Research and Development Of The Beam Line For SC200 Superconducting Proton Cyclotron

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Introduction

Beam line is a series of discrete magnetic element**(dipoles,quadrupole)** that determine the beam's position, direction and shape and others **(steering,beam profile monitors,beam stops,collimator,and degrader…)**

The beam line of SC200 can transfer the **70-200MeV proton beam** after degrader to the different treatment room and meet the different therapy need. It also can quickly stop proton beam to ensure the safe in the therapy .

The beam line of SC200 consist of **energy selection section** (45-degree horizontal symmetry achromatic bending sections), **matching section**, **period matching section**, **45 horizontally symmetrical achromatic bending section** ,**the fixed beam room match section and Gantry section.**

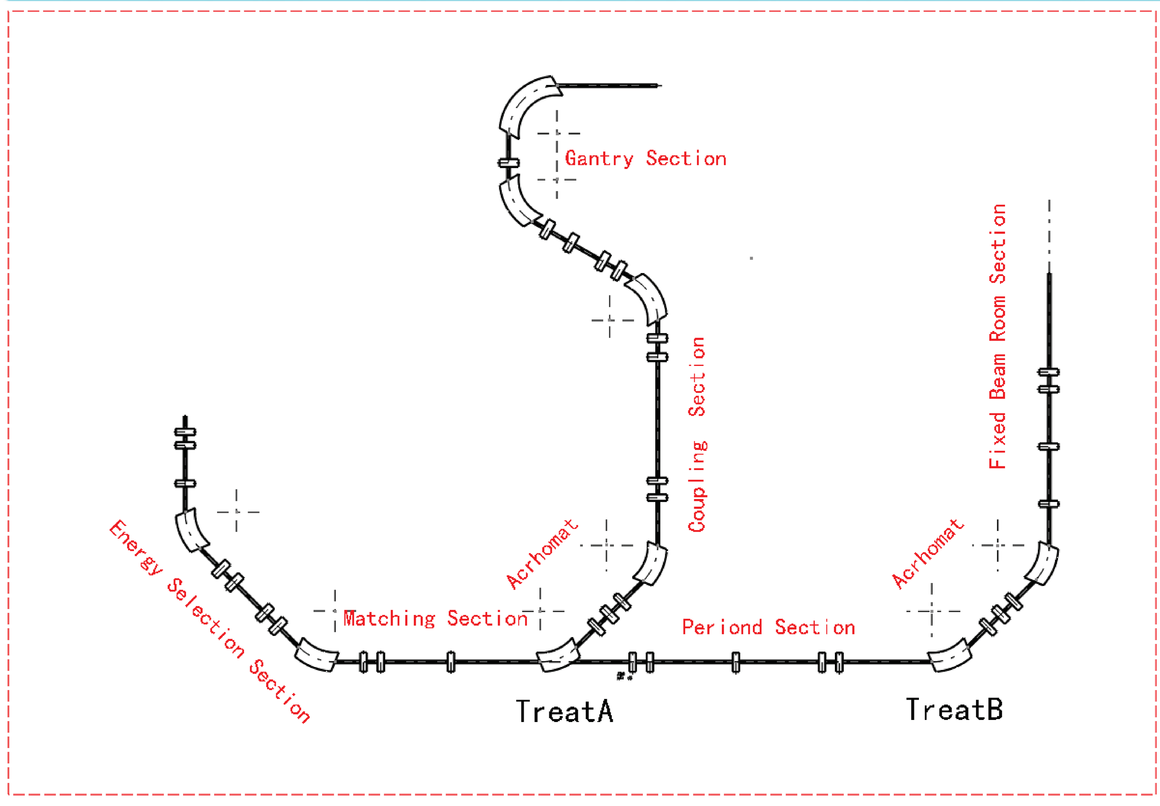
The optical calculation design of the SC200 beam transport line is based on the **Charged particle beam transmission principle**. The design process is guided by the following principles:

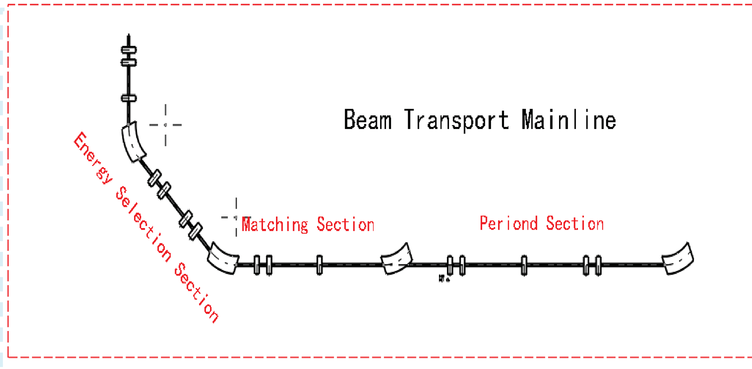
(1)The beam line is divided into several functional sections .**It simplifies complex issues avoiding different requirements for interaction.**

(2) It is necessary for reducing the size of the magnet and the vacuum tube and improving the stability of the beam to make the envelope of beam not change dramatically or too large as far as possible. At the same time, **both dispersion and its derivatives should be set as zero to avoid its effects on the beam**.

(3) In general, it is more convenient to describe beam transport line using the envelope of beam. There are several program based on the beam envelope and the transfer matrix method for the optical design of beam such as **TRANSPORT , TRACE3D and MADX**. And here the **TRANSPORT code** was used for the optics calculations

The beam line layout of SC200





components	Mainline	TreatA + Gantry	TreatB
Dipole magnet			
Angle / quantity	45º/2	45º ,60º,90º/2,2,1	45º/2
Effective length (m)	1.2566	1.2566/1.5708/2.3562	1.2566
Maximum magnet filed of dipole magnet（200MeV) (T)	1.343	1.343/1.432/1.432	1.343
Edge(º)	22.5º	22.5º/30º/30º	22.5º
Radius of diploe magnet (m)	1.6	1.6/1.5/1.5	1.6
Quadrupole			
quantity	15	12	7
Effective length (m)	0.2/0.25	0.2/0.25	0.2/0.25

The initial emittance :

ε_x= 16π mm.mrad , ε_y= 16π mm.mrad

The initial TWISS parameter:

$\alpha_x=\alpha_y$= -6.66654 , $\beta_x=\beta_y$= 7.99986

Energy selection section: two 45° dipole magnet, 4 quad H focusing + 3 quad H defocusing , a horizontal slit

Matching section:
2 quad H focusing + 1 quad H focusing

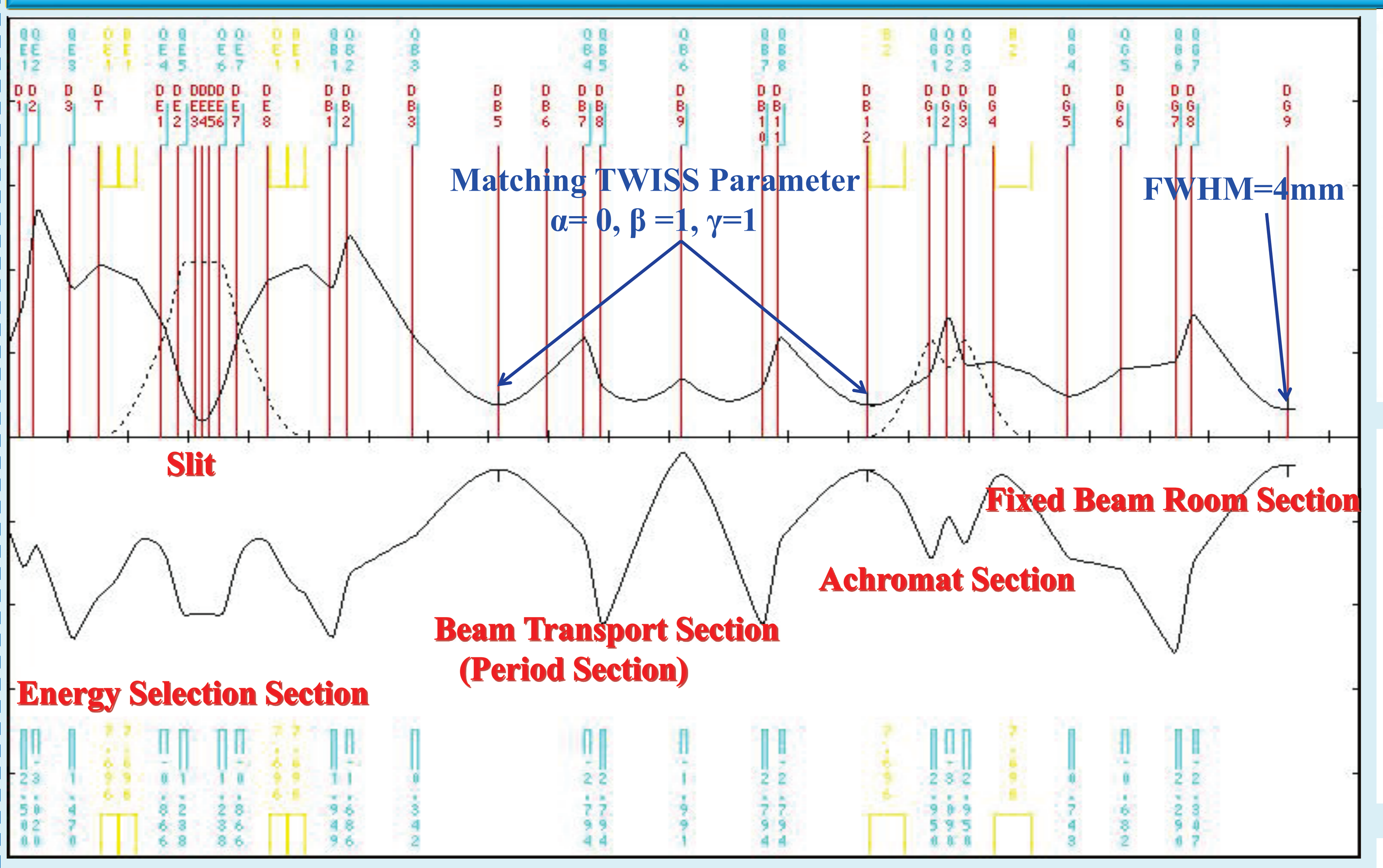
Period matching section:
two doublet+ 1 quad H defocusing

Achromat section: one triplet

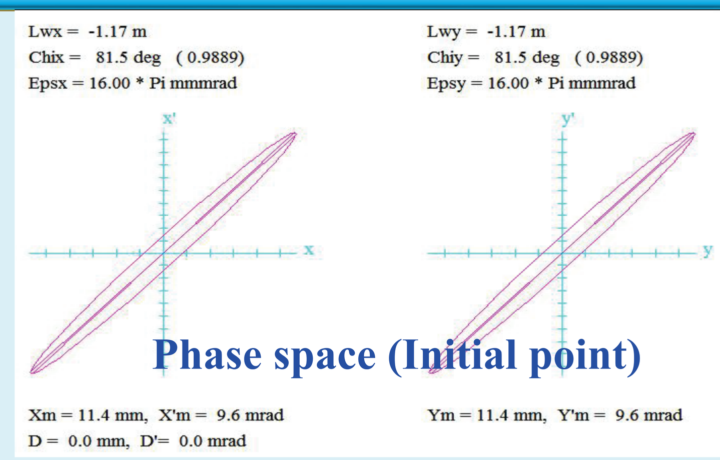
Fixed beam room section :
2 quad H focusing + 2 quad H defocusing

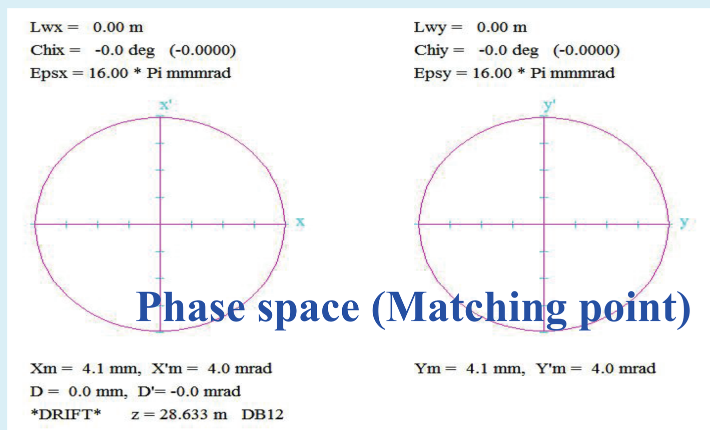
Coupling section:
1 quad H focusing + 1 quad H defocusing

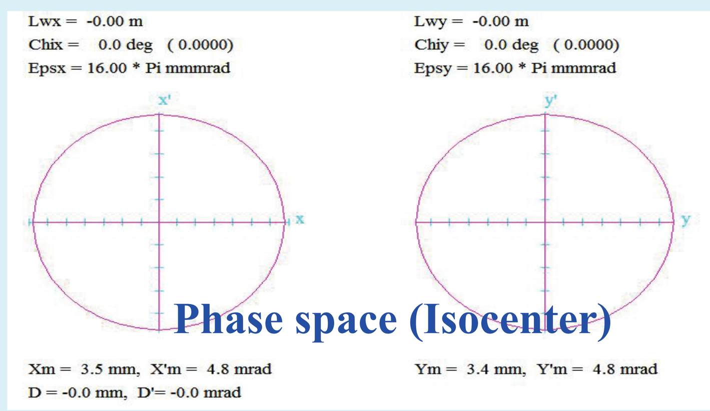
Energy selection section + The Fixed beam room



Energy range	70 – 200 MeV
Beam momentum spread （Δp/p ）	Δp/p = 1.0%
Maximum Beam Envelope	27.24mm (Located at QE2)
Beam FWHM at IC of the Fixed beam room (in vacuum)	4mm-10mm
Horizontal Slit Size	5.3mm-42.24mm (Δp/p =0% - 1.0%)
The magnet filed of dipole magnet	0.769-1.343T







Energy selection section:

- The first 45° dipole give the beam a **large horizontal dispersion**
- 1 quad H defocusing + 1 quad H focusing → **Max H beam size**
- **Horizontal Slit** to Select the required energy
- All above elements are aimed at finally **achieving a achromatic system system** (D=0, D'=0)

Periodic matching section:

This section is designed to get identical beam characteristics for all treatment rooms.The beam is transported through this section with **NO CHANGE**:

① **Horizontal size** **Horizontal divergence** (in x direction)
② **Vertical size** **Vertical divergence** (in y direction)

All treatment rooms are connected by a series of period matching section.

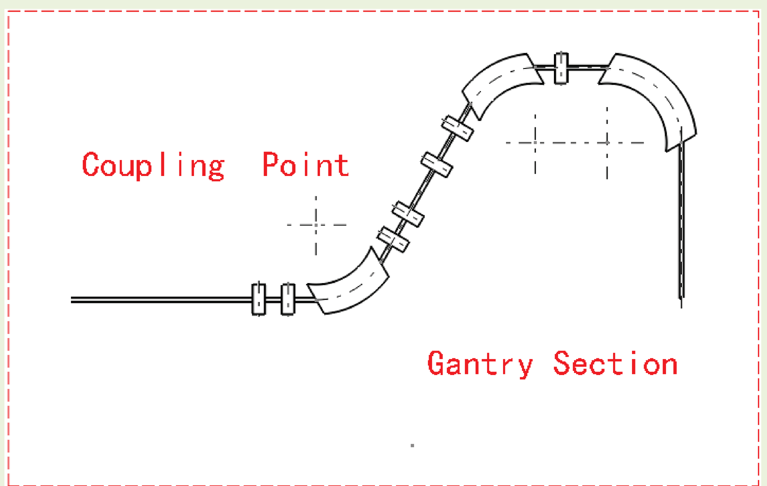
Achromat section and Fixed beam room section:

- Deflection of the beam from the matching point towards a treatment room
- **Forming a achromatic system system (D=0, D'=0)**
- **FWHM=4-10mm** at the isocenter
- The beam has **circular shape** at the isocenter

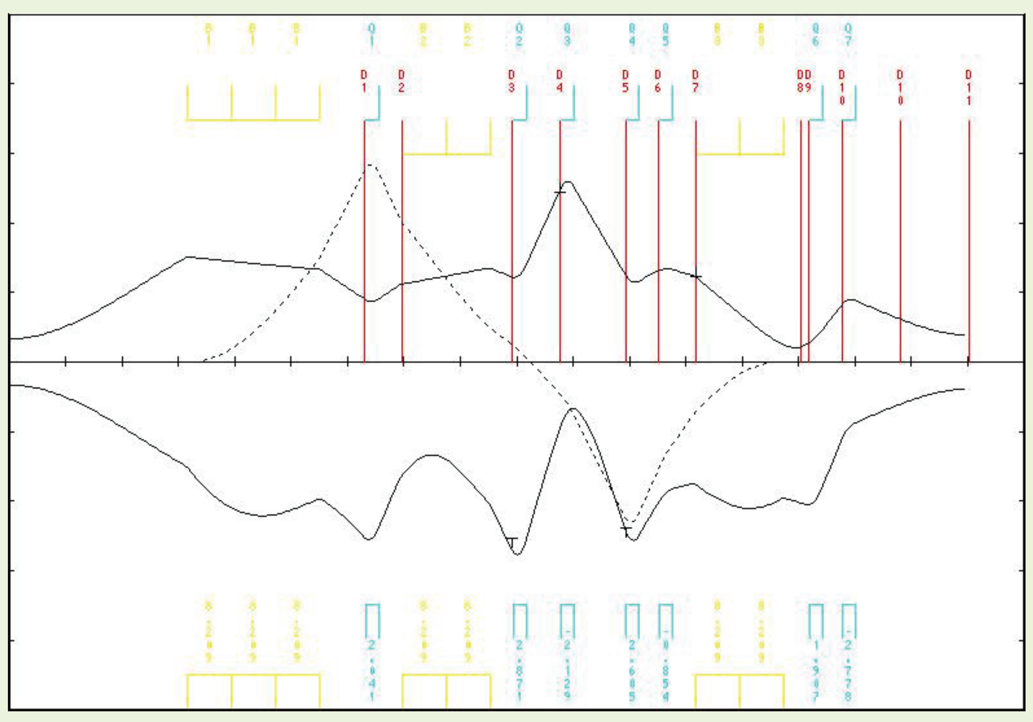
Gantry section

Parameter	Value
Layout type	isocentric, ±185° rotation, 60° -60° -90° dipoles, achromatic
Beam delivery type	downstream PBS
Quadrupolee (quantity and effective length)	7/0.25m
Dipole magnet (radius and Edge)	1.5m /30°
Maximum beam envelope	27mm
Energy range	70 – 200 MeV
Beam momentum spread (Δp/p)	<= 0.8%
Beam FWHM at IC (in vacuum)	4-10mm

The radius of Gantry is 4.65m
The length of Gantry is 9.6m
SAD:3.15m



Layout of the Gantry **beam line**
60° -60° -90° dipoles magnet,
7 quadrupoles, 2 beam profile monitors,
2 trajectory correction magnets



Upper plot = vertical plane of the gantry
Lower plot =horizontal plane of the gantry
dashed line =dispersion function
The coupling TWISS parameter is α= 0, β =1, γ=1
Beam emittance max. 16π mm.mrad

Conclusion & Reference

we designed two beam line base on the 70MeV proton beam which have the maximum emttiance (16π mm.mrad both in the x and y direction). And then we can calculate the magnet filed of dipole and the magnetic filed gradient of quadrupole for the 70-200MeV proton beam. The maximum beam envelope is **27.24mm** and the maximum **beam momentum acceptance is equal to 1% . The fixed beam room can achieve the FWHM of beam varing from 4 to 10mm(in vaccum)**

GANTRY dose delivery systems are now acknowledged as a necessary part of a medical hadron therapy facility. Since GANTRY is a most expensive part of such a facility, it's parameters should be carefully chosen and optimized. Because the gantry rotates ,it mixes the horizontal and vertical planes.it is thus required that **both planes have exactly the same characteristics at the entrance point of the rotating system**. For similar reason of plane mixing ,the beam characteristics at the isocenter must fulfill the same conditions .This ensures that the same beam is delivered irrespective of the gantry angle. Here TRANSPORT computer code was used for optics calculations. **We present a new optic scheme of isocentric GANTRY.** First we assumed the initial emittance is ε=16π mm.mrad and the beam has circular shape at isocenter (FWHM=4-10MM), and **the principle of beam line inversion (BLI) will be applied here. The beam is bent with three magnets at 90, 60 and -60 degrees correspondingly, is focused by seven quadrupole (Q1-Q7).**And finally we get that the maximum momentum spread of gantry is 0.8%,the coupling point matching parameter is α= 0, β =1, γ=1,the radius of gantry is 4.65m ,the length of Gantry is 9.6m,the FWHM at isocenter is 4-10mm and it can transfer 70 -200MeV proton beam to the isocenter.

Reference

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