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ACCELERATOR Aspects of the ISIS Upgrade

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ABSTRACT
A brief account is given of the future plans to attempt to increase the intensity of the ISIS proton beam.

I. INTRODUCTION

The accelerator aspects of the upgrade planned for ISIS include raising the operating energy of the 50 Hz proton synchrotron from 750 to 800 MeV and increasing the mean output current above the 100 μA level. There will be limits set to the current obtained, both by space charge effects and by the practicalities of handling the increased beam loss, but the design aim is to achieve a current approaching 200 μA. A time scale for the upgrade of three years is envisaged.

Included in the upgrade plans are a new or improved ion source, a separate power amplifier for the injection line debuncher cavity, and, for the synchrotron itself: higher power tests of the main magnet power supply, improved programming of the trim quadrupole power supplies, additional diagnostics, an increased power capability for the acceleration system, two additional steering magnets per transverse plane, six sextupole and eight octupole magnets and their associated pulsed power supplies, and a number of operational periods for machine studies. These items are to provide, respectively, increased injected beams, greater control of the input beam momentum spread, checks for magnet and magnet power supply reliability, harmonic correction for gradient errors, improved input matching, greater control for rf beam loading, improved closed orbits, chromaticity and transverse instability control, and a detailed evaluation of machine performance. Features of these plans are discussed in relation to the present ISIS synchrotron performance.

II. PRESENT PERFORMANCE OF THE ISIS SYNCHROTRON

At present the ISIS synchrotron operates routinely for neutron, neutrino and muon production at a proton energy of 750 MeV and a mean current of 100 μA. The current corresponds to two 100 ns pulses, each with $6.25\ 10^{12}$ protons, separated by a time gap of 230 ns and repeated every 20 ms. At this level, the injection efficiency for the 70 MeV beam (H^-) is 97 to 98% (with a 2% stripping loss), the acceleration efficiency is typically 88 to 92% and the extraction loss is less than 0.1%. Almost all of the acceleration loss is at low energy below 85 MeV.

The machine performance deteriorates if the beam rf feed-forward compensation is out of adjustment and also if the closed orbit deviations are not corrected adequately. Normally, it is sufficient to tune up the synchrotron at the start of a four week running period and to make only minor adjustments subsequently. Low and high energy beam losses, and the resulting activations, are localised in the long extraction straight section. There is a small high energy loss at the extraction septum and the low energy beam, which is lost during acceleration, spirals radially inwards to the edge of the aperture, where most of it is contained in a longitudinal beam loss collector, upstream of the septum.

In experimental periods, accelerated beams have been increased from 1.25 10^{13} ppp (particles per pulse) up to 1.7 10^{13} ppp, that is, from the equivalent of 100 to 136 μA. However, it is difficult to maintain the beam at this level, and though the injection efficiency remains in the 97 to 98% range, the acceleration efficiency falls to 80% or less. Nearly all the loss is still at low energy, below 85 MeV, but there is some halo growth and a small increase in the extraction loss. To achieve the 1.7 10^{13} ppp, the low energy collectors are withdrawn from their normal positions to allow larger emittance beams, which are obtained by 'injection painting' over the ring acceptances. Most of the beam loss remains concentrated in the collector-extraction straight, though small losses do appear at other locations.

At low intensities, the betatron tunes may be varied over a wide region of the Q-diagram without affecting the performance, but at increased intensities, the operating point is important. The Q-values are ramped over injection to compensate for the combination of the changing guide field and the natural values of the chromaticities. At the field minimum, the tunes are brought to a maximum to allow maximum space charge tune depressions. Subsequently, the vertical-Q has to be lowered from 3.87 to 3.72 to limit the effect of the vertical resistive wall head-tail instability. This is a disadvantage for handling the space charge, but an advantage, when at the natural chromaticities, as it allows the lost beam of small horizontal betatron amplitude to spiral to the longitudinal collector without being lost vertically in an unprotected location.

Studies[1] have indicated that the early longitudinal loss is a sensitive function of the inter cavity phase transients, introduced as the six rf cavities are swung into phase, towards the end of injection. As the longitudinal space charge forces increase, so does the sensitivity of the beam loss with respect to these transients. Particles near the boundary may spill out of the phase stable region, so the setting of the rf beam feed-forward compensation becomes more critical.

During the first millisecond of acceleration, the beam bunches more tightly and two effects contribute to the tune spread. There is the major effect due to the transverse space charge forces and a secondary effect on the chromaticities due to the enhanced momentum spread. The latter gives a tune spread of ±0.04 for the maximum $\Delta p/p$ of $\mp 8\ 10^{-3}$ for uncorrected chromaticities, while the former is larger by more than a factor of ten for the design limit of 2.5 10^{13} ppp. At the maximum of 1.7 10^{13} ppp achieved to date, the predominant loss is longitudinal, but it is believed that the transverse tune spreads are already important.

III. INJECTION IMPROVEMENTS

Two main improvements are planned, an improved or new ion source and a separate power amplifier for the injection line debuncher cavity. In addition, more care is to be taken in setting up the linac to obtain greater repeatability of its mean output energy and longitudinal emittance. An increase of two is needed in the H^- ion source output and development will continue on the existing Penning source and also on a higher volume multi-cusp source. The debuncher cavity is powered at present from the fourth linac tank and the control for the beam loading is inadequate. A separate power amplifier is thus to be installed.

IV. SYNCHROTRON DIPOLES AND QUADRUPOLES

Synchrotron dipoles and quadrupoles are powered in series, with the units of each superperiod connected separately to one of the ten legs of a common choke which, in turn, is in parallel with a capacitor bank, to achieve overall series resonance. Separate trim quadrupoles are powered to obtain Q-adjustments. On raising the operating energy from 750 to 800 MeV, the voltages on the main magnets, the choke windings and the capacitors are all increased to near or just above their maximum voltage ratings. Thus, there will be extended running periods to confirm heating estimates and overall reliability. Also increased currents are required in the trim quadrupole magnets which will require some modified programming. Harmonic correction for gradient errors is to be investigated at low energies to see if enhanced Q-spreads may be contained.

V. INCREASED POWER FOR RF SYSTEM

Each of the six rf cavities is presently powered by one 250 kW tetrode, and the plan is to add a second 250 kW output tube in parallel. This increases the output power capability and at the same time lowers the input drive requirements, allowing both the shunt impedance of the cavities to be lowered and the accelerating voltage to be raised somewhat at mid-cycle. Copper sulphate liquid resistors may be adjusted to lower the shunt impedance, and this leads to an improved performance for the beam feed-forward compensation system. The beam loading power doubles at 2.5 10^{13} in place of 1.25 10^{13} ppp and is a maximum at the mid-point of the cycle. The planned increase in total accelerating voltage is to eliminate the tendency for small beam losses at this time.

VI. CORRECTION MAGNETS

Two additional dipole steering magnets per transverse plane are to be installed and also sets of sextupole and octupole magnets. These will be provided with programmable or pulsed power supplies. At present, there are four vertical and four horizontal steering magnets and they are used to provide fourth and third harmonic closed orbit correction. Further harmonic orbit correction will be obtained with the additional steering magnets. Six sextupoles are to be used for chromaticity correction and they are to be introduced as three sets of two to limit the possibility of resonance excitation. Eight octupoles are to be installed, similarly, as two sets of four and they are to provide Q-spreads to combat the vertical instability observed between 2 and 4 ms of acceleration. The major aim is to raise the Q_v-value at the time of high transverse space charge, 0 to 2 ms, while reducing the chromaticity; this should allow a larger space charge tune depression and enable the lost beam of small radial amplitude to spiral safely to the longitudinal collector.

VII. MACHINE PERFORMANCE AND DIAGNOSTICS

Additional diagnostics are to include high frequency pick-ups for the linac and injection line, and one or more beam envelope monitors for the ring. The former are to allow improved understanding of the linac performance and the latter, to study injection matching. The major concern in seeking a higher intensity is the control of the enhanced beam loss. It is believed that a higher intensity will only be achieved at a reduced acceleration efficiency and that the operational intensity will be determined by the practicalities of handling the beam loss. Thus, machine studies will concentrate on ensuring that the lost beam is contained in the beam loss collection system. If the loss reaches unacceptable levels, a modification of the acceleration system may be considered; in this, a subsidiary rf system would provide an initial linear rotation of the two bunches in $(\Delta p/p, \phi)$ space.

VIII. TIMESCALE

The three year timescale is set both by the funding rate and the scheduling, which must not disrupt the ISIS science programme. At this stage it is not easy to estimate the number of machine study periods that will be needed to evaluate the higher intensity performance of the synchrotron.

References

[1] I.S.K. Gardner et al, Progress at ISIS and Possible Future Developments, Proceedings of the 2nd European Particle Accelerator Conference, Nice, 1990.