Linear collider test facility: ATF2 final focus active stabilisation pertinence

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LINEAR COLLIDER TEST FACILITY: ATF2 FINAL FOCUS ACTIVE STABILISATION PERTINENCE *

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Abstract

Beam motion at the Interaction Point (IP) of ATF2 has to be less than 10nm relative to the instrumentation used for measurements. Due to ground motion (GM), the beam can pass off-axis through the quadrupoles of the beam line and hence be deflected. It was shown in previous studies that good spatial coherence of the GM over a few meters makes the relative motion of the Final Doublets (FD) small enough for the tolerance not to be exceeded. However, since the coherence drops rapidly with distance, other quadrupoles further upstream can be expected to induce significant effects. In this paper, an evaluation taking into account all ATF2 quadrupoles is presented, using a GM generator with parameters tuned to dedicated measurements done recently along the ATF2 beam line and propagating to the IP with the optical transfer matrices. It was shown that although large IP beam motion can indeed be induced by some specific upstream quadrupoles, the combined effect of all is small because of compensations. The tolerance can thus be achieved without specially stabilising these quadrupoles.

INTRODUCTION

For the Beam Size Monitor (BSM) installed at the ATF2 IP to measure a beam size of 37nm with less than 5% error, relative beam motion should be less than 10nm [1]. Due to GM, the main source of vibration at the nm scale, the beam can pass off-axis through the quadrupoles of the beam line and hence be deflected. Because beam-based feedback is efficient only above 0.1Hz, due to the beam repetition rate of 1Hz [2], one has to take care of quadrupole motion above 0.1Hz relative to the IP.

Studies of mechanical stability concentrated on the FD, where the β-function, and thus the optical lever arm for IP beam motion, are the largest in the whole system. GM measurements on the floor showed however good coherence over the few meters separating it from the IP measurement system [3], and it was hence decided to mount both on supports rigidly fixed to the floor, to maintain this coherence as much as possible [4] [5]. Relative motion measurements performed after final installation have since validated this choice and shown that the specified tolerance is well satisfied [6].

Upstream quadrupoles were also fixed rigidly to the floor.

Corresponding β-functions are smaller than at the FD [2].

However, since coherence in the GM falls off rapidly with distance, some of them may induce significant IP beam motion, and would then require dedicated stabilisation.

In this paper, an update of the parameters of a GM generator widely used in the linear collider community [7] is first described, to fit recent GM measurements on the ATF2 floor. A calculation of the relative IP beam motion induced by the vibrations of all ATF2 quadrupoles is then presented, taking into account both the spatial coherence in the GM and the optical transfers to the IP.

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GROUND MOTION GENERATOR

A generator widely used in the LC community to simulate spatial and temporal properties of GM is described in [7], with input parameters which can be fitted to reproduce measurements done on various sites in the world.

Thanks to new measurements done on the floor of the ATF2 beam line, using CMG-40T geophones and ENDEVCO 86 accelerometers, its parameters have been updated to enable realistic ATF2 simulations.

Choice of the updated parameters

GM is composed of three types of motion that the generator can reproduce: systematic motion below 10^{-5}Hz, diffusive (ATL) motion from 10^{-5}Hz to 0.1Hz and wave-like (propagation) motion above 0.1Hz. Since relative motion is considered above 0.1Hz, only the wave-like motion parameters were updated.

Amplitude, frequency and width parameters

In the generator, absolute GM for wave-like motion is described by combining 3 waves with amplitudes (a_1, a_2, a_3), frequencies (ω_1, ω_2, ω_3) and widths (d_1, d_2, d_3). The corresponding Power Spectrum Density (PSD) is given by [7]:

$$p_3(\omega) = \sum_{i=1}^{3} \frac{a_i}{1+[d_i(\omega-\omega_i)/\omega_i^{\,2}]^4} \qquad (1)$$

These parameters have been adjusted (see Table 1) such that the theoretical absolute motion PSD fits the one measured at ATF2 (see Figure 1). Three sets of GM measurements were made, under different conditions [6], and that with the largest magnitude (day-time during beam operation) was conservatively chosen. The theoretical PSD was fitted rather than that reconstructed from the generator data, to avoid the extensive generations needed to obtain a smooth PSD curve.

Table 1: Updated frequency, amplitude and widths.

Parameters	**1st wave**	**2nd wave**	**3rd wave**
f [Hz]	0.2	2.9	10.4
a [m²/Hz]	$1.0*10^{-13}$	$6.0*10^{-15}$	$2.6*10^{-17}$
d [1]	1.1	3.6	2.0

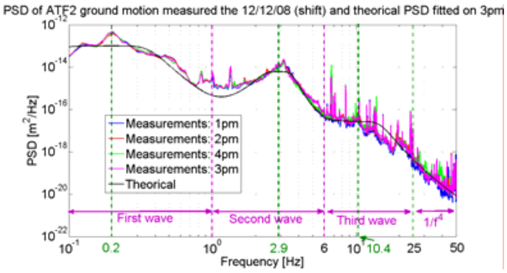

Figure 1: PSD of ATF2 GM measured on 12/12/08 during beam operation and fitted theoretical PSD (see Eq. 1).

Velocity parameters

The last parameters to update are the three wave velocities. With L the distance between two points, c(ω, L) the correlation and p(ω) the PSD of the absolute GM, the PSD of the relative GM is given by [7]:

$$p(\omega, L) = 2p(\omega)[1 - c(\omega, L)] \qquad (2)$$

With J_0 the Bessel function of the first kind (order 0), the correlation of a wave with velocity v is given by [7]:

$$c(\omega, L) = J_0 \frac{\omega L}{v} \qquad (3)$$

From Eqs. (1), (2) and (3), the correlation and PSD of the relative motion can be obtained for the three waves. As shown in [8], the velocity parameters can be adjusted for these theoretical correlations to fit the measured ones: v_1=1000m/s, v_2=300m/s and v_3=250m/s. Results are shown in Figure 2 for several distances from the IP.

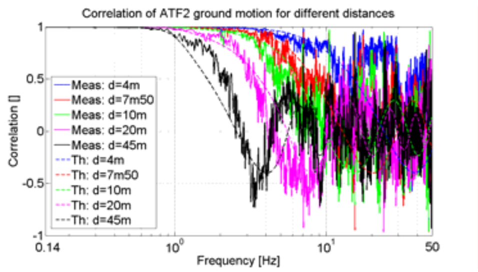

Figure 2: Measured correlation for several distances from the IP and theoretical one fitted on measurements.

The measurements show that the correlation falls with increasing distance, and the theoretical correlation follows this behaviour.

Relative motion

The integrated RMS of the relative motion is computed from the generator, with updated amplitude, frequency, width and velocity parameters, and compared to the corresponding measurements for different distances. The good agreement can be seen in Figure 3, where the integrated RMS of the absolute motion, calculated from the measured PSD of Figure 1, is also shown.

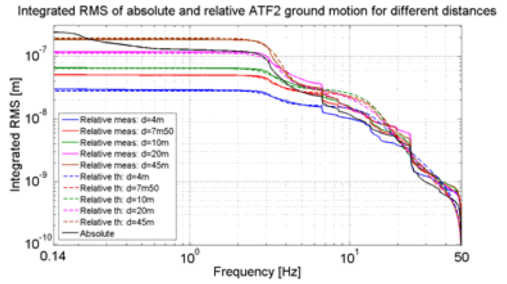

Figure 3: Integrated RMS of relative motion (and of absolute motion) for several distances (measured/fitted).

The increase in relative motion with distance is mainly due to the second wave (w_2, a_2, d_2). In fact, the first wave has a very good correlation up to at least 45m, contrary to the second wave whose amplitude is very high. Like for the correlation, the theoretical relative motion reproduces well the measured one.

Finally, Figure 4 shows the RMS of the relative motion versus distance, integrated from 0.1Hz to 50Hz, obtained from the measured data, from the theoretical formula and from the generated data. The integrated RMS of the absolute motion is also shown, as in Figure 3.

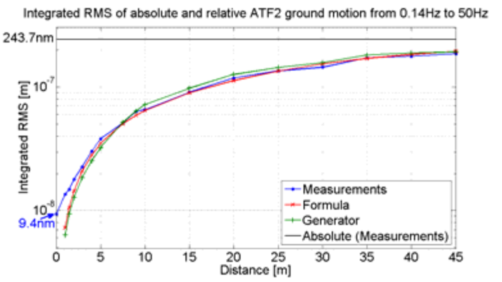

Figure 4: Integrated RMS of relative motion ([0.1;50]Hz) versus distance (measurements, theoretical, generator).

Relative motion increases with distance, reaching about 190nm at 45m (the absolute motion is about 250nm). For each distance, the generator and theoretical formula agree well with the measurements, confirming the quality of the tuning of the parameters. Below 4m, measured and theoretical relative motions are overestimated due to respectively very high signal to noise ratio needed and lower correlations than in reality (measurements).

RELATIVE BEAM MOTION AT THE IP

Consider KL_i the strength of quadrupole QFF_i, $dy_i(t)$ its motion relative to the IP, obtained from the updated generator, and $R34_i$ the optical transfer matrix element relating vertical angles at QFF_i and vertical offsets at the

IP, calculated with the MAD optics code. The beam motions $y_i(t)$ and y(t) at the IP due to the motions of, respectively, QFF_i and all the quadrupoles, can be written:

$$y_i(t) = -KL_i R34_i dy_i(t) \text{ and } y(t) = \sum_i y_i(t)$$

Note that the signs of the KL_i are different for focusing and defocusing quadrupoles, and the ones of the $R34_i$ depend on the betatron phase advances between each quadrupole and the IP. Thus, the sum y(t) can be partially compensated. From $y_i(t)$ and y(t), the integrated RMS $Y_i(f)$ and Y(f) have been calculated to get relative motions from 0.1Hz to 50Hz (sign not given with this calculation). Also, the integrated RMS $dY_i(f)$ has been calculated from $dy_i(t)$. This last calculation differs from that in Section "Relative motion", but it was checked with generated data that almost the same result is obtained [8].

Relative IP beam motion from each quadrupole

Figure 5 shows the results for Yi(f) and dYi(f) for all quadrupoles from the IP to the start of the beam line.

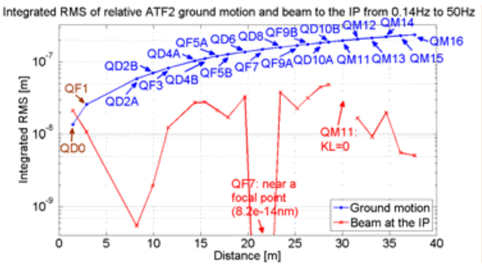

Figure 5: Integrated RMS of quadrupole motions relative to the IP and induced beam motion at the IP.

Quadrupole motion relative to the IP increases with distance as seen previously. Because QD0 and QF1 are the closest to the IP, their motions relative to the IP are the lowest (due to the good spatial coherence at low distance). The motions which they induce on the beam at the IP (13.5nm and 25.7nm) are hence less than from some upstream quadupoles where β-functions take large values. For example, QD10A and QD10B induce beam motions at the IP of 45 and 48nm, respectively.

The effect of all quadrupole motions must thus be analysed, and not only that of the FD (where a partial cancellation also occurs due to the different KL signs).

Relative IP beam motion from all quadrupoles

Figure 6 shows the integrated RMS of the IP beam motion due to the motions of both QD0 and QF1, of all quadrupoles except QD0 and QF1, and of all quadrupoles including the FD. QD0 and QF1 alone induce beam motion of only 10.5nm, as expected due to the partial cancellation. Taking into account all quadrupoles except (including) the FD was expected to give large effects, but in fact yields only 11.1nm (14.3nm) motions at the IP, due to a lucky compensation between magnets, from the different signs of the focusing/defocusing quadrupoles and from the different betatron phase advances.

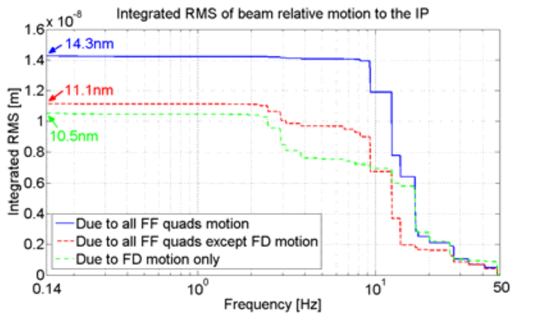

Figure 6: Integrated RMS of IP beam motion due to the combined motions of three sets of quadrupoles.

It was checked changing the generator parameters that this lucky compensation is robust and not fortuitous [9].

CONCLUSION

Motion of some of the ATF2 quadrupoles can separately induce relatively large beam orbit shifts at the IP, of up to 50nm, due to high β-function values and the loss of GM coherence with increasing distance from the IP. However, these effects are luckily well compensated when the effects of all quadrupoles are combined, yielding a residual effect of only 14nm, to be compared with a tolerance of 10nm. Moreover, this value may be lower in reality, since the motions of QD0 and QF1 relative to the IP gave values of 5.1nm and 6.5nm when measured directly [6], while the present simulation gives 13.5nm and 25.7nm. In fact, the theoretical correlation is less than the real one below 4m, resulting in some overestimation of the motion for the shortest distances.

Consequently, the ATF2 quadrupoles should not require any special stabilisation and the current scheme of rigidly fixing them to the floor should be enough. Nonetheless, in order to have a prototype for the CLIC project, an active stabilization system will be studied for ATF2.

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