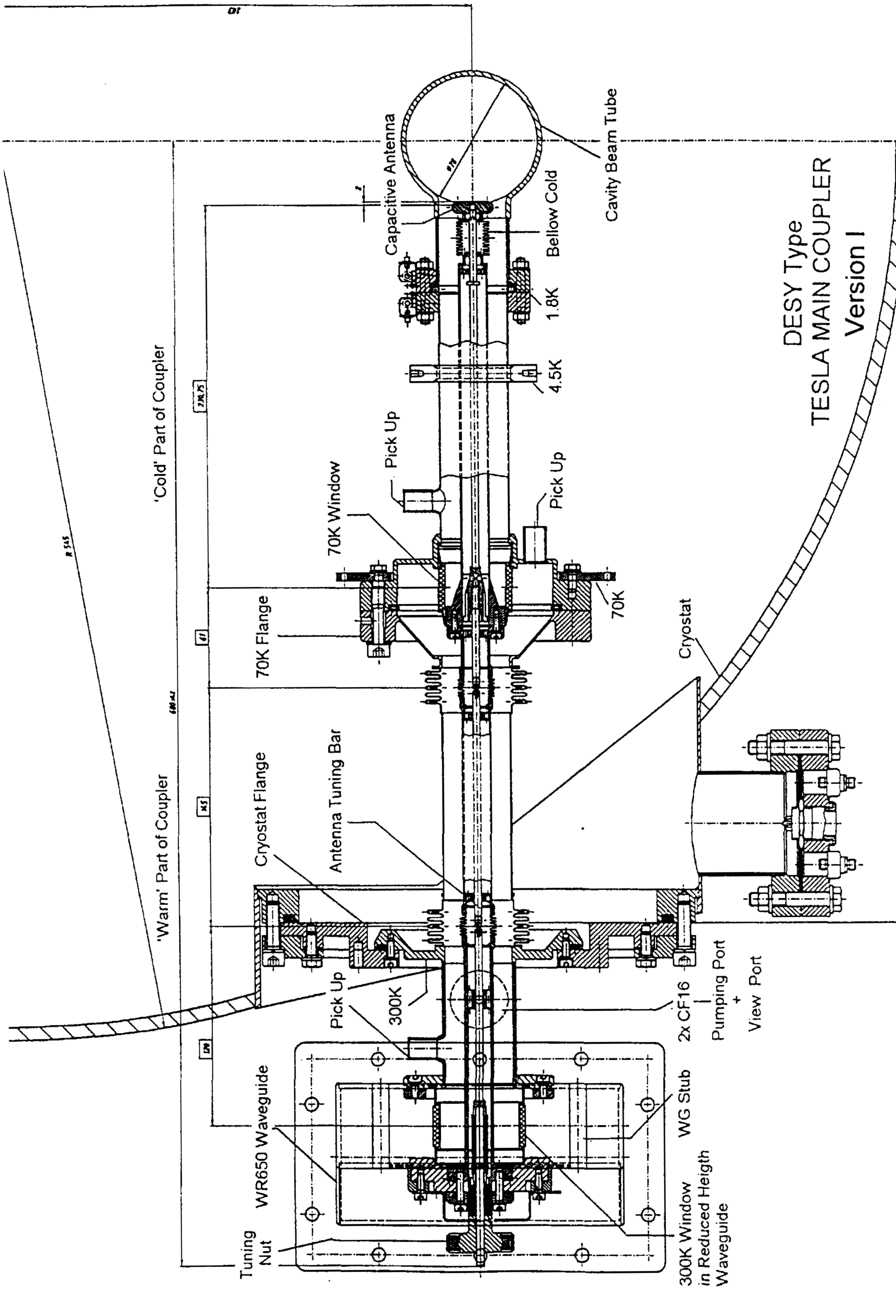


Figure 2

8 complete couplers were delivered from FNAL, 4 complete couplers were manufactured by DESY.

The first TTF module needed 8 input couplers : 5 of the FNAL type couplers and 3 DESY type couplers have been installed. One additional FNAL type coupler was used for the superconducting capture cavity of the injector.
First cool down of a complete TTF module was on May 20, 1997. Module operation with rf power was started on May 29. The system was successfully operated up to an average gradient of 16.7 MV/m at the flat top of the pulse.

Main Components of the Couplers

Each coupler (Figures 1 , 2) consists of a coaxial cold part and a coaxial warm part with a coax to rectangular waveguide transition. The cold part is mounted directly onto the superconducting cavity coupler port. Thus it's 'cold' window closes the vacuum of the cavity as well as the vacuum of the whole cavity string before leaving the clean room. Removing the cold coupler part might severely degrade the performance of the cavity string by introduction of dust. The DESY type TTF coupler (Figure 2) has a cylindrical cold ceramic window while the FNAL type TTF coupler (Figure 1) has a conical cold ceramic window. The warm coaxial parts of both couplers connect to a flange near the cold window and are mountable and removeable from outside the cryomodule. Their separate vacua are closed towards the waveguide air atmosphere by 'warm' ceramic windows. In case of the DESY coupler it is again a cylindrical ceramic window which is integrated into the transition area. The FNAL coupler has a doorknob coax to waveguide transition and a flat 'pillbox' window in a separate piece of waveguide. This window was available on the market. Both coupler types have bellows to make them flexible. Qext tuning is done in case of the FNAL type coupler by a transmission mechanics which moves the middle part of the coupler axially and thus changes the inner conductor antenna end position. This construction needs external support of the doorknob transition . In case of the DESY type coupler Qext is varied by a tuning nut which directly moves the capacitive antenna tip by an axial rod inside the inner conductor.

Processing and Test before Installation to the TTF Module

Three test stands have been built for processing and testing of the couplers before assembly to the cavities. Each of two stands allow testing of two couplers connected in series and terminated by an rf absorber. One of both is 'warm'. The other one is a cryostat and allows to have the cold coupler parts at 70 K in vacuum . A third stand is also only warm and replaces the second coupler by a piece of waveguide with a waveguide pillbox window closing the coupler cavity side vacuum. The original idea was to condition and test all couplers on the test stands. This was not realized because most of the coupler parts were too late for this procedure. Only 2 FNAL type couplers and 3 DESY type couplers were tested and processed in a teststand before assembly to a cavity.
A horizontal test cryostat Chechia [2] was built for testing and processing of each cavity individually with it's coupler. Due to late deliveries only 7 of the 8 module cavities were tested and processed there together with 5 cold parts of the FNAL type couplers and 2 cold parts of the DESY type couplers. A tight assembly schedule led to the situation : all warm parts of the FNAL couplers which

were installed to the module saw no rf before. The eighth cavity including it's coupler was installed into the module without testing it in Chechia.

Initially the DESY type couplers performed up to only about 400 kW in the test stand at TW operation. The limitation was due to a sparc discharge phenomenon at the air side of their 'warm' ceramic window. The sparc originated in a very small area of electric field enhancement in air at the edge of the ceramic metallization (Figure 3). The ceramic window was redesigned (Figure 4) and exchanged: the high field area at the ceramic to metal transition is shifted into the ceramic bulk and the peak field is reduced by less radius (because inside the ceramic the metalization corner in reality is round). The critical electric break down field in the ceramic is 20 .. 30 times higher than in air. This measure led to full specified performance of 1 MW. Only one of the three DESY type couplers in the module was equipped with the corrected 'warm' window.

The FNAL couplers got up to full specified performance in the test stand. They also were successfully tested up to full performance with the superconducting cavities on resonance and detuned.

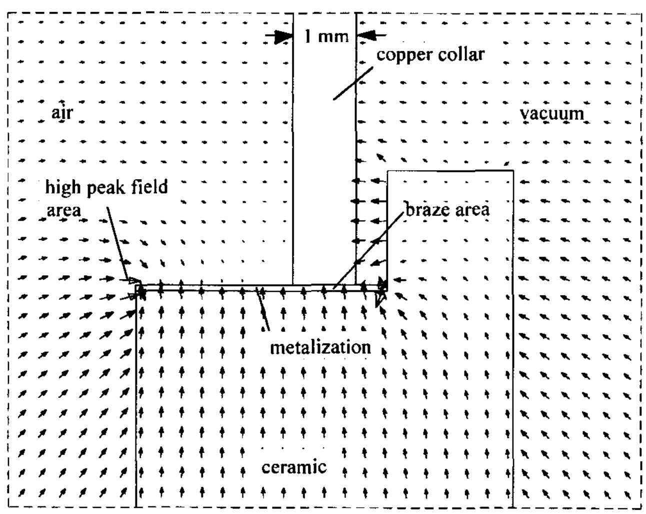


Figure 3 electric field at metal to ceramic (brazed) transition, original version

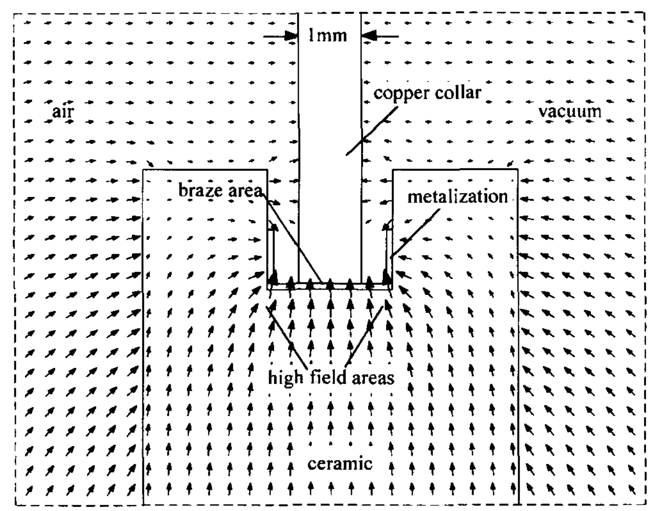


Figure 4 electric field at metal to ceramic (brazed) transition, new version

Diagnostic System

A diagnostic system for monitoring the coupler behaviour and for interlocking was used in the coupler test stand, in Chechia and in the first module too. Positions of some of the main elements for diagnostics are shown in Figures 1 and 2.

Both coupler types are equipped with several electron pick up antennas for diagnosing activities due to multipacting and gas discharges. In addition there is a view port which is equipped with a photomultiplier for light detection in case of starting break downs. Sparking at the airside of the warm window is detected by a phototransistor. The warm window temperature is measured by an infrared sensor. Resistors are used for measurement of the temperatures at the cold window and the cavity coupler flange. In the test stands and Chechia the individual coupler vacuum signals (cold side and warm side) were used as the main information allowing or limiting further power increase. After installation to the module the warm side coupler vacua were connected to one line and the cold side coupler vacua were connected by the cavity string. Hence both vacua are available only as common informations of all couplers. Especially the cold coupler side vacuum response turned out to be very weak because the system pumping capability of the cavities is very high as soon as they are cooled down.

The diagnostic system is a tool to protect the couplers against damage during processing or during TTF operation and it allows measurement and rough locating of multipacting activities.

Multipacting /Processing/Operation Behaviour :

Processing of a coupler is a procedure of cleaning it's surfaces by removal of adsorbed gases and dirt if existing, and of destroying emitters like sharp micro-edges on the surface. This was necessary after each disassembly/assembly cycle and also for each operation type like traveling wave, coupler warm or cold , cavity on resonance or cavity detuned. It was done automatically by a computer using the informations of the diagnostic system.

The processing procedure was cycling the rf power slowly between low and high values. Beginning pulse length was 20μsec. After finishing the first power cycle this pulse length was doubled and so on. Finally the rf power was sweeped slowly between zero and maximum power for a few hours at full pulse length. The pressure increase due to the resulting gas and electron activities of the couplers allows for pumping away the desorbed gases and vaporized dirt..

In general both coupler types showed following behaviour :

The process is initially dominated by rf ionized gases and electron activities at every power level. Later these activities reduce and shrink towards defined power bands of multipacting. After days or weeks -depending on the initial cleanliness of the individual coupler- there are no charged particles and no pressure responses any more because production of electrons and particles disappears with increasing surface cleanliness. In this stage even multipacting was not observable any more at both coupler types.

It turned out that after some time of non operation first the multipacting bands reappear gradually and may need new conditioning because otherwise multipacting during normal operation could initiate coupler break down and lead to interlock events.

Multipacting is dangerous for couplers and has been studied in the last years very thoroughly [3]. Some results of these investigations are given in Figure 5. It shows a summary of coaxial line multipacting at rf full reflection and scaling laws for application to different coaxial lines and different reflection factors. The circles of the horizontal line at position log((f*d)^4*Z)=19.7 correspond to the DESY coupler of Figure 2 and indicate multipacting areas (black lines) at incident power levels readable from the abscissa. Each horizontal line characterizes a specific coaxial line at given diameter, impedance and frequency. The line at 21.5 corresponds to the warm part of the FNAL coupler. Obviously this coupler has a wider power operation area without multipacting due to it's bigger diameter. It's multipacting close to 250kW is of high order and hence less stable. The computed and measured multipacting power levels are compared in Figure 6.

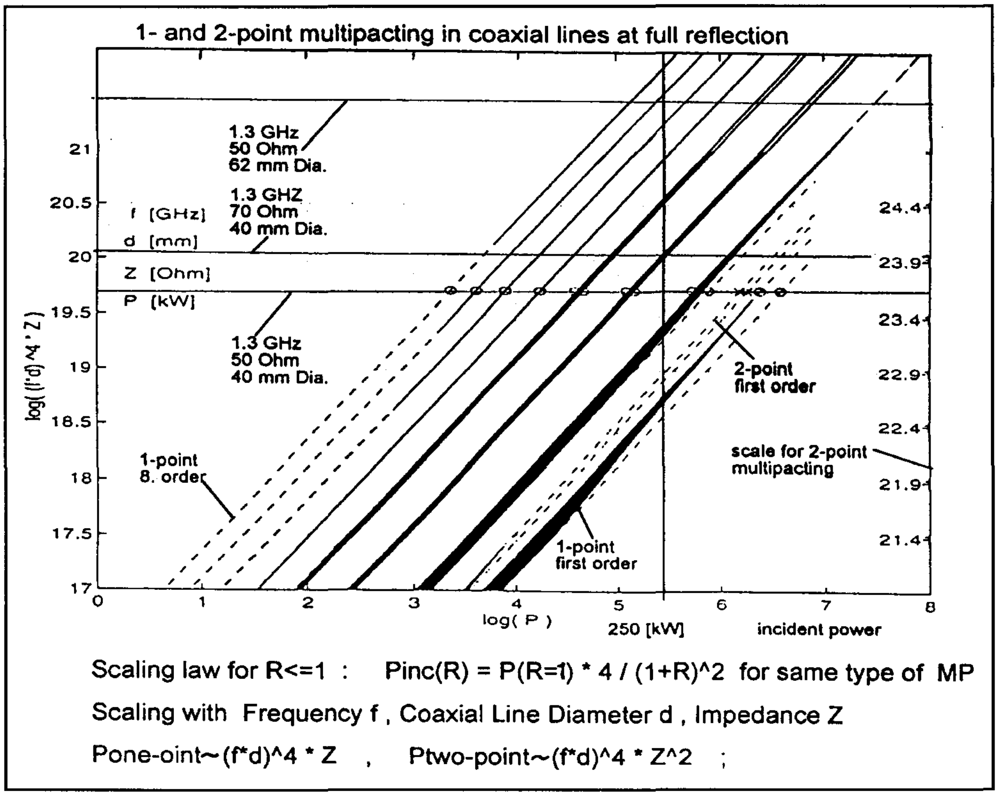


Figure 5 Summary of coaxial line multipacting without bias voltage

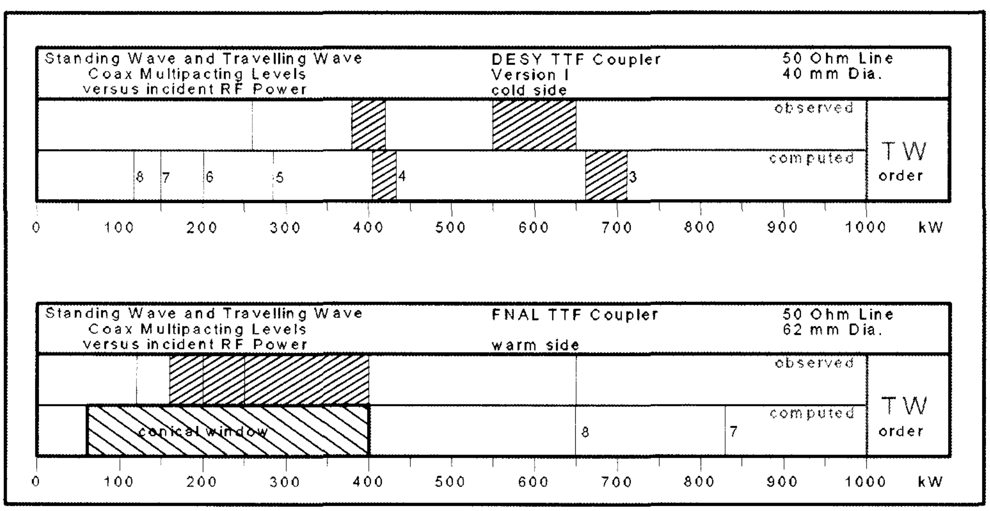


Figure 6 Computed (see Figure 5) multipacting thresholds for the DESY TTF-Coupler Version I coax line and the FNAL TTF-Coupler coax line and it's conical window , compared with the observed thresholds

An additional important result of the multipacting analysis are computations which allow to predict at which bias voltage on a coaxial line inner conductor multipacting is suppressable.

Experience from the Prototype Couplers in the first module

Couplers and cavities were operated inside the module at power levels up to 300 kW per cavity, repetition rates of 2 Hz .. 10 Hz and pulse lengths ≤ 600μsec. Qext was adjusted to 1.8 * 10^6.
Typical operation with beam through the module was at 150 kW .. 200 kW per cavity for test and calibration purposes. Nearly no interlock events were caused by the couplers. All the couplers worked fine at cavity on resonance and at detuned cavity in full reflection condition. Limitations of rf power were mainly due to cavity performance. Both coupler prototypes were successful. A problem for the 2 uncorrected DESY type couplers came up when driving without interlock at rf power higher than the limitation. Their 'warm' windows sparked at the air side and had to be cleaned again.
Nevertheless the main effort of realizing those couplers was concentrated to fulfill the demanding specification. Hence there are many details of both couplers which turned out not to be optimal. The experienced problems are expressable in a list of requirements for improvement :
simplify coupler construction ; easy production, manufacturing, technology ;
ultimate cleanliness of all parts ; easy to clean parts especially at the cavity side ;
more control of materials especially ceramic material ;
prevent metal coatings of the ceramic by brazing vapors ;
reduction of hydrogen by furnacing ; careful checking of copper coatings ;
essential reduction of price ;
consideration of actual results of multipacting analysis [3] by
proper choice of dimensions and introduction of a high voltage bias ;
This list could be continued.

New DESY-TTF-Coupler Designs

The experiences and difficulties of coupler manufacturing , mounting , operation , cost and the aim of further improvements by considerating the results of multipacting analysis and by introduction of a bias voltage for the inner conductor led to continuation of TTF main coupler development work.
A new DESY type TTF coupler version II was developed (Figure 7). It tries to combine the best features of both existing designs :
waveguide doorknob transition from the FNAL-Coupler ; Qext-tuning mixed from DESY type I and FNAL coupler ; mininmized number of bellows ; bigger warm side pumping port ; 'cold' window like DESY type I , but improved geometry of ceramic ; 'cold' window without multipacting according to computations [3]; 70 Ohm 'cold' coaxial line instead of 50 Ohms for shifting of multipacting thresholds ; high voltage bias system by introduction of an isolating Kapton foil into the doorknob ; self supporting coaxial line to waveguide transition.
An additional separate vacuum window inside the waveguide like used for the FNAL coupler is needed.

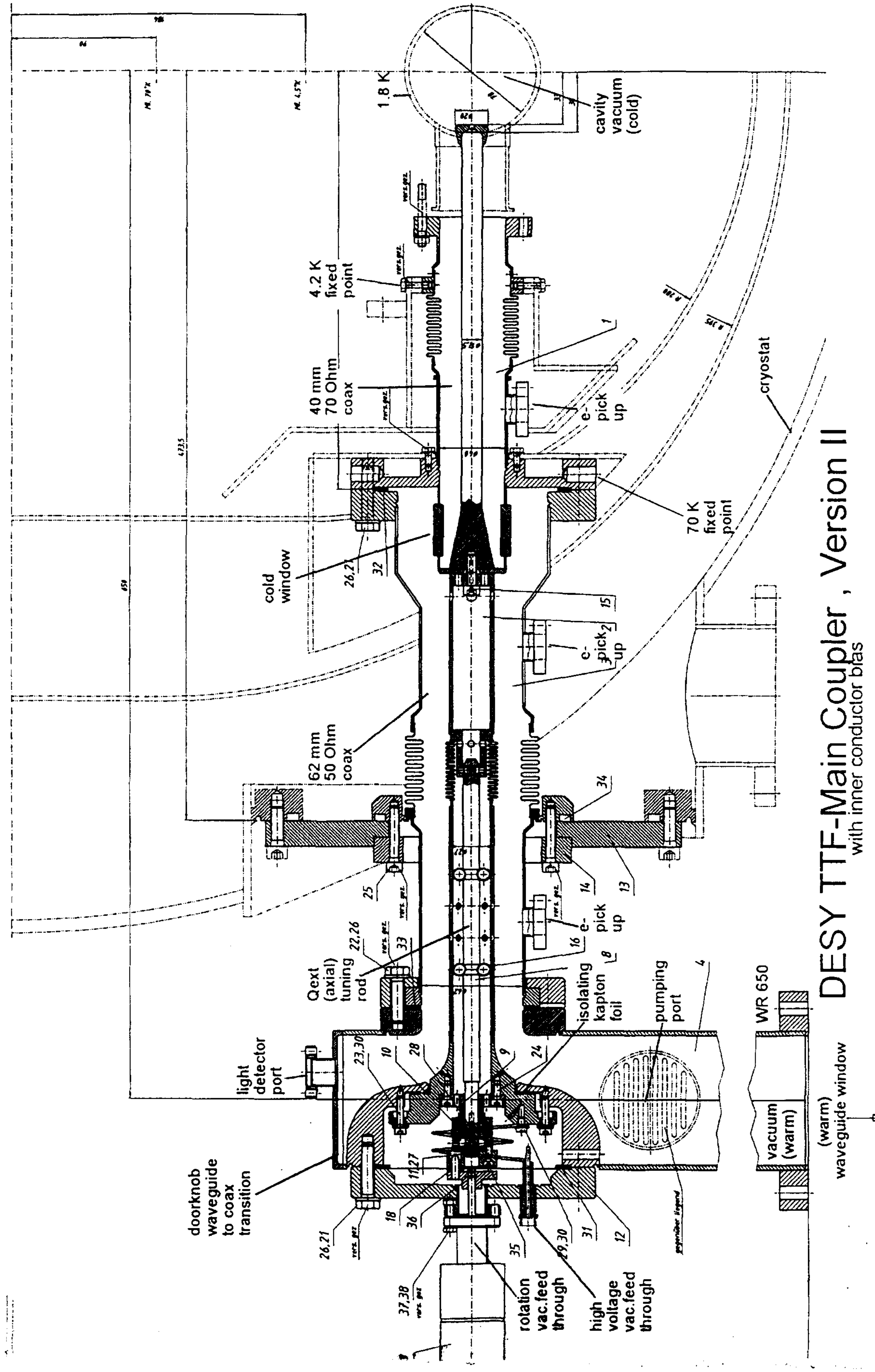

DESY TTF-Main Coupler , Version II
with inner conductor bias
cavity vacuum (cold)
1.8 K
4.2 K fixed point
40 mm 70 Ohm coax
e- pick up
70 K fixed point
cryostat
cold window
62 mm 50 Ohm coax
Qext (axial) tuning rod
isolating kapton foil
pumping port
WR 650
light detector port
doorknob waveguide to coax transition
vacuum (warm)
(warm) waveguide window
rotation vac.feed through
high voltage vac.feed through

Figure 7

One simplified version of this design has been built. Mainly the outer conductor bellows and the copper coating inside the (stainless steel) outer conductor and inside the waveguide were left out.
First very successful tests of this coupler were carried out on the room temperature teststand without HV bias in TW operation (31.08. .. 08.09.97). Due to a mistake of the antenna tip length there was a power reflection of 30%.
1MW at up to even 1.3 msec pulse length was achieved and no limitation was visible. During processing the observed multipacting was dominated by the predictable coaxial type (according to computations). This means that the cold window area showed no additional specific multipacting. However it was found that the Kapton foil inside the vacuum after each exposition to air needs a day of 200°C heating in order to get rid of absorbed gases and to achieve a proper vacuum better than 10^{-8} Torr in the worst case with rf on. The dominating component of the residual atmoshere in the coupler was hydrogen. It's partial pressure was with and without rf about 10 times higher than all the other gas components. This was similar at the prototype couplers.
After having the coupler conditioned without bias application of high voltage bias to the inner conductor led to a surprise. Each applied bias voltage between +3.5 kV and -3.5kV produced new multipacting levels at first already at low rf power. New conditioning was necessary to operate the coupler at any constant high voltage level in the given range. Having done the conditioning the coupler was also operable at that HV level.
An unexpected problem occured when trying to order more of the waveguide windows. The waveguide window used for the FNAL coupler turned out to be not available on the market any more. Similar available waveguide windows are two or three times as expensive.
The way out was construction of a vacuum capable waveguide window at DESY. A prototype of this window (Figure 8) is already existing and has been succesfully tested first between air and SF_6. Higher than 1.8 MW even in standing wave operation at worst wave position was achieved.
In addition a DESY Version III TTF coupler (Figure 9) was developed with an integrated cylindrical window in the coax to waveguide transition similar to DESY type version I but with the improved 'warm' window design. The integrated window without doorknob promises to cut down the cost compared to a separate waveguide window. Version III has no difference of the cold part compared to Version II. It is equipped with a bias part which mainly is an exchangeable ring capacitor around the base point of the inner conductor at the waveguide end. Advantageous is to have the isolating Kapton foil outside the vacuum between two metal rings.
Actually there are 10 couplers of DESY TTF Version II under production for the next module. Delivery will be at beginning of 1998. 10 further ones are ordered. Additionally production of 20 waveguide windows of the DESY type was started.
Production of a prototype Version III coupler is just beginning.

Conclusions

The first TTF module has been operated very successfully with 8 high rf power input couplers of two different prototypes. Experiences of production, handling and operation of those two coupler types have been acquired. It turned out to be important to reduce complexity and cost as far as

possible, to simplify handling and to make rf operation more safe and easy by introducing new knowledge about multipacting and it's suppression by a bias voltage. Consequently coupler development for TTF is still going on. Two new TTF coupler types were developed up to now and are described here. In addition a high power waveguide window was developed as a seperate unit. It is needed to complete a coupler which has no integrated vacuum window at it's waveguide side.
One of the new coupler designs and the high power waveguide window are already tested and put to series production for the next TTF modules. The actual coupler performances are summarized in the following table.

Achieved TTF-Coupler Performances						
Coupler Type		TTF Specification			Limitation	Remarks
empty fields = not applicable or not yet measured	DC-Bias	210 kW 5Hz 1.33 msec TW SW	1000kW 1Hz <=0,5 msec TW SW	tested max performance		SW operation only with Cavity; TW in test stand
		reached				
FNAL	no	yes yes	yes yes		no	proven : fully operable
DESY TTF Version I *original ceramic*	no	yes yes	no	TW 400kW SW 300kW	yes	sparc in air at warm ceramic
DESY TTF Version I *new warm ceramic*	no	yes yes	yes		no	after warm ceramic redesign
DESY TTF Version II	yes	yes	yes	1,3 msec at 1MW TW	no	simplified protoype so far
DESY TTF Version III	yes					under construction
Waveguide Window		tested at 2HZ , 5Hz , 1.5 msec up to :				between air and SF6, no vac. test yet
		TW		> 3.3 MW	no	
		SW	Voltage min	3.05 MW	yes	sparcing
		SW	Voltage max	1.8 MW	at 2.4 MW	strong sparcing

References

[1] Conceptual Design of 500 GeV e+e- Linear Collider with Integrated X-ray Laser Facility, Brinkmann, Materlik, Rossbach, Wagner , DESY 1997-048

[2] P.Clay et al., Cryogenic and Electrical Test Cryostat for Instrumented Superconducting RF Cavities (CHECHIA) , Contribution to the CEC/ICMC'95.

[3] Erkki Somersalo, Pasi Ylä-Oijala, DieterProch, Jukka Sarvas , Computational methods for analyzing electron multipacting in rf structures , Particle Accelerators, to be published

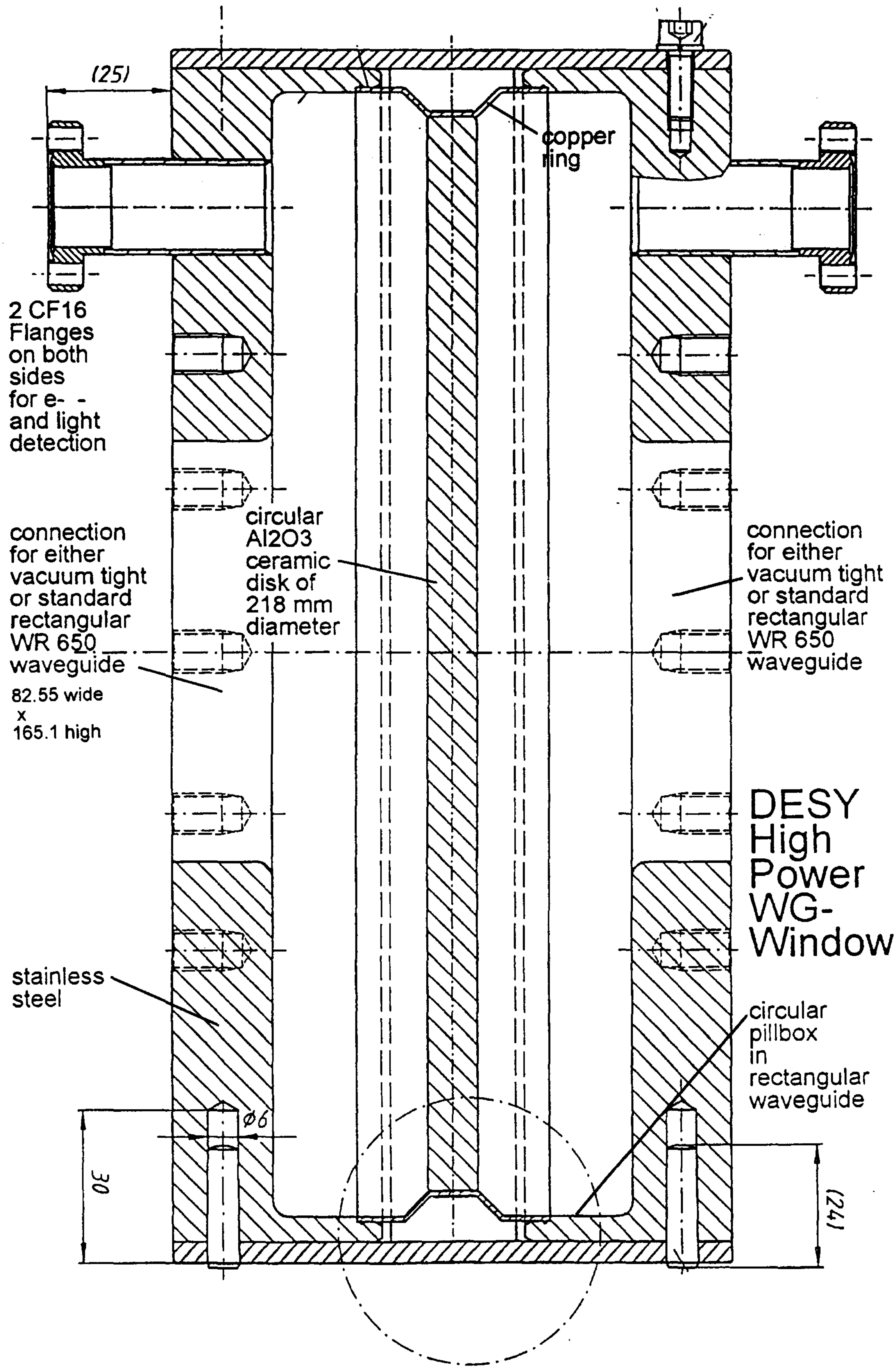
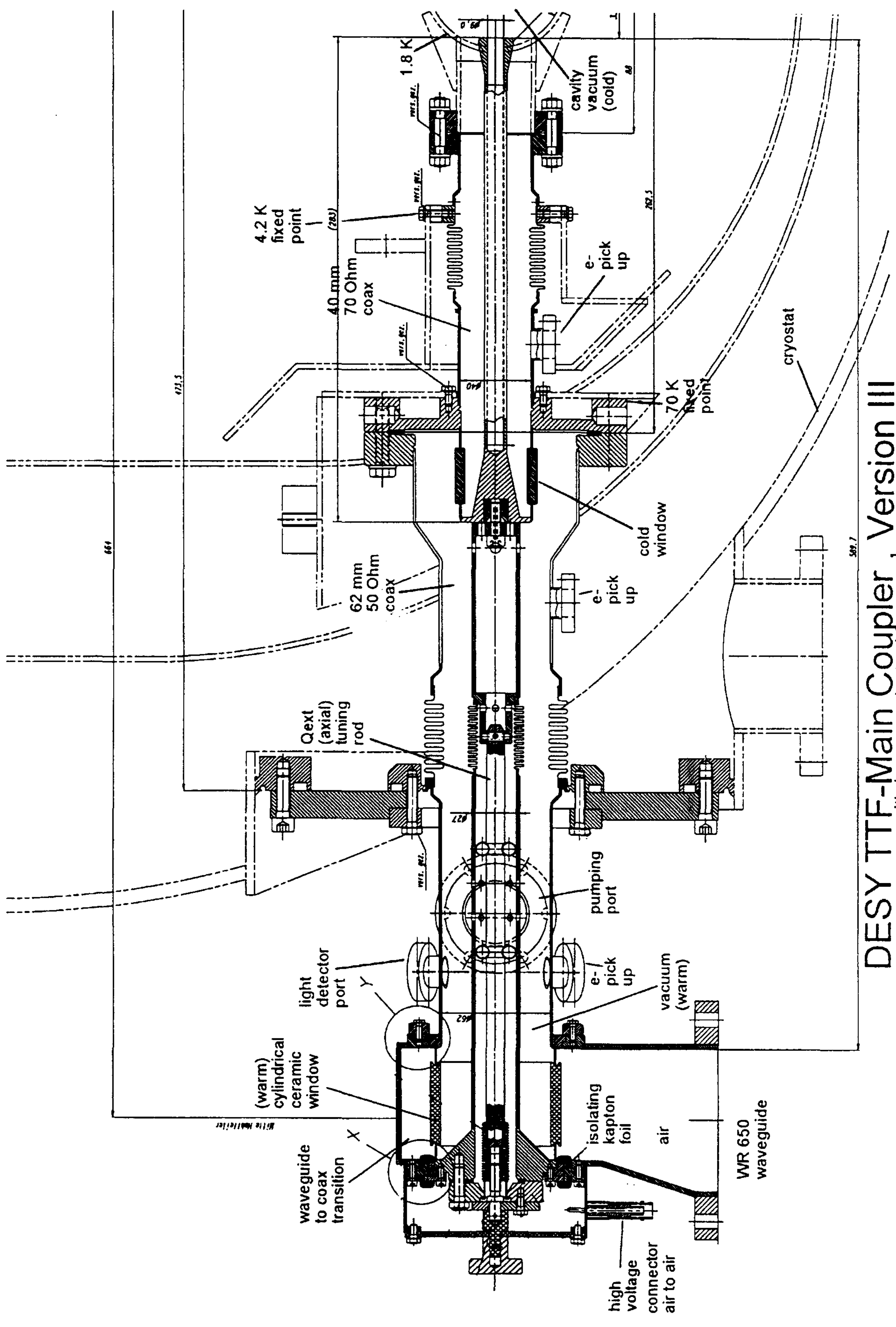

(25)
copper
ring
2 CF16
Flanges
on both
sides
for e- -
and light
detection
connection
for either
vacuum tight
or standard
rectangular
WR 650
waveguide
82.55 wide
x
165.1 high
circular
Al2O3
ceramic
disk of
218 mm
diameter
connection
for either
vacuum tight
or standard
rectangular
WR 650
waveguide
DESY
High
Power
WG-
Window
stainless
steel
circular
pillbox
in
rectangular
waveguide
Ø6
30
(24)

Figure 8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isolating kapton foil
air
WR 650 waveguide
waveguide to coax transition
high voltage connector air to air

Figure 9