Proton Beam Separation for Simultaneous Operation of Two Installations at the INR Linear Accelerator

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In order to use efficiently a proton beam from the linear accelerator of the MMF an installation based on a pulsed magnet has been performed allowing dividing the proton beam between the experimental hall and the isotopic production facility. This configuration will allow increasing the measuring times on the MMF experimental installations up to 2000 hours per year parallel to the export program of the metastable isotopes production.

The linear accelerator of protons of the INR of the Russian Academy of Sciences is being improved in order to expend the experimental reach [1, 2]. Now it is planned to use one of the three existing installation in the experimental building (RADEKS (Fig.1), IN-06 and SVZ-100) in parallel with the export program of the metastable isotopes production at the isotope complex. This modernization will allow increasing an annual operating time of the pulse neutron sources up to 2000 hours per year.

Fig.1. *The neutron source RADEX, the 50 m flight path.*

Partition of a proton beam is made by a pulsed magnet pro ducted with a participation of the NIIEFA (St. Petersburg). This magnet is installed at the "160 MeV" (Fig. 2) channel of the proton transportation beam.

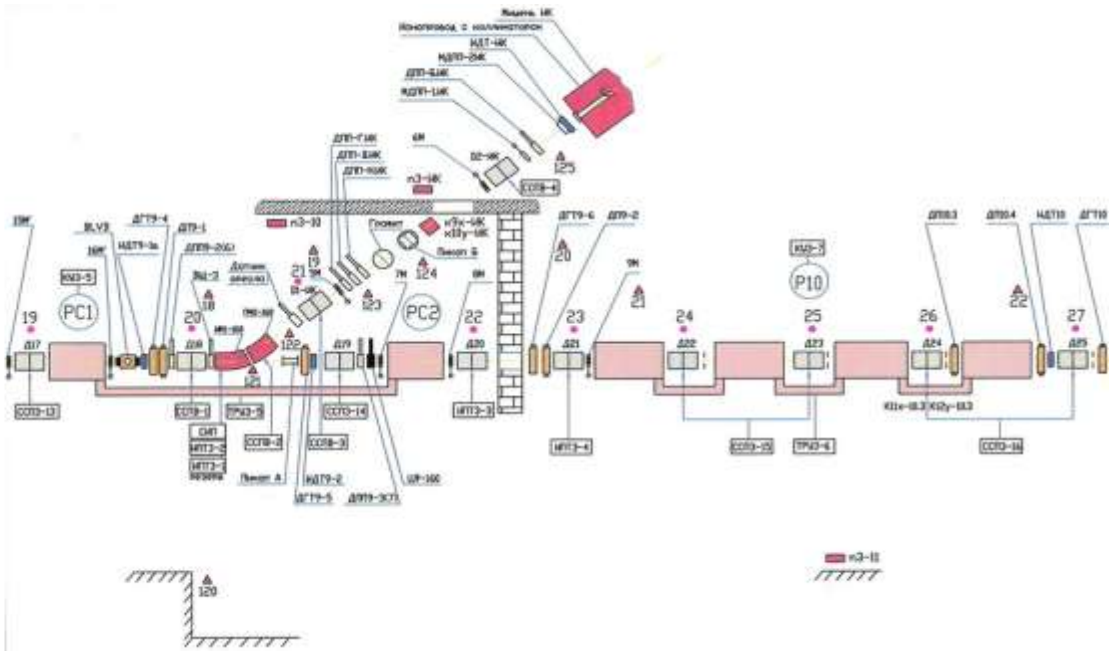

Fig.2. *The experimental scheme with the pulsed magnet. Protons are accelerated from left to right.*

The pulsed magnet deviates protons to the target of an isotope complex with a start frequency of ***f*.** The initial part of accelerator gives proton pulses with a frequency of f_0. The pulses, corresponding to a difference between a start frequency of an initial part of the accelerator and the pulsed magnet, passing a magnet at a zero magnetic field induction, come at the RADEX target with a frequency of (f_0-f).

Possible modes of a proton beam division are shown in the Table 1.

Table 1. Modes of a proton beam distribution.

Mode of a proton beam division	Initial part of the accelerator f_0, Hz	Pulsed magnet and target of the isotope complex f, Hz	Neutron source RADEX (f_0-f), Hz
№1	50	40	10
№2	50	25	25
№3	100	50	50

Modes No. 1 and No. 2 at the proton energy of 143 MeV do not require any additional expenses connected with the charge of triodes and klystrons, and power consumption increases to 140.000 kW*h per day out of which 74% is caused by the isotope production.

The mode No. 1 the pulsed magnet works at frequency of 50 Hz as blocks of 4 pulses with a pause at every fifth pulse. The obvious advantage of this mode is that the maximum heat-conducting power from the licensed export rubidium-82 target corresponds to an average current of 120 μA at the energy of 143 MeV. Considering available reserves of increasing of the pulsed current (Fig. 3) and a duration of the proton pulse, this current can be achieved at a frequency of 40 Hz. This fact allows using other 10 Hz at the experimental complex.

The mode No. 3 is considered in perspective as the primary operation mode. For its realization it is necessary to carry out the improvement of the HF accelerator systems for overcoming amplitude instability doubling effect of the accelerating field in the RF cavities.

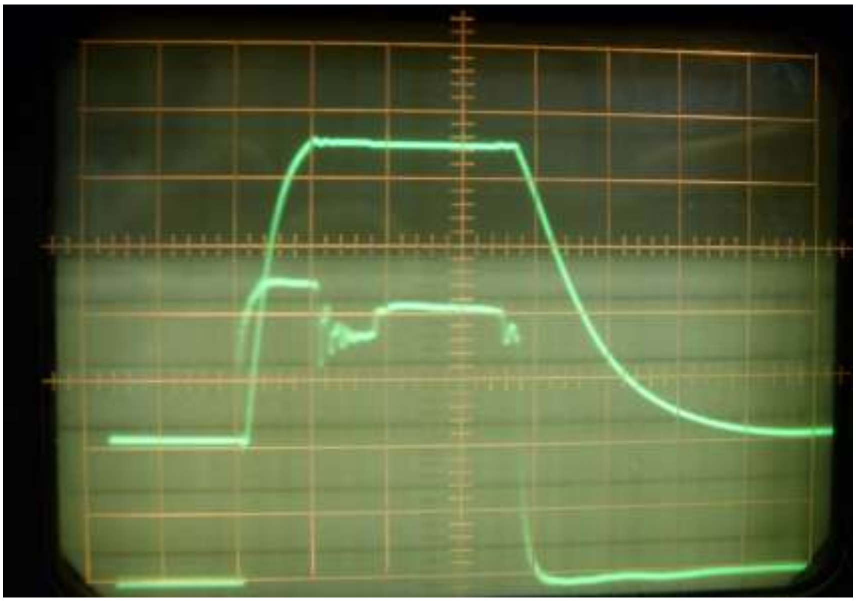

Fig. 3. *Top curve corresponds to the measured signal of the Alvarez accelerating resonator of the accelerator initial part. The stabilized area of accelerating field is 260 μs. The bottom signal is a pulse of RF amplifier's anode modulator. Increase of amplitude at the last 200 μs compensates RF accelerating field stability during appearance of proton beam in the resonator. Scale is 100 μs per division.*

As can be seen from the Figure 3, the anode modulator of the final amplifier cascade comes on in the initial time moment on the maximal power (the bottom curve), field in accelerating resonator (the top curve) exponentially grows. At 120 μs it reaches a nominal power RF field level, the automatic regulator of phases and amplitudes (ARPA) reduces power of the amplifier and field in the resonator is supported at a stable level. The proton beam is injected after in 180 μs from the start of a pulse. In order to avoid depression of the field in each accelerating resonator, the ARPA system increases power of the amplifier. The accelerating field is supported at a stable level with deviations of less than 0.5 %. As the second rectangular emission on the bottom curve of the Figure 3 is caused by a proton beam, there is undoubted existence of reserves both in the proton pulse duration and in the amplifier power which allows increasing pulsed proton beam current.

Now the pulsed magnet is made and installed in the accelerator tunnel (Fig. 4) on the proton beam line. The glass part of the vacuum transportation channel, mounted between magnet poles, has proved the functionality, including thermo-mechanical loadings during casual proton beam deviations to the walls of the chamber.

A target of the isotope complex is placed behind a wall of the tunnel, at a distance of 12 m after leftward beam rotation to 27 degrees. At a zero magnetic field induction of the pulsed magnet proton beam passes (Fig. 4) forward and is transported to installations of the experimental complex.

It is necessary to mention that a certain progress in a problem of RF power input into accelerating cavities of an initial part of the accelerator is outlined (Fig. 5). Preliminary cascades of the amplifier are transferred onto triodes GI-57A (Fig. 6) which are still manufactured by the Russian industry in contrast to triodes GI-51A. The success was achieved in spite of the maximal work frequency of 175 MHz (GI-57A) indicated in the technical passport.

Fig. 4. *Location of the pulsed rotary magnet (with electric isolation of poles) at the"160 MeV" part of the proton beam channel.*

Fig.5. *Initial part of the accelerator (f =198.2 MHz). A total length of the Alvarez resonators is 70 m.*

Fig.6. *Electric vacuum lamps of preliminary amplifier cascade at the initial part of the accelerator. On the left side the old triode GI-51A is shown, on the right side new triode GI-57A is placed. (P= 300 kW, f=198.2 MHz).*

Exit cascades of the RF amplifier in accordance to the technical project were made at the metal - ceramic triodes GI-54A with pulsed RF power of 5 MW. The GI-54A has complicated cell design of a grid flange and now is taken out of production. Instead of them, triode GI-71A (Fig. 7) with a pulsed power of 3 MW has been produced, tested and licensed. At the moment four amplifier cavities out of 7 are already modified using this triode. The optimization of the anode volume resonator's design of the exit and preliminary cascades is now being carried out, with a purpose to shift breakdown occurrence in the anode amplifier volume cavities to higher level of the pulsed power.

Fig.7. *New metal-ceramic coaxial triode GI-71A of the exit RF amplifier cascade. (f=198.2 MHz, P=3 MW).*

Now pulsed current of 16 mA is used when the accelerator is serving on the target of the isotope complex. The activity for increasing of the pulsed current is realized at the injector, RF systems and other equipment. In the nearest future the pulsed current (see Tab.2) is expected at a level of 30 mA.

Table 2. Pulsed RF power, delivered into the resonators during acceleration of pulsed currents 10, 20 and 30 mA up to energy 160 Mev.

Cavity number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Frequency	198,2 МГц					991 МГц			
Proton energy,Mev	20	50	75	95	100	113	127	143	160
v/c	0,205	0,311	0,376	0,418	0,428	0,451	0,475	0,497	0,518
P_0, MW*	1,1	2,07	2,25	1,85	1,05	2,24	2,24	2,12	2,11
ΔU, Mev	20	30	25	20	5	13	14	16	17
P (10mA), MW	1,3	2,37	2,5	2,05	1,1	2,37	2,38	2,28	2,28
P (20 mA), MW	1,5	2,67	2,75	2,25	1,15	2,50	2,52	2,44	2,45
P (30 mA), MW	1,7	2,97	3,0	2,45	1,2	2,63	2,66	2,6	2,62

** At average RF power, which corresponds to temperature stabilization of accelerating cavities 25 ^0C*

At the first stage of the pulsed magnet commissioning, it is supposed to use at the experimental complex a proton beam (E=143 - 209 MeV, I =16 mA, t = 1 - 200 μs and f =10 Hz). It is planned to devote a main part of the additional measuring time to the RADEX [3, 4], which is situated on the straight line beam relative to the accelerator. In such conditions it is possible to provide more stable regime of the beam transportation and smaller pulsed current losses (resulting in the appearance of induced radioactivity).

It is also planned to serve the RADEX in two regimes: with a short pulse (1 μs) for nuclear physical tasks and with a long pulse (30 - 200 μs) for the experiments on condensed matter physics. Duration of a short pulse is limited by the synchronization system of accelerator start pulses, running at the frequency of 1 MHz, and also by a high-speed performance of the chopper installed in front of the resonator RFQ at the beginning of the accelerator.

The expected neutron intensity is equal to 10^{15} n/sec for pulse duration 200 μs and $5 \cdot 10^{12}$ n/s for pulse duration of 1 μs.

For nuclear physical tasks the optimal thickness of water moderator is 3 cm, at which the resonance neutron flux is maximal. For solid-state experiments this thickness is 6 cm. Due to combination of these tasks, it is planned to provide the RADEX with a replaceable moderator, and also a replaceable target ampoules with a variable thickness of tungsten plates according to the energy of incident protons in the range from 143 up to 500 MeV [5].

The construction of the experimental building is being realized on the 100 m flight path of the RADEX, consisting of two neutron guides. At the moderator temperature of 77 K (0,006 eV) cold neutrons pass the 100 m flight path during about 100 ms. Under the circumstances a maximal frequency of 10 Hz is limited by recycle neutrons background.

As to the fast and resonance neutrons, the resolution of 10 ns/m is enough to realize a wide range of experiments. Thus, as a result of the creation of the proton beam division system, the RADEX becomes the universal installation operating over 2000 h/year, both on physics of resonance neutrons, and on solid-state experiments. A possibility for carrying out experiments with cascade neutrons with the energy from 143 up to 209 MeV, and in perspective up to 500 MeV on the 100 m flight path of central neutron guide.

In conclusion, it should be noted, that during coming years it is planned to involve all length of the accelerating structure of the accelerator's main part (Fig. 8). The energy of protons will be increased up to 500 MeV in accordance with the new klystrons arrival.

Fig.8. *Basic part of the accelerator (f=991 MHz). The total length of the accelerating structure is 360 m.*

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