FIELD STABILISATION WITH RESONANT LINE COUPLERS*

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Abstract

A new concept of field stabilisation of RFQ structures has been tested. Applications of these ideas on other RF acceleration structures are presented and properties of these resonant line couplers are discussed.

Introduction

For proper beam dynamics field amplitudes and phase along the accelerator structure must be kept constant. Therefore RF stability during operation and tuning tolerances are very important for the design of RF structures.

New schemes for stabilising RFQs have been proposed using resonant loops and changing the operation to $\pi/2$-mode[1]. This is especially important for the four vane structure, which is mostly used for light ion injectors. The problems of RF stability influence the beam dynamic design too, because the length and frequency of the structure are not longer free parameters.

The four vane resonator can be described as four weakly coupled cavities operating in approximately TE_{210}-mode. The first part of this paper deals with the development of coupling loops for azimuthal stabilisation to minimize the influence of neighbouring TE_{111}-modes. The longitudinal part is a less specific RFQ problem and is determined by the influence of the higher modes TE_{211}, TE_{212}, etc. The coupled resonator model is not a good approximation for this case, because the properties are more related to a transmission line at cut-off. So stabilisation via postcouplers like in the Alvarez structure is the corresponding method.

Azimuthal Stabilisation

Several schemes for azimuthal stability have been proposed. At first vane coupling rings (VCR) have been used[2], which correspond to Magnetron straps. They work very efficiently, but besides mechanical problems they have the disadvantage that they drive the four vane cavity below cut-off, thus reducing the group velocity along the structure furthermore.

Applying the VCR rings only in the end cell and using them for tuning in addition, as we first thought to do in our HERA RFQ[3] is a possible solution for short cavities.

A solution, which makes use of resonant coupling and $\pi/2$-mode operation are inductivly or capacitivly coupled short resonant transmission lines. For capacitive coupling a position near to the vane tip must be chosen and the capacity must be as high as possible. A direct connection to the vane is possible too, being equivalent to a resonant VCR. Inductive coupling can be made strong without coming close to the sensitive electrode region, therefore these solutions have been developed.

Fig. 1 shows several schemes of resonant loop line couplers (RLC), as first presented in[1]. In figs. 2a,b one line is excited to $\lambda/2$ oscillations. The resulting flux can be switched by choosing the orientation of one of the loops corresponding to a phase shift of 180 degrees. In fig. 2c the flux in a cavity forces the line to give an energy flow, but there is no excitation or stored energy W in the RLC. An unbalanced flux in the cavity (or different effective loop sizes) gives a contribution from the modes of figs. 2a and 2b. Other modes of the coupler ($N \times \lambda/2$) can be used as well. The orientation of the loops must be changed like between fig. 2b and fig. 2c to give the proper phase of the oscillations and stabilisation of the operating mode. The direction of the current I is assumed to be parallel to the line. The coupler scheme can be adopted to the case, where the magnetic field B is parallel to the line by turning the loops by 90 degrees. If the flux and the currents are orientated in this way, the current in the coupler line is perpendiculare to the cavity current, the whole stabilizer can be arranged inside the cavity, as shown in fig. 2d.

For azimuthal stabilisation the two loops are to be placed in two different quadrants as indicated in fig. 1. Our beam dynamic design for the HERA RFQ facilitates the RF stabilisation, because we have a relatively short (ν = 202 MHz, length l_c = 1.2 m) structure and so we looked for a scheme with only two stabilizers.

The next step was the installation of the coupler at the endplate, which avoids any mechanical problems with the vanes, the most sensitive part of the RFQ. Fig. 3 shows a schematic view of the mechanical arrangement.

The magnetic flux squeezed around the vane end respectively the current in the end cell charging the vane end to end plate capacitor induce a voltage in each sideloop of the resonant loop coupler (RLC). With proper orientation of the loops this voltages cancel, when the magnetic flux in the end cell is equal and produced by the quadrupole working mode. The nonresonant power flow between the two end cells connected can be deduced also. In case of inbalance of the quadrupolefield the loop will be excited into $\lambda/2$ oscillations. This equalizes the power in the end cells and loads the dipole modes. The frequency of the working mode is not affected in first order, while for the dipole modes the RLC is an additional inductance and changes the stored energy and the frequency. Fig. 4 shows mode spectra for a 440 MHz RFQ model, which demonstrates the similar action of the shortening strap VCR and one resonant ring RLC at one end of the structure. One RLC-coupler at each end of the RFQ is sufficient for shifting the dipoles away. With choosing a ring instead of a straight connection like in fig. 2 it was possible to place the coupler completely inside the cavity, because the currents in the ring are always perpendicular to the cavity currentas indicated in fig. 2d. The tuning of the ring to the proper frequency of the quadrupole mode is done by changing the distance to the end plate thus having a simple tuning range of ± 20 %. It should be mentioned that a single ring with four loops cannot work on both dipole modes. The phase between the dipole modes is an additio-

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nal degree of freedom, which allows a four loop ring only for very strong detuning. The measurements showed that these resonant loops connected with the ring are very efficient and mechanically simple. For RFQs with length l_C to vane length λ_0 ratio of $l_C/\lambda_0 \leq 1$ one loop per vane end gives sufficient mode separation. So for the HERA RFQ project[3] we will apply the resonant loops to improve azimuthal RF stability.

Longitudinal Stabilisation

As for the azimuthal stabilisation the first attempt to stabilise the RFQ longitudinally was done with the use of a coaxial manifold[4]. This scheme corresponds to a multidrive system but suffers from weak coupling between the two resonators. Schemes using a loop have at first been thought to improve this coupling strength respectively to make it resonant[5]. Using the loops themselves as a resonant coupling device between parts of the RFQ resonator gives a flexible and strong stabilisation.

In the longitudinal case the problems of unflatness can be characterized by the small group velocity of resonant structures near cut-off. Stabilizers have to improve this energy flow by bypassing the longitudinal impedance as indicated in fig. 5 . A resonant line can simply be represented by a series L,C with vanishing impedance at resonance. The coupling to the "TE-line", represented by the impedance Z_C, can again be done galvanic, capacitively or inductively. Capacitive as well as direct coupling seem to be simplier, but they are difficult to tune and give always an additive capacitive load for the structure. As in the case of azimuthal stabilisation mechanical and operational reasons favour inductive coupling. Fig. 6 shows basic set-up. The electric length of this coupler is a multiple of $\lambda_0/2$. Fig. 7 shows the dispersion diagram for the cavity and the coupler. Fig. 8 shows the field tilt D as function of a symmetric frequnecy perturbation of the end cells of the RFQ.

Tuning of the coupler was done with a phase shifter outside the cavity. The effects are described in fig. 9 , which shows mode spectra for increasing coupler frequency. Properly tuned and with RF drive in the cavity center the coupler has the effect of taking away the TE_{211}-mode response as shown in fig. 10 for the detuned 440 MHz RFQ and the $5x\lambda/2$ coupler.

The frequency difference between TE_{210} and TE_{211} has been increased by RLC from 8 MHz to 13 MHz indicating a change of group velocity.

Tilting of a balanced field distribution can be done by changing the orientation of one of the loops to the magnetic field. A field ratio of 3:1 at both ends of the RFQ could be achieved. In case of a TE-resonator the RLC could be placed inside the cavity and tuned like the end cell coupler for the azimuthal stabilisation.

Application for other structures is possible too. For an Alvarez the RLC looks like in fig. 2c. A chain of single couplers could be taken as well as a number of loops in series, as shown in fig. 11. First experimental results with the RFQ indicate that such a single multiloop line is effective too. A longer cavity is needed to make more detailed experiments. The distance between loops is a multiple of $\lambda_0/2$. They can be compared with postcouplers, which are excited by the electrical field of the drift tube and being excited change the magnetic field of both sides of the stem. As for postcouplers the number of RLCs can be chosen according to the unflatness expected.

Geometrical problems related with coupling strength and tuning to resonance in case of permanent quadrupole drift tubes are difficult to solve[6]. For the RLC this would have no effect.

Up to now no real disadvantagesof the RLC could be seen, tuning range, high average power design and mechanical simplicity seem to be favourable.

References

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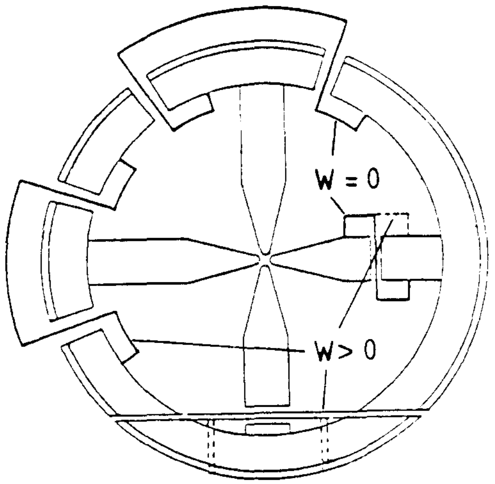

Fig. 1 Azimuthal resonant loop coupler schemes (stored energy W)

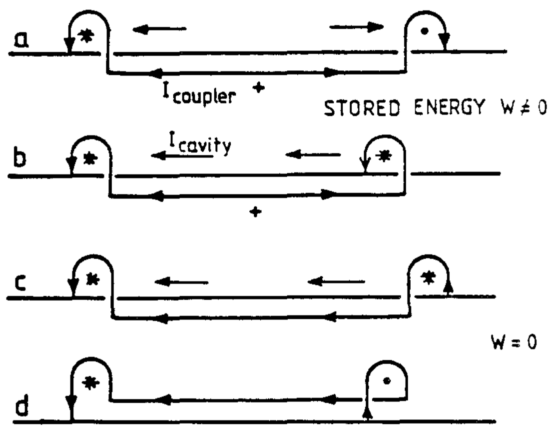

Fig. 2 Resonant and nonresonant loop coupler schemes

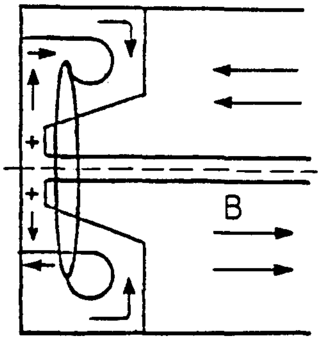

Fig. 3 End cell resonant coupler

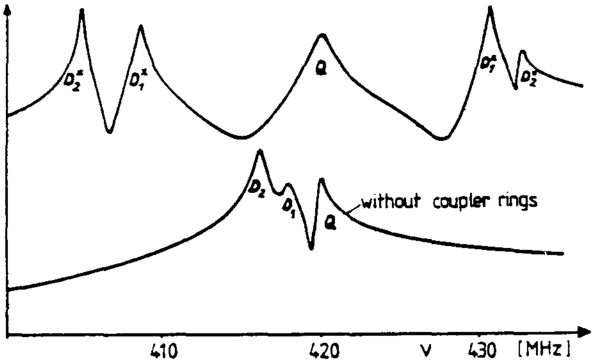

Fig. 4 Mode spectra of RLC coupled RFQ

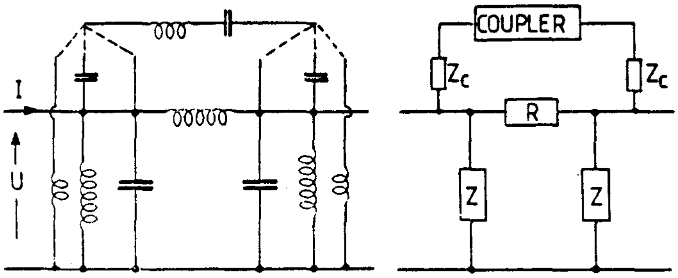

Fig. 5 TE line representation of resonant coupling

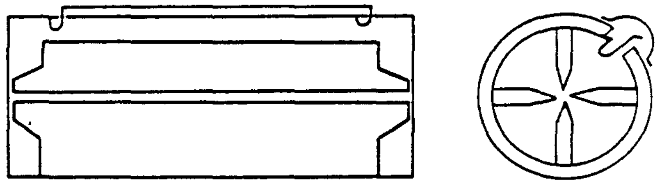

Fig. 6 Set-up for longitudinal stabilisation with one RLC

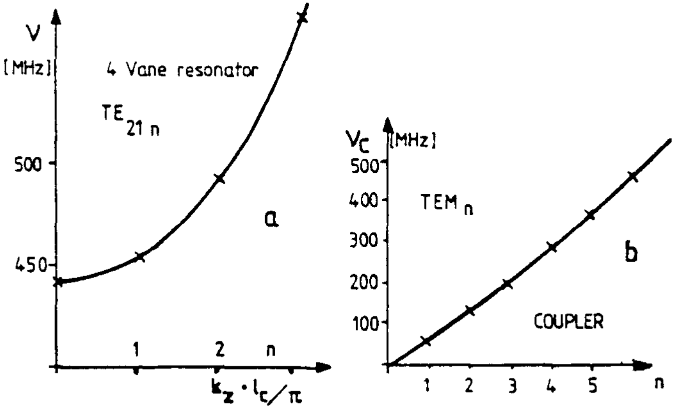

Fig. 7 Dispersion diagram for four vane resonator (a) and the coupler (b)

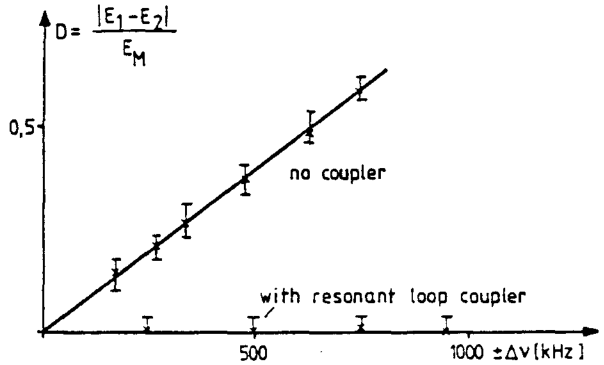

Fig. 8 Field tilt versus detuning frequency

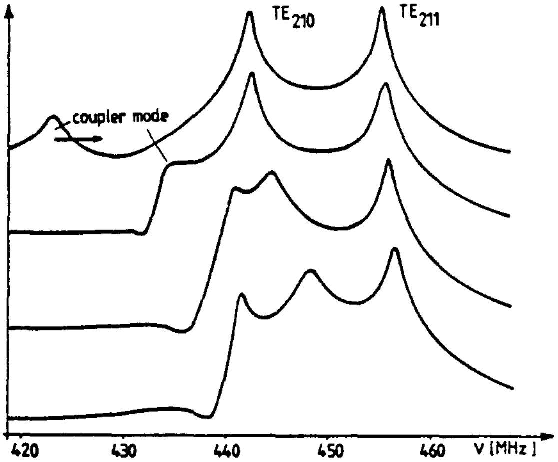

Fig. 9 Mode spectra for increasing frequency of the resonant coupler

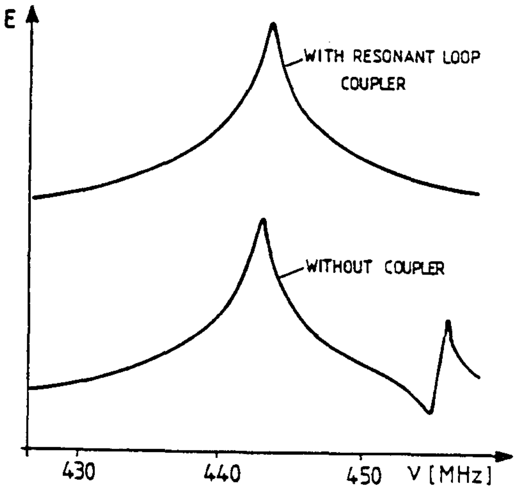

Fig. 10 Mode spectra for central drive

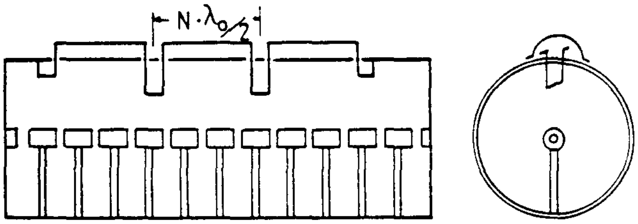

Fig. 11 Series loop line coupler in an Alvarez structure