PRELIMINARY DESIGN OF THE TPS LINAC TO BOOSTER TRANSFER LINE

Y.C. Liu*, S.Y. Hsu, K.T. Hsu, K.B. Liu, C.S. Fann, H.P. Chang, G.H. Luo, K.K. Lin
NSRRC, HsinChu, Taiwan

Abstract

The preliminary design of the LTB (linac to booster) transfer line of the proposed TPS (Taiwan Photon Source) project is considered in this study. The layout presented in this report is based on the booster lattice and the choice of linac parameters. These parameters are adopted from previous report of booster design and typical commercial available products of linac. The simulation result indicates that the desired optical functions at a given location can be readily obtained by varying the appropriate focusing strength of quadrupoles. It provides tuning capability to match various possible options of optical functions at injection location. This report is presented together with design consideration of a set of beam diagnostics instruments.

INTRODUCTION

The TPS project was proposed in 2004 and the design report was submitted to the NSC (National Science Council) in 2005 [1]. It is decided that a detailed feasibility study concerning component parameters shall be carried out and the results will be provided for further evaluation. Consequently, the LTB transfer line has been studied in this case for the purpose of finalizing the parameters of linac and the injection elements of the booster.

Considering the electron acceleration arrangement of a typical 3GeV light source, the electrons are generated and accelerated by a 100MeV linac and a 3GeV booster [2]. After reaching the final beam energy of 3GeV, the electrons are injected into the storage ring for user operation.

The guidelines to design a LTB transfer line are listed as follow.

- transfer electrons with appropriate beam envelope
- utilize LTB transfer line as an energy filter for booster acceptance
- transfer electrons to be injected into the booster efficiently
- be able to characterize the 100MeV electron beam

The arguments of the guidelines are based on the following expectations.

- An appropriate beam envelope ensures that both beam size and its divergence match to the acceptance of the booster lattice.
- The major bending magnet in the LTB transfer line is utilized as an energy filter to ensure the complete capture of booster rf bucket.
- It shall fulfill the demand of high transfer efficiency between LTB for the future top-up operation.
- It provides appropriate tuning knobs to characterize beam properties both transversely and longitudinally.

The proposed lattice of the transfer line is calculated by using the AGILE program [3] and the result has been checked by using the MAD program [4]. The calculated result indicates that the desired optical functions at a given location can be readily obtained by varying the focusing strength of quadrupoles. It provides tuning capability to match possible change of optical functions in the booster ring. A brief description of the analysis of beam property using analyzing magnet at downstream of linac is also presented.

INITIAL AND BOUNDARY CONDITIONS

The design lattice of the transfer line presented in this report is based on the corresponding design of booster ring and choice of linac parameters. These parameters are adopted from commercial available products of linac and previous booster design [5].

Items to be considered for layout are listed as follow.

- beam parameters at the exit of linac:
  A set of typical beam parameters of commercial available linac are applied in this study. They are: $\beta_{x,y}$ = 7m; $\alpha_{x,y}$ = -1.5.
- lattice parameters at the booster injection section:
  The proposed beam trajectory of entering the booster ring is on-axis injection. Therefore the following parameters are utilized, i.e. $\beta_{x,y}$ = 3m; $\alpha_{x,y}$ = 1; D_x = 0m.
- arrangement of the radiation shielding:
  The shielding wall arrangement is to separate linac from the booster tunnel. This arrangement will benefit the linac commission without interfering with the booster installation. Also, this separate shielding wall is convenient for future routine maintenance, tune-up, and the stability of temperature control.
- linac beam characterization:
  A beam property measurement setup is considered in this study. It utilizes the analyzing capability of the switchyard magnet to characterize the 100MeV electron beam. Beam diagnostic instrument will be equipped with a beam dump for safety concern.
- tuning capability of beam focusing and steering:
  The focusing and steering of the LTB transfer line shall provide relaxed strength and flexible capability for beam tuning. The calculated result presented in this note gives one of the feasible arrangements with present magnet elements.
- injection into the booster:

* yichihl@nsrrc.org.tw

The calculated result provides information on the specification of pulse magnets and is useful for further analysis of injection process.

- dimension of pre-injector:
  Estimation on the dimension of electron gun, linac, and bunching section shown in the layout is taken from the existing commercial products.
- the circumference of the booster ring: 499.2m.

LATTICE OF THE LTB TRANSFER LINE

Few sets of quadrupole triplet are used as a focusing element in the transfer line. It is applied along the path whenever focusing element is required. One of the major purposes of this selection is to adopt similar arrangement reported in reference-[6] and to treat it as a guideline in using the lattice design program "AGILE" [5]. The advantage of using triplet focusing element is to simplify the workload of fabricating the components. Three sets of triplets are used in this study assuming that they are the same copy of hardware product. The disadvantage of this selection is that not all triplets fit the boundary condition of geometrical requirement. Therefore, the focusing strength of each quadrupole is independently powered with appropriate settings, as indicated in the following illustration.

The calculated optical function of the LTB transfer line is shown in figure-1. The arrangement of the magnet elements is similar to the case presented in reference [6] with modifications of focusing strengths and locations to compensate for the different layout of shielding wall proposed in the TPS project.

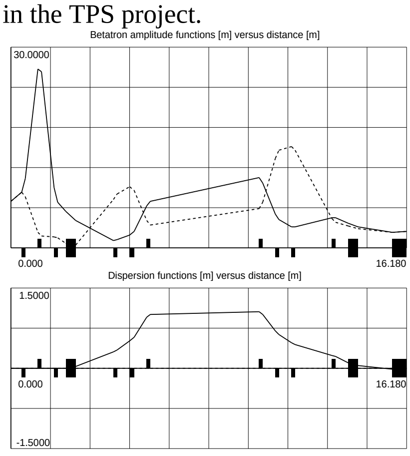

Figure1: The calculated optical functions of the LTB transfer line.

Considering the performance of a commercially available linac reported in the literature, a normalized emittance of : $\varepsilon_n = 50\pi$ mm.mrad is usually achievable [7]. It gives a corresponding geometrical emittance of : $\varepsilon \sim 1$ mm.mrad for a 100MeV electron beam. The associated beam size at the exit of linac is $1\sigma_{x,y} \sim 1$mm on both planes.

The first triplet manipulates the beam profile so as to have minimum vertical beam size at the switchyard magnet, as shown in figure-2. The dispersion property shown in figure-1 provides possible analysis on beam energy spread at the beam dump location. The measurement on beam emittance can also be achieved by installing a screen monitor in front of the first bending magnet, i.e. the switchyard magnet, for beam profile measurement. On the other hand, the beam transmission from switchyard magnet to booster ring is about 15m, including the shielding wall in between. It is handled with sets of quadrupole magnet with moderate strength so as to guide the beam toward the injection point. A DC bending magnet is incorporated in the study for beam injection so that the field strength of the injection septum can be reduced. This will greatly relieve the engineering concern of septum magnet both electrically and mechanically. A pulsed injection septum is put at the end of the transfer line to bend the electron beam so as to cross the beam centerline of the booster with expected angle at the kicker location for on-axis injection. The calculated results of AGILE and MAD agree with each other. "MAD" will be used as a checking tool whenever confirmation of the calculated result is needed.

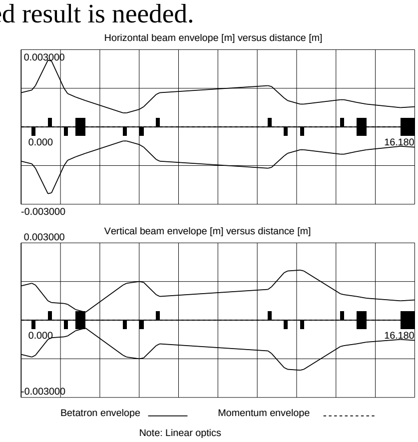

Figure 2: The calculated beam envelope of the LTB transfer line.

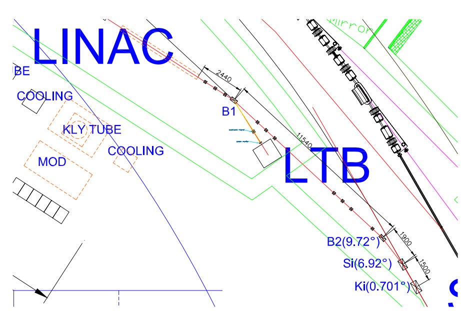

Figure 3: The layout of the LTB transfer line.

The layout of the LTB transfer line is shown in figure-3, a 2-D AutoCAD layout. It starts at the exit of linac and ends at the booster injection kicker. The shielding wall arrangement of present version provides reasonable space for switchyard beam dump and linac modulator.

LINAC BEAM PROPERTY CHARACTERIZATION

Two of the major parameters of the 100MeV electrons, beam emittance and beam energy spread, are to be determined. The beam emittance can be obtained by deducing the optical functions from the measured transverse beam profile. The appropriate location of the screen monitor for beam profile measurement is in front of the switchyard magnet in order to keep it in the dispersion free region. The beam energy spread measurement can be carried out by making use of the switchyard magnet to bend the electrons toward beam dump. With expectation of beam energy spread <+/-0.5% and the 3m beam path between analyzing magnet and beam dump, a typical measurement setup can be arranged. It involves the needs of a magnet current resolution of 50mA and a horizontal scraper with 0.5mm resolution capability in fulfilling the requirement. A possible arrangement of the associated components nearby beam dump is shown in figure-4.

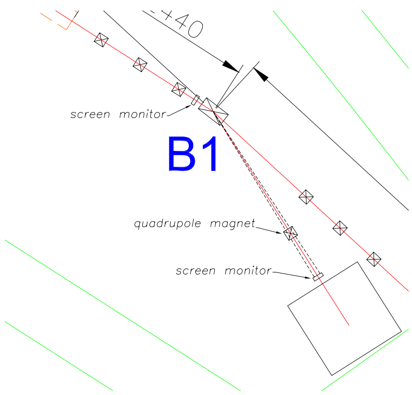

Figure 4: Illustration of the proposed arrangement of the beam dump and associated components for beam property characterization.

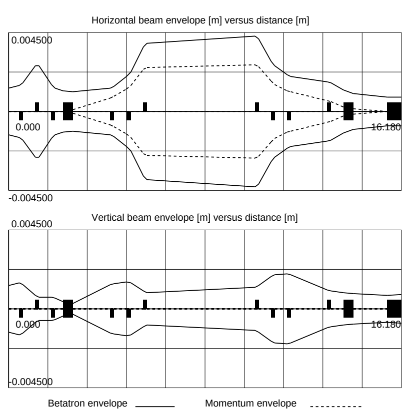

Figure 5: The calculated beam envelope of the LTB transfer line with $\Delta E/E = 0.5\%$.

The calculated beam envelope with energy spread of $\Delta E/E = 0.5\%$ is shown in figure-5. It suggests that a choice of location to install an energy slit would be sitting between Q6 and Q7.

TUNING CAPABILITY FOR INJECTION

Beam injection into the booster is assumed to take place at the middle of the straight section. The lattice parameters and $\alpha_{x,y}$ may appear values with opposite sign, depending upon which straight section is to be chosen. In order to demonstrate the tuning capability of the LTB transfer line for beam injection into the booster, the following test has been performed.

- change the matching condition of $\alpha_{x,y} = \alpha_{x,y}$ to $-\alpha_{x,y}$
- choose Q8, Q9, Q10 as tuning knobs for calculation
- observe the amount of variation of the quadrupole settings

This practice works well with reasonable adjustment of these elements and fulfils the matching conditions as required

SUMMARY

The preliminary design of the LTB transfer line lattice is discussed in this report. It fits well to the proposed arrangement of linac, booster, and shielding wall. The first draft of the components layout is presented according to the information retrieved from the design. The proposed switchyard magnet and beam dump combination provide capability for beam property characterization. Focusing strength of the quadrupoles appears to be moderate with tuning capability in fulfilling various injection requirements.

Optimization of the transfer line design requires efforts for further exploration:

- Correctors for beam trajectory steering shall be considered and implemented.
- Three sets of quadrupole triplet, with the same mechanical arrangement, have been applied in this study. This limits the optimal utilization of the triplets. Careful re-examination of its arrangement is worth studying.

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