OPERATION AND RESEARCH ACTIVITIES AT THE INR ACCELERATOR COMPLEX

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Abstract

The INR Accelerator Complex based on the high-intensity proton linear accelerator is under operation. Status of the Linac and main user facilities is given in the paper. Participation of the INR accelerator team in some international collaborations for particle accelerator research, development and construction is briefly described.

INTRODUCTION

The INR Accelerator Complex including a high-intensity proton Linac, Neutron research complex, Isotope production facility and Beam therapy complex is located in science city Troitsk 20 km far from Moscow. Old name of the Complex is "Moscow Meson Factory (MMF) and we use this name too although the main purposes are shifted now to research, development and operation at the facilities mentioned above.

In recent time just two high-intensity high-power proton/H-minus linacs were under operation: LANSCE (former LAMPF) at LANL, Los Alamos, USA and MMF at INR in Troitsk. Last decade the interest to high-power (~ 1 MW) proton linac is increased mainly due to use it as a spallation neutron source as well as injector/driver for high-energy high-intensity proton ring accelerators, neutrino factory, muon collider and radioactive ion accelerators. Some high-intensity linacs under operation, construction, commissioning and design are shown in Table 1.

First superconducting proton linac in the world 1.3 GeV 1.4 MW SNS Linac at ORNL, USA is now more powerful proton linac in the world (about 500 kW at the moment). Construction was complete in 2006 and now the machine is in commissioning stage to reach the design parameters as well as first experiments at the instruments around the target are in progress. This facility is dedicated for nanomaterials research by neutron scattering methods. J-PARC (JAERI/KEK, Japan) 400 MeV/600 MeV proton linac also is near completion and starts already commissioning with energy about 200 MeV. This machine will be used in nearest future for many purposes such as material science, neutrino physics, nuclear waste transmutation problems etc.

So use of the INR proton Linac in a multi-purposes complex is absolutely actual now.

OPERATION OF THE INR PROTON LINAC

The INR proton Linac (Fig.1,2,3) 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 six 198.2 MHz DTL RF stations and 31 991 MHz CCL RF stations including one reserve station per each from five Linac sectors. The detail description of the INR proton Linac is given in /1,2/. Designed, achieved and operational Linac parameters are summarized in Table 2.

The Linac started its regular operation 1993 and provided till now 79 beam runs with about 2000-2400 hours per year. It's very important that reliability of operation is rather good now by means of many technical and organizational improvements – about 80-90% (percentage of a beam on user's target from a full beam run time). Main criteria for the Linac tuning before start of high-intensity operation mode (more 100 µA average current) is that the beam losses should be not more than

Table 1. High Intensity Proton Linacs

Linac	Pulse length, ms	Rep. rate, Hz	Pulse current, mA	Average current, mA	Energy, MeV	Power, MW
LANSCE	0.625	60	16	1.0	800	0.8
INR	0.1	100	50	0.5	600	0.3
SNS	1.0	60	38	1.4	1000	1.4
J-PARC	0.5	25	50	1.25	400/600	1.0 (RCS)
ESS SENER	1.2	50	107	3.35 0.125	1300 50/400	5.0 1.0
CERN SPL LINAC 4	0.4	50	40	1.0 0.1	3500-5000 160	4.0
FNAL		10		0.25	8000	2.0
PEFP	1.33	60	20	1.0	100/1000	0.9
CSNS	0.2	25	15/30/40	76/151/315	81/132/230	0.5 (RCS)
ADS	-	CW	10 - 20	10 - 20	600 - 1000	10 - 100

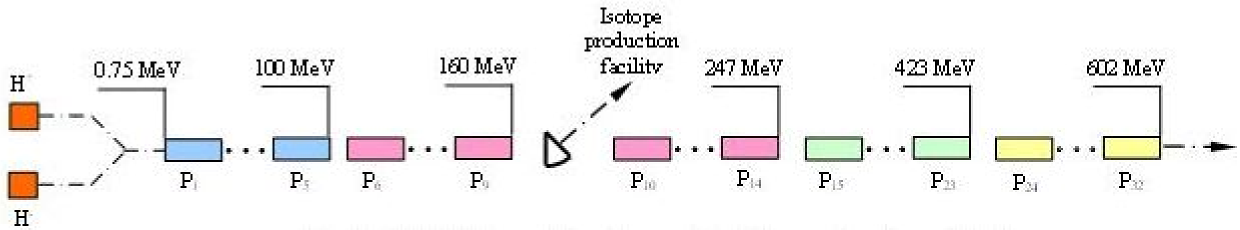

Fig.1 The INR Proton Linac diagram (P_1……P_{32} – accelerating cavities)

0.1%. Tuning procedure normally take 3-4 shifts and includes phase scan for the DTL part and Δt-procedure for the CCL one.

Table 2: The INR Proton Linac Parameters

Parameter	Design	Achieved	April 2008
Particles	p, H-minus	p, H-minus	p
Energy, MeV	600	502	209
Pulse current, mA	50	16	12
Repetition rate, Hz	100	50	50
Pulse duration, µs	100	200	0.3 - 200
Average current, µA	500	150	120

The features of accelerator operations for main Linac users are as follows:

· Isotope production – high intensity mode, average current from 70 to 120 µA. Main problems are beam loss and operation reliability.

· Neutron complex – short beam pulse 0.3 - 60µs, high intensity. Problems to be solved are beam diagnostics, phase stabilization in phase reference lines, accelerating fields stabilization, transient processes.

· Proton therapy – small pulse and average current about 1 µA require a special beam diagnostics and additional phase reference lines stabilization system.

Fig.2 DTL part of the Linac

The tasks and problems to be solved for a further Linac operation take place because of the machine age as well as common situation in industry. First of all a number of klystrons on hand now limiting proton energy by 209 MeV instead of designed 600 MeV. Many efforts have to be done to restore the klystron production in industry or to have an appropriate funding to design and produce it at some firm abroad (we have offers from Toshiba and Thales). Stopping of some RF and modulator tubes production require replacement them by available ones with corresponding modernization of rf stations (for instance tube GI-54A will be replaced by GI-71A, GI- 51A by GI-57A). Some drift tubes of the DTL part should be repaired or replaced by new ones and it’s in progress now.

Fig.3 CCL part of the Linac

The nearest tasks we are planning for the Linac are as follows:

- completion of H-minus injector and low energy beam transport line;
- bringing a process of two beam operation (protons and H-minus simultaneously) to routine operation;
- modernization of 160 MeV intermediate extraction region, installation of new kiker-magnet, providing of flexible beams distribution between experimental and isotope production facilities;
- modernization of the DTL RF System;

- doubling of the repetition rate to 100 Hz;
- increase of proton energy as more klystrons become available.

At the same time upgrade possibilities for the INR proton Linac have to be considering towards a modern spallation netron source with power about 1 MW or more. It could be replacement of a few CCL modules by superconducting cavities in the accelerator tunnel to increase energy to about 1 GeV /3/ or increase a beam pulse length to 1 ms or something else in dependence from a possible budget and time scale.

EXPERIMENTAL AREA AND THE LINAC APPLICATIONS

Experimental Area at the exit of the proton Linac consists of Neutron complex and Beam therapy irradiation facility. Systems of beam formation and transportation to targets of the experimental facilities at the moment are under modernization, including beam diagnostics and control systems.

Neutron research complex includes three main facilities: Spallation neutron source IN-06 with a number of multipurpose instruments, Spectrometer on neutrons slowing down in lead LNS-100 (100 tons of pure lead) and Time of flight TOF spectrometer RADEX. The facilities design, experimental possibilities and first results are described in detail in /4/.

Purpose of the Beam therapy complex is oncology tumors treatment by proton beam and/or by γ irradiation. Proton beam with energy from 70 to 250 MeV in dependence from a tumor depth is transporting to the irradiation chamber, γ irradiation is providing by 6 MeV electron linac SL-75-5 /5/. Low intensity of the proton beam require a special diagnostics and control system. In nearest future there is a plan to use H-minus beam from the INR Linac to provide a parallel work with Neutron complex / Isotope production facility. Construction of the first turn of the Beam therapy facility is complete in 2007 and accepted by the State Commission. Commissioning as well as a lot of formalities to start a regular treatment process for patients are in progress now.

The proton Linac has an interruption in the regular accelerating structure at 160 MeV where a beam is turning by two bending magnets to the Isotope production facility IPF /6/. Special beam position and shape as well as a control system for precise tuning of the beam on the target have been developed and implemented. IPF is operating mostly for production of Sr-82 for positron-emission tomography. Many other isotopes for medicine and industry such as Pd-103, Ge-68, Se-72, Cu-67, Sn-117m, Ac-225 etc could be produced at the IPF in commercial scale.

INR PARTICLE ACCELERATORS RESEARCH ACTIVITY FOR INTERNATIONAL COLLABORATIONS

INR accelerator team is widely participating for a long time in many collaborations for the particle accelerators development at many Laboratories abroad.

For the LHC which is under commissioning at CERN now INR successfully complete three addendums to the Russian Federation – CERN LHC Agreement: Inter Tank Bunch Shape Monitors, Survey Targets (about ten thousand) and Ceramic Pipes for rotating long Coils. Participation of the INR at the CERN Linac 4 development and construction is under discussion now.

Since 2002 INR participates at the SNS (ORNL, USA) Linac construction and commissioning. Among many items of the collaboration (about 20) very important work is development of the Bunch Shape Monitors BSM to achieve precise with a minimum of a beam loss tuning of the warm part of the Linac. Three BSMs are installed in first CCL Module that allows not only directly and precisely measure of the bunch longitudinal phase length and to observe the bunch shape evolution but also to restore a longitudinal emittance at the exit of the DTL /7/. Two more BSMs will be installed in this year at the exit of the SNS Linac to provide a measurement of the momentum spread. For the CCL precise tuning by operators at the control room Δt-procedure was developed and implemented. INR also has developed and supplied for the SNS Beam loss monitoring system a set of different neutrons monitors.

Collaboration with DESY, Germany was started in beginning of 1990-th for development, construction and operation of the Test Stands for S-band and TESLA linear colliders. Since then a lot of work has been provided. As an example INR developed, constructed and delivered to DESY, Hamburg facility for superconducting cavity hydroforming, where this promising technology was successfully demonstrated and proved. We are participating now at the Photo Injector Test Stand PITZ collaboration at DESY, Zeuthen. INR is responsible for design, tuning and commissioning of a normal conducting booster cavity based on the Cut Disk structure proposed and developed at the INR /8/. We also propose to use such a structure for future International Linear Collider ILC Positron Pre-Accelerator as the capture sections which should operate with an accelerating gradient up to 15 MV/m at long RF pulse 1 ms /9/.

Optimization of the Annular Coupled Structure for J-PARC Linac (KEK/JAERI, Japan) recently was complete that allows to start a production of the structure in industry /10/.

More recent activity is INR participation in X-ray Free Electron Laser XFEL International collaboration. INR suppose to be responsible for design and construction of Transverse Deflecting Structure TDS for three special diagnostics sections of the XFEL to measure longitudinal beam profile, the slice energy spread and the slice emittance.

The list of other INR collaborations for particle accelerators research and development is rather large (LANL, TRIUMF, ANL, FNAL, etc) and can't be described in detail in this paper due to a limited volume.

CONCLUSION

The INR proton Linac is under operation with about 2000 hours per year. Proton energy at the moment is 209 MeV limited by a number of klystrons on hand, average current is till 150 µA. The main Linac users are Neutron research complex, Isotope production facility and Beam therapy complex.

INR is actively participating in many international particle accelerators collaborations for R&D, construction and commissioning.

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