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IMPROVEMENT OF THE 108 MHZ RF-AMPLIFIERS FOR THE UNILAC ALVAREZ STRUCTURE

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Summary

Damping of parasitic oscillations, preventing high frequency tube failures and an alternative tube allow now to offer two solutions for at least 1.3 MW with the existing final amplifier for the 108 MHz Unilac Alvarez structure. This peak power, delivered with 25 % duty cycle at 50 Hz, satisfies all requirements of the Unilac operation, even for acceleration of gas stripped Uranium ions.

Introduction

The rf-generators for the two 108 MHz Alvarez tanks of the Unilac poststripper structure were originally designed for 1.6 MW peak power at 25 % duty cycle and 50 Hz. This power level was based on the assumption of an average charge state of 25+ for Uranium after stripping in gas at 1.4 MeV/u and, in addition, on a rather conservative estimate for the power losses of the anticipated tanks. Both the estimates of the power losses and the extrapolated charge state turned out to be too cautious (e.g. measured mean charge state is 28+) so that a peak power of about 1.1 MW is sufficient for operation instead.

During the design phase of the Unilac there was no tube on the market which could fulfill these specifications in the desired frequency range. Therefore an in-house development of the final amplifier stage was decided together with a tube manufacturer. After some initial successes resulting in a peak power of 1.6 MW at short duty cycles there was a long period where the generator could only operate at about one quarter of the full ratings.[1,2] The reason seemed to be that parasitic oscillations could not be properly suppressed thus leading to sparking inside the tube. Therefore a comprehensive program was started to eliminate the problem of parasitic oscillations of this amplifier.

Tube and Final Amplifier Design

The grid controlled power tetrode TH518 is predominantly used for the Alvarez final amplifiers. Fig. 1 shows a scheme of the amplifier circuits. The plate circuit consists of a folded full-wave resonator. The grid 1 - grid 2 circuit is a folded $\lambda/2$ coaxial line with a movable short circuit at the end. The low input impedance of the grounded grid tube is transformed by a $\lambda/4$ coaxial line and can be tuned by a serial and a parallel stub line to real 50 Ω. The output coupler is made by a movable $\lambda/4$-loop. The supplied dc voltages are about 24 kV for the anode, 1500 V for the screen grid, 600 V for the control grid (adjustable).

The TH518 was developed out of a family of medium and short wave tubes. This explains their long active system of about 20 cm. To get a gain of more than 13 dB even with a grounded grid made it necessary to have a transconductance up to 2 A/V. This means distances less than 1 mm between grid 2 and grid 1 and also between grid 1 and cathode, at a diameter of these electrodes of approximately 15 cm. All known tubes of this mechanical size and with transconductances like the one mentioned above offer the possibility to fulfill the phase- and amplitude-relations for the self-excitation of parasitic oscillations in the frequency range from 500 MHz to 2500 MHz. This is due to the finite transit time of the electrons which produces an additional phase shift, and because of internal resonances together with a good magnetic inter-electrode coupling.[3] In connection with the coaxial resonant circuits of the used amplifier the TH518 has a tendency to produce parasitic self-oscillations mainly at frequencies about 750 MHz and 1200 MHz.[4] By calculation similar frequencies can be found as TE_{110} and TE_{210} resonances of the interelectrode regions of the active valve system. Within this coaxial system, those modes do not have a Poynting's vector in the z-axis. This explains their high Q. Besides the rf-losses of the circumferential currents on the electrodes, this Q is only limited by the fact that the boundary conditions at the end of the active system demand for mode transformations, which more or less permit a coupling to the outer surrounding of the tube.

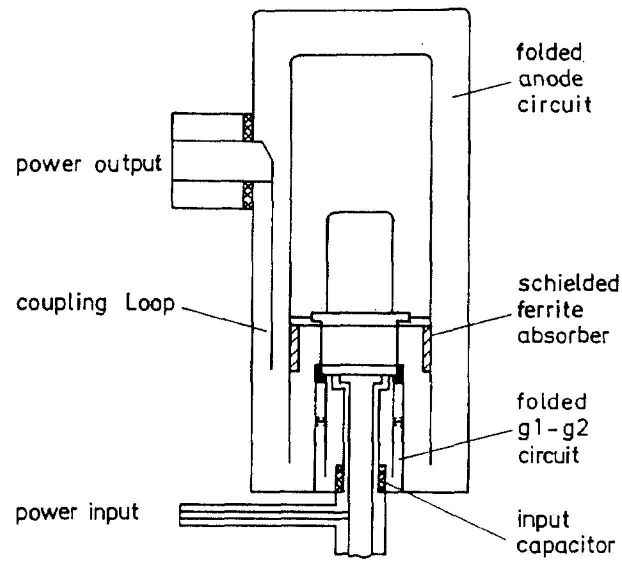

Fig. 1 Scheme of the 108 MHz final amplifier

For the grid 1 -cathode region and the grid 1 - grid 2 region, where great impedance steps between the active parts and the tube internal support structure exist, the coupling of external damping devices to the forementioned TE modes is so small that it was not possible to find a remarkable influence on the parasitic oscillations, although very carefully calculated absorbers were made and tested in elaborate experiments in the amplifiers.[5]

Measurements showed that parasitic oscillations are not observed if there is no metallic shielding around the anode-grid 2 area. Then the energy can radiate through the insulator between anode and grid 2 into the outer space. This is the case in low frequency generators with lumped circuits, but not in our application.

Therefore the following considerations concentrated on damping the anode circuit, though this is the worst place for a damping device because of the high field densities. Laboratory tests started measuring the resonances of the tube with two weakly coupled capacitive pick-ups, which were mounted in two holes of a dummy tube's anode.

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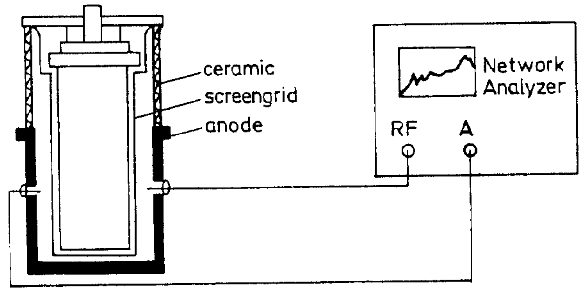
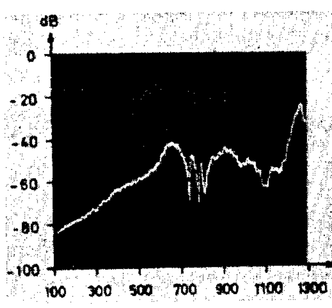


Fig. 2 Experimental set-up to find tube resonances by a swept frequency transmission measurement

Fig. 3 shows the measured transmission with free space around the dummy tube, while Fig. 4 was made under the same conditions, but with the tube inside the cavity. Dominant resonance peaks can be seen at frequencies of about 600 MHz, 750 MHz, 1000 MHz and 1200 MHz in Fig.4.



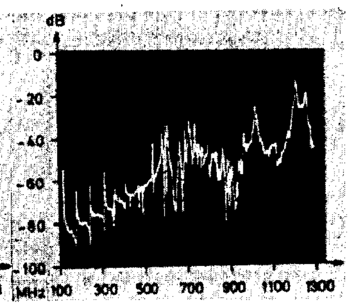
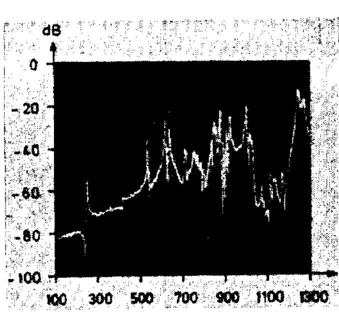


Fig. 3 Transmission with free space around the tube

Fig. 4 Transmission with tube inside the cavity

Studies to damp those resonances were done next with a cavity model, in which absorbers could be tested much easier than within the amplifier cavity. Experiments with inductive and capacitive coupling of resistive loads and lossy dielectric devices to the cavity showed no satisfying results, neither with wide band nor with resonant coupling systems.



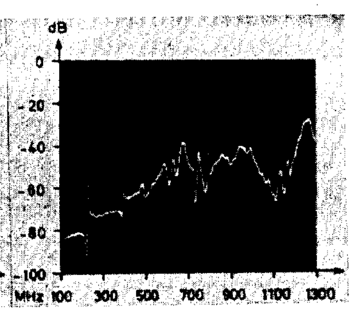


Fig. 5 Transmission without absorber

Fig. 6 Transmission with ferrite absorber

Fig. 5 shows the transmission through the tube inside this cavity model without damping measures. Fig. 6 shows the influence of the most effective absorber, which could be found for this dummy, indicating that all high frequency resonances are damped more than 10 dB and that the Q of the remaining resonances became rather low. This absorber was built by many ferrites directly covering the anode ceramic of the valve. Naturally this absorber cannot work with high voltages and high power rf, but an electromagnetic mode-selective shielding of the ferrites with an additional high pass characteristic could be found, which decouples the ferrites from the fundamental frequency of 108 MHz and nevertheless provides adequate suppression of the higher mode resonances of the tube.

This absorber was first tested in the final amplifier with dc pulsing of the grid voltage, without rf. Thereby it is possible to operate the tube under conditions which favor the excitation of parasitics much more than rf-operation at even the highest power levels, without the risk of destroying the tube. Even under these conditions the amplifier did not show parasitic oscillations in the range up to 200 Amps dc anode current at 23 kV anode voltage.

In a next step up to 800 kW rf-power could be achieved with modified tubes, still without parasitic oscillations. This limitation was given by further high frequency problems due to tube technology.

A Siemens tube RS2074 SK, which replaced the TH518 in a modified amplifier, could not deliver useful rf at the beginning because of strong parasitic oscillations at 950 MHz and 1310 MHz. With the above described absorber in the cavity this tube was able to produce 800 kW peak power without parasitics immediately. Another RS2074 SK with some improvements ran over 80 hours with a peak power of 1.3 MW and a mean power of 330 kW without disconnections. Tests at 1.6 MW are going to be prepared.

Fig. 7 shows the harmonic and parasitic spectrum from 0 to 1800 MHz of the RS2074 SK at maximum rf-levels without and Fig. 8 with absorber.

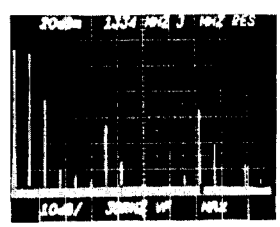


Fig. 7

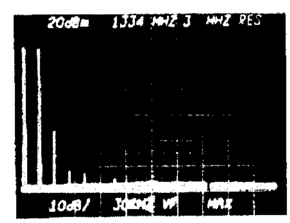


Fig. 8

With further improvements at the TH518 1.6 MW have been achieved at 400 kW average power in a short experiment, recently. However, these results have to be confirmed by long time tests.

Conclusion

It could be shown that by proper damping measures in the anode circuit the existing final amplifier of the Alvarez structure can be operated together with a suited tube at power levels up to 1.6 MW.

References

[1]D. Böhne, "The Unilac, Development and Present Status", Proceedings of the 1976 Proton Lin. Acc. Conf., Chalk River, AECL-5677 (Nov. 1976)

[2]D. Böhne, "Status Report on the Unilac", Proceedings of the 1979 Lin. Acc. Conf., Montauk, N.Y., BNL-51134 (Sept. 1979)

[3]B.T. Zarubin, V.V. Kushin, B.P. Murin, Acad. of Science, USSR Radiotechn. Inst. Mosk., Report No. 28, 1977

[4]R.W. Müller, G. Hutter, A. Gasper, K. v. Venrooy, GSI Report PB-5-75

[5]G. Schaffer, GSI Internal Report 3/79