NEW APPROACHES IN HIGH POWER RFQ TECHNOLOGY

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Abstract

There is a clear tendency for the utilization of continuous wave c.w. high power RFQs in a huge variety of applications like nuclear waste transmutation or material research. They can serve as injectors for the production of secondary particles like neutrons or rare isotopes and can be applied for post acceleration of the latter ones. These RF-structures have to withstand an enormous amount of RF-power dissipated on the surfaces (up to several 10s kW per meter) and the associated thermal load. NTG Company gained lots of experience especially in the field of 4-rod c.w. RFQ design. Most recent developments to handle such high RF-power dissipation shall be reported.

INTRODUCTION

RFQ structures play a central role within the accelerator chain of high power applications such as EUROTRANS, IFMIF, FRANZ, SARAF, ReA3 and the HLI-Injector at GSI [1-6]. They require a high measure of reliability at power levels of easily 30 to 50 kW per meter structure length or even above meeting the design parameters precisely to the point. This applies in particular to the RF power level and the corresponding inter-vane voltage. An RFQ with more than hundred accelerating cells has a very stringent velocity profile and hence provides no considerable acceleration if the electrode voltage is only a few per cent below the actual design value.

In this context it is of great importance to place special emphasis on topics like field tuning, precise layout and manufacture of electrode surfaces and alignment. The RFQ can easily compensate for deviations from the design electrical field mapping up to a certain degree. For example if the electrode voltage is a little below the actual design value in a certain electrode section the particle bunch is shifted automatically to a slightly higher RF phase and thus is accelerated at a voltage level rather close to the design value. The disadvantage is a smaller bucket size. Again one can compensate for that (within limits) by increasing the overall inter vane voltage. But that is at the expense of altered beam dynamics and most important of a higher RF power consumption, which cannot easily be accomplished if the design value is already rather high.

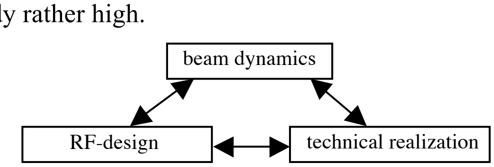

Figure 1: Interaction of three major topics at the design of a 4-rod-RFQ.

Beside the need for carefully balanced RF and beam dynamics design the technical realization capabilities and constrains needs to be considered already at the early theoretical design phase in order to find an optimum. Thus the general design of a 4-rod RFQ can be divided in three major sub topics: beam dynamics, RF-design and technical realization, which have to interact in a most efficient way (Fig. 1).

HIGH POWER TUNING PLATES

The 4-rod RFQ resonant RF-structure is made up mainly of so called stems, electrodes and tuning plates. Two stems, one tuning plate and the associated electrode section are forming a basic resonant λ/4-RF-cell. The whole 4-rod RFQ consists of a chain of up to 40 strongly coupled ground cells resonating in ground mode, which is here often called π-mode, since the current flow in adjacent RF-cells is in opposite direction. The resonance frequency of each RF-cell can be changed by moving the tuning plate up to increase, down to lower the frequency. Having a chain of strongly coupled resonators the frequency change of a single cell has an attenuated average effect on the whole systems resonance frequency and despite of that an effect on the local RF-amplitude which can be used for field balancing. Since the resonator is driven in ground mode, any local down-tuning increases the local inter-vane voltage level by mixing or adding field distributions of higher order modes [7].

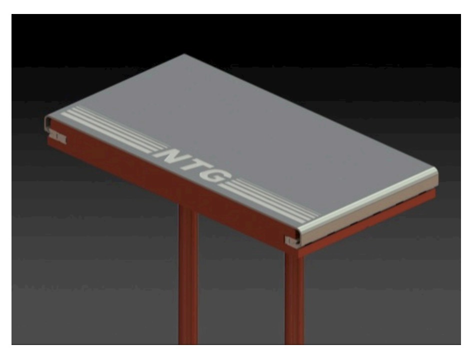

Figure 2: New high power 4-rod RFQ tuning plates.

The tuning plate represents the short cut end of a Lecher-line, which can be seen as part of the equivalent circuit diagram consisting of a Lecher line (two parallel stems) with a short cut (tuning plate) on one side and a capacitive load (electrodes) on the other side. Thus the RF-current is at its maximum at the tuning plate and can e.g. for the SARAF 4-rod RFQ with its 62.5 kW/m at 176 MHz easily be at the level of around 100 A/cm in spots [8]. For field and frequency tuning it is convenient to use movable plates with sliding contacts to the stems.

Conventional finger contacts made of silver plated copper-beryllium alloys can reliably stand up to 30 A/cm. This value can be found in literature [9] and has been repeatedly confirmed by dedicated experimental investigations accomplished by NTG at the IAP in Frankfurt and under operational conditions with 4-rod structures [10].

Figure 3: DC test of RF finger contact.

One finger was separated and connected to a DC power supply to find out the maximum DC current that can be transported without destruction of the contact. Although this simple experiment can only provide a rule of thumb for real life conditions in vacuum with RF-load under certain mounting conditions, the results agree remarkably with literature values.

The basic idea is to find experimentally the maximum direct current I_{max} providing a destructive thermal load due to resistive losses and then calculating I_{max} for RF-conditions providing the same thermal load on the contact. For transformation from DC to RF-conditions one has to consider the reduced conducting cross section due to the skin effect. Considering relations between conductive cross section A, dissipated power P related to resistive losses and the resistance R one gets:

$$I_{max} \propto \sqrt{A} \qquad (1)$$

The reliability of the above described RF-contact test procedure with DC was also successfully approved by testing special custom made RF-contacts originally used for the SARAF-RFQ [4, 11]. RF-contact is provided here by a massive Inconel® spring plate of 400 μm with a 70 μm layer copper and a silver finish on both sides with a total conductive cross section of 140 μm for DC current. (The Inconel® core can be neglected in terms of electrical conductivity.) This must be set into relation with 5 μm skin depth at 176 MHz, which is a factor of 28 between the available cross sections A and corresponding 5.3 between the maximum tolerable current penetrations I_{max}.

Experiments have again been accomplished by NTG at the IAP of Frankfurt University. A part of 10 mm was cut out of the tuning plate and brought into vacuum to avoid convectional cooling (Fig. 4-5). The contact disintegrated at $I_{max,DC}$ = 400 A (Fig. 6), corresponding to an RF-current of $I_{max,176\,MHz}$ = 75 A/cm.

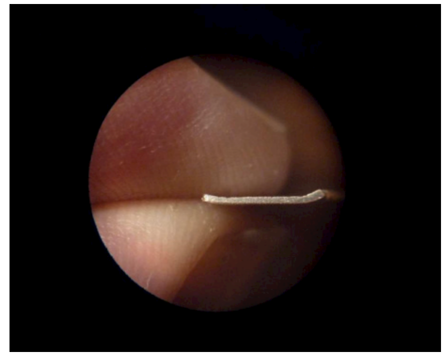

Figure 4: Cross section of Inconel® RF-contact.

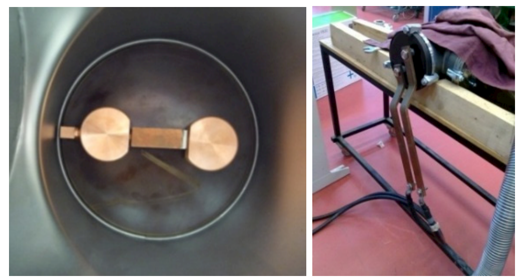

Figure 5: Inconel® RF-contact test bench.

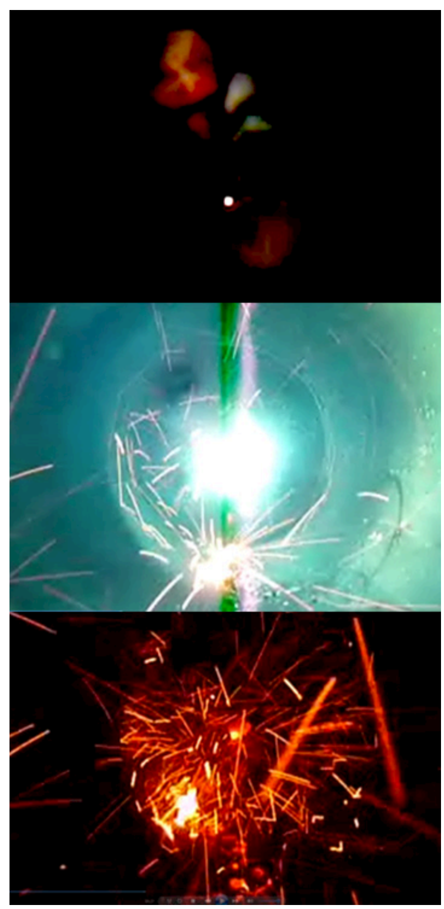

Figure 6: Inconel® RF-contact at 400 A/cm DC corresponding to 75 A/cm at 176 MHz.

These test results led to the development of new high power 4-rod RFQ tuning plates as shown in Fig. 1. These tuning plates provide a very much improved thermal conductivity between the actual RF-contact and the water cooled body at least by a factor of 10 compared to the Inconel® design due to a massive 1 or 1.5 mm silver plate. The mechanical contact is accomplished by a separate spring/wedge system. The wedge is brought into position providing a tight mechanical contact only when the plate is in final position with the advantage of not having mechanical stress on the contacts while moving them in or out.

The new high power 4-rod RFQ tuning plates have now successfully been applied at SARAF and to the HLI-RFQ of GSI, their application at other projects like FRANZ is planned.

HIGH POWER RFQ-STEMS

A sophisticated cooling system is crucial for a proper functionality at high power applications. This applies in particular to the RFQ-stems. They not only have to be equipped with their own cooling circuit, but also must provide the water connection of the electrodes cooling system to the periphery. Experience has shown that it is beneficial to guide the aquiverous pipes through a borehole inside the stems other than outside. The resulting cavity inside the stem must carefully be shield against RF-noise, as otherwise damaging of connecting parts like vacuum or water seals can occur.

New production techniques have been explored and developed for realization of a more efficient stem cooling system. The new design provides much improved cooling efficiency especially in critical regions like the very top of the stem, where a heating of $\Delta T = 110$ K has been calculated at maximum for the SARAF design [4] (Fig. 7).

Figure 7: New high power 4-rod RFQ stem.

CONCLUSION

NTG Company spent a lot of effort on research and development of components for next generation high power 4-rod RFQs with the result of very attractive high performance components and turnkey RFQ solutions. Two examples have been described in detail. The following list names some additional new developments without completeness to round up the picture:

- High power RF-coupling loop concept.
- RF-rigid coaxial feed-through for cooling water circuits.
- Improved concept for high power RF-tuners (plunger).
- Improved manufacturing techniques and more efficient cooling system on electrodes.

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