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TRANSVERSE PHASE SPACE TIME DEPENDENCE OF LAMPF'S HIGH INTENSITY H+ BEAM*

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Summary

The LAMPF H+ injector is pulsed 120 times a second with pulse lengths from 500 to 750 μsec long. Large transients in transverse phase space, lasting 100 to 200 μsec after turn-on, are regularly observed. The magnitude of these transients appears to increase with increasing currents and source brightness. Because high-current accelerators require great precision in phase-space tailoring to avoid excessive emittance growth during acceleration, these transients cause severe operational problems and can no longer be neglected in the beam tuning procedure. Measurements of transverse phase space as a function of time for the 750-keV, 30-mA peak current H+ beam are presented.

Introduction

To successfully accelerate a beam through a linac the beam must be matched to the admittance of the linac. A mismatch can result in large oscillations of the beam envelope which can lead to excessive emittance growth, causing loss of beam. For high-average-current machines, such as LAMPF, the loss of even a small fraction of the beam (<<1%) will lead to unacceptable levels of activation along the accelerator. For a pulsed machine, time-dependent changes in the transverse phase space may occur during turn-on. If so, the questions must be posed; at what time during the pulse should the beam be matched and how serious are the mismatches at other times?

With the very high average currents proposed for some future accelerators, these turn-on transients could become troublesome, even for "DC" machines. This paper describes the present state of our understanding of these turn-on transients in the LAMPF H+ beam.

Indications of the Problem

As the intensity and brightness of the LAMPF H+ beam is increased, it has become more and more critical to match the beam correctly into the linac. Normally matching is done 150 μsec after source turn-on. The time dependence of the beam lost along the accelerator is clearly shown by loss monitors which measure a different loss during the first one or two hundred microsecond part of each beam pulse than during the remainder. Another indication of possible problems is the variation in total beam current throughout a beam pulse. Although the current from the ion source has a fast rise time and then becomes flat, the accelerated current has the characteristic time dependence shown in Fig. 1. This problem is caused by apertures which are inserted to reduce beam halos produced in the source and transport line. A variation in beam size during the pulse results in intensity variations in the accelerated beam. Among the deleterious effects produced by this current modulation is the time-dependent beam loading placed on the accelerating cavities, which often results in beam loss due to improper acceleration. The problem of correctly tailoring the beam current is not yet solved and is under active investigation.

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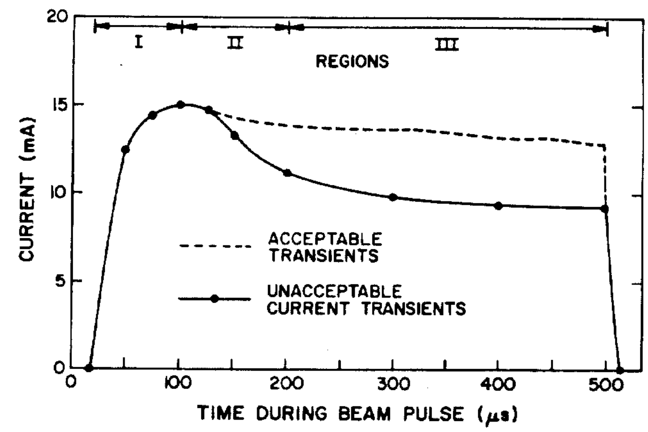

Fig. 1.

Observational Characteristics

The H+ beam at LAMPF exits the 750-kV column and is delivered to the 201-MHz drift tube linac through a 13-meter-long H+ transport. The H+ source normally runs at 80 to 120 pulses per second; each pulse is from 500 to 750 μsec long. The peak current exiting the column is 30 mA; 5 mA of H_2^+ are lost at the first bend, and the remaining H+ beam is tailored down by jaws and apertures such that a peak current of 14 mA enters the 201-MHz linac. The H+ beam is bright with 95% of the beam contained in an emittance area of 1.5π cm-mrad.

Though the transverse-phase-space time dependence is far from being completely understood, numerous experiments performed using the H+ transport show complex relationships between the transverse phase space of the beam and such variables as source rise time, transport vacuum and the effects of jaws, apertures, and their bias. LAMPF's H+ transport is well suited for studying these effects, with extensive diagnostic equipment, including three emittance-measurement stations and proven computer codes available to model the transport system. Along with the high-duty emittance gear, two other devices have proven invaluable in untangling the causes of the observed transverse-phase-space time dependence. One of the devices is a deflector located just after the exit of the 750-kV column and before the first bending magnet in the transport. By deflecting the first 200 μsec of beam out of the transport, source-dependent transients can be separated from transients due to space-charge-neutralization phenomena. The second device consists of an insulated section of the beam pipe which can be biased from -1000 V to +1000 V. The current measured on this pipe can be used to help understand electron generation along the transport line.

The transverse phase space measured by the emittance gear is parameterized using the notation of Courant and Snyder[1]. A typical example of the time dependence of one of the transverse-phase-space parameters, β, is shown in Fig. 2. Although the time dependence varies for different tunes, the general characteristics are the same and can be observed at the different emittance-measurement stations along the transport. In Fig. 1 and 2 the 500-μsec-long beam pulse is divided into regions labelled I, II, and III. In region I, the observed transients are due to source turn-on transients coupled with the initial neutralization of the beam. These effects are measured by experiments that vary the source rise time and deflect the beginning of the beam out of the transport, while observing changes in the electrons collected on the biased pipes and changes in the emittance.

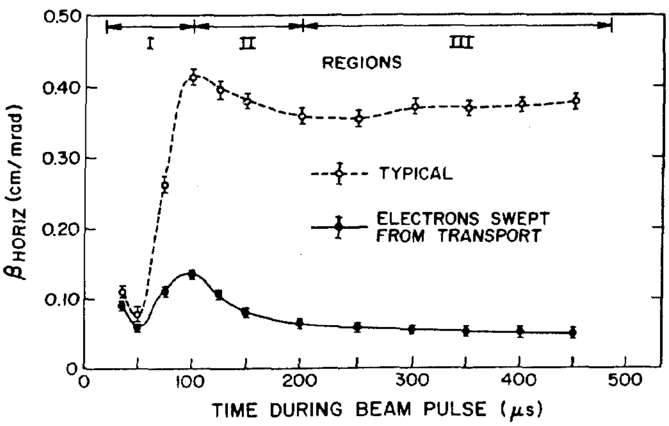

Fig. 2.

Region II contains troublesome current transients which lead to beam loading of the rf due to varying currents through jaws and apertures. Fig. 1 shows both an acceptable and unacceptable plot of H+ current, after jawing. The transients in region II are not clearly understood.

In region III, slow variations in the transverse-phase-space parameters are normally observed. The magnitude of these variations depends on the vacuum in the transport and on the tune of the transport magnets. The dominant effect in this region is believed to be space-charge neutralization due to ionization of residual gas molecules. Simple calculations[2] show that for a beam of 750-keV protons through H_2 gas at a pressure of 1.0×10^{-6} torr, complete neutralization occurs in approximately 600 μsec, assuming capture of all electrons created by ionization. Transport codes indicate that if neutralization occurs at a rate such that the beam is neutralized in 600 μsec, much greater variations in the phase-space time dependence will be observed than are actually measured in region III. The fact that such large transverse-phase-space time dependence is not observed may be due either to the beam being highly neutralized in the first two regions of time, (regions I and II) or that the rate of neutralization is much smaller than expected and only partial neutralization takes place in region III.

Currents measured when the insulated pipe is biased negatively are essentially zero; positive bias results in increasing (negative) currents until a plateau is reached around 200 V. The electron currents measured have a rise time equal to that of the source and normally remain constant during the beam pulse. They arise from ionization of the residual gas and from secondary emission due to beam striking the transport vacuum pipe or emittance-defining apertures. When the insulated, biased pipe is located near the exit of the 750-kV column, electron currents on the order of 30 mA are measured, due to secondary emission from H_2^+ ions striking the transport walls. In a later region of the transport, separated from the H_2^+ ions and resulting electrons by two bending magnets, normally observed electron currents are on the order of 0.2 mA. These currents vary with vacuum and tune. Removing the electrons from the beam with the biased pipe also affects the beam's time dependence. Fig. 2 compares emittance measurements made at the end of the transport when electrons are present or swept out of the first three meters of the transport.

For one particular tune the transverse-phase-space parameters in region III showed much larger time-dependent transients than normal. Current measurements showed unusual (∿1%) losses of beam in the transport and insulated pipe current measurements showed electron currents proportional to the proton losses. The measured electron currents were an order of magnitude greater than those one might expect from ionization of residual gas molecules, and were due to secondary emission and possibly thermionic emission. The new data was compared with earlier measurements where little or no H+ beam scraped the pipe.

In this particular case, what seems to have occurred is a type of regenerative feedback loop. Beam scraping the pipe creates energetic electrons. These electrons pass through the beam, partially neutralizing the beam. In this case, the partial neutralization of portions of the beam cause its width to grow, more protons scrape the pipe causing greater neutralization. A similar hypothesis can be set up concerning the transients noted in region II. A feed back loop involving secondary emission from H_2^+ ions exiting the column may exist, coming to equilibrium during region II.

Conclusion

Facilities designing new high-intensity low-energy transports should pay close attention to possible effects of space-charge neutralization and resulting time dependences of transverse phase space. Close attention should be paid to vacuum regulation, jaw and aperture positioning, and bias, and tune sensitivity to space charge variations. Enough diagnostics should be included to define the beam throughout the transport, and the diagnostic equipment should be capable of sampling the beam for its full duration. Consideration should also be given to external methods of controlling the neutralization of the beam. Source transients may be eliminated by deflecting the beginning portion of the beam pulse. Unwanted beam and ion species from the source should be dumped before any acceleration, or dumped in regions where the primary beam is not affected by further neutralization. For high-intensity H- beam-transport systems, such as the one being designed at LAMPF to fill the proton storage ring under construction, space-charge-neutralization phenomena will not be the same as those for intense H+ beam transports. In understanding the relationships between neutralization and transverse time dependence for high-intensity H+ beams, one might hope to avoid these problems for high-intensity H- beams as well. Failure to recognize time-dependent transients of intense beams may result in severe turn-on problems.

References

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2. L. R. Evans and D. J. Warner, IEEE, Trans. Nucl. Sci., NS-18, 1068 (June 1971).