ELIMINATION OF PARASITIC OSCILLATIONS IN RF TUBE AMPLIFIER FOR HIGH POWER APPLICATION

E. Feldmeier, Heidelberg Ion Beam Therapy Center, Universitätsklinik Heidelberg, Germany
G. Hutter, W. Vinzenz, B. Schlitt, GSI, Darmstadt, Germany

Abstract

For the heavy ion therapy center HIT in Heidelberg a 1.6 MW power amplifier for 217 MHz was built to supply the 7 MeV/u IH cavity. The inherent parasitic oscillations of the RF tube increases rapidly the anode current until the system switches off. For the elimination of those parasitic oscillations ferrite material is used. The electro magnetic fields are simulated to find an optimal positioning of the ferrite material in the anode cavity such that only the parasitic oscillations are attenuated without affecting the fundamental mode.

INTRODUCTION

A dedicated clinical cancer therapy center designed by GSI was built at the Universitätsklinik in Heidelberg, Germany [1,2]. The facility is designed to treat about 1200 patients per year using the intensity controlled raster scan method developed by GSI. Since 1997 more than 400 patients have been successfully treated with carbon ions at GSI.

During the last two years the HIT accelerator and its subsystems were commissioned [3]. In December 2007 the carbon beam reached therapy quality in the treatment rooms. The start of the clinical operation is planned for December 2008.

The facility consists of the 7 MeV/u injector linac, a 430 MeV/u synchrotron, an experimental area, two treatment rooms with horizontally fixed beam lines and one treatment room with an isocentric gantry.

The injector linac consists of a 400 keV/u RFQ and a 7 MeV/u IH drift tube linac with an effective acceleration length of 5.5 m.

The RF system of the compact injector operates at 216.816 MHz. It consists of three RF tube amplifier working in pulsed operation at 200 kW (RFQ) and 120 kW/1.4 MW (IH) with a pulse length of 500 µs and a duty cycle of 0.5%. The 200 kW tube amplifier and the preamplifier for the 1.6 MW final stage was built commercially by THALES/THOMSON. The final stage of the 1.6 MW amplifier was designed and manufactured by BERTRONIX, Munich. This stage was mechanically assembled in Munich and delivered to GSI for the commissioning and RF tests. For the clinical application a very stable and reliable operation is mandatory. To get more options the stage is constructed for two different tube types, the THALES TH 526 and the EIMAC E 8973. In the beginning of the project it was not decided which tube would be used for standard operation. During the commissioning the TH 526 was chosen.

PARASITIC OSCILLATIONS

One of the main problems during the commissioning was the parasitic oscillations of the TH526 which appear with different strengths at 478 MHz, 818 MHz, 875 MHz, 1024 MHz, 1240 MHz, 1468 MHz and 1680 MHz.

Parasitic oscillations occur even without RF when the tube is pulsed to the A-working point. Using the control grid voltage the tube should be set to a working point with an anode current of 6 A. When increasing the anode current to more than 2 A the parasitic oscillations set in and lead to an uncontrollable operation in which the tube cannot be locked by the control grid anymore. The problems occur mainly with the parasitic oscillations at 875 MHz and 1240 MHz.

It was shown earlier [4] that oscillations can be suppressed successfully by using ferrite material in the anode circuit and between grid 1 and grid 2. This paper proposes a new method find an optimal position for the ferrite material.

FIELD SIMULATIONS

The ferrites have to be positioned at locations where the H-field of the parasitic mode is large in order to suppress these modes most effectively. To find the optimal position for the ferrite rods and slabs the electro magnetic field distribution within the cavity is numerically calculated using CST Microwave Studio. It is sufficient to calculate the fields in the anode cavity of the amplifier. One part of the anode cavity is the amplifier tube which however is an active component that cannot be simulated within the used FIT method [5].

The electron flux in the tube represents a conductive area in the active system of the tube. In the simulation this area is represented by a conductive material with a conductivity σ which can be calculated as

$$\sigma = \frac{1}{2\pi \cdot L} \cdot \frac{I_A}{U_A} \cdot \ln \frac{R_2}{R_1}.$$

L denotes the length of the active system, R_2 and R_1 are the outer and inner radii of the cylindrical cavity, respesctively. The anode current I_A and voltage U_A are measured.

First one has to verify that one gets the correct frequency of 216.816 MHz for the fundamental mode. To correct for uncertainties in the geometrical dimensions and inaccuracies in the mapping of the active tube system, for example the leakage of the field through the grid, one may move the position of the cavity bottom slightly.

The next step is to verify that besides the fundamental mode also the higher eigenmodes coincide with the measured frequency spectrum. This test assures the quality of the calculated fields.

In Fig. 1 the input reflection parameter S_{11} at the RF 50 Ω output line is shown as a function of frequency. The fundamental mode appears at 216.7 MHz while higher modes are at 247.6 MHz and 345.6 MHz. The accuracy is sufficient as the corresponding measured modes are located at 216.816 MHz, 248 MHz and 343 MHz.

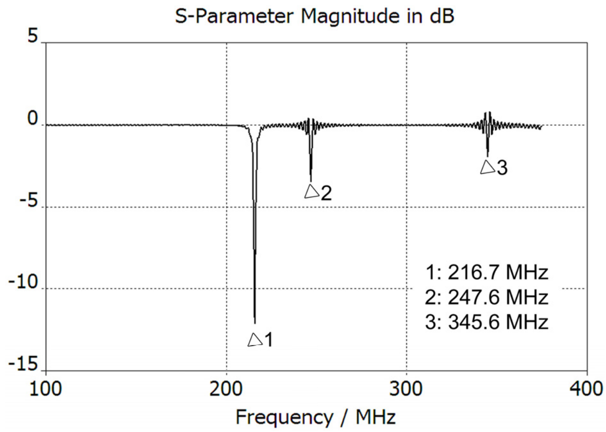

Figure 1: simulated |S11| as function of frequency.

Now the H-field distribution is calculated at the parasitic mode frequencies of 875 MHz and 1240 MHz. Fig. 2 displays the geometry of the amplifier including the tube on top. The red cylinder in the upper part of the model indicates the active system of the tube where the conductive material is placed. The lower part of the model represents the anode cavity. At the bottom the outcoupling loop to the 50 Ω RF line can be seen.

The parasitic frequencies which originate from the tube do not correspond to eigenmodes of the complete amplifier structure. Therefore the structure is stimulated with 875 MHz and 1240 MHz to calculate the H-field distribution of the parasitic mode. The field distributions for the fundamental mode as well as for the parasitic mode are shown in Fig 2. One can see that in the areas denoted by 1 the parasitic fields are large whereas the fundamental mode is weak, so that one expects to suppress the mode at 1240 MHz.

The photograph displayed in Fig. 3 shows the actual setup that has been devised based on the simulations. The area denoted by 1 correspond to the 6 ferrite slaps that are positioned on teflon tubes.

The more dangerous mode is however at 875 MHz. Without any ferrites this mode grows exponentially and triggers the safety shutdown sequence. The H-fields of this mode are displayed in Fig. 2b. There are no obvious locations for the ferrites because in the areas of large H-fields the fundamental mode also has large fields (Fig. 2a). Previous experiments have shown that ferrite rods at positions indicated by 2 and 3 damp the 875 MHz mode without too much effect on the fundamental mode.

Area 2 corresponds to the 16 ferrite rods held by small teflon bricks at the bottom. At area 3 a teflon ring with 72 holes to hold further ferrite rods is placed next to the tube ceramic. For the first test all 72 places were filled. It turned out that the fundamental mode was suppressed too much. Using only 36 ferrites the effect on the fundamental mode was insignificant.

As it is often not possible to find locations where large H-fields of parasitic modes coincide with small fields of the fundamental mode one has to find a compromise.

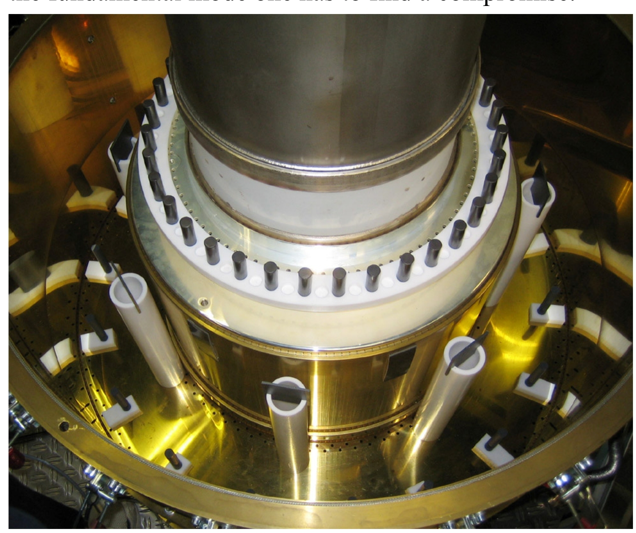

Figure 3: Ferrite arrangement as result of considerations based on the theoretical simulated H-field distribution.

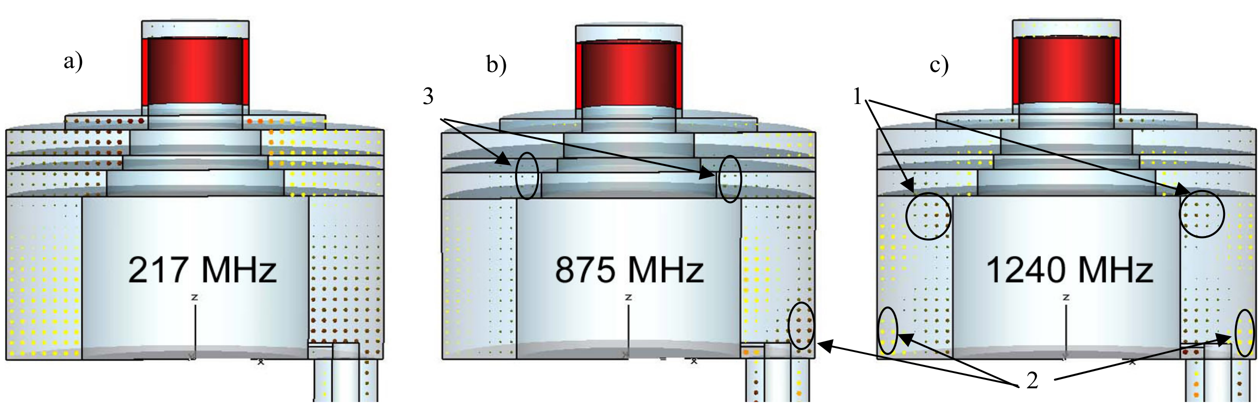

Figure 2: (a) H-Field distribution for the operating frequency 216,816MHz, (b) for the parasitic mode at 875MHz, and (c) for the parasitic mode at 1240MHz.

It is also helpful to select ferrite material that has a higher permeability at the parasitic frequency than at the operating frequency.

RESULT

Fig. 4 shows the spectrum measured with a small coupling loop in the anode circuit when only 36 ferrite rods are placed in area 3 on the teflon ring, all other ferrites are removed. The first strong peak denotes the fundamental peak and is followed by its equidistant harmonics. The other strong peak is the parasitic mode at 1240 MHz. At the dangerous frequency 875 MHz no signal is seen. Thus the ring of 36 ferrite rods suppresses this mode sufficiently.

After introducing the ferrite slaps at area 1 and additional rods at area 2 the spectrum shown in Fig. 5 is obtained. As expected from the simulation the parasitic mode at 1240 MHz is completely suppressed. Furthermore, the amplitudes of the harmonics decay more rapidly.

It should be mentioned that at the area 3 the electric field is rather strong so that the ferrites have to be manufactured with rounded edges to avoid sparking.

Before optimization anode currents larger than 2 A lead to an uncontrollable operation. After optimization the anode current can be increased up to 60A without excitation of the parasitic modes. A stable and dependable operation is therefore guaranteed.

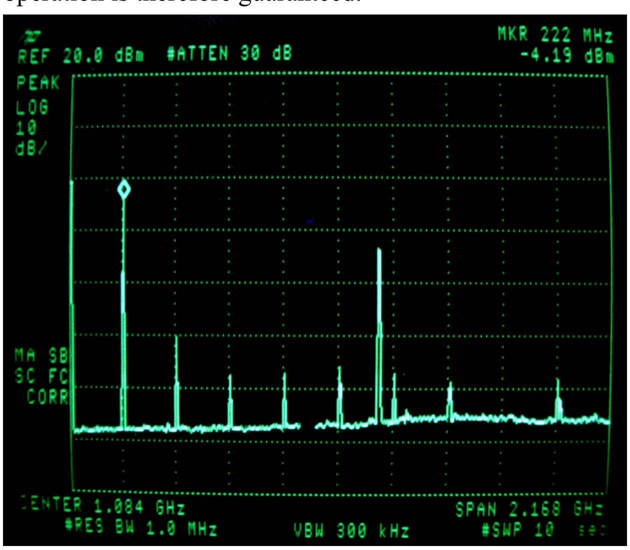

Figure 4: Measured spectrum with a coupling loop in the the anode circuit with ferrites only in area 3.

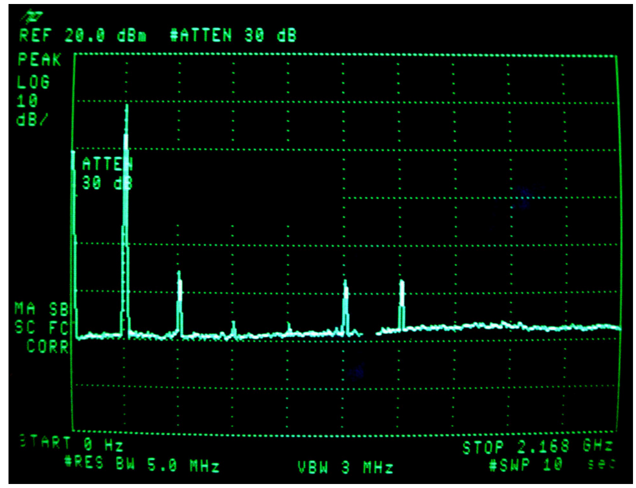

Figure 5: Measured spectrum with the new optimized ferrite setting.

OUTLOOK

To commission the 1.4 MW final stage amplifier for the second designated tube type EIMAC E8973 new calculations have to be performed as this tube has a different geometry and thus different parasitic modes. It remains to be seen in how far the present arrangement has to be modified to allow also the operation with this tube.

It is desirable to perform systematic investigations of available ferrite material with respect to its properties and to study the possibility to produce new ferrite material optimized for this application.

REFERENCES

[1] H. Eickhoff, D. Böhne, Th. Haberer, B. Schlitt, P. Spiller, J. Debus and A. Dolinskii, “The proposed dedicated ion beam facility for cancer therapy at the clinic in Heidelberg”, Proc. EPAC 2000, Vienna, p. 2512, and references therein.

[2] H. Eickhoff et al., “HICAT - The German Hospital Based Light Ion Cancer Therapy Project”; EPAC 2004, p. 290.

[3] B. Schlitt et al., “Commisioning of the 7 MeV/u, 217 MHz injector linac…”, Proc. LINAC 2006, Knoxville, p. 150.

[4] G. Hutter et al., “The 101 MHz amplifier system of the new CERN lead injector”, PAC 97, p. 3123.

[5] T. Weiland, “A discretization method for the solution of Maxwell's equations for six-component fields”, Electronics and Communications AEUE, vol. 31, no. 3, pp. 116-120, 1977.