OPERATION OF THE VICKSI-CYCLOTRON WITH TANDEM INJECTOR

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Motivation for an alternate Injector

VICKSI is a combination of a 6 MV single ended High Voltage Engineering CN-Van-de-Graaff and a separated sector four fold symmetry isochronous cyclotron[1,2,3]. The VICKSI Accelerator Facility went into operation in 1978. The cyclotron has a fixed injection radius and a fixed extraction radius for all beams, giving an energy gain factor of about 17. Therefore the energy of the extracted beam is determined by the energy of the injected beam. With the beam energies obtainable from the 6 MV single-ended Van-de-Graaf the cyclotron was practically never operated at its bending limit. This presented a challenge to install a second injector enabling us to obtain higher injection energies, so the cyclotron can be operated at its bending limit for all ion species.

A second reason for an alternate injector is given by the limitations of the ion source of the single ended injector. Due to severe space and power limitations and the lifetime requirements the source can only produce ions coming from gaseous substances. With an injector using an external source we can produce a much greater variety of ion species.

The increased availability of the facility with two injectors was a third reason to install a second injector. Considering all our given limitations, we decided, an 8 MV vertical tandem would be our best choice as alternate injector. In 1981 we received the approval for the project. After receiving the building permits, the construction of the tower for the tandem began in April 1982.

In January 1986 the final acceptance tests for the 8 UD tandem were completed. At present we are running in the VICKSI facility with the tandem injector.

Running in of VICKSI with tandem injector

Figur 1 shows an artists view of the VICKSI accelerator facility with the two injectors. Detailed descriptions of the facility and its subsystems have been given earlier[2,4], therefore we will limit ourselves to describe only features which are pertinent to the present discussion:

The ion source is located on a 200 kV platform. Presently we have only sputter-sources for negative ions available. In the beam line between the platform and the tandem a double-drift harmonic bunching system[5] is installed, with which a time focus at the stripper of the tandem terminal can be produced. The terminal stripper can be operated either as gas- or foilstripper. Behind the stripper an offset quadrupol triplett charge state selection system is installed. Behind the tandem we have a second stripper which increases the charge state of the ions out of the tandem to the charge state necessary for injection into the cyclotron. The bending unit behind the post stripper is designed to provide an isochronous beam path from object to image point. This is necessary to preserve the short pulse length of about 1 nsec produced by the double drift bunching system. In the middle of this unit are the analyzing slits for the proper selection of the wanted charge state and for the energy regulation of the tandem.

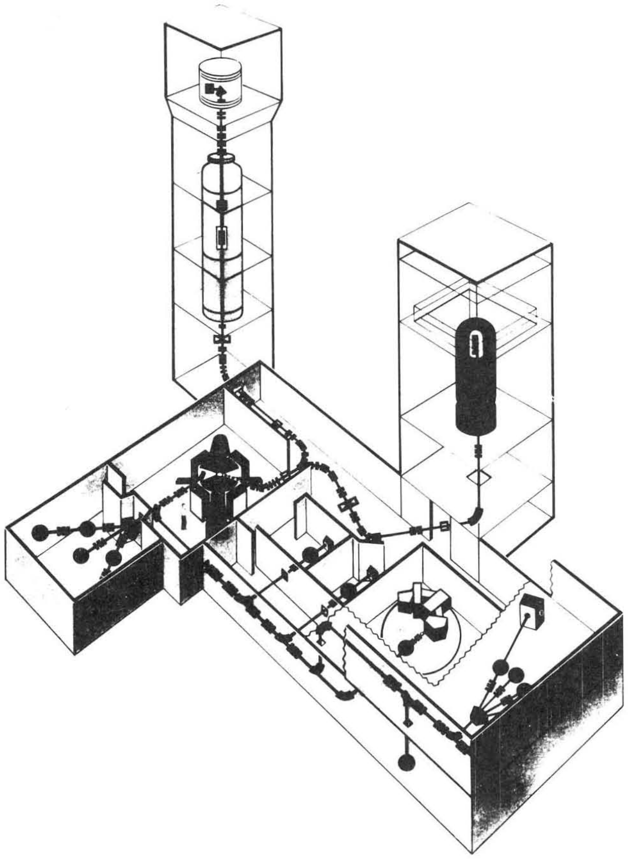

Fig. 1 An artists view of the VICKSI accelerator facility with two injectors

During the first running in period we have limited ourselves to use only the same ion species which were used for the tandem acceptance tests, namely: ^{12}C, ^{32}S, and ^{58}Ni. In the meantime we have also produced a ^{28}Si beam. The production of other ion species is no basic problem, but it was delayed since it requires manpower and time to prepare the optimum sputter targets and to test and optimize the performance of the ion source. During the running in period a host of other minor problems had higher priority.

To prove that the VICKSI cyclotron with the tandem injector can produce the high energy beams it was desiged for (see energy-mass-curve in figure 2) we developed a 384 MeV ^{12}C-beam, a 880 MeV ^{32}S-beam, and a 790 MeV ^{58}Ni-beam. These are beams on the upper boundary of the energy mass region for the VICKSI cyclotron with tandem injector. The quality and intensity of the ^{12}C-beam was excellent. For the S- and Ni-beams however the beam intensities were considerably smaller than what we had calculated and expected.

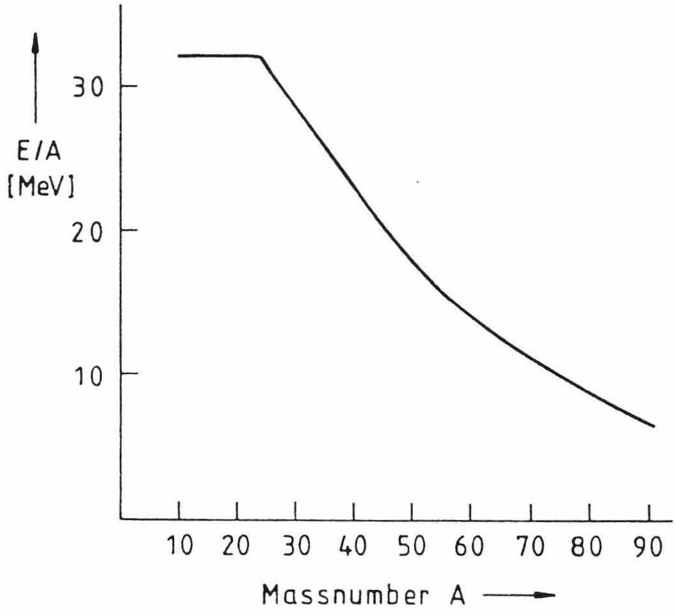

Fig. 2 Energy versus Mass diagram for the VICKSI cyclotron with Tandem injector

An investigation into where the losses were occuring revealed, that a combination of several reasons was responsible for the unexpected low beam intensities.

Terminal Gas Stripper.

First we observed, that the target thickness of the gas stripper in the tandem terminal was far thinner than the pressure reading had indicated. Therefore the stripping efficiency was considerably below our calculated values. By increasing the gas flow to the stripping chamber we were able to get a saturation thick target for the required energies of the incoming beams. However, then the vacuum in the accelerator tubes of the tandem is already affected. Therefore we might need to go to a two stage differentially pumped gas stripper to be sure that the tube vacuum will not be affected by operating the terminal gas stripper.

Terminal charge state selection system.

We also observed that particularly for heavier beams it was mandatory to use the charge state selection system in the terminal: If all charge states produced in the terminal stripper go through the high energy tube, ions with up to five different energies will get to the post stripper. Each of these beams will than again produce several beams with different charge states. One thus can often obtain as many as 20 to 25 beams of different charge states and energies, some of which have almost identical magnetic rigidity but different energy. A sample of different beams and their respective rigidities and stripping efficiencies is shown in figure 3 for a S-beam at 7.8 MV terminal voltage. If the desired beam lies very close to another beam which might have a much higher intensity, it becomes impossible to stabilize the tandem on the proper beam. Therefore the charge state selection system in the tandem terminal must be in operation to assure, that only one beam with the desired energy gets to the stripper behind the tandem. The charge state selection is achieved with a quadrupole-triplett, whose axis is displaced against the beam axis. Furthermore the inner part of the triplett is displaced against the two outer parts. This triplett provides a steering and a focussing effect in such a way, that at a given distance behind the triplett the selected charge state is on axis, with the proper direction and in focus. All other charge states are either out of focus, or displaced from the axis or both. An aperture at this location on the beam axis will than leave only the selected charge state unaffected. The alignment of the stripper channel exit, the offset-triplett, and the selection aperture is rather critical, and any misalignment can lead to considerable loss in transmission. We observed, that with a carbon beam the selection of the desired charge state is achieved already with a 22 mm selection aperture. In that case we have 100 % transmission. Choosing a 6 mm aperture, which is necessary for the heavier elements leads to a loss of about a factor of 2 to 3. This seems to indicate a misalignment of the system.

B x Rho (KG x m)	stripping efficiency	charge states	
0.3655941E+01	0.2935860E-02	4	14
0.3736400E+01	0.1518550E-02	5	15
0.3782530E+01	0.1010962E-03	6	16
0.3817375E+01	0.5457795E-02	3	12
0.3937168E+01	0.2449662E-01	4	13
0.3971468E+01	0.1520544E-03	2	10
0.4003286E+01	0.1822113E-01	5	14
0.4034699E+01	0.2852312E-02	6	15
0.4042953E+01	0.9849890E-04	7	16
0.4164409E+01	0.9054915E-02	3	11
0.4265265E+01	0.6064029E-01	4	12
0.4287649E+01	0.4870112E-04	8	16
0.4311231E+01	0.7893011E-01	5	13
0.4312483E+01	0.2212222E-02	7	15

Fig. 3 Rigidities, stripping efficiencies and charge states out of the terminal stripper and out of the post stripper for a S-beam at 7.8 MV terminal voltage

Beam losses in the post stripper region.

When we compare the intensities of the beam before the stripper to the intensities of the selected charge state after the stripper, there can be a discrepancy of up to a factor of three between the measured and tabulated efficiencies. It is not clear yet, what the reason for this discrepancy is.

Transmission through the cyclotron.

When we operate the cyclotron with beam from the tandem injector, the turns in the cyclotron are not quite as narrow and clear as we are used to from the CN-injector. This is due to the fact, that we are lacking one bend after the buncher to get rid of particles with wrong RF-phases. These particles wash out the turns in the cyclotron and they are partly responsible for the disadvantage that we have not totally separated turns at extraction. Therefore we are looking into the possibility to install phase selection slits at an inner orbit of the cyclotron. Furthermore with the Dee voltages we are using now, the turn separation at extraction for the high energy beams will decrease to about 3 mm compared to about 10 mm we have today. This will also reduce the extraction efficiency considerably. We are planning to operate the Dees at voltages up to 125 kV in the future, which seems possible without major changes on the RF-systems.

Some of the injection and extraction elements of the cyclotron are used at the maximum currents or voltages, when we are at the highest energies. This does not seem to affect the transmission very much. No plans for any changes on these elements are foreseen.

Conclusion and Outlook

The operation of VICKSI with the new tandem injector was not quite as straightforward as we had hoped. We have however been able to show that the desired high energies can be reached. Most of the reasons for the unexpected low intensities at maximum energy are recognized and measures to either prevent the losses or to increase the intensity are in progress. By increasing the maximum current in the main magnet coils by 10 % we also could push the bending limit up to an energy constant of K = 136 MeV. In very recent test-runs we successfully developed a 4nA-beam of 960 MeV $^{32}S^{15+}$ and a 150 uA beam of 410 MeV $^{12}C^{6+}$. That is beyond the design aim for the Tandem Project.

One of the severe limitations for VICKSI and a reason for the delayed operation of VICKSI with tandem is the lack of manpower, especially as the tandem project was pushed through without reducing the normal operation of VICKSI significantly. Due to this we had very little time available for beam tests of the cyclotron with tandem injector. Nevertheless we are confident, that the remaining problems can be solved and that in the near future VICKSI will produce beams even beyond the specifications which were the basis for the tandem proposal.

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