SOLVING THE PROBLEM OF HEATING OF RF CONTACTS IN CAVITY TUNERS

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Abstract

The accelerating cavity of the ASTRID Electron Synchrotron was studied. The cavity is a capacity loaded TEM cavity resonating at 104.95 MHz. Two plungers driven in parallel keep the cavity in tune, yielding a tuning range of about 0.8 MHz to compensate the beam loading. The RF spring contact liners placed on the entrance of the plunger housing are used to isolate the plunger housing from the RF field. The surface current flowing through the contacts limits the power in the cavity to less than 5 kW due to heating. We analyse the electrodynamics of the tuner and investigate two options of a new tuner geometry, one with contacts and one without contacts. The new design should remove the power limitation due to contact problems.

1 INTRODUCTION

There are many methods of RF cavity frequency adjustment. For accelerating cycles with a low repetition frequency a mechanical plunger moved in a housing is used to tune the cavity resonant frequency. Independent of method, the frequency is changed due to a redistribution of the electrical or magnetic component of the electromagnetic field. The frequency variation is proportional to the integral field perturbation. The behaviour of the fundamental and the HOM modes in the ASTRID cavity with the plunger position has been investigated[1]. The necessary frequency change is set by the reactive beam loading. Conventionally the magnetic component is perturbed, since the electrical component is responsible for the acceleration. It is done by inserting the plunger in the maximum magnetic field. However, the maximum magnetic component coincides with the maximum surface current, which causes a heating of the surface proportionally to H^2. The electromagnetic field can penetrate inside the housing of the plunger and excite its eigenmodes. It causes heating of the bellow as well. To prevent the penetration of the electromagnetic field into the housing, sliding electrical contacts are used. This shielding of the housing helps to avoid heating of inside elements, but a problem of heating of contacts themselves arises. The transient resistance between the sliding contacts and the plunger surface is determined by the contact pressure, the cleanliness of the surfaces and the spotty wear. Moreover, the damage of the plunger surface by the sliding contacts looks as scratches perpendicular to the current direction on the plunger surface, leading to amplification of the heating effect. All these circumstances make the work with such plungers unreliable and restrict the power delivered to the cavity to a level less than around 5 kW. To find a solution to this problem we investigated the electrodynamics of the tuner.

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2 ELECTRODYNAMICS OF TUNER

2.1 Antenna effect

We observed experimentally that the maximum heating of the cavity takes place around each tuner housing entrance with two maxima located with 180° symmetry relative to the entrance and lying on the line joining the entrances. We have investigated the electrodynamics of the cavity together with the plunger and can explain the nature of this phenomena by two effects. The first one is due to the antenna effect. Figure 1 schematically shows the current construction of the cavity with plunger removed from the housing and the magnetic component distribution simulated by MAFIA. In the current construction the contacts are installed on the entrance to the housing. The original (without plunger) magnetic component distribution of the cavity TEM mode is inversely proportional to the radius $H \propto 1/r$ and it is disturbed by the plunger. The plunger is a good conductor and plays the role of an antenna with the length l_{ant} inserted in the cavity. It generates a mixing mode, which converts the cavity TEM mode into the coaxial TE11 "plunger-housing" mode. The mixing mode is distributed along the plunger without the $1/r$ damping and therefore the magnetic field is amplified on the surface of the cavity near the entrance with the factor $\propto \frac{R_{cav}}{R_{cav}-l_{ant}}$. Hence the heating power grows by the square of this value. Due to this effect the power dissipated on the surface around the tuner housing entrance is higher in comparison with other places and in our case this factor is about 1.5.

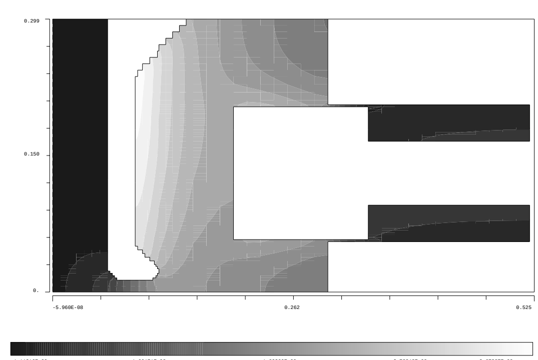

Figure 1: The magnetic field distribution in the cavity with the plunger.

2.2 TE11 coaxial “plunger-housing” mode

Obviously, if we place the contacts just at the entrance of the housing, we get the high current flowing through the contacts. So, we have to move the contacts deeper into the housing and the depth depends on how far the electromagnetic field penetrates. To answer this question we should know what modes are excited in the housing. Let us consider the electrodynamics of the system “cavity-plunger-housing”. Since the slot between the plunger and the housing could be considered as the coupling element between two resonant volumes, the cavity itself and the housing, the intensity of the mode excited in the housing is proportional to the integral:

$$A_s \propto \frac{1}{\frac{\delta\omega}{\omega_s}Q_s}\int_{slot}(\omega_s \dot{E}_c \dot{E}_s^h - \omega_c \dot{H}_c \dot{H}_s^h)dv \;, \tag{1}$$

where $\dot{E}_s^h$,$\dot{H}_s^h$ are the eigenmode components of the housing, $\dot{E}_c$,$\dot{H}_c$ are the fundamental mode components of the cavity, Q_s is the quality factor of S -th mode, $\delta\omega = \omega_s - \omega_c$ and ω_s, ω_c are the eigen frequencies of of S -th mode and the cavity fundamental mode correspondingly. From the distribution of the cavity fundamental mode (in this case TEM mode) we can conclude that the coaxial mode TE11 with one variation along azimuth can be excited in the housing. The TE11 cut off frequency f_{cut} is determined by the inside radius of the housing r_h and the outside radius of the plunger r_p

$$\frac{\pi^2 f^2}{c^2}(r_h + r_p)^2 \approx \left[1 + \frac{1}{3}\left(\frac{r_h - r_p}{r_h + r_p}\right)^2\right] \;. \tag{2}$$

For our case the cut off frequency equals 640 MHz. Thus, TE11 is beyond cut off frequency mode. But it penetrates into the housing with a length proportional to the damping decrement equal to $\tau = 7 \div 8$ cm. Figure 2 shows the distribution of the magnetic component inside the housing and around the plunger moved into the cavity. In this figure the vertical Z direction shows the value of the magnetic field in the XY plane passing through the centre of the cavity and the housing.

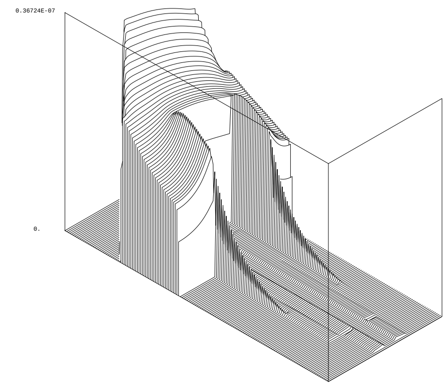

Figure 2: Magnetic field inside cavity and housing.

The exponential decay and the decrement value corroborate that this mode is exactly the TE11 mode. If we want the flowing current through contacts reduced by a factor of k_1=10, the contacts have to be moved into the housing by $l = 2.3\tau$. Taking into account the antenna effect k_2=1.5 and the reflection of the power from the contacts k_3=2, the depth has to be $l = 3.4\tau$. Since the stroke of the plunger is 10 cm, the plunger housing height has to be about 35 cm.

2.3 TEM coaxial “plunger-housing” mode

If the cavity TEM mode has a different value of the magnetic component at opposite points relative to the entrance of the housing, the TEM coaxial “plunger-housing” mode can be excited as well. Owing to the big capacity between the drift tube of the cavity and the plunger itself, the resonant frequency of this mode can cross the working frequency of the cavity. The 3D MAFIA code simulation confirms this assumption. Figure 3 shows the distribution of the TEM coaxial “plunger-housing” mode magnetic component. The electrical component has a small value, because the capacity is located outside the housing. Since the TE11 mode damps very fast, the residual field inside the housing is determined by the TEM coaxial “plunger-housing” mode. The change of magnetic component symmetry corroborates that. To remove this mode from the working region we have to change the induction, which is proportional to the inside volume of the housing. Due to a necessity to damp TE11 we are restricted to decrease the housing size and we can only decrease the resonant frequency of the plunger mode. We have developed two options of new tuner design with and without contacts.

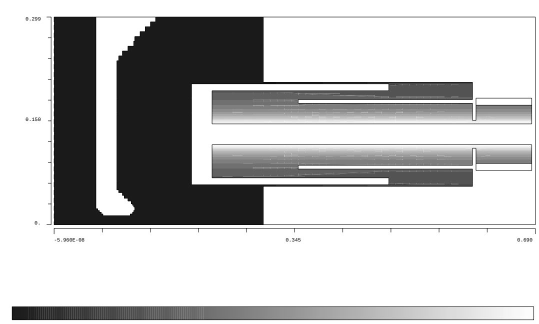

Figure 3: The TEM coaxial “plunger-housing”.

3 TWO OPTIONS OF NEW TUNER DESIGN

3.1 With contacts

To increase the inside volume of the housing we use the idea of an enclosed coaxial. Figure 4 shows a quarter of the cavity geometry generated by MAFIA mesh generator. The plunger is made like an empty cup and the additional built-in cup is inserted into the plunger and is mounted on the upper flange of the housing. The contacts are installed on the second cup and they slide on the inside surface of the plunger. This construction decreases the plunger mode frequency and removes the contacts from the maximum magnetic field. Unfortunately, the latter has little effect due to the small housing size to resonant wave length ratio.

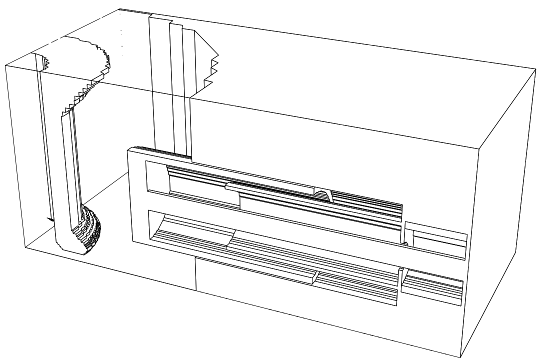

Figure 4: The tuner geometry.

3.2 Without contacts

In the first option the contacts play the role of bellow shielding. The bellow can be heated only by the TEM plunger mode if the TE11 mode is damped. But if we do not use contacts at all, the entrance inside the housing for electromagnetic field will be open, the induction will grow significantly and the plunger mode frequency will go down by a factor of two. The heating of the bellow has to decrease inversely proportional to the detuning. So, the second option is characterised by the absence of contacts. Actually, in this design we do not need the additional built-in cup from a electrodynamics point of view, but it increases the vacuum resistance between the bellow surface and the accelerating gap in the cavity. Figure 5 shows the drawing of the tuner port, which could be used in two options with and without contacts. To improve the cooling conditions of the bellow we moved it out from the housing. In both cases we cool the housing externally at the entrance as well as the plunger itself.

4 CONCLUSIONS

We have investigated the main reasons for RF contact heating:

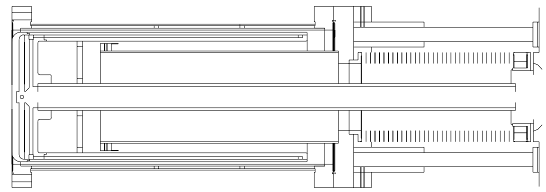

Figure 5: The tuner design.

- The antenna effect amplifies the magnetic field near the entrance inside the housing.
- The beyond cut off coaxial mode TE11 penetrates inside the gap “housing-plunger”.
- The TEM “plunger-housing” mode due to the significant capacity between the plunger and the drift tube of the cavity has a resonant frequency in the working region of the fundamental mode.

We have developed two options of a tuner design with and without contacts and both meet the required conditions for the tuner. Experimental verification will be made in 1997.

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6 REFERENCES

[1] S.P. Møller, T. Korsbjerg, and E. Zaplatine, “Astrid Electron cavity study”, this proceeding.