MULTIPURPOSE RESEARCH COMPLEX BASED ON THE INR HIGH INTENSITY PROTON LINAC

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Abstract

Scientific Complex based on 600 MeV Proton Linac is in operation at the Institute for Nuclear Research, Troitsk, Moscow and provides the beam for both basic and applied research. At present proton beam with the energy up to 209 MeV and with the average current up to 130 µA is used for three Neutron Sources and Beam Therapy Complex, located in the Experimental Area, as well as for Isotope Production Facility. The status of the Linac and the Experimental Area is presented. Accelerator tuning procedures providing minimization of beam loss are described as well.

INTRODUCTION

INR Accelerator Complex is located in science city Troitsk (Moscow) 20 kilometers to the south-west from Moscow circular road. It includes the high-intensity proton Linac, Experimental Area with three neutron sources and Beam Therapy Complex as well as Isotope Production Facility (IPF). Though the initial name of the Complex was Moscow Meson Factory in the recent years the main activity has been shifted towards neutron studies, isotope production and other researches connected with the above mentioned experimental facilities.

In nineties INR accelerator was the second large high intensity and medium energy linac after LANSCE (former LAMPF) at LANL, Los Alamos, USA. In the last decade two new linacs of this type with improved parameters have been put in operation (SNS and J-PARC) and several more ones are being constructed or designed now. This activity shows the urgency of the researches made at the accelerators of this type and confirms extreme topicality of the INR multi-purposes complex.

LINEAR ACCELERATOR

General Description and Parameters

The detail description of the INR proton Linac is given in [1, 2]. The simplified diagram of the accelerator is shown in Fig. 1. The accelerator consists of proton and H-minus injectors, low energy beam transport lines, 750 keV booster RFQ, 100 MeV drift tube linac (DTL) and 600 MeV coupled cavity linac (CCL, Disk and Washer accelerating structure). There are seven 198.2 MHz RF channels for five DTL tanks and RFQ (including one spare channel) as well as thirty two 991 MHz RF channels for 27 CCL accelerating cavities and one matching cavity (including three spare channels and one channel for equipment tests). Design, obtained and currently available operational Linac parameters are summarized in Table 1.

Table 1: Main accelerator parameters.

Parameter	Design	Obtained	September 2012
Particles	p, H-minus	p, H-minus	p
Energy, MeV	600	502	209
Pulse current, mA	50	16	15
Repetition rate, Hz	100	50	50
Pulse duration, µs	100	200	0.3÷200
Average current, µA	500	150	130

The accelerator is in regular operation since 1993. 102 accelerator runs with total duration of more than 38000 hours have been carried out so far including 63 runs of total duration of 18000 hours within the last decade. The availability of the beam for the users is 80÷90 % of the total beam time.

Main Current Goals

The main goal for the nearest future is improvement of accelerator efficiency. To attain this goal two problems have to be solved. The first one is increasing the beam pulse repetition rate from the current 50 Hz to 100 Hz. The second one is distribution of the beam between IPF and Experimental Facility. To double the beam pulse repetition rate the repetition rate of RF system pulses as well as that of proton injector must be doubled.

The activity on increasing RF pulses repetition rate is in progress for several years, but has been intensified recently [3]. The studies with the aim of increasing proton injector repetition rate are also being conducted. Completion of building of H-minus injector enabled a task to be formulated on simultaneous acceleration of proton and H-minus beams. It is supposed that two beams will be accelerated pulse by pulse each with the rate of 50 Hz.

With the aim of distributing the beam between IPF and Experimental Facility the intermediate beam extraction area (160 MeV) has been upgraded [4]. Instead of the first DC bending magnet (Fig.1) the pulse magnet along with the power supply developed and fabricated in D.V.Efremov Institute (St. Petersburg) [5] has been installed. The tests of the system including the tests with the beam have been done [4]. The maximum frequency of the magnet pulses is 50 Hz so the possibility to direct up to half of the beam pulses to IPF will be implemented.

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The pulses directed to the Experimental Area are positioned between the magnet pulses. The DC supply of the magnet is also foreseen thus enabling a full beam to be extracted to IPF.

To improve an ultimate beam current at IPF target the fast beam circular scan installation has been developed and is being fabricated. Scanning frequency equals to 5 kHz which corresponds to one full circle within the 200 µs beam pulse.

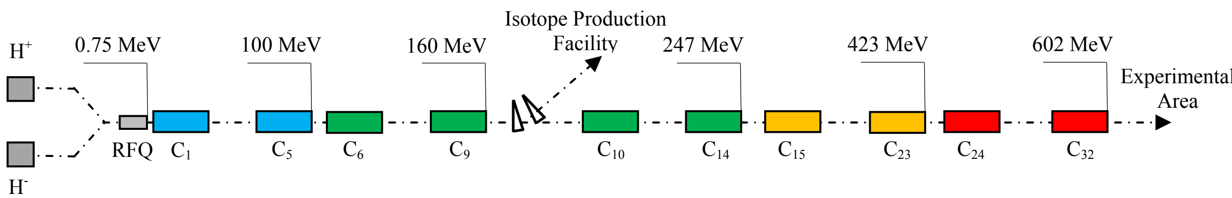

Figure 1: Simplified diagram of the accelerator ($C_1 \div C_{32}$ – accelerating cavities). The sectors of the accelerator are marked with different colors (five sectors totally).

One of the problem systems of the accelerator is RF system of DTL linac. The main problems are due to stopping production of grid tubes GI-51A and GI-54A for power amplifier as well as the modulator tube GMI-44A. The activity on replacement the tubes GI-51A and GI-54A by GI-57A and GI-71A correspondingly is in progress for several years. There were doubts if the tandem of two new tubes can provide sufficient RF power for the most powerful RF channel #2. However the doubts disappeared after the tests of the tandem in this channel during several runs of the accelerator [6]. Moreover the manufacturer of the tube GI-71A "S.E.D.-SPb" started its modernization with the aim to increase the gain. We hope that with the modernized tube the difficulties of obtaining higher RF power will become less severe. As for the modulator tube GMI-44A the manufacturer "S.E.D.-SPb" has started to develop a restoration technology. In case of positive result a possibility of restoration of big amount of used tubes in hand will arise.

Available amount of klystrons limited the maximum energy to 502 MeV within the course of accelerator commissioning (Table 1). Now the capabilities of industry to produce the klystrons enable to balance at the level of 209 MeV.

EXPERIMENTAL AREA

Experimental Area is shown in Fig. 2. All the equipment of experimental area is foreseen to work with the beam of 600 MeV but now the power supply system is restricted and enables to work with the energies up to 300 MeV. At present the following facilities are in operation: Spallation neutron source IN-06 with a number of multipurpose instruments, 100-ton spectrometer LNS-100 on slowing down in lead, RADEX facility (a modified beam stop) with neutron guides and stations for time-of-flight spectrometry, Beam Therapy Complex.

Simultaneously with building of H-minus injector the beam separation system was created in Experimental Area. The system is intended for separation of proton and H-minus beams and is based on Lambertson Septum Magnet [7]. When two beams are accelerated simultaneously the system enables to pass the proton beam directly to RADEX facility and to deflect H-minus beam towards Beam Therapy Complex. Formation of beam size is foreseen by inserting a strip foil with a proper central hole in front of the septum magnet. The recharged protons are directed to the beam stop. Recently the line to the Beam Therapy Complex has been equipped with a wedge-shape degrader. The particles lose the energy depending on wedge thickness thus providing fine energy adjustment within the range of 209÷70 MeV.

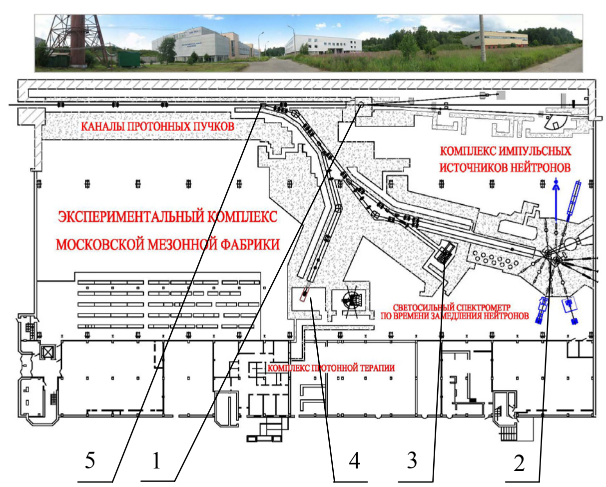

Figure 2: Experimental Area (1 - RADEX facility, 2 - Spallation neutron source IN-06, 3 - LNS-100 spectrometer, 4 – Beam Therapy Complex, 5 – beam separation area).

PECULIARITIES OF ACCELERATOR TUNING

The experience of accelerator operation showed that to implement a high beam intensity and low beam loss mode of operation definite tuning procedure have to be fulfilled. The procedures are related to longitudinal and transverse tuning. Normally the longitudinal tuning is done first.

Longitudinal Tuning

The base of longitudinal tuning is setting the design parameters of amplitudes and phases of RF fields in

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accelerating cavities. In DTL linac a phase scan procedure applied for the cavities in series is the main one. The RF phase of the cavity under the test is adjusted within a wide range and the current of the accelerated beam is measured downstream of the cavity. To separate the accelerated particles from non accelerated the degraders of proper thickness are used. In our linac we have one degrader installed at the exit of DTL linac with four plates in series. The thickness of the plates is selected in such a way that the signals from different plates correspond to the intensities of the beam accelerated in different cavities. As an example Fig.3 demonstrates a phase scan curve for the third DTL cavity. The width of the curve depends on the size of the bucket and hence on the amplitude of the accelerating RF field. It is implied that the amplitude is set to the nominal value when the width of the curve equals to the nominal one calculated preliminary. The phase is set to the nominal one by shifting from one of the curve edges by the preliminary calculated value.

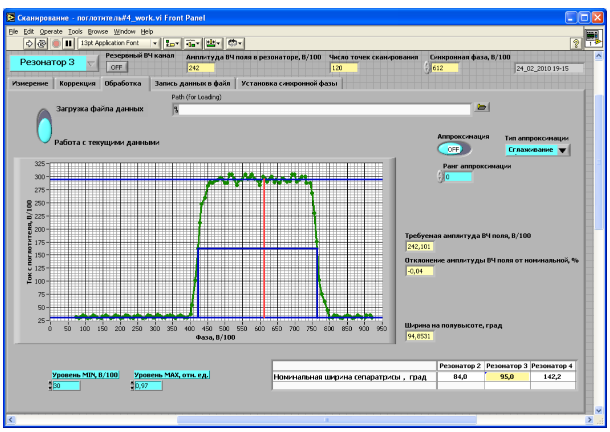

Figure 3: Phase scan results for DTL cavity #3.

To set the phase and the amplitude in the last DTL cavity #5 a dependence of phase difference of the signals induced by the beam in two beam current harmonic monitors installed at the entrance and at the exit of the cavity versus phase is measured (Fig. 4).

Vertical spread of the measured function univocally corresponds to the amplitude of RF field. The phase is set by shifting the phase by the calculated value with respect to the phase position of the vertical middle of the curve.

To check the overall stability of DTL linac the energy at the exit is measured with a time of flight method. Normally the errors can be effectively corrected by fine-tuning the phase of DTL cavity #5 thus compensating the energy errors.

To set the amplitudes and the phases in the cavities of CCL linac (above 100 MeV) the ΔT procedure is used [8,9]. In this procedure the changes of the time of flight through the tuned cavity (Δt_1) and through this cavity plus the subsequent switched off one (Δt_2) are measured when the tuned cavity is turned on and off. The measurements are done for different phases in the tuned cavity in the vicinity of the nominal one. Then the function Δt_1 is plotted versus Δt_2. Figure 5 demonstrated the results of the procedure for CCL cavity #1.

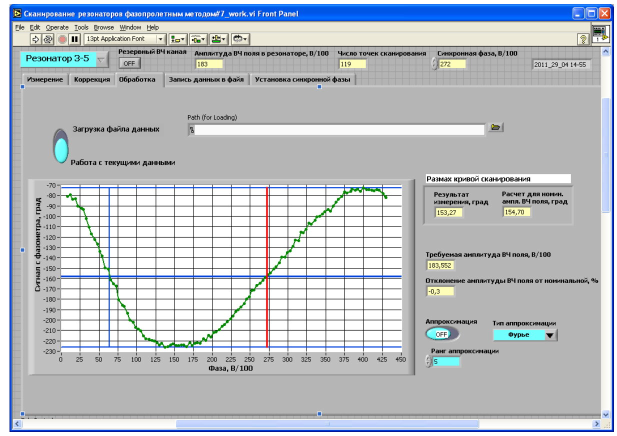

Figure 4: Phase scan results for DTL cavity #5.

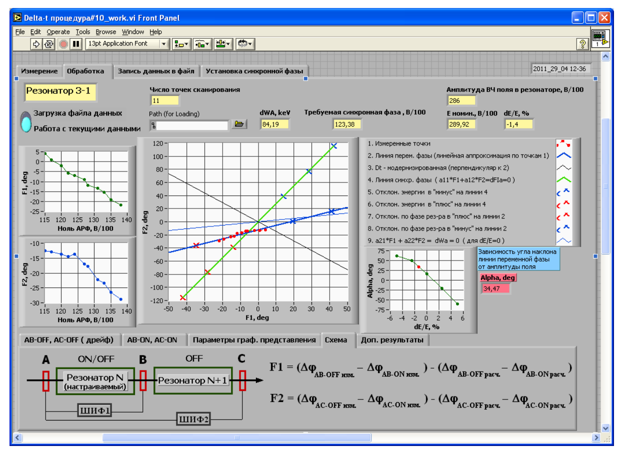

Figure 5: Results of ΔT procedure for CCL cavity #1.

The tilt of the plotted experimental function depends on the amplitude of the accelerating field. Measuring the tilt one can find the amplitude. The position of the function relatively to the plot centre depends on the cavity input energy and input phase shifts with respect to nominal ones. ΔT procedure is a linear one and is valid for small shifts in energy and phase. Preliminary setting of phase is made by observing beam loading versus phase. Normally the centre of the phase area with beam acceleration is a good phase point for starting ΔT procedure. The procedure is used for all the accelerating cavities up to 209 MeV. Setting the phase and the amplitude in the matching cavity located in the intermediate extraction area (160 MeV) is done similarly to DTL cavity #5.

As for RFQ and two buncher cavities their amplitudes and phases are normally fine tuned to obtain a maximum beam current.

Transverse Tuning

Transverse tuning includes beam matching and beam center correction at certain accelerator areas. The first matching and correction is done at the transition area form DTL to CCL. For matching purpose the beam profiles are measured with several wire scanners and

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phase ellipses are restored. The profiles are also measured with increased gains of electronics to get information on beam halo. The behavior of beam profiles in time within the beam pulses is also observed. The result of profile measurement is demonstrated in Fig.6.

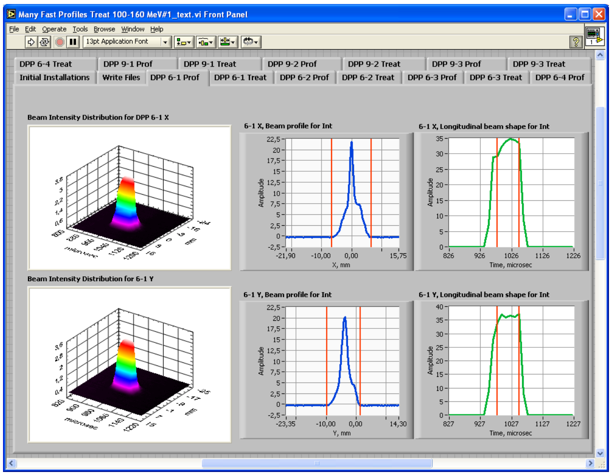

Figure 6: Example of beam profiles at DTL to CCL transition area.

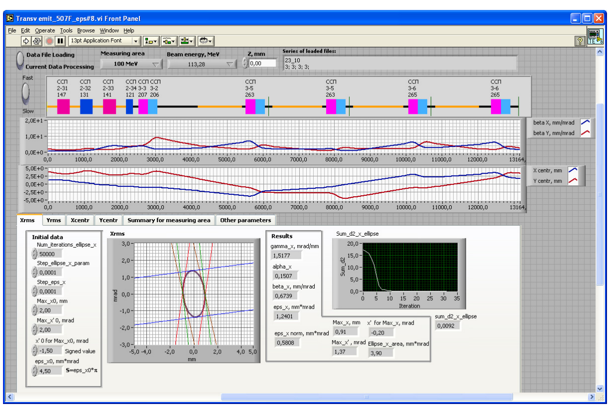

Figure 7: Results of beam profile data treatment.

The parameters of the restored emittance ellipses are used to calculate quadrupole settings in order to match the beam with the subsequent lattice. The variety of settings can be found but the one providing minimum beam size at the matching area is selected. After setting the selected quadrupole parameters one more cycle of measurements is done in order to check the matching results. Figure 7 demonstrates the results of profile data treatment. The lattice, the beam envelopes, the behavior of beam center and the restored emittance ellipse are presented.

Beam centre position correction is done with corrector windings of the quadrupole doublets. Two corrector windings are used for each plane. The first step of the correcting procedure is the measurement of the beam centre positions with several wire scanners. The measured coordinates are transformed to the selected longitudinal position (usually the entrance of the first corrector) and the corresponding point in phase plane is found. Then the correcting currents are calculated to shift the found point to zero after the second corrector. To check the results of correction beam positions are measured one more time. Figure 8 demonstrates the results of correction at the intermediate extraction area. The lattice and the beam centre positions before and after correction are shown.

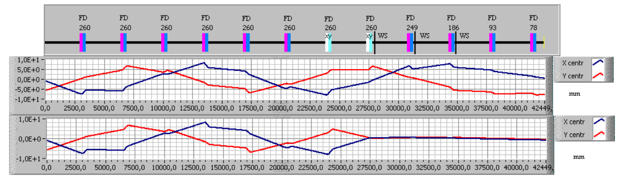

Figure 8: Results of beam correction.

Five areas for matching and correction along the accelerator are foreseen.

There are special procedures for tuning injection lines as well. However their description is outside this report. In majority cases optimization of injection line elements to maximum accelerated current is sufficient.

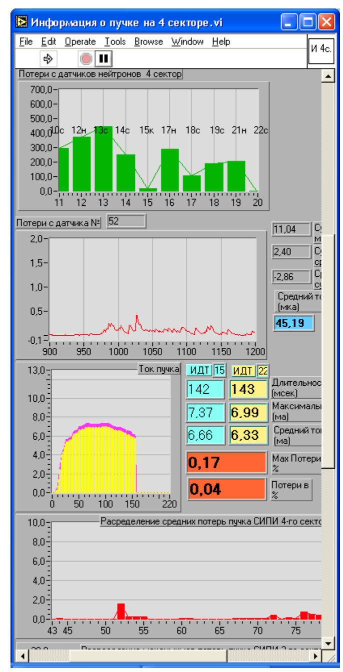

Figure 9: Information on beam losses in accelerator sector #4.

Beam Loss Minimizing

Final tuning of the accelerator is made by the operator, minimum beam loss being a criterion. There are 120 beam loss monitors based on photo-electron multipliers as well as 30 neutron detectors along the accelerator. The information on beam loss available to operator (Fig. 9) includes beam current pulses at the entrance and at the exit of the accelerator sector (Fig. 1), distribution and amount of beam loss along the sector obtained with beam loss monitors and neutron detectors as well as the signals from the loss monitors.

Final stage of accelerator tuning is more art than science and it is impossible to formalize and describe it. It depends on operator experience and preferences.

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It should be noted that the minimum beam loss can be obtained without fulfilment of the tuning procedures above described, several sets of accelerator parameters being possible. However the condition thus found appears to be unstable and difficult to maintain for a long period. The experience shows that the stable conditions can be obtained only in case the procedures above described are carried out and the subsequent adjustments are done within the restricted margins.

CONCLUSION

Multi-purpose Scientific Complex based on 600 MeV Proton Linac is in operation at the Institute for Nuclear Research. Permanent modernization of the accelerator and the Experimental Area enables not to only maintain the complex in operational state but also to improve beam parameters and complex capabilities. The existing experimental facilities are the basis for variety of both basic and applied researches.

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