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STATUS OF U70

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Abstract

The report overviews present status of the Accelerator Complex U-70 at IHEP of NRC "Kurchatov Institute" (Protvino). The emphasis is put on the recent activity and upgrades implemented since the previous conference RuPAC-2018, in a run-by-run chronological ordering.

History of the foregoing activity is recorded sequentially in [1].

GENERALITIES

The entire Accelerator Complex U70 comprises four machines — 2 linear (I100, URAL30) and 2 circular (U1.5, U70) accelerators. Proton mode (default) employs a cascade of URAL30–U1.5–U70, while the light-ion (carbon) one — that of I100–U1.5–U70.

Since the previous conference RuPAC-2018, the U70 complex operated for five runs in total. Table 2 lists their calendar data. The second run of 2021 is being planned for October–December of 2021.

Details of the routine operation and upgrades through years 2018–21 are reported in what follows, run by run.

RUN 2018-2

The run lasted from October 01 till December 12 2018 in the two modes and with four beam energies — proton (0.7 and 50 GeV) and carbon (250 and 456 MeV/u).

At the 1st half of proton mode, 50 GeV proton beam was directed to applied research at the radiographic facility.

To this end, the facility was fed with the fast-extracted bunched beam with equal bunches of 3–4·10^{11} ppb.(see Fig. 1) To attain electric energy conserving operation, the flattop length was cut short to 0.6 sec.

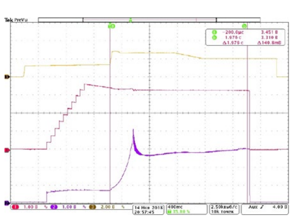

Figure 1: Fast extraction to radiographic facility. Traces from top to bottom: envelope of RF electric field, beam DC current; bunch peak current.

At the 2nd half of the proton mode, research activity was focus to expand the range of the working beam intermediate energy in U-70 (350÷1320 MeV for proton and 250÷455 MeV/u for carbon). The presence of extracted beams of intermediate energies opens up new possibilities for proton radiography, radiobiological studies, etc. To this end, the U70 magnet lattice was toggled to regulated power supply unit [2]. Magnetic cycle for slowing down (from 1320 to 700 MeV) proton beam was created. Proton bunch from U1.5 (1.8·10^{11} ppb) was injected in U-70 on the injection plateau (356 Gs) then, after adjustment RF and magnet field correction systems, was slowed down to 0.7 GeV and circulating at extraction plateau (230 Gs) (1.2·10^{11} ppb). All efforts to decrease extraction plateau field (less than 230 Gs) lead to rapid loss of all beam intensity. Same research was repeated in carbon mode. In this case, carbon beam was slowed down from 456 MeV/u to 250 MeV/u and circulating at extraction plateau (250 Gs).

Closer to end of the run the regulated power supply unit was switched to the DC mode at 455 MeV/u, the main ring being operated as beam storage and stretcher ring at flatbottom DC magnetic field. The beam was extracted slowly with a stochastic extraction scheme [3] capable of yielding 0.6 s long square-wave spills. The in-out transfer ratio amounted 55-57%, close the top expected value of around 68% The beam was used for applied radiobiological and biophysical research (see Fig. 2) by teams from four institutes listed in the 2nd row of Table 1.

Figure 2: Screenshot of the Radio-Biological Workbench work monitor.

RUN 2019-1

It was an intermediate-energy ad hoc one-month long run dedicated to the several sequential tasks:

First, to provide more time for studies and finer tuning of deceleration regime (455÷180 MeV/u).

Second, obtain the regimes of deceleration, of circulation and slow extraction of a beam of carbon nuclei two different energies 300 and 200 MeV/u.

Third, testing new irradiation field-forming system based on electromagnetic wobbler magnets. Testing new

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144-channel mosaic ionization chamber for spatial transverse (x, y)-pattern.

All the tasks accomplished successfully (see Fig. 3, Fig. 4).

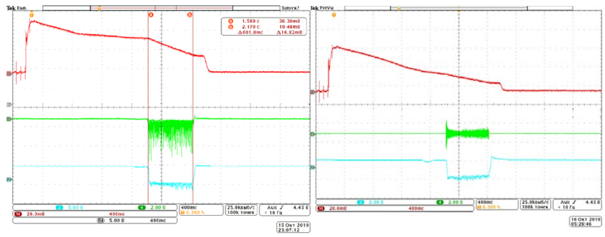

Figure 3: Slow extraction of 300 MeV/u (left) and 200 MeV/u (right) carbon beam. Traces from top to bottom: Beam DC current, ionization chamber in the head of BTL#25 (left) or deflecting noise (right). feedback signal for noise AM.

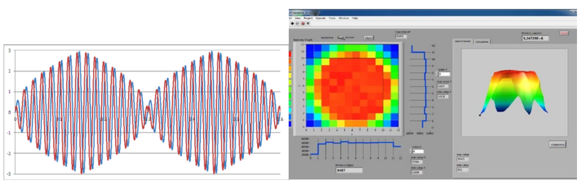

Figure 4: Wobbler electromagnets spiral sweep mode. Currents (left) and Spatial transverse (x, y)-pattern (right).

After accomplished R&D tasks the beam (455 MeV/u, $3.0 \div 4.6 \cdot 10^9$ ipp) was used for applied radiobiological and biophysical research by teams from institutes listed in the 3^d row of Table 1.

RUN 2019-2

The run went on from October 19 till November 24, 2019. The complex was engaged in two modes — proton (50 GeV) and carbon (200÷455 MeV/u) ones.

At proton mode, the 50 GeV proton beam was used for both, applied and fundamental research.

To this end, the flattop (0.67 sec) accommodated two sequential slots 0.150 sec and 0.52 sec.

The 1^{st} slot was serviced by the first fast extraction at radiographic facility (top-priority beam consumer that called for beam intensity of $3.0 \div 4.5 \cdot 10^{11}$ ppb. Beam structure was either single-bunch or multi-bunch with an arbitrary orbit filling with equal bunches, on demand.), while the 2^{nd} one — by second fast extraction at NEUTRON facility (Fig. 5). When NEUTRON facility finished on 2^{nd} slot beam fed SPASCHARM (BTL #14 via IT#24), VES (BTL #4 via IT#27), (FODS (BTL #22 via CD#19) or SVD (BTL #22 via CD#19) in parallel (Fig. 6). In their captions and in what follows, BTL is a Beam Transfer Line, IT is an Internal Target, CD is a bent-Crystal Deflector, all numbered by the # of the relevant (host) straight section (SS) in the U70 lattice. Traditionally now, the run had ended with the 455 MeV/u carbon beam mode for radio-biological studies. The beam (455 MeV/u and 300 MeV/u) was used for applied radiobiological and biophysical research by teams from institutes listed in the four row of Table 1.

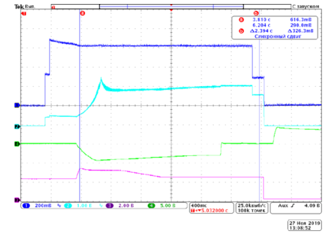

Figure 5: Sequential beam sharing at flattop with two fast extractions. Traces from top to bottom: beam DC current; bunch peak current, B-field ramp rate, envelope of RF electric field.

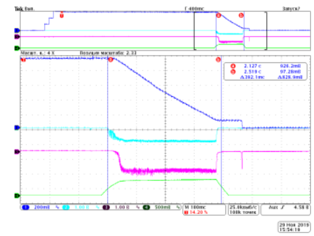

Figure 6: Parallel beam sharing (50 GeV, $8 \cdot 10^{11}$ ppp net). Traces from top to bottom: beam DC current, spill of secondary particles beam from IT ## 24 and 27, driving current of the enclosing orbit bump between ## 24 and 30.

RUN 2020-1

In course of this run, U70 was again employed in two modes — proton (50 GeV) and carbon (456 MeV/u) ones. To meet beam user demand, proton mode of the run was broken into 3 segments with different priorities assigned either to fundamental or to applied fixed-target research. These used to call for a non-compliant set of beam structure, extractions and the BTLs involved.

During first segment of proton part the azimuthally uniform (de-bunched) 50 GeV proton beam was used for fundamental physics at three experimental facilities. The top-energy slow stochastic extraction has fed the OKA (BTL#8), SPIN (BTL#8(21)) and FODS (BTL#22 via CD#30) facility with $3 \div 3.5 \cdot 10^{11}$ protons per a low-ripple spill (0.45 s long) at the flattop (Fig. 7).

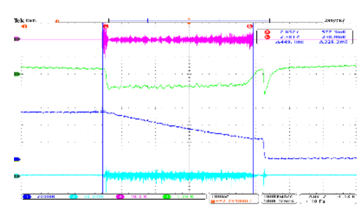

Figure 7: Slow stochastic extraction at the flattop. Traces from top to bottom: phase noise, beam feedback signal for AM-modulation of the noise, beam DC current, spill of secondary particles beam from CD # 30.

During second segment beam used for an applied research with the proton radiographic (top priority) and NEUTRON facility, the U70 was operated in single- and multi-bunch modes with (3–4.5) 10^{11} ppb.

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During third segment beam used for an applied research with the proton radiographic (top priority) facility and SPASCHARM (BTL #14 via IT#24), VES (BTL #4 via IT#27) and HYPERON (BTL #18 via IT#35) in parallel.

At carbon mode, the regime of deceleration and slow extraction of a beam of carbon nuclei with an energy of 350 MeV was prepared. 256-channel mosaic ionization chamber for spatial transverse (x, y)-pattern was tested. After R&D session, the beam (455 MeV/u) was used for applied radiobiological and biophysical research by teams from institutes listed in the five row of Table 1.

RUN 2021-1

It was the first spring run since 2018. The run went on from February 24 till April 30, 2021. The complex was engaged in two modes — proton (50 GeV) and carbon (200÷455 MeV/u) ones.

The proton mode was similar to the RUN 2019-2. As at RUN 2019-2, the flattop (0.67 sec) accommodated two sequential slots 0.150 sec and 0.52 sec.

The 1st slot was serviced by the first fast extraction at radiographic facility (top-priority), while the 2nd one — by second fast extraction at NEUTRON and SPIN (via CD#30) facility. When NEUTRON and SPIN facility finished on 2nd slot beam fed SPASCHARM (BTL #14 via IT#24), HYPERON (BTL #18 via IT#35), VES (BTL #4 via IT#27) or ISTRA (BTL #4 via CD#27) in parallel.

At R&D session of carbon mode, all 6 regimes 455, 400 (new regime), 350, 300, 250 (new regime) and 200 MeV/u was prepared for applied radiobiological and biophysical research by teams from institutes listed in the five row of Table 1.

UPGRADING THE POWER SUPPLY PLANT OF THE U1.5 RING MAGNET

Upgraded power supply plant of the U1.5 ring magnet now includes new modular electrical substation (10 kV, 30 Mw), new capacitor bank (15 kV, 28 mF), a set of non-standard electrical equipment with Automated Process Control System (APSC). Upgraded power supply plant of the U1.5 ring magnet has been working since RUN-2020-1.

CONCLUSION

Accelerator Complex U70 at IHEP of NRC "Kurchatov Institute" continues its routine operation for fixed-target physics and applications and has accomplished five regular machine runs since the previous conference RuPAC-2018, refer to Table 2.

Table 1: Engagement of the Off-Site Institutions in Carbon-Beam Sub-Runs

Institution	2018-2	2019-1	2019-2	2020-1	2021-1
MRRC of NMRCR, http://mrrc.nmicr.ru	+	+	+	+	+
ITEB of RAS, web.iteb.psn.ru	+	+	+	+	+
IBMP of RAS, www.imbp.ru	+	+	+	+	
FMBC of FMBA, fmbafmbc.ru		+	+		
JINR, www.jinr.ru		+			
VNIIFTRI, www.vniiftri.ru		+	+		
MEPHI, https://mephi.ru/				+	
IMB of BAS, www.bio21.bas.bg	+				

REFERENCES

[1] S. Ivanov, *et al.*, "Status of U70" in *Proc. 26th Russian Particle Accelerator Conf. (RuPAC'18)*, Protvino, Russia, Oct. 2018, pp. 55-59.

[2] An. Markin, V. Kalinin, O. Lebedev, D. Hmaruk, "Upgrading of the power supply for magnet U70 synchrotron", in *Proc. 26th Russian Particle Accelerator Conf. (RuPAC'18)*, Protvino, Russia, Oct. 2018, pp. 335-336.

[3] S. Ivanov, *et al.*, "Slow Extraction of a Carbon-Nuclei Beam from the U-70 Synchrotron", *Instruments and Experimental Techniques* vol. 64, May 26, 2021, pp. 343-351.

Table 2: Five Runs of the U70 in Between RuPAC-2018 and -2021

Run	2018-2	2019-1	2019-2	2020-1	2021-1
Launching linac URAL30, booster U1.5 and U70 sequentially (I100 in parallel with a delay)	October, 01	September, 16	October, 19	October, 19	February, 24
Beam in the U70 ring since	November, 06	October, 07	November, 24	November, 21	March, 24
Fixed-target physics program with extracted top-energy beams (either of protons or of carbon nuclei)	November,12 – 20, 9 days	-	November,25-December, 2, 8 days	November,26-December, 15, 20 days	March, 29 – April, 12, 45 day
No. of multiple beam users (of which the 1st priority ones)	4 (4)	4 (4)	11 (6)	12(8)	10(9)
MD sessions and R&D on beam and accelerator physics, days	19	13	6	18	12
Light-ion acceleration program, intermediate energy only	November,21–December,12,17½ days	October,07–27, 20½ days	December, 03–12, 9½ days	December, 16–30, 14½ days	April, 13–30, 17½ day