THE BEAM LOSS COLLECTION SYSTEM IN THE ESS ACCUMULATOR RINGS

C. M. Warsop, Rutherford Appleton Laboratory, Oxfordshire, U.K.

Abstract

The two 50 Hz, 1.334 GeV rings of the European Spallation Source (ESS), will each handle an average beam power of 2.5 MW. The requirement for small and controlled loss, with activation low enough for hands on maintenance, has dominated the machine design. Interactions with the stripping foil are expected to cause <0.02% regular losses in the rings. Ideally, this and all other loss will be efficiently localised on collector systems located in well shielded regions of the rings. A recent increase to the ring circumference, to reduce foil heating, has proved beneficial for collector placement. The design of the loss collection systems is presented along with features important for optimal performance, e.g. jaw location and geometry. The nature of the expected losses, and their effect on collector efficiency, is also considered. A Monte Carlo code developed to model the beam loss collection process is described. Simulation results so far, and plans for work required to finalise the designs, are summarised.

1 ESS RINGS AND COLLECTORS

1.1 The ESS Accelerators

The ESS accelerators [1] consist of a 1.334 GeV linac, which develops the 5 MW beam power, and two 50 Hz accumulator rings operating in parallel. Each ring accumulates $2.34x10^{14}$ over the 700 turn charge-exchange injection process, shortening the beam pulse to provide the ~ 1 μs lengths required at the target. The linac beam is chopped to allow lossless capture in the ring RF system, which preserves a gap for fast extraction.

The ring design has recently been revised [1] because of concerns over foil heating. The mean radius is increased from 26 to 35 m, reducing the number of injected turns and foil temperature. The lattice change has involved the addition of another triplet cell to the long straights, which has been helpful for collector placement.

1.2 The Ring Collector Systems

The collector designs remain essentially as in [2]. There are three collector systems: (i) the betatron system, (ii) the momentum tail system, and (iii) the general momentum system.

The betatron system consists of double jaws at relative betatron phases of 0° (primaries) and 17°, 90°, 163° (secondaries), in both transverse planes. Where the phase shifts are similar, the horizontal and vertical systems are combined. Primary, secondary and aperture acceptances are 260, 285 and 480 π mm mr respectively. Jaws are flat, matching the rectangular machine apertures, but with a single angled edge (9°) to enhance efficiency. This system will intercept most loss, and is placed in a dedicated, well shielded dispersionless straight. Energy loss in the foil produces an enhanced betatron motion, which peaks 180° from the foil. The momentum tail system is placed at this location, forming an integral part of the betatron system. The primary jaws of the general momentum system are placed near the first peak in normalised dispersion (~2 $\mathrm{m}^{1/2}$) after the main collector straight. Secondary jaws are also included, about 160° downstream. Longitudinal collimation takes place for particles significantly exceeding both the betatron secondary limits, (>285 π mm mr), and the longitudinal acceptance (dp/p > |0.8%|).

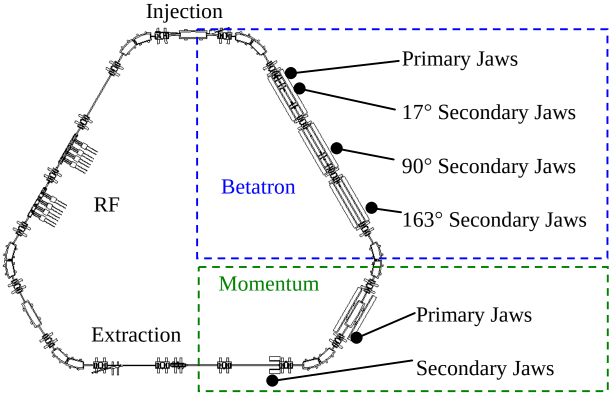

Figure 1: ESS Ring and Collectors

1.3 Collector Jaw Design

The preferred material for the collector jaws is graphite: it produces low levels of activation, and has good thermal properties. However, to enhance scattering angles and reduce collector lengths, materials of higher atomic mass will also be used where required. Graphite collectors will be between 1 and 2 m long depending on space constraints.

Each collector jaw is to consist of one or more remotely adjustable sections; mechanical designs will follow collector upgrades presently underway at ISIS. Primary collectors will have a short adjustable upstream section (~50 mm) of high atomic mass material, followed by longer adjustable sections of graphite to make up the full length. Advantages of the split adjustable jaws include: correction for beam-collector misalignments, and flexibility e.g. configuring the primary as a deflector, or deflector-absorber. To allow proper collector set up, diagnostics that monitor the local loss levels and temperature on each jaw will be included. All main collectors will be water cooled; the average total heat load is expected to be 500 W per ring.

Overall design will follow similar ‘active maintenance’ principles used on ISIS. The collector assemblies will be composed of modular sections, designed for quick removal and servicing. The collector straights will be enclosed in sealed concrete shielding. Provision will be made for protecting the machine components, and intercepting secondary particles. For the main collector modules, graphite lined aluminium or steel box constructions are envisaged, with the highly active jaws enclosed inside.

2 ANALYSIS OF LOSSES

2.1 Loss Types

The purpose of the beam loss collection system is to maximise localisation of beam loss and resultant activation, and to protect the machine from physical damage. **Uncontrolled losses**, i.e. those distributed around the ring and not on the collector system, must be kept to levels of 1 nA/m/GeV (0.01%) to keep activation low enough for hands-on maintenance. **Controlled loss**, i.e. that localised on the collector system, can be higher but should be minimised. As well as increasing activation hazards, higher controlled loss requires correspondingly increased collector efficiency.

Regular loss, i.e. losses occurring at 50 Hz, 24 hours a day during operational running, are the most important to control. Of significant, but secondary importance are **Irregular losses**. These are higher levels of loss that occur before the beam trips off due to a fault condition, or losses tolerated at low rep rates during machine set up. It is assumed that comprehensive beam loss monitoring is included to protect the machine.

2.2 Loss Mode

Beam is lost when it exceeds one or more of the machine acceptances. For the ESS rings, the important limits are the transverse and momentum acceptances of the ring and, to prevent loss at extraction, the acceptances of the RF and extraction systems.

The manner in which beam comes to exceed acceptances, the *loss mode*, affects the collection efficiency. The loss mode can be defined by the plane and growth rate. For transverse losses, at slow growth rates (<10 μm/turn), operation conforms to the usual model with secondary collectors just intercepting out-scatter from the primaries. In this regime, great gains in efficiency are possible with impact depth enhancing measures. At fast growth rates (>100 μm/turn), the collection process changes, with more particles hitting the secondary jaws first. In this regime it is generally more important to remove beam quickly, before apertures are reached, and this requires more jaws. For momentum loss these arguments still hold, but dispersive radial motion must also be included.

2.3 Expected and Possible Loss Modes

The dominant expected regular losses (0.02%) are associated with the foil. Elastic scattering in the transverse plane, and ionisation energy loss straggling in the longitudinal, will produce a significant spread of growth rates. Possible space charge emittance growth will tend to produce slower growth rates. Experience on ISIS has shown that when running a high power machine for 1000’s of hours a year, unexpected regular losses do occur. The ability of the collection system to control these has a direct effect on operational levels. Irregular or fault loss can be in any plane, at a wide range of growth rates. The better protection there is against these losses, the less likely is down time due to machine damage. It is clearly advantageous to design collectors to deal with as many loss modes as possible.

2.4 Loss Mode and Collector Operation

Most of the expected regular losses will be localised on the betatron system. The collector designs allow for slow and fast transverse loss. The single angled edge at smaller acceptances enhances impact depths and thus the efficiencies for slowly growing particles. Secondary jaws intercept a large fraction of the out-scatter. The provision of double jaws at larger emittances, and a comprehensive set of secondary collectors, ensure the quick removal of faster loss. In particular, double flat primary jaws remove particles quickly to prevent loss at extraction. The primary betatron jaw on the inner radius, which also serves as the momentum tail collector, will function efficiently for large or small momentum errors.

General longitudinal losses are expected to be very small, but a basic momentum collimation system is provided to intercept ‘unexpected’ losses, and possible low momentum out-scatter from the main betatron system. Important features will follow those of the betatron system.

Shaping of the collector in the beam direction also influences the collection efficiency for different loss modes. Short deflector primary jaws enhance efficiency for slow growth, whilst longer deflector-absorber jaws are preferable for the quick removal of fast loss. The proposed split, independently movable, sections will allow the configuration to be optimised for particular circumstances. A betatron kicker system, for halo particles in the beam gap, is also under consideration.

3 PARTICLE TRANSPORT SIMULATION

3.1 *Aims of the Simulation*

A Monte Carlo code has been developed to model the interaction of lost protons with the collector jaws, and determine their final destination. Only primary protons are considered; secondary particles are assumed scattered into surrounding shielding. To produce a simulation optimal for the particular application, use has been made of well established methods and routines, as well as the production of new code and enhancements where required.

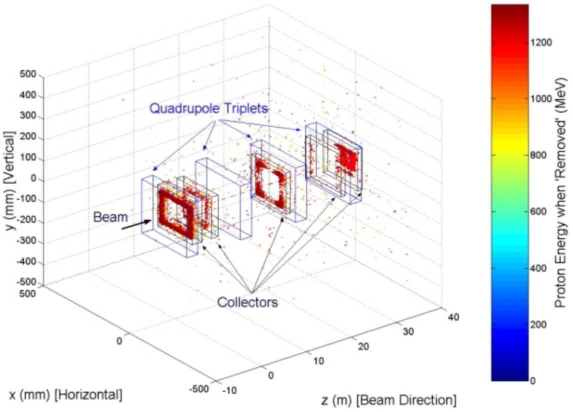

Figure 2: Proton Loss Distribution on Betatron System

3.2 *Transport in Matter*

Particle transport is based on the well established ‘condensed step random walk’ method [3]. The path of the proton is split up into small steps, over which many multiple scattering events occur, but for which the energy change is small. In collector problems, accurate modelling of particle scattering near material boundaries is important, and so step sizes are made as small as other constraints will allow.

Elastic multiple scattering of protons is treated using the CERN/GEANT implementation of the Moliere distribution. The output of these routines has been checked against published experimental proton data. The treatment of *ionisation energy loss* is based on the ACCSIM collimator routines, which in turn are based on CERN routines. Energy dependent step sizing has been optimised to maximise accuracy whilst not making layers so thin that the Moliere distributions become invalid. An option exploiting the fast *straggling* routine FLION [4] has also been added. Energy loss output has also been checked against established tables. Inelastic and single elastic *nuclear interactions* are included, using published energy dependent proton cross sections. Single elastic nuclear scatters are treated by a simple optical model [5], and based where possible on fits to experimental data.

3.3 *Collector and Accelerator Geometry*

To model correctly the collection process, the effect of the precise geometry of the jaws is included. Collector geometry is defined by 8 flat planes, with variable transverse and longitudinal orientations. These form an irregular octagonal transverse cross section, that is variable along the beam direction. Sections of the vacuum chamber may also be defined in a similar way. Beam is transported between collector sections via standard beam matrices.

3.4 *Advantages and Intended Use*

The accurate modelling of the jaw geometry gives realistic interactions with all collector interfaces. It is possible to build up a model of a complete straight, or even the whole ring, and study spatial loss distributions. All systems of collectors can be included simultaneously and their collective operation assessed. Presently, the code is being used in studies for upgrades of the ISIS collectors. It is hoped the code will become a valuable tool to help optimise loss control on ISIS.

4 SIMULATION RESULTS AND PLANS

First simulations of the betatron collectors in the revised ESS lattice indicate that, for typical growth rates (~10 μm/turn), multi-turn efficiencies of just under 90% may be expected. Of the 10% loss escaping the betatron system, a large fraction will be at low momentum and intercepted by the general momentum system. Simulation of fast loss, i.e. single turn removal of large emittances, indicate 95% efficiencies. There is still scope for optimisation, and higher efficiencies may be possible. An extensive set of simulations is planned to check and optimise the behaviour of the collector systems under most plausible loss modes.

5 SUMMARY

Revisions to the ESS lattice have been helpful in optimising the beam loss collection system, though the essentials of the design are unchanged. Extensive Monte Carlo simulations are now underway which will allow final assessment and optimisation of the design.

REFERENCES

[1] “ESS Feasibility Study”, Vol. 3, ESS 96-53M, and “ESS Accelerator Programme Status”, ESS 99-95-A.
[2] C.M.Warsop, “Beam Loss Collection in the ESS Accumulator Rings”, Proc. EPAC’98, Stockholm.
[3] M.J.Berger, “Monte Carlo Calculation of the Penetration and Diffusion of Fast Charged Particles”, Meth. Comp. Phys., Vol 1, 1963, P.135
[4] A.D.Bukin, N.A.Grozina, Computer Physics Communications: 78(1994)287
[5] G.R.Satchler, “Introduction to Nuclear Reactions”, Macmillan, 1990, P. 161.