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Simulations on CLIC stripline measurements at ALBA

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Transverse field homogeneity and beam impedance measurements are required for the CLIC extraction stripline. A possible test bench for these measurements is the ALBA storage ring. This internal note studies the possibility to perform the homogeneity measurements via closed orbit distortion with the ALBA BPMs and correctors.

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Transverse field homogeneity and beam impedance measurements are required for the CLIC extraction stripline. A possible test bench for these measurements is the ALBA storage ring. This internal note studies the possibility to perform the homogeneity measurements via closed orbit distortion with the ALBA BPMs and correctors.

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1.0	08.02.2013	All	M.Pont general scheme change.
1.1	18.02.2013	All	U.Iriso comments and corrections.
1.2	21.02.2013	All	G.Benedetti comments and corrections.

References

[1] C. Belver-Aguilar, *CLIC DR EXTRACTION KICKER DESIGN, MANUFACTURING AND EXPERIMENTAL PROGRAM*, LCWS12 International Workshop on Future Linear Colliders, 25 October 2012, Arlington, USA.

Contents

1 Introduction

This report analyzes the proposal to measure the magnetic field homogeneity of one of the CLIC extraction kicker striplines at ALBA storage ring. The stripline has the following properties: [1]

Effective length	1.7 m
kick @ 3GeV	1.5 mrad
Good field region	± 1 mm
Field Homogeneity	10^{-4}

Table 1: CLIC stripline parameters.

It has been decided to install the stripline to kick in the vertical plane.

The high required precision will be an issue and will probably go to the limit of the accelerator possibilities. For this reason, two different measurement strategies are studied in this report. The first measurement assumes some knowledge of the accelerator optics model. The second measurement would be directly using BPM data, but some extra BPMs should be installed. The first is called closed orbit measurement (COM) and the second local orbit measurement (LOM).

2 COM feasibility analysis

The kick given to the beam is measured as a closed orbit difference at the machine BPMs. To study the stripline homogeneity, the beam needs to pass through different vertical positions at the stripline when it is powered.

Up to three situations are considered. y_1 is the orbit obtained powering the stripline to the nominal value. y_2 is the orbit powering the stripline to the nominal value plus the necessary correctors to make the beam go through the desired position at the stripline. y_3 is the orbit without powering the stripline but with the necessary correctors to make the beam go through the desired position at the stripline when it was powered.

The kick given by the stripline will be characterized by $\delta y = y_2 - y_3$.

2.1 Compatibility with physical acceptance

The CLIC stripline could be alocated in any of the ALBA straight sections. The straight sections are named SSS (for the short one, it is 2m long), MSS (the medium one, it is 4m long) and LSS (the long one, it is 8m long). In table 2 their lengths and minimum beta values (at their the center) are reported.

	SSS	LSS	MSS
Length	2 m	8 m	4 m
$\beta_{y,min}$	5.2 m	6.8 m	1.2 m
$\beta_{x,min}$	9.2 m	11.3 m	2.1 m

Table 2: ALBA Straight section parameters.

For each case, the possible orbits during the measurement are compared with the acceptance of the machine. For an appropriate comparison, all orbits and apertures have been projected to the injection point according to their model beta functions.

Figure 1 and 2 show the maximum orbits for the two extreme cases when the beam goes through -1 mm and +1 mm at the stripline center position.

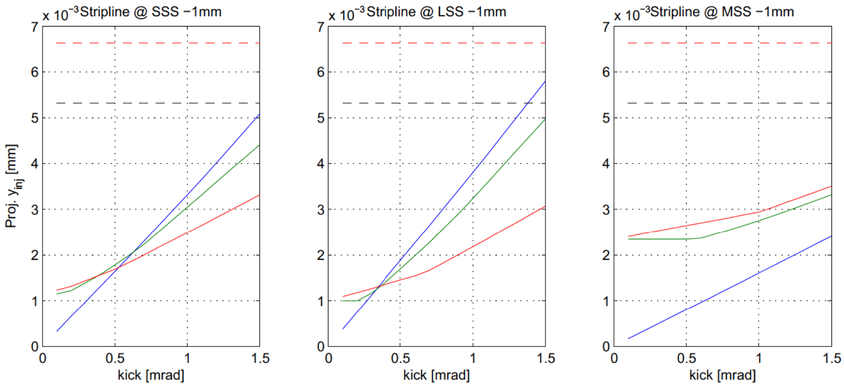

Figure 1: Projected maximum orbit distortion at the injection point as a function of the CLIC stripline kick. The beam position at the middle of the stripline is -1 mm. The blue line represents the effect of the stipline itself. The green line also includes the effect of the correctors to center the beam at the right position at the stripline. The red line has the same corrector setting but with the stripline OFF. The dashed lines represent the projections of the vertical acceptance limitation at the injection point. The black dashed line represents the dipole absorbers. The red dashed line represents the IVU undulators.

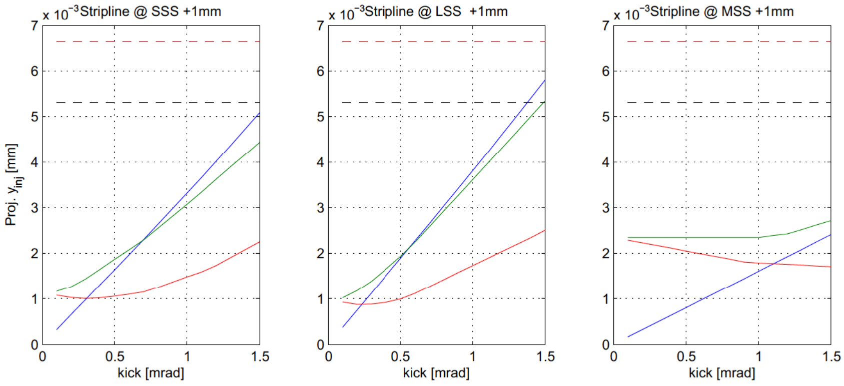

Figure 2: Projected maximum orbit distortion at the injection point as a function of the CLIC stripline kick. The beam position at the middle of the stripline is +1 mm. The blue line represents the effect of the stipline by itself. The green line also includes the effect of the correctors to center the beam at the right position at the stripline. The red line has the same corrector setting but with the stripline OFF. The dashed lines represent the projections of the vertical acceptance limitation at the injection point. The black dashed line represents the dipole absorbers. The red dashed line represents the IVU undulators.

The previous plots show that any of the straight sections can be used to measure the stripline. However, placing it at the LSS limits the maximum kick available since in this case, the y_1 and y_2 orbits may exceed the physical aperture. Regarding kick limitations, the MSS is the safest option as the beta functions are much smaller than in the other sections.

2.2 BPMs response under perturbed lattices

With the aim to evaluate how precise would be using the BPMs to measure stripline kick in the real machine, some randomly perturbed lattices are used. Each lattice is perturbed with a random distribution of misalignments, rotations and quadrupole and dipole value errors. Table 3 shows the parameters of the random Gaussian error distribution used.

hor. misalignment	σ_x	100 μm
vert. misalignment	σ_y	150 μm
rotation	σ_ϕ	150 μrad
dipole error	σ_b	0.01 %
quadrupole error	σ_k	0.01 %

Table 3: Sigma values for the Gaussian error distribution used to generate the perturbed lattices.

This values are chosen to generate lattices with coupling levels around 0.5%, which is our measured value. For each lattice, the closed orbit and the beta beating are corrected. The orbit is corrected down to the $1\mu m$ level and the beta beating down to 1% level. The optics correction is done using LOCO as with the real machine. For each possible location of the stripline, 20 different lattices where considered. Hence for the $k-th$ lattice the response of the $j-th$ BPM is a function $\delta y_{j,k}(y_{str},\alpha)$ of the beam position at the stripline y_{str} and its kick α. For each BPM the standard deviation $\sigma_j(y_{str},\alpha)$ and the mean $\delta\hat{y}_j(y_{str},\alpha)$ are:

$$\begin{aligned} \sigma_j(y_{str},\alpha) &= std[\delta y_{j,k}(y_{str},\alpha),k]; \\ \delta\hat{y}_j(y_{str},\alpha) &= mean[\delta y_{j,k}(y_{str},\alpha),k]; \end{aligned} \tag{1}$$

The absolute $AU_j(y_{str},\alpha)$ and relative uncertainty $RU_j(y_{str},\alpha)$ are then given by:

$$\begin{aligned} AU_j(y_{str},\alpha) &= \frac{\sigma_j(y_{str},\alpha)}{\delta\hat{y}_j(y_{str},\alpha)} \\ RU_j(y_{str},\alpha) &= \frac{std[\delta y_{j,k}(y_{str},\alpha)-\delta y_{j,k}(0,\alpha)]}{\delta\hat{y}_j(y_{str},\alpha)} \end{aligned} \tag{2}$$

The relative uncertainty is refereed to the kick at the center of the stripline $y_{str}=0$. The results for the simulated relative uncertainty are shown in figures 3, 4 and 5.

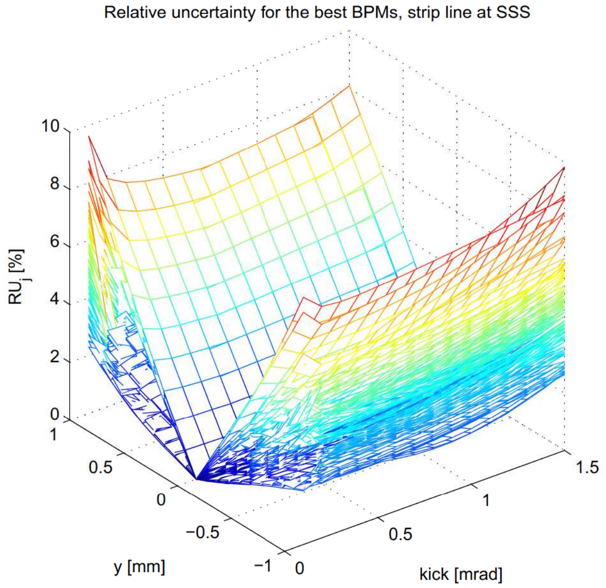

Figure 3: Relative uncertainty of the stripline kick measure when it is located at the short straight section. Every mesh corresponds to one BPM response. The result at the center of the stripline is taken as the reference value for the relative uncertainty. No BPM is better than 2% in the entire ±1 mm range.

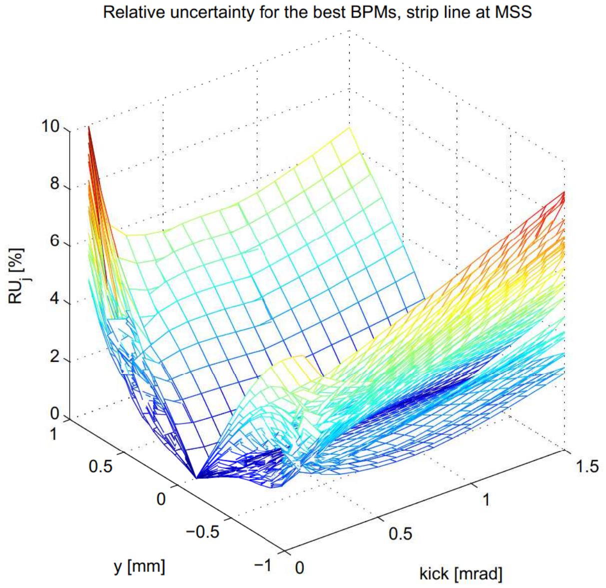

Figure 4: Relative uncertainty of the stripline kick measure when it is located at the medium straight section. Every mesh corresponds to one BPM response. The result at the center of the stripline is taken as the reference value for the relative uncertainty. No BPM is better than 2% in the entire ±1 mm range.

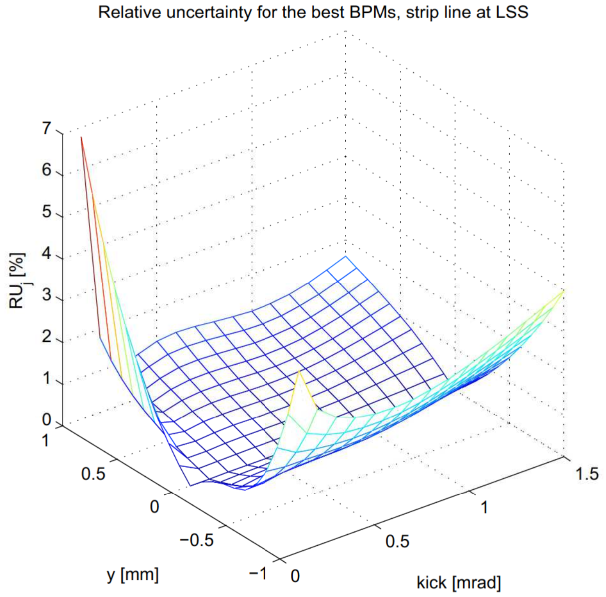

Figure 5: Relative uncertainty of the stripline kick measure when it is located at the long straight section. Every mesh corresponds to one BPM response. The result at the center of the stripline is taken as the reference value for the relative uncertainty. No BPM is better than 2% in the entire ±1 mm range.

2.3 Conclusion

The needed uncertainty for the CLIC's stripline homogeneity measurement is 10^{-4}, in the measurement range of $\pm 1mm$. At ALBA, with the COM method, the minimum value that could probably be achieved is around 10^{-2}. Hence, even averaging for the 104 BPMs (not really improving by a factor $1/\sqrt(104)$ since not all BPMs have the same uncertainty) the measure could not be performed at the required uncertainty.

3 LOM feasibility analysis

The large uncertainty level reached by COM is due to the fact that the optics, i.e. the real beta functions, is known at the level of 1%. To go beyond this level of uncertainty, other approaches could be considered. For example, installing two extra BPMs attached to the stripline vacuum chamber. In such case, the stripline would be surrounded by four BPMs without any other magnet. Hence, the kick to the beam could be measured with a much smaller uncertainty. For this approach to give the desired uncertainty in the measures, the distance of the new BPMs to the existing ones should be large enough. Hence only MSS and LSS sections can be used.

3.1 Measurement description

The measurement of the stripline kick α will be taken as a function of the 4 BPMs readings: y_1, y_2, y_3 and y_4. The BPM readings are named with index going from left to right, the stripline is located between BPMs 2 and 3 as shown in figure 6:

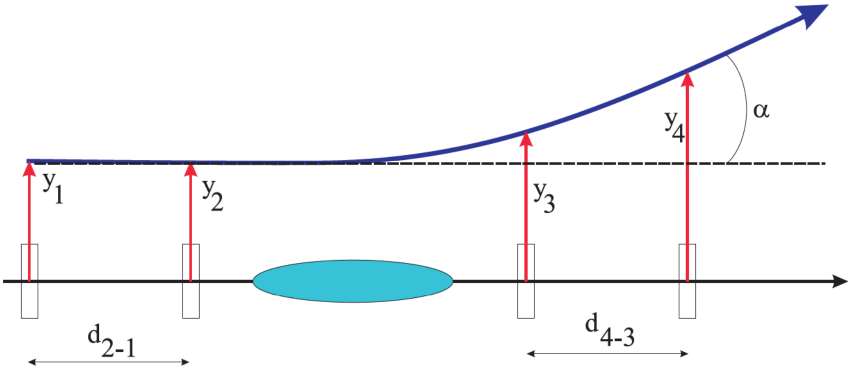

Figure 6: Measurement setup. The stripline is represented by a blue ellipse. The BPMs are represented by rectangles. The beam closed orbit is represented by a blue line. The reference line is represented by a black line passing through the centers of the BPMs.

The measurement is given by:

$$\alpha = \frac{y_4 - y_3}{d_{4-3}} - \frac{y_2 - y_1}{d_{2-1}}, \tag{3}$$

where d_{2-1} is the distance from BPM 1 to BPM 2 and equivalently d_{4-3} is the distance from BPM 3 to BPM 4. The paraxial approximation is taken. It is a correct approximation since the error associated to this approximation is $O(\alpha^3) \sim 10^{-9}$ mrad. This affects the relative uncertainty at the level of 10^{-6} which is negligible.

The propagated uncertainty associated to this measurement $\Delta\alpha$ is given by:

$$\Delta\alpha^2 = \frac{2d_{4-3}^2\Delta y^2 + (y_4 - y_3)^2\Delta d^2}{d_{4-3}^4} + \frac{2d_{2-1}^2\Delta y^2 + (y_2 - y_1)^2\Delta d^2}{d_{2-1}^4}, \tag{4}$$

where Δd is the uncertainty associated to the distance between BPMs and Δy is the uncertainty associated the BPM reading. We will assume the typical BPM resolution as uncertainty, $\Delta y = 1\mu$m and the alignment precision uncertainty as $\Delta d = 100\mu$.

This uncertainty can be divided in a systematic and a random contribution:

$$\begin{aligned} \Delta\alpha_{rand}^2 &= 2\left[\frac{1}{d_{4-3}^2} + \frac{1}{d_{2-1}^2}\right]\Delta y^2, \\ \Delta\alpha_{syst}^2 &= \left[\frac{(y_4 - y_3)^2}{d_{4-3}^4} + \frac{(y_2 - y_1)^2}{d_{2-1}^4}\right]\Delta d^2, \end{aligned} \tag{5}$$

The distance between BPMs is around 1 m for the MSS and 3 m for the LSS. The reading difference of the first pair is zero and the second pair around 1.5 mm and the measured kick $\alpha = 1.5$ mrad. With such assumptions, the systematic component of the uncertainty is 10^{-4}. This uncertainty component is irrelevant for the homogeneity measurement. Hence, the relative uncertainty would be:

$$\begin{aligned} RU_{MSS} &= \frac{\Delta\alpha_{rand}}{\alpha} = 1.3 \times 10^{-3} \\ RU_{LSS} &= \frac{\Delta\alpha_{rand}}{\alpha} = 0.4 \times 10^{-3}, \end{aligned} \tag{6}$$

Repeating this measurement n times decreases the uncertainty Δy a factor $\sqrt{n}$, hence for the measurement to reach the target precision, it should be done around 200 times for the MSS and 20 for the LSS. Since the data rate of the BPMs is $10Hz$, the measurement with the desired uncertainty would be performed in three minutes at the MSS and in two seconds at the LSS. The homogeneity measurements would imply several of those measurements. To avoid any effect from the orbit drift with time, the LSS would be slightly more convenient.

The value of α may not be zero when the stripline is off. This is due to the offsets of the BPMs or to any other magnetic or electric kick in between the BPMs. This offset value should be subtracted from the measure. This is a correct result since in paraxial approximation the angles add linearly.

4 Conclusions and proposed tasks before installation of the CLIC stripline

A priori, LOM seems to be a better candidate to reach the requirements of the CLIC stripline homogeneity measurement. However it includes manufacturing two extra BPMs.

Both approaches (LOM and COM) can be tested in situ before the installation. The SSS in sector 2, where the ALBA tune excitation stripline is installed, is equiped with 4 BPMs. The set up would not be as precise as required for the CLIC's stripline since the distance between the BPMs is shorter (and actually the CLIC's stripline would not fit in this SSS). Also in between the BPM pairs there is a sextupole and a corrector magnet included in the sextupole. Despite this set up would not allow for an absolute calibration, it would be a definitive test for the feasibility of the measurement at the required precision.