2.3 Storage Ring magnets

The storage ring magnets system is designed to provide the guide field for bending and focusing of the electrons at the maximum energy of 2.4 GeV.

The system includes 36 dipole and 174 quadrupole magnets. Some of the dipole magnets could, in the future, be replaced with superconducting dipoles in order to produce hard X-rays synchrotron radiation (in the 100 keV photon energy region).

Chromaticity correction will be accomplished with the help of 120 sextupole magnets, half of them having additional horizontal and vertical dipole windings for the closed orbit correction. The global orbit correction using these steerers should be capable of up to 50 Hz operation. In case it will prove to be difficult to achieve, the synchrotron radiation beamlines will be equipped with fast local bump correction system.

Global coupling correction scheme will be implemented as additional windings in the sextupole magnets.

2.3.1 General description of the magnets/girder concept

The quadrupoles and sextupoles of each of the 4 straight sections of each of the 12 achromats will be supported by a straight girder. The eigenfrequencies of the girder loaded with all magnets and equipped with the movers and eventual further support structure should be above 40 Hz. The eigenfrequencies should not coincide with the multiples of 50 Hz. Maximum vertical deformation under full load should be below 50 µm.

The girder should provide precision joints for each magnetic or diagnostic element. The individual elements on the girder should be aligned to better than 30 µm. The precision fixation of the magnets and BPMs on the girder is to be realised by precision grooves in the girder and in the supports of the individual elements. This would also allow for the fiducialisation of the girder by a jig.

The girder will be equipped with a hydrostatic levelling device above each mover for the vertical plane and wire offset measuring devices for the horizontal plane. It will be equipped with cooling water manifolds for all devices on each girder, as well as with pre-cabling of the temperature- and water flow interlock switches.

The dipole magnets will form the connecting bridge from one girder to the next. These dipole magnets will be installed individually after the installation of the magnet/girder assembly. Since the magnets and diagnostic devices will sit in precision joints on the girder they will form one large rigid item not necessitating the fiducialisation of individual magnets or items other than the girder itself.

Each magnet on the girders must be splitable in or close to the mid plane of the magnets in order to allow the installation and removal of the total sector vacuum chamber including the sector pumps and diagnostic devices (the sector vacuum chamber connects over two gate valves on both ends to the adjacent straight sections, having a total length of ca. 19 m. The sector vacuum chamber is expected to be baked out in a special heating bed on the technical gallery. The only in-situ bakeable parts of the storage ring vacuum system will be the straight section chambers).

The magnet/girder assembly should allow to speed up the installation of the SLS storage ring in the radiation shielding tunnel.

Accompanying drawings

In order to verify in detail the above mentioned concept of precision pre-aligned magnets positioning on girders and to allow the design work on other major SLS components to proceed, PSI has collaborated with the Budker Institute of Nuclear Physics, Russia on a complete engineering study of the magnets/girder package. This study resulted in a comprehensive set of drawings for all of the magnetic elements and girders with movers representing a possible design of the magnets/girder package.

These drawings have been included in a specification document that was included with the call for tender for the complete magnets/girder package that ha been issued at the beginning of February, 1998. The design of the elements is to be finalised the placement of the contract (expected for the end of April, 1998). The drawings are included in an accompanying document and necessarily contain certain assumptions concerning parts of the magnets and girder design that will be the responsibility of the manufacturer. Certain features shown on the drawings are tentative, and will be subject to adjustment by the manufacturer during the design phase. This reservation applies particularly to:

- coil shape and cross section
- position of coil on the pole
- external shape of magnet lamination
- shape and cross section of yoke support pieces
- design of the region of the lamination mating with support pieces
- whether the dipole cores are made of straight blocks or are uniformly curved
- the choice of “smooth curve” or “a few straight lines” pole profiles

2.3.1 Bending magnets

The dipole magnets are of two types, referred to as BX for the central dipole of the Triple Bend Achromat (TBA) with magnetic length of 1.4 m and BE, corresponding to the end dipoles of the TBA with the magnetic length of 0.8 m. The dipoles will operate at a maximum induction of 1.6 T with a 41 mm gap to contain the beam vacuum chamber.

The magnets are of two piece construction which gives magnetic field symmetry about the median plane. The upper and lower halves are shown on drawing BX02.

In the tentative design included in this specification, the cores will consist of straight blocks, thus the shorter BE magnet is a straight magnetic element with parallel ends. The BX magnet consists of three straight sections. The central section has the same dimensions as the short magnet and has in the horizontal plane a rectangular form. The lateral blocks have a parallelogram-like form in the horizontal plane and are assembled so that their axes form an angle of 7 degrees with the central section axis. The matching surfaces of three blocks are glued and the lateral ends of this completely assembled magnet are parallel to each other.
The advantage of this design is the simplicity of the production of both separate magnet units and auxiliary parts for assembling of the magnet as a whole. During the process of assembling and fixating of the laminations all reference surfaces of stacking units are flat and do not have any curvature. During the process of compressing, the laminations are ordered with equal angle relative to reference surfaces and feel equal inner stresses and strains. The process of clamping is more accurate and simple.

This approach results in an increased horizontal good field region requirement due to the sagitta of the particle’s trajectory in the magnet. The manufacturer will be free to offer the dipole magnets that will be uniformly curved over their length, with a radius of curvature to match the beam trajectory in the gap, thus minimising the sagitta allowance in the good field region width.

The pole profile (Profile A) specified on the drawing of the lamination BX03 consists of a small number of straight lines and is optimised for a particular value of magnet excitation. This pole profile serves as the basis for the present call for tender. An alternative pole profile - Profile B - (dimensionally very similar to the present one, essentially smoothing out the straight lines, also shown on the drawing) would insure better field quality tracking for a range of magnet excitations. The manufacturer will be free to choose between these two options, based on economic grounds.

Dipole yokes and laminations

The yoke is assembled from up to 1 mm thick laminations with two 45 mm thick end-plates. The required dimensions and tolerances for the laminations are shown on the drawing BX03, they are the same for the BE dipole. Thus only one stamping tool is required for the punching of the laminations.

The yoke is split in the median plane to allow access for coils and vacuum chamber. The upper and lower yokes are aligned relative to each other with special precise pins and key. These pins, key and grooves are fabricated with high precision and provide the positioning of two dipole parts with required relative accuracy. This technique is designed to allow to disassemble and reassemble the complete magnets without loosing accuracy. There are two notches (15x30 mm, not shown in the accompanying drawing) running along the outside of each half yoke, provided for fixing of the transportation grippers.

The two magnet halves should be keyed with respect to each other in the longitudinal direction with the accuracy ±0.1 mm.

The end plates will be made of the same laminations. Dimensions and tolerances of the end-plates are shown on drawings BX05 and BE05. Each end-plate has three machined end shims to correct the end field to provide the correct magnetic length and to control the variation of magnetic length with radial position. After magnetic measurements of the first magnet, the final shape of the end shims has to be defined.

Dipole coils

The magnets will be excited by coils mounted on the central pole limbs, above and below the magnet pole gap. The coils will be fabricated from solid conductor, with a central water cooling hole, fiberglass tape insulated and epoxy impregnated. The coils for the two types of dipoles have the same number of turns.

All of the dipole magnets will be run in series, powered by a single power supply. In order to optimise the power supply and power consumption (operating current below 600 A, current density below 3.5 A/mm^2), the preliminary PSI design considers each coil consisting of three double layer pancakes. using, e.g., a standard OUTOKUMPU conductor with a 6.1 mm diameter cooling hole. and the dimensions of 13 mm x 15 mm. Use of non-standard size conductor should be considered, e.g. a coil consisting of four double layer pancakes with the dimensions of 13x11 mm and cooling hole diameter of either 4.5 or 5 mm would further reduce the operating current to 418 A. Strong preference would be given to the lower maximum current solution.

Parameters

The following mechanical parameters are mandatory, the two values given correspond to the magnet made out of straight blocks and the curved core magnet design:

		straight	curved
Pole width	mm	180	166
minimum top, bottom, back leg thickness	mm	100	93

The following dipole length parameters mandatory:

		BX	BE
Pole iron length (straight blocks version)	m	1.3774	0.7802
Maximum allowed length of the magnet (including coils)	m	1.625	1.025

(The reference temperature for all these dimensions is 20°C.)

The following electrical excitation parameters are mandatory:

Maximum current	600 A
Maximum current density	3.5 A/mm^2

The following thermal and cooling parameters are mandatory:

Max. pressure at input manifold	10	bar
Pressure differential available	6	bar
Design temp. rise in coil at 6 bar	10	°C

The following magnet parameters correspond to the preliminary design of the dipole magnets:

Name of magnet	BX	BE
Energy	2.4 GeV	2.4 GeV
Deflection angle	14°	8°
Number of units	12	24
Magnetic length	1.4 m	0.8 m
Magnetic flux density	1.397 T	1.397 T
Bend radius	5.7296 m	5.7296 m
Magnetic gap	41 mm	41 mm
Relative field homogeneity	2×10-4	2×10-4
in the area(hor. × vert.)	24×24 mm^2	24×24 mm^2
Number of ampere-turn	46800 A	46800 A
Number of turn/magnet	84	84
Copper conductor size	13×15 mm^2	13×15 mm^2
Diameter of cooling duct	6.1 mm	6.1 mm
Cross section of copper/duct	163.8/29.2 mm^2	163.8/29.2 mm^2
Current density	3.4 A/mm^2	3.4 A/mm^2
Conductor length	288 m	187 m
Total resistance of the magnet coil (at 30°C)	31.5 mOhm	20.4 mOhm
Total inductance of the magnet	55 mH	31.4 mH
Time constant (L / R)	1.7 sec	1.5 sec
Number of cooling circuits	6	6
Temperature rise	10°	10°
Volume flow rate	6×2.4 l/min	6x1.6 l/min
Pressure drop	2.5 bar	0.7 bar
Voltage/magnet	17.5 V	11.4 V
Power loss/1 magnet	9.76 kW	6.3 kW
Power loss/all magnets	117 kW	152 kW
Voltage/all magnets	210 V	273 V
Current	557 A	557 A
Length of iron	1377.4 mm	780 mm
Overall width	711 mm	705 mm
Overall height	470 mm	470 mm
Overall length	1638 mm	1041 mm
Weight of copper	420.3 kg	273 kg
Laminae thickness	0.5 - 1.0 mm	0.5 - 1.0 mm
Minimal stacking factor (yoke laminae)	0.97	0.97

In addition, two examples of the dipole coil parameters for 418 A excitation current are given below:

Magnet coil (13x11x∅5) parameters

Number of ampere-turns	46800 A	46800 A
Number of turns/magnet	112	112
Copper conductor size	13×11 mm^2	13×11 mm^2
Diameter of cooling duct	5 mm	5 mm
Cross section of copper/duct	123.2/19.6 mm^2	123.2/19.6 mm^2
Max. Current density	3.39 A/mm^2	3.39 A/mm^2
Conductor length	379.3 m	245 m
Total resistance (at 30°C)	55 mOhm	35.6 mOhm
Total inductance	97.6 mH	55.75 mH
Time constant (L / R)	1.8 sec	1.57 sec
Number of cooling circuits	8	8
Pressure drop	2.5 bar	1.13 bar
Voltage / 1 magnet	23 V	14.9 V
Power loss /1 magnet	9.63 kW	6.22 kW
Power loss / all magnets	115.6 kW	149 kW
Voltage / all magnets	276 V	357 V
Current	418 A	418 A
Weight of copper	420.3 kg	273 kg

Magnet coil (13x11x∅ 4.5) parameters

Number of ampere-turn	46800 A	46800 A
Number of turn/magnet	112	112
Copper conductor size	13×11 mm^2	13×11 mm^2
Diameter of cooling duct	4.5 mm	4.5 mm
Cross section of copper/duct	126.9/16.1 mm^2	126.9/16.1 mm^2
Max. Current density	3.29 A/mm^2	3.29 A/mm^2
Conductor length	379.3 m	245 m
Total resistance (at 30°C)	53.5 mOhm	34.56 mOhm
Total inductance	97.6 mH	55.75 mH
Time constant (L / R)	1.82 sec	1.6 sec
Number of cooling circuits	8	8
Pressure drop	5.1 bar	1.55 bar
Voltage / 1 magnet	22.36 V	14.45 V
Power loss / 1 magnet	9.347 kW	6.04 kW
Power loss / all magnets	112.2 kW	145 kW
Voltage / all magnets	268 V	347 V
Current	418 A	418 A
Weight of copper	431 kg	278.2 kg

Magnetic measurements

After all electrical, mechanical and thermal tests have been completed, each magnet will be magnetically measured. The magnetic length of the magnet will be measured at the vertical centre of the gap, at 5 radial positions relative to the pole centre:

0 mm, ± 10 mm, ± 20 mm

The measurements will be carried out with DC excitation at five current levels, corresponding to the energy of the electrons of 1.5, 2, 2.4, 2.6, 2.7 GeV.
PSI believes that the required accuracy, reproducibility and speed of measurements can be achieved by equipment using one of the prototype magnets as a reference, connected in series with the test magnet.

Dipole magnet supports

Dipole magnet, equipped with three supports, will form a bridge between the two adjacent girders. These supports will reference to the high precision grooves on the girders. The first dipole support is located on the axis of the first girder and provides transverse and longitudinal fixation. The second and third supports are mounted on the second girder. One of them moves freely in longitudinal direction relative to the second girder, the other is free to move in both the transverse and longitudinal directions.

The physical connection between the supports and the magnets will only engage on the lower half of the magnets, so that the upper section can be removed without destroying the magnet alignment. It should also be possible to lift the complete magnet from the support assemblies with a minimum of mechanical interference.

Drawings

The following drawings are provided:

Drawing number	Description		Shorthand
300 30.20.21	BX dipole,	overview	BX01
300 30.20.22	BX dipole,	cross section	BX02
300 30.20.23	BX dipole,	lamination	BX03
300 30.20.24	BX dipole,	coil	BX04
300 30.20.25	BX dipole,	half yoke	BX05
300 30.20.31	BE dipole,	overview	BE01
300 30.20.34	BE dipole,	coil	BE04
300 30.20.35	BE dipole,	half yoke	BE05
300.30.20.36	Vacuum chamber	stay clear	B06

2.3.2 Storage ring quadrupole magnets

Quadrupole magnets are of three types: QA, QB and QC with magnetic lengths 0.2 m, 0.32 m and 0.44 m respectively. The magnets will be excited by coils mounted on the poles. These will be wound from solid conductor with a central water cooling hole. The quadrupole magnets will be powered by individual power supplies.

The magnets are of two piece construction with magnetic field symmetry about both horizontal and vertical planes.

Twelve (12) quadrupoles of each of the three types of magnets have yokes that extend to the inside and the outside of the ring to let the synchrotron radiation beam lines pass through and to maintain the magnetic field symmetry (see vacuum chamber stay clear requirements in the drawing QA07). They have the same pole profile as the rest of the quadrupoles (see drawing QAW04). These variants have the corresponding names QAW, QBW, QCW (see Table C.2.2).

The number of yoke segments from which the complete magnet is assembled is to be determined by the manufacturer, with the agreement from PSI. In the tender drawings, a magnet made of four parts is presented in order to ease the mounting of the coils. Similarly, the presented scheme of the magnet assembly, respecting the tight tolerances placed on the quadrupole positioning on the girder is only a possible solution, the manufacturer is free to make an alternative design, to be approved by PSI.

The end part of each quadrupole pole has machined end-shims to correct the gradient field integral. After the magnetic measurements of the prototype magnet, the final shape of the end shim has to be defined and adopted for series production.

The endplates of the magnet halves are made out of non-magnetic stainless steel ($\mu < 1.005$) with maximum thickness of 50 mm. They are intended to fix the magnet on the girder with the tolerance on the magnetic centre of the magnet better than 30 µm.

Parameters

The following mechanical parameters are mandatory:

Parameter	units	QA	QB	QC
Inscribed radius	mm	30		
Pole width	mm	95		
Minimum yoke thickness	mm	60		
Yoke length	m	0.2	0.32	0.44
Maximum allowed length (including coils)	m	0.33	0.43	0.55

The following electrical excitation parameters are mandatory:

Maximum current	120 A
Amp-turns/pole, peak value	7400 At
Maximum current density	5 A/mm^2

The following thermal and cooling parameters are mandatory:

Max. pressure at input manifold	10	bar
Pressure differential available	6	bar
Design temp. rise in coil at 6 bar	10	°C

The following magnet parameters correspond to the preliminary design of the quadrupole magnets

Parameter		QC
Max. Gradient	T/m	20
Magnetic length	m	0.44
Ampere-turns	A-t	7440
Turns/pole		62
Max. current	A	120
Conductor size	mm	6.4×6.4∅4.4
Conductor area	mm^2	24.9
Current density	A/mm^2	4.8
Water circuit/magnet		4
Temp. rise	°C	10
Water flow rate	l/min	1.2
Water flow speed	m/s	1.33
Water pressure drop	bar	6.3

Magnetic measurements

After all electrical, mechanical and thermal tests have been completed, each quadrupole will be magnetically measured. The following measurements will be made:

i) the gradient length of the magnet

ii) the magnetic centre

iii) the quadrupole field quality expressed in terms of the coefficients of all harmonics from: 4-pole to 20-pole included. The precision should be better than $2 \cdot 10^{-4}$.

The measurements will be carried out with DC excitation at about 10 different gradient levels (to be specified later).

Drawings

The following drawings are provided:

Drawing number	Description		Shorthand
300 30.20.41	SR quadrupole,	front view 1	QA01
300 30.20.42	SR quadrupole,	cross section 1	QA02
300 30.20.43	SR quadrupole,	side view	QA03
300 30.20.44	SR quadrupole,	front view 2	QAW04
300 30.20.45	SR quadrupole,	lamination 1	QA05
300 30.20.46	SR quadrupole,	lamination 2	QAW06
300.30.20.47	Vacuum chamber	stay clear	QA07

2.3.3 Storage ring sextupole magnets

The sextupole magnets will be excited by coils mounted on the poles. These main coils will be wound from a solid conductor, with a central water cooling hole. The yoke will be laminated and will have a closed “O” shape. The non-magnetic end plates ($\mu < 1.005$) are intended to provide the sextupole height similar to the quadrupole height (to allow the sextupole alignment relatively to other magnets) and to fix the magnet on the girder.

Twelve out of the 120 sextupoles will have extended supports on the inside and the outside of the ring to let the synchrotron radiation beam lines pass through and to maintain the magnetic field symmetry (drawing SW04, vacuum chamber stay clear requirements: SW07).

About half of the required 120 sextupoles will contain additional steering correction coils, one coil mounted on each of the poles (see drawings S01, S02, S04). They will provide horizontal and vertical dipole field for the closed orbit correction, as well as the skew quadrupole field for the beam coupling correction. These coils will be fabricated from solid conductor and will be cooled naturally, by convection to air and heat conductance to the water cooled main coils. They will be powered with frequency up to 50 Hz.

The number of yoke segments from which the complete magnet is assembled is to be determined by the manufacturer, with the agreement from PSI. In the tender drawings, a magnet made of six parts is presented in order to ease the mounting of the coils, but the manufacturer is free to offer alternative magnet segmentation. Similarly, the presented scheme of the magnet assembly, respecting the tight tolerances placed on the sextupoles positioning on the girder is only a possible solution, the manufacturer is free to make an alternative design, to be approved by PSI.

Parameters

The following mechanical parameters are mandatory

Inscribed radius	34	mm
Pole width	60	mm
Minimum top, bottom and side yoke thickness	50	mm
Pole iron length	200	mm
Maximum allowed length of magnet (including coils and connection buses)	330	mm

The following thermal and cooling parameters are mandatory:

Max. pressure at input manifold	10	bar
Pressure differential available	6	bar
Design temp. rise in coil at 6 bar	10	°C

The following electrical excitation parameters are mandatory:

Maximum current	140 A
Amp-turns/pole, peak value	3500 At
Maximum current density	4 A/mm^2

A somewhat lower maximum current (120 A) would be preferable to be able to use the same power supplies for both quadrupoles and sextupoles.

The following electrical excitation parameters for the correction coils are mandatory:

Ampere-turns/coil, peak value	1500	At
Maximum current	7	A

Such a coil could, for example, be made out of 240 turns of ∅2.02 mm (copper ∅1.8 mm) wire and would have 55×17 mm dimensions.

The following magnet parameters correspond to the preliminary design of the sextupole magnet:

Table of the sextupole parameters

Parameter		S200
Max. Gradient	T/m^2	640
Magnetic length	m	0.20
Yoke length*	m	0.20
Yoke + coils length	m	0.29
Total length**	m	0.33
Bore radius	mm	34
Pole width	mm	60
Copper weight	kG	33
Total weight	kG	210
Ampere-turns/pole	A-t	3500
Turns/pole		25
Max. Current	A	140
Conductor size	mm	6.5×6.5∅3
Conductor area	mm^2	34.32
Cooling hole area	mm^2	7.07
Total conductor length	m	94
Current density	A/mm^2	4
Resistance/magnet***	mΩ	49
Inductance/magnet	mH	14
Time constant	s	0.29
Voltage drop/magnet	V	6.8
Power loss/magnet	kW	0.9
Temp. rise	°C	10

Magnetic measurements

After all electrical and mechanical tests have been completed, each sextupole will be magnetically measured. The following measurements will be made:

i) the sextupole gradient length of the magnet

* The yoke length is preliminary, to be specified after 3D calculation
** Total length includes yoke length, coils and connection buses
*** Resistance and other relevant values are given for 30° C

ii) the magnetic centre
iii) the sextupole field quality expressed in terms of the harmonic coefficients. The precision should be better than $5 \cdot 10^{-4}$.

The measurements will be carried out with DC excitation at 10 current levels, covering the range between minimum and maximum field level.

Drawings

The following drawings are provided:

Drawing number	Description		Shorthand
300 30.20.61	SR sextupole,	front view	S01
300 30.20.62	SR sextupole,	cross-section 1	S02
300 30.20.63	SR sextupole,	side view	S03
300 30.20.64	SR sextupole,	cross section 2	SW04
300 30.20.65	SR sextupole,	lamination	S05
300 30.20.66	SR sextupole,	magnet coil	S06
300.30.20.67	Vacuum chamber	stay clear	S07

2.3.4 Girders

Girders are used to support and to position with high precision the storage ring magnets. Each girder together with the magnets that are placed on it (quadrupoles and sextupoles) form an "assembly". The girder itself is a welded box structure of rectangular cross section with inner ribs and side supports. The upper girder plate serves as a reference surface and contains a high precision axial guide groove that coincides in the longitudinal direction with the electron beam axis direction in the straight section. The upper plate forms the interface surface between the magnets and the girder.

The girders are of two types, referred to as GL for the 4.5 m long girder and GS for the 3.7 m long girder.

Relative positioning of the assemblies is achieved with the help of the girder movers that form part of the girder supports. Six movers per girder are used to form a four-point support that allows girder movement in two transverse (x, y) and three rotational (x, y, z) degrees of freedom. A girder mover consists of housing with support, stepping motor drive and eccentric cam shafts. There are two types of movers: a "single mover" that is used for vertical positioning only, and "double mover" for movement in both horizontal and vertical degrees of freedom.

Girder movers are placed on supports that in turn are mounted on concrete pillars. The supports have a hollow profile with base and top plates. The concrete pillars are not part of this tender request.

The complete magnets/girders/movers package has been modelled with an FEM code and its static and dynamic properties have been optimised. The results of the optimisation provided the basis of the present design and were used to define the main dimensions.

Main tolerances for the assembly:

Magnets positioning:	horizontal	< 30 µm
	vertical	< 30 µm
Movers precision (step size)		
	horizontal	< 3 µm
	vertical	< 3 µm

It will be equipped with cooling water manifolds for all devices on each girder, as well as with the interconnection blocks for pre-cabling of the temperature- and water flow interlock switches. The water manifolds should be properly insulated from the girder to minimise the girder vibrations caused by the water flow.

Girder body

The girder body is an open hollow box structure with internal ribs and side brackets that are placed onto the movers. The two types of girders differ mainly in their length. The structure has rectangular cross section. In the preliminary design included here, the top plate thickness is 40 mm, the rest of the walls, ribs and side supports have the same thickness of 30 mm.

The axial locations of the 2 inner ribs and side support surfaces are defined to maximise the girder transverse and torsional stiffness and at the same time minimising the amount of material and simplifying the construction. The vertical placement of the side supports is designed to minimise the lever arm of the applied torsion.

The finish of the side brackets bottom surfaces has tight tolerances to enable high precision alignment and positioning of the girders, as well as to minimise the friction (i.e. forces acting on the movers and motor torque). The single mover surface (vertical positioning only) can be manufactured as a flat plate. For the double mover (vertical and horizontal positioning) a "support prism" with support surfaces at right angles is required. The contact surfaces will be made of hardened steel.

Three grooves in the top plate will be used as high precision reference surfaces. The magnets will be referenced with interface blocks to these surfaces, thus pre-aligned to high tolerances, without provisions for any further alignment needed. The positioning in the horizontal plane in the transverse direction will be achieved with the help of the centre high precision groove. The transverse interface block references to the precision ground side surfaces of the groove in the top plate and to the corresponding surfaces in the end-plates of the magnets. Vertical positioning is done using the other two grooves in the upper girder plate that are positioned symmetrically to the central groove. Here the interface blocks reference to the precision ground bottom surfaces of these grooves and to the corresponding precision surfaces on the magnet end-plates. Furthermore, two T-shaped grooves facilitate the fastening of the magnets to the girder.

The top plate of the girder body will be used as a high precision reference surface. The magnets will be placed onto this surface, pre-aligned to high tolerances, without provisions for any further alignment needed. The positioning in the horizontal plane (in both transverse and longitudinal direction) will be achieved with the help of three high precision grooves in the top plate. Vertical positioning is done using two strip-like grinded horizontal surfaces on the upper girder plate that are positioned symmetrically relative to the central groove.

Dipole magnet, equipped with three supports, will form a bridge between the two adjacent girders. These supports will reference to the high precision grooves on the girders. The first dipole support is located on the axis of the first girder and provides transverse and longitudinal fixation. The second and third supports are mounted on the second girder. One of them moves freely in longitudinal direction relative to the second girder, the other is free to move in both the transverse and longitudinal directions.

Before the final machining of the reference surfaces, the girder should be exposed to high temperature annealing in order to reduce inner stresses remaining after welding and preliminary machining and to prevent possible long term deformations.

The following mechanical parameters are mandatory:

Part	GL	GS
Total length [m]	4.5	3.7
Distance between supports [m]	2.8	2.0
Height difference between the girder top surface and magnets support surfaces [m]	0.16	0.16
Girder transverse profile (W x H x thickness) [m]	0.5 x 0.5 x 0.03	

The following table lists the main tolerances:

Part	Tolerance	
Distance between supports, axial	± 0.1	mm
Support surfaces, vertical difference between	± 0.1	mm
Groove geometry, width	- 0.025	mm
Top girder surface	0.03	mm
Top girder surface finish (roughness)	2.5	µm
Support surfaces finish (roughness)	2.5	µm
Groove surfaces finish (roughness)	2.5	µm

Girder mover

Each girder mover consists of housing, stepping motor (option), and cam shafts with eccentricity. The cam shafts are axially fixed via a pair of bearings. The girder is mounted on the cam shafts via special bearings to minimise friction and to allow for the required rotational degrees of freedom. It should be possible to exchange the individual movers with the whole girder assembly in place.

The following parameters are mandatory:

Part	Parameter	
Stepping motor, max. torque (after gear box)	200	N·m
Stepping motor, number of steps	200	
Gear box with 3 stages, gears ratio	100 : 1	
Shaft eccentricity	5.0	mm
Mover working window, vertical + horizontal	± 5	mm

The following table lists some of the main tolerances:

Part	Tolerance	
Vertical distance between cam shaft axis and the base support surface	+ 0.05	mm
Bearing support diameter	+ 0.02	mm
Shaft diameter	- 0.02	mm
Eccentricity, Diameter	- 0.02	mm
Eccentricity, distance between the axes	± 0.02	mm
Neighbouring mover (sum total tolerance)	+ 0.1	mm
Camshaft support surfaces finish (roughness)	1.6	µm

Mover base support

The base support consists of a concrete or granite pillar with 2 mover supports. Mover support is a piece of rectangular structure tubing with base and top plates welded onto it. The possibility of casting of this structure (with the same outer dimensions) instead of welding is not ruled out.

Drawings

The following drawings are provided:

Drawing number	Description		Comment
300 30.20.81	Design view,	SR layout	Girders, Magnets
300 30.20.82	Design view,	SR section	Girders, Magnets
300 30.20.84	Detail view,	Girder housing HL	long version
300 30.20.86	Detail view,	Girder housing HS	short version
300 30.20.87	Overview,	Mover	double version
300 30.20.88	Detail view,	Mover housing	double version
300 30.20.89	Overview,	Mover	single version
300 30.20.90	Detail view,	Mover housing	single version
300 30.20.91	Detail view,	Eccentric cam	
300 30.20.92	Overview,	Support	
300.30.20.93	Overview	Dipole supports	

In addition, the following drawings have been included for illustrative purposes. Some of the details shown in these drawings correspond to previous versions of the design exercise and serve merely to illuminate the overall concept of magnet pre-alignment on the girders.

Drawing number	Description		Comment
	3-D view	Girder GL	Girder, Mover, Magnets
	3-D view	Girder GS	Girder, Mover, Magnets
300 30.20.83	Overview,	Girder GL	long version
300 30.20.85	Overview,	Girder GS	short version