Status VLEPP RF Power Multiplier (VPM)

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1 INTRODUCTION

In past few years the theory of RF pulse compression was developed and discussed in details [1,2,3]. VPM (VLEPP RF Power Multiplier) represents a new approach in scheme realization of these devices and uses special type of the cavities in it's RF energy storage system [4,5]. In this paper the most attention is concentrated on the special features of the VPM.

2 QUALITATIVE DESCRIPTION OF THE VPM

Principle of operation of this device is the same as used by SLED [1] - storing of the energy during the most duration of the RF pulse from klystron and then, after phase reversion of the pulse by π, radiation of the storage energy during much shorter interval equal to the filling time of the accelerating structure. And as a result output power increased by factor of 3-5. Usually compression efficiency is equal to 65-75%. In the SLED case, where single cavities are used for storing the energy, output pulse decaies exponentially. At SLED II [2], cavities are replaced by the resonant lines and therefore the output pulse is flat. VPM contains two mutually coupled cavities. As mentioned in previous paper [5], in this case it is possible to achieve much squarer output pulse than in original SLED scheme. So the VPM is intermediate between the two schemes SLED and SLED II.

To achieve high quality factor, to be used in the RF power compression systems, more than 100000, storage cavity has to has large size. But in this case the spectrum density of the cavity is very high, that it becomes hard to operate in the single mode regime. As a solution of this problem it was proposed to use barrel shaped open cavity (BOC) [4]. In BOC, electromagnetic energy of the modes with large number of azimuthal variations is concentrated near the surface of the cavity and only so called "whispering gallary" modes can exist. All the other modes that have at the close frequencies smaller number of azimuthal variations are radiate rapidly, so the spectrum of cavity is quite rare. Here we wouldn't discuss the theory of BOC, and only note that the quality factor of this cavity is [6]:

$$Q_{tm} = \frac{2a}{\sigma} \qquad (1)$$

where a -radius of the cavity and σ-skin depth of the material. It's easy to see that for copper, if ratio of diameter to wavelength is more than 10, then the quality factor is more than 100000.

For experimental investigations of the properties of BOC, was fabricated cavity with the next geometry parameters : $a = 200mm, R_0 = 90mm$ - curve radius of the profile of cavity, $h = 160mm$ - height of cavity. Operating mode - $TM_{51,1,1}$. It was used special technology in this cavity fabrication to provide the finest quality of the surface and the best respectivity of cavity surface shape to the theoretical one (Fig. 1). Proper frequencies and quality factors of the cavity with this geometry were estimated with the help of the theoretical equations [6] and computer simulation.

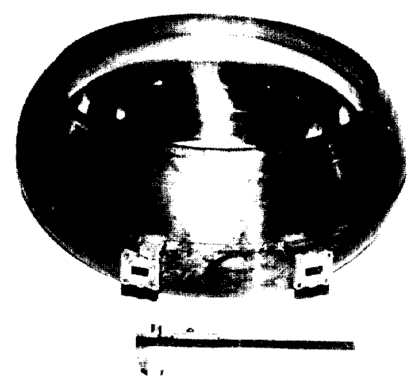

Figure 1. Common view of the BOC

The value of the quality factor was measured by phase method. Relative error was less than 3%. Experimentally observed value of the quality factor was 2.7×10^5, also there were no any oscillations in bandwidth more than 100 MHz with the center at operating frequency. For identification of the oscillation were measured azimuthal and radial field distributions at the median plane of cavity. In Table 1. are gathered theoretical [6], calculated and experimental values of resonant frequency and quality factor of the cavity with given geometry parameters.

Table 1

	Theoret.	Calc.	Experiment
$F(GHz)$	13.973	14.031	14.027
$Q_0/10^5$	3.67	3.31	2.70

Experimental results show good adequacy to the theoretical one. Further optimization of the VPM make it possible to use cavities with smaller value of the quality factor, so next generation of cavities obtain another geometry parameters: $2a = 258mm, R_0 = 75mm$, type -

$TM_{31,1,1}, F = 14.025GHz, Q_0 = 2.0 \times 10^5$ (experimental data).

The next distinguishing feature of the VPM is that cavities operate in the travelling wave regime. Common view of the VPM is shown at Fig. 2. Cavities are coupled by mean of the fields, that radiate from cavity to cavity. Dispersion and filling time in this case are functions of the height of each cavity. Feeding of the VPM is organized from the waveguide, which laying around the perimeter of input cavity.

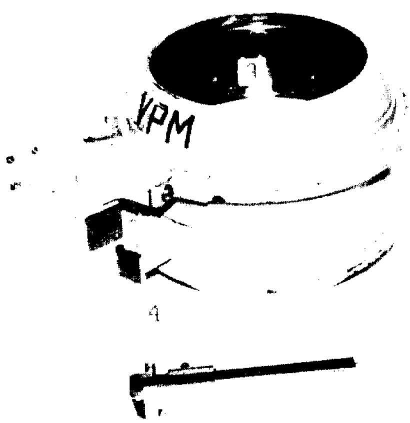

Figure 2. Common veiw of the VPM :1-feeding guide,2-storage cavities, 3-coupling slots,4-control outputs.

To organize the best coupling between the input cavity and feeding waveguide, phase velocities at operating frequency must be the same in both . This determines the width of waveguide. Input cavity is excited from the waveguide through small vertical slots. Number of slots N is equal $(4m+1)$ where m - number of azimuthal variations in the cavity. So there are two kinds of motion of the RF power in the system, first - in Z-axes direction and second - rotating around each cavity surface like TWC.

3 CHOICE OF PARAMETERS

Computer simulation of the system, based on the circuit analyses, was used for optimization of the VPM. Results of optimization for the VLEPP case are presented below.

Input parameters are : duration of the input RF pulse $T_{in} = 500ns$, filling time of the accelerating structure $T_{out} = 100ns$, durations of the fronts and phase reversion time $t_r = 20ns$. Single cavity parameters : number of azimuthal variations $m = 31$, F = 14.0 GHz,$Q_0 = 2 \times 10^5$. The goals of the optimization were maximal efficiency and the most rectangular shape of output pulse.

Efficiency as a function of the loaded quality factor of the input cavity $Q_l = Q_0/(\beta+1)$ (β - ratio of the power emitted from the coupling aperture to the power dissipated in the cavity wall), for the optimal value of coupling coefficient between cavities - k, is shown at Fig. 3 a). Optimized values of these parameters are: $Q_l = 0.065 \times 10^5$ ($\beta = 30$) and $k = 6 \times 10^{-4}$. Efficiency about 73.0% and average power gain - 3.7, were obtained at these parameters.

Next figure (Fig. 3 b)) shows the dependance of efficiency as a function of unloaded quality factor of the cavities. In our case we have point near the optimal value of Q_0, as for the next increasing of efficiency,it is necessary to use cavity with more large diameter. For example : to increase efficiency by 3% one need to increase 2 times diameter of the cavities. Note that all this calculations were done for optimal values of Q_l and k.

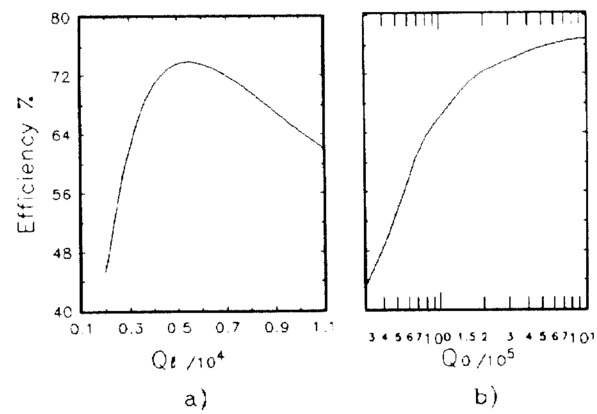

Figure 3. a) Efficiency vs. Q_l of the first cavity, b) efficiency vs. Q_0.

If the proper frequencies of single cavities are not identical, then the results will be asymmetric field distribution at the frequencies of the system, and hence different values of Q_l at these oscillations. Thus it is possible to change the shape of the output pulse. For our case it was defined that the optimal frequency detuning between proper frequencies of the cavities ΔF is 3.5 MHz. Hence for the same efficiency, peak power decrease by 10%, and the shape of output pulse becomes more close to rectangular one. So optimized VPM input parameters for the VLEPP case are :

- $Q_l = 0.04 \times 10^5 (\beta = 50)$
- $k = 5.5 \times 10^{-4}$
- $\Delta F = 3.5$ MHz

and output :

- efficiency $\eta = 73.2\%$
- power gain $M = 3.7$

4 FIRST EXPERIMENTS AT VPM

At Fig. 4 are shown the input and output pulses that were observed at low power tests on one of the stages of the VPM development [7]. Average multiplication of the RF power in this case was 6.6 db. Measured value of SWR at operating frequency was less than 1.1. The next figure (Fig. 5) show computer simulation of the process. Input parameters for calculations were taken from experimental data: $Q_0 = 2 \times 10^5, Q_l^0 = 8.4 \times 10^3, Q_l^\pi = 3.6 \times 10^3, F^0 - F^\pi = 25MHz, \Delta F = 9MHz$. And were defined as: $k = 0.015$ and $\beta = 60$. Output parameters are gathered in Table 2.

The parameters of this model are not optimal and are in progress now. However we can see good agreement of experemental results to predicted one. Now it seems, that VPM has some advantages in comparison with the traditional schemes - simplicity, relatively small size, no needs to use any additional devices (3db-couplers, wave type transformers, highly overmoded circular waveguides etc.), high electrical strength and the shape of the output pulse quite close to rectangular.

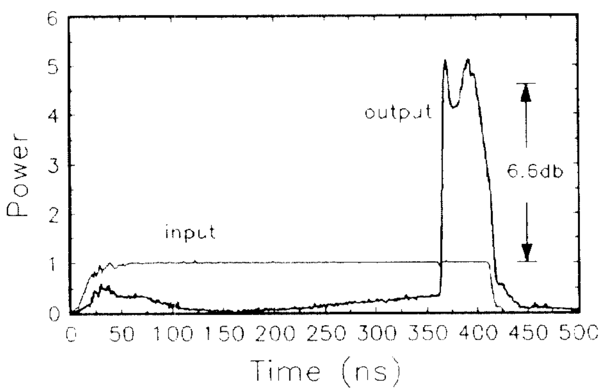

Figure 4. Experimental data

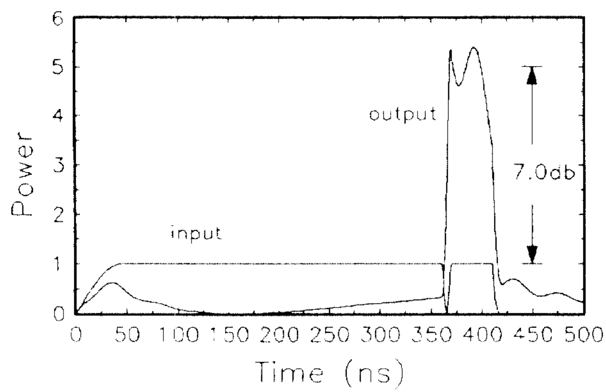

Figure 5. Computer simulation

Table 2

	Simulation	Experiment
Efficiency%	57	52
Power gain	5.0	4.57

5 SUMMARY

Experimental investigations of the BOC has shown that this kind of cavities possess by the properties that are sufficient to be used in the RF power pulse compession - high quality factor (more than 100000) and quite rare frequency spectrum with density about one harmonic per 100 MHz band. Low power tests at the VPM contaning two open cavities operating in the travelling wave regime demonstrated that VPM provides the base parameters which are needed for the future VLEPP RF power pulse compression system.

6 REFERENCES

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