RECENT DEVELOPMENTS OF THE TRIUMF CYCLOTRON AS AN H^- INJECTOR FOR THE KAON FACTORY

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Summary

The TRIUMF facility is presently based mainly on the 500 MeV H^- cyclotron delivering simultaneous proton beams up to 200 μA intensity to various users. Recently a proposal for a KAON Factory facility has been submitted where the H^- cyclotron is to be used as an injector. This has to be modified to allow direct extraction of a $\gtrsim$100 μA H^- beam. A feasibility study has been performed and shows that direct H^- extraction from the cyclotron is indeed possible with an efficiency greater than 90%. Experimental evidence of this will be presented. Other modifications for beam quality, beam intensity and reliability are introduced in the 500 MeV cyclotron progressively in line with the high level of performance required from the cyclotron. These will be briefly discussed.

Introduction

The TRIUMF facility has recently celebrated its first ten years of operation. The 500 MeV H^- cyclotron presently produces routinely two or three simultaneous proton beams, of variable energy, with a total current of 150 μA. Extracted peak currents of 208 μA cw and 250 μA pulsed have been demonstrated, exceeding the original design goal of 100 μA operation. Developments for upgrading the intensity to 300 μA during the next two years and to 500 μA within the next five years are proceeding. Other cyclotron developments are being actively pursued. These include (i) an optically pumped polarized ion source with a potential of 50 to 100 μA extracted (the source intensity is at present adequate to ensure 5 to 10 μA extracted); (ii) rf booster cavities to triple the energy gain per turn and hence reduce electromagnetic stripping losses in the 400-500 MeV region; (iii) third harmonic flattopping of the fundamental rf waveform for separated turn extraction and improved phase space acceptance in the centre region.

In a parallel effort the design of a 30 GeV 100 μA 10 Hz synchrotron proton facility has been completed, a formal proposal has been written and review committees have met to evaluate the scientific, technical and economic merits of the project. Because of the high value of a project of this size on the Canadian scientific and technological scene and its high scientific potential for particle and nuclear physics (the proposal obtained an extremely good review from the international technical-scientific review committee), the project makes such a compelling case for Canada that it is very likely to be funded.

The use of the present cyclotron as an injector for the 30 GeV facility hinges on the capability of extracting from the present cyclotron an H^- beam of more than 100 μA, so that an external accumulator ring can be injected via charge exchange through stripping. This will solve at least in part the problem of matching the continuous stream of beam bunches produced by the cyclotron at 23 MHz to the 10 Hz pulsed beam structure required by the synchrotron. Through charge exchange several cyclotron bunches can overlap in the same phase space in the injection accumulator ring. However, only a limited number of passages through the foil (about 100 per particle) can be allowed in order to avoid excessive heating of the foil and a large emittance growth through multiple scattering. More turns can be accumulated if the beam is moved away from the stripping foil to paint the acceptance of the accumulator in all six dimensions of phase space. It has been shown[1] that a total of about 10,000 bunches can be efficiently accumulated in to the same longitudinal phase space with the average particle making only 100-200 traversals through the foil.

An alternative to this injection system would be a LAMPF type linear accelerator of energy 800 MeV, say. The cost and manpower implications of this alternative however are substantial and suggest that the TRIUMF cyclotron be used at 450 MeV where H^- extraction is feasible. The demonstration of the feasibility of H^- extraction is another major development effort and will be described below.

The Kaon Factory Proposal

The TRIUMF Kaon Factory design has been recently described.[2,3] Only the major parameters (see Table 1) and some of the design criteria will be given in this section.

Table 1

Synchrotron Design Parameters

		Booster	Driver
Energy		3GeV	30GeV
Radius		4.5 R_T= 34.11m	22.5R_T= 170.55m
Current		100μA = $6x10^{14}$/s	100μA =$6x10^{14}$/s
Repetition Rate		50 Hz	10Hz
Charge/Pulse		2μC =$1.2x10^{13}$ppp	10μC =$6x10^{13}$ppp
No. Superperiods		6	12
Lattice Structure	Focusing	FODO	FODO
	Bending	OBOBBOBO	BBBBBOBO
No. Focusing Cells		24	48
Maximum $\beta_x X \beta_y$		15.8m x 15.2m	38.1m x 37.5m
Dispersion η_{max}		4.0m	9.09m
Transition $\gamma_t = 1/\sqrt{\bar{\eta}}$		9.2	∞
Tunes ν_x X ν_y		5.23 x 7.22	11.22 x 13.18
Space Change $\Delta\nu_y$		-0.15	-0.09
Emittances at Injection	ε_xx ε_y	139π x 62π (μm)	37π x 16π (μm)
	ε_{long}	0.064eV-s	0.192eV-s
Harmonic		45	225
Radiofrequency		46.1→61.1MHz	61.1→62.9MHz
Energy gain/turn		210keV	2000keV
Maximum RF Voltage		576kV	2400kV
RF cavities		12 x 50kV	18 x 135kV

The layout of the proposed facility is given schematically in Fig. 1. The acceleration process between 450 MeV and 30 GeV is accomplished through two fast cycling synchrotrons and two dc storage rings. From the cyclotron vault the 450 MeV H^- beam is transported to the Accumulator ring (A) which has a radius of 34.11m, 4.5 times larger than the effective radius of the cyclotron extraction orbit. The accumulation period is 20 ms (Fig. 2). The beam is then injected into a 3 GeV Booster (B) cycling at 50 Hz, situated in the same tunnel. Bucket-to-bucket transfer is planned to minimize losses.

The injection frequency in the accumulator is 46.1 MHz, double the TRIUMF frequency, so that 45 rf buckets, one every 22 ns, are actually available to the continuous sequence of bunches produced every 44 ns by the cyclotron. It takes nine TRIUMF turns (45 bunches) to fill one turn of the accumulator in two revolution

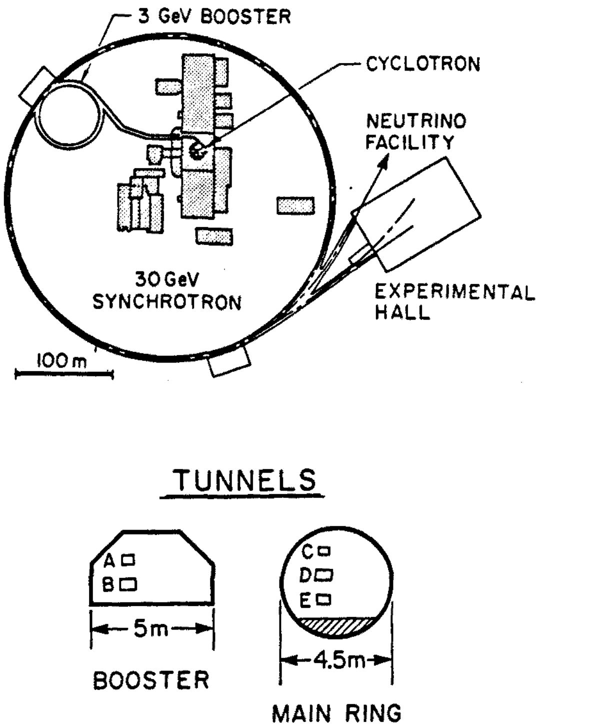

Fig. 1. Proposed layout of the KAON Factory and cross sections through the tunnels.

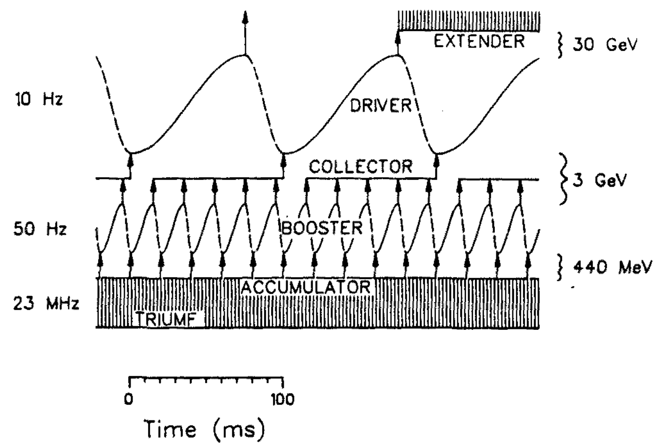

Fig. 2. Energy-time plot showing the progress of the beam through the five rings.

periods. Successive buckets in the accumulator receive cyclotron bunches on alternate turns. It is convenient to maintain a gap in the time structure of the beam, to allow time for switching extraction kicker magnets on and off. This can be accomplished by eliminating the bunches corresponding to half a turn every four a half turns of cyclotron operation. With separated turns in the cyclotron this is possible through ion source pulse programming, otherwise a fast pulser is required on the 450 MeV line. The result is a 110 ns gap in the accumulator (shrinking to 80 ns at 30 GeV) every 40 bunches, or 0.87 μs (0.62 μs at 30 GeV).

The 3 GeV value of the Booster energy was set mainly because of cost minimization. It is convenient to have most of the total required frequency swing (from 46.1 to 62.3 MHz) take place in the 3 GeV Booster, since the beam power here is only 300 kW and total peak rf voltage around 600 kV. Also, due to adiabatic damping of the betatron oscillation in the Booster, the beam size and therefore the magnet aperture requirements at energies above 3 GeV are substantially reduced.

The cycling rate of the Driver synchrotron (D) is 10 Hz, which implies a five times larger radius, i.e. 170 m. The total energy gain per turn requirement is 2,000 keV implying a total maximum rf voltage of 2,400 kV (18 cavities at 135 kV). However, the frequency swing is now substantially reduced (61.1 to 62.9 MHz) which makes the cavity design simpler. A Collector ring (C) above the Driver in the same tunnel has the main function of collecting five trains of 40 bunches from the booster every 20 ms and to stack them head-to-tail to form a ~3 μs pulse to be injected every 100 ms into the Driver synchrotron (Fig. 2). It also allows the longitudinal phase space to be increased appropriately, so that active dumping by feedback can be used to cure longitudinal instabilities.

In the Driver the fast cycling rate keeps the charge per pulse down to N=10 μC (6 x 10^{13} protons) and restricts the time available for instabilities to develop. The circulating current of 2.8 A is 20% higher than that in the Argonne IPNS and not quite double the 1.5 A at which the CERN PS operates. Intensity-dependent effects, such as tune shift, instabilities and beam loading, therefore lie in a well-understood region. The higher average current is made possible not only by the higher cycling rate but also by the higher injection energy which limits the space charge tune shift $\Delta\nu \sim -N/\beta^2\gamma^3$ (β and γ are the usual relativistic speed and energy parameters).

A 30 GeV stretcher ring or Extender (E) is provided in the driver tunnel for slow extraction. The fast extraction beam from the driver will be switchable on a pulse-to-pulse basis between the Extender, for coincidence experiments with kaons other hadrons and antiprotons, and a neutrino production target.

The rings use separate function lattices, designed for a very high transition energy. Dual frequency magnet power supplies provide a 3:1 rise to fall ratio, reducing the peak RF voltage requirements for the booster and driver to the values quoted above. High-γ_t lattices are obtained mainly by creating a superperiodic structure with missing magnet cells and by choosing the horizontal tune just below the number of superperiods.[4] The empty cells provide natural spaces for the installation of rf cavities and injection and extraction equipment. Identical lattices and tunes are used for the rings in each tunnel, providing structural simplicity, similar magnet apertures and straight-forward matching for beam transfer.

Feasibility of H^- Extraction From the Cyclotron

H^- ions are routinely injected into the TRIUMF cyclotron at 300 keV with >60% acceptance, accelerated to 500 MeV with >80% transmission, and extracted by stripping with 99.95% efficiency. The beam loss due to electromagnetic stripping is 8% and occurs between 440 MeV and 500 MeV. It is at present the major factor contributing to the build-up of activation at the periphery of the machine, and limits high intensity operation. By extracting at ~450 MeV, the induced activation would be reduced by an order of magnitude, leading to easier maintenance (more hands-on and less remote handling) and increased reliability. Another reason for extracting at this energy is that ν_r=1.5 at 430 MeV.

Direct extraction of an H^- beam requires the use of electrostatic and magnetic channels. In the TRIUMF cyclotron however a major difficulty is caused by the fact that the peak energy gain per turn of 0.3 MeV corresponds to a radius gain per turn of only 1.5 mm, which is comparable to the amplitude of radial incoherent oscillations. This coupled with a phase width of ±5° leads to overlapping turns. Since the effective

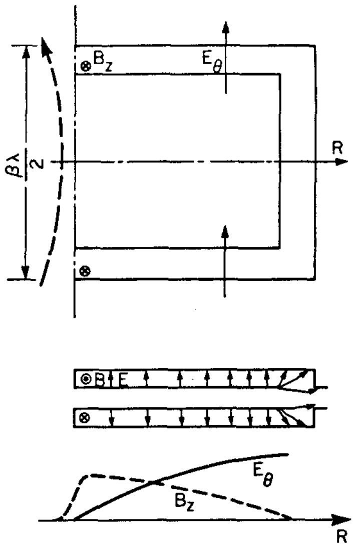

Fig. 3. The booster cavity shown in plan view (top) and in cross section (middle). The midplane fields as seen by the circulating particles are also shown (bottom).

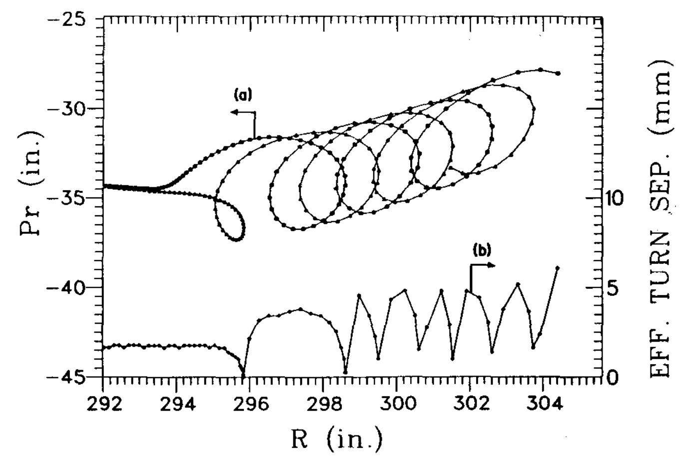

Fig. 4. Curve (a) shows a coherent oscillation generated by the rfd (110 V/mm•m) for $\nu_r>3/2$; $p(in)=4.3\times10^{-7} p(eV/c)$. Odd and even turns are joined separately. Curve (b) shows the effective turn separation produced.

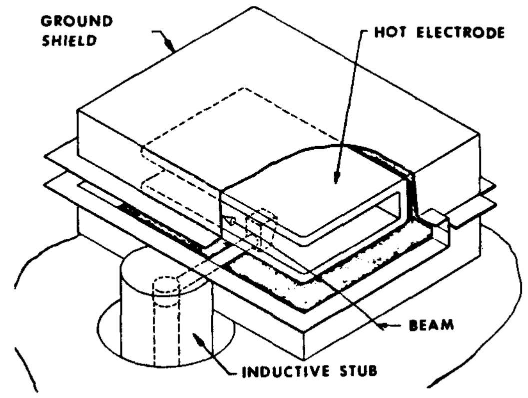

Fig. 5. Outline of the rf deflector.

thickness of an extraction septum could hardly be reduced much below 0.5 mm, and since successive turns overlap, the extraction efficiency would not be much better than 50%. Two methods were considered to improve this situation.

Firstly, two or three 150 kV rf cavities, operating at the 4th harmonic of the 23 MHz fundamental rf frequency can be installed inside the cyclotron vacuum chamber to boost the energy gain per turn to 900 or 1200 MeV. Turn separation can therefore be increased by a factor three to four to 4.5 mm and 6 mm and extraction efficiency to 80 ~ 90%. An rf booster cavity (RFB) is shown schematically in Fig. 3. It is $\lambda/4$ wide in the radial direction and $\beta\lambda/2$ long in the azimuthal direction so that the ion receives two comparable energy kicks per passage. Each cavity is formed with two symmetric separate units mounted on the the cyclotron chamber floor and lid separately. It was determined that the leakage from the cavity does not excite substantial stray RF fields in the cyclotron chamber.

Alternatively and perhaps more elegantly an rf radial deflector unit (RFD), can be installed in the ν_r=1.5 resonance region (430 MeV) to perturb radially the accelerated beam bunches with alternate inward and outward kicks.[5] It operates at 11.5 MHz and provides a peak radial electric field of ~2 kV/cm along 50 cm of orbit. A given bunch receives inward and outward kicks on successive turns, but because ν_r is 3/2 all kicks increase the displacement from the equilibrium orbit in a coherent mode. Successive bunches passing through the RFD receive kicks that alternate between inward and outward; thus different "even and odd" paths are formed in phase space. A given particle occupies a position on each path on alternate turns. It will be extraced from an even or odd path depending upon which path reaches the extraction radius first. Extraction takes place over 2 turns even for a "separated turn" microemittance. An example is given in Fig. 4 for a general orbit code calculation assuming an RF impulse of 110 V/mm•m.

One can notice that the turn separation is again increased to 5 ~ 6 mm if one considers the 5th or 6th coherent oscillation generated by the resonance. The RFD unit is shown schematically in Fig. 5. An open C-type structure is used. This is connected to a cylindrical coaxial inductive stub designed to operate as a $\lambda/4$ resonator. The power requirement is about 4 kW for a 27 kV peak on the deflector.[6]

The ray tracing code Goblin and the matrix multiplication code COMA were used to investigate optimum voltages and positions of the RFD and of the RFB cavities. The density pattern obtained with an RFD field impulse of 110V/mm.m is given in Fig. 6a. The dilution factor (ratio of beam density with RFD off and RFD on) is of the order of 4 to 5 on the fourth oscillation. For typical values of the accelerated emittance and phase interval, say 1 mm mrad and ±6°, turn separation and beam density appear to be directly correlated. The beam intercepted by a 1 mm wide obstruction (simulating the septum of an electrostatic channel including shadow effects) has been calculated to be about 10% in the fourth minimum of the diagram of Fig. 6a, corresponding to an extraction efficiency of ~90%.

The dilution factor increases with the RFD voltage, but the extraction efficiency does not necessarily increase. A limit is reached at 200 V/mm•m (50 kV), where the internal RFD excited orbit would start overlapping with the geometry of extracted orbits reducing the angular clearance required for the electrostatic septum. Also, if the oscillation is too large, a destructive resonance effect excited by a small residual gradient in the 3rd harmonic of the magnetic field, can take place. The dilution and therefore the extraction efficiency can be enhanced by the simultaneous use of the RFD and one or two booster cavities. The effect using one 150 kV booster cavity is shown in Fig. 6b.

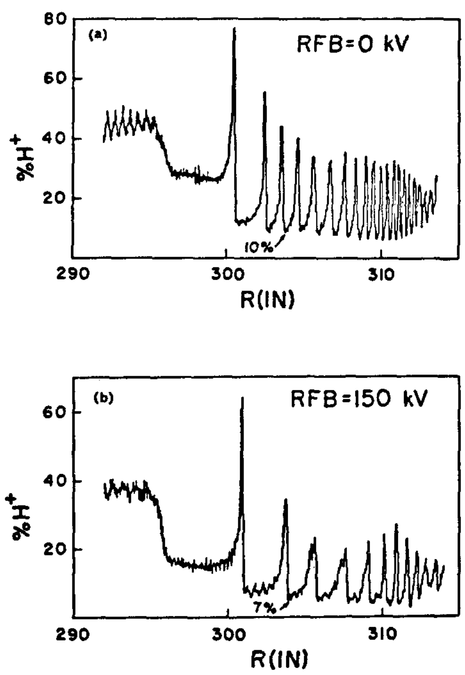

Fig. 6. Comparison of calculated dilution patterns produced by the rf deflector for: (a) rf booster off, (b) rf booster on for the same effective rf deflector strength (110 V/mm•m).

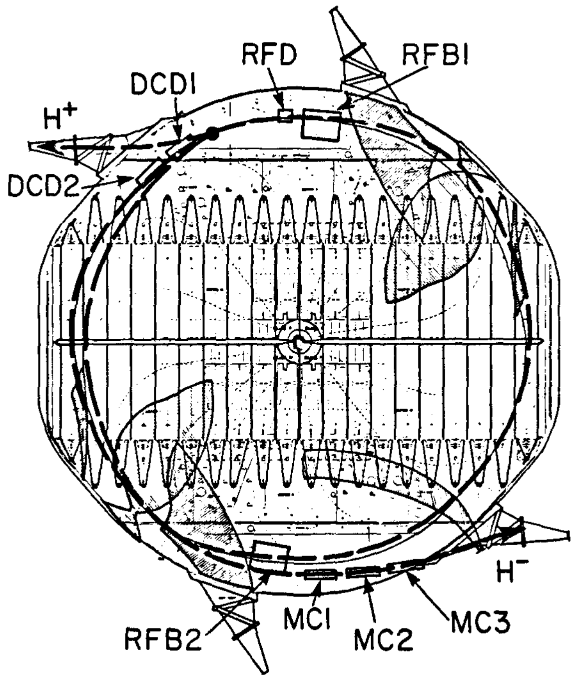

Fig. 7. Layout of the H^- extraction scheme. DCD: electrostatic channel, RFB: rf booster, RFD: rf deflector, MC: magnetic channel.

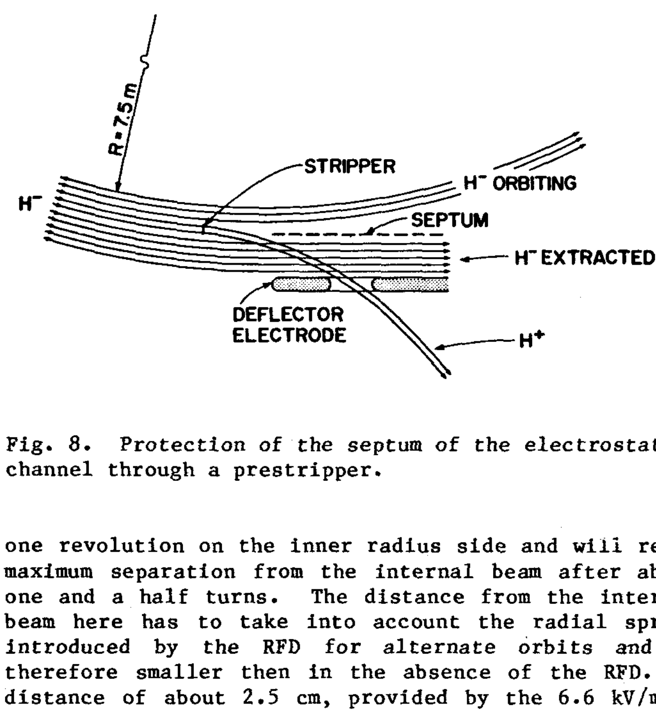

Fig. 8. Protection of the septum of the electrostatic channel through a prestripper.

Extraction efficiency increases from 90% to 93%. With two booster cavities the efficiency would increase to 95%. Perhaps more importantly the energy at which good efficiency can be obtained increases from 450 MeV to, say, 475 MeV still with reduced H^- loss.

A possible layout of the extraction elements in the vacuum tank of the cyclotron is given in Fig. 7. The extraction elements have, whenever possible, been inserted in regions free from existing devices, although modifications to cryopanels, probes and service access ports are envisaged where necessary. The azimuthal positions of the rf booster cavities and of the RFD cavity are not too critical. Radially the field of RF booster cavities starts at a radius corresponding to 350 MeV and the field of the RFD cavity at a radius of 425 MeV.

The first electrostatic deflector (DCD) is positioned about 100 turns (with booster voltage off) after the entrance of the RFD in a position where the RFD has created a minimum in beam density (Fig. 6). To avoid heat and radiation damage to the septum and other equipment, an artificial separated turn situation is created by intercepting the fraction of beam which would hit the septum with a prestripper foil located just upstream along the orbit (Fig. 8). The foil is situated azimuthally in a position which will extract the prestripped beam down an existing beam line. Immediately downstream, in the shadow of the prestripper, are the two electrostatic channels required to provide a transverse momentum gain larger than ~6 kV/mm.m. This can be obtained with two positive voltage 40 kV electrostatic channels, each 13 mm wide and 1 m long, or one only 13 mm wide and 1.3 m long, 60 kV channel. High positive voltage holding in the 0.5 Tesla field of the cyclotron is difficult. It requires careful design and a series of measurements and modifications are being carried out on a DCD in a laboratory vacuum chamber with magnetic field equivalent to the cyclotron. At the moment the conservative approach with two channels is being retained.

After receiving the deflection from the DCD electrodes the deflected beam will oscillate at a ν_r slightly above 3/2. It will clear the dcd system after one revolution on the inner radius side and will reach maximum separation from the internal beam after about one and a half turns. The distance from the internal beam here has to take into account the radial spread introduced by the RFD for alternate orbits and is therefore smaller then in the absence of the RFD. A distance of about 2.5 cm, provided by the 6.6 kV/mm.m momentum gain above is considered sufficient to insert a first septum magnet for the final extraction. A total of three magnetic channels are presently envisaged to provide the total 1.4 T.m deflection required to exit the cyclotron along an acceptable trajectory. The first septum magnet channel has to be small enough to fit the space between internal and extracted beam and its fringe field has to be small enough not to perturb substantially the internal beam. The design is based on a structure of water-cooled copper conductors (see Fig. 9) producing a field of 700 gauss over a distance of ~ 0.7 m, with a radial gradient not exceeding 50 G/cm. A prototype is being built and will be tested very soon with the beam. The

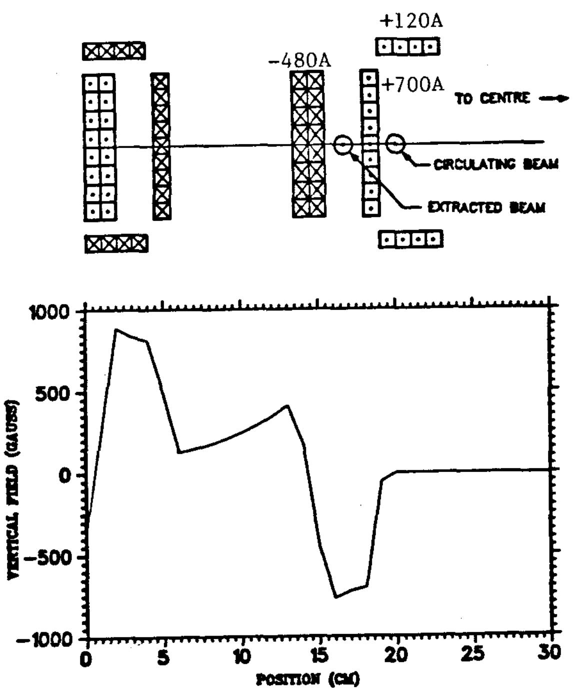

Fig. 9. A cross section through the first magnetic channel, and the vertical component of magnetic field on the median plane.

second and third channels will likely be of a coaxial cos θ current distribution type of design. Such channels are capable of operating at higher internal fields while producing little external fringe field.[7] Their dimensions have not yet been finalized, but they will be progressively stronger as the separation from the circulating beam increases.

A view of a prototype electrostatic channel is given in Fig. 10. A 1 m long unit was constructed for the first beam tests. In this unit the septum consists of 140 vertical spring-loaded molybdenum foils 5 mm wide, 0.076 mm thick, separated by two mm gaps, located in position by two matching stainless steel templates contouring the 450 MeV orbit and centered on the beam plane. The antiseptum is made of type 347 stainless steel, air cooled and supported by aluminum insulators below the median plane, to avoid radiation damage. Positive and negative voltage holding of +40 kV and -80 kV respectively can be routinely achieved in the laboratory and have been used in the cyclotron tests.

Beam Measurements

H^- extraction tests are carried out in the cyclotron during maintenance-development shutdown periods, which occur twice a year and last for several weeks. Normally, before the tests, the beam phase acceptance is limited through slits to a ±5° phase interval and incoherent and coherent oscillations are limited to 2 mm and 1 mm amplitude respectively.

The behaviour of the beam perturbed by an RFD unit was studied first. A radial differential probe scan (Δr=1.25 mm) obtained with an integrated RFD field of 110 V/mm.m is given in Fig. 11. The peak structure and the dilution factor are in very good agreement with the predictions of Fig. 6a. The small density oscillations with RFD off are due to ellipse stretching and subsequent precession due to a small residual gradient in the third imperfection harmonic of the magnetic

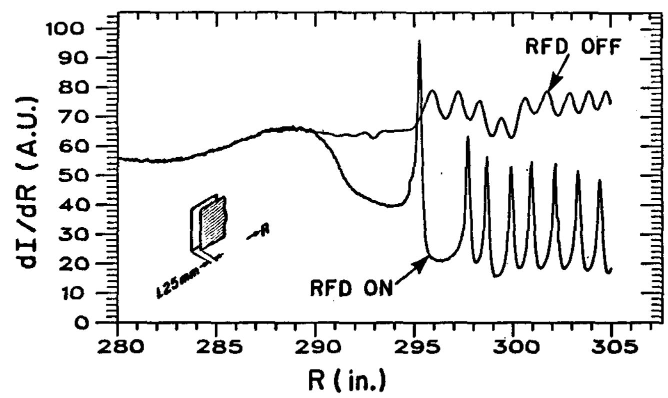

Fig. 11. Beam density measured by a differential probe head, 1.25mm wide, for RFD off and RFD on (110 V/mm•m). Beam density is reduced by a factor of 4.

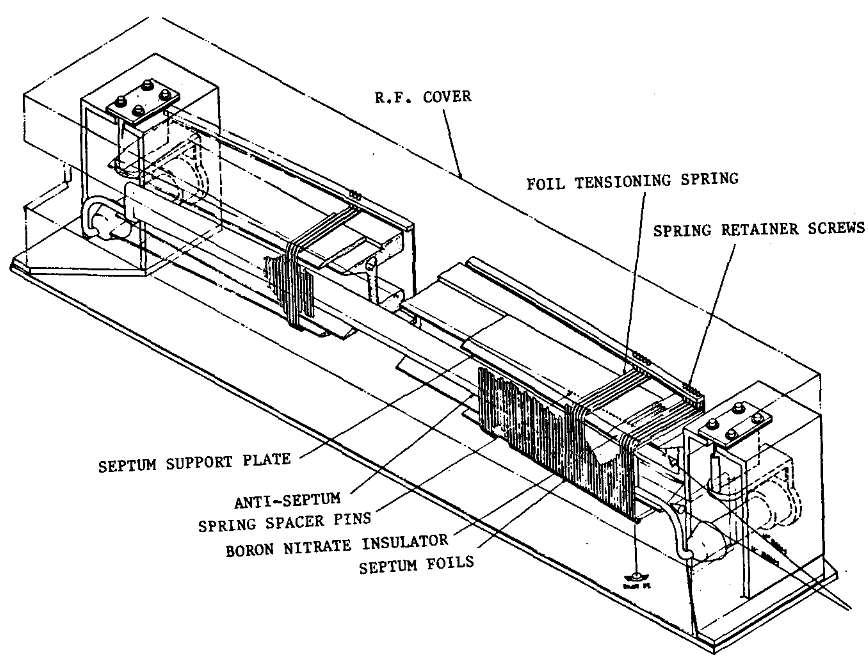

Fig. 10. Sketch of the electrostatic deflector.

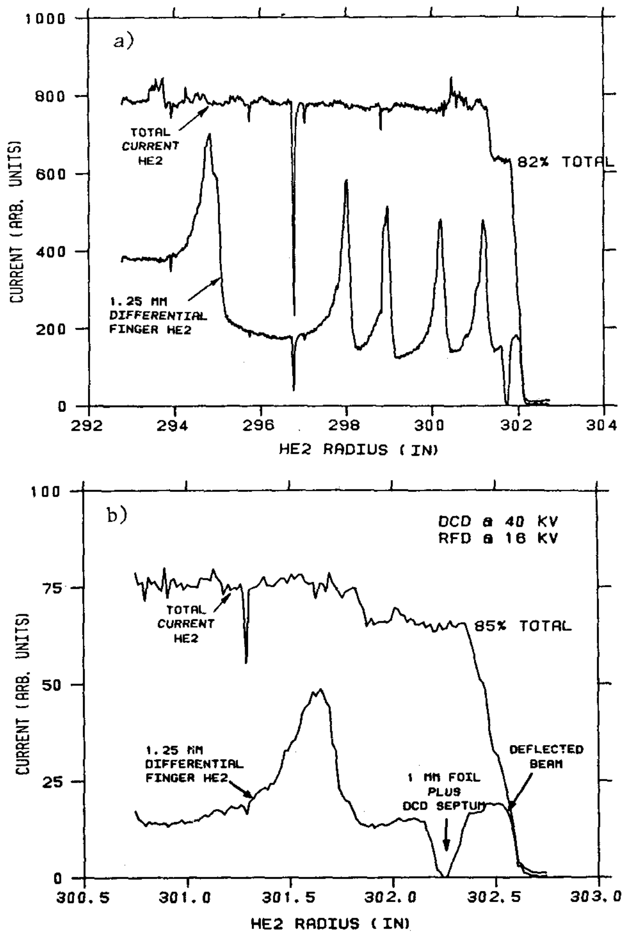

Fig. 12. a) The rfd turn dilution pattern as measured on the differential head of probe HE2. In addition the total current is plotted to show the H^- transmission through the DCD of 82%. The DCD septum is positioned in the 5th minimum. b) Expanded view of the turn pattern near the DCD. The deflected beam and the shadow produced by the prestripper foil and the septum may be seen. The transmission through DCD is 85%; DCD voltage = 40 kV, RFD voltage = 16 kV, extracted beam current = 20 μA peak.

field.[8] Detuning the isochronism below 400 MeV or the centering had little effect on the dilution pattern proving the inherent stability of the extraction scheme.

In another series of measurements the DCD was installed in the cyclotron with the RFD. An extraction stripping foil 1 mm wide was used upstream of the septum as a prestripper. The resulting radial differential scan obtained from a probe at an azimuth immediately downstream of the deflector, is given in Fig. 12a and is self-explanatory. A small region without beam can be observed in the fifth density minimum, followed by a peak corresponding to the extracted beam. The total current scan confirms the sudden current loss at the same radius due to prestripper and septum, and 82% transmission is observed. During another measurement (Fig. 12b), the voltages of the RFD, DCD and the radial and angular position of prestripper and septum could be optimized to give 85% extraction efficiency. During these tests one of the two DCD drive mechanisms stalled. This prevented further optimization of the radial position of the septum with respect to the optimum RFD voltage and the optimum minimum in the dilution pattern could not be used. We are confident that, once the initial equipment problems are

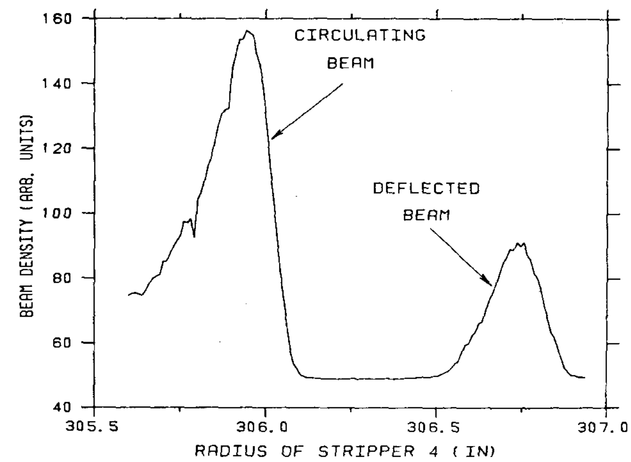

Fig. 13. The beam deflected by the DCD. The beam density was measured by scanning stripper 4 probe in radius.

corrected, 90% transmission be achieved. Note that the 1 mm prestripper and septum position could be arranged so that no beam was intercepted by the septum, proving the accuracy of the construction and of the alignment of the septum with respect to the beam orbit. A further reduction of the prestripper width is possible. The prestripped beam was extracted down an existing beam line during the test.

In Fig. 13 the radial distribution of the internal and separated beam are explored at an azimuth one and a half turns downstream with respect to the prestripper and DCD. The opposite extraction foil, X_4 (0.75 mm wide) is being used to scan the density. A distance of 15 mm is measured between the internal beam and extracted beam with 40 kV on the DCD and 16 kV on the RFD. The pattern is in complete agreement with COMA computer simulations. During these tests the maximum DCD voltage was 42 kV, limited by excessive leakage current along some of the insulators.

The current extracted in a 5% pulsed mode was 1 μA. This corresponds to a 20μA equivalent beam. The current limitation is determined mainly by the restricted acceptance in the centre region. Relaxing this acceptance slightly and using (i) a brighter ion source, (ii) improved bunching and (iii) third harmonic rf flattopping will give the required increase to 100 μA or more.

Other Cyclotron Improvements

Resonator Improvements

The TRIUMF rf resonator system has in the past been one of the weaker cyclotron systems, mainly because of cavity distortion associated with leakage of rf energy from the rf cavity into the beam cavity.[9] In brief, the eighty ~3 m long cantilevered segments forming the 16 m wide, 50 cm high, flat dee to dee cavity were subject to heating due to the rf leakage. The resultant heat-induced distortions cause additional leakage, leading to a potential runaway condition which can result in melting of structural components. This has not occurred during the last five years. Now, temperatures of segments are constantly monitored and the leakage mechanism is understood and can be partially controlled by altering the ground-arm to hot-arm distance at the tip of the segments. An example of the measured and calculated leakage pattern based on a superposition of TM_{310} and TM_{410} modes with appropriate amplitudes and phases is shown in Fig. 14. New, rigid and stable cooled strongback segments have been built

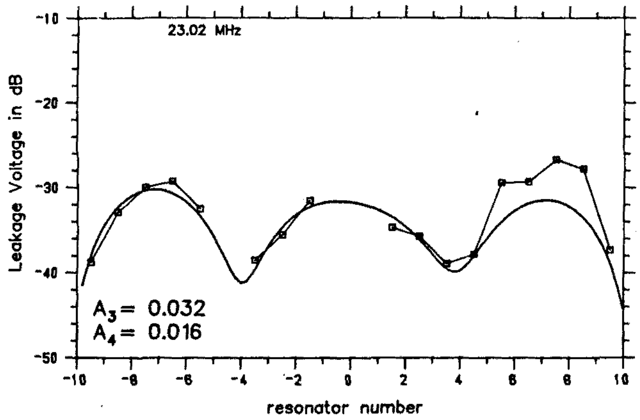

Fig. 14. RF leakage on the strongback is composed of the TM_{310} and the TM_{410} modes with amplitudes A_3 and A_4, respectively. The squares are the measured leakages and the smooth curve is the theoretical fit.

and are being installed in the cyclotron cavity in critical positions where the leakage power is normally amplified by multipactoring effects.

Two significant milestones have been achieved in light of the new emphasis for third harmonic flattopping. In a teststand cavity consisting of two cyclotron segments placed symmetrically above each other and connected by side flux coupling guides, a stable, flattopped waveform was produced and maintained at full power and 80 kV voltage. Multipactoring problems were overcome and automatic feedback loops for phase and amplitude controls were realized and optimized. In another effort, on the 1:10 model, solutions for a uniform third harmonic voltage behaviour along the dee gap were explored and a larger scale (1:3) model for detailed tailoring of the modifications is under construction. Replacement of the central region segments will proceed before full power tests in the cyclotron can take place.

Ion Sources

A DC multicusp type ion source using a magnetic filter to enhance the volume production of H^- ions, has been developed for the TRIUMF cyclotron.[10] 2 mA of H^- have been achieved within the TRIUMF acceptance (0.15 π mm mrad, normalized). Calculations show that this current is adequate to extract 500 μA from the cyclotron in the future.[11] The source requires much less maintenance than the operating Ehlers H^- ion source: filaments last at least five times as long. The new source is also significantly less noisy than the Ehlers' source. High frequency (~1 MHz) noise from the Ehlers' source varies in an uncontrollable manner between 2 and 10%. Noise from the cusp source never exceeds 1%. Low noise is essential in transporting the high brightness beam through the 45 m long injection line.

Polarized protons have been an important probe for the TRIUMF physicists. It is anticipated that the existing programme will remain strong in the future and that experiments using polarized protons will be carried out at the Kaon Factory energy. The present Lamb shift type polarized ion source routinely provides up to 600 nA at 500 MeV. This current is barely adequate for experiments which use the polarized proton beam to provide a secondary beam of polarized neutrons. In addition, several experiments using slits in the cyclotron (to produce a high quality beam with low momentum spread) also require higher currents. In order to meet these needs, TRIUMF has developed an optically pumped polarized ion source,[12] based on the proposal by Zavoskii,[13] Haeberli,[14] and Anderson.[15] The prototype source is now being transferred from the laboratory to a new 300 kV high voltage terminal for injection of the beam into the cyclotron. Based on the measured current, emittance and polarization it is expected that when installed about 5 μA of 60% polarized protons will be available for experiments. Unique features of this source include a 28 GHz ECR ion source operating in a cw mode to produce 5 keV protons, and a single broad band dye laser (which has been modified with an intra-cavity etalon to reduce its bandwidth to 6 GHz) to polarize sodium vapour electrons. In order to increase the polarization to 80% the magnetic field in the sodium vapour region will be raised from the present 12 kG to 25 kG in the future.[16] An increase in current to values suitable for kaon physics experiments is planned and will be achieved by raising the sodium vapour density and increasing the laser power to maintain the polarization.

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