ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPL107

INFLUENCE OF VIBRATORY EFFECTS ON THE BEAM PARAMETERS OF SUPERKEKB

L. Brunetti*, G. Balik, S. Chandran, A. Dominjon, S. Grabon, E. Montbarbon, F. Poirier,
Université Savoie Mont Blanc, CNRS, LAPP - IN2P3, 74000 Annecy, France,
M. Masuzawa, S. Uehara, KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
P. Bambade, IJCLab, 91400 Orsay, France

Abstract

SuperKEKB is an asymmetric lepton collider with a circumference of 3 016 meters, which collides 7 GeV electrons (High Energy Ring (HER)) with 4 GeV positrons (Low Energy Ring (LER)). To optimize the luminosity, all the undesirable effects on beam parameters must be analyzed in detail, especially close to the interaction point where the Belle-II detector is operating. The presented study investigates the influence of mechanical vibrations on the luminosity. For this purpose, four seismic sensors have been installed and collect data 24 hours a day, two on the ground and another two located on the supports of the two cantilevered cryostats, inside which the last focusing magnets on both sides of the interaction point (the most critical for vibration) are mounted. The luminosity is measured thanks to the LumiBelle2 fast luminosity monitor, which is based on diamond detectors installed in both beam lines. Vibration-induced disturbances in the luminosity frequency spectrum are investigated for several types of perturbations, in particular the ones resulting from ground motion amplified by the dynamical behavior of the cryostat, as well as from external vibrations sources.

INTRODUCTION

The innovative approach of the presented diagnostic is to process real time vibration measurements close to the Interaction Point (IP) in order to evaluate the vibration levels with respect to time and study the correlation between luminosity and vibration. If the disturbances do not have any effect on the beam and if the two beams are perfectly steady, luminosity should remain constant, and should then have a flat response in frequency domain. However the analysis of the luminosity measurements shows that the Power Spectral Density (PSD) has many peaks. The main target of this study is to identify which peaks are due to vibration.

INSTRUMENTATION

Vibration measurements

Four Guralp T6 tri-axial geophones (CMG-6T) [1] are installed on site since 2019. One is placed on the ground while the other is on the cryostat support. This was done on each side of the BELLE-II detector [6]. These very sensitive electromagnetic sensors perform velocity measurements in 3 directions (one vertical and two horizontal) and have a flat frequency response from 0,03 Hz to 100 Hz. The actual operating range is however closer to [0,3-100] Hz due to measurements conditions constraints. Only the two main relevant directions are selected: the vertical and the horizontal axis transverse to the beam [6]. The measurements are now processing twenty-four hours a day with an acquisition of ten minutes per hour (to limit the amount of data). [2]

Luminosity measurements

A fast luminosity monitor, called LumiBelle2, measures the rate of the radiative Bhabha process at zero degree scattering angle. It is based on sCVD diamond detectors and is placed in both electron and positron rings (Fig.1). It was developed and successfully operated during the Phase-2 commissioning of SuperKEKB. The main purpose of this system (4 channels) is to provide integrated luminosity signals at 1 kHz with a relative precision better than 1% [5] as input to the dithering feedback system needed to maintain an optimum horizontal overlap between the two colliding beams at the IP.

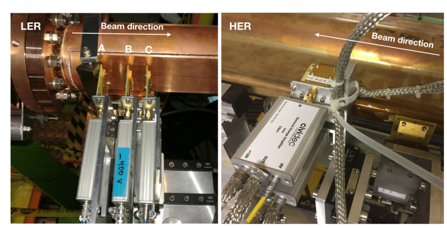

Figure 1: Experimental layout in both ring (left: LER, right: HER) of the luminosity measurements

DIAGNOSTICS

Diagnostics based on vibration measurements are common in a number of field, e.g. for preventive maintenance, mechanics optimization, site analyses, earthquake detection... In this specific study, the combined analysis of synchronized vibration and luminosity measurements provides increased possibilities, especially to evaluate effects of vibration on beam-beam parameters directly from the experimental data. The spectrograms in Fig.2 show several examples of vibration measurements over time (comparison of day-night (1a/1b), earthquake detection (2),...) provided together with the corresponding luminosity measurements to identify external sources (3) or assess the behavior of mechanical systems (4).

* brunetti@lapp.in2p3.fr

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPL107

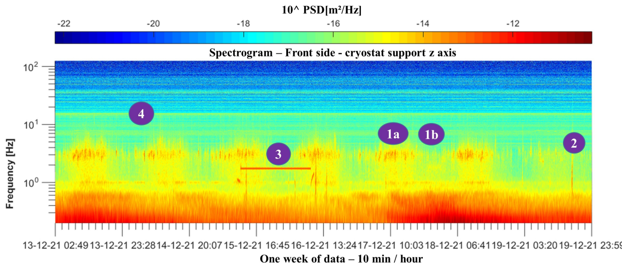

Figure 2: Spectrogram of one week data from a sensor placed at one side of the Belle-II detector

Comparison day-night (1)

Fig.3 shows both day-night vertical and transversal PSD, obtained on the ground, on both sides of the Belle-II detector. The low-frequency part of the spectra (below few Hz) is characterised by seismic motions such as the tidal motion and micro-seismic peaks with frequencies of the order of [0.1-0.25] Hz. For frequencies above few Hz, spectra are dominated by technical noise induced by electric motors or systems installed in the accelerator tunnel, and by cultural noise from road traffic nearby, railways and industry. This comparative graph reveals the significant difference in vibration levels all over the day, with the presence of higher amplitude peaks in both directions.

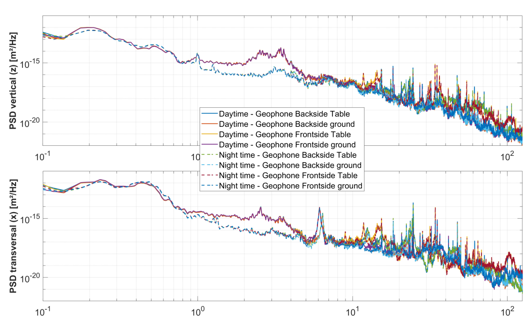

Figure 3: Day-night vertical and horizontal PSD on both sides of Belle II detector.

Earthquake detection (2)

The geophones, used here, perform vibrations measurements but are also effective to detect all earthquakes which could lead to a decrease of the beam energy prior to the stopping of the operation.

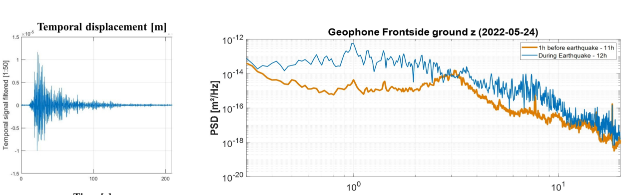

Figure 4: Temporal measurement and PSD displacement during an earthquake.

It should be noted that such earthquakes with a high level over a wide bandwidth as observed on the shown PSD could be used as excitation to better estimate the behavior of structures such as the BELLE-II detector [4].

Identification of sources

A more specific study could be done by combining vibration and luminosity analysis. For instance, an initially unknown disturbance source, that was regularly observed to cause luminosity disturbances in the low-frequency range [1-2]Hz as shown in Fig.5 (left figure - luminosity PSD), was confirmed by ground motion measurements in Fig.5 (right figure - Vibrations PSD). The source has been identified as an experiment from a centrifugal force generator at a civil work institute located near the KEK site.

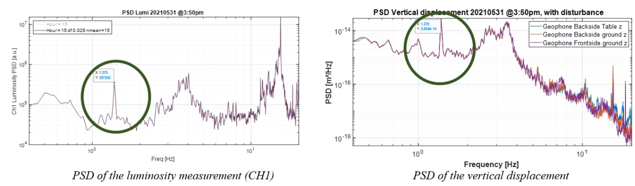

Figure 5: PSD of the luminosity (left) and vibrations (right) with a peak at the same frequency due to the external disturbance.

Influence of the last focusing magnets

It is known that the cantilever cryostat inside the Belle-II detector oscillates and the frequencies of the bending modes have been identified [8].

The most critical cryostat is the QCR-R which has a first bending mode around 15 Hz. Furthermore, due to the specificity of SuperKEKB, HER and LER magnets are not at the same distance from the IP in the beam direction (z axis). Given this main bending mode, differential oscillation amplitudes are then induced between the last focusing magnets embedded in this cryostat (for LER: QC1RP, QC2RP and for HER: QC1RE, QC2RE), as shown in Fig.6, result in various effects on the beams.

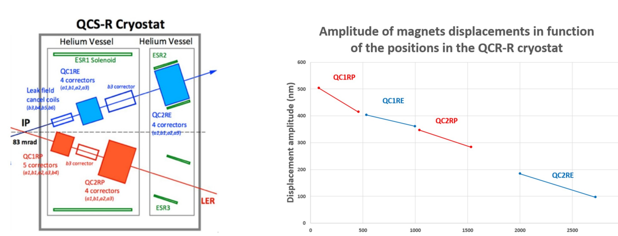

Figure 6: Positions of focusing magnets in the QCR-R cryostat (left) - Maximum amplitudes of the deformation (right)

The study consists in determining if the differential movements of the magnets significantly influence the luminosity. On Fig.7, it is highlighted that the main peaks observed in vibrations, in particular the first mode of the cryostat, also correspond to peaks of perturbations in the luminosity [6].

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPL107

It is then demonstrated that the cryostat oscillation has a significant negative effect on the stability of the experiment performance.

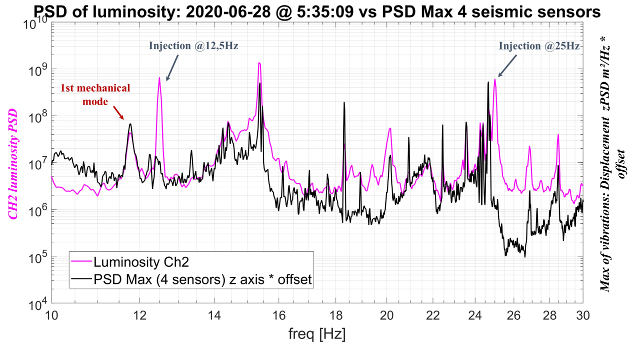

Figure 7: Comparison between the PSD of luminosity and the PSD max (z-axis) of the four sensors located around the BELLE II detector in [10-30] Hz bandwidth.

QUANTIFICATION

The previous study demonstrates the frequency matching between the vibrations due to the first mode of the QCR-R cryostat and the dynamics of the luminosity. The objective is now to verify that the measured amplitude change in luminosity matches the estimation in the optics simulation as a function of the measured movement of the cryostat. Indeed, by considering the cryostat bending amplitude as the maximum of the misalignment of these focusing magnets [8], the theoretical beam offset induced at the IP could be obtained using the accelerator physics simulation program named Strategic Accelerator Design (SAD) [3].
This study is in progress and with the estimate of the differential vertical offset between the two beams at the IP, the variation in luminosity could be evaluated along the vertical direction as:

$$L(y) = L_0.exp(-\frac{y^2}{2.(\sqrt{2}.\sigma_y)^2}) \qquad (1)$$

where y is the residual vertical offset at IP, L_0 is the nominal luminosity without dithering and beam-beam offset and σ_y the vertical beam size.
In this prospect, it can already be observed that the amplitude of the signal disturbed by the bending mode is about 2 to 20% of the average luminosity, depending on the luminometer channel, the beam type (HER or LER), the beam size, the energy of the two beams and the alignment. The blue curve in Fig.8 represents the raw data, the black one the average and the red one the filtered signal over the bandwidth that corresponds to the first bending mode of the cryostat [13,5-16]Hz.
Note that the ratio will likely increase with the decreasing of the beam size and increasing beam currents.

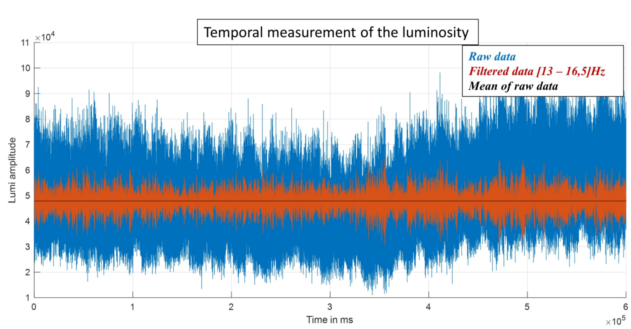

Figure 8: Example of time measurement of a luminometer

CONCLUSION

This study shows the potential of expertise that can result from a vibratory analysis coupled with a dynamic luminosity analysis. The work in progress consists in verifying that the results obtained in simulations correspond well with the measurements on site. Given the similarities between parameters of SuperKEKB and FCC, it should be noted that all these studies are conducted jointly with the Future CERN Collider (FCC) collaboration.

ACKNOWLEDGEMENTS

This program is supported by the "Toshiko Yuasa" France Japan article Physics Laboratory (TYL-FJPPL). [9]

REFERENCES

[1] *Guralp*, `https://www.guralp.com`

[2] SuperKEKB vibration weekly reports, `https://lappweb.in2p3.fr/SuperKEKB/`.

[3] *SAD*, `https://acc-physics.kek.jp/SAD/`

[4] H. Yamaoka *et al.*, “Analysis of earthquake effects on BELLE II detector and SuperKEKB accelerator”, *International Workshops on Accelerator Alignment conference*, CERN, 2022. `https://indico.cern.ch/event/1136611/`

[5] C. G. Pang *et al.*, “A fast luminosity monitor based on diamond detectors for the SuperKEKB collider”, *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 931, pp. 225–235, Jul. 2019. `doi:10.1016/j.nima.2019.03.071`

[6] M. Serluca *et al.*, “Vibration and luminosity frequency analysis of the SuperKEKB collider”, *Nuclear Inst. and Methods in Physics Research*, vol. 1025, Feb. 2022. `doi:10.1016/j.nima.2021.166123`

[7] T. Hirai *et al.*, “Real-time luminosity monitor for a b-factory experiment”, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 458, pp. 670–676, 2001. `doi:10.1016/S0168-9002(00)00766-X`

[8] H. Yamaoka *et al.*, “The Mechanical and Vibration Studies of the Final Focus Magnet-cryostat for SuperKEKB”, in *Proc. IPAC’14*, Dresden, Germany, Jun. 2014, pp. 3770–3772. `doi:10.18429/JACoW-IPAC2014-THPRI005`

[9] *FJPPL*, `https://http://fjppl.in2p3.fr/cgi-bin/twiki.source/bin/view/FJPPL/WebHome`