STATUS OF THE URAL30M LINAC — A NOVEL INJECTOR TO THE ACCELERATOR COMPLEX OF IHEP

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INTRODUCTION

The existing proton linac, codenamed URAL30, was commissioned in 1977. It applies a through front-to-end RFQ-focusing extended to the top energy of 30 MeV [1]. Since 1985 till now, this facility operates as an injector to the 1.5 GeV booster proton synchrotron of IHEP [2, 3].

By now, many parts and subsystems of the URAL30 no longer comply with up-to-date requirements and thus call for replacement. A-few-year-long scientific research efforts allowed launching design of a novel, upgraded machine, the URAL30M one.

This accelerator consists of the following basic systems: an ion gun, a matching beam-line, the RFQ proper, four sections comprising the accelerator main part, RF power system, a technological sub-system, a control system, and a beam diagnostics system.

Since the URAL30 cavities are made of plain steel, a corrosion inhibitor is used in its cooling system. Nevertheless, it is a crucial component of accelerating system, and it should be modernized. To this end, cavities and containers in the URAL30M are all made of aluminum alloy of vacuum melt. This eliminates the cooling system corrosion problem. A thin vacuum-tight inner galvanic copper coating of cavities plus indium-sealed vacuum joints allow for getting vacuum better than 10^{-8} Torr which is required to accelerate H^- ions as well.

A new RF power supply system for the URAL30M machine would allow for a flexible control over amplitude and phase of RF field in cavities. To this end, low-level electronic controllers upstream of the major RF power amplification chain would be employed, the net cascade anode voltage being kept invariable. The anode voltage modulators are based on addition, with pulsed transformers, of voltages yielded by a few thyristor cells circuited in parallel.

The URAL30M is currently being manufactured in IHEP. For the time being, the conventional (smooth) RFQ and four RFQ-DTL (i.e., RFQ Drift-Tube Linac) sections are subjected to the pre-commissioning tests. Beam-based experiments proper are carried out with the RFQ and three sections of the main accelerator part to follow. The fourth section is being subjected to a low-level RF tuning and is about to accept the beam by the end of 2006.

OUTLINE AND MAIN PARAMETERS

The primary requirements to the accelerator and beam parameters are dictated by operating regime of the entire accelerator complex. Beam pulse length is 10 μs, pulse repetition rate is 25 Hz inside a packet, packet-to-packet recurring frequency being 0.2 Hz. Operating radio frequency is 148.5 MHz. The top current is 100 мA (protons), or 25 мA (ions H^-). Output energy of beam is 30 MeV. Fractional momentum spread after debuncher is less than ±0.2%. Normalized transverse emittance (at 90% population level) is 0.3 π·cm·mrad. All these figures constitute the primary technical requirements to the URAL30M project.

Table 1: Parameter list of the URAL30M

Parameter	RFQ	RFQ-DTL
Cavity type	2H	H, SH, SH, SH
Max voltage U, kV	140	210, 340, 350, 310
Max voltage U_A, kV	—	105, 235, 245, 155
Max voltage U_Q, kV	—	105, 105, 105, 155
Max E-field on surface, kV/cm	250	300, 300, 300, 380
Number of periods	91	41, 31, 25, 31
Focusing pattern	FD	FD, FD, FD, FD
Aperture diameter, mm	11.5	12, 12, 12, 14
Length overall, mm	2461	3985, 4696, 4952, 7238
Gap efficiency	0.06–0.65	0.67–0.85, 0.59–0.93, 0.93–0.96, 0.89–0.94
Capture ratio, %	95	100, 100, 100, 100
Stable phase angle, deg	–90, –30	–30, –30, –30, –30

Parameters of the accelerating and focusing channel employed are listed in Table 1. Main part of the accelerator consists of four RFQ-DTL sections. Their parameters are listed consequentially, section by section. U denotes a cavity (or a vane-to-vane) voltage, U_A is an accelerating voltage across an axially symmetric gap, U_Q is a focusing voltage across a quadrupole gap.

In the first three RFQ–DTL sections of the accelerator, a period of acceleration comprises one axial and one quadrupole gap. In the forth section, a period has a pair of quadrupole gaps that also do accelerate the beam [2].

Calculated parameters of the accelerated beam in the URAL30M are listed in Table 2.

Table 2: Beam parameters in the URAL30M

Parameter	RFQ	RFQ-DTL
Beam energy, IN, MeV	0.100	1.8, 7.3, 15.1, 22.3
Beam energy, OUT, MeV	1.8	7.3, 15.1, 22.3, 30
Emittance, normalized, @ 90% and 25 mA, π cm·mrad	0.11	0.13, 0.15, 0.17, 0.17
Momentum spread, %	8.8	2.1, 2.1, 1., 1.5
Phase advance μ, rad	1.–1.2	0.7, 0.7, 0.7, 0.7
Acceptance, π cm·mrad	0.75	0.85, 0.85, 0.85, 1.2
Bunch width, deg	28	25, 20, 24, 31

CAVITIES AND ELECTRODES

In the URAL30M machine (refer to Fig. 1), measures are foreseen to facilitate a better section-to-section matching of beam. The particular attention is paid to an interface between the RFQ and the RFQ-DTL. To this end, accelerating rate at exit from the RFQ approaches that at entry to the RFQ-DTL. In the RFQ itself, a new form of electrodes is used to increase accelerating rate towards end of the section. Electrodes with a trapezium-shape are used instead of conventional sine-wave modulated ones. Longitudinal emittance of beam is minimized. A more regular transverse focusing pattern is foreseen — a FD periodicity is applied in both, RFQ and RFQ-DTL sections. On the contrary, the RFQ-DTL section of the former URAL30 relies on a FFDD layout.

To maintain improved stability of operation, maximal *E*-field on the surface tips of electrodes is lowered down. Voltage jumps in between sections are reduced noticeably. Vane-to-vane voltage U is now ramped along the cavity length, downstream of beam motion. This allows for compensating of a certain descent in accelerating rate inherent in an invariable-voltage option (the URAL30).

The accelerating structure itself diverges essentially from that of the URAL30. An old-fashioned *H*-cavity (refer to Fig. 2) is used in the first section of the URAL30M only. Other sections employ the so-called sector *H*-cavity (an *SH*-cavity). The latter exhibits higher shunt impedance and enables much an easier assembly of the electrodes. This procedure is not a trivial task at all since it must yield the prescribed partition of the overall voltage U in between accelerating and focusing gaps. To this end, support stems of intermediate (spacer) electrodes must be installed at a well-controlled angle with respect to the vertical plane of the cavity symmetry. The design goal is to provide constant voltage across quadrupole gaps, while keeping the voltage across accelerating gaps ramped along the beam path. Contrary to the URAL30, the modernized URAL30M has lengths of accelerating gaps varying along the cavity axis. Preliminary testing of the first two RFQ-DTL sections of the URAL30M indicates that emittance growth is now significantly lower, as compared to its predecessor. All the more, the URAL30M has a shorter length of 23.4 m.

Figure 1: The URAL30M linac.

Schematic layouts of the cavity cross-sections are shown in Fig. 2.

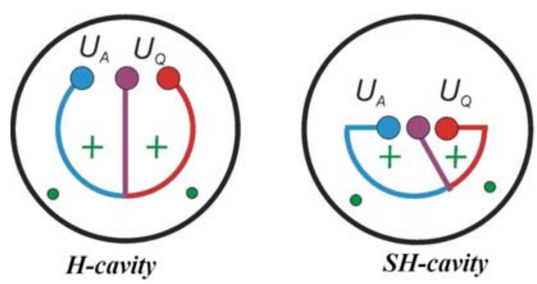

Figure 2: Two *H*-cavity options for the RFQ-DTLs.

EXPERIMENTS WITH A BEAM

For the time being, low-level RF tuning of the fourth section is being accomplished. Beam parameters are measured downstream of the RFQ and the first two main-part sections, at the energies of 1.8, 7.3, and 15.1 MeV, respectively. The third section was installed, and beam at its exit is now obtained.

Beam parameters were diagnosed downstream of every section of the accelerator and, then, compared to outcomes of numerical simulations. Working parameters of the RF field (magnitude of field and its phase) were evaluated. Later, these might be corrected during final tuning of the accelerator.

Preliminary beam tests were performed over all the sections installed. The beam parameters were as follows: 5 mA current of protons, 10 μs pulse length, 0.5 Hz pulse repetition rate. Given these conditions, 100% of beam was accelerated through the RFQ and the two sections to follow. Then, some 50 mA of accelerated beam were obtained at exit from the second section, beam current at entry to the RFQ being 80 mA.

In the "ion source – RFQ" beam transfer line, a few problems were encountered. Namely, need for beam cleaning to get rid of contamination with heavy gas species impurities, attaining a proper on-axis centering of beam, getting prescribed r. m. s. parameters of beam transverse phase portrait compliant with beam dynamics simulations. All these tasks were solved by means of a dedicated custom-made matching insert comprising two axial magnetic lenses, two magnetic dipoles, and a collimator array.

Fig. 3 shows a typical transverse phase portrait of the beam at exit from the ion gun. It was measured in between the two magnet lenses of the insert in question. Such a shape of the portrait is due to a presence parasitic gas species with masses 2, 3, 14, and 16–32, in atomic mass units, plus a distinctive Coulomb-force distortion (the S-shaped beam footprint).

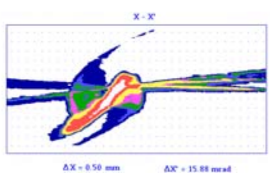

Figure 3: Phase portrait at exit from ion source.

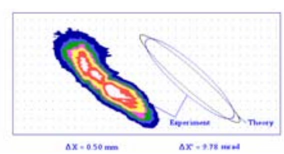

Figure 4: Transverse phase portrait, at entry to the RFQ.

Fig. 4 shows the relevant portrait shot at exit from the matching insert, i.e. at entry point to the RFQ. This figure illustrates a high efficiency attained of the beam-portrait filtering and a satisfactory accuracy got in obtaining beam r. m. s. parameters that are prescribed by beam dynamics modeling.

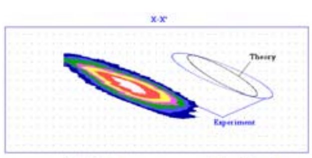

Figure 5: Phase portrait, at the RFQ exit, in *X-X′* plane.

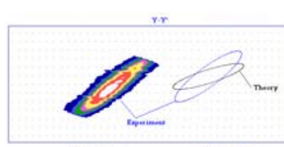

Figure 6: Phase portrait, at the RFQ exit, in *Y-Y′* plane.

Figs. 5 and 6 show the transverse phase-plane portraits acquired at exit from the RFQ section. Both the planes are monitored. In addition, for comparison, the r. m. s. ellipses are plotted. These are either taken from beam dynamics calculation, or deduced from the experimental beam observations.

Figs. 7 and 8 show the similar plots as Figs. 5 and 6, but both taken at exit point from the first section, at beam energy of 7.25 MeV.

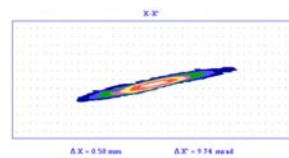

Figure 7: Phase portrait, at exit from the first section, in *X-X′* plane.

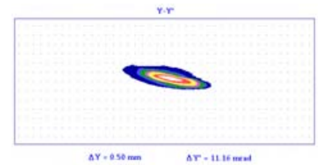

Figure 8: Phase portrait, at exit from the first section, in *Y-Y′* plane.

Such a measurement program is now being carried out with beam at exit from the second section, at beam energy of 15.1 MeV.

Also, a significant amount of efforts is aimed at increasing the through beam current transmission efficiency and further improvement of beam quality. Here, the focus point is to get better matching between the RFQ and the first RFQ-DTL section of the main part of the accelerator.

CONCLUSION

It is the URAL30M machine that yielded us first experimental demonstration of a feasibility to increase accelerating rate in structures with an RFQ focusing. There were only theoretical assumptions on the subject matter available prior to these experiments. The increase in rate of acceleration is reached due to ramping of a voltage across axial gaps downstream of beam, voltage across focusing gaps being kept invariable throughout. The prescribed voltage distribution is attained with a proper tuning of capacities inherent in accelerating and focusing gaps. Such an approach has called for development of a dedicated technique of tuning sector H-cavity with an inclined installation of spacer electrodes support stems.

Now, all the experimental activity with the accelerator is carried out with a 22.3 MeV beam. The fourth section that is to accelerate beam from 22.3 to 30 MeV has passed through a low-level radio-engineering tune-up and will be lined up to the rest of the machine by the end of 2006.

A full-scale complex tuning and pre-commissioning of the entire accelerator aimed at attaining its design parameters is planned to 2007.

REFERENCES

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[3] O. Belyaev et al, Proceed. of LINAC 2004, Luebeck, Germany, p. 285–287.