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ANALYSIS OF CHARGE-EXCHANGE INJECTION FOR NAL

M. S. Livingston

October 6, 1969

Charge-exchange injection is a technique for filling the aperture of an accelerator or storage ring with protons which is not subject to the restriction of invariant phase space density which holds when using beams of protons. In charge-exchange injection beams of negative hydrogen ions or neutral hydrogen atoms are directed toward a gas jet or a thin foil located in the aperture, where they are stripped of electrons to become protons. Thus, protons are created at the proper energy, on or near the equilibrium orbit, and within the transverse phase space of the accelerator. Injection can be continued for many turns, each turn adding protons within the acceptance phase space. The "brightness" of the beam can, in principle, be increased up to the space-charge limit.

In contrast, in the normal method of horizontal multi-turn injection using protons one injects several turns past a septum into the radial betatron oscillation phase space. The number of turns is limited by the available radial aperture, and the "brightness" is limited by that of the injected beam. A typical example is the injection into the booster at NAL, which is limited to 4 turns and a total pulse length from the linac of about 11 μsec.

Status of Development

The most significant progress of charge-exchange injection has been made at the Institute for Nuclear Physics at Novosibirsk (G. I. Budker, Director) by G. I. Dimov and his associates. They have carried on a program of development of negative hydrogen ion sources and studies of charge-exchange injection into a synchrotron. The purpose is to provide a method for filling a storage ring with high-intensity protons. Adequate intensities cannot be obtained from a proton source when using existing techniques of multi-turn injection past a septum. The successful development of charge-exchange injection seens essential to the continued progress of the storage-ring program at Novosibirsk.

They have developed high-intensity negative hydrogen ion sources,[1,2] reporting beam currents of H^- and H^o of 15 mA and 600mA respectively, in bench tests at an extraction voltage of 13.5 kV. Using another source in an electrostatic generator they have produced a H^- beam of 0.8 mA at 1 MeV energy and have used this beam for charge-exchange injection into a synchrotron.[3] The H^- beam was first stripped of electrons in a gas jet to form an H^o beam, which was then directed through the magnetic fringing field to a second gas jet in the aperture of the synchrotron where it was further stripped to H^+. The stored proton intensity obtained in this test was 10^{12} protons ($I \sim 1$ A).

At Argonne National Laboratory they are engaged in a long-range program[4] to increase the intensity of the ZGS above its present space-charge limit at an injection energy of 50 MeV. A major feature of this program is to build and install a 500-MeV fast-cycling booster synchrotron between the present 50-MeV linac and the ZGS. Raising the injection energy in the ZGS to 500 MeV will increase the space-charge limit by a factor of 18. In order to achieve such an increase in intensity a large number of turns of beam must be injected into the booster in each pulse from the linac--much too large to be achieved with proton injection into the radial betatron phase space. The Argonne staff are convinced that the desired proton intensity in the booster can be achieved by the use of charge-exchange injection.

A negative hydrogen ion source was built at Argonne which produced a 200-microamp beam of H^- accelerated to 50 MeV in the linac. This beam was used to study charge-exchange injection. It was directed against a thin plastic foil converter in the aperture of the ZGS; an intensity of 2×10^{11} protons/pulse was injected and 3×10^{10} protons/pulse was accelerated to full energy. Further tests are scheduled with an improved ion source expected to produce 1 mA or more of H^- ions. Still higher intensities may be required to reach the planned goal.

Significance for NAL

Both laboratory programs described above have a purpose for which the development of charge-exchange injection is a valid and essential element. This same situation does not apply at NAL. In the planning of NAL the beam currents in each component accelerator were designed to approach closely the space-charge limits. This balance determined the choice of injection energy of 200 MeV into the booster and of 8 GeV into the main ring. The NAL staff confidently expect to achieve the design intensities using proton injection and presently available techniques involving pulsed inflection septums. The use of negative hydrogen ions and charge-exchange injection would not increase accepted intensities significantly above those available with proton injection. The only way in which significantly higher intensities could be attained at NAL would be to make major changes in the basic parameters of the system. In order to raise the space-charge limits the injection energies into the booster and the main ring would have to be increased. Such major changes are not anticipated in the present construction program. So, until there is some justified demand to increase the output beam intensity at NAL above the present space-charge limit, it does not seem useful to invest effort in a development program of charge-exchange injection.

REFERENCES

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