100 MW ACTIVE X-BAND PULSE COMPRESSOR*

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1 INTRODUCTION

It is widely accepted that microwave pulse compressors are required to achieve the high power and short pulse lengths for high-gradient linear accelerators. Compressors are categorized within two main classes: passive (e.g., SLAC Energy development-SLED) [1,2] and active [3]. Active compressors have great potential for application with linear accelerators. The current Omega-P/IAP program is to develop and study the operation of a novel active microwave compressor that utilizes an oversized waveguide and electrically controlled Bragg reflectors. An active pulse compressor has been developed that is able to provide output pulses of at least 100 MW power with pulse duration of 100 ns at X band, and with a power gain of 12-15. The compressor is being evaluated using 1-1.5 μsec pulses from the Omega-P/NRL 11.424 GHz magnicon being operated at NRL. This paper describes design of the compressor and the magnicon-compressor microwave circuit, and gives first experimental results from low-power tests.

2 DESIGN OF ACTIVE BRAGG COMPRESSOR (ABC)

In the framework of the Project for realization of a Microwave Active Bragg Compressor (ABC) with its output power of at least 100 MW, we manufactured an ABC prototype. This is an evacuated version made of copper. The compressor design is distinguished from prior active compressors in that microwave energy is stored in a resonator operating in the "breakdown-proof" TE_{01n} mode, with n>>1. The testing of prototype designs of such a compressor using ~100 kW-level microwaves (f = 9.4 GHz) showed that a compressor of this design is able to provide power gains up to 20.

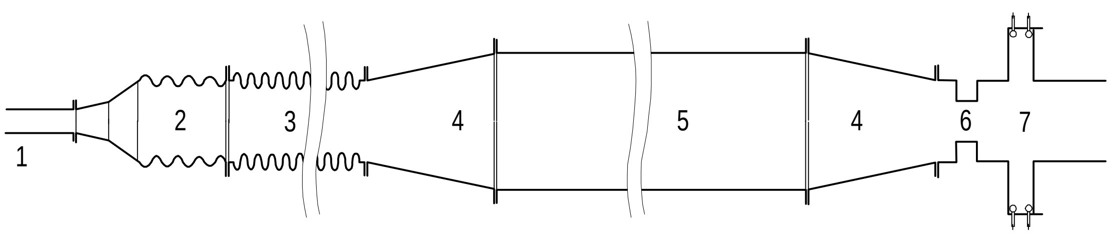

Fig.1. Schematic diagram of the Active Bragg Compressor operating in the TE_{01} mode: 1 - input waveguide, 2 - TE_{01}-mode converter, 3 - input Bragg reflector, 4 - smooth tapered transition, 5 - storage cavity, 6 - over-critical narrowing of the waveguide, 7 - output reflector with electrically controlled gas discharge switches.

The scheme of the compressor is shown in Fig.1. The compressor consists of mode converters ($TE_{01} \rightarrow TE_{11}^{o}$, $TE_{11}^{o} \rightarrow TE_{01}^{o}$) connected with smooth tapered transitions and a resonator formed by a Bragg reflector, a section of a cylindrical waveguide and an output reflector. The central part of the resonator is a section of an over-sized 1m long waveguide 80 mm in diameter which is equipped with a tapered 400 mm long transition to a narrower waveguide. The diameter of the latter waveguide was 55 mm, and the TE_{01} mode is the only propagating mode of all the axially symmetric ones.

* Supported by the U. S. Department of Energy, Division of High Energy Physics.

The output reflector consists of the active and passive sections. The active section is based on a step-wise widening of a circular waveguide. This stepped widening section comprises a cylindrical TE_{311} mode resonator containing a quartz ring-shaped gas-discharge tube. The discharge tube is used to switch in about 10 nsec from the regime of energy storage to the regime of energy extraction. The diameter of the wider waveguide is 140 mm, and it can excite high order axially symmetric modes. The passive section is a waveguide section with a narrowing beyond cutoff. This combined output reflector makes it possible to reduce the intensity of the electric field in the region of the gas-discharge tubes in the active section. By changing dimensions of the cutoff waveguide narrowing in the passive reflector section, one can change the transmission coefficient and, thus, control the amplitude and duration of the compressed pulse. ABC is evacuated via three pumping ports. The compressor was tested for vacuum. It was evacuated up to the pressure 10^{-6} Torr.

Specified characteristics of the TE_{01} mode compressor

Input pulse duration	2.1 μs
Output pulse duration	100 ns
Power amplification	17
Compression efficiency	60%
Inherent Q-factor of the whole resonator	150000
Specified load Q-factor provided by the input Bragg-type reflector with power reflection coefficient 98.5%.	56000

3 LOW POWER TEST MEASUREMENTS

The compressor was tuned in two stages. Initially the output reflector was adjusted in such a way as to provide a match of the maximum non-transmission and in the operating frequency of the compressor. Then, by changing the length of the cylindrical waveguide, the resonator was tuned precisely to the frequency of f_0 = 11.424 GHz at the minimum of the compressor-reflected signal. When a high-voltage pulse was fed in, the microwave power stored in the resonator was discharged from the resonator in the TE_{01}^{o} operating mode.

The efficiency of pulse compression was optimized by changing the length of the step-wise widening of the waveguide. The measurements were performed when the resonator was excited in the CW regime. A characteristic oscillogram of the compressed pulse is shown in Fig. 2. The compression coefficient was determined by the ratio of the peak power of the compressed pulse, P_p to the power P_0 at the compressor input. The compression coefficients obtained in the experiment amounted to k = 11-12 at a half-width pulse duration of τ_p = 45-55 ns.

Based on the experimental data, compressor efficiency in the pulse excitation regime was found. According to [4] energy accumulation in the resonator is described by the following expression:

$$W(t) = W_0[1 - \exp(-t/2\tau)]^2$$

where $W_0 = (4\beta/(1+\beta))P_0\tau$ is the energy accumulated in the resonator in the stationary state, $\beta=Q_0/Q_e$ is the coefficient of resonator coupling with the input aperture, Q_0 and Q_e are the inherent Q-factor of the resonator and Q-factor of the coupling, $\tau = Q_L/\omega$ is characteristic time of excitation of the loaded resonator with $Q_L = Q_0Q_e/(Q_0 + Q_e)$. Total efficiency of pulse compression in the compressor, η, is determined by expression

$$\eta = \eta_1\eta_2$$

where $\eta_1 = W_p/W_0$ is the efficiency of transmission of the accumulated power to the load, $W_p = \int P_p(t)\,dt$ is energy in the compressed pulse, $\eta_2 = W(t)/W_i$ is efficiency of power accumulation in the resonator, and $W_i = P_0 t$ is energy at the compressor input at time moment t. The value of τ required for efficiency determination was found by measuring the loaded Q-factor of the resonator. According to these measurements $Q_L = 2.3\cdot10^4$ and τ = 300 ns. The value of β determined in the experiment was 2.2.

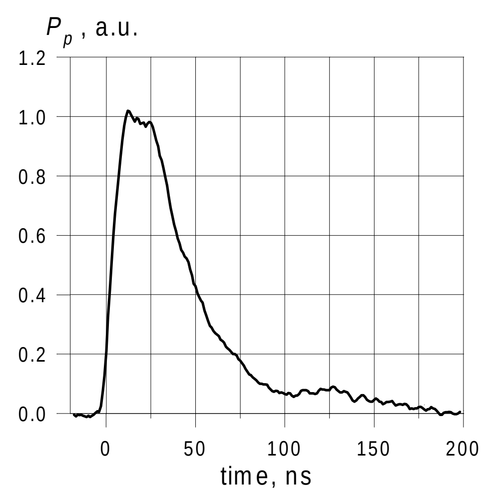

Fig.2 Envelope of compressed microwave pulse.

Efficiency of pulse compression calculated from the experimental data for cases of resonator fed with pulses of different duration is shown in Fig. 3. The same figure shows the curve for efficiency of power accumulation (upper curve) in the resonator. It is seen from the figure that when pumping pulses with a duration of 1 μs are used, the total compression efficiency will be 50%. This efficiency proved to be somewhat lower than the value of efficiency of power accumulation η_2, because of energy losses in the Bragg reflector. These losses can be eliminated by using the scheme of compressor excitation by means of a 3-db coupler with a common power input-output element.

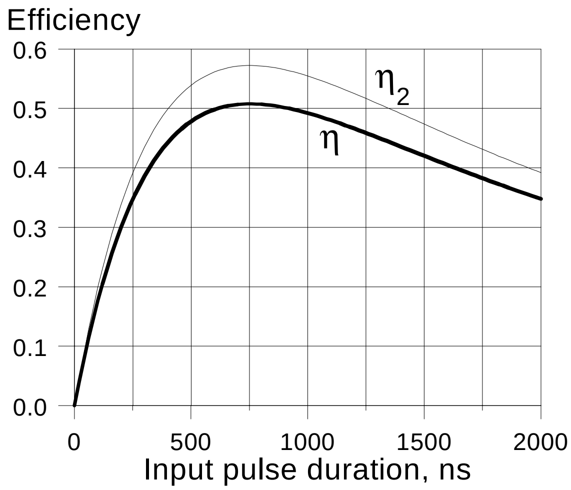

Fig.3 Total efficiency (η) and energy storage efficiency(η_2) vs input pulse duration.

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