THE TRANSPORT LINE UPGRADE PROPOSAL OF HEFEI LIGHT SOURCE*

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Abstract

A 53 m long transport line connects the storage ring of Hefei Light Source (HLS) with its injector, which is a 200 MeV linac. In its preliminary design, there exist phase space mismatch between transport line and storage ring, which maybe results in lower injection efficiency and sensitivity of injection process to injected beam conditions. We have studied new focusing parameters and its performance can be improved to some extent, while perfect dispersion matching can't be achieved due to deficiency of focusing structure. Then, a new configuration of transport line with little hardware upgrading was put forward, where the complete match of phase space was obtained and new skew quadrupoles were introduced to make dispersion function matching. This matching would be helpful to improve the injection efficiency and reliability of HLS.

INTRODUCTION

HLS uses a 200 MeV linac as the injector of 800MeV storage ring, whose circumference is 66m and beam intensity is about 300mA. Optical parameters of the storage ring at injection point are $\beta_x = 21.57m$, $\alpha_x = -0.032$, $\beta_y = 4.20m$ and $\alpha_y = -0.166$. The transport line brings 200MeV electron beam from linac to storage ring, and must meet the requirement of optical matching between the storage ring and transport line. Dipoles and quadrupoles are used to transfer and focus the beam, to realize matching of phase space.

Transport line includes four modules according to functions: the first is horizontal acromat which composed of horizontal dipoles and quadrupoles and redirects beam towards storage ring, the second is optical matching cell composed of quadrupoles, the third is vertical acromat which composed of vertical dipoles and quadrupoles and brings beam into horizontal plane of storage ring, the fourth is septum, which adjusts injection angle. The transport configuration was shown in figure1. In this paper we focus on minimizing the mismatch factor and reducing dispersion function at injection point.

CURRENT STATUS

The transfer line design is optimized to transfer the beam efficiently and to meet the optics requirements at the injection point. The current structure of HLS transport line consists of four modules (see figure 1).

1) Horizontal acromat section, from pulsed switching magnet to the second dipole (BM2) with a horizontal deflection angle of 22.5×2degree, makes the horizontal dispersion function and its derivative zero at the exit of second dipole.
2) Optical matching section, which is a dispersion-free section, from the second dipole (BM2) to the third dipole (BM3). In this cell the concerned point is beam envelope to assure efficient transport. Also we can vary the gradient of quadrupoles in this section to meet the matching requirement at injection points without destroying achromatic conditions in the end of transport line.
3) Vertical acromat section, from the third dipole (BM3) to the fourth dipole (BM4) with a deflection angle of 22.5×2degree. Transfer the to the storage ring's level.
4) Injection section, it composed of one horizontal septum magnet, which deflects the beam to the storage ring. It is a dispersive section, so that the horizontal dispersion function and its derivative make sensitivity of injection process to energy spread and energy shift of injected beam.

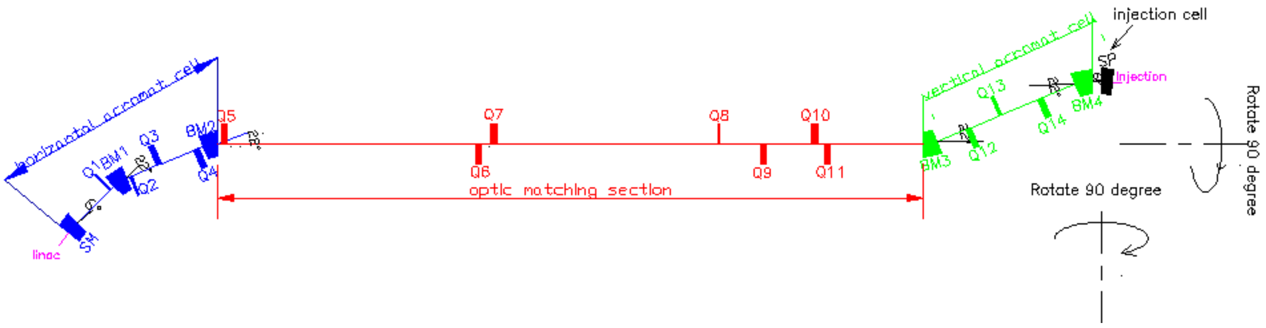

Figure1: Layout of current HLS transport line.

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The difficulty with the current transport line is that there is isolated horizontal septum magnet at the end of the beamline; it can not form an achromatic structure in the horizontal direction, which may be effect injection efficiency of off-energy particles.

NEW FOCUSING PARAMETERS

Mismatch Factor

We use mismatch factor M to quantify mismatch from injector to storage ring. Define mismatch factor M as follows [1]:

$$M = [\frac{1}{2}(R+\sqrt{R^2-4})]^{\frac{1}{2}} - 1 \quad (1),$$

where $R=\beta G + B\gamma - 2\alpha A$, $\gamma x^2 + \beta(x')^2 + 2\alpha x x' = \varepsilon$, $Gx^2+B(x')^2+2Axx'=\varepsilon$ are the two ellipse of injector and storage ring.

If the above two ellipse exactly matched the mismatch factor will be zero.

Reducing Dispersion

Before we have discussed dispersion matching scheme of HLS transport line, where two dipoles were introduced to form horizontal acromat and beam transport trace was changed [2]. There is a drawback of that scheme, that components needed upgrade are too much.

In order to minimize dispersion, also based on current structure of one horizontal septum at the end of the transport line, we add skew quadrupoles at the vertical deflection section and use coupling to minimize the horizontal and vertical dispersion simultaneously.

Add two skew quadrupoles with a length of 0.1m at vertical acromat section, varying their position and gradient to meet the focusing parameters at the end of the transport line (use MAD-X) [3]. The dispersion function and its derivative are about four orders smaller than origin design (listed in table1).

If insert three skew quadrupoles in the vertical acromat section with a length of 0.1m ,varying the skew quadrupoles gradient, position, and normal quadrupoles strength of this section. After matching both of the horizontal and vertical dispersion function and their derivative are close to zero (shown in talbe1).

Table 1: Dispersion Function Comparison Between Current Value and New Computed Value

parameter	Current value	2skew magnet	3skew magnet
η_x	-2.6×10^{-2}	-1.1×10^{-5}	7.7×10^{-6}
η_x'	-0.1	-3.7×10^{-6}	5.6×10^{-7}
η_y	3.4×10^{-3}	-3.7×10^{-6}	-5.4×10^{-7}
η_y'	-6.2×10^{-5}	-4.2×10^{-6}	-1.5×10^{-7}

The gradient of old structure has to be varied at vertical acromat section to matching dispersion at storage ring's injection point, whose value is zero. The gradient of old structure and the new designation are listed as table 2.

Table 2: Quadrupole Gradients of New Design and Old Design at Vertical Acromat Cell

quadrupole	Quadrupole coefficients	
	current structure	new design
Q12	-3.91730	-4.74235
Q13	5.80000	4.90221
Q14	-3.27594	-2.43788
SQ1	—	18.58164
SQ2	—	13.30432
SQ3	—	7.067138

Phase Space Matching

The follow equation gives the ideal beta function value of transport line at injection point [4].

$$\beta_{xi}^2 + \frac{(n\sigma_{x0}+T)\times\beta_{xi}^{\frac{3}{2}}}{2\sqrt{\varepsilon_{xi}}} = \frac{\beta_{x0}^2}{2} \quad (2),$$

where subscribe xi denote the injection beam parameters and subscribe $x0$ denote beam parameters of stored beam at injection point. For HLS $n=3$, $T=2mm$, $\varepsilon_{xi} = 4.5\times10^{-7}\,m\cdot rad$, $\varepsilon_{x0} = 1.5\times10^{-7}\,m\cdot rad$ and $\beta_{x0}=21.56659\,\mathrm{m}$. Solving the equation we will get the optimised horizontal beta value $\beta_x = 9.05492\mathrm{m}$, Based on this beta function and looking forward to minimize mismatch factor, vary the quadrupoles gradient of the matching section to meet the above given beta function and also minimize the mismatch factor. After matching with MAD-X the mismatch factor can decreased from 1.06 to 0.54 in horizontal direction and from 2.49 to 0.90 in vertical direction. Table3 gives the quadrupoles gradient of the optical matching cell in old design and new design.

Table 3: Quadrupole Gradient of New Design and Old Design at optic Matching Cell

quadruple	Quadrupole coefficients	
	current structure	new design
Q5	1.91700	2.28441
Q6	-1.80000	-1.90214
Q7	1.93200	1.99783
Q8	2.50000	4.56982
Q9	-1.14800	-1.21189
Q10	1.70000	1.72430
Q11	-1.60000	-1.79673

The optics is optimally chosen in order to keep the beam envelope to acceptable values throughout the transfer line. The number of hardware that need upgraded is kept to minimum while achieving the design goal. The beta function, dispersion and its derivative in upgraded design are shown respectively in figure 2 to figure 4.

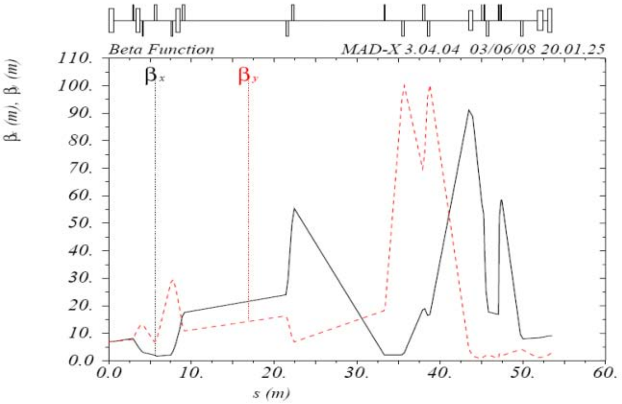

Figure 2: Beta function of the upgraded transport line.

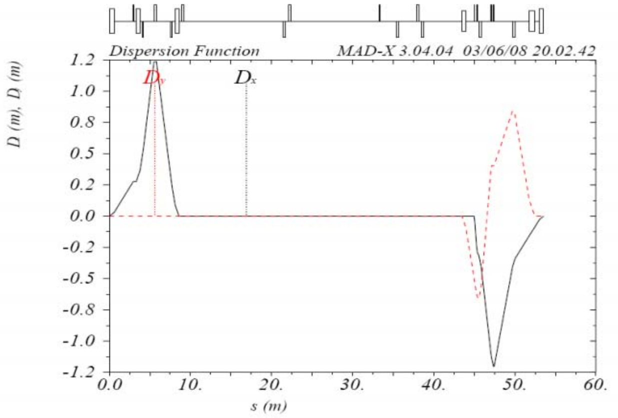

Figure 3: Dispersion of the upgraded transport line.

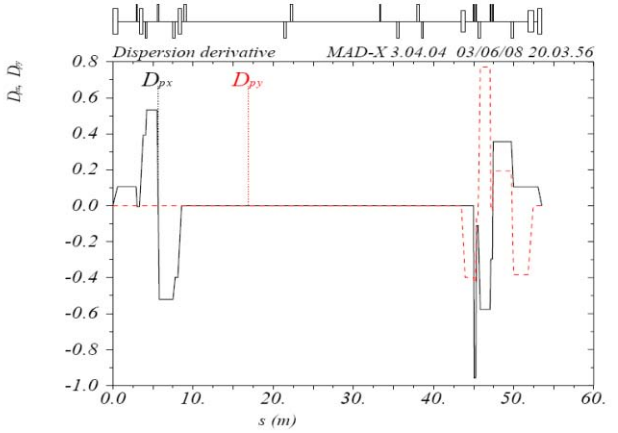

Figure 4: Dispersion derivative of the upgraded transport line.

UPGRADING PROPOSAL

The poor performance of the original transport line may caused by phase space mismatch and high horizontal dispersion at injection. Based on the above analysis we hope upgrade the HLS transport line with a little hardware reconstruction, and change quadrupoles gradients of current structure to match phase space at injection point of storage ring. Since the first horizontal acromat cell has not changed any, the transport trajectory of bean is maintained, and then amount of reconstruction was minimized. In the new design we proposed to use horizontal-vertical coupling to reduce horizontal dispersion at injection point. As coupling can occur just by a geometrical reason without any explicit coupling elements, skew quadrupole magnets should be added. Two skew magnets (SQ1 and SQ2) are inserted between BM3 and Q12, the other one (SQ3) is inserted between Q12 and Q13. The layout of upgraded transport line design was shown in figure 5. Other structure showed in figure1 is not changed. The funds and periods of upgrading would be reduced.

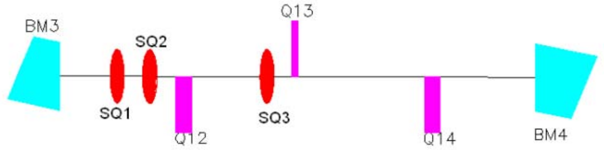

Figure 5: Adding three skew quadrupole in the vertical deflection cell.

CONCLUSION

An upgrade proposal of HLS transport line is presented. The unreasonable design of the current transport line is that η and η' is not matched to storage ring, due to the single septum magnet at the end of transport line. This may be cause beam loss in the injection process. In this paper we put forward a plan of using coupling to minimize η and η', accomplished this by adding skew quadrupoles and varying quadrupoles gradients. At the same time, we can reduce phase space mismatch factor by optimizing quadrupole strengths. The calculation results shown that the goal can be achieved by above method. Advantages of the upgrade proposal were in that it can successfully match phase space and reduce dispersion with a little hardware upgrading. The funds and period for upgrading are minimized.

ACKNOWLEDGEMENT

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