TIME DELAY LINE CHOOSING FOR RF POWER UPGRADE SYSTEM

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Abstract: The paper contains theoretical reseach results of time delay lines based on smooth circular or rectangular wavaguide and circular iris-loaded waveguide. The main problem of this research was choosing of delay line with satisfactory parameters for application in RF power upgrade systems. Different delay lines were compared on group velocity, power dissipation, tolerances on geometrical sizes. Calculation have shown that circular smooth and iris-loaded waveguide give a possibility to construct delay line with satisfactory parameters at frequencies up to 15 GHz.

Introduction

The RF power upgrade systems seems to be the only sourses of extremly high power RF pulses (about hundreds and more megawatts). Such a pulses are needed for high gradient electron linacs feeding and also can be used for acceleration of other particles. Moreover they can be applied for some other purposes where a short high power RF pulses are needed. The main working principle of these systems is as following. The generator RF pulse energy within the pulse duration or the main part of it is storeing at special elements. Then all stored energy extracted from the system during the time interval much shorter that the initial one. This results in RF pulse power increasing while its duration decreasing. High quality resonant cavities or time delay lines are available for energy storage.

RF energy upgrade systems with storage cavities are much more widely used due to their relative simplicity and compactability. And thats why they are well enough studied [1-4] . Nevertheles this systems are not free from some disadvantages Aspecially it can be pointed out that the output RF pulse shape efficiently defferes from rectangular one and the maximum value of the system efficiency cannot exceedes 82 %.

Upgrade systems with time delay lines as an energy storage elements are free of this disadvantages [5,6] . This systems form a plane top RF pulses and can possess a 100 % efficiency. In general the systems efficiency dependns upon delay lines energy losses. Values of binary systems [5] efficiency η and power multiplying coefficient K_p for different losses in delay lines are contained in the table.

Requirements for time delay line parameters

Data contained in the table shows that a power dissipation about 15...20 % is acceptable in the most cases. For practical use minimum geometrical sizes and acceptable electrical strength are also desired. Requirement for electrical strength is caused by the RF power level that the system operated on which is about hundreds of megawatts. This fact practically excludes using of dielectric filled waveguides. That's why smooth rectangular or circular waveguides and iris-loaded circular waveguides are of interest for time delay line construction.

TABLE

Energy losses, %	2 stages		3 stages	
	K_p	η	K_p	η
0	4.00	1.00	8.00	1.00
5	3.85	0.96	7.65	0.96
10	3.70	0.92	7.30	0.91
15	3.55	0.89	6.95	0 87
20	3.40	0.85	5.61	0.83
30	3.09	0.77	5.92	0.74

Energy losses are given for the line with maximum delay time.

For not high power level (below approximately 1 MW) application of dielectric filled waveguides seems to be rather effective.

Smooth rectangular waveguide

The main wave type in this waveguides is the TE_{10} one. This wave advantage is that dimensions of a waveguide can be chosen in such a way that it will be the only wave propagated in a waveguide. And there are no problems with wave type filters. Wave decreasing coefficient α for TE_{10} wave is defined as :

$$\alpha = \frac{k}{b\,\beta_{gr}}\left[1 + 2\,\frac{b}{a}\left(\frac{\lambda}{2a}\right)^2\right] \qquad (1)$$

where $\alpha = -\ln(E(l)/E_0)$ (E_0 is the wave amplitude at the entrance end of the waveguide, $E(l)$ - wave amplitude at the output end while l is a length of the waveguide) ; $k = (\pi f \varepsilon_0/\sigma)^{\frac{1}{2}}$ - proportional coefficient (f - frequency, ε_0 - electric constant ; σ - walls material conductivity) ; $\beta_{gr} = (1 - (\lambda/\lambda_c)^2)^{1/2}$ - wave group velocity (where λ and λ_c are free space wavelegth and critical wavelength in waveguide, respectively) ; a and b - waveguide dimensions (a is the dimension of the perpendicular to the wave polarization plane wall).

Some calculated results obtained with the help of equation (1) are plotted on fig. 1. Here are given power dissipation $A = 20\alpha \ln e$, normolized power dissipation A/t and waveguide length L/t (where t is a delay time) v. s. wavelength parameter $\Delta\lambda/\lambda_c = (\lambda_c - \lambda)/\lambda_c$. It can be seen that a power dissipation A increases and a

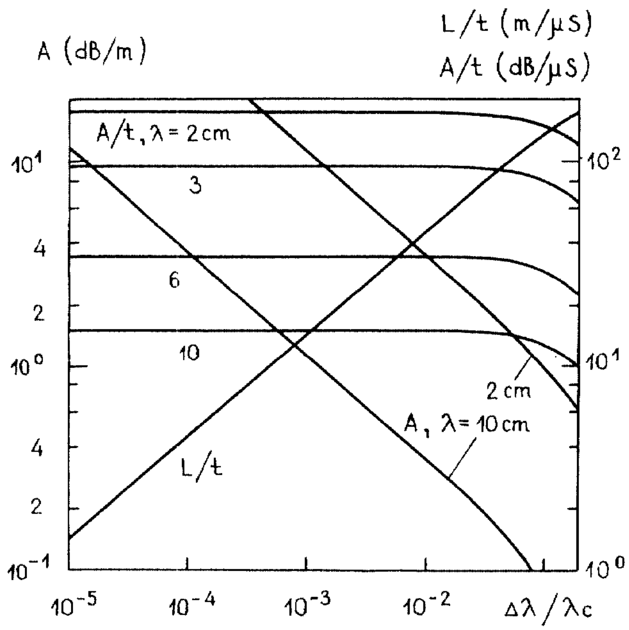

Fig.1. Plots of power dissipation A, normolised dissipation A/t and normolised length L/t as a function of $\Delta\lambda/\lambda_c$ for different values of λ, for rectangular waveguide.

normolized length L/t decreases with the wavelength λ get closer to λ_c. But at the same time normolized dissipation A/t remains practically constant and slightly drops with λ goes far from λ_c. A little A/t decreasing observed while increasing a waveguide dimension b. This decreasing is about 45 % for ten times dimension b growth. Therefore power dissipation in delay line based on smooth rectangular waveguide for definite delay time is determined by the exited mode and the a/b relation. In this case the delay line length should be chosen from the point of view to obtain necessary delay time and acceptable electric strength : electric field grows up with β_{gr} decrease.

Smooth circular waveguide

The TE_{01} mode in smooth circular waveguide is not the lowest one but it is of interest in our case due to its anomaly small dissipation. The main disadvantage of this mode is that the TH_{11} mode has the same value of λ_c. So if there are no any special filters that can damph the TH_{11} mode this two modes will propogate in the waveguide together.

The critical wavelenhth λ_c for TE_{01} mode is as following :

$$\lambda_c = \frac{2\pi}{\mu_{01}} R \qquad (2)$$

where μ_{01} is the first root of the Bessel function derivative and R is the waveguide radius. The wave dissipation coefficient α for TE_{01} mode is :

$$\alpha = \frac{k}{2R\beta_{gr}} \left(\frac{\lambda}{\lambda_c}\right)^2 \qquad (3)$$

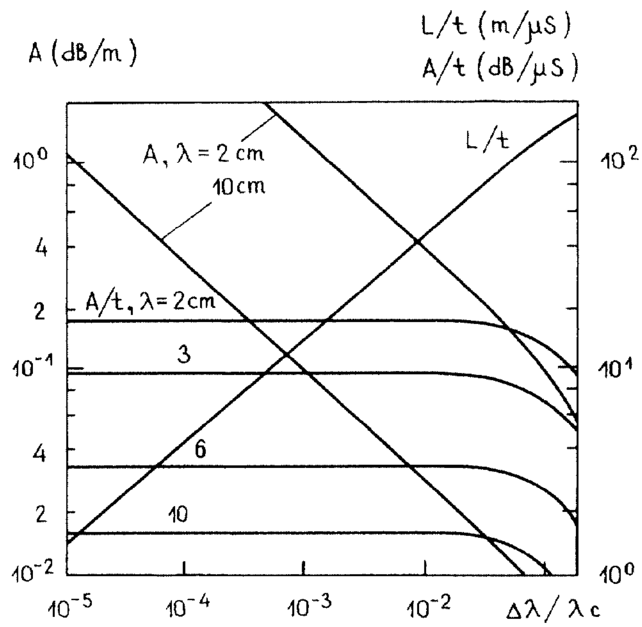

Fig.2. Plots of values A, A/t and L/t as a function of $\Delta\lambda/\lambda_c$ parameter for circular smooth waveguide.

Calculated results for power dissipation A, normolized length L/t and dissipation A/t are given at fig. 2 as a function of $\Delta\lambda/\lambda_c$. The curves are given for several values of λ. This results are quite like those at fig. 1. Normolized dissipation A/t is aslo practically independent from wavelength parameter $\Delta\lambda/\lambda_c$. But one can see that in this case power dissipation in delay line is in about an order lower then for rectangular waveguide. When exiting the TE_{02} mode the dissipation is roughly twice lower then for the TE_{01} one but it is more complicated to prevent any lower mode propogation in the waveguide.

Circular iris-loaded waveguides

Circular iris-loaded waveguides (CIW) are the periodic waveguide systems that can slowing down a wave phase and group velocities both. From the point of view of using CIW as a time delay line we are interested only in group velccity decreasing. In CIW one can achieve a significant lowing of β_{gr}. This waveguides are well enough studied and can be relatively simply calculated. For this structures we are interested in TH_{01} mode as well as in TE_{01} TE_{02} and TE_{03} modes.

With the help of electrodynamic calculation of the structure given at fig. 3 the delay line parameters are defined. The calculated results are plotted at fig. 4. Normolized dissipation A/t for every mode considered is close to minimum possible one it can possess. For TH_{01} mode A/t values are given for several values of phase velocity β_{ph}. One can see the dissipation decrease tendency for β_{ph} growing up. Nevertheless for $\beta_{ph}>10$ this decreasing don't exceedes several percents. This mode dissipation is calculated for the following parameters (according to fig. 3) : a/b = 0.3513 ; a/λ = 0.1350 ; t/λ = 0.0201 , oscilation type $\pi/2$. It can be pointed out that parameters a/λ influence especially on the β_{gr} value. And for β_{gr} changing from 0.015 up to 0.50 the dissipation A/t remains practically constant.

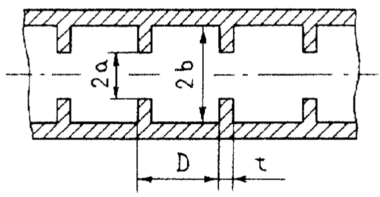

Fig.3. Circular iris-loaded waveguide structure.

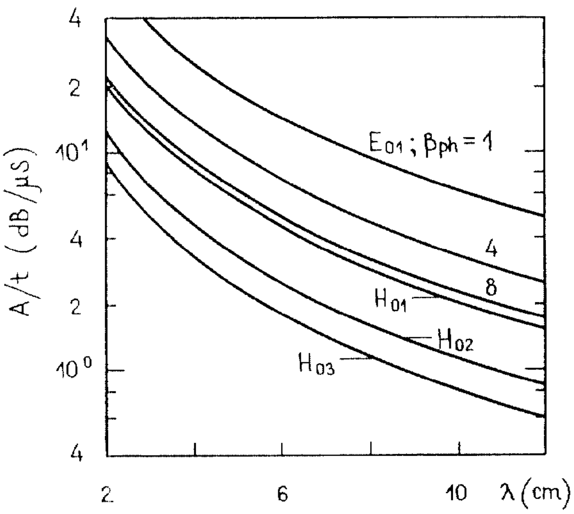

Fig.4. Plots of normolised power dissipation A/t as a function of wavelength λ for different modes in CIW.

Normolized dissipation A/t for TE_{01} mode is nearly the same as for TH_{01} one Here we haven t such an evident dependence of A/t on β_{ph}. The lowest values of A/t can be achieved when the parameters a/λ and β_{ph} are chosen in such a way that β_{gr} is negative and slightly differs from zero. This also concerned the TE_{02} and the TE_{03} modes For the TE_{01} mode calculations are carried out for parameters values : a/b = 0.4760 ; a/λ = 0.4020 ; t/λ = 0.0927 ; β_{ph} = 4.8 ; oscillation type $\pi/2$. Here parameters a/λ influenced practically on β_{gr} as it for TH_{01} mode.

A proper parateters choosing can decrease the A/t value twicely more. So an acceptable value of power dissipation can be achieved in delay lines based on CIW that is about 0.7 - 1.0 dB/μs at 10 - sm band.

Analysis of results

The investigation done shows that all considered types of delay lines can possess an acceptable values of power dissipation and geometrical length. A definite waveguide type and the delay line length are chosen according to nessesary wavelength band, RF pulse duration (needed delay time), power level and available precision of manufacturing.

For example, a rectangular waveguide can be used at 10 - sm wavelenhth band as a delay line for RF pulses about 1 μs long. In this case the delay line should be 4.2 m for λ/λ_c = 0.9999, and the a - dimension of the waveguide should be manufactured with accuracy better then 1 μm. For input power of 1 MW electric field strength in waveguide should be about 180 MV/m.

In 2 - sm wavelength band an acceptable values of power dissipation (less then 1 dB) can be achieved for a delay lines based on rectangular waveguide when RF pulses duration doesn't exceed approximatly a units of nanoseconds. Circular smooth and iris-loaded waveguides can be used here within RF pulses duration up to 50...60 ns. If there are no firm requirements for delay line length an acceptable power dissipation can be achieved for delay times about 0.1 μs. In this case the delay line length would be roughly 16 m.

To construct a compact delay lines in considered wavelength bands one can use an iris-loaded waveguides. For approximatly the same parameters as for smooth waveguide there manufacturing accuracy is about an order lower. More over the advantage of CIW delay lines is that operating with TE_{01}, TE_{02} or TE_{03} modes one needn't use any special filters to prevent any parasitic modes propogation.

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