EFFICIENCY ENHANCEMENT OF ACTIVE HIGH-POWER PULSE COMPRESSORS

S.V.Kuzikov, Yu.Yu.Danilov, A.A.Vikharev, Institute of Applied Physics, Russian Academy of Sciences, Nizhniy Novgorod, Russia

Abstract

A microwave pulse compressor operated with a superposition of eigen quasi-degenerated modes is considered. A proper choice of eigen frequencies and Q-factors allows essential reduction of diffraction losses during power storage. Peculiarities of power extraction by means of a high-power RF switch are analyzed. 30 GHz projects of multi-megawatt compressors based on: 1) dual-mode circular cross-section cavity as well as 2) four-mirror cavity with active grating are discussed.

INTRODUCTION

An active pulse compressor have a storage cavity whose Q-factor is modulated by means of RF switch, like it is shown in Fig.1. In regime of energy storage the Q-factor is high, in order to accommodate all input power. In regime of power extraction the mentioned electrically controlled switch has to open the cavity for a time to be much less than output pulse duration.

Efficiency of active pulse compressors is restricted by several factors (see, for example [1]). One of them is that some part of input feeding pulse is reflected by coupling element of the storing cavity (Fig. 2).

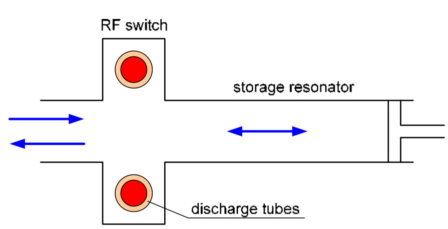

Figure 1: Active pulse compressor.

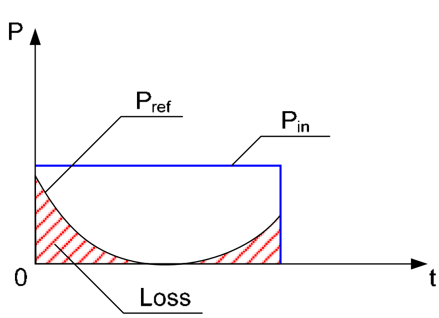

Figure 2: Input and reflected pulse shapes in regime of power storage in single-mode cavity.

These losses, caused by reflection, can be minimized by an optimal choice of resonant frequency and coupling factor. Nevertheless, it was shown many years ago that in optimal case efficiency of single-mode feeding is limited by value - 81.4% [2], while two-mode cavity promises more efficiency [3]. In this paper we suggest to use a multi-mode cavity, in order to obtain the best performance.

THE USE OF MULTI-MODE CAVITIES TO INCREASE FEEDING EFFICIENCY OF COMPRESSORS

Let us consider a high-Q multi-mode cavity connected with a completely matched waveguide (Fig. 3). Such cavity has a number of complex eigen frequencies which correspond to leaky eigen waves. Leakage of several leaky waves simultaneously looks like a beating process with exponentially decreasing magnitude. Therefore, we have to optimize real and imaginary parts of eigen frequencies in order to represent desirable feeding pulse by a superposition of few leaky waves.

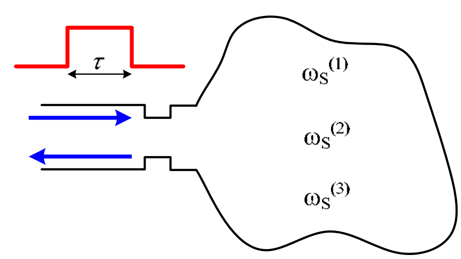

Figure 3: Feeding of multi-mode cavity.

In a case of rectangular pulse shape without phase modulation an efficiency of feeding can be written, using integral form:

$$|\eta|^2 = \left|\int_0^1 U(x)dx\right|^2 \Big/ \int_0^\infty |U(x)|^2\, dx, \qquad (1)$$

where, x=t/T – is a normalized time, T – is a pulse duration, and U(x) is a sum of leaky wave's fields:

$$U(x) = \exp(i\omega_0 Tx)\cdot\sum_n a_n \cdot \exp(i\Delta\beta_n x - \gamma_n x). \quad (2)$$

Here the normalized variables was used:

$$\Delta\beta_n = (\omega_n' - \omega_0)\cdot T, \gamma_n = \omega_n'' \cdot T, \qquad (3)$$

where $\omega_n^{'}, \omega_n^{''}$ - are real and imaginary parts of frequency of n-th eigen mode (the parameters to be optimized), and ω_0 – is a carrier frequency. Note, if U(x) coincides with the desired rectangular envelope, the efficiency (1) equals 100%.

Mathematically now problem is formulates as an optimization of magnitudes and complex eigen frequencies in order to provide best representation of the desired rectangular pulse shape by superposition of finite number of leaky eigen modes. There are simple considerations to be satisfied in order to provide the best representation. In particular, an absence of phase modulation in the desirable pulse requires a symmetry of leaky waves spectrum as it shown in Fig. 4:

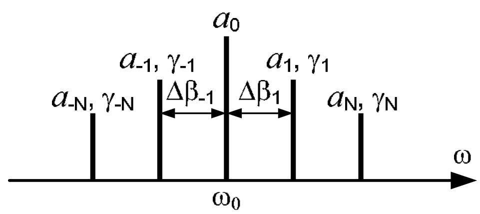

Figure 4: Necessary spectrum of leaky eigen waves.

$$\Delta\beta_{-n} = -\Delta\beta_n, \gamma_{-n} = \gamma_n, a_{-n} = a_n^*. \quad (4)$$

Efficiency of feeding was optimized for single-, double-, and three mode cavities (one, two, and three terms in formula (2) respectively) [6]. In a case of single mode cavity optimization leads to well known mentioned results with 81.4% efficiency. In a double-mode cavity maximum of efficiency is 91.4%, a three-mode system provides 95%. If the total number of modes goes to infinity, the optimized efficiency goes asymptotically to 100%. The resulted pulse shapes for the simplest cases of double and three mode cavities are shown in Figs. 5, 6 correspondingly.

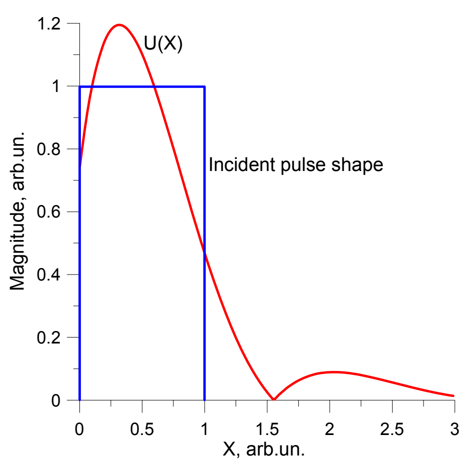

Figure 5: Leakage of power from optimized double-mode cavity (red curve) and the desirable pulse shape (blue curve).

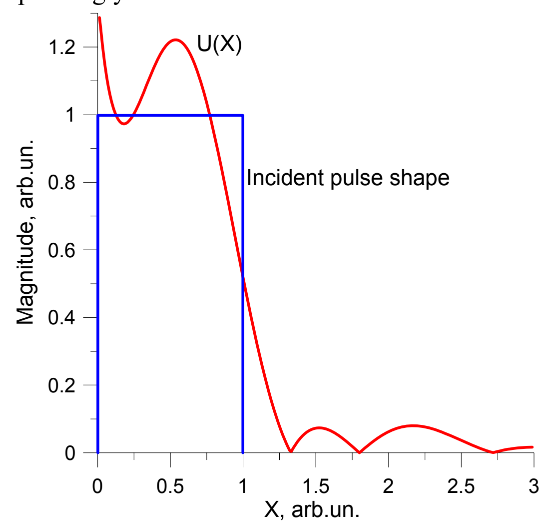

Figure 6: Leakage of power from optimized three-mode cavity (red curve) and the desirable pulse shape (blue curve).

HIGH-POWER MULTI-MODE PULSE COMPRESSORS

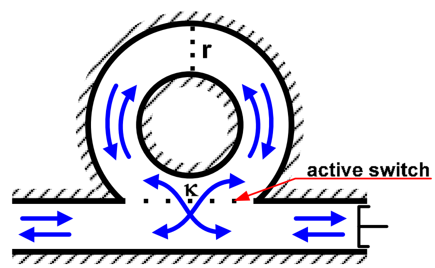

Figure 7: Model of traveling wave cavity.

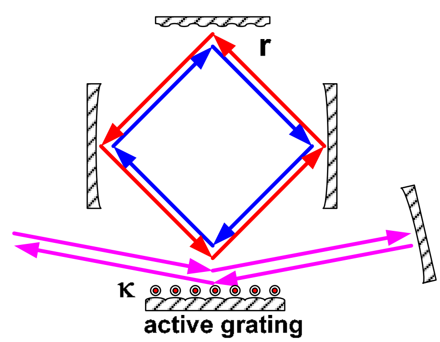

Figure 8: Double-mode four-mirror pulse compressor.

Let us consider ways to make the double mode compressor with the optimized parameters. Because optimal difference of frequencies is small enough (can not be more than typical width of spectrum of feeding pulse), it is natural to use cavities with degenerated modes. The necessary difference of frequencies can be provided by

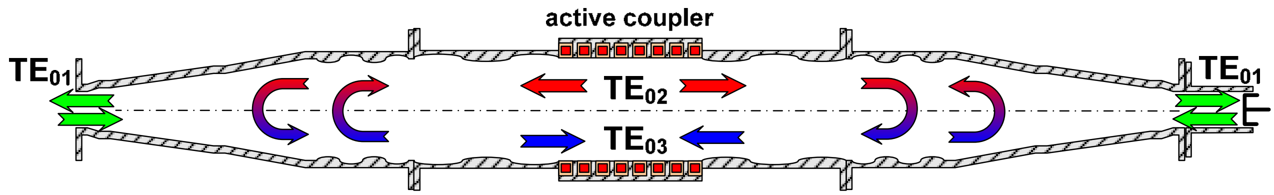

Figure 9: Double-mode TE01-TE02-TE03 pulse compressor.

means of small coupling between modes. For example, traveling wave cavity (Fig. 7) can be used, where initially degenerated modes of opposite rotations are coupled by means of additional reflector r.

High-power version of such type compressor is a four-mirror cavity, in which one corrugated mirror is responsible for coupling between modes of opposite rotation (Fig. 8). Another high-power version of double-mode compressor is an active compressor (Fig. 9) based on superposition of TE01-TE02-TE03 modes which was suggested recently [4-7].

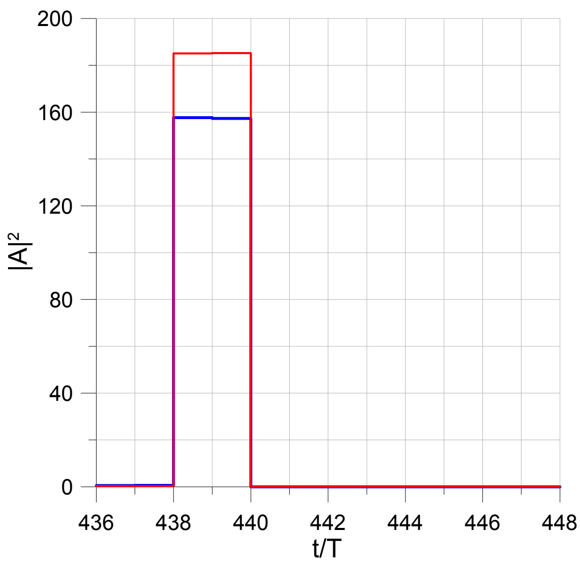

Figure 10: Output pulses of single-mode and two-mode SLED-II compressors.

Analysis of extraction regime of the considered pulse compressors shows that output pulse has peak power bigger in comparison with single-mode compressors, which is approximately proportional to the gain of efficiency. It is shown by example in Fig. 10 where the output pulse (blue curve) of single-mode SLED-II pulse compressor is compared with the pulse (red curve) of two-mode SLED-II compressor.

CONCLUSION

A method to enhance asymptotically up to 100% feeding efficiency of active pulse compressors has been suggested and tested numerically. The found maximum of efficiency in a case of rectangular pulse shape equals 91.4% for two-mode cavity and 95% for three-mode cavity.

The considered projects of quasi-optical pulse compressors promise high efficiency and high reachable output power.

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