THE BRIDGE COUPLING CAVITIES IN THE SEPARATED DRIFT TUBE LINAC STRUCTURE

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Abstract

The Separated Drift Tube Linac (SDTL) structure was proposed for medium energy range of proton linacs. The accelerating cavity consists of several SDTL units with focusing lenses between sections. To drive several SDTL sections from single RF source, application of both RF power dividers and coupling bridge cavities seems feasible. Through bridge couplers, the field distribution, in both amplitude and phase, is automatically stabilised among connected sections in the lowest order. Additional rf power dissipation of an order of several percents is inevitable in the bridge coupler because of its standing-wave operation. In this paper particularities and limitations for coupling bridges in the SDTL tanks are considered. Well known cylindrical bridge cavities (CBC) may be used. To maintain features of the SDTL structure as the easy-to-do low-cost one, Rectangular Directly Coupled Bridges (RDCB) look more preferable. Developed and realised in Moscow Meson Facility linac, RDCB operates in TE_{10N} mode and originally has no mode mixing problem. To simplify manufacturing procedure, RDCB design is based on parts of standard waveguide. The philosophy of SDTL-RDCB tank and results of preliminary consideration are presented.

1 INTRODUCTION

Attractive features of the bridge coupled system are well known and have been proved experimentally for Coupled Cells accelerating Structures (CCS) at high frequencies ≈ 1000 MHz in several laboratories. The bridge coupling cavities can also be applied for SDTL structure [1], taking into account SDTL particularities. The consideration of bridge coupler in SDTL structure has been performed [2] as one option possible for 200 MeV linac accelerating structure. Two concepts of coupling bridges are possible. Both CBC and RDCB have been considered. Below we summarise results of consideration [2] and results of further investigations for SDTL-RDCB tank.

2 CONCEPTS OF COUPLING

2.1 Coupling with intermediate coupling cell

Application of CBC for high frequency (700 MHz) SDTL was considered in [3]. Following the well known concept [4], a CBC is attached to the SDTL section through intermediate coupling cell (Fig.1a). In the chain of coupled cells, which describes total tank, bridge cavity is equivalent to modified accelerating cell which is displaced from beam axis. In order to reduce the rf losses in the bridge cavity one should provide asymmetrical coupling in intermediate cell $k_2 > k_1$. If total tank has M SDTL sections, $M-1$ bridges

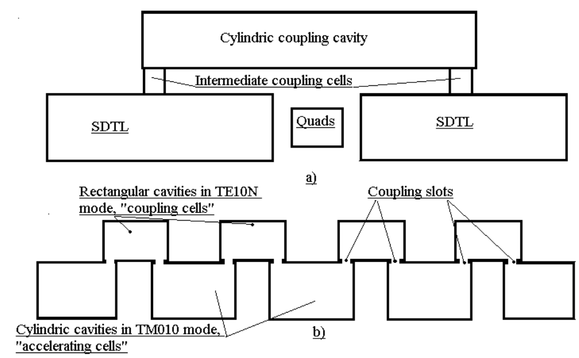

Figure 1: A sketch of the tanks coupled by CBC (a) and RDCB (b).

and $2(M-1)$ coupling cells, there will be $4M-3$ modes in the TM_{010}-like passband. Central operating mode is the $\pi/2$ mode, position of nearest modes mainly depends on k_1 value, the bandwidth of the passband - on k_2 value. Additional rf losses for such option were estimated as 3.3% for $k_2/k1 = 4$, k_2=1.8% [2]. As the result of comparison of different CBC types, the multy-cell bridge cavity [5] looks as a preferable CBC solution.

2.2 Direct coupling

Another concept of coupling bridge cavities is possible [6]. To illustrate the philosophy of RDCB, let consider bi-periodic chain of coupled cavities (Fig.1a) . First type of cavities are cylindrical ones, exited in TM_{010} mode. The second type of cavities are rectangular ones, exited in TE_{10n} mode. To simplify manufacturing procedure for rectangular cavity, let chose transversal dimensions equal to dimensions of standard waveguide recommended at operating frequency. With such choice we automatically solve mode-mixing problem for RDCB, because dimensions of waveguide are defined for single mode operation of TE_{10} wave. Both types of cavities are coupled trough coupling slots, forming the chain of coupled cavities, in which cylindrical cavities are equivalent to accelerating cells, and rectangular cavities - for coupling ones. The coupling slots are placed to couple H_ϕ component in cylindrical cavity with H_x in rectangular one. Let define the mode in the rectangular cavity, for example TE_{10N}, and choose the length of the cavity to have the frequency of this mode equal to operating frequency of accelerating cells. We get usual chain of coupled cavities which is well known from CCS description [4]. If one match frequencies of accelerating mode (operating mode of the tank, really it is the frequency of SDTL sections taking into account effect of coupling slots) and coupling mode (the frequency of rectangular cavity also taking into account effect of coupling slots), one will have accelerating system, consisting from two types of cells, with continuous dispersion curve. If we have M SDTL sections in the tank and $(M-1)$ bridges, operating passband will have $2M-1$ modes. Central, operating mode is $\pi/2$ mode, with strong field in accelerating (SDTL) sections and weak field in coupling cells (RDCB) and with all properties of stabilisation. One should take into account that for odd N mode TE_{10N} has H_x component of different signs at the ends of the bridge. This case at operating $\pi/2$ mode phase shift between SDTL sections is 2π. For even N coupling coefficients k_c at the ends of RDCB has the same sign and phase shift between SDTL sections is π. The evident question to be answered - how can we match such directly coupled bridges with the driving waveguide, if there are no field in the bridge cavity at operating mode? This statement is only the result of our analysis based on single-mode approximation to describe RDCB. In the study of multy-mode approximation for RDCB description, one will find weak, but nonzero field in bridges at operating mode, sufficient to match with driving waveguide. For odd N the field in RDCB at operating $\pi/2$ mode can be represented as the sum over TE_{10n} modes with even n, for even N - with odd n. RDCB were proposed for high energy accelerating structures, tested at high rf power level with the Disk and Washer and Annular Coupled structures [7] and long time successfully operate in the main part of the Moscow Meson Facility linac.

3 PARTICULARITIES

If coupling bridges are attached to the ends of SDTL sections, they will couple both operating TM_{010} modes and all high order TM_{01m} modes, including nearest TM_{011} ones. With increasing of k_c bandwidths rise both for TM_{010} passband and for TM_{011} one too. If passbands will overlap, one will have mode mixing problem, leading to serious problems with the field distribution at the operating mode and reduction of the stability. There will be slope in the field distribution at operating frequency, related with TM_{011} mode influence which is especially dangerous in the transient. The frequency difference ΔF between TM_{011} and TM_{010} modes can be estimated as:

$$\Delta F \approx \frac{f_0}{8N_p^2\beta^2} \tag{1}$$

where N_p is the number of periods in the SDTL section, β is relative velocity of particles. For particular case 5 period SDTL sections with operating frequency f_0 =324 MHz [2] TM_{011} mode is far enough for β =0.3, ΔF =17 MHz, and closer, ΔF =3.8 MHz, for β =0.55. To reduce TM_{011} mode passband influence, one should restrict the value of coupling coefficient k to keep the bandwidth of the TM_{010} passband several times less than ΔF. The coupling with TM_{011} (and all odd TM_{01n} modes too) mode can be avoided by the coupling of the bridge coupler in the middle of the SDTL cavity [3]. This [2] case CBC should have the length $7\beta\lambda$ and for f_0 =324 MHz it is equal to 1940-3560 mm, 0.3 $\geq$ β $\leq$0.55. Practically we have to place in parallel additional line of cylindrical cavities, comparable in dimensions with SDTL sections. It leads to increasing of the costs for accelerating system manufacturing.

If 4, 6 or 8 sections are coupled with bridges, coupling at the ends of SDTL sections is possible, because coupling with TM_{011} mode at one end compensates such coupling at another end. If two SDTL sections are coupled with bridge couplers, coupling in the middle of the section looks reasonable.

Coupling slots decrease the frequency and we have local detuning of order 2 $\div$ 4 MHz in one SDTL period. This detuning is big enough and should be compensated by increasing of the gap length to avoid deterioration of the field distribution inside SDTL section.

4 THE EXAMPLE OF SDTL-RDCB TANK

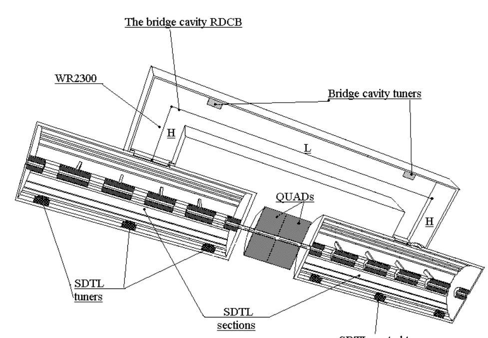

Figure 2: The sketch of SDTL-RDCB tank

Let consider two SDTL sections coupled in the middle with RDCB (Fig.2). The inter-section length is $2\beta\lambda$ [2] and RDCB should provide 0 phase shift between sections, so TE_{10N} mode with odd N should be chosen. It means, that RDCB length along 'middle line' $L+2H$ (see Fig.2) should be close to $N\Lambda/2 \approx L+2H$, where Λ is wavelength of the TE_{10} wave in the waveguide. In addition to [2], below we consider RDCB produced from standard waveguide WR2300 (Λ =151.53 cm at f_0 =324.0 MHz). To combine requirements of distance between coupling slots $L = 7\beta\lambda$ and the total length of the bridge coupler $L+2H \approx N\Lambda/2$, RDCB should be formed in Π-shape (Fig.2). For the beginning of the SDTL accelerating structure β=0.314 TE_{105} RDCB mode is suitable. With the increasing of β along the structure H decreases to maintain total length $L+2H$ and when H becomes insufficient from technological requirements, TE_{105} RDCB mode have to be changed to TE_{107} one. RDCB is equipped with two plug tuners (Fig.2). With simultaneous moving of RDCB tuners we can change own frequency of RDCB, tuning position of nearest modes practically without changing of operating frequency of total cavity. With opposite moving of RDCB tuners one changes level of rf field between SDTL sections. It is very useful also to have several tuners in SDTL section. Two tuners near ends are intended to control operating frequency and field distribution inside SDTL section. It may be shown, that standard deviation of the electric field distribution σ_e in SDTL section (without post couplers) is related with standard deviation of frequencies of SDTL cells σ_f as:

$$\sigma_e \approx \sigma_f \sqrt{\frac{4}{N_p} \sum \frac{f_m^4}{(f_0^2 - f_m^2)^2}} \tag{2}$$

where f_m are the frequencies of high TM_{01m} modes and TM011 one provides the biggest contribution into σ_e. Two tuners near ends of the SDTL section allow to compensate TM_{011} mode contribution and release tolerances for SDTL manufacturing in 3 times. Moreover, SDTL tuners in the first and last cells are useful to compensate detuning of cells due to absence of a half of stems. Central SDTL tuner is intended to compensate detuning of the middle cell due to coupling slot. If this compensation is done, the central tuner is not necessary. Numerical simulation of rf parameters has been performed for the SDTL-RDCB tank cavity for β =0.314 by using 3D code MAFIA with total number of mesh points near $1.5 * 10^6$. RDCB tuners are suggested 15 cm in diameter and 4 cm in length. SDTL tuners are supposed 10 cm in diameter and 4 cm in length. At first, reference values for SDTL section (without RDCB) have been obtained for operating frequency. RDCB tunes by adjusting H parameter (see Fig.2). The coupling slot 24 cm x 27 cm reduces the frequency of middle SDTL cell at 2.61 MHz and this reduction was compensated by increasing of the gap length at 2.4 mm. After RDCB tuning for TM_{010} mode passband were obtained - operating frequency f_0 =323.999 MHz, another TM_{010}-like modes with frequencies f_- =322.286 MHz and f_+ =325.627 MHz. The k_c value for this case is $k = \frac{f_+ - f_-}{f_0} = 1\%$. For this SDTL-RDCB options numerical calculations show no additional rf losses with respect to reference values for SDTL sections (reduction in shunt impedance Z_e is 0.16%). There are two reasons for additional rf losses - rf losses in the RDCB cavity and redistribution of rf currents at the SDTL walls due to coupling slot influence. The own quality factor Q of RDCB cavity is high ($\approx$ 48000) and comparable with Q-factor of SDTL sections ($Q \approx$ 53000). By choosing high Q RDCB cavity we decrease additional rf losses in the bridge. The dimensions of coupling slot were optimized to reduce rf currents redistribution in SDTL walls. Results of SDTL-RDCB with usual coupling slots also show [2]. tolerable decrease in $Ze \approx$0.5 $\div$ 7% for coupling $k_c \approx$0.4 $\div$ 3%. No significant distortions in the field distribution at operating mode in SDTL sections have been found ($\sigma_e \approx$0.1%). With increasing of the at 1 cm length of one RDCB tuner and decreasing for another the ratio of average electric field between SDTL sections changes at 1.67%, operating frequency changes at 1.5 kHz. With the removing of one SDTL end tuner (it corresponds detuning of the end SDTL cell at 650 kHz) operating frequency of the tank changes at 70 kHz (in fine agreement with averaging of frequency errors) and the change in average field level between SDTL section is 0.05%. Inside detuned SDTL section field slope 2.9% exists in good agreement with estimation (2).

5 SUMMARY

The multi-cell CBC may be used for coupling of the SDTL sections. For the operating frequency 324 MHz bridge cavity diameter is $\approx$ 650 mm, diameter of coupling cell is $\approx$ 420 mm. To avoid mode mixing in SDTL cavities, coupling coefficient should be small, leading to the reduction in the passband width and closing of the nearest modes.
RDCB may be a good option for the coupling of SDTL sections. In comparison with CBC with intermediate coupling cells RDCB have:
- better mode separation with smaller rf losses,
- smaller transverse dimensions,
- flexible tuning of rf field between SDTL sections,
- simpler manufacturing and tuning procedure.

6 ACKNOWLEDGMENTS

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