PROTON BEAM LINE FOR THE ISIS SECOND TARGET STATION

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Abstract

The ISIS facility, based at the Rutherford Appleton Laboratory in the UK, is an intense pulsed source of Muons and Neutrons used for condensed matter research. The accelerator facility delivers an 800 MeV proton beam of 2.5×10^{13} protons per pulse (ppp) at 50 Hz to the existing target. As part of the facility upgrade, which includes increasing the synchrotron intensity to 3.7×10^{13} ppp using a dual harmonic RF system, it is planned to share the source with a second, 10 Hz, target station. A beam line supplying this target will extract from the existing target station beam line. Measurements and models characterising the optical functions around the extraction point of the existing line are discussed. The optical design, diagnostics and beam correction systems for the second target station beam line are presented.

GENERAL LAYOUT

The second target station lies south of the existing ISIS facility. The beam line feeding the new target extracts horizontally from the existing Extract Proton Beam line (EPB) and transports an 800 MeV beam over 143 m to Target Station 2 (TS-2). The transport line travels through the old NIMROD experimental hall, Hall 1, and then onto a new TS-2 experimental building. A general layout is shown in fig 1.

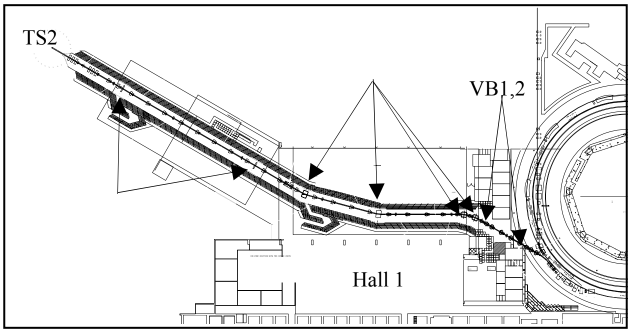

Fig 1: Layout of the Second Target Station Beam line

BEAM REQUIREMENTS

The target beam requirements are to deliver a circular beam with 18 mm half width and centroid position stability to < 1 mm. The transverse distribution is assumed gaussian and with 3σ at the required half widths. Measurements show the extracted beam emittances are approximately gaussian with $\varepsilon_x = 29.6$, $\varepsilon_y = 28.7$ π mm mrad at 1 standard deviation. To attain the required position stability the dispersion is achromatic at the target.

The transmission requirements are to control the beam envelope and trajectory to minimise beam loss. Thus protecting beam line components and facilitating hands on maintenance. The existing EPB has >99.9% transmission efficiency. It uses 100 mm half aperture components and limits the nominal maximum beam envelope to 75% occupancy. This envelope is based on the design 100 % beam width parameters, $\varepsilon_{x,y} = 300, 230$ π mm mrad, $\Delta p/p = 0.8$ % [1]. Operationally the beam is aligned to < 5 mm with minimal operating problems. These are the design criteria for the TS2 beam line.

The lattice has been designed using MAD[2]. This is a linear lattice design code hence space charge has not been included in any envelope calculations.

INPUT BEAM PARAMETERS

The EPB beam envelope in the TS2 extraction region has been modelled using TRANSPORT[3] and fitted to profile measurements. It was found that the nominal operating optic did not close dispersion at the correct points. A correction to this optic was calculated and applied. The theoretical correction envelope and a fit to measurement after correction are shown in fig 2. The envelopes show good agreement. The twiss parameters at the first extraction kicker, K1, for each case, are shown in table 1. The theoretical parameters are used for the beam line design.

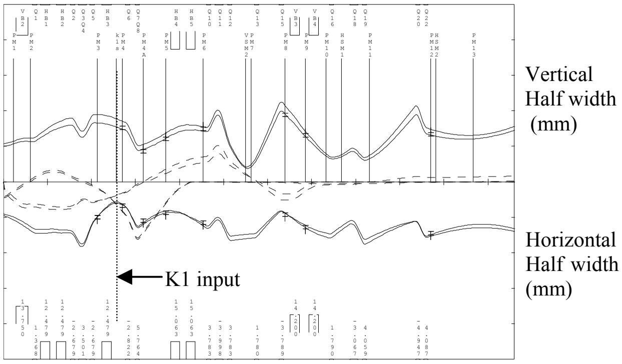

Fig 2: Theory and Measured Beam Parameters in EPB.

Table 1 : TS2 input parameters at K1 entrance

	Theoretically Corrected Optic		Measured fit to Applied Correction	
	H	V	H	V
α	0.19	0.81	0.16	0.78
β (m)	1.64	14.78	1.40	13.87
D (m)	1.27	-0.79	1.26	-0.77
D'(mrad)	0.57	0.16	0.55	0.19

EXTRACTION

The extraction system is in the horizontal plane and consists of two kicker magnets and a septum. The existing EPB magnet EHB4 will be replaced with a 'C' style magnet. This reduces the total displacement required at the septum exit. A schematic of extraction is shown in Figure 3.

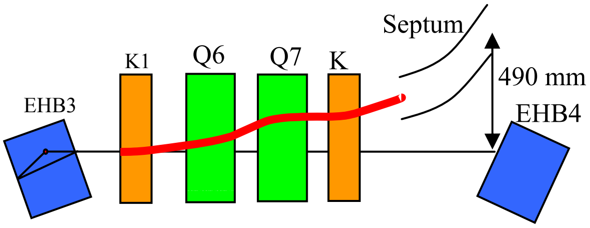

Fig 3: Schematic detailing Target 2 Extraction.

There are two stages to the extraction system. The first kicker, K1, deflects the beam horizontally through EQ6 and EQ7. The maximum envelope excursion through EQ7 is 75 mm. The nominal magnet aperture is 100 mm. The second kicker, K2 further deflects the beam centroid to 141 mm at the entrance to the septum. This is sufficient to clear two beam half widths (~ 35 mm), a septum thickness of 20 mm and up to 20 mm of trajectory error between TS-1 and TS-2 beams. The kickers operate at 10 Hz, have a rise time < 20 ms and maintain maximum field for 0.4 µs to cover the extracted beam.

The septum parameters have been chosen to deflect the beam by 490 mm and have exit angle of –30˚ to the X axis of the synchrotron co-ordinate system. This reduces the type of horizontal dipoles used in the remainder of the beam line. The magnet parameters are given in table 2.

Table 2: New EPB and Extraction Magnet Parameters

	Length (m)	B Field (T)	Angle (mrad)
EHB4	1.04	1.506	321.8
K1	0.50	0.118	12.1
K2	0.50	0.877	90.0
Septum	1.46	1.030	307.5

BEAM LINE FROM SEPTUM TO TARGET

The first section of the beam line from the septum to HB2 is the most optically and geometrically demanding. After extraction the beam is dropped 1.526 m and turned horizontally left through 30°. For modularity in the remainder of the beam line the dispersion is closed at the exit face of HB2. The optic is shown in Fig 4.

The second section, from HB2 to VB4, turns the beam right through 30 degrees and increases the beam height 0.87 m. Both bending sections are achromatic. This is achieved using a 10 m FODO structure with 90° phase advance in each plane. Hence two cells in the horizontal bend region and four cells in the vertical bend region close dispersion. The slight perturbations in the beta functions are due to the focusing effects of the rectangular dipoles. These have been minimised using the quad families upstream of each bend section. The optic is shown in fig 5.

The final section of the beam line delivers the beam to target. A triplet structure has been used in this region to supply a beam waist at target in both planes. For maximum flexibility a structure has chosen to supply the required beam size containing either the full 100 % design emittance or measured 3σ emittance. The former case requires larger quadrupoles with up to 160 mm bore radius if 75 % occupancy is to be preserved. This optic is shown in fig 6.

The magnet parameters for the beam line are given in table 3. The lengths of the quadrupoles and vertical dipoles have been kept the same to reduce the number of magnets types and hence manufacturing cost.

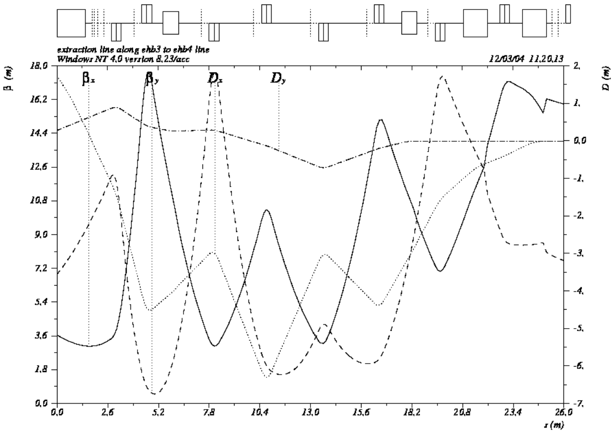

Fig 4:Beam line Optic from the Septum to HB2

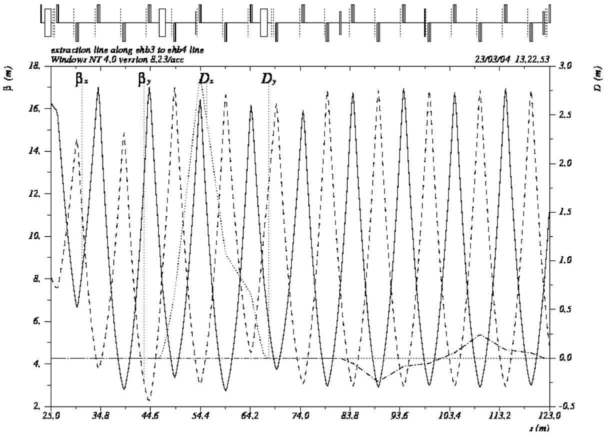

Fig 5: Beam line optic from HB2 to VB4

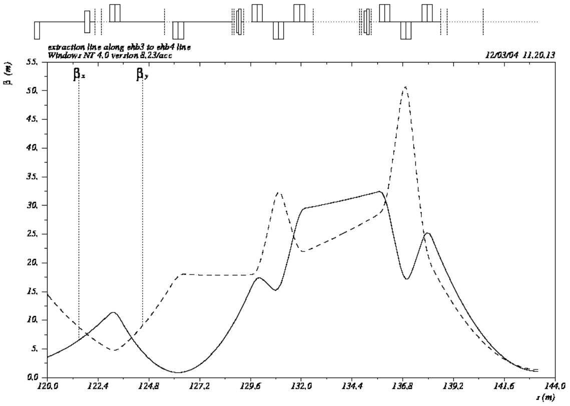

Fig 6: Beam line optic from VB4 to target

Table 3: Quadrupole and Dipole Magnet Parameters

Name	Length (m)	B (T) or dB/dr (T/m)	Angle (°)	Half Aperture (mm)
Q1-Q30	0.5	0.99-7.4	-	100
Q31-Q36	0.5	2.85-8.18	-	160
VB1/2	0.80	0.76	7.16	100
VB3/4	0.80	0.13	1.24	100
HB1/2/3/4	1.25	1.02	15	100

DIAGNOSTICS AND BEAM CONTROL

The diagnostic requirements for this beam line are to protect components, provide beam parameter information and allow operation within defined limits.

Machine protection will be provided by the use of 15 Beam Loss Monitors (BLM) and 5 Intensity Monitors (IM). Suitable locations of the IM's allow extraction, transmission and target beams to be measured. Suitable signal analysis provides trips under high beam loss conditions.

Trajectory and beam widths will be measured using 36 'HARP' type profile monitors and 6 position monitors. The profile monitors are placed upstream of each quadrupole. Position monitors placed downstream of the septum measure the extraction position and monitors near the target control the beam on target. It is envisaged that a feedback loop using steering magnets, position monitors and target halo monitors will keep the beam on target to less than 1 mm.

BEAM LINE STABILITY STUDIES.

Input Beam Studies

The beam line sensitivity to varying input parameters has been studied by running two cases. The first uses the original ISIS EPB design [3]. The second uses the nominal operating optic. These have a large variation compared to the chosen input parameters.

For each scenario the beam line quadrupoles were fitted to the required optical parameters. The target Twiss parameters were achieved and the dispersion functions was controlled to <0.1 m which is sufficient for beam line operations.

Magnet Alignment and Trajectory Control

During beam line installation each magnet element will be installed and aligned to a certain tolerance. These are expected to be ± 0.25, 0.25 and 0.5 mm for dx, dy and ds respectively with corresponding 1 mrad angular errors in each plane. Each magnet miss-alignment acts on the dispersion function and beam centroid trajectory. Using MAD's random functions many beam line alignment distributions can be generated. Its fitting routines can then be used to find trajectory corrections for each case.

Studies over 500 distributions showed the uncorrected trajectories are ± 30 mm in each plane. Fitting with the main dipoles alone controls the trajectory to ±10 mm. The addition of a further 6 steering magnets allows alignment to ± 5 mm, as shown in Fig 7. A further 4 steering magnets would reduce the trajectory distortions to ± 3 mm. For all cases the position at the target was aligned to < 1 mm as required. The steering magnets were placed 180° phase advance from the main dipole. For all the studies 2 steering magnets per plane were used to control the beam on target position.

The dispersion function at target varied by up to ± 0.5 m for the uncorrected case. After trajectory correction this was reduced to ± 0.02 m. The pulse to pulse energy variation of the ISIS extracted beam is ±0.4 MeV. This will give a pulse to pulse position variation of ± 0.5 mm for the uncorrected case and 0.02 mm for the trajectory corrected cases. Both are within an acceptable operating limit.

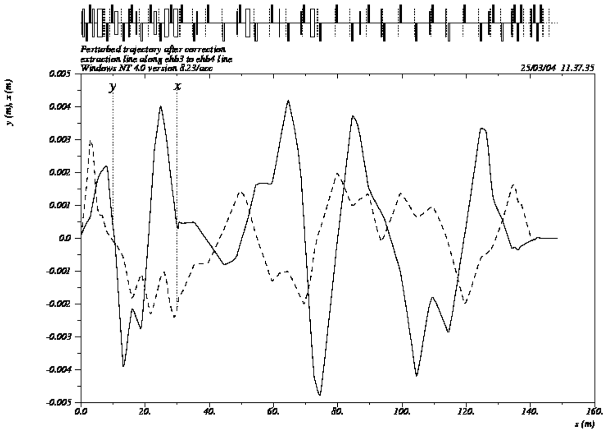

Fig 7: Typical Aligned Beam trajectory with 10 steering magnets

Field Errors.

Magnet field errors have not been included in any of the stability studies presented. The design specification is for field homogeneity across the beam aperture to be > 99%. This will be sufficient for a single pass line. Any field errors which do perturb the envelope will be small and can be removed by retuning the beam line.

SUMMARY

A beam line solution has been found to satisfy the target geometry and beam requirements. The optical constraints are based on the existing, successful, EPB design criteria. This will allow the use of existing hardware designs. Stability and correction studies show that the beam line can run within the existing EPB operating tolerances.

REFERENCES

[1] Estimates for SNS Extraction at 800 MeV. G H Rees. SNS/0/N4/82

[2] The MAD Program Version 8.16. Hans Grote. CERN/SL/90-13 (AP) Rev 4

[3] PSI Graphics Transport framework by U. Rohrer based on CERN-SLAC-FERMILAB version by K.L. Brown et al.