HIGH STABILITY OPERATION OF THE ISIS PULSED SPALLATION NEUTRON SOURCE AT 200 µA

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ABSTRACT

The ISIS pulsed spallation neutron source now operates with a high intensity of 200 µA. The tuning of such high intensity accelerators is dominated by the successful control and minimisation of beam losses. It is found that there may be a gradual drift in parameter space that limits the synchrotron to a sub-optimal performance. Minimisation of beam loss is critically dependent on the stability of operation of the fast cycling synchrotron, which becomes very sensitive at high intensity, particularly to the intensity and injection conditions. A considerable improvement in stability at 200 µA has been obtained by fitting two new servo systems; one controls the ion source current to stabilise injected intensity and the other controls the synchrotron radial beam position before bunching is complete. Tuning of the synchrotron at high intensity has been simplified by the development of a multiplexing system that allows one pulse in 128 to operate at betatron tunes without tripping on beam loss. This permits fine tuning of the synchrotron whilst operating close to full intensity, before switching all pulses to the new tunes once improvement has been established.

1 INTRODUCTION

The commissioning of ISIS to the full design intensity of 200 µA has been restricted by the limited time available, within the operational requirements for the neutron scattering programme, to control and minimise beam losses for operation at higher intensities. Full intensity was obtained in experimental studies in February 1993 and for a brief period in an operational run in March 1994. For a considerable period subsequent to this it proved extremely difficult to raise the intensity above 180 µA, even in experimental studies. This was eventually shown to be associated with a particular system, adopted operationally, for the minimisation of beam loss.

In the short periods of running at 200 µA it became clear that in order to run consistently at such an intensity, very stable beam conditions were required, particularly at injection and early trapping when space-charge is at a maximum. The ability to fine-tune the synchrotron when operating close to full intensity is also very advantageous. The techniques developed to meet these requirements are described, together with re-tuning methods for the accelerators to obtain very stable operation at 200 µA.

2 TUNING THE ACCELERATORS

Very early in the commissioning of ISIS a set of ‘standard settings’ was established to minimise the time required to tune the accelerators from start-up. As the intensity was increased and parameters moved to tune for the higher intensity, whilst minimising and controlling beam losses, it became customary procedure to use the final parameters from the previous operational run as the starting parameters for the next. Using this procedure the intensity was gradually increased to 200 µA. The progress to full intensity was dictated by the priority given to the operational neutron scattering programme and the need to establish stable high trapping and acceleration efficiencies at each step with control and minimisation of beam losses. In the synchrotron the lost beam is stopped on specially designed collectors [1] located in approximately one tenth of the circumference

In February 1993 full intensity(2.5 x 10^{13} ppp) was obtained experimentally and was achieved for a brief period operationally in March 1994. In October 1993 stable operation was obtained at 190 µA, but apart from a brief spell at 200 µA in March 1994, performance fell back gradually to 180 µA and it became very difficult to raise the intensity above this value. It was observed that there were significant changes in the beam profiles in the transfer line from the linac to the synchrotron, but the excitation of the optical elements in the line had not changed significantly. It was thought that this may be due to changes in the ion-source, ion-source optics or the matching from the ion-source to the linac, but after extensive study of historical data no correlation could be found. Eventually a detailed comparison was made of all the accelerator parameters with the settings of October 1993. The most significant differences were the settings for the four linac accelerating cavities’ quadrupole and RF parameters. These parameters had been gradually tuned to minimise beam loss in the linac and the RF phases, particularly of cavity 3, had been adjusted to improve trapping in the synchrotron.

Resetting the linac back to the October 1993 parameters restored the profiles in the transfer line to 'normal' and a 200 µA beam was quickly established.

As a result of this experience, the settings for 200 µA are now used at the start of every run. Resetting back to these parameters after any subsequent tuning during the run will ensure that a gradual drift away in parameter space does not occur.

3 STABILISING INJECTED INTENSITY

Operating at full intensity, the fast cycling synchrotron is very sensitive to intensity fluctuations from the linac. These may result from many factors, ion-source stability, space charge neutralisation, optical matching and RF phase and amplitude stability. The ion-source operates with several feed-back systems, but these have limited gain and for historical reasons it is only possible to increment the output in steps of 5 µs. Similar gain limitations apply to the amplitude and phase servo systems for the RF accelerating cavities.

To take account of all possible contributions to intensity fluctuation it was decided to measure the total injected intensity on each beam pulse by integrating the signal from a beam toroid current transformer, just prior to injection. This signal is fed to a comparator amplifier where it is compared with a DC level proportional to the required beam intensity. The output of the comparator is then used to turn off the extraction volts of the ion-source when the set intensity is reached.

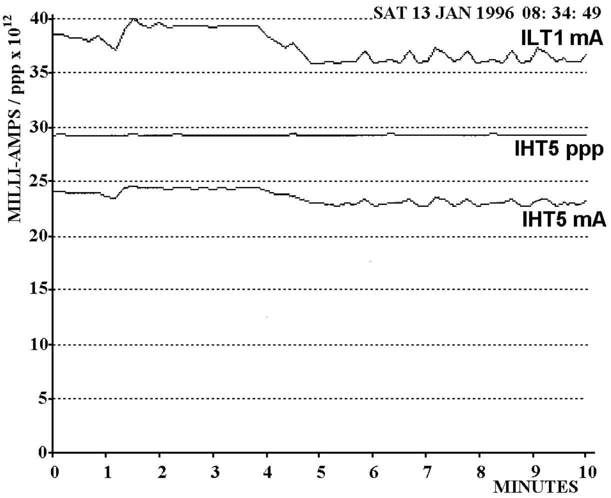

Figure 1. Ion-source current, ILT1, injected current into synchrotron, IHT5, and injected intensity.

The introduction of this servo has improved the injected intensity stability from ± 5% to ± 0.5%, as shown in Figure 1. In addition, tuning the synchrotron has been made easier by allowing the intensity to be incremented by 0.5% steps instead of ~2.5%.

4 STABILISING EARLY RADIAL POSITION

Though the intensity servo considerably improved the stability at injection there remained some instability, both at injection and the early part of trapping and acceleration, from the synchrotron main dipole field. To keep the beam on its correct radius, a radial servo-loop varies the acceleration frequency to minimise the sum of the non-normalised signals from the ring beam position monitors. Unfortunately these monitors do not give a good signal when the beam is only partially bunched and it was customary to gate the control loop off for the first millisecond or so. During this period any correction to the radial position was applied by adding a fixed "trim function" to the input of the acceleration frequency voltage controlled oscillator. This worked well as long as the synchrotron dipole field remained stable, any field fluctuations at this time could not be tracked and the frequency corrected resulting in radial steering of the orbit and possible beam loss.

To overcome this a programmable function was used as a "demand" signal for the radial loop. The form of this function was determined empirically by finding a value for any given time that was mid way between the limits that would produce beam loss. Once set up it mimicked the non-zero output obtained from the beam position monitors when the beam radius was correct. The use of this function allows the use of the radial loop, during trapping and the early part of acceleration, to maintain a stable radial position for the beam despite fluctuations in the guide field.

5 TUNING ON THE 'FLY'

Tuning of the synchrotron when running at full current, i.e. full intensity and 50 Hz repetition rate, is extremely difficult since any experimental adjustments which cause an increase in beam loss may trip off the accelerator. For this reason the synchrotron is normally tuned with the beam at full intensity, but with the beam pulsing at a sufficiently lower repetition rate so that the beam loss protection can be over-ridden. Starting from a 'standard parameter set' minimises the tuning time, but time at the start of an operational run is always limited. Also, the ion-source performance changes with repetition rate and the performance of other equipment may change as it gradually reaches thermal equilibrium.

To overcome this a multiplexing system has been developed that allows the synchrotron to be tuned experimentally, without tripping on beam loss, whilst running at full intensity and repetition rate. A parallel system of control equipment has been installed for the parameters that are most frequently adjusted:

- Horizontal Steering Dipoles (Horizontal closed orbit)
- Vertical Steering Dipoles (Vertical closed orbit)
- Trim Quadrupoles (Betatron tune Q_H and Q_V)
- Trim Quadrupoles (Harmonic Q-values)
- RF Gap Voltage Function
- RF Frequency Law Trim Function
- Vertical 'Sweeper' Dipole (Controls 'painting' of vertical betatron phase-space at injection)
- Octupole Magnets

Each system can be individually programmed with both a NORMAL and an EXPERIMENTAL set of parameter functions with time. The synchrotron is controlled by the NORMAL functions, whilst the EXPERIMENTAL values can be switched in at a much lower repetition rate. This is usually one pulse in 128, but 1 in 64 and 1 in 32 are available. Adjustments are made only to the EXPERIMENTAL values to study fine tuning of the machine to increase intensity without increasing beam loss to above the trip level.

Tuning in the pulsed experimental mode is carried out by first establishing reference data for the NORMAL function operation. For this mode the total beam loss and intensity signals as a function of time are averaged on a sampling oscilloscope and stored and displayed. The EXPERIMENTAL functions are switched in every 1 pulse in 128 and the oscilloscope is triggered on the same pulse. Tuning can be carried out on this cycle and compared with the reference data, while the affect on machine performance is << 1%. When an improvement is established, the machine can be run initially at 50 Hz on the EXPERIMENTAL values and if satisfactory, these are then transferred to the NORMAL functions.

The success of this method depends to a large extent on the pulse to pulse stability of the beam, since any variations in the 1 in 128 pulse cycle make it difficult to carry out meaningful adjustments. However, the system can now be used successfully for the fine tuning of ISIS at full intensity since the new injected beam intensity servo-system and the greater stability obtained for the early closed orbits have significantly improved the pulse to pulse stability in the synchrotron.

The success of the improvements described culminated with ISIS operating at 200 μA with high stability for the last two operational cycles before the annual long shut-down. For each of the two cycles an average current of 181 μA was obtained for the scheduled running time. The success of the 'standard parameter settings' is illustrated in Figure 2, which shows how quickly 200 μA operation was re-established after the shut-down for the Christmas festivities.

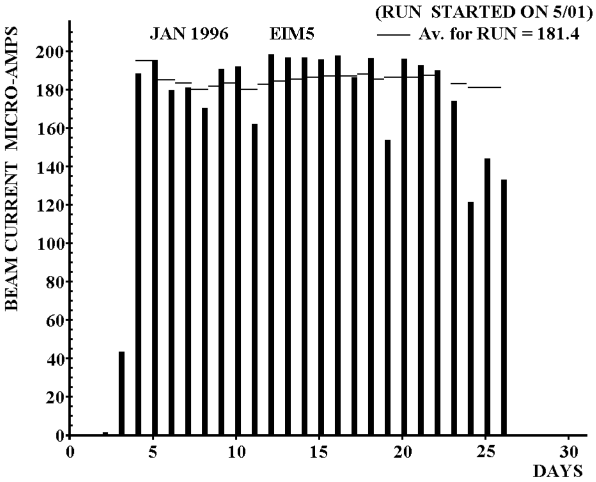

Figure 2. Operational cycle of ISIS running at 200 μA showing average current per day and average current for the cycle

6 CONCLUSION

It has been found that concentration on the control and minimisation of beam loss in high intensity accelerators may lead to a gradual drift in parameter space that can limit the accelerators to sub-optimal performance. As a result, at the start of every operational run, the accelerators are now initially tuned to a particular set of parameters that has been established empirically. Subsequent tuning during the run is allowed, provided reduced beam loss is not at the expense of intensity and an increase in intensity is not accompanied by an unacceptable increase in beam loss.

The development of two servo-systems to stabilise the injected intensity and the radial position during trapping and early acceleration have significantly stabilised the accelerator performance at the full intensity of 200 μA.

The improvement in stability, together with the development of a multiplexing system that allows one pulse in 128 to operate at different tunes without tripping on beam loss, has considerably simplified operations and allowed fine tuning of ISIS when close to full intensity.

REFERENCES

[1] P.E.Gear, BEAM INDUCED RADIATION PROBLEMS AND CURES, this Proceedings.