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PROPOSED BUNCHING SCHEME FOR A POLARIZED H^- INJECTOR*

George R. Swain and Andrew A. Browman
Los Alamos National Laboratory
P. O. Box 1663, Los Alamos, NM 87545

Improvements to the polarized H^- injector at LAMPF will include a two-stage buncher and beam chopper. The buncher scheme will permit the compression of a major part of the current in 20 rf cycles of the drift-tube linac (100 nsec) into a single rf cycle (5 nsec), thus making possible time-of-flight experiments with the polarized H^- beam. A proposed first buncher stage would use a ramp drive waveform; the second stage, a sinusoidal waveform. Design and sensitivity calculations are summarized, including beam energy considerations, buncher and chopper drive requirements, and longitudinal and transverse beam dynamics. The calculations indicate that about 70% of the beam from the source may be bunched in the 1-nsec acceptance region of the linac, with less than 0.1% of the beam in neighboring rf cycles.

1. Introduction

The injector for the polarized H^- ion beam (P^- beam) is one of three injectors for the linac of the Los Alamos Clinton P. Anderson Meson Physics Facility (LAMPF) at Los Alamos National Laboratory. An accelerating column brings the P^- beam to 0.75 MeV, and a transport line combines this beam with those from the other injectors and brings it to the entrance of a drift-tube linac operating at 201.25 MHz. The present transport line includes a spin precession magnet, a P^- prebuncher, an electrostatic inflector and a bending magnet (these produce 9 degree bends in the beam line at the points where the other beams come in), a main buncher, and magnetic quadrupoles as necessary for transverse focusing.

Planned improvements for the P^- line include changing from a Lamb-shift source to an optically-pumped ECR source, and adding a two-stage bunching system. This paper only deals with the bunching system portion of the improvements.

The proposed bunching scheme will permit the compression of most of the current in twenty drift-tube linac rf cycles into a single cycle, thus making possible time-of-flight experiments with the polarized beam. (If only a chopper is used to space out the beam pulses, the intensity of the beam would be too low.) New equipment necessary to implement this scheme includes a ramp buncher, a low-frequency prebuncher, and a chopper, as shown in Fig. 1. The ramp buncher is the first bunching stage, and will incorporate a section of beam tube with a sawtooth voltage waveform applied. It will be located in the P^- high-voltage dome. The low-frequency prebuncher is the second bunching stage, and will use an rf cavity located downstream of the accelerating column and spin precession magnet. The chopper will be located in the vicinity of the low-frequency prebuncher. (The chopper is necessary to take out the small fraction of the P^- beam which cannot be bunched within the single intended linac rf cycle.)

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2. Design Considerations

At low beam energies, transit-time effects are important. It is planned to use wire grids at the entrance gap of the ramp buncher to confine the fields to a small space and thus minimize the effect of the retrace portion of the sawtooth waveform. (The beam will be partly bunched by the time it reaches the exit gap, and grids will not be necessary there.) The chopper will be of the slow-wave type.

For a two-stage buncher to work efficiently, the voltage swing used for the first stage should be large compared with the energy spread in the beam, but yet reasonably small compared with the voltage used at the second stage. The required voltage swing increases as the beam energy is increased and decreases as the length of the bunching section is increased. Also, as the required voltage swing is increased, the design of the power supply to drive the ramp buncher becomes more difficult.

The length between the ramp buncher gaps should be a multiple of $\beta\lambda$, where β is the relativistic velocity and λ is the wavelength corresponding to the ramp waveform fundamental frequency. This is necessary in order to keep the beam bunch away from the retrace portion of the ramp waveform at the second gap. Since such a spacing for the second gap produces a debunching action at that gap, it is advantageous to place the gaps as many $\beta\lambda$ lengths apart as possible, in order to keep the required ramp voltage swing down.

The period chosen for the ramp buncher should be large enough to permit interesting time-of-flight experiments, but not so large that the bunching efficiency falls off too much. (See Fig. 2 for an example of the variation of bunching efficiency with ramp period.) Increasing the period also increases the required voltage swing for the first stage.

At LAMPF, the present energy spread of the beam from the P^- source is estimated to be less than 50 eV (σ=10 ev). To have the ramp buncher work properly, it is thus probably necessary to accelerate the 500 eV

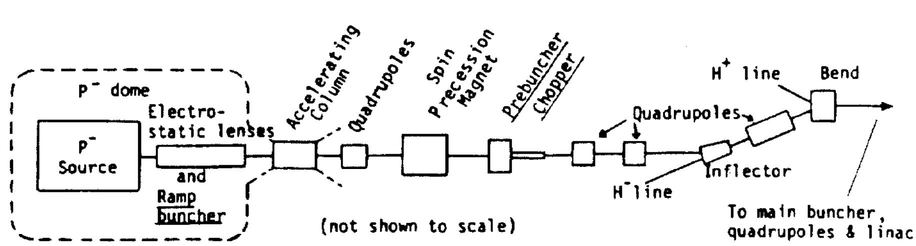

Fig. 1 Schematic of P^- beam line, with new equipment needed for bunching system (underlined items).

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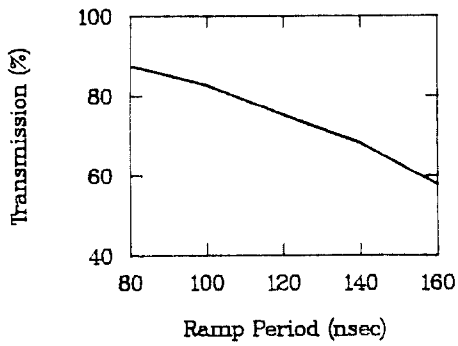

Fig. 2 Amount of beam which can be bunched in 1 nsec at 0.75 MeV versus ramp period with a ramp buncher (about 40 cm long) and low-frequency prebuncher for an initial beam with σ=10 eV energy spread.

beam coming out of the source to a higher energy, on the order of a few kilovolts, before applying the bunching. The bunching efficiency falls off as the energy spread increases. One series of calculations indicated the fraction of beam that could be bunched in 1 nsec at 0.75 MeV decreased about linearly from 80 to 50% as σ went from 20 to 150 eV.

After the ramp buncher and accelerating column, the P^- beam will pass through both a low-frequency P^- prebuncher and a 201.25 MHz main buncher. (The main buncher amplitude is set for the other beams, and is not a free parameter for use in the P^- beam bunching design.) The calculations indicate that the low-frequency prebuncher amplitude needs to be about 26 kV peak to bunch most of the beam in the 1-nsec wide acceptance region of the linac.

With the space and other constraints discussed above for LAMPF, the calculations indicate there is a window of feasibility for the two-stage buncher scheme for beam energies in the 4 to 7 keV range at the ramp buncher and for periods at least in the range of 16 to 20 times the linac rf period.

3. Analysis Tools and Techniques

The general plan of analysis was to examine the longitudinal beam dynamics in detail, and then check certain aspects of the transverse dynamics or combined longitudinal and transverse dynamics as needed. The longitudinal dynamics were studied with a computer code named LTAB, which follows the velocities and arrival times of an array of particles. LTAB includes provision for modeling accelerating columns, choppers, and buncher cavities, as well as gridded or ungridded gaps in the beam pipe with dc, ramp, or harmonic voltages applied. The code allows up to 51 different initial energies and up to 200 different initial times within the low-frequency period. The different particles over the energy space are not assumed to represent equal beam currents; a weighting function assigns importance to them according to the initial energy spread distribution, and another function keeps track of the fraction of beam removed by the chopper during the chopper pulse rise and fall times, if applicable. Sensitivity calculations were used to assign tolerances for the various design values. Considerations when varying a parameter to test its sensitivity included seeing that the fraction of beam bunched in 1 nsec at the linac entrance did not fall off more than a few percent, that the total pulse width at the linac entrance stayed well within one rf period and the pulse stayed reasonably symmetric, and that the average beam energy was not seriously affected.

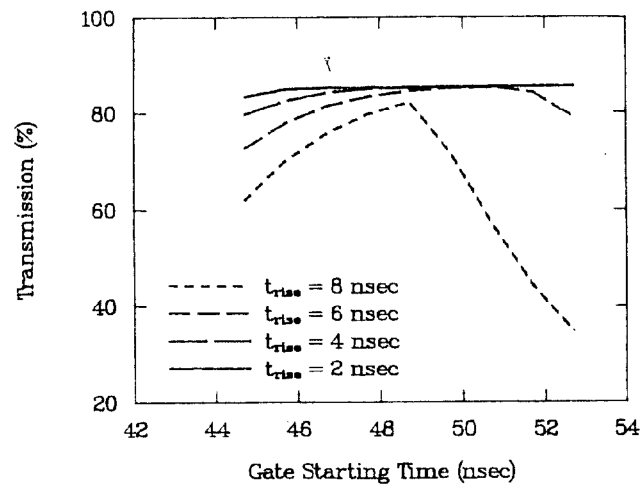

Fig. 3 Example of output from a parameter sensitivity calculation, in this case, the sensitivity of transmission to chopper rise time and jitter.

Figure 3 shows an example of a graph for a particular sensitivity study.

For studies involving transverse dynamics only, the envelope tracing code TRACE was used. For example, the low-frequency prebuncher increases the energy spread of the beam, and this code allows one to check the beam centroid shifts at the linac entrance arising from displaced-energy components of the beam going through the inflector and bending magnet. TRACE is also useful in determining quad magnet settings to achieve a desired transverse beam matching at the linac entrance.

Another particle-tracing code named RAY has been developed to study the combined longitudinal and transverse beam dynamics. RAY allows one to examine the transverse emittance growth occurring at ramp or harmonic buncher gaps, the spin precession magnet, and at bending elements. The input file format for specifying the beam line elements for RAY is identical for many types of elements to that used in the input file for the new LAMPF version of TRACE, which makes shifting from one code to the other fairly straightforward. Particle coordinate output from RAY may be obtained in the same format as that from the drift-tube linac analysis code PARMILA, and hence the output processing programs written for PARMILA may be used for RAY output.

4. Other Transport Line Considerations

The focusing elements need to be set such that the beam is reasonably small transversely at ungridded ramp buncher gaps and at the prebuncher, inflector, and main buncher. It is desirable to keep the peak-to-valley ratio for the transverse beam profiles as low as possible in order to make the tune insensitive to small parameter changes. In the case of the P^- line at LAMPF, the last part of the 0.75 MeV transport line has to be set up to accommodate the higher currents of the other beams, and a high peak-to-valley ratio (see Fig. 4) is unavoidable. Six-dimensional particle-tracing calculations using the RAY code were used to check that the additional beam energy spread introduced by the various bunching stages did not produce an undue amount of transverse emittance growth. The calculations indicate that the expected beam bunch may be placed well within the transverse admittance regions for the linac (Fig. 5).

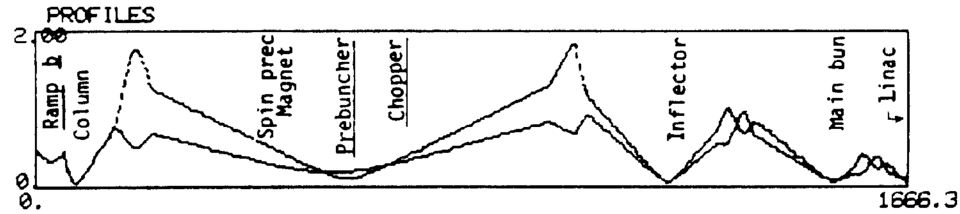

Fig. 4 Transverse beam profiles for the P^- line.

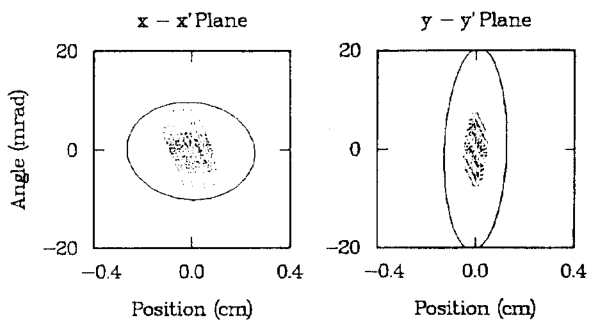

Fig. 5 Expected beam bunches at the linac entrance. The ellipses indicate the acceptance regions.

5. Specifications and Drive Requirements

For a bunching scheme with a ramp buncher just before the accelerating column and for which the current in 20 rf cycles at 201.25 MHz is to be compressed into one cycle, the design and sensitivity results for the proposed P^- beam bunching components may be summarized as follows:

- Ramp buncher beam and construction specifications:
  - Incoming beam energy, 6500 ± 30 eV
  - First gap (gridded gap: grid may be either parallel wires or mesh, a few % beam loss):
    - Length of gap, 0.5 ± 0.1 cm
    - Grid wire: 0.00254 cm (1 mil) tungsten wire assumed
    - Grid wire spacing, 0.5 cm preferred (0.1 to 0.6 cm feasible)
  - Second gap:
    - Length of gap, 1.0 ± 0.2 cm
    - Diameter, 7.62 ± 0.20 cm
  - Length between gap centers, 44.34 ± 0.10 cm
  - Length, 2nd gap to accel. column, approx. 7 cm
- Ramp waveform specifications:
  - Total ramp period, 99.38 nsec (20 times 201.25 MHz rf period)
  - Retrace time, 10 nsec assumed
  - Ramp voltage swing:
    - Peak-to-peak voltage swing, 2500 V (allow up to 3000 V)
    - Repeatability needed for voltage swing, ± 100 V
    - DC component of ramp voltage, 6000 ± 30 V with respect to P^- dome (ramp voltage swings from about 4750 V to about 7250 V)
    - Permissible time jitter for ramp, ± 0.6 nsec
    - Permissible droop from linear ramp, 10% or less (circuit RC time constant, 420 nsec or greater)
  - Circuit capacitance (estimates):
    - Ramp buncher tubes and gaps only, 50 pf
    - Complete with cable and feed-throughs, 100 to 200 pf
  - Peak current (during retrace time), 25 A if C = 100 pf

- Low-frequency prebuncher specifications:
  - Frequency, 10.0625 MHz (same as ramp buncher and chopper)
  - Peak voltage amplitude across gap of cavity, 26.5 kV (53 kV peak-to-peak)
  - Stability required:
    - Amplitude, ± 1 kV or ± 4%
    - Phase, ± 0.7 nsec or ± 2.2 deg at 10.0625 MHz

- Chopper specifications:
  - Gate width, 16 nsec full width at half maximum (allow 10 to 25 nsec)
  - Stability required for gate width, ± 2 nsec
  - Permissible time jitter for gate, ± 2 nsec
  - Rise and fall time for gate, 2 to 6 nsec

6. Staging

It is planned to initially use a sine-wave buncher in the P^- dome in place of the ramp buncher. The power supply for a sine-wave buncher is much easier to design than the supply for a ramp buncher, and this will allow us to defer the ramp buncher supply development until after the chopper supply development is complete. With enough voltage, one might use the same gap configuration for the sine-wave buncher as for the ramp buncher. However, we expect to use ungridded gaps (spaced $\beta\lambda/2$ apart) placed as far upstream as possible in the space which eventually may be occupied by the ramp buncher.

7. Further Work

Further studies will see if there is any useful advantage to placing the first buncher stage upstream of the last electrostatic lens elements in the P^- dome, and check that the final buncher system designs will work adequately with a beam from the future optically-pumped ECR source.

8. Conclusions

The analysis of the proposed P^- bunching scheme indicates that about 85% of the current exiting the argon cell in the P^- dome in a time interval equal to 20 rf cycles of the drift-tube linac may be bunched into one rf cycle. Approximately 70% of the current exiting the argon cell may be compressed within the one nanosecond interval that is accelerated by the drift-tube linac. It is expected that the current in the side lobes (adjacent rf cycles) may be held to less than 0.1%, since the calculations (which covered 200 initial times and 51 initial energies over a $\pm 3\sigma$ range) showed all of the particles remaining after chopping to lie within a 4 nsec interval at the start of the drift-tube linac, which is within 80% of one rf cycle. Transverse emittance growth arising from the introduction of the bunching stages does not appear to be excessive.