Scaling of FRS Magnets

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Scaling of the integrated field strengths or gradients of magnets by one common factor is used for changing the Bρ-settings of the FRS. To avoid different results due to hysteresis of the iron a ramping procedure can be used. The program MGSKAL is used to do the scaling.

Ramping procedure

Since 2006 only the dipoles are ramped. The procedure is built into MGSKAL and does:

start value -> I_min=30 A for 30 s -> I_max=900 A for 15 s -> I_min=30 A for 30s -> new set value

In total the procedure takes 2 min. Negative currents or degaussing are not available.

Effect of hysteresis

The hysteresis disturbs most at low field strength. In June 2016 the effect was tested on TS4MU1. The values are given in time order as measured. Fields were decreased in steps and first the B-field measured before ramping and then after ramping. Afterwards the next lower step was set. Assuming the same effect also for the other FRS dipoles and a FRS standard mode with a typical dispersion coefficient of 7800mm for the section S2-S4, a corresponding peak shift in horizontal plane can be given.

I [A]	no ramp B[T]	after ramp B[T]	ΔB [T]	[mm] Δx
0				
540	1.0246	1.0249	-0.0003	-2.3
450	0.8572	0.8546	0.0026	23.7
360	0.686	0.6839	0.0021	24.0
270	0.5142	0.5124	0.0018	27.4
180	0.3426	0.3410	0.0016	36.6
90	0.1755	0.1746	0.0009	40.2
0	0.0017	0.0016	1E-04	

Obviously the Hall probe did not have a good absolute calibration at that time (27.06.2016).

As the set values are always approached from below and increase of the magnetic field can be done without ramping and yields the same B-field.

I [A]	no ramp B[T]	after ramp B[T]	ΔB [T]	[mm] Δx
0	0.0017	0.0017	0.0000	
900	1.6183	1.6181	0.0002	1.0

The result also show that small corrections by only $\Delta B/B < 1\%$ can usually be done without ramping but not many of such changes in sequence.
A waiting time of around one minute is needed before eddy currents are completely canceled. Often one can see this as an increase of the Hall probe value after ramping.

Warm up

Another important effect is the temperature of the magnets and perhaps the power supplies. Directly after a cold start the achieved B-fields are still lower than after 15 minutes of operation.
Example: TS4MU1 at 540A after ramping: B =1.0249 T, the same 30 min later B=1.0261 T
-> dB/B = 0.12% or Δx = 9.1 mm at S4.

Software insufficiencies

Based on the 19 points for integral field strength from the initial magnet mapping the BL (for dipoles) or B'L (for quadrupoles) were fitted in three separate polynomials. They are not exactly continuous at the boundaries. For the inverse calculation a separate set of polynomials is used and not the exact inverse function. In addition values are stored with too few digits. In consequence after scaling by a factor F=1.000 the result is a slightly modified current compared to the start value. It may be confusing that the set values are not preserved, but at least the effect is only in the order of $dI/I \sim 1x10^{-4}$. A future control system should use better mathematics and Newton iteration for a better inverse function. Scaling many times by F=1.000 does not seem to increase the difference more.

Hall probe calibration

The Hall probes in the FRS dipoles are not regularly calibrated. They show aging and the one in TS3MU1 also radiation damage. When used only for relative scaling this can be ok, but also a deviation from linearity and an offset can be and then scaling is not correct anymore. We can assume that the geometry of the magnets has not changed since the magnet mapping and the dipoles have mirror plates on both ends. Then also the length of the path inside the dipole magnets stays the same, by design $L = 2 \pi * 11.25m * 30°/360° = 5.89049$ m, however, the mapper data show a longer L_eff = BL / L (+1.5 to +0.5%) with a shortening due to saturation at high B-field. At very low fields the mapper data cannot be so accurate enough. For I< 100A the data show a decrease of the effective path length L_eff by about -0.3%, but it is expected to be constant. There probably is an offset in the data.

One could simply introduce a modified polynomial for the Hall probe calibration which converts the measured Hall voltage directly to the expected B-fields.

Appendix: Mapper data

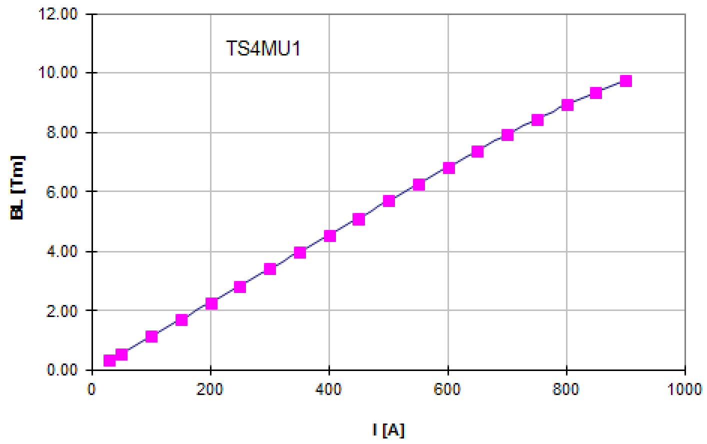

Fig.1: BL in the main field as function of current in dipole TS4MU1.

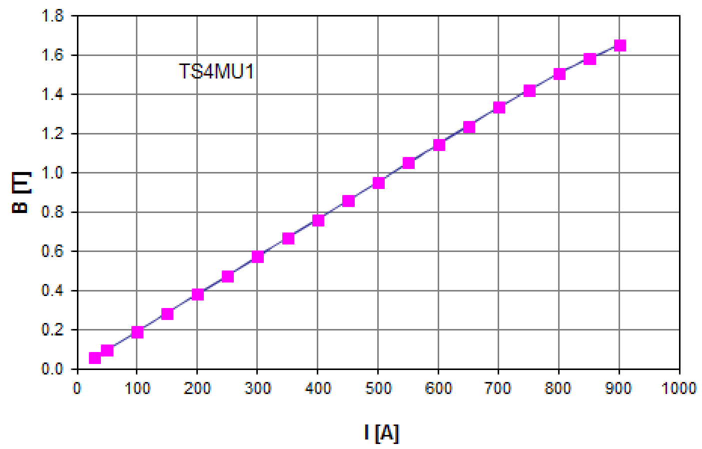

Fig.2: B in the main field as function of current in dipole TS4MU1.

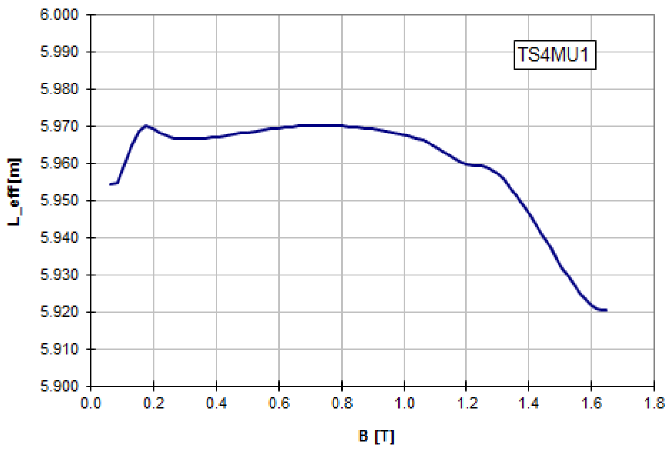

Fig.3: L_eff derived from the mapper data for B and BL of dipole TS4MU1 as function of B. Additional wiggles probably are due to systematic measurement errors in B or BL.

Table: Magnet mapping points for the four dipoles to S4 as function of current.
B measured in main field and integral along reference path. L_eff = BL / B.

I [A]	B [T]	BL [Tm]	Leff [m]
TS3MU1			
30	0.060394	0.359649	5.9550
50	0.097386	0.580252	5.9583
100	0.191668	1.14358	5.9665
150	0.286962	1.71262	5.9681
200	0.382577	2.28365	5.9691
250	0.478386	2.85604	5.9702
300	0.574236	3.4282	5.9700
350	0.670112	4.0003	5.9696
400	0.765981	4.57228	5.9692
450	0.861792	5.14383	5.9688
500	0.957542	5.71493	5.9683
550	1.05309	6.28557	5.9687
600	1.14827	6.85469	5.9696
650	1.24338	7.42111	5.9685
700	1.33812	7.98013	5.9637
750	1.42971	8.51832	5.9581
800	1.51578	9.01875	5.9499
850	1.59568	9.48204	5.9423
900	1.66956	9.90935	5.9353
HFSMU1			
30	0.060345	0.359283	5.9538
50	0.097629	0.581584	5.9571
100	0.192299	1.14712	5.9653
150	0.287463	1.71526	5.9669
200	0.382924	2.28527	5.9679
250	0.478540	2.8564	5.9690
300	0.574231	3.42748	5.9688
350	0.669936	3.99845	5.9684
400	0.765652	4.5694	5.9680
450	0.861297	5.13985	5.9676
500	0.956895	5.70993	5.9671
550	1.052350	6.27848	5.9662
600	1.147510	6.84465	5.9648
650	1.242220	7.40451	5.9607
700	1.335650	7.94921	5.9516
750	1.424860	8.46744	5.9426
800	1.507300	8.9439	5.9337
850	1.583450	9.38268	5.9255
900	1.652990	9.78226	5.9179
TS4MU1			
30	0.059066	0.351703	5.9544
50	0.096171	0.572948	5.9576
100	0.190614	1.13717	5.9658

150	0.285584	1.70423	5.9675
200	0.380864	2.27321	5.9685
250	0.476309	2.84337	5.9696
300	0.571818	3.41345	5.9695
350	0.667353	3.98346	5.9691
400	0.762912	4.55353	5.9686
450	0.858385	5.12302	5.9682
500	0.953822	5.6922	5.9678
550	1.04917	6.26017	5.9668
600	1.14427	6.826	5.9654
650	1.23894	7.38532	5.9610
700	1.33237	7.9288	5.9509
750	1.42161	8.44636	5.9414
800	1.50402	8.92368	5.9332
850	1.57996	9.36237	5.9257
900	1.64919	9.7613	5.9188
TS3MU2			
30	0.060823	0.362794	5.9647
50	0.098317	0.586762	5.9681
100	0.19268	1.15153	5.9764
150	0.287537	1.71892	5.9781
200	0.382691	2.28816	5.9791
250	0.478002	2.85852	5.9802
300	0.573389	3.42888	5.9800
350	0.669009	4.00041	5.9796
400	0.764355	4.57022	5.9792
450	0.859536	5.13896	5.9788
500	0.954632	5.70711	5.9783
550	1.0494	6.27343	5.9781
600	1.14446	6.84159	5.9780
650	1.23853	7.39822	5.9734
700	1.33227	7.94022	5.9599
750	1.42213	8.45785	5.9473
800	1.50477	8.93353	5.9368
850	1.58227	9.37806	5.9270
900	1.65263	9.78032	5.9180