UNILAC Status and Developments

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Status of Operation

In 2000 both injectors – the new high current injector HSI and the high charge state injector HLI – were used for routine operation. The UNILAC was mainly operated in the time – sharing mode, for some fractions of beam time the three-beam operation was practiced. The scheduling of beam time and operation statistics in 2000 are reported in ref.[1].

As in the last year, long periods of beam time were used for the acceleration of carbon for the cancer therapy from the HLI with very high efficiency. For UNILAC experiments rare isotopes were accelerated by the HLI to take advantage of the low consumption rate of the ECR source (^{26}Mg, ^{60}Ni, ^{64}Ni, ^{36}Ar, ^{58}Fe, ^{70}Zn). ^{70}Zn and ^{64}Ni ions were used successfully for the search for super heavy elements. Over 60 days for each ion the availability was above 90%, interruptions occurred only for refilling of the ECR source with material every 5-6 days. For SIS injection the beam was mainly accelerated by the new injector linac HSI. PIG, MUCIS and MEVVA sources were in operation. The highest particle intensities were reached for argon from the MUCIS. More details on the status of high current acceleration are given in the following paragraph.

High Current Operation and Developments

Besides the routine operation of the linac, the commissioning of the HSI was continued. The scheme of the HSI is shown in Fig. 1.

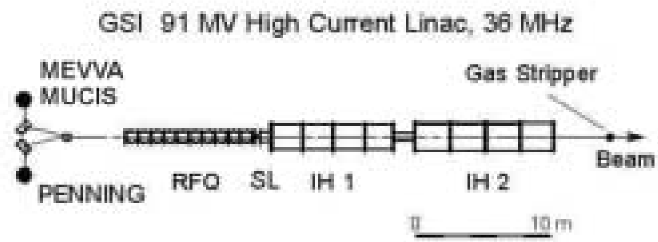

Fig. 1 Scheme of the new high current injector (HSI)

The aspects and status of the high current operation are reported in several contributions to the international linear accelerator conference 2000 (refs. 2-8). In table 1 the achieved beam intensities are listed. The design intensities at the end of the LEBT could be attained only for gaseous light ions up to argon from the MUCIS. Beam experiments indicated limitations of the beam transport of high current from the ion source through the dc pre-acceleration gap. Furthermore, the stability of the MEVVA ion source has to be improved at high intensities. As shown in table 1 the transmission of the whole HSI decreases to about 50% at high intensities. The RFQ is the bottleneck as emerged from many measurements. The transmission of the IH drift tube linac is better than 90% over a wide range of beam intensities and ion species. The beam loss within the RFQ can not be explained completely by large transversal input emittances; measurements of the emittances resulted in normalized 90%-values from 0.25 up to 0.45 π·mm·mrad without any significant influence to the RFQ transmission. Mismatch problems due to space charge effects or misalignment inside the RFQ are not excluded. Computer simulations and beam measurements are underway for better understanding of the RFQ behavior.

Table 1 Achieved beam intensities and comparison with design

		LEBT (Achieved)	LEBT (Design)	HSI-Transmission
MUCIS	H_3^+	3.5 mA	0.8 mA	-
	D_3^+	3.5 mA	1.6 mA	-
	N^+	4 mA	3.8 mA	-
	$^{18}O^+$	5 mA	4.8 mA	45 %
	CO^+	6 mA	7.5 mA	45 %
	$^{40}Ar^{1+}$	18 mA	10 mA	45 %
	$^{86}Kr^{2+}$	3 mA	11.5 mA	50 %
	$^{129}Xe^{2+}$	0.75 mA	17.5 mA	-
MEVVA	C^+	5.5 mA	3.2 mA	-
	$^{92}Mo^{2+}$	0.65 mA	12.4 mA	67 %
	$^{52}Cr^{1+}$	5.5 mA	14 mA	40 %
	$^{58}Ni^{1+}$	10 mA	15.5 mA	50 %
	$^{238}U^{4+}$	4-6 mA	16 mA	50 %

The argon intensity at the RFQ entrance could be increased above the design level (see table 1). By that the theoretical current limit of 10 emA Ar^{1+} was reached. In Fig. 2 the transmission of a high intensity argon beam from the LEBT to the end of the UNILAC is shown. The measurements are compared with the design values of current and transmission.

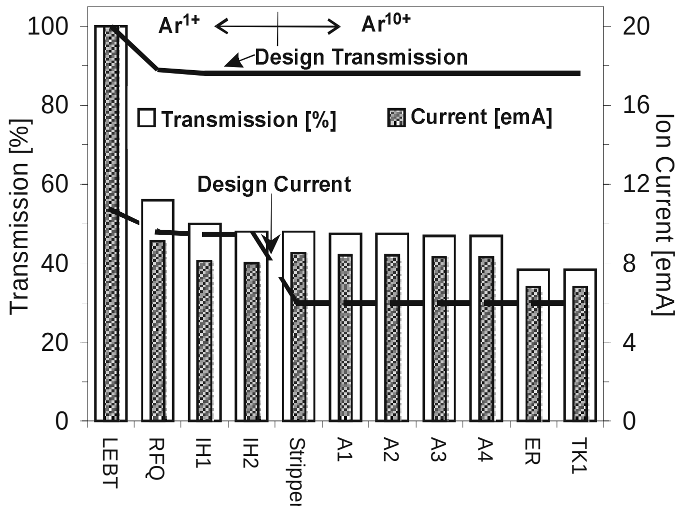

Fig. 2 Measured argon beam intensities along the UNILAC

In February 2000, a U^{4+} beam from the MEVVA source was accelerated for the first time. As listed in table 1, the design goals for the intensity of uranium could not be attained. A maximum intensity of 10 emA was measured at the end of the LEBT, but the fluctuations of ion source current - up to 25% - prevented a successful tuning and stable operation of the accelerator facility. At the lower level of 4 emA a better reproducibility of the beam pulses could be achieved by optimization of source parameters. If the reduced transmission of the HSI by a factor of two is taken into account, the gap between present performance and design goal is a factor 6 to 8. Subject of improvements of the MEVVA source is the reduction of noise at the required intensity level [9]. Higher intensity and brilliance of the beam are expected by optimizing the transport from the ion source through the gap with solenoid focusing.

Fig. 3 summarizes the emittance measurement data at several energy stages of the HSI (120 keV/u, 750 keV/u and 1.4 MeV/u) and after the Alvarez linac at 11.4 MeV/u. The measurements were taken at 6.5 emA of Ar^{1+} at the HSI exit. The Ar^{10+} current came up to 7 emA after stripping and charge state analysis. The emittance growth agreed to the computer simulations.

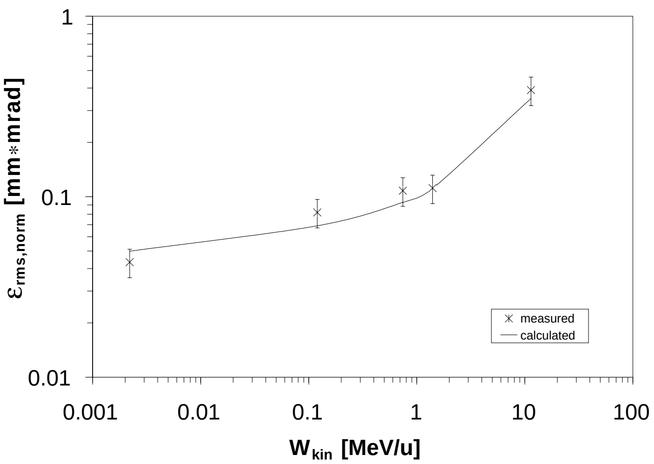

Fig. 3 Transversal emittance for several energy stages of the HSI and at 11.4 MeV/u; beam intensities: 6.5 emA Ar^{1+} at the HSI exit, 7 emA Ar^{10+} after the Alvarez

The RFQ and the superlens SL of the HSI (see fig. 1) still show pronounced dark current contributions at voltage amplitudes above 75% of the design level. There was no essential improvement after a long operation time at the U^{4+} rf voltage level (91% of the maximum design level). Further conditioning tests are planned in the year 2001. Both IH tanks, IH1 and IH2, show modest dark current contributions. In 2000 all rf structures of the HSI were conditioned up to the voltage level for $^{238}U^{4+}$.

Proton and Deuteron Acceleration at the UNILAC

After the replacement of the Wideröe prestripper accelerator by the HSI, the performance for light ions has been changed. With the Wideröe injector maximum intensities of protons and deuterons were attained by injection of H_3^+ and D_3^+ molecules resp. It was shown that the molecules – without gas stripping at 1.4 MeV/u – could be accelerated without loss up to 11.4 MeV/u. When the molecules pass the carbon foil stripper before injection into the synchrotron SIS, they break up into protons or deuterons. 280 μA deuterium D_3^+ were measured before the carbon foil and then transferred to 840 μA deuterons. $2 \cdot 10^{11}$ particles per pulse were accelerated in the synchrotron.

The new injector linac is optimized for maximum particle intensities of heavy ions (Kr to U). The maximum mass to charge ratio A/q is 65, the intensity limit is calculated by $0.25 \cdot A/q$ emA (electrical current). For singly charged ions the intensity limit is even lower (60%) compared to the Wideröe linac, but with better ion source performance and with the new LEBT, the previous maximum intensity should be surpassed.

The adjustment of the low rf power level is not a trivial task. The rf power needed for D_3^+ is by a factor 98 lower compared to the power of $^{238}U^{4+}$, for H_3^+ it is a factor 393. After an elaborate tuning of the rf transmitters and the control electronics, stable conditions for the rf phase and amplitude control could be adjusted only for D_3^+. At this low power level multipactoring did not occur.

Therefore, beam tests were performed with D_3^+ from the HSI, protons were injected from the ECR source into the high charge state injector HLI. During the first run an intensity of 600 μA deuterons were attained at SIS injection starting with an intensity of 1 mA D_3^+ at the RFQ entrance. By further improvement of ion source performance, HSI and poststripper transmission, an intensity of 3 mA D^+ should be feasible to fill the synchrotron to the space charge limit of 10^{12} particles per pulse.

From the ECR source H_2^+ molecules were extracted with an intensity of 100 μA. Due to the overall transmission of 50%, at least 100 μA protons can be expected at SIS injection at present, up to $5 \cdot 10^{10}$ protons per pulse can be accumulated in the SIS.

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