Commissioning results of the Amsterdam Pulse Stretcher/ Storage Ring *AmPS*

R. Maas, F.Kroes, J. van der Laan, G. Luijckx,
J. Noomen, Y. Wu

NIKHEF-K, P.O. Box 41882, 1009 DB Amsterdam, the Netherlands.

Abstract

AmPS has been built to enhance substantially the main specifications of the 1 % duty factor 550 MeV electron accelerator facility MEA. The maximum energy will be raised to 0.9 GeV while the duty factor increases from 1 % to approximately 100 %. To this purpose the ring AmPS was added to the facility. Simultaneously the linac was upgraded both in current and energy. Two modes of operation for the ring are implemented: a Pulse Stretcher mode with 3 turn injection creating an external beam, and a Storage Mode with multi turn injection for internal target physics. The commissioning of the ring started in April 1992. Within two months 10 % duty factor beams could be delivered for electron scattering experiments. Meanwhile the performance of the machine has been improved dramatically. The actual performance of the ring is presented and is compared with the initial design goals.

I. INTRODUCTION

At NIKHEF–K electron scattering experiments for nuclear physics research are carried out. A 500 MeV electron linac delivered typically 50 μA beams of 1%–duty factor to the experimental area. Since coincidence scattering experiments (e,e'X) got more emphasis, the available low duty factor became a serious handicap to carry out these type of experiments. With the addition of the Pulse Stretcher AmPS to the facility, in conjunction with an increase of the linac energy to 900 MeV (zero–current; beamloading 2.6 MeV/mA), it will be possible to deliver near–CW beams in the energy range 250–900 MeV to the experimental area.

The maximum peak current of the linac will be 80 mA; at this value a degradation of the energy spread is expected: $|dp/p| \approx$ 1–2%. Such an energy spread will exceed the momentum acceptance of the ring. Therefore an Energy Spectrum Compressor (ESC) has been installed between linac and AmPS. At the present low values of the injection current (typically 10 mA), the linac + ESC system delivers beams with energy spread of typically 0.03% (FWHM).

Another option is the Storage Mode: in this case the circulating beam is not extracted, but used in conjunction with an internal target (e.g. gas jet) to carry out scattering experiments. The present 2856 MHz RF system can be used to store a beam at energies up to about 550 MeV. In order to be able to store beams at the maximum energy, a 476 MHz RF system will be installed during the winter of '93–'94.

II. PULSE STRETCHER

AmPS was originally designed as a Pulse Stretcher. The basic design of the machine has been described in [1]; an overview of the AmPS project is given in [2]. The main parameters of the Stretcher are summarized in Table 1.

Table 1

Main parameters of AmPS in Stretcher Mode

Energy, min–max	250–900	MeV
circumference	211.62	m
current (injected)	80	mA
current (extracted)	65	μA
injection frequency	400	Hz
injection duration	3	turn
RF–frequency	2856	MHz
momentum compaction α	0.027	
harmonic number *h*	2016	
horizontal tune ν_x	8.300	
vertical tune ν_y	7.21	
horizontal chromaticity χ_x	−15.0	
vertical chromaticity χ_y	+ 0.2	
synchr. loss (@900 MeV)	17.6	keV/turn

In order to slowly extract the beam from the machine, third integer resonance extraction is used. As non–linear elements four extraction sextupoles are used (AmPS has basically a four–fold symmetric lattice). The extraction is accomplished by phase–modulating the RF voltage of the cavity. The non–synchronous motion, in combination with the large negative value of the chromaticity, effectively brings the tune close to the resonant value. The unstable particles are intercepted by an electrostatic (wire) septum and from there directed into the extraction channel.

Commissioning experiments have been performed at a beam energy of E = 410 MeV, and an injected (peak) current of 10 mA. Since we started with single–turn injection, only one injection kicker needed to be used. The injection frequency was reduced to 50 Hz in order to avoid too much radiation. The average current under these circumstances (single–turn injection) is $\bar{i} = (f_{inj} \times \hat{i}_{inj}) / f_{rev} = 0.35 \mu A$

The proper location of the injection septum is x=+16.5 mm off–axis in order to create the proper conditions for extraction (see [1]). From the Storage Mode runs, see Section III, the septum was still in on–axis position. Rather than changing its position, we created a local bump in the closed orbit around the injection location of –16.5 mm.

During the extraction time (20 ms at f_{inj} = 50 Hz, which corresponds to appr. 28000 rev's) a phase shift is applied to the RF voltage, such that the phase shift increases as the extraction progresses. This procedure 'shakes' the particles out of the bucket, and once out, the synchrotron losses carry the particles into the unstable part of the phase space (the chromaticity has a large negative value). Since the extraction depletes the population of the bucket, the phase shift per unit of time has to increase as the extraction progresses in order to ensure a constant extracted current. The total phase shift during the extraction was about 1400 degrees.

Currently the phase shifts are defined by linear interpolation between only 16 points over the whole extraction cycle, thus making careful adjustment of the phase shifts not possible. Software is being developed to divide the extraction cycle into 1000 different regions, allowing fine tuning on a almost turn-by-turn basis. When passing the ϕ = 360° point, the phase is quickly (120 ns, corresponding to less than 1/5 th of a turn) restored to zero. Details about this phase shift procedure can be found in [3]. Since the energy spread of the injected beam is so small, only 4–5 kV RF voltage is needed to generate a bucket large enough to capture the injected pulses. Indeed, it was quickly found that too large an RF voltage inhibits the extraction process.

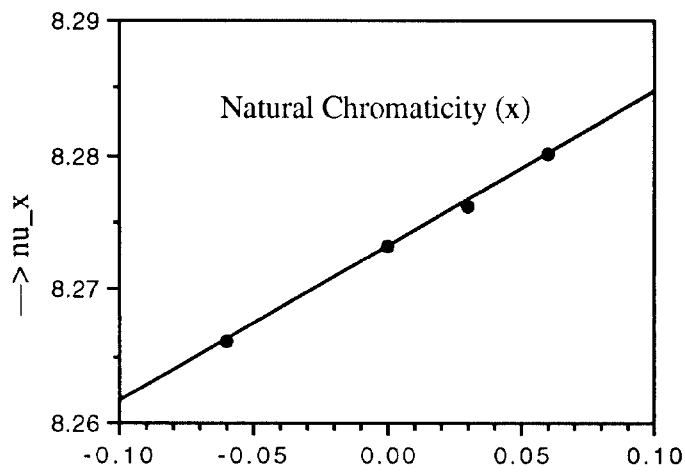

Fig.1 *Relation between Δf_{RF} (f_{RF} = 2856 MHz) and ν_x for zero–sextupole strength (natural chromaticity): χ_x = –9.03.*

The extracted beam was directed into a small Faraday Cup, about 25 m distance from the extraction point. Close to the Faraday Cup a scintillator was placed. By inserting a beam viewer a few meter upstream of the scintillator, the time structure of the extracted beam could be observed. The current in the ring was measured with a parametric current transformer (pct) from Bergoz. The horizontal tune was measured by applying a FFT algorithm on the signal of a stripline monitor. This method is possible because in Stretcher Mode the beam is injected off–axis in the horizontal plane. The vertical tune was measured by storing the beam, and then applying a small fast (< 0.7 µs) vertical kick by a specially–designed kicker. Once adjusted to ν_y = 7.22, this value was not changed anymore.

The chromaticity, defined as $\chi_z = \Delta\nu_z/(dp/p)$, z = x, y, was measured by varying the RF frequency and observing the resulting tune change:

$$\chi_z = -\alpha . f_{RF} \frac{\Delta \nu_z}{\Delta f_{RF}}, \quad z = x, y \qquad (1)$$

where α is the momentum compaction. Eq. (1) was used to check the parametrization of our chromaticity control. Fig. 1 gives an example of such a measurement.

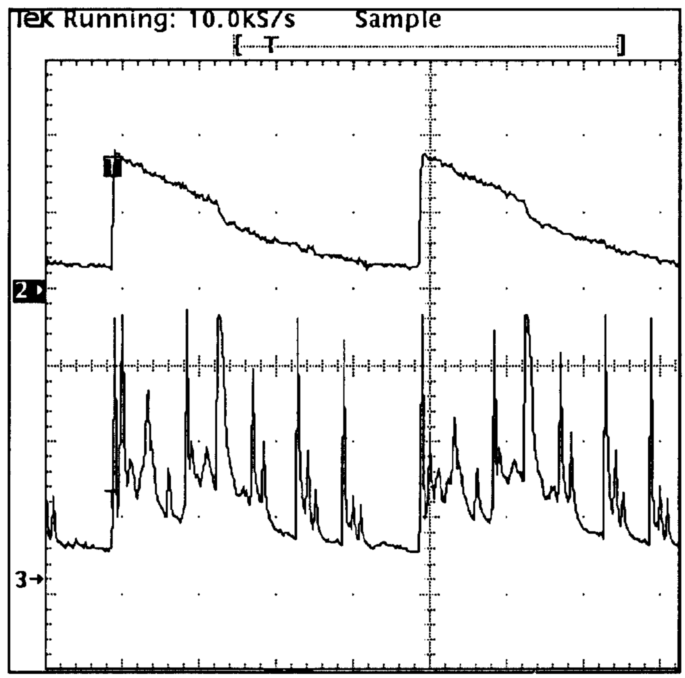

Fig.2 *Ring current (top) and scintillator signal (bottom) during two injection/extraction cycles. Injection frequency is 50 Hz; the ring current is 20 mA (two–turn injection).*

The proper conditions for extraction were first checked by applying constant RF, and observing the light from one of the four available synchrotron monitors. RF capture was accomplished by slightly retuning the field of the ring dipoles. Once this was set, the RF was phase modulated. The extracted beam was first observed on some view screens in the extraction channel. From this information it was possible to make a better phase space match in y between incoming beam and machine. The extracted current was optimized by optimizing RF parameters and extraction sextupoles settings.

more–turn injection

By switching on the second injection kicker and increasing the length of the injected beam pulse to 1.4 μs, the doubling of the circulating current, see Fig. 2, indicated that two turns got injected. The obvious extension to three–turn injection (the design goal) could not be tested yet due to (a software–related) inability to extend the MEA beampulse beyond 1.4 μs. Finally the injection frequency was increased to 200 Hz; under these conditions the max. extracted current was 2.5 μA, which means an extraction efficiency exceeding 90 %. No attempt has been made yet to measure the emittance of the extracted beam.

Particles captured inside the bucket can also be expelled from it by changing the RF power level during extraction (amplitude modulation, AM). This method was tried briefly and produced a very 'clean' signal on the scintillator. Due to machine problems this short experiment could not be repeated. This method will be tried again later on.

III. STORAGE MODE

In Storage Mode each quadrant of AmPS is tuned identically (as opposed to Stretcher Mode, where the injection area is tuned slightly different). Experiments were also carried out at E = 410 MeV. The storage time at V_{RF} = 40 kV and i = 10 mA was τ = 2.5 min. Since this storage time is approximately equal to the Touschek lifetime (f_{RF} = 2856 MHz), no serious attempts were made to improve this. The beam behaviour as observed by the synchrotron ports indicated that probably quite some higher harmonics were picked up by the beam.

As we were virtually not able to determine the trajectory of the closed orbit, this is not too surprising. By moving the horizontal tune close to 8.33, we were able to *store* three distinct beams: these beams are probably trapped in the three islands adjacent to the three unstable fixed points. Being so close to the resonance reduces the stable part of the phase space to zero, so there is no room any more for the 'central' beam.

IV. CONCLUSIONS

The results obtained so far in Stretcher Operation indicate that the machine behaves as expected. It seems important that we improve our (non–interfering) monitoring system in order to measure – and correct – the closed orbit. The two fast injection kickers and the associated timing system work quite well as we succeeded in two-turn injection without any additional adjustments.

The results in Storage Mode so far are encouraging; but only when we attempt to store higher beam currents at higher energies (using the new 476 MHz system) might we learn more about the behaviour of AmPS. For internal target physics experiments the lifetime obtained so far is already sufficient to carry out meaningful experiments.

V. REFERENCES

[1] R. Maas and Y. Wu, *Optics of the Amsterdam Pulse Stretcher*, In Proc. 1989 IEEE Particle Accelerator Conf., p. 1698, 1989.

[2] G. Luijckx et al., *The Amsterdam Pulse Stretcher Project (AmPS)*, In Proc. 1989 IEEE Particle Accelerator Conf., p. 46, 1989.

[3] F.B. Kroes, E. Heine, T.G.B.W. Sluijk, *A fast amplitude and phase modulated RF source for AmPS*, In Proc. 1991 IEEE Particle Accelerator Conf., p. 684, 1991.