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Comparison of Tunneling Methods for JLC

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Abstract

Due to the very low vertical beam emittances required for future Linear Colliders to achieve high luminosities of some $10^{34}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$, these machines will be extremely sensitive to ground motion, leading to vibration of the focusing magnets. Therefore, ground motion has to be studied in detail. For JLC, two different tunneling methods are being discussed. To compare both methods regarding the coherence properties of motion of the tunnel floor, seismic measurements have to be performed in several sample tunnels, designed for purposes other than accelerator installation. The obtained data can then be used as input data for simulation algorithms to study beam dynamics under the influence of ground motion. Recent results of these investigations will be presented.

1 Introduction

To achieve high luminosities of some $10^{34}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$, all Linear Collider schemes currently under study require very low emittance beams. To avoid luminosity degradation due to beam offset at the interaction point (IP), ground motion induced jitter of the focusing elements has to be kept within tight tolerances. Allowing for a luminosity loss of 3%, the tolerable beam motion σ_y of two Gaussian beams with rms beam size σ_{beam} can be derived using

$$\begin{aligned} \mathcal{L} &= \mathcal{L}_0 \cdot 0.97 \\ &= \mathcal{L}_0 \cdot \exp\left(-2\frac{\sigma_y^2}{4\sigma_{\mathrm{beam}}^2}\right). \end{aligned} \qquad (1)$$

Assuming uncorrelated motion of the N_q quadrupoles in the main linac and a periodic FODO lattice with β-function scaling as $\beta \propto \sqrt{E}$, the rms vibration tolerance σ_q can be estimated as [1, 2]

$$\begin{aligned} \sigma_q &= 0.25 \cdot \sqrt{\frac{\sigma_{\mathrm{beam}}^2}{N_q}} \cos\frac{\mu}{2} \\ &= 0.25 \cdot \sqrt{\frac{\epsilon_{\mathrm{end}} \cdot \overline{\beta}_{\mathrm{end}}}{N_q}} \cdot \cos\frac{\mu}{2}. \end{aligned} \qquad (2)$$

Here ϵ_{end} and $\overline{\beta}_{\mathrm{end}}$ denote the geometric emittance at the end of the main linac and the average β-function of the last FODO cell, respectively. μ is the phase advance per FODO cell. In the case of JLC, the resulting vibration tolerance is about 10 nm [3]. It should be noted here that this formula holds only for the quadrupoles in the main linac, while in the final focus system the tolerances are tighter by a factor of about 5 to 10 [4, 5], but there they cannot be expressed by eq. (2).

Due to the extreme sensitivity of linear collider beam motion to ground vibrations, much effort has been spent during recent years in order to determine spectra and correlation properties of ground motion [6, 7, 8]. Since the properties of ground motion were found to be very site-depending due to different geological conditions at the various locations (see fig. 1), it turned out that a careful choice of the future linear collider site is necessary.

Since it is expected that various tunneling methods will lead to different properties of the resulting tunnel floor regarding correlation of vibrations [3], seismic measurements in various tunnels built for purposes other than accelerator installation are under consideration. The obtained results will then be used as input data for simulation codes in order to investigate the beam jitter amplitudes resulting from vibration of magnets mounted on the floor of the future accelerator tunnel.

2 Tunneling methods

Basically, two different tunneling methods are under consideration for the construction of the JLC tunnel. In the New Austrian Tunneling Method (NATM), the tunnel is excavated by blasting the surrounding rock and stabilizing it using shotcrete. Additionally, systematic rock bolting can be used to further sta-

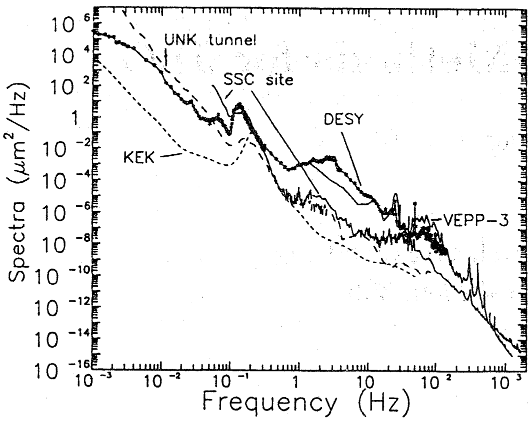

Figure 1: Comparison of ground motion power spectra measured at KEK (Tsukuba, Japan), SSC (Waxahachie, Texas, USA), VEPP-3 (Novosibirsk, Russia), UNK (Protvino, Russia) and HERA (DESY, Germany) [6]

bilize the tunnel if necessary. In the next step, the tunnel is water-proofed, and then arch lining is applied by a travelling form. Finally, the tunnel floor is built using concrete. This method results in a semicircular cross section of the tunnel.

The second method utilizes a large drilling machine to bore the tunnel and is therefore referred to as Tunneling Boring Method (TBM). Again, shotcrete is used to stabilize the tunnel against water leaks. After water-proofing, the tunnel walls are supplied with the lining consisting of concrete segments. In contrast to NATM, TBM results in a circular cross section of the tunnel, which might be less suitable for accelerator installation.

Both tunneling methods will have some effect on the solid rock mass surrounding the tunnel, since they will introduce little cracks there. These destructions are expected to be significantly larger for the NATM tunneling method due to the blasting, than for TBM, resulting in worse correlation properties of ground motion. It was experimentally confirmed that the power spectrum densities of relative motion of two points in such tunnels are significantly larger by a factor of about 5 [7]. On the other hand, careful lining may overcome these deficiencies. For example, the concrete tunnel floor for both methods may be connected to the undistorted rock using bolts of sufficient length, therefore overcoming the problem of cracks in the surface layer.

3 Measurements

To determine the correlation properties of ground motion, two identical seismometers have to be used. Taking signals $x(t), y(t)$ from both instruments simultaneously, the correlation $\gamma(\omega)$ can be calculated from the Fourier spectra as

$$\gamma(\omega) = \frac{\langle X(\omega)Y^*(\omega)\rangle}{\sqrt{\langle X(\omega)X^*(\omega)\rangle\langle Y(\omega)Y^*(\omega)\rangle}}. \quad (3)$$

Here,

$$X(\omega)Y^*(\omega) = \lim_{T\to\infty}\left[\frac{2}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} x(t)\cdot\exp(-i\omega t)\,\mathrm{d}t \int_{-\frac{T}{2}}^{\frac{T}{2}} y(t)\cdot\exp(i\omega t)\,\mathrm{d}t\right] \quad (4)$$

is the mutual power spectrum of $x(t)$ and $y(t)$, respectively. $X(\omega)X^*(\omega)$ and $Y(\omega)Y^*(\omega)$ are similarly defined. As usual the asterisk denotes complex conjugate, while the average has to be taken over different spectra. As an example, figure 2 shows coherence properties of ground motion obtained at DESY.

Denoting the ratio of correlated to uncorrelated

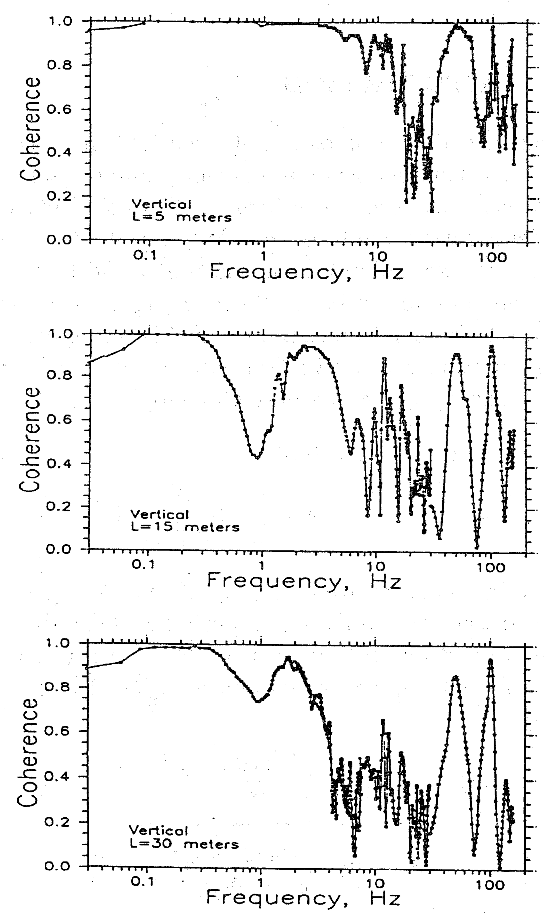

Figure 2: Coherence spectra of vertical ground motion at three different distances of 5 m, 15 m and 30 m, measured in HERA hall West [6]

ground motion power spectrum densities as β, the modulus $|\gamma(\omega)|$ of the correlation, which is usually referred to as the coherence, can be expressed as

$$|\gamma(\omega)| = \sqrt{\frac{\beta(\omega)}{1+\beta(\omega)}}. \quad (5)$$

Therefore, the coherence $|\gamma(\omega)|$ can be interpreted as a measure of the ratio of correlated to uncorrelated ground motion.

While the ground motion power spectrum $p(\omega)$ in a single point can be roughly approximated as

$$p(\omega) = \frac{B}{\omega^4}, \quad (6)$$

the power spectrum $\rho(\omega, L)$ of uncorrelated motion of two points at a distance L was experimentally found to be

$$\rho(\omega, L) = \frac{A \cdot L}{\omega^2}, \quad (7)$$

with A and B being proportionality constants.

In the time domain, the latter corresponds to a variance σ^2 of the motion of the two points after a time interval T as

$$\sigma^2 = A \cdot T \cdot L, \quad (8)$$

and is therefore referred to as the ATL rule [9].

4 Simulation of beam jitter

To investigate the effects of ground motion on beam properties in linear colliders, two complementary simulation algorithms have been developed [10]. Both codes can be adapted to any measured power spectra and correlation properties of grond motion. While one of them, based on digital filtering of white noise random signals, is very useful in determining the effect of the magnitude of the ATL constant A on the beam, the second one employs inverse Fourier transforms to get the time signals of motion of each magnet from the power spectra. This latter code is therefore appropriate to determine the effect of ground motion waves travelling at some angle θ to the linac, therefore leading to potentially very long effective wavelengths.

As an example, figure 3 shows the resulting rms beam jitter at the end of the main linac of the S-band Linear Collider SBLC being designed at DESY.

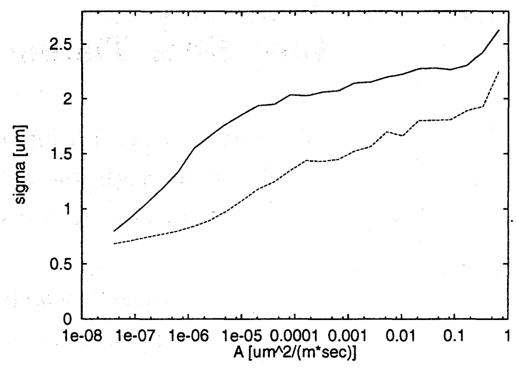

Figure 3: Resulting rms beam jitter at the end of the SBLC main linac as a function of the proportionality constant A in the ATL rule [10]. The solid line represents the rms jitter amplitude resulting from pure ground motion, while the dashed line shows the corresponding value with active stabilization of quadrupoles [11].

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