E155 Technical Note
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Calibration of the A-line by Spin Precession (including Synchrotron Radiation)

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I. Summary:

This note summarizes the corrections to the magnet fields and spin precession due to synchrotron radiation losses in the A-line bend magnets. The geometry of the system is taken from the transport deck ALINE33T T, and the notation used here refers to the 14 bend magnets in the order seen by the incoming beam. It is also assumed here that the flipcoil energy uses the reference magnet which is set to be the beam energy at the target.
The spin precession is to be measured by the End Station A Møller detectors. The measured asymmetry is given by:

$$A_{meas} = A_{M\o ller} \ * \cos(\Theta_{prec}) \tag{1}$$

where

$$\Theta_{prec} = \pi * [0.3088793 * \mathrm{E}_{target} + 0.109802 \times 10^{-7} * \mathrm{E}_{target}^4].$$

The A-line bends have trim windings T1 - T6 added to two magnets at a time, starting with number 3, the first large bend magnet. Because of the energy loss, the upstream magnets need more current to preserve the orbit of the beam. The fields in these magnets and other parameters are given by (for $13 < \mathrm{E}_{target} < 53$ GeV):

Coefficients for A-line Magnets and Parameters
Parameter = A * E_{target} + B * E_{target}^4

Parameter	A	B	units
$\mathrm{E}_{accelerator}$	0.9999517	0.705176 e-7	GeV
$\Theta_{spin\ prec.}$	0.3088793	0.109802 e-7	$\times\pi$ radians
$\mathrm{B}_{reference}$	0.3848118	0.000000	KGauss
B(1-2)	0.2244404	0.157306 e-7	KGauss
B(3-4 + T1)	0.3847952	0.245695 e-7	KGauss
B(5-6 + T2)	0.3847982	0.201026 e-7	KGauss
B(7-8 + T3)	0.3848012	0.156357 e-7	KGauss
B(9-10 + T4)	0.3848043	0.111689 e-7	KGauss
B(11-12 + T5)	0.3848073	0.067020 e-7	KGauss
B(13-14 + T6)	0.3848103	0.0223513 e-7	KGauss

Calibration of the flipcoil energy scale is best done by seeking nearby crossover points of the Møller asymmetry. For E155, these points are at 14.5 π and 15.5 π rotations of the spin. The following table lists energies for an E155 running plan.

E_{target} GeV	Spin Precession $\times\pi$ radians
46.455	14.4
46.774	14.5
47.093	14.6
48.368	15.0
49.642	15.4
49.960	15.5
50.278	15.6

The measured asymmetries should be fit with an amplitude $A_{M\o ller}$ and an energy scale $E_{flipcoil} + \Delta$ using the above coefficients from equation (1) to determine the correction Δ to the flipcoil reading.

II. Discussion:

Calibration of the A-line energy and the flipcoil system has been a usual procedure undertaken during the commissioning of the End Station A experiments. The recent experiments E154 and E155 have a continuing need for the calibration because of the changes to the A-line magnets as part of the 50 GeV Upgrade. E155 plans to run at the highest point of longitudinal spin, E(target) = 48.37 GeV, which corresponds to 15 π radians in spin rotation. At this high energy, synchrotron radiation losses amount to 384 MeV. The amount of synchrotron loss is determined by the geometry of the A-line and grows with energy as E^4.
The A-line transport system has 14 active bend magnets, not counting the several small corrector magnets used for fine tuning, and ignoring the quads. For this discussion, the corrector magnets will be assumed to be set to zero. The geometry of the A-line is assumed to be correctly given by the transport deck ALINE33T T which can be found on PRESCOTT 191 on the VM system or aline33t.t on nfs/juno/u30/ea/prescott/.
Synchrotron energy loss is given by M. Sands, Report SLAC-121, equation 4.3. The energy loss is

$$\Delta E = \frac{C_\gamma}{2\pi}\frac{E^4}{\rho^2}\Delta L, \tag{2}$$

where $C_\gamma = 8.84627 \times 10^{-5}$, and the units are GeV and meters.
To accommodate the synchrotron energy losses, the A-line bend magnets have trim coils added. The coils are added to two bends at a time, giving 6 trim corrections to the last 12 bends. Parameters of the bends are:

Magnet	Length meters	Radius meters	Θ_{bend} degrees	trim coil
B1	0.648	148.51	0.25	no
B2	0.648	148.51	0.25	no
B3	3.024	86.622	2.0	T1
B4	3.024	86.622	2.0	T1
B5	3.024	86.622	2.0	T2
B6	3.024	86.622	2.0	T2
B7	3.024	86.622	2.0	T3
B8	3.024	86.622	2.0	T3
B9	3.024	86.622	2.0	T4
B10	3.024	86.622	2.0	T4
B11	3.024	86.622	2.0	T5
B12	3.024	86.622	2.0	T5
B13	3.024	86.622	2.0	T6
B14	3.024	86.622	2.0	T6
B-reference	3.024	86.622	2.0	no

The geometry of the A-line completely specifies the magnet settings and spin precession, given an incoming beam energy. Alternately, given the energy of the beam at the target, the magnet settings, spin precession, and incoming beam energy are determined. It is appropriate from the users standpoint to set the flipcoil reading to be the beam energy *at the target*, and for the control system and beam operators to set up the A-line magnetic fields and incident beam energy accordingly.
As an illustration, the following energies correspond to spin precessions of interest:

Spin Precession $\times\pi$ radians	Target Energy GeV	Accelerator Energy GeV	B-reference magnet KGauss
5.0	16.1848	16.1895	6.2281
6.0	19.4196	19.4295	7.4729
7.0	22.6529	22.6710	8.7171
8.0	25.8838	25.9148	9.9604
9.0	29.1119	29.1615	11.2026
10.0	32.3362	32.4119	12.4433
11.0	35.5559	35.6667	13.6823
12.0	38.7701	38.9270	14.9192
13.0	41.9776	42.1938	16.1535
14.0	45.1775	45.4683	17.3848
14.5	46.7741	47.1087	17.9992
15.0	48.3683	48.7516	18.6127
15.5	49.9600	50.3969	19.2252
16.0	51.5489	52.0450	19.8366

This table can be accurately summarized by:

$$\Theta_{spin\ precession} = 0.308879 * \mathrm{E}_{target} + 0.10980 \times 10^{-7} * \mathrm{E}^4_{target}$$

$$\mathrm{E}_{accelerator} = 0.999952 * \mathrm{E}_{target} + 0.70518 \times 10^{-7} * \mathrm{E}^4_{target}$$

$$\mathrm{B}_{reference\ magnet} = 0.384812 * \mathrm{E}_{target} + 0.00000 * \mathrm{E}^4_{target},$$

where the units are $\Theta_{spin\ precession} \times \pi$ gives radians, $\mathrm{E}_{accelerator}$ is in GeV, and $\mathrm{B}_{reference\ magnet}$ is in KGauss. In general these parameters and the bend magnetic fields have the form

$$\text{Parameter} = A * \mathrm{E}_{target} + B * \mathrm{E}^4_{target}$$

The table below (and on page 1) gives the parameters and the coefficients A and B.

Fit Coefficients for A-line Magnets and Parameters
Parameter = A*E_{target} + B*E^4_{target}

Parameter	A	B	units
$\mathrm{E}_{accelerator}$	0.9999517	0.705176 e-7	GeV
$\Theta_{spin\ prec.}$	0.3088793	0.109802 e-7	$\times\pi$ radians
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