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Laboratori Nazionali di Frascati

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MECHANICAL AND MAGNETIC QUALIFICATION OF THE FOCUSING SOLENOIDS FOR SPARC

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Abstract

Mechanical and magnetic measurements have been carried out to determine the geometric and magnetic characteristics of the focusing solenoids that will be mounted on the first two accelerating sections of the SPARC LINAC. This paper describes the procedure used and provides the geometrical and magnetic data necessary for the alignment of these solenoids in the SPARC hall [1].

1 INTRODUCTION

A linear accelerator is under construction at the Frascati National Laboratories of INFN for the SPARC project [2]. The main goal of this project is the promotion of an R&D activity oriented to the development of a high brightness photoinjector to drive SASE-FEL experiments. The main components of the SPARC linear accelerator are: a 1.6 cell RF gun, 3 S-band SLAC-type accelerating sections, and a 6-module 12-m long undulator. A layout of the machine is shown in Fig. 1, where also the so called "by pass transfer line", to be dedicated to an experiment of magnetic compression of the beam, and the "seeding" experiment are shown.

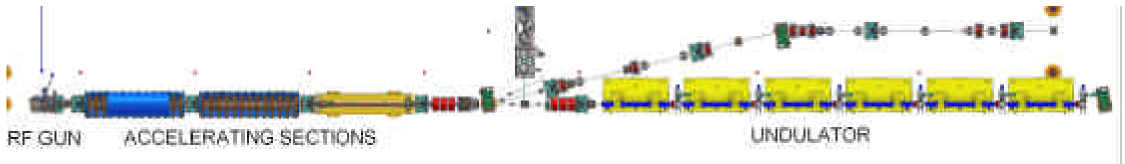

FIG. 1: Layout of the SPARC linear accelerator

Two of the three accelerating sections of the SPARC LINAC have been delivered to LNF by Mitsubishi, while the third one comes from SLAC as part of a collaboration agreement. Each one of the first two sections is embedded in an array of 13 solenoids, required to produce a magnetic field for additional focusing in order to comply with the Ferrario working point matching conditions for emittance compensation [3].

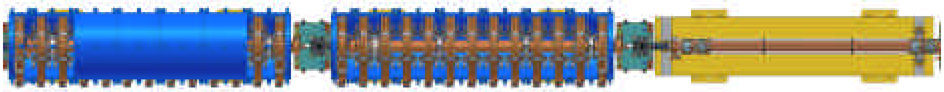

FIG. 2: The three accelerating sections

In addition to the 26 solenoids, two spare solenoids have been realized and are ready to be assembled on the LINAC in the case that a malfunctioning one should be substituted. The total number of coils is therefore 28, and all of them have been measured in order to define their geometrical and magnetic features.

2 MEASUREMENTS

For a proper and correct accelerator functioning it is important to align the focusing solenoids on the machine with their magnetic axes precisely coincident with the beam axis. Preliminary operations are therefore the geometrical characterization, to determine the geometrical axis, and the magnetic measurements, to determine the magnetic axis position with respect to the geometrical one. The concept of the solenoid's "magnetic axis" will be explained later on when the plotting of the magnetic field variation will be analyzed and described.

2.1 Coordinate measuring techniques

Different coordinate measuring techniques have been used for this job. For the first set of coils the measurements have been performed with two theodolites (Leica T3000 [4]), both connected to a PC and controlled by a specific software (Leica Axyz). For the second set it has been possible to use a laser tracker (Leica LTD840), newly purchased by the INFN Frascati Laboratories.

FIG. 3: Leica Theodolites

FIG. 4: Leica Laser Tracker

The laser tracker is a versatile instrument that requires less human effort and allows precisions of approximately the same magnitude as the theodolite system (angles: ±0.2''; distances: ±0.02mm), but with a quicker measuring process. Another difference between the two measuring systems is that the laser tracker needs necessarily a Corner Cube Reflector (CCR) as a target, while a theodolite collimation may use any visible target. A third important difference is that the laser tracker allows to keep the target under control even during movement. In both cases the data may be collected and treated by means of Leica Axyz. This software not only gives the possibility to control the instruments (Laser Tracker or Theodolites), and to read and store data from them, but it also offers tools for nearly every type of geometrical analysis.

2.2 Geometrical Characterization

The characterization consists in determining the geometrical axis and referring to it three reference points, fixed to the solenoid, that have to be visible during the alignment on the machine. In order to do this the coils have been supplied with special supports, on which precision holes have been machined, where targets can be positioned (FIG.5).

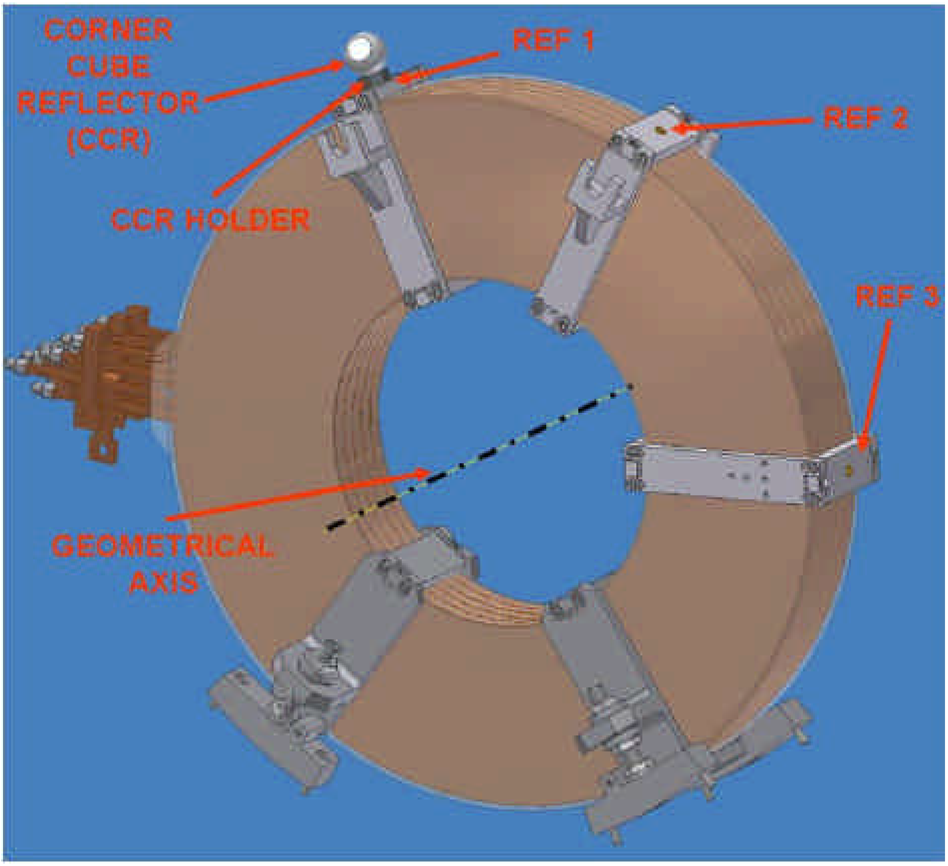

FIG. 5: The focusing solenoid

Once the geometrical axis has been identified, as the axis of the coil internal cylindrical surface, it is used to build a coordinate system fixed to the solenoid having (FIG.6):

- the origin in the solenoid midplane
- the x-axis coincident with the coil geometrical axis
- the y-axis conveniently placed on the midplane of hydraulic and electric connection block

The 3D coordinates of the three coil reference points can be measured and stored as the "geometrical coordinates"

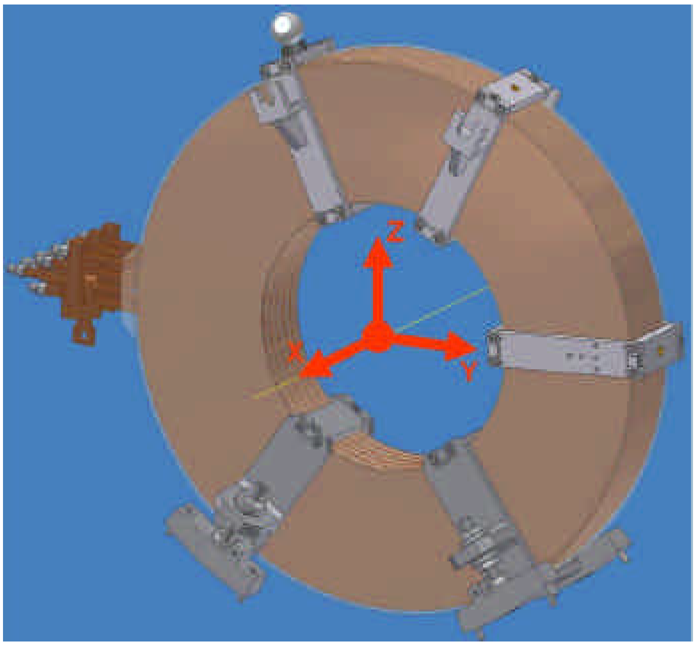

FIG. 6: The Coordinate system fixed to the solenoid

2.3 Magnetic Measurements

Once the characterization is done, the magnetic field intensity inside each coil is measured by a Hall Effect Teslameter [5], whose Hall plate is mounted on a 3D movement machine (FIG. 7). Four out of five movement axes are motorized. By scanning the volume inside the solenoid it is possible to map the magnetic field in the zone of interest.

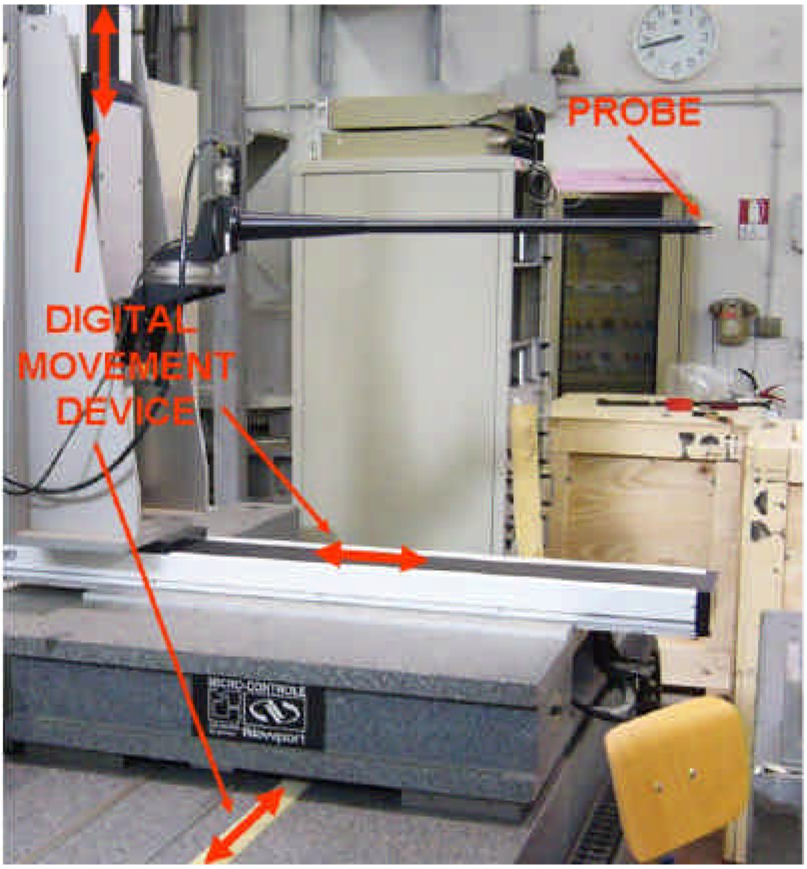

FIG. 7: The 3D movement machine holding the Hall probe

In order to evaluate the offset between the geometrical and the magnetic axis the coil must be placed in front of the magnetic measuring machine with its coordinate system coincident with the machine one, defined as follows: (FIG. 8):

- the origin in the center of the probe (in an arbitrarily assigned position)
- the x, y, and z axis parallel to the three main device movements

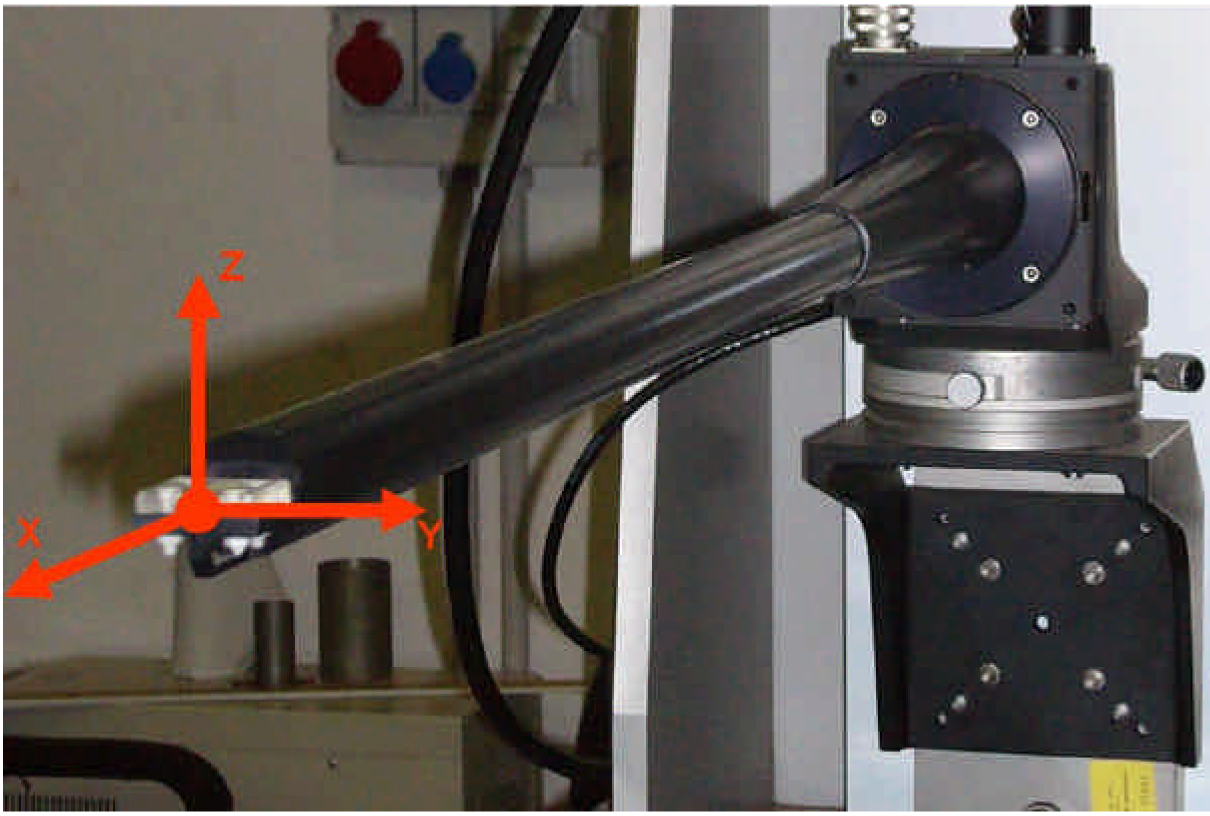

FIG. 8: The Coordinate system fixed to the probe

A complete 3D magnetic field scan may be time consuming: in some cases a single 2D study on the midpoint cross-section is convenient and for short solenoids, as SPARC ones are, it is also enough accurate. The midpoint cross-section in the solenoid coordinate system (FIG.6) is the plane x=0. The magnetic field analysis has been performed on this plane, studying the variation of B along the two principal radial directions (y-axis and z-axis).

2.3.1 The magnetic field produced by the solenoid

The SPARC focusing solenoids are quite atypical from a geometrical point of view. Unlike classical solenoids they have a large diameter and a short length. For this reason the magnetic field in the core is not essentially uniform, as it is in long solenoids, but it is strongly influenced by border effects. The variation of the magnetic field as a function of the radial position, on a plane perpendicular to the solenoid axis, is shown in FIG.9 and has a parabolic behavior.

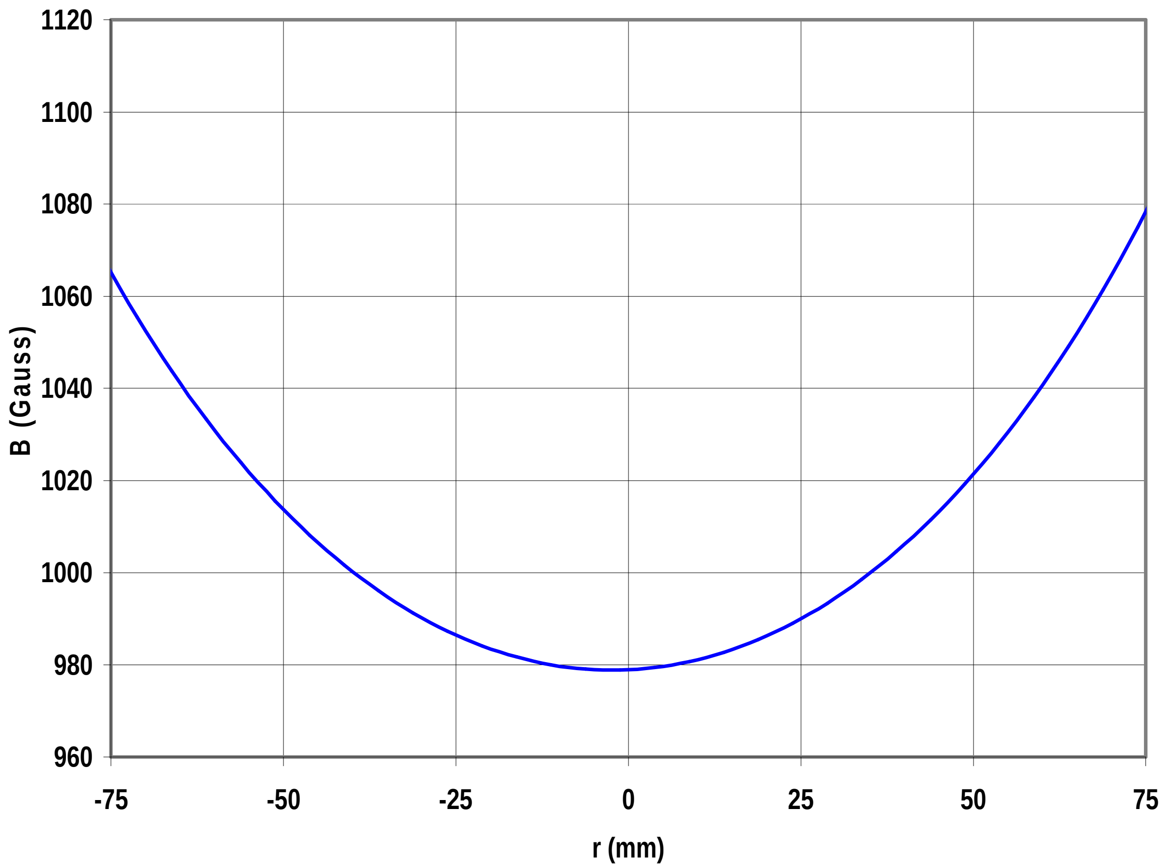

FIG. 9: The magnetic field variation

The vertex of this parabola is the point with null derivative (?B/?r=0). In a small area around this point the variation of the B field is very low. In other words the field is approximately homogeneous. The condition of maximum field homogeneity is important for the beam stability.

The magnetic center is the point $C_M=(0,y_M, z_M)$ on the plane x=0, that satisfies both conditions $?B(0,y_M, z_M)/?y=0$ and $?B(0,y_M, z_M)/?z=0$. It is then an acceptable approximation to consider the magnetic axis as the vector parallel to the coil's geometrical axis intersecting the center of the magnetic field on the midpoint cross-section.

The magnetic offsets Δy and Δz are the translation components necessary to move the solenoid from the condition of geometrical axis aligned on the SPARC beam axis to the condition of magnetic axis aligned.

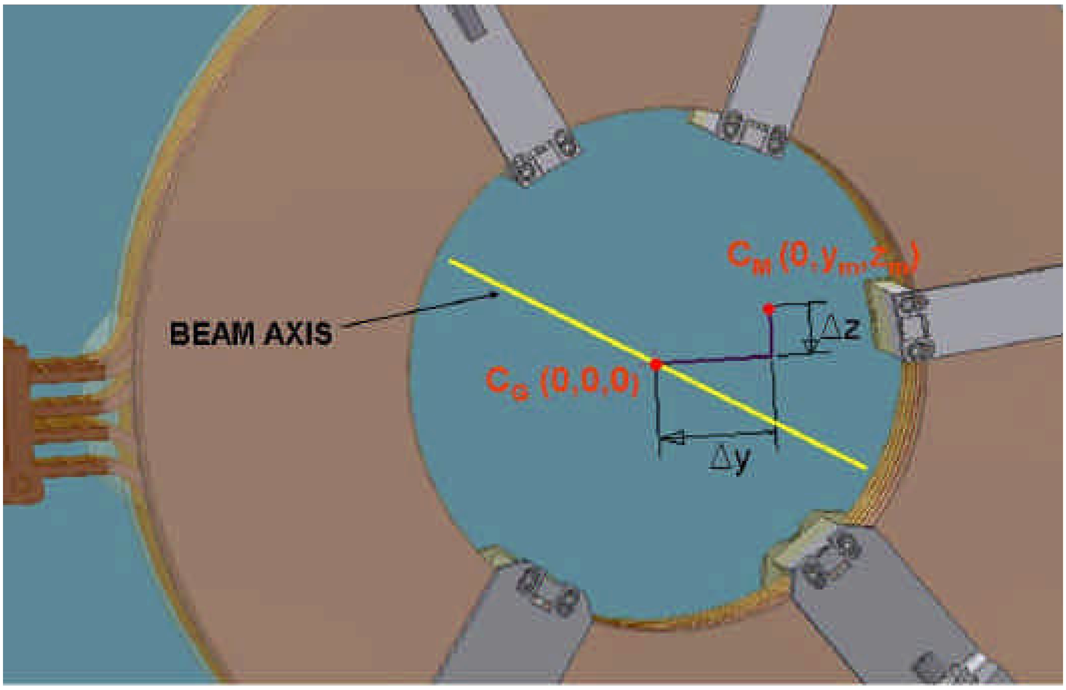

FIG. 10: Geometrical axis aligned with the beam axis

As it is possible to see in FIG.10 the magnetic offsets are:

- $\Delta y = -y_M$
- $\Delta z = -z_M$

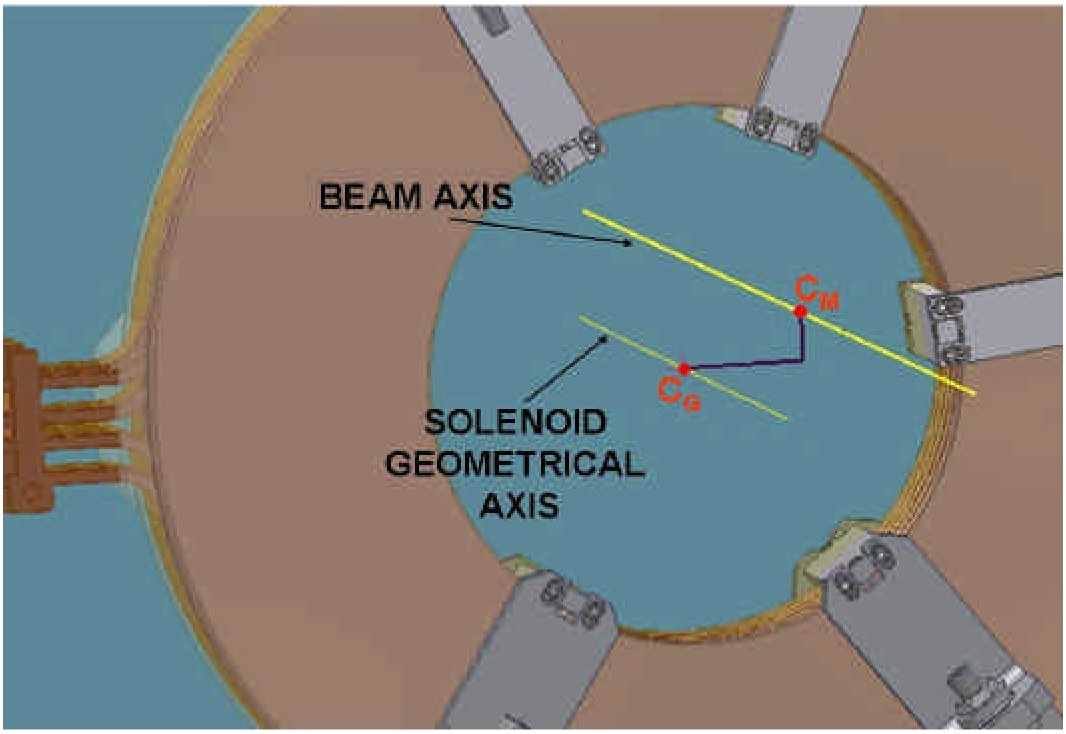

FIG. 11: Magnetic axis aligned with the beam axis

3 GEOMETRICAL AND MAGNETIC DATA FOR ALIGNMENT

The geometrical coordinates (X_0 ,Y_0 , Z_0) , the magnetic offsets (Δy and Δz), and the consequent magnetic coordinates (X ,Y , Z) are listed in tables 1 and 2. All the values are expressed in millimeters.

Solenoid Serial Number		Geometrical Coordinates			Magnetic Offsets		Magnetic Coordinates		
		X0	Y0	Z0	ΔY	ΔZ	X	Y	Z
1	Ref 1	-0.595	-144.686	311.137	-1.314	-0.153	-0.595	-146.000	310.984
	Ref 2	-0.698	146.394	309.402			-0.698	145.080	309.249
	Ref 3	-0.567	341.947	23.844			-0.567	340.633	23.691
2	Ref 1	-1.741	-148.501	323.042	-1.550	-0.570	-1.741	-150.051	322.472
	Ref 2	-0.759	149.725	322.385			-0.759	148.175	321.815
	Ref 3	1.286	355.254	24.532			1.286	353.704	23.962
3	Ref 1	-0.483	-145.464	311.209	-1.231	-0.720	-0.483	-146.695	310.489
	Ref 2	-0.347	144.582	311.249			-0.347	143.351	310.529
	Ref 3	-0.201	342.238	24.525			-0.201	341.007	23.805
4	Ref 1	-0.958	-143.257	311.574	-1.399	-0.126	-0.958	-144.656	311.448
	Ref 2	-0.387	145.808	310.346			-0.387	144.409	310.220
	Ref 3	-1.098	342.971	23.380			-1.098	341.572	23.254
5	Ref 1	-1.431	-144.633	310.744	-1.790	-0.803	-1.431	-146.423	309.941
	Ref 2	-0.069	145.650	310.519			-0.069	143.860	309.716
	Ref 3	-0.980	342.309	23.062			-0.980	340.519	22.259
6	Ref 1	-0.059	-144.147	310.860	-1.836	-0.577	-0.059	-145.983	310.283
	Ref 2	1.332	146.032	310.389			1.332	144.196	309.812
	Ref 3	-0.628	343.039	22.302			-0.628	341.203	21.725
7	Ref 1	-0.443	-143.959	311.381	-1.690	-0.230	-0.443	-145.649	311.151
	Ref 2	-0.122	146.085	310.340			-0.122	144.395	310.110
	Ref 3	0.133	343.116	23.923			0.133	341.426	23.693
8	Ref 1	0.262	-145.443	310.424	-2.050	-0.618	0.262	-147.493	309.806
	Ref 2	-0.324	145.665	310.944			-0.324	143.615	310.326
	Ref 3	-1.538	342.548	25.451			-1.538	340.498	24.833
9	Ref 1	-0.322	-145.099	310.393	-2.089	-0.221	-0.322	-147.188	310.172
	Ref 2	-0.368	143.627	311.255			-0.368	141.538	311.034
	Ref 3	0.307	342.072	24.838			0.307	339.983	24.617
10	Ref 1	-0.737	-145.728	310.947	-1.538	-0.600	-0.737	-147.266	310.347
	Ref 2	-0.163	145.297	310.722			-0.163	143.759	310.122
	Ref 3	-0.673	342.168	24.572			-0.673	340.630	23.972
11	Ref 1	-0.830	-144.660	311.132	-1.289	-0.268	-0.830	-145.949	310.864
	Ref 2	-1.083	145.823	310.335			-1.083	144.534	310.067
	Ref 3	-0.592	342.256	22.553			-0.592	340.967	22.285
12	Ref 1	-0.703	-142.614	312.093	-1.521	-0.573	-0.703	-144.135	311.520
	Ref 2	-0.485	148.612	309.726			-0.485	147.091	309.153
	Ref 3	0.782	342.473	21.169			0.782	340.952	20.596
13	Ref 1	-0.586	-144.014	311.104	-1.144	-0.442	-0.586	-145.158	310.662
	Ref 2	-0.123	146.400	310.801			-0.123	145.256	310.359
	Ref 3	0.583	342.306	22.669			0.583	341.162	22.227
14	Ref 1	-0.158	-146.145	310.794	-1.200	-0.480	-0.158	-147.345	310.314
	Ref 2	-0.493	145.566	310.571			-0.493	144.366	310.091
	Ref 3	-1.142	342.242	24.447			-1.142	341.042	23.967

TAB. 1: First section solenoids: geometrical coordinates, magnetic offsets, magnetic coordinates

Solenoid Serial Number		Geometrical Coordinates X0	Y0	Z0	Magnetic Offsets ΔY	ΔZ	Magnetic Coordinates X	Y	Z
15	Ref 1	-0.784	-149.248	323.721	-1.230	-0.267	-0.784	-150.478	323.454
	Ref 2	-0.592	152.088	322.444			-0.592	150.858	321.214
	Ref 3	0.707	356.504	23.466			0.707	355.274	22.236
16	Ref 1	0.572	-151.188	323.253	-1.353	-0.704	0.572	-152.541	322.549
	Ref 2	0.320	151.416	323.153			0.320	150.063	321.800
	Ref 3	-0.458	356.069	24.201			-0.458	354.716	22.848
17	Ref 1	-0.051	-147.406	325.096	-0.960	-0.920	-0.051	-148.366	324.176
	Ref 2	-0.190	153.981	321.507			-0.190	153.021	320.547
	Ref 3	-0.226	356.238	20.229			-0.226	355.278	19.269
18	Ref 1	0.025	-150.121	323.783	-1.529	-0.846	0.025	-151.650	322.937
	Ref 2	0.073	152.015	322.758			0.073	150.486	321.229
	Ref 3	0.530	357.445	22.939			0.530	355.916	21.410
19	Ref 1	-0.667	-147.469	324.373	-1.215	-0.336	-0.667	-148.684	324.037
	Ref 2	-0.527	154.758	321.317			-0.527	153.543	320.102
	Ref 3	0.270	357.290	20.613			0.270	356.075	19.398
20	Ref 1	-0.325	-151.461	322.743	-1.000	-0.520	-0.325	-152.461	322.223
	Ref 2	0.098	150.836	323.283			0.098	149.836	322.283
	Ref 3	-0.343	355.960	24.883			-0.343	354.960	23.883
21	Ref 1	-0.381	-151.482	321.762	-1.190	-0.120	-0.381	-152.672	321.642
	Ref 2	-0.969	149.540	323.310			-0.969	148.350	322.120
	Ref 3	0.029	356.179	26.859			0.029	354.989	25.669
22	Ref 1	0.365	-148.331	324.433	-1.250	-0.600	0.365	-149.581	323.833
	Ref 2	0.273	153.825	322.079			0.273	152.575	320.829
	Ref 3	0.618	356.310	21.601			0.618	355.060	20.351
23	Ref 1	-0.327	-148.036	324.401	-1.343	-0.733	-0.327	-149.379	323.668
	Ref 2	0.389	153.036	322.147			0.389	151.693	320.804
	Ref 3	-0.279	356.464	22.848			-0.279	355.121	21.505
24	Ref 1	0.410	-149.709	323.670	-1.430	-1.000	0.410	-151.139	322.670
	Ref 2	0.003	152.339	322.921			0.003	150.909	321.491
	Ref 3	0.023	356.293	23.743			0.023	354.863	22.313
25	Ref 1	-0.225	-150.787	323.729	-1.020	-1.300	-0.225	-151.807	322.429
	Ref 2	0.240	151.786	323.253			0.240	150.766	322.233
	Ref 3	-0.326	356.358	23.695			-0.326	355.338	22.675
26	Ref 1	-0.289	-150.932	323.448	-0.944	-0.790	-0.289	-151.876	322.658
	Ref 2	-0.021	151.706	322.433			-0.021	150.762	321.489
	Ref 3	-0.681	355.321	26.016			-0.681	354.377	25.072
27	Ref 1	-0.758	-145.934	324.805	-1.328	0.000	-0.758	-147.262	324.805
	Ref 2	-0.313	155.382	320.009			-0.313	154.054	318.681
	Ref 3	0.571	355.866	19.082			0.571	354.538	17.754
28	Ref 1	-0.137	-148.914	324.250	-1.220	-0.791	-0.137	-150.134	323.459
	Ref 2	0.255	152.931	322.398			0.255	151.711	321.178
	Ref 3	0.094	356.618	22.721			0.094	355.398	21.501

TAB. 2: Second section solenoids: geometrical coordinates, magnetic offsets, magnetic coordinates

FIG. 12 shows the magnetic center position distribution, for all the 28 SPARC focusing solenoids, with respect to the geometrical center C_G (0,0,0).

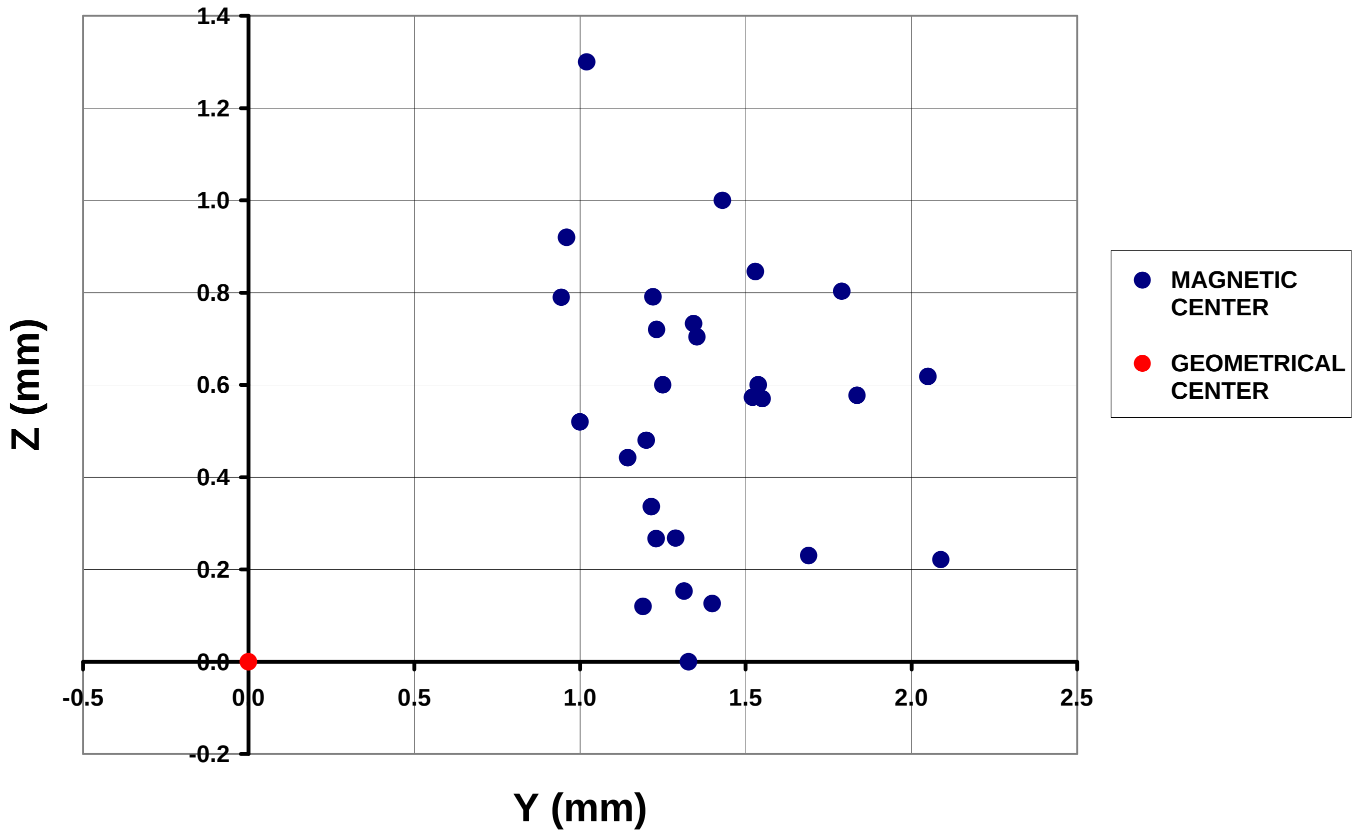

FIG. 12: Magnetic center distribution

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