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THE LINEAR ACCELERATOR AND PULSE COMPRESSOR OF THE SNQ*-PROJECT

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Abstract

The Spallation Neutron Source is one of Germany's most important scientific projects proposed at present. Its main purpose is to provide short neutron bursts of high intensity which are produced by a pulsed proton beam hitting a target. The proton beam itself will also be used directly for a series of very important experiments in nuclear physics. The performance requested from the proton accelerator part of the project with respect to average intensity and pulse rate limits the choice of all technical solutions to a combination of a high duty Linac and an additional pulse compressing synchrotron ring.

The concept of the accelerator part of the SNQ-project, in particular the Linac, will be described. The Linac may be subdivided into three sections, namely the Injector with two RFQ-structures and a beam merging by funneling, the Alvarez-Accelerator and the High Energy Linear Accelerator with its single cell structure. For the ring shaped pulse compressor two technical solutions are being investigated. One is a isochronous storage ring and the other is a FFAG-synchrotron, which can also accelerate at a fast rate.

Basic Parameters of the Linear Accelerator

	Stage I	Stage II
Particle	protons	
Final energy .... Mev	350	1100
dc beam current during pulse ....mA	200	
Time averaged current ....mA	5	
Repetition frequency ....Hz	100	
Accelerating structures and rf-frequencies...........MHz - RFQ - Alvarez-structure - Single cell structure	 100.625 201.250 201.250	
Beam pulse duration.......... ms	0.25	
Mains power.................MW	9.5	24

* (from German: Spallations-Neutronen-Quelle)

The Basic Concept of the SNQ Accelerator

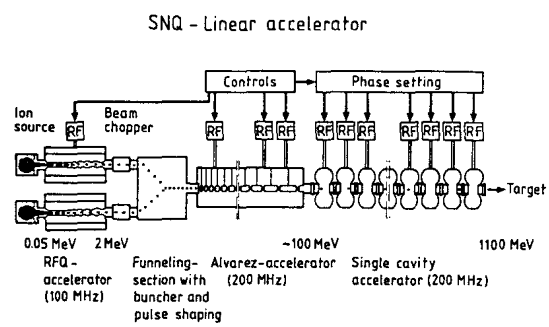

Fig. 1 Schematic illustration of the SNQ rf-accelerator

The concept of the SNQ accelerator is shown schematically in Fig. 1. Two ion sources operating in parallel with an extraction voltage of ∿ 50 keV inject into two RFQ (Radio Frequency Quadrupole) - structures. These RFQ's run at 100 MHz rf-frequency with a relative phase shift of 180 degrees and accelerate the beams to an energy of 2 MeV. In a funneling section, which includes devices for bunching and pulse shaping, the two beams are merged together according to the "zipper principle" which results in a pulse sequence of 200 MHz. This is exactly the frequency on which the subsequent Alvarez structure operates, which means that each of its rf-buckets is filled for optimal accelerating efficiency. At an energy around 100 MeV the Alvarez-structure becomes rather inefficient and a single cell (i.e. uncoupled) accelerating structure will take over for higher particle energies. In the following we will briefly describe the main items.

The Injector

The current, which can be accelerated in an RFQ structure, depends on the initial particle energy and on the frequency. In a linearized model a current limit can be estimated, which is represented by the solid line in Fig. 2.

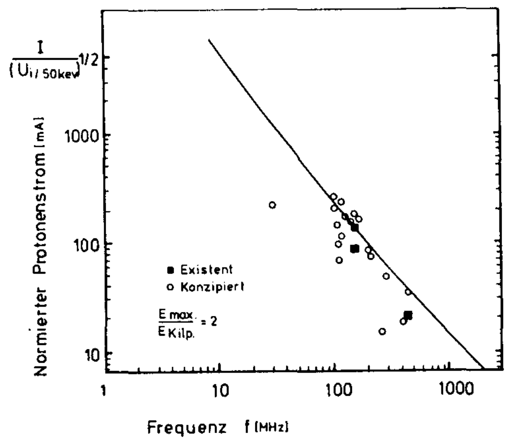

Fig. 2 Maximum RFQ proton current as a function of frequency and injection energy U_i

One reads from Fig. 2 that a current of 200 mA can probably not be accelerated safely in a 200 MHz RFQ from 50 keV to 2 MeV as is required. However, by using two 100 MHz RFQ and by funneling the beam in order to feed the Alvarez accelerator with 200 MHz bunches, the situation is fourfold relaxed since each of the RFQ operates at the lower frequency of 100 MHz with higher current limit and has to accelerate only half of the current.

The funneling section, whose overall length will be about 15 m, will contain beam chopping devices and several bunchers and rebunchers to maintain the bunch structure of the beam over the whole distance. Merging of the two beams is achieved by a series of bending and septum magnets and a rf-deflector. The latter operates at 100 MHz and will give a kick in opposite directions to the bunches arriving at 180 degrees phase intervals (Fig. 3).

The Alvarez Accelerator

Alvarez accelerators at 200 MHz have been operating successfully and reliably at various laboratories over many years now and even pulse currents of 300 mA have been achieved, although for a pulse duration short enough to allow the stored energy in the cavities to be run off. This will not be possible in the SNQ-Alvarez accelerator. This is why well controlled distributed power feeding into the structure during the pulses will be required,

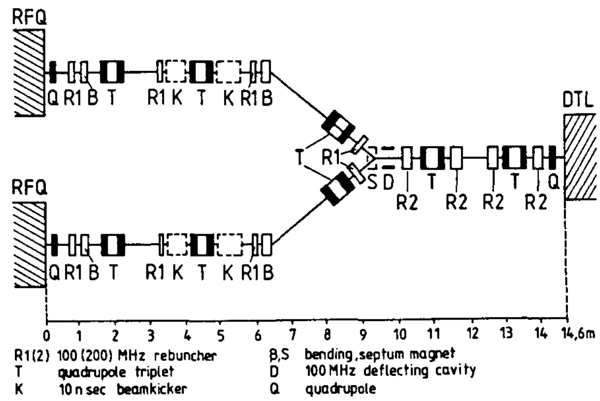

Fig. 3 Concept of the funneling section

together with the usual measures to achieve a finite group velocity (i.e. energy flow) along the accelerator by two overlapping pass bands. Another design feature of the SNQ-Alvarez accelerator is the practically negligible beam emittance growth along the structure despite the rather high space charge.

The beam focusing elements will be located, as usual, in the drifttubes. Use will be made of conventional quadrupoles, which offer the advantage of easy, empiric adjustment, or of permanent-magnet-quadrupoles, provided that it can be proved that there are no problems with radiation. Even a mixed system is not excluded.

The High Energy Linear Accelerator (HELA)

Towards higher particle energies an Alvarez accelerator will become less efficient than other accelerating structures because of the increasing particle velocities.

Fig. 4 shows the calculated shunt resistance of a 200 MHz Alvarez accelerator suited for our purpose (smooth line) as a function of particle energy.

For the high energy part of the accelerator a structure consisting of 640 single cells with separate rf-feeding into each cell has been chosen (dotted line) for a variety of reasons.

With a coupled cavity structure, the mechanical dimensions of the cavities have to be matched to the velocity of the particles.

As a consequence the energy of the beam is predetermined at each point of the accelerator and virtually no variation is possible.

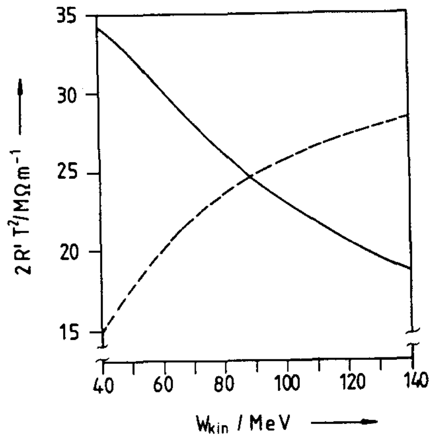

Fig. 4 Shunt resistance of the Alvarez (——) structure, including stems, and the HELA (---) structure;

$2 R' T^2$ is the effective shunt resistance per length in the linac style.

In contrast to this, with a single cell structure the relative rf-phases between the cavities are controlled by electronic means and can be changed very rapidly. Thus, if one or a few of them fail, the phase in the following cavities can be readjusted to the new local beam velocity and operation can continue with virtually no interruption. Suitable provisions for automatic exchange of rf-amplifiers with the accelerator in operation will be made. In order to avoid high induced voltage by the beam across the gap of those cavities, whose rf-feeding had failed, electric damping of the cavity is being studied.

With respect to the rf-supply to the accelerating gap, the optimally distributed feed points with the single cell structure offer in any case the important advantage for rapid pulsing that no energy flow along the accelerating structure is necessary.

Due to the still varying ß along the HELA, the single cells could be optimized in their design individually, it can be shown however, that with one standard cell being used all along the HELA, the overall efficiency does practically not suffer.

The accelerating cavities (and rf-amplifiers), which are now all of identical design, can be manufactured in relatively large series rather than individually. This cannot be done with coupled structures, where in principle no tank will equal any other, except if one tolerates some phase slip between the beam and the rf wave. (Even in the latter case there would still be about a dozen different types.)

In Fig. 5 we have plotted the shunt resistance of the standard cell as a function of particle energy compared with the best results for a Disk and Washer structure.

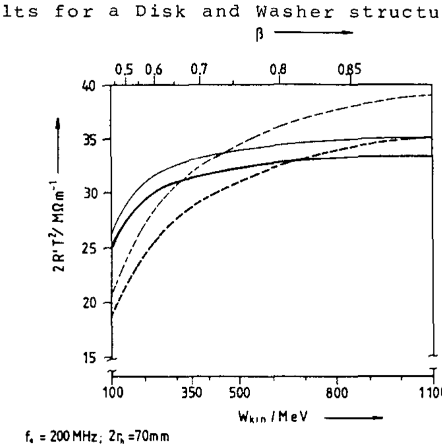

Fig. 5 Calculated Effective Shunt Resistance per Length of

—— Single-Cell Cavity, uncorrected SUPERFISH values

--- D+W Resonator, uncorrected SUPERFISH values

—— Single-Cell Cavity, incl. 5 % additional losses caused by windows, tuners and the surface roughness

--- D+W Resonator, incl. 10 % additional losses

Finally, the single cell concept also offers a non-negligible advantage with respect to the transverse focusing elements. These can be distributed in a much more homogeneous way than with long rf tanks.

Fig. 6 shows the layout of one group of eight single cells being mounted on one common girder.

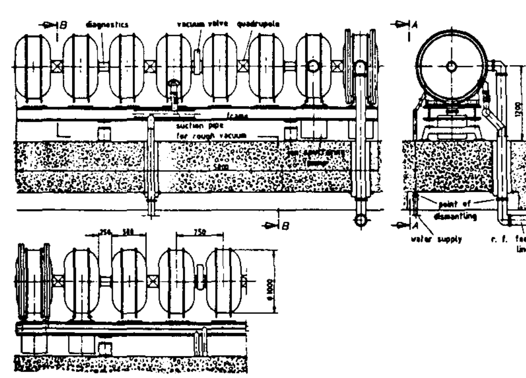

Fig. 6 Layout of HELA-Group

Preliminary calculations suggest that the transverse beam focusing can be made largely independent of the particle energy. Thus the energy variation described above can be achieved without the need to readjust the beam optics.

The Control System

The single cell concept allows operation to continue even if the rf power generator of one or more single cells fail. A consequence of a single cell which does not accelerate any more is a change of the phase advance in the following cells. The phase mismatch is 1.3° and 0.2° for all following cells if the failure occurs at a cell operating at 100 MeV and 350 MeV, respectively, provided the single cell is detuned in order not to be charged up with rf power by the beam. Otherwise the phase change increases to values of 4.6° and 0.7° while the batch is passing. The presence of a non-accelerating single cell is signaled to the control system and the phase of the rf power in the following cells is changed to compensate for the resulting beam delay. If necessary the correct end energy can be maintained nevertheless by slightly decreasing the absolute value of the stable phase angle. It should be emphazized that the actions just described to compensate for a faulty rf generator of a single cell are performed within msec, i.e. between two pulses and that the operation of the accelerator continues without any interruption. Then, during operation, the error can be further diagnosed and the faulty component may be replaced.

The single cavity control system is shown in Fig. 7. The inner three control loops to the left of the cavity are conventional. The resonance frequency is kept constant by mechanical tuning.

In the other two loops the rf amplitude and the phase are stabilized. Because of the options to operate the high energy part of the SNQ accelerator at different stable phase angles, with small and large rf amplitudes and for different pulse currents, the control loops need input settings (E) for the phase generator, (D) for the amplitude loop, (C) for the amplifier chain, and (B) for the tuner. The phases are set with respect to a 200 MHz reference rf signal which is delayed

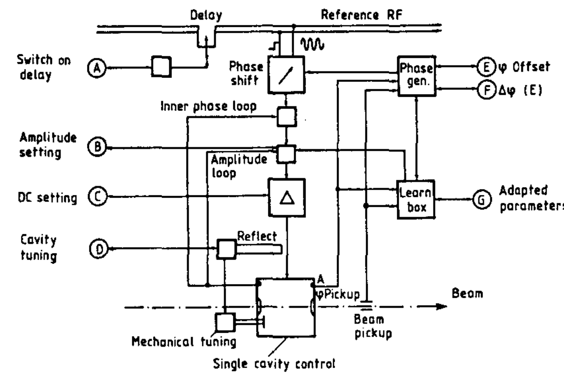

Fig. 7 Block diagramme of the single cavity control system

for each single cell according to the arrival of the bunches in the center of the accelerator gap of a single cell. In a similar way the "switch on" signal is delayed, for example by counting a present amount of rf-cycles, in order to assure the precise charge-up with rf power when the first bunch of a batch enters the single cell.

The technologically more advanced control loops are on the right hand side of Fig. 7. Pick-up signals for the rf phase and beam are fed into the phase generator for determining the actual phase advance φ_s which is compared with the setting value (E) in order to activate properly the phase shifter device. The offset value is corrected by the feed back value $\Delta\varphi$(E) which originates from the end energy measuring device at the end of the accelerator.

A still more sophisticated part in the cavity control system is the learn box which observes the error signals during many batches. Based on an analysis of the information collected from many batches the learn box may change directly the setting value for rf phase and amplitude or create with the support of a computer from a higher level a complete new set of parameter values (G) which are better adapted to the actual situation than the original settings.

Pulse Compressors

A circular accelerator using the SNQ-linac as an injector could highly improve the spectrum of applications of the facility for many users. It would allow the compression of the

Linac pulses by a factor of about 1000 in time. This could be of great interest for some experiments (Neutrinos from the main target, muons and epithermic neutrons).

Because of this a detailed feasibility study for an isochronous compressor ring (IKOR) was done in a joint KFA/KfK SNQ study.

The basic component of IKOR is a ring magnet with alternating gradient and separated functions. Due to the isochronous operation, an rf system can be avoided which otherwise would be necessary in order to maintain a gap in the circulating beam for the purpose of ejection. Injection is performed by charge exchange. The H^- beam of the accelerator is first converted into a H^0 beam by stripping off one electron by a high gradient magnet placed in the transfer channel. Subsequently, the beam is converted into a proton beam by removing the remaining electron through a stripping foil in the ring. Because of the high intensity of 2.7 x 10^{14} protons per pulse and, secondly, due to the high repetition rate of 100 Hz, beam dynamics and radiation protection aspects dominate the design.

Immediately at the completion of injection, the compressed beam would be extracted by a fast kicker in a single turn. The excitation of the kicker must coincide with a void in the circulating beam to avoid particle losses. The void is created by chopping the beam at the low energy end of the Linac. A schematic layout of IKOR is shown in Fig. 8.

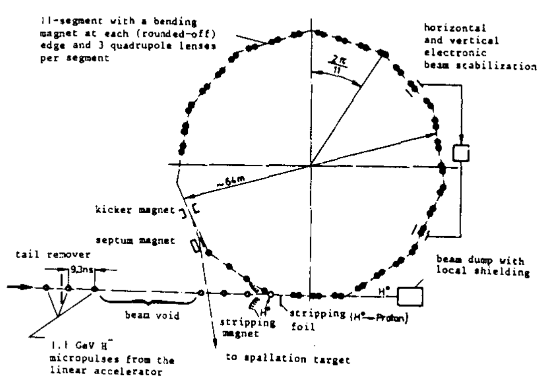

Fig. 8 Schematic layout of IKOR

An alternative possibility to the combination of an 1100 MeV Linac and a compressor would be an FFAG synchrotron, which is an accelerator with a time-constant magnetic guiding field, where particles of all energies between injection and extraction have stable equilibrium orbits. This type of accelerator would be more flexible with respect to injection and extraction energy. Already 350 MeV could be accepted as injection energy for the ring. Further, a FFAG accelerator can be designed for higher extraction energies without the economic penalty of the linear accelerator. On the other hand, an FFAG-accelerator is more complicated than a compressor storage ring. Compared to the compressor, the main differences are the rf system for acceleration and the extended magnetic field to guide particles of different energies.

A schematic layout of an FFAG-compressor is shown in Fig. 9.

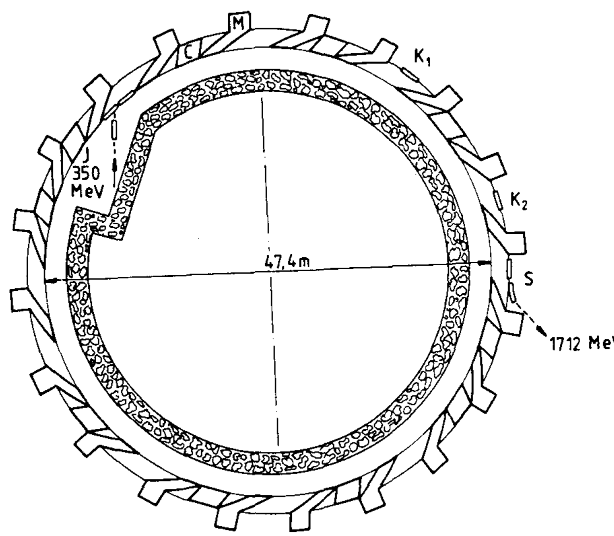

Fig. 9 Schematic layout of an FFAG-compressor