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Gun Solenoid Clamp Misalignment Tolerance

Problem Definition

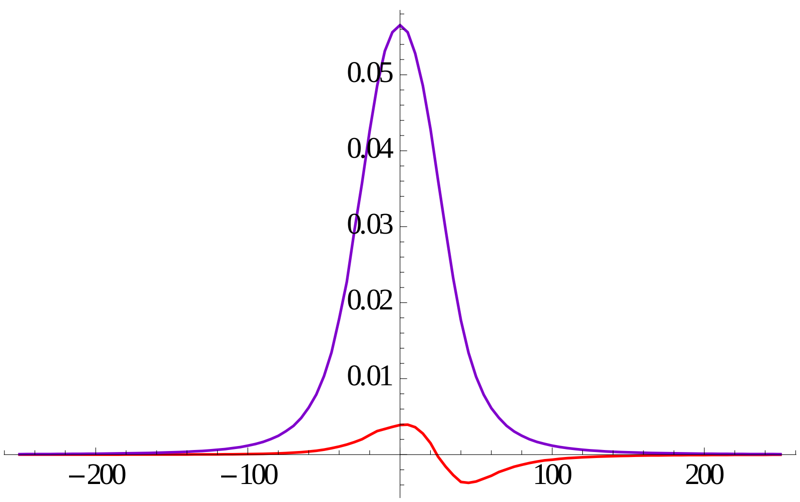
The question is how transport optics through the gun solenoid is affected by transverse misalignment of the field clamps with respect to the solenoid.

For general optical elements there is an agreed transverse alignment tolerance of flat distribution from 0 to ±200 μm, often shorthanded as RMS=150 μm. There is no reason why an element cannot be aligned to this accuracy and if not, its reason should be understood and decision made as to whether exception is allowable. So in this sense the question here is really whether the field clamp will impose an even tighter alignment tolerance than 200 μm, not looser. If it is looser, we should simply go for the ±200 μm (RMS 150 μm) tolerance because of other concerns such as residual orbit envelope, correctability, etc. In any case the analysis below is likely to break down quickly with offsets larger than a couple of mm.

If the gun solenoid belongs to those cases of exceptional alignment difficulty, the best achievable accuracy (and justification) should be given, whose impact should then be evaluated in the context of this analysis, up to its range of validity. It should also be evaluated in other contexts such as orbit envelope, correctability, etc.

Contribution of clamp to solenoid field

The difference (below, red) in on-axis filed between the gun solenoid and "solenoid plus one clamp" at the same excitation is given by Thomas. The ratio between the peaks of the two curves below is ~0.07.



Method

At small enough relative transverse offset between the solenoid and the clamp, the following method was attempted to provide a first order idea of this misalignment effect.

- Astra calculation of ensemble of particles through the "difference field" (red curve above) was made

- Transport coefficients up to 5th order were extracted from the above data

- Modification to baseline solenoid transfer matrix due to higher order components of "difference field" transport at transversely offset coordinates is evaluated.

- Procedure is repeated for a few momentum and solenoid field values, keeping the same ratio between the solenoid field and the "difference field"

Result

As a representative case, at 300 keV and solenoid peak B at 550 G, close to baseline number, the modification to baseline transfer matrix is a messy expression containing all terms 2nd order in the offsets[1]. A simplified result, for example, when there is only X misalignment δX, is

$$\delta M_{\delta X} = \begin{pmatrix} -0.0033 & 0.035 & -0.0089 & -0.0071 \\ -0.0201 & -0.0054 & 0.0798 & 0.0421 \\ 0.0264 & 0.0104 & -0.0011 & 0.1112 \\ -0.2361 & -0.0834 & -0.0053 & -0.0384 \end{pmatrix} \times \delta X^2$$

In comparison the baseline solenoid matrix at peak B 550 G and 300 keV is

$$M = \begin{pmatrix} 0.006 & 0.158 & -0.007 & -0.183 \\ -2.696 & 0.004 & 3.13 & -0.004 \\ 0.007 & 0.183 & 0.006 & 0.158 \\ -3.13 & 0.004 & -2.696 & 0.004 \end{pmatrix}$$

Both are in units of Meter and MeV/c.

Numerical examples

Taking δX, δT, δY, δP, the 4 transverse position and angle (alternatively transverse momentum) misalignments, to be 1 mm or 1 mrad respectively the above modification takes on values below (All matrices are in Meter and MeV/c):

δX=1 mm:

$$\delta M = \begin{pmatrix} -0.33 & 3.5 & -0.89 & -0.71 \\ -2.01 & -0.54 & 7.98 & 4.21 \\ 2.64 & 1.04 & -0.11 & 11.12 \\ -23.61 & -8.34 & -0.53 & -3.84 \end{pmatrix} \times 10^{-8}$$

δT=1 mrad:

$$\delta M = \begin{pmatrix} 0.98 & 0.8 & -4.62 & -1.44 \\ 0.63 & 4.31 & 35.21 & 16.84 \\ 3.11 & 4.28 & -1.55 & 0.19 \\ -36.38 & -40.89 & -1.75 & 0.61 \end{pmatrix} \times 10^{-8}$$

δY=1 mm:

[1] By cylindrical symmetry about Z only odd power coefficients are present. Considering only modification to linear transport and ignoring 5th order elements led to this final form.

$$\delta M = \begin{pmatrix} -0.11 & 11.27 & -2.79 & -1.09 \\ -0.72 & -3.69 & 23.58 & 8.41 \\ 0.92 & 0.75 & -0.33 & 3.5 \\ -7.92 & -4.31 & -0.6 & -0.42 \end{pmatrix} \times 10^{-8}$$

δP=1 mrad:

$$\delta M = \begin{pmatrix} -1.55 & 0.21 & -3.13 & -4.3 \\ -1.8 & 1.47 & 36.25 & 45.39 \\ 4.59 & 1.47 & 1. & 0.58 \\ -35.27 & -18.77 & 0.63 & -14.33 \end{pmatrix} \times 10^{-8}$$

Some symmetry between coordinates survived numerical noise during computation.

This is a case with 2 simultaneous misalignments:

δY=1 mm & δP=1 mrad:

$$\delta M = \begin{pmatrix} -6.6 & 15.51 & -7.3 & -15.34 \\ -0.62 & 1.36 & 70.42 & 168.92 \\ 5.73 & -0.07 & 5.08 & 7.26 \\ -44.91 & -24.36 & -0.5 & -12.76 \end{pmatrix} \times 10^{-8}$$

Conclusion

It does not appear, allowing for the crude method used, that relative misalignment between the solenoid and the clamp on the order of 1 mm/1 mrad will change the transport optics appreciably. On the other hand without justifiable difficulty in aligning the solenoid the standard ±200 μm (RMS 150 μm) tolerance, considered feasible to all optical elements except the SRF cavity, should not be lightly abandoned due to other factors such as orbit envelope. Relaxing this tolerance to the mm level may require evaluation case by case in other contexts. Beyond this level the current method does not provide reliable answer and the impact on solenoid transport itself may become unacceptable.

The problem does stem from the fact that the solenoid and the clamps are independently mounted. If they were installed as an integral piece the problem could be reduced to a much more tractable one.