A SIMPLIFIED MODEL OF THE INTERNATIONAL LINEAR COLLIDER FINAL FOCUS SYSTEM

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Abstract

In this paper, we present a simplified vibration model of the SID detector, where the QD0 doublet is captured inside the detector and the QF1 magnet is inside the machine tunnel. Ground Motions spectra measured at the SLD detector hall at SLAC have been used together with a spectrum of the technical noise on the detector. The model predicts that the maximum level of rms vibration seen by QDO is below the capture range of the IP feedback system available in the ILC. With the addition of an active stabilization system on QD0, it is also possible to achieve the stability requirements of CLIC. These results can have important implications for CLIC.

INTRODUCTION

Ground motion and mechanical vibrations are one of the main sources of Luminosity Loss at the Final Focus System (FFS) of the future Linear Colliders, where the beams are nanometric and are required to be stable better than fractions of their size. Reliable vibration models are therefore needed during the design process to establish the real effectivness of the supporting scheme adopted, toward the protection of the FFS from the external vibration sources. Where the beam structure allows it, as for ILC, intra-trains Luminosity Feedback schemes are possible, losening the maximum vibration budget up to few hundreds of nanometers. Where this is not possible, as for CLIC [1], a combination of a carefull design of the support with active stabilization system is required. Further complications arise from the optics and beam dynamic requirements, which place the final doublet very close to the IP (~4m), captured in the innermost part of the forward region of the detector, and from the push-pull operation mode where two detectors need to perform fast (few days) swap on the IP after each data runs (~1 month). The SiD detector at the ILC has developed a support scheme for the FFS which allows the reduction of the vibrations and a “fast” push-pull. If coupled with an active stabilization system, this design can be applied effectivety also to CLIC, where the IP Feedback system is not efficient. In such scheme the QD0 doublet is supported from the Iron of the Door and therefore moving with the detector, while the QF1 magnet is stationary in the machine tunnel (Fig.1). In order to evaluate the level of vibration seen by the QD0 and the QF1 we developed a linear vibration model with lump-mass and springs, which represent the fundamental parts of the detector. The variables are the vertical degrees of freedom and the input are the ground vibrations and the detector noise generated by the technical systems on the detector. A closed loop analysis has been implemented to study the effects of the active stabilization.

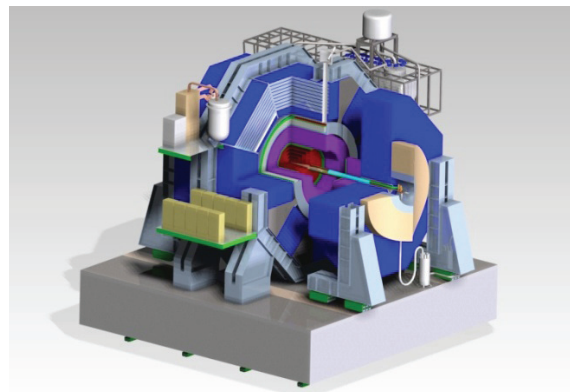

Figure 1 Artist view of the ILC SiD detector.

DESCRIPTION OF THE MODEL

A simplified model of the SiD detector is shown in Fig.2. The last four quadrupoles (QD0 and QF1 on each side) are represented by masses m_0 and m_1. The detector structure is represented by m_s and m_p, both having a vertical and tilt degree of freedom. The system includes also a model of the ground, represented by k_g [2].

Table 1: Numerical Values of the Parameters

Variable	Value	Units
m_1	1,00E+03	[Kg]
m_0	1,00E+03	[Kg]
m_s	8,00E+06	[Kg]
m_p	3,49E+06	[Kg]
I_s	1,34E+08	[Kg m^2]
I_p	1,21E+08	[Kg m^2]
k_q	1,00E+09	[N/m]
k_g	1,00E+11	[N/m]
k_p	3,48E+10	[N/m]
k_s	3,16E+10	[N/m]
c_q	1,41E+05	[Ns/m]
c_g	5E+06	[Ns/m]
c_p	1,15E+07	[Ns/m]
c_s	6,28E+04	[Ns/m]
L_0	7	[m]
L_1	6	[m]

The magnitudes of the transfer functions from the ground to the quadrupoles are shown in the Fig.3. We see on the figure that the quality factor of the four peaks below 30 Hz is about 10, i.e. that the modal damping is around 5 %

ISBN 978-3-95450-139-7

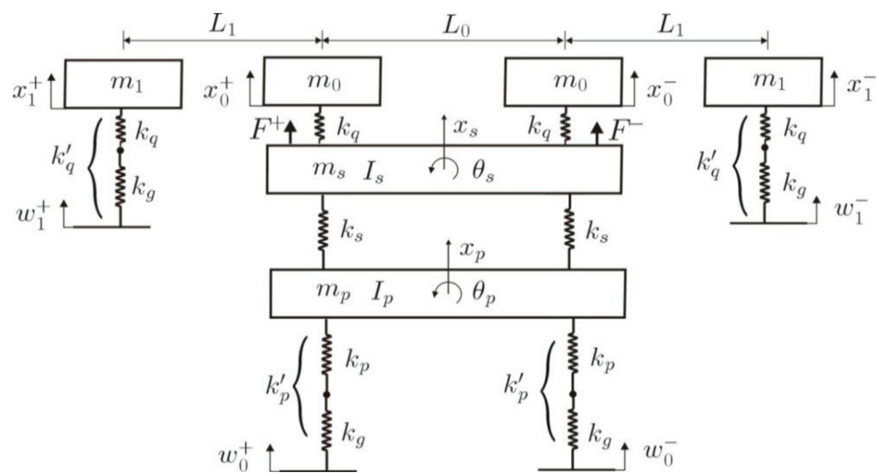

Figure 2: Lumped mass model of the ILC final focus with the SID configuration.

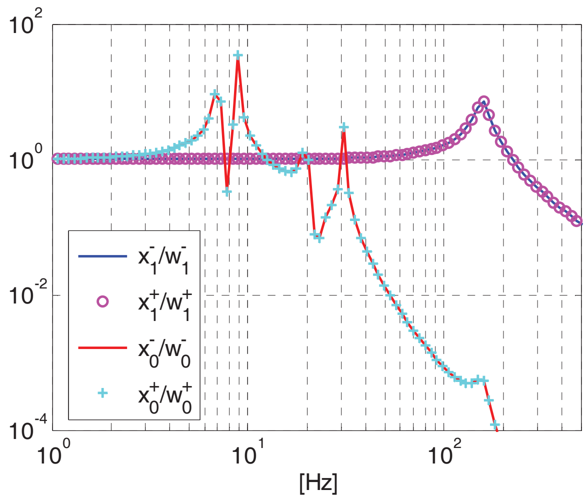

Figure 3: Transfer functions between the ground and the quadrupoles.

In the model described in Fig. 2, the beam-beam offset at the interaction point y, is given by:

$$y = C_0(x_0^+ - x_0^-) + C_1(x_1^+ - x_1^-)$$

where $C_0 = 1.27$ and $C_1 = -0.466$.

INFLUENCE OF THE GROUND STIFFNESS

The ground stiffness k_g is an important parameter. The lower the ground stiffness value is, the more relevant the role of the QF1 doublet is in the beam-beam jitter at the interaction point. When the k_g parmeter value is low (e.g $k_g = 3e8N/m$), the first resonances of QD0 are shifted to the left. The cross-over frequency decreases to approximately 1Hz, which leads to substantial isolation at 5 Hz. In that scenario, the limiting factor for the luminosity is the stability of the QF1. Alternatively when the ground stiffness is high (e.g $k_g = 1e11N/m$), the cross-over frequency of QD0 reaches 12 Hz so that the isolation at 5Hz disappears. The beam-beam jitter is mainly determined by the QD0 doublet stability. Figs.4 and 5 show a comparison of both scenarios.

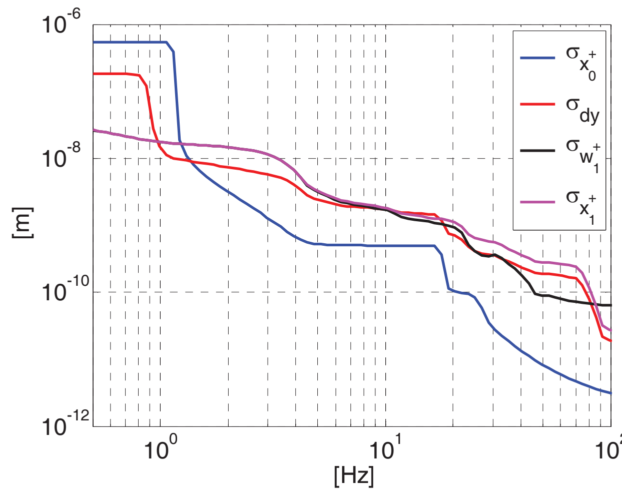

Figure 4: Integrated RMS for $k_g = 3e8N/m$.

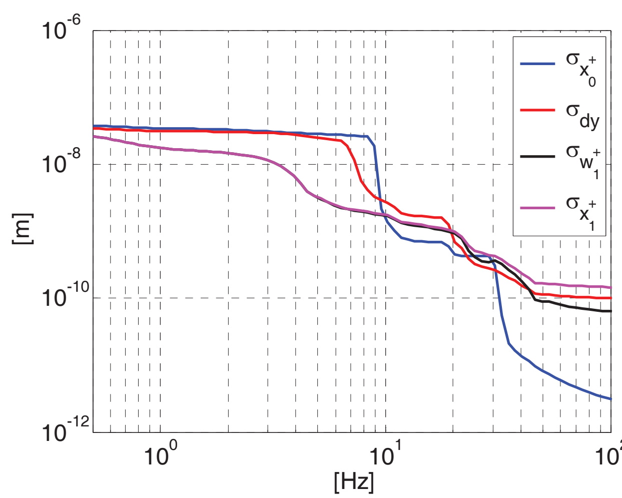

Figure 5: Integrated RMS for $k_g = 1e11N/m$.

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EFFECT OF THE TECHNICAL NOISE

The technical noise includes various types of incoherent environmental disturbances (electronics, ventilation, cooling…). In this study, it is represented by random forces. Two models have been considered. In the first one, used to model the disturbances applied on the detector mass m_s ($F^+$and F^- in Fig. 2), the PSD of the force is decreasing at low frequency as

$$\Phi_{F^+} = \Phi_{F^-} = \frac{N_0 f^2}{1 + (^f/_{f_0})^4}$$

where N_0 and f_0 are parameters. It is assumed that F^+ and F^- are not correlated, i.e. that their cross PSD is equal to zero. We take $N_0 = 10^{-2}\ (N^2/Hz^3)$ and $f_0 = 21\ (Hz)$. In this case, the RMS value is $\sigma_{F^+} = \sigma_{F^-} = 10\ (N)$. The second model is used to model the disturbances applied directly on the quadrupoles. The PSD of the typical white noise describing vibrations coming from water cooling, ventilation and acoustic noise is given by

$$\Phi_{F_2} = \frac{N_{02}}{1 + (^f/_{f_{02}})^2}$$

where $N_{02} = 0.75\ (\frac{N^2}{Hz})$ and $f_{02} = 35\ (Hz)$. In order to evaluate the acceptable level of technical noise, we have calculated the beam-beam offset for various amplitudes of the disturbing force, ranging from $N_{02} = 0.75\ (\frac{N^2}{Hz})$ to $N_{02} = 2.5\ (\frac{N^2}{Hz})$ (i.e. a variation of the RMS value from $\sigma_{F2,min} \approx 0.02N$ to $\sigma_{F2,max} \approx 11N$). For the ILC, it has been estimated that σ_y should not exceed 200nm at 5 Hz. For this reason we will study the effect of the technical noise on σ_y at 5Hz. Figure 6 shows a quadratic evolution of σ_y as a function of the amplitude of the technical noise.

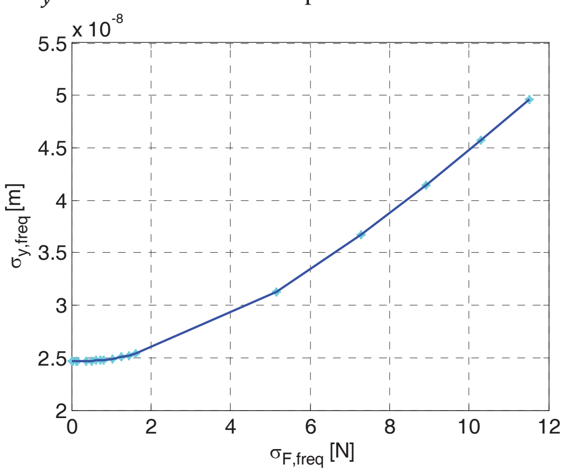

Figure 6: Evolution of the beam-beam offset at the interaction point $\boldsymbol{\sigma_y}$ at 5 Hz as a function of the amplitude of the technical noise on QD0

PASSIVE ISOLATION

In order to investigate the effect of the isolation of the QF1s on $\Phi_{x_1}$and Φ_y, we consider a small value of F_2, i.e.$\sigma_{F2,min} \approx 0.02N$. In the previous sections, it has been shown that, provided that, if F_2 is not too large, the dominant contribution to Φ_y comes from the QF1 rather than from the QD0. However, as the resonance frequency f_{QF1} of the QF1 decreases, the passive isolation of the QF1 increases, and both the QD0 and the QF1 contribute to Φ_y by the same amount. For $f_{QF1} \approx 2Hz$, the contribution of the QF1 to the Φ_y becomes smaller than the contribution of the QD0. On the other hand, when $f_{QF1} \approx 150Hz$, the QF1 are less isolated than the QD0, and their contribution to the beam-beam offset becomes larger. The results are shown in Figs. 7 and 8, respectively for $f_{QF1} \approx 2Hz$ and $f_{QF1} \approx 150Hz$.

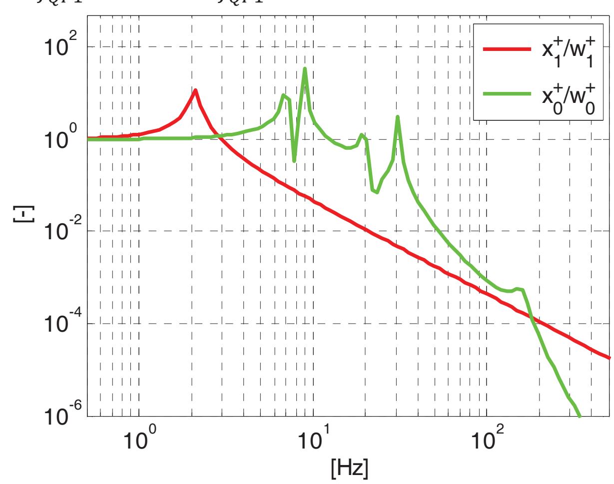

Figure 7: Transfer functions of the quadrupoles for $f_{QF1} \approx 2Hz$ with $\sigma_{F2} \approx 0.02N$.

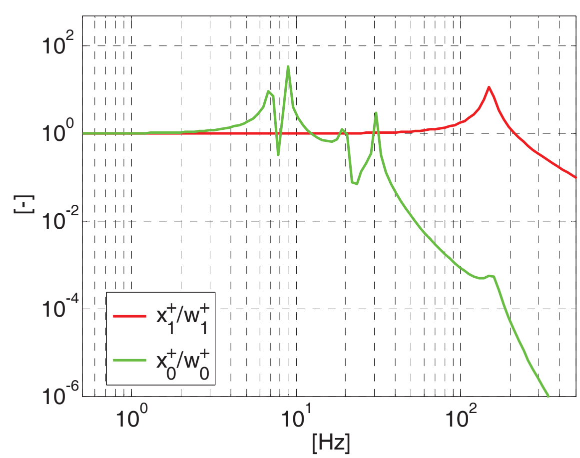

Figure 8: Transfer functions of the quadrupoles for $f_{QF1} \approx 150Hz$ with $\sigma_{F2} \approx 0.02N$.

Figure 9 shows the RMS value of the beam-beam offset integrated down to 5 Hz, RMS $\sigma_{y,5Hz}$, as a function of the resonance frequency of QF1 on its support stiffness. For $f_{QF1} \geq 40Hz$, $\sigma_{y,5Hz}$ is essentially independent of f_{QF1}. However, for$f_{QF1} \leq 10Hz$, $\sigma_{y,5Hz}$ is connected to f_{QF1}.

ISBN 978-3-95450-139-7

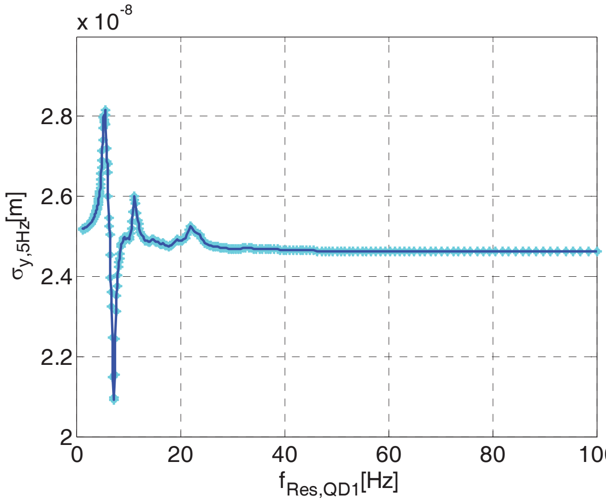

Figure 9: $\sigma_{y,5Hz}$ as a function of f_{QF1}.

ACTIVE ISOLATION

In this section, we study the capability of an active isolation of the quadrupoles on the beam-beam offset. The strategy chosen for the active isolation is based on a inertial sensors. The resonance of the sensor is 2 Hz, and the damping is 0.3. In order to achieve the best compromise between isolation from ground and robustness to external disturbances we start with an intermediate configuration where the resonance frequencies of the quadrupoles have been decreased at 15 Hz. Figure 10 shows the transfer functions between the ground and the quadrupoles when the feedback control

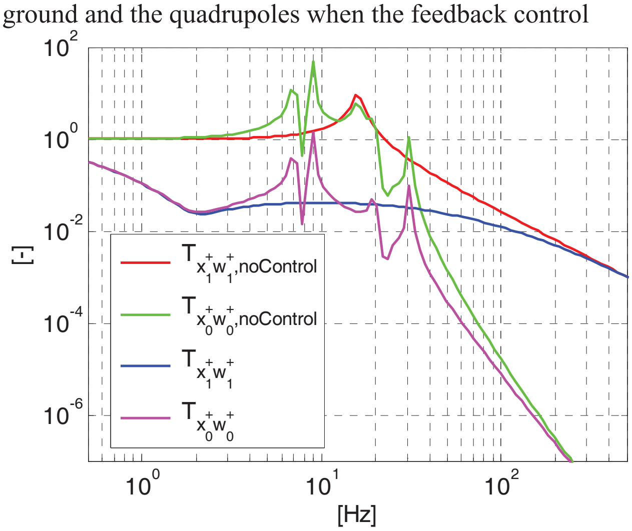

Figure 10: Transfer functions between the ground and the quadrupoles, with and without control.

is turned off and on. The same controller is applied to the four feedback loops: a lag at low frequency and a lead at high frequency. Both filters are used to increase the phase margins. An advantage of this active isolation strategy is that it increases the isolation at low frequency, and also improves the robustness to the technical noise. Figure 11 shows the response when the controller is turned on and off. The stability level of QD0 is well below the requirements of the ILC but not good enough for those of CLIC. However, the active control strategy enables the QF1 to reach the stability requirements of CLIC.

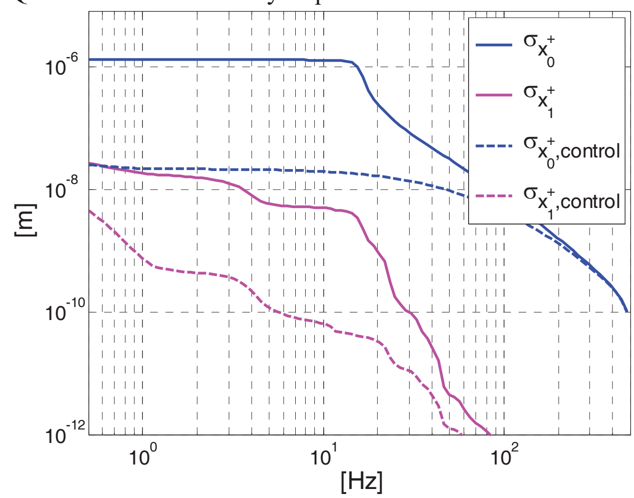

Figure 11: Integrated RMS when the control is turned on and off.

CONCLUSION

We developed a simplified vibration model of the SID detector, where the QD0 doublet is captured inside the detector and the QF1 magnet is inside the machine tunnel. Ground motion spectra measured at the SLD detector hall at SLAC have been used together with a conservative spectrum of the technical noise on the detector. The model predicts that the maximum level of rms vibration seen by QDO is well below the capture range of the IP feedback system available in the ILC. However this level of vibration is still too high for CLIC. With the addition of an active stabilization system, it is possible for QF1 to reach the stability requirements of CLIC. These results need to be reinforced by experimental measurements of the technical noise, which are planned in the near future.

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ISBN 978-3-95450-139-7