BROADBAND R.F. POWER AND HIGHER ORDER MODE WAVEGUIDE COMPONENTS FOR PETRA'S SUPERCONDUCTING CAVITIES

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Summary

Superconducting rf-resonators save electrical power and have a much higher accelerating gradient than convential cavities. In the PETRA storage ring, instabilities attributable to the rf-transverse impedance[1] limit the stored beam current and therefore the luminosity. With superconducting cavities, far fewer cavity cells are required and the cells can have a larger relative aperture, resulting in less total rf-system transverse impedance. For this reason superconducting cavities (SC) are being developed at DESY[2] to investigate and solve the many problems which are connected with low temperature rf and its application to accelerating structures for storage rings. In this paper we will describe the components developed to solve some of these problems:

1. High-power broadband waveguide (WG) vacuum window located outside the cryostat to couple simultaneously 60 kW of fundamental mode power to the SC and to pass up to 5 kW of Higher Order Mode (HOM) power induced by the beam and coupled out to the feed WG by the feed coupler.
2. High-power low-loss connection of superconducting niobium WG from the cavity to copper-plated stainless steel WG inside the cryostat.
3. Waveguide broadband Kaptan window to pass up to 5 kW of HOM power to an external termination (But still located within the body of the cryostat).
4. Waveguide broadband water load termination to absorb up to 5 kW of HOM power.
5. Waveguide "harmonic absorber" to absorb HOM power from the cavity going to the feed line.

General Description

The DESY SC is made up of two separate cavities each composed of nine elliptical niobium cells suspended in liquid helium in a common cryostat. Rf-power from a 1000 Mhz klystron is devided by a magic tee and feeds through a "harmonic absorber"assembly, then through a broadband ceramic vacuum window to the waveguide coupler located on the ends of the cavities near the center of the cryostat. HOM power is extracted from the cavity via WG couplers located near the outer ends of the cryostat. The HOM waveguide is cut-off to one Ghz (thus fundamental power does not couple out). The waveguide is terminated by a broadband water load which is housed within the cryostat.

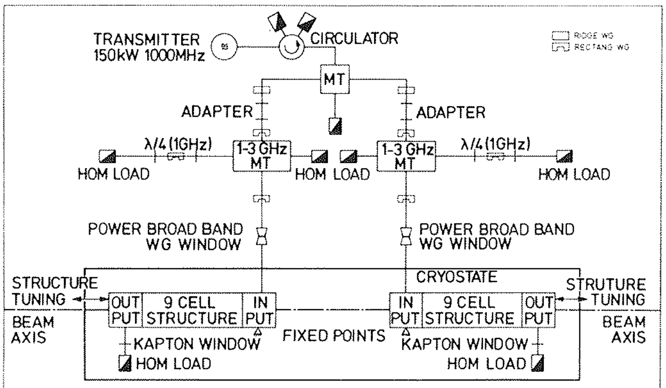


FIG.1 SUPER CONDUCTING CAVITY RF SUPPORT SYSTEM

At the design PEATRA beam current of 4 bunches of 5 mA each a 9 cell DESY SC will develop about 5 kW of HOM power in the frequency range of 1.4 to 3.0 Ghz which must be terminated by extracting to external terminations. If it were not removed, the circulating rf-currents would cause heating which would result in excess liquid helium consumption and excite wake fields which could disturb subsequent beam bunches.

Earlier SC which have been tested in PETRA have used coaxial current or voltage couplers in each cell to terminate HOM power. In the DESY 9 cell structure there is sufficient coupling from cell to cell to allow us to terminate all the HOM's by coupling only at the ends (The feed coupler WG is rotated 70 degrees from the HOM coupler WG). DESY will use waveguide coupling because the beam tube to WG transition has good coupling the power feed WG is able to load HOM power. The HOM coupler WG, on the other end of the cavity is cut off to 1 GHz, thus no fundamental power is wasted to the HOM termination. Waveguides, being larger, make a more complex cryogenic design. There is a section of copper-plated stainless steel WG from the cold niobium SC coupler to the outside of the cryostat which acts as a thermal insulator[3] and can be cooled with counterflow boiloff helium gas[4].

The bandwidth of a normal rectangular waveguide in the TE 10 mode is not sufficient to cover our range of 1.0 to 3.0 Ghz in the power feed line or 1.4 to 3.0 Ghz in the HOM load line. We have achieved the required bandwidth by using ridge waveguide.

Vacuum Windows

Vacuum windows are required both in the power feed WG and in the HOM WG to separate the UHV of the storage ring vacuum at the interior of the SC from the atmospheric feed line and the water cooled HOM termination. The design philosophy for the power feed WG window is to keep, as far as possible, a constant impedance throughout the window structure. Round ceramic window disks are easiest to make and also easiest to seal, so the ceramic window is in a circular waveguide. The window assembly tapers from a normal rectangular WG at the exterior of the cryostat to double ridge waveguide in the transition from rectangular to circular. The taper is used to compensate the cross section change and result in an exponential broadband transformation between the impedance of rectangular WG and the round dielectric-filled WG. To dimension this taper continously, we used a computer program which relates the cross-section impedance and the cutoff frequency to the dimensions[5]. After the ceramic seal the WG tapers back to rectangular again.

FIG. 2A REFLECTED POWER (TENTATIVE DATA)

The ceramic disk is hard-soldered into a ring which through knife edge sealing to a copper ring allows it to be easily removed for cleaning or replacement by simply unbolting it.

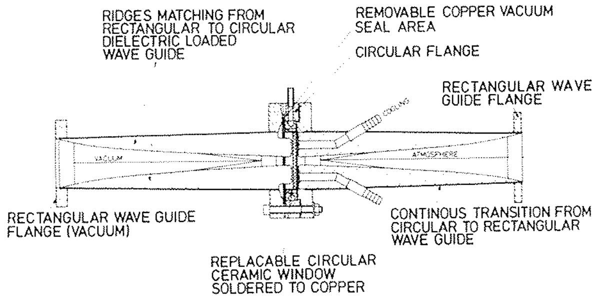


FIG.2 BROADBAND WAVE GUIDE R.F POWER FEED WINDOW

The window between the cavity and the HOM termination must be broadband as well. In this case, because the HOM power is relatively low, we decided to use a kaptan (polyamid) window which is thin enough to have negligable impedance transformation effect. Windows of this type have been successfully used at 10 kW . This kaptan window is placed between the SC HOM WG coupler flange and the stainless steel flange of the HOM water load termination and sealed with indium wire. The HOM kaptan window is effectively a safety window to protect the UHV of the SC in the unlikely event of a water leak in the HOM termination (which is of bakeable UHV construction).

Normal to SC WG flange transition

There are two flange transitions of normal conducting stainless steel WG to SC niobium WG needed for each 9-cell cavity. One of these is for the power feed WG and the other is for the HOM WG. Normally in a WG flange assembly there are some tenths of an Ohm resistivity at room temperature[7] .

If room temperature conditions held, we might expect to loose 6 W to the liquid helium which is too much when compared to a total loss of only 27 W for the complete 9-cell SC when powered to a field gradient of 3 MV/m. We needed to test the loss of various metals such as indium, lead, and aluminium when used as a flange sealer at cryogenic temperatures. to test the loss we built a superconducting cavity made of two short circuited niobium WG's flange connected in the middle. The metal gasket is a vacuum seal and at the same time an rf contact. To assure that the contact is made only on the inner rf-surface, the flange is chamfered 1.5° with the angle opening outward. (This compensates for flange bending.)

The purpose of this test was to produce, by resonance, a current across the flange connection which equals the current which will later be produced by the 60 kW of feed power[8] . The test cavity cross section was 182 mm x 65 mm (the cross section of the power feed WG), the test cavity length was 523 mm, required for TE 102 resonance at 1000 MHz. This TE 102 resonance put the maximum current across the connecting flanges located in the middle of the cavity. From the total test cavity losses at 4.2° K in the TE 102 resonance, the upper limit of flange loss is computable. From the Q change caused by the flange at the same resonance mode, the flange losses are directly computable. The relation of transported WG power and cavity loss power under conditions of equal flange current in the TE 102 resonance mode where the cavity length equals WG length is, at the chosen dimensions:

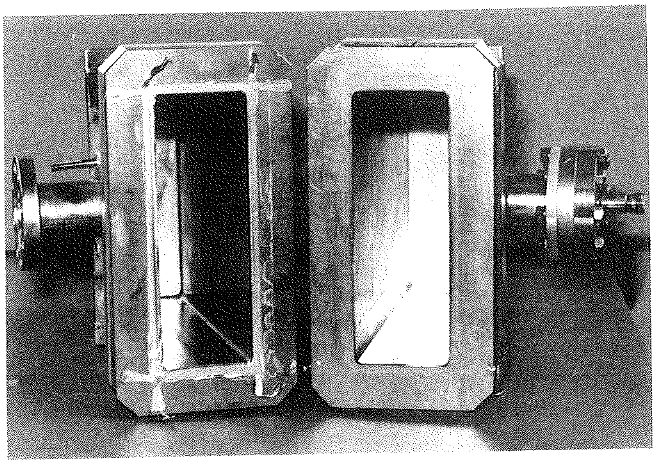


Fig. 3 Disassembled Indium Sealed Flange

Power(Transported,TE10)=0.105 X Q(Test Cavity) X Power (Lost, TE102 resonance) Equation (1)

The WG "one wide side" current produced across the flange in the TE 102 resonance is given by:

I(eff, TE102 Amps)=0.028 X $[$Q(Test Cavity) X power (Lost,TE102 Watts)$]^{1/2}$ Equation (2)

These relations show that is is easy to reach, at superconducting Q's currents corresponding to high transported WG power. The experimental results at 4.2° K show that we could power up to 10 Watts of TE102 dissipation loss at a Q of $1.6x10^7$. A flange current was produced equivalent to that which 16.8 MW of forward power would cause. From Q measurements at 2° K, where the indium is superconducting also, the cavity Q for 4,2° K without the influence of the indium could be computed to be nearly $8x10^7$. Thus the equation:

R(Flange in Ohms)=2784 X ((1/Q(measured)-1/Q(theoretical)) Equation (3)

leads to a total flange resistance of $1.4x10^{-4}$ Ohms at 4.2° K.

Using Equation 2 it is possible to compute the total flange loss directly from:

Power(flange,watts)=I(eff,TE102)squaredX R(flange)

= 8 Watts (at 10 W total cavity loss).

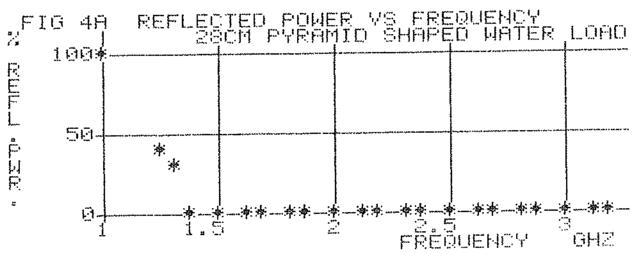
The test results show that the loss of an indium-sealed 4.2° K flange connection - 29 MW for 60 kW - is low enough; thus we utilized this construction for our high-power low-temperature WG-to-SC R.F. feed and also for connecting the HOM coupler WG to the normal-temperature stainless steel of the HOM water load termination.

HOM Water Load Termination

The HOM termination must load energy over the broad band-width of 1.4 to 3.0 GHz. It must be suitable for 5 kW average power, yet be as short as possible. Preferably it should connect directly to the SC coupler WG flange, retain the cavity UHV integrity, and be enclosed within the cryostat to allow movement without restraint of the HOM end of the cavity for tuning purposes.

In the development of this load we considered the following: commercially available WG loads, coaxial loads (with a coaxial vacuum window) fitted to a broadband ridge WG adapter, loads of lossy material such as ferrite or of lossy metal such as stainless steel. Our final consideration was water, either in long tubes or wedges.

Our tests with water wedges which were one free-space wavelength long gave very good VSWR over the required frequency range, as is shown in the test data of power absorbed vs frequency.



We chose to use the water pyramid and solve the associated problems. We are using a welded quartz glass pyramid in which the water flow fills from the outside and drains to a tube inserted in the tip. The load must have its own water system to prevent overpressure -- the quartz glass assembly can only withstand 1.5 atmospheres pressure and the vacuum on the inside of the WG already contribute 1 atm. The water system is fitted with a heater and control system to prevent freezing, and, if the circulating system fails, the water automatically drains to the sump by gravity. In the unlikely event of a water leak to the vacuum, the cavity UHV is protected by a kaptan-foil window which is rated for the maximum pressure of the pumping system. Replacing the water load requires only warming up the liquid helium, which can be done with the cryostat and cavity in place. The water load is built into a waveguide which is cutoff at 1.2 Ghz and below; over the HOM bandwidth it is near unity VSWR.

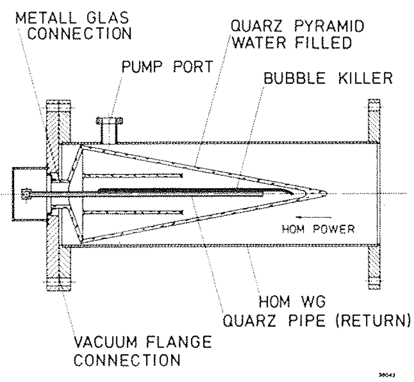


FIG. 4b HOM BROADBAND WATERLOAD TERMINATION

HOM WG Feed Line Absorber

Just as HOM power couples out to the HOM termination, it also couples out the feed coupler to the feed waveguide. Tests at the output of the circulator which protects the klystron indicated that it would present a full reflection to HOM power. But, the HOM power must be absorbed somewhere! For this purpose we investigated installing a "harmonic absorber" in the WR 975 feed waveguide. Usually "harmonic absorbers" are made using many little waveguides beyond cutoff to the fundamental (in our case 1 GHz) located in the WG broad wall. Each little waveguide is terminated in lossy material.

The delivery of such convential harmonic absorbers would have been too late for the scheduled test of our cavity. Ridge waveguide magic tees are available with sufficient bandwidth ratios to cover the range from our fundamental frequency to the highest frequency of our higher order modes. We realized that such a broadband magic tee could be utilized as the key element in fabricating a wide-band absorbtive filter.

The design of our filter works in the following manner: One Ghz feed power enters the E arm of the magic tee, divides in half, goes to each of the colinear ports, is fully reflected by the fitted HOM terminations (which are cutoff below 1.2 Ghz). The reflected 1.0 Ghz feed power sees a 1/4 wavelength longer path in one of the colinear arms, returns to the H port in phase with the reflected power from the other colinear arm, and combines to proceed on to the SC via the high power broadband WG window. HOM power from the cavity exciting the feed coupler enters the H arm, divides in half, proceeds out the colinear arms, and is terminated by the fitted HOM water load terminations. We are at present assembling the components to test this filter over a frequency range of the same bandwidth ratio but 6 times higher than our HOM frequency (where WG is much smaller!).

Acknowledgment

We owe many thanks to the various DESY workshops and the construction group for fabricating our unusual devices. Special thanks to J. Susta for designing the niobium flange seal test WG and pushing it step by step through the Lufthansa electron beam welding department, and of course to D. Proch and W. Ebeling for encouragment and help in cryogenic testing.

Conclusion

The development of these components is ongoing. We will not be satisfied until all components perform reliably as the SC accelerates the PETRA beam. Some components, such as the flange seal and HOM water load are well along. Others, such as the power feed window and HOM WG feed line absorber, are undergoing tests. All components have yet to be tested at full power.

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