POWERFUL 30-GHz JINR-IAP FEM: RECENT RESULTS, PROSPECTS AND APPLICATIONS*

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Abstract

The paper is devoted to progress in development and application of the JINR-IAP FEM. This Bragg FEM generates 30 GHz / 20 MW / 200 ns pulses at a repetition rate of 1 Hz. A test facility to study surface heating effects in a special copper cavity, which is modeled on a high-Q accelerating structure, has been constructed based on the FEM source. Investigation of the cavity heating stress was performed with a pulse temperature rise of 200 - 220 °C in a sequence of ~ $6\cdot10^4$ pulses.

To advance the FEM into sub-mm wavelengths, a novel operation of Bragg resonator based on coupling of propagating and quasi-cutoff modes was proposed. Results of the proof-of-principle experiment are discussed.

OPERATION OF 30-GHz JINR-IAP FEM

The JINR-IAP FEM-oscillator was elaborated during the last few years. A schematic diagram of the FEM is shown in Fig.1. The induction linac LIU-3000 (JINR), which generates a 0.8 MeV / 200 A / 250 ns electron beam with a repetition rate of 1 Hz, drives the FEM-oscillator. Transverse velocity in the magnetically guided beam is pumped in a helical wiggler of 6 cm period. One of the main advantages of this FEM is the use of a reversed guide field [1, 2], which provides high-quality beam formation in the tapered wiggler section with a low sensitivity to the initial beam spread. Another main advantage is the use of a Bragg resonator having a step of phase of corrugation [3, 4], that provides high electrodynamical mode selection. As a result, stable single-mode operation with high electron efficiency was achieved in the FEM [5]. At the present stage the FEM generates 20 MW / 200 ns pulses at 30 GHz with the spectrum width of up to 6 MHz, which is close to the theoretical limit.

STUDY OF COPPER HEATING STRESS

The parameters achieved allow the FEM to be used in several applications. The test facility to study surface heating effects at 30 GHz was constructed based on the FEM source [6]. Information about the lifetime of the accelerating structures is important to design components for the next generation colliders [7, 8].

The experimental set-up is shown in Fig.2 and includes a two-mirror confocal transmission line and mode converters to transport the RF-power from the FEM to the test cavity. A special copper cavity ("test cavity") operating with $TE_{0,1,1}$ mode and having a Q-factor ~ 1500 was designed to model temperature regime in a high-Q accelerating structure of the CLIC (CERN) project. The profile of the cavity surface was optimized to enhance the RF magnetic field in a certain zone and provide the required temperature rise during each RF-pulse. The resonant frequency of the cavities is also mechanically tuned to coincide with the frequency of the FEM source. A directional coupler is included to measure both the incident and reflected powers. After a certain number of

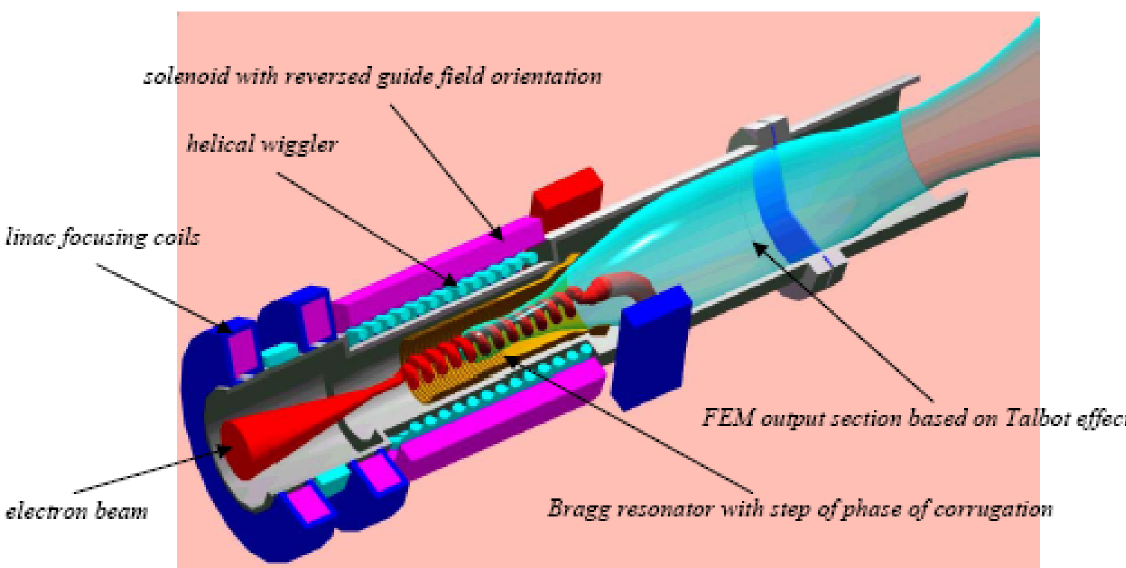

Figure 1: Schematic diagram of the JINR-IAP FEM.

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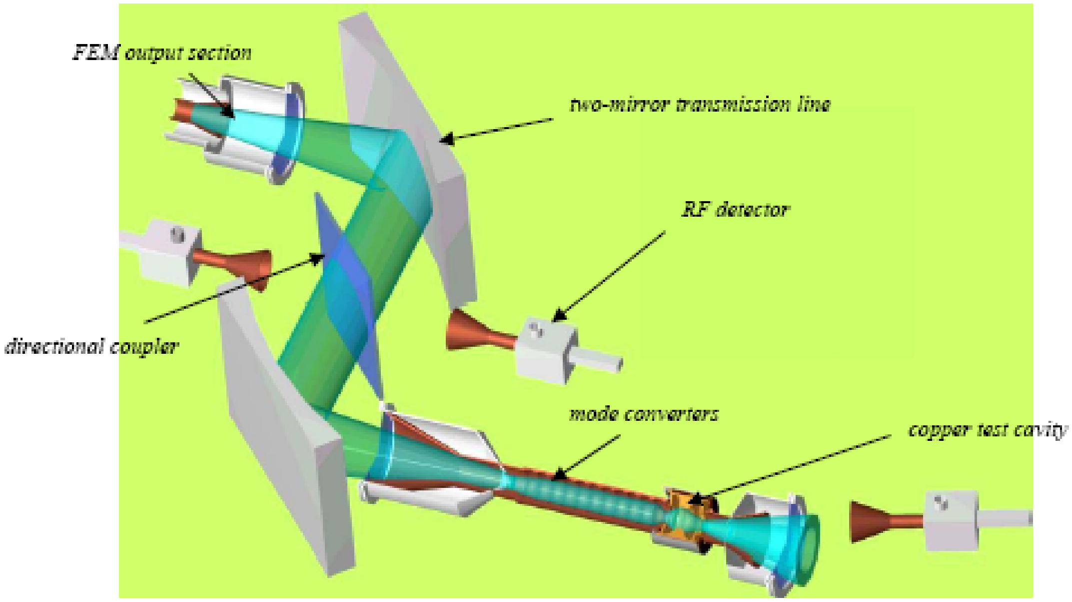


Figure 2: Schematic diagram of the test facility for studying surface heating effects based on JINR-IAP FEM.

pulses the Q-factor of the cavity is monitored using anetwork analyzer to detect early signs of surface damage.

Results of the experiments proved ability of the FEM to be used for the aforementioned application. “Cold” and “hot” tests of all components of the experimental set up demonstrated good agreement with designed parameters. Results of the FEM operation at the high-Q load are shown in Fig.3. When frequency of the test-cavity was tuned to the FEM generation frequency it was observed that during the RF-pulse the reflected signal decreased and the test-cavity became transparent. As a result, accumulation of the RF-power in the load was achieved. The statistical distributions of pulse duration and RF-power after the test cavity, which was measured by a calorimeter, are shown in Fig.4.

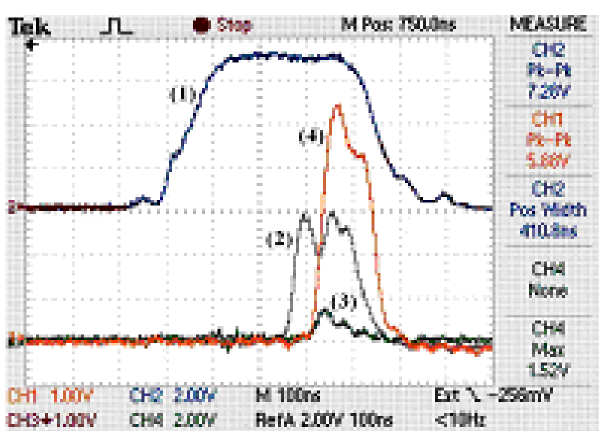
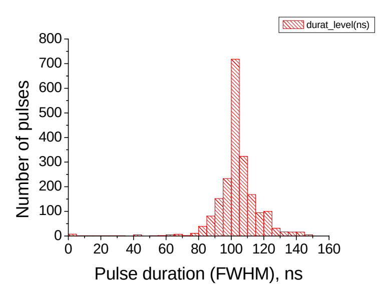


Figure 3: Results of experimental studies of the FEM operating at the test resonator: oscilloscope traces of (1) beam current at the FEM entrance (60 A / div.), (2) RF-pulse radiated from the FEM (5 MW / div.), (3) RF-pulse reflected from the test resonator (15 MW / div.) and (4) RF-pulse passed through the test resonator (0.5 MW / div.); time scale is 100 ns / div.

In this experiment the test cavity was designed to provide a temperature rise of up to 240 °C during each pulse in various regions of its inner surface. Photographs of the surface of the test cavity after irradiation with $6{\cdot}10^4$ pulses are given in Fig.5, together with the calculated distribution of the temperature rise during each pulse. Enlarged views for two zones with a temperature rise of 240 °C and 150 °C are also shown in the right column. It is seen that for a given number of pulses degradation of the surface was observed when the temperature rise exceeded 160 °C. After $6.3{\cdot}10^4$ pulses the destructions in the central part of test resonator resulted in appearance of the surface RF-breakdown.



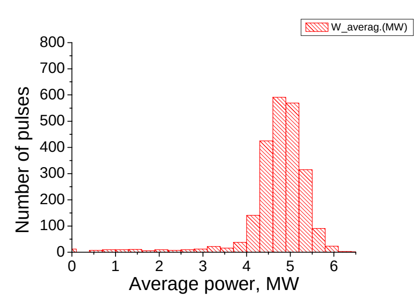


Figure 4: Statistic distributions of pulse duration and RF-power after the test cavity in the series of 10^4 pulses.

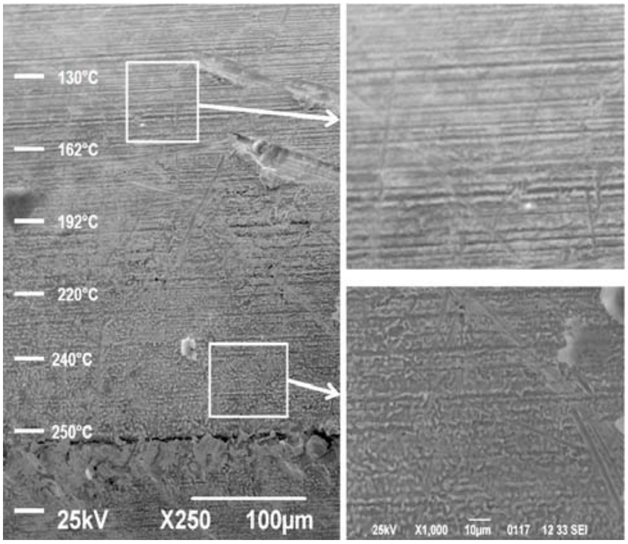


Figure 5: Photograph of the central part of test cavity after irradiation of $6 \cdot 10^4$ 30-GHz pulses.

BRAGG FEM WITH QUASI-CUTOFF FEEDBACK WAVE

Many possible applications of the FEM require shortening the radiation wavelength. However traditional Bragg resonators, which operate via coupling of two counter propagating waves with rather high group velocity [3, 4], lose their selectivity with the increase of oversize parameter. To solve this problem, a novel type of Bragg structure (advanced Bragg structure) based on coupling of propagating and quasi-cutoff waves [9] can be used. In this scheme a beam of wiggling electrons interacts with a propagating wave, but the latter is coupled at the Bragg corrugation with a quasi cut-off mode trapped inside the cavity. The trapped mode provides the feedback mechanism leading to the self-excitation of the whole system while, in steady-state, the efficiency is almost completely determined by the interaction with the propagating wave, synchronous to the beam. The main advantage of the novel FEM scheme is provision of higher selectivity over transverse mode index than traditional schemes of Bragg FEM. To decrease the Ohmic losses associated with excitation of a cut-off mode it is reasonable to use a two-mirror scheme of the resonator with the up-stream Bragg reflector based on excitation of quasi-cutoff feedback mode and conventional Bragg reflector with rather small reflectivity as a down-stream reflector [10].

A prove-of-principle experiment using the novel FEM scheme was performed at the accelerator LIU-3000. The two-mirror Bragg resonator was constructed with a regular section of radius of 8.47 mm and length of about 40 cm. The up-stream Bragg reflector was 20 cm long and had an axial-symmetric corrugation with a period of 10.6 mm and a depth of 0.5 mm. This corrugation provided coupling of two counter-propagating $H_{1,1}$ waves and quasi-cutoff $H_{1,2}$ wave in the vicinity of 30 GHz. Results of "cold" tests are shown in Fig.6a and demonstrate a very narrow reflection zone near the operation frequency. The traditional down-stream Bragg structure with a length of 10 cm and a period of 5.3 mm reflects the incident $H_{1,1}$ wave (operating wave) into a backward propagating $H_{1,1}$ wave. This Bragg mirror provides reflection over a much wider frequency range (Fig.6b) compared to the advanced Bragg mirror (Fig.6a). It should be noted that the period of advanced Bragg reflector is two time longer than the period of traditional Bragg reflector.

Results of first operation of the FEM using the novel feedback mechanism are shown in Fig.7. Stable single-mode operation at a frequency of 30.1 GHz was observed. The measured output power was about 10 MW. It is important that oscillation at this mode was obtained at any wiggler fields from the zone of self-excitation. At the same time these experiments demonstrated that the oscillation frequency depended on the cavity temperature: increase of the system temperature during its hour operation lead to the oscillation frequency shift of about 50 MHz.

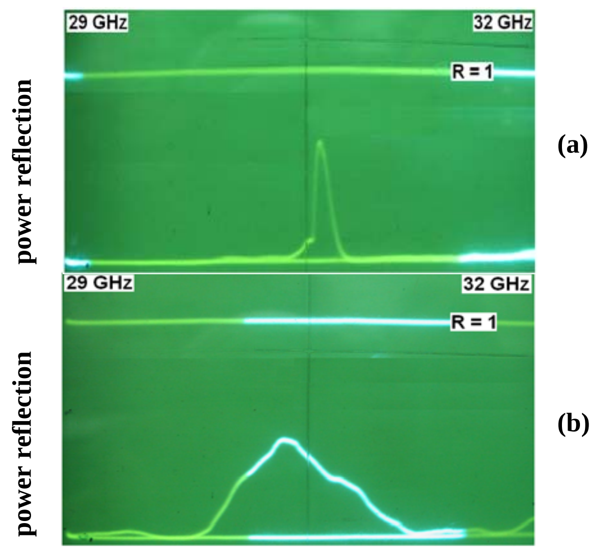


Figure 6: Results of "cold" tests of advanced (a) and traditional (b) Bragg reflectors.

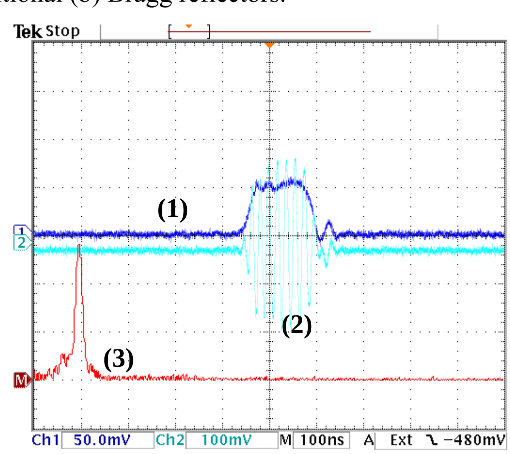


Figure 7: Typical oscilloscope traces of (1) RF-pulse (100 ns / div.), (2) heterodyne beating signal and (3) frequency spectrum (50 MHz / div.).

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