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THE EXPERIENCE OF BIG PULSED CURRENT ACCELERATION ON THE LINAC I-2

by

I. M. Kapchynskij, V. A. Batalin, N. V. Lasarev, V. I. Bobylev,
E. N. Daniltsev, L. V. Kartsev, A. M. Kosodaev, A. A. Kolomiets,
V. V. Koloskov, B. K. Kondratiev, R. P. Khoujbida and V. I. Edemskij

Institute of Theoretical and Experimental Physics
Moscow, USSR

ABSTRACT

Information is given about the operation of the linear accelerator I-2 injector of the ITEP proton synchrotron. The accelerated beam intensity is increased now up to 200 mA. Beam parameters, when big proton current is accelerated, are given; the operating conditions of the rf cavities are discussed under the acceleration of an intense beam.

Some additional devices were put into operation. Among their number: preinjector modulator charging voltage stabilizer and apparatus for proton beam ejecting in the atmosphere during the pauses between main injection pulses in the synchrotron.

The linear accelerator I-2 has been operating as an injector of the ITEP PS for about six years. The average yearly output quota for the PS is about 5000 hours. Concurrently, some physical and chemical investigations are carried out with the proton beam ejected from the linac into the atmosphere. The average value of every day beam current was about 80-90 mA up to the middle of 1971. As a result of a reconstruction of the matching channel (the focusing channel between the preinjector and the linac), the accelerated beam current has been successfully increased up to 200 mA. Every day current was raised to the level of 160-170 mA. In 1971, the linac was equipped with apparatus which gave the possibility of ejecting the accelerated beam into the atmosphere during the pauses between main injection pulses to the synchrotron.

The reconstruction of the matching channel was undertaken after discovering the fact that an increase of the preinjector current over 400 mA did not raise the value of the linac beam current. The structures of the old and improved matching channels are shown in Fig. 1. The old matching channel consisted of six quadrupole doublets with 40 mm apertures. Four of them were dismounted and the aperture at these locations was increased to 90 mm. Two pulse solenoids were installed instead of these doublets, but as the preinjector optics were able to handle the transport to the linac, there has as yet been no necessity to use the solenoids. Two retained doublets are used for beam matching with the linac. Beam drift through the channel was observed by beam transformers, BT1 and BT2, at the inlet of the channel, BT3 after 1/3 of the whole length of the channel, and BT4 at the entrance of the linac directly.

Figure 2 shows how the beam passes through the matching channel. (The subscripts on the currents correspond to the beam transformer pickups on Fig. 1.) With the old channel, it is clear from the curves I that beam passing through the first third of the matching channel got worse for currents greater than 400 mA. The behaviour of the beam in the remaining part of the channel was still worse.

The top current at the end of the channel does not exceed the value of 200 mA, and after the linac, 110 mA. These data for the improved channel (curves II, Fig. 2) show that beam passing through the first third of the channel practically does not depend upon the current values. Drift through the following part of the channel also improved, but the reduction of the curve shows that under 500 mA, more protons are dissipated on the section with 40 mm diameter and at the linac entrance. It must be noted that correlation of accelerated and injected currents (Fig. 2c) shows that Coulomb limitation is not yet reached. This is in agreement with theoretical predictions.[1]

The acceleration of currents of 180-190 mA with pulse duration of 25 μsec is being realized by rf energy stored in the resonators. Because of beam loading, the accelerated field level decreases, but the initial amplitude can be raised to such values, that during the beam pulse the field level is approximately correct. The accelerated beam shape is shown on Fig. 3c. Some part of the energy delivered to the beam may be compensated by the power amplifiers. The experiments showed that, by selecting the proper point of the load characteristic, it is possible under the existing system of feeding the resonators to relax the effect of beam loading to the end of the pulse, but not by more than 5-10% of the total amplitude of the field droop.

Considerable accelerating field droop brings an appreciable synchronous phase shift and, hence, to the initiation of a longitudinal phase oscillation. Experimental data for a beam current of 170 mA are shown in the Fig. 3a. It is noticeable that changes of synchronous phase are rather big and different in the first and second resonators. This fact causes corresponding displacement of the energy spectrum of the accelerated protons. The experimental study of longitudinal oscillations was carried out by the fixed-tuned spectrometer method,[2] allowing values of the rf field parameters to be found at which the above-mentioned spectrum changes became the smallest. Field levels were chosen in such a way that in the middle part of the beam pulse (approximately at the tenth microsecond), 2.5 phase oscillations should have gone into the length of the first resonator ($\phi s = 44°$), and 1.5 ($\phi s = 31°$) into the second. The average momentum and the half-width of the spectrum during the 170 mA beam pulse is shown in Fig. 3b.

Accelerated field amplitudes are constantly measured in every resonator by means of three pick-up loops distributed along the resonators. This gives the possibility of studying the rf field distribution. Comparison of accelerating field droops measured by different loops showed that the field distribution in the resonators is being changed under the acceleration of big beam currents (Fig. 4).

The linac I-2 gives pulses for the PS with interchanging pauses of 0.8 and 3.2 sec, though all systems can easily operate with an average frequency of about 1 pulse per second and beam pulse duration from 3 to 50 microseconds. So, there is the potential possibility of using the linac for experiments with 24 or 6 MeV proton beams apart from the work for the PS. Manufacture of a number of electromagnetic devices and creation of a second channel for ejecting the accelerated beam are required to realize this possibility. The dc bending magnet (Fig. 5) deflects the linac beam to the PS injecting channel. The second channel is situated on the linac axis continuation. For directing the accelerated beam into the second channel, the magnetic field of the dc bending magnet is compensated by the pulsed field of a special six-turn loop placed in slits in the pole tips inside the vacuum chamber. When the analysing magnet is switched off, the beam drifts to the direct channel equipped with pulse quadrupole lenses and steering magnets. The lenses have no visible poles; their magnetic circuits are made of ferrite rings. The steering magnet core is formed of transformer iron. The beam passes into the atmosphere through a 0.3 mm aluminum foil.

The pulsed electromagnetic devices are fed from current-pulse generators. Half of the resonance period of capacitor discharge is used for shaping of the current pulses. The duration of a half period is chosen to be about one millisecond, because of the required field stability during the beam pulse. As discharge devices, thyristors are used in multiple-series connection. The current amplitudes in the lenses and steering magnet coils can reach 1000 A. The dc magnetic field compensation results from a loop current of 17.1 kA. The stability of the residual field in the bending magnet gap is a result of the parameters of dc and pulse circuits and is equal to 0.07%. Under combined work of the linac, it is necessary to shape the starting pulses for the second channel devices and linac, so as not to interfere with the work of the PS. This is performed by a specially designed timer. Such combined operation of the linac began in October 1971. Beam losses following the bending magnet under pulse loop operation do not exceed 10%; beam current in the atmosphere, more than 100 mA. The second channel is regularly used for experiments.

References

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3. V. I. Bobylev, N. V. Lazarev, A. M. Kozodaev and others, Prib. Tekh. Eksp., No. 4, p. 103, 1972.

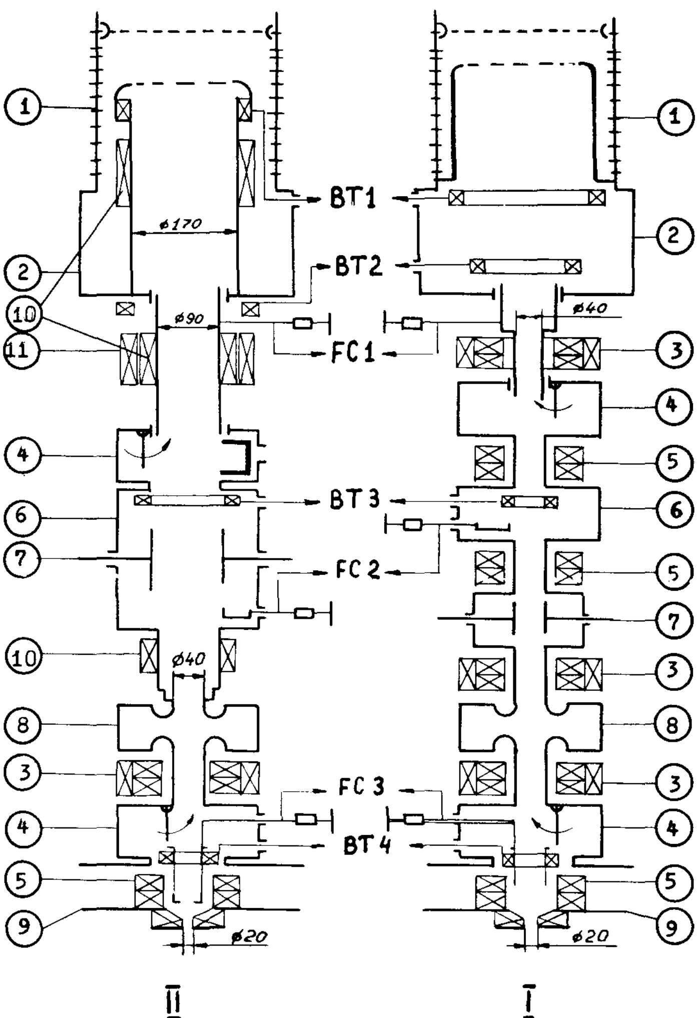


Fig. 1. Structures of old (I) and improved (II) matching channels. BT, beam transformers; FC, Faraday cups; 1, accelerating column; 2, vacuum chamber; 3, quadrupole doublet, 2 ML-25, with steering magnet; 4, vacuum shut-off; 5, doublet, 2ML-25; 6, observation station; 7, deflecting plates; 8, buncher; 9, linac; 10, solenoid; 11, steering magnet.

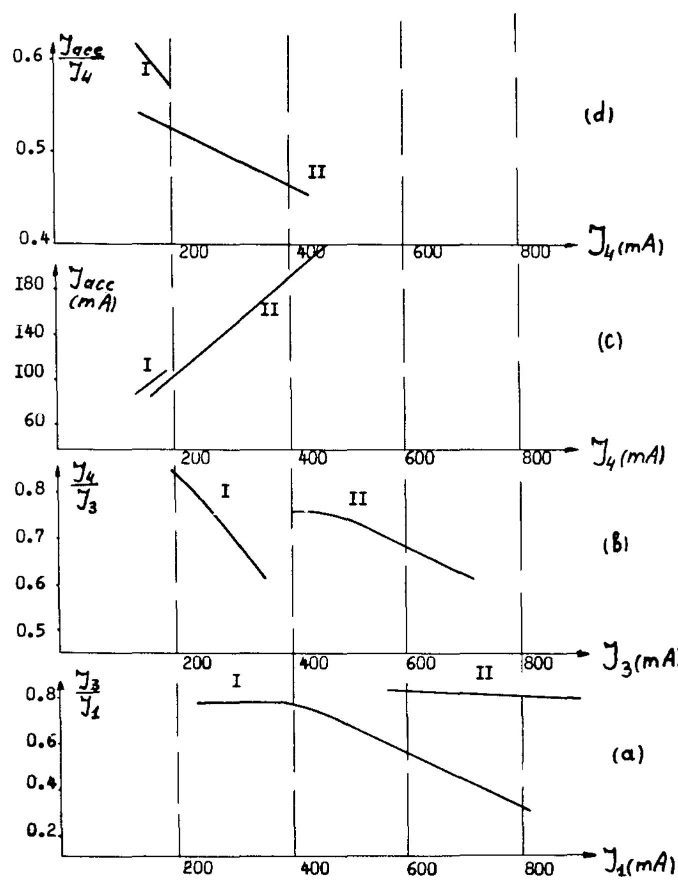
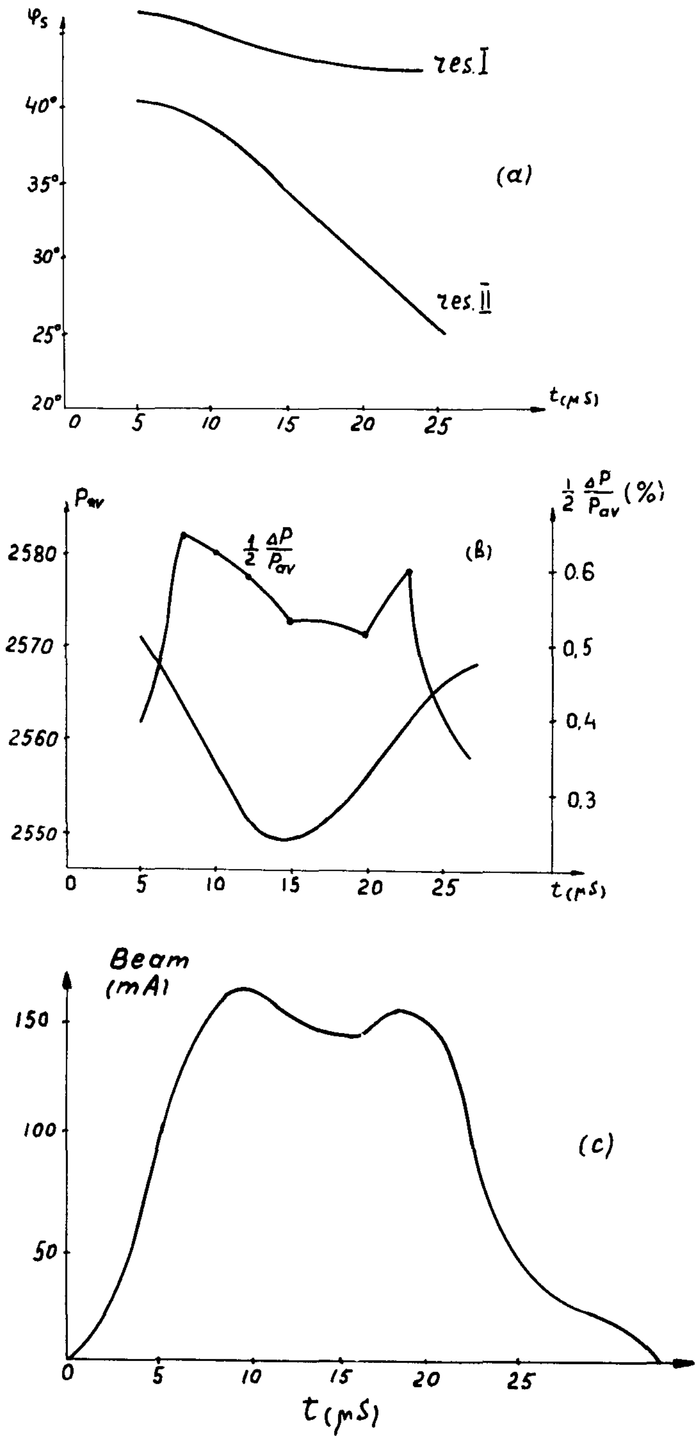


Fig. 2. Beam passing through the matching channel.



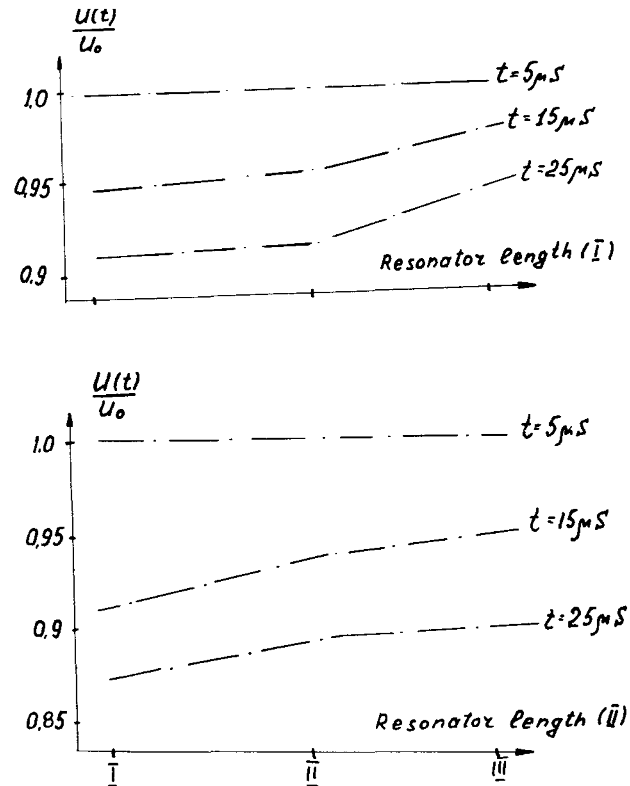


Fig. 4. Field distribution in the resonators under acceleration of the big beam.

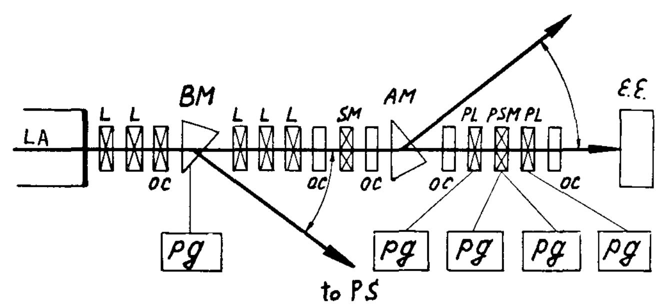


Fig. 5. Beam transport system and the second channel equipment: LA, linac; L, lenses; OS, observation stations; BM, bending magnet; SM, steering magnets; AM, analyzing magnet; PG, pulse generators; PL, pulse lenses; PSM, pulse steering magnets; EE, experimental equipment.

Figs. 3a, b, c. Linac and beam parameters during the pulse.
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DISCUSSION

Sluyters, BNL: If I understand your first graph, your column delivers 800 mA with 600 mA just before beam transformer 4. I calculate that you have injected 420 mA into your linac to obtain 200 mA of accelerated beam, yielding a capture efficiency of 50%. Is this right?

Bobylev: Yes, this is right.

Sluyters: Under these conditions, what is the emittance of the injected beam compared with the ejected beam?

Bobylev: These measurements are just now being completed and are too fresh to be published.

Sluyters: Is it true that you have a 400-mA beam loss between your column and the linac?

Bobylev: Yes, this occurs in the last third of our focussing channel where the aperture of our quadrupole doublets is 40 mm. Here the main part of the current is lost and this is the problem for the next stage of our construction.

Curtis, NAL: Can you describe your method for measuring the emittance?

Bobylev: This method is described in our magazine, "Apparatus and Techniques of Experiments." The principle of these measurements involves sweeping the beam across two slits.