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To cite this version:

K. Bertsche, W. Wittme, B. Bolzon, L. Brunetti, A. Jérémie, et al.. Vibration Budget for SuperB. 2011 Particle Accelerator Conference (PAC11), Mar 2011, New York, United States. à paraître, pp.THP069, 2011. <in2p3-00591896>

HAL Id: in2p3-00591896
http://hal.in2p3.fr/in2p3-00591896

Submitted on 10 May 2011

VIBRATION BUDGET FOR SUPER*B*[*]

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Abstract

We present a vibration budget for the Super*B* accelerator. We include ground motion data, motion sensitivity of machine components, and beam feedback system requirements.

INTRODUCTION

The Super*B* accelerator design [1] attains at least 50 times higher than current B-factories due to smaller beam sizes and a crabbed waist crossing angle scheme at the IP (interaction point). The beam size (1σ) at the IP will be about 10 μm (horizontal) by 40 nm (vertical). These small beam sizes will make the luminosity very sensitive to mechanical vibration and electrical noise.

Relative vertical misalignment of the two beams at the IP by only 8 nm will result in a 1% reduction in luminosity. The corresponding horizontal alignment tolerance of is 250x looser (2 μm). The vertical beam angle at the IP for a 1% luminosity loss is fairly loose at 200 μrad, and the horizontal beam angle tolerance is looser still. We will focus on vertical beam position at the IP, since this presents the greatest alignment challenge.

The values presented here are for a closed orbit with tunes near a half-integer in the Super*B* v.12 lattice.

VIBRATION SENSITIVITY

IR Cantilever

The final quadrupoles in the IR (interaction region) are of special concern due to their high strength and large beta functions [2], both of which amplify their influence on beam position at the IP. The transfer function of each IR component's vertical displacement to beam displacement at the IP is shown on the drawing in Fig. 1. For example, if the HER QF1 moves vertically by 100 nm, the beam will move vertically by -7 nm at the IP.

HER and LER IR components are shared in a common cryostat. Linear motion of an IR cryostat will shift these components coherently. The transfer function for either the HER or the LER component displacement to the IP is roughly the same, causing roughly equal beam displacements at the IP. Though the transfer function for motion of a single QD0 is about 0.7, the transfer function for deflection of the cryostat in a bending mode is about 0.007, a 100x reduction in sensitivity. We will conservatively assume that the cancellation may be a factor of 5 worse, and will use a worst-case transfer function of 0.035 for a single cryostat, with 0.05 for the RMS sum of both cryostats.

Cryostat rotation causes HER and LER components to move in opposite directions, causing individual beam displacements to coherently add rather than to subtract. This sets tight tolerances on cryostat rotation. The IR components should be supported in a way which minimizes torsional torques around the cryostat axis.

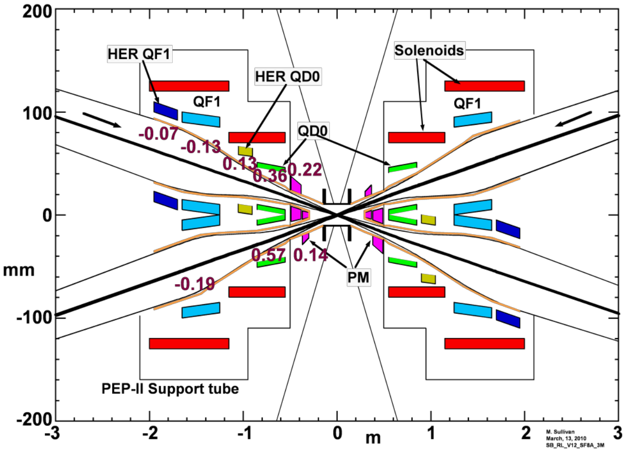

Figure 1: Vertical vibration transfer functions (beam displacement at IP for a given component displacement) for each Super*B* IR component.

Remainder of Machine

The RMS sum of deflection sensitivities for the quadrupoles in a final focus arc (excluding the IR quadrupoles addressed above) results in a transfer function of <0.1. I.e., if each quadrupole moves randomly by 100 nm in an uncorrelated manner, the beam position at the IP will move by <10 nm. The RMS sum of both final focus arcs of both rings gives a transfer function of <0.2.

The RMS sum of deflection sensitivities of all quadrupoles in the regular arc cells of one ring results in a transfer function of <0.1, and the RMS sum of both rings gives a transfer function of <0.14.

VIBRATION BUDGET

Based on these vibration sensitivities, the vertical vibration budget in Table 1 is proposed. A fast luminosity feedback system is assumed to have >10x vibration reduction, to be discussed below.

The corresponding transfer functions for horizontal motion at the IP are 5-15x larger than for vertical. But this should not present a problem since the horizontal alignment tolerance is 250x larger than the vertical. Vertical angular alignment at the IP is sensitive to vertical motion of arc quadrupoles, but this is about 8x less

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[*] Work supported by the Department of Energy under contract number DE-AC03-76SF00515.

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significant to luminosity than is vertical beam position at the IP.

Table 1: Proposed vertical vibration budget for Super*B*

Vertical Vibration Budget for Super*B*				
	RMS motion per element	Transfer fn (RMS sum, both rings)	Differential displacement at IP (nm)	
			No fdbk	With fdbk
IR cryostat linear motion	<800 nm	<0.05	<40	<4
IR cryostat rotation	<2 μrad	0.02 m/rad	<40	<4
Final focus quads, excluding IR	<200 nm	<0.2	<40	<4
All arc quads	<200 nm	<0.14	<30	<4
Total			<75	<7.5

EXPECTED VIBRATION LEVELS

Ground Motion Measurements

Ground motion has been studied in detail at one proposed Super*B* site, the INFN/LNF laboratory in Frascati, Italy. The power spectral density (PSD) of ground motion is shown in Fig. 2. Cultural noise in the 3-30 Hz range is significantly elevated during morning commute hours due to the proximity of a main road.

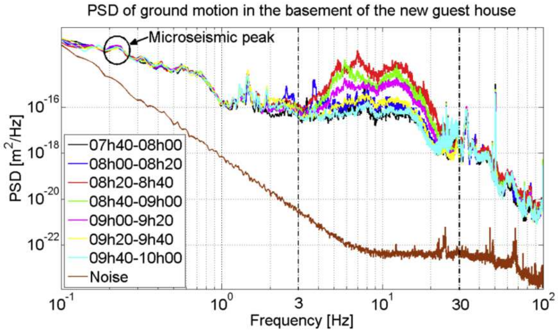

Figure 2: Vertical ground motion at the INFN/LNF site

We assume that the Super*B* accelerator will be 25-50 m underground. Ground motion is significantly attenuated with depth. This attenuation has been measured in a 50 m deep hole (Fig. 3); a 25 m depth will yield similar results.

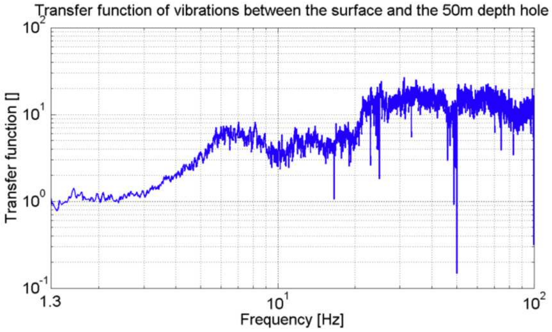

Figure 3: Attenuation of vertical motion with depth

The above data has been simplified for modeling purposes, yielding the curves in Figs. 4 and 5.

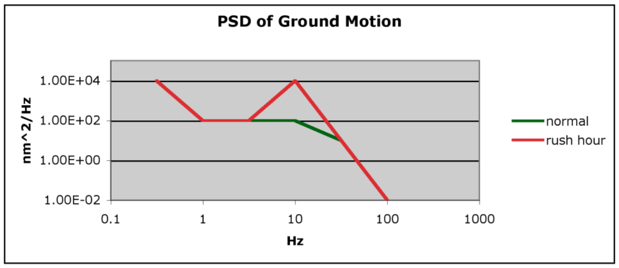

Figure 4: Idealized ground motion spectrum for modeling

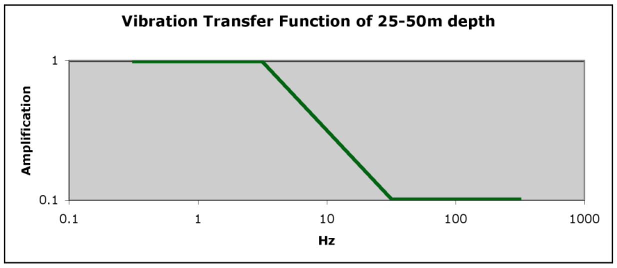

Figure 5: Idealized transfer function due to depth

Vibration Amplification

Supports for normal quadrupole magnets (in contrast to IR magnets) can be fairly stiff. It should be possible to push any structural resonances to frequencies between 10-100 Hz and to damp them. We expect only a small vibration enhancement in this range, as shown in the vibration transfer function of Fig. 6.

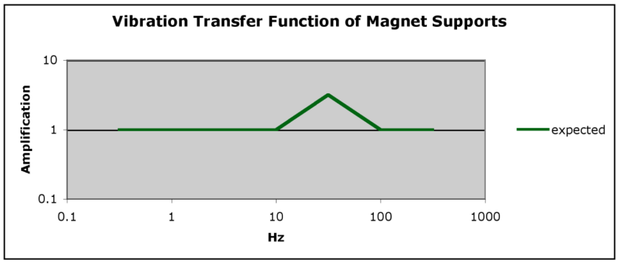

Figure 6: Vibrational behavior of normal magnet supports

The IR magnets will be mounted in a cryostat cantilevered into the IP. A cantilever produces a geometric amplification of ground motion over a range of frequencies, even if perfectly rigid, because tilting of the ground due to seismic waves causes vertical deflections at the tip of the cantilever. Based on a cantilever of about 2 m, a support base of 1-2 m, and ground velocity of 100-200 m/sec, this enhancement is expected to be less than a factor of 3 and in the range of 10-100 Hz, similar to the magnet support curve of Fig. 6.

The cantilever is expected to have low frequency resonances as well, in the range of 3-30 Hz. Combining geometric and resonance effects, we estimate the cantilevered cryostat to behave as shown in Fig. 7.

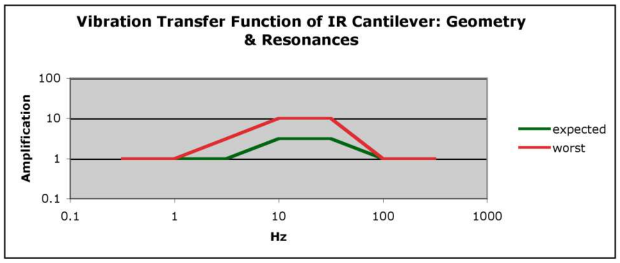

Figure 7: Vibrational behavior of IR cryostat, including geometric amplification of ground motion and resonances

Fast Luminosity Feedback

A fast luminosity feedback system is planned to address beam drift and jitter due to mechanical and electrical sources. A feedback system with roughly 10x the bandwidth of PEP-II has been proposed [3], and a faster feedback system based on ILC designs has been discussed. The feedback system is expected to allow correction to about 300 Hz (100 Hz minimum), and to provide about 30x (10x minimum) vibration reduction at low frequencies. The transfer function for the feedback is shown in Fig. 8.

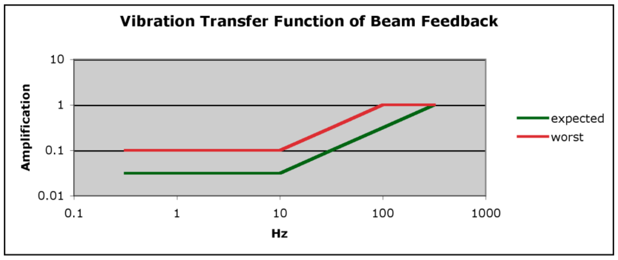

Figure 8: Performance of fast luminosity feedback system

Resulting Vibrations

With the ground motion spectrum of Fig. 4 as a driving term for the IR cryostat and the ring quadrupoles, we calculate the equivalent vertical beam displacement noise spectrum at the IP (Fig. 9) and the integrated RMS vertical beam displacement (Fig. 10). Even with the assumed worst case site, cantilever and feedback performance, the relative beam displacement is less than 6.3 nm (the vibration budget excluding a 4 nm contribution from cryostat rotation).

SUMMARY AND CONCLUSIONS

The small beam sizes at the IP of the Super*B* accelerator pose stringent vibration requirements. Beam position at the IP is very sensitive to individual motion of IR components. However, the present IR design with shared elements in a common cryostat will cause coherent motion of these elements, greatly reducing the vibration sensitivity of the IR. Cryostat vibration should be kept below 800 nm RMS, and cryostat rotation less than 2 μm RMS. Vibration of the remaining final focus quadrupoles and of the arc quadrupoles should be kept to less than 200 nm RMS. A fast luminosity feedback system should have a bandwidth of at least 100 Hz, achieving at least 10x vibration reduction at low frequencies.

With these requirements in the v.12 lattice sited underground at INFN/LNF, the vibration budget presented here can be met even during the noisiest part of the day, limiting vibration-induced luminosity loss to less than 1%.

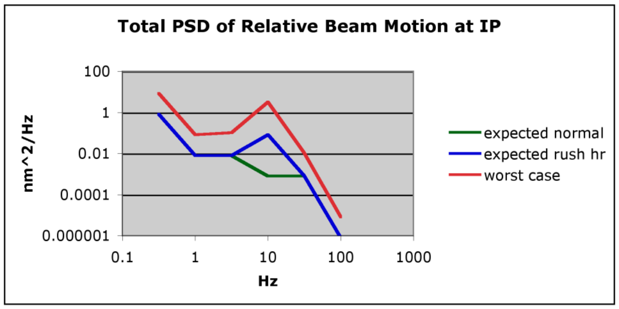

Figure 9: Power spectrum of beam relative motion at IP. Includes ground motion, magnet supports, IR cantilevers, and beam feedback.

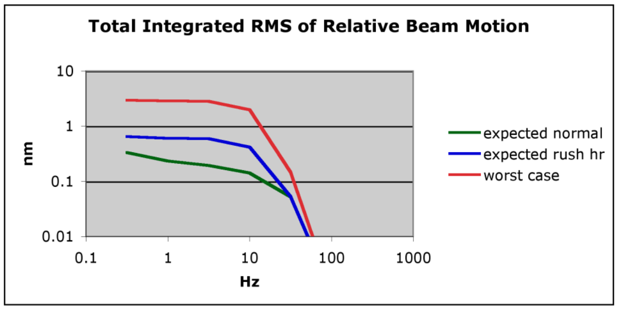

Figure 10: RMS relative beam motion at IP. Includes ground motion, magnet supports, IR cantilevers, and beam feedback.

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