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SOLUTION TO THE TRANSVERSE PHASE SPACE TIME DEPENDENCE PROBLEM WITH LAMPF'S HIGH INTENSITY H+ BEAM*

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Summary

The 750 keV H+ beam at LAMPF has a transverse phase space time dependent transient during the first 200 μs of each 750 μs long macro-pulse. The time dependence is documented in an earlier report.[1] Further studies indicate that the time dependence is due to space charge neutralization resulting from secondary emission of electrons produced by collisions of the H+ and H_2+ beams on the transport walls. One of several possible solutions has been tested and has proven successful in eliminating the time dependence of the beam entering the linac.

Introduction

The H+ beam at LAMPF runs 80-120 pulses per second; each pulse has a length of 500-750 μs. The beam current is 30 mA at the exit of the 750 kV column. The primary transverse tuning is done in the 750 keV transport. The beam is tailored by the use of jaws and apertures to a current of 10-14 mA for injection into the drift-tube linac. A well matched beam at the linac entrance has less than 0.5% transverse loss in the linac (approximately 30% of the beam is lost longitudinally in the first two rf tanks of the linac). Time dependent transverse phase space transients cause increased beam loss due to mismatches, and large 20-30% beam current variations occur as the size of the beam changes at the jaws and apertures.

The 750 keV H+ transport system is shown in Fig.1. Many transport elements are not shown, including the quadrupole magnets and diagnostic elements. Of importance are the two deflector systems and their positions. Note that deflector #1 is located before the first bend in the transport. As much as 7 mA of beam are species other than H+, primarily H_2+, and are lost in this region of the transport. The jaws which phase space tailor the beam and limit the beam current are located before deflector #2. The deflectors are used in experiments to help determine the cause of the time dependent phase space transient, and they also provide a solution to the time dependence problem.

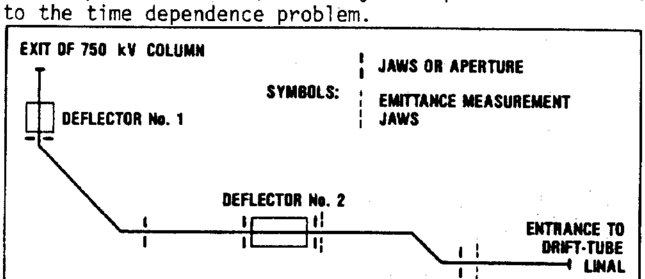

Fig. 1. - LAMPF's 750 keV H+ transport; the position of deflectors used in experiment are indicated.

Experiment

Each deflector is used separately to determine where in the transport the time dependent transient originates. The portion of the macro-pulse which contains the time dependence is deflected. The remainder of the undeflected beam is investigated for additional time dependence. Fig. 2 shows the time structure of the beam deflector system. If the time dependent transient is eliminated in the undeflected portion of the beam, then the cause of the transient is located before the deflector. Deflector #1 does not remove the transient while deflector #2 does remove the transient as shown in Fig. 3. These results, along with the earlier reported electron current measurements, indicate the probable cause of the transverse phase space time dependence.

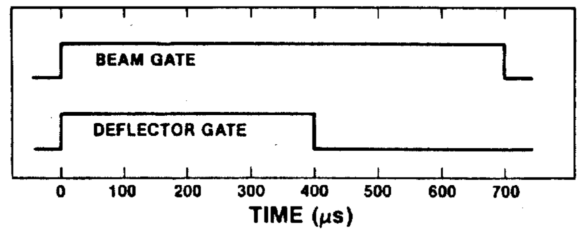

Fig. 2. - Relation between the beam gate and the deflector gate used to deflect the time dependent portion of the beam.

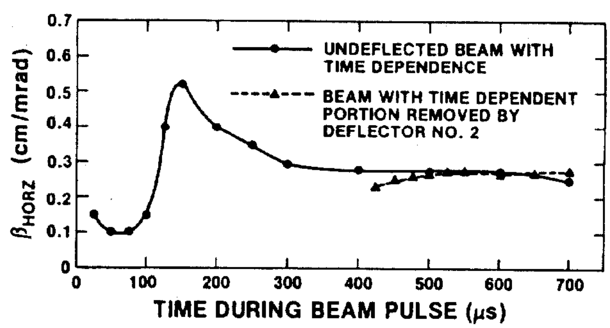

Fig. 3. - One of the Courant-Synder parameters measured as a function of time showing the removal of the time dependent transient by deflector #2.

Large amounts of neutralizing electrons are produced by ion impingement on the transport walls before the first bend. The subsequent space charge neutralization causes the time dependent variation of the beam. This may occur in a complex manner, including some feedback mechanism between the neutralizing currents and the beam. Neutralization of the beam due to stripping of the residual gas cannot account for the time dependence. If this were the dominant mechanism, then deflector #2 would not be able to eliminate the severe time dependence, since the vacuum is similar in both regions of the transport.

Solution

There are several possible solutions to eliminate the observed time dependent transients. Each has technical drawbacks for our particular situation at LAMPF. These solutions include increasing the vacuum pressure at the exit of the 750 kV accelerating column, sweeping the neutralizing electrons from the beam in this same region, and deflecting the initial

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turn-on transient of the beam using deflector #2.

The first solution, increasing the vacuum at the exit of the 750 kV accelerating column to completely neutralize the beam, also increases the vacuum in the column. The subsequent electron current greatly increases spark discharges of the column, and increases the radiation to intolerable levels. Beam constraints at the column exit make baffles and pumping schemes impractical.

The second solution is to sweep the electrons from the transport region where troublesome neutralization is suspected to occur, between the 750 kV accelerating column and the first bending magnet. This is difficult because the 5-7 ma of H_2+ does not impinge on the transport at one location. Measurements of the H_2+ component of the beam and subsequent transport calculations show the envelopes for the H_2+ beam and H+ beam as in Fig. 4. Since the H_2+ ions impinge on the transport throughout a large region, it is necessary to bias a large section of the transport to sweep out the neutralizing electrons before they interact with the H+ beam. This, too, is impractical and the cumulative effect of such a bias could affect the primary H+ beam.

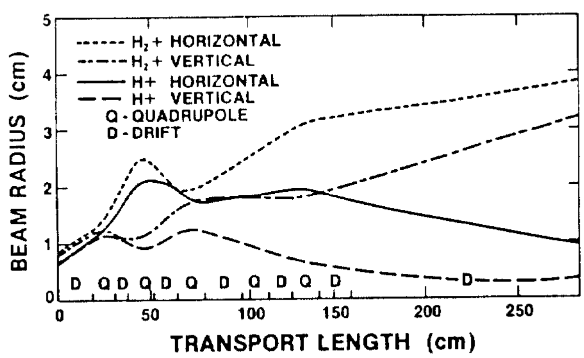

Fig. 4. - H_2+ and H+ beam envelopes between the exit of the 750 kV column and the first bending magnet in LAMPF's 750 keV H+ transport.

The third solution, to deflect the time dependent portion of the beam before it enters the linac with deflector #2, is the best solution for out transport system. This solution introduces three problems of concern. First, the intense H+ beam must be turned on slowly over a period of 30-50 µs such that the rf power may be increased properly to maintain the correct amplitude in each rf cavity. The deflector system, though, turns the beam on too quickly in the linac for the rf cavities to maintain the proper amplitude. The subsequent longitudinal beam losses cause high activation levels. The solution to this problem has been successfully tested. It consists of an additional deflector which works as a chopper. The beam is turned on into the linac with successively longer short pulses over a period of 50 µs. The average beam as seen by the rf cavities gradually increases. This procedure is represented in Fig. 5. Some beam loss is produced during the turn-on and turn-off of the short pulses. This is due to the rise time of the deflector and the fact that the beam entering the linac during this transient is improperly steered. The faster the deflector turn-on, turn-off transients, the less the beam losses. The need for fast deflector turn-on, turn-off times, requires a special power supply and a deflector circuit with a low capacitance. Most commercial power supplies with this requirement have a short duty cycle; therefore, these supplies cannot be used for the long 200-400 µs deflection of the time dependent portion of the beam. Two separate deflector systems are used.

The necessity of two separate deflector systems leads to another common problem, that of space. To solve this problem, one system is being designed to combine both the long pulses deflector system and the short pulse deflector system. In light of these problems, care has been taken in the design of the new low energy H- transport for high intensity beams to the Proton Storage Ring to include space for such a deflector system. This space is located close to the linac entrance such that any time dependent transients originating in the transport or ion source may be eliminated.

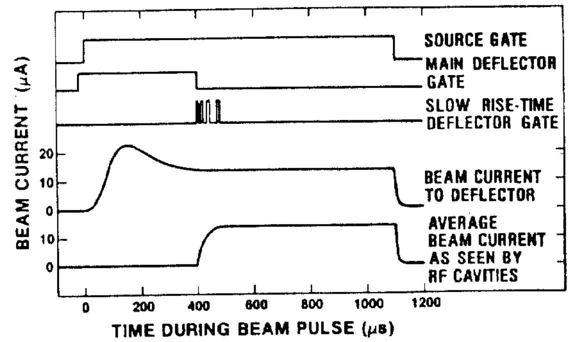

Fig. 5. - The relation between the beam gate, the deflector gates, and the resulting currents to produce a steady state, slow rise-time beam.

The third problem encountered is the increased duty factor of the ion source. At present, the H+ ion source is run at a maximum duty factor of 9%. But if an additional 400 µs of beam is needed for each macropulse, the source duty factor needs to increase to 14%. There is some worry that the source's lifetime will be reduced at this duty factor and that considerable development time will be necessary to improve the source.

Conclusion

To reduce beam losses in an accelerator, the transverse phase space must be well matched to the acceptance of the machine. Time dependent transients do not allow a proper match throughout the beam pulse. If jaws and apertures are used to tailor the beam, then time dependent transverse phase space transients may cause dramatic changes in the peak current of the beam. For beam intensities great enough to affect the power in the rf cavities, these variations in current can cause rf instability. Therefore, care should be taken to eliminate causes of time dependent transients in the design of low energy transports.

One of the causes discovered for such transients is space charge neutralization. Other causes can include source warm-up and bias potentials which "sag" during the beam pulse. One solution to such problems is to turn the source and transport on early, deflecting the beam until the time dependent transients die away. This requires adequate space in the transport and an ion source which can run for longer duty cycles than the planned duty cycle for accelerated beam. Also, a second deflector system may need to be installed to provide a gradual, controlled beam turn-on into the accelerator.

Acknowledgement

The author thanks A. Browman for his helpful suggestions and work towards solving this problem.

Reference

(1) J. Hurd, and A. Browman, Transverse Phase Space Time Dependence of LAMPF's High Intensity H+ Beam, IEEE Transactions on Nuclear Science, NS-28(ul 28), No. 3, 2658-2659 (June 1981).