Tolerable Vibration Levels for LIGO Optics

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14 February 1989

Abstract

The laser beam entering the arms of a LIGO interferometer is highly dewiggled by the mode cleaner cavity(ies) in the beam conditioning part of the system. In order to take full advantage of this highly purified beam, one has to avoid rewiggling of the beams by vibrating optical components. The present note gives estimates of the vibration levels which are acceptable for each optical component between (and including) the main mode cleaner and the interferometer arms. Component induced wiggle is acceptable when it is equal or lower than the residual wiggle at that component.

1 Acceptable Beam Wiggle Levels

The levels of acceptable beam wiggle are given in in Table 1, for the paths between the recycling mirror and the input to the 4 *km* arms (lines 6-9) and for the path between the main mode cleaner and the recycling mirror (lines 14-17). The derivation of the numbers for each entry is discussed below. The theory and formulæ are contained in Appendices 1[1], 2[2], 3[3].

[1]Appendix 1: Alex Abramovici, *Do Wiggle Effects Depend on Mode CLeaner Length?*

[2]Appendix 2:Alex Abramovici, *Variable Transmission Mirror for Recycling*

[3]Appendix 3:Dana Z. Anderson, *Alignment of Resonant Optical Cavities*, Appl. Optics **23**, 2944 (1984)

1	f Hz	10	50	215	1000
2	Source	Burst	Burst	Periodic	Periodic
3	$\delta l(f)/l$ $Hz^{-1/2}$	$2 \cdot 10^{-24}$	$4.6 \cdot 10^{-25}$	$2.15 \cdot 10^{-25}$	$2.15 \cdot 10^{-25}$
4	Storage time ms	8	1.6	2.3	0.5
5	Finesse	1,875	375	548	118
6	$\epsilon(f)$ $Hz^{-1/2}$	$4.7 \cdot 10^{-7}$	$4.3 \cdot 10^{-9}$	$4.3 \cdot 10^{-9}$	$2 \cdot 10^{-10}$
7	Angular wiggle $rad \cdot Hz^{-1/2}$	$4.3 \cdot 10^{-12}$	$3.9 \cdot 10^{-14}$	$3.9 \cdot 10^{-14}$	$1.8 \cdot 10^{-15}$
8	Lateral beam displacement $m \cdot Hz^{-1/2}$	$8.5 \cdot 10^{-9}$	$7.7 \cdot 10^{-11}$	$7.7 \cdot 10^{-11}$	$3.6 \cdot 10^{-12}$
9	Beam pulsation $Hz^{-1/2}$	$4.7 \cdot 10^{-7}$	$4.3 \cdot 10^{-9}$	$4.3 \cdot 10^{-9}$	$2 \cdot 10^{-10}$
10	Coupler transmission %	0.33	1.68	1.15	5.32
11	Loss in 4 km cavities %	11.4	2.35	3.4	0.75
12	Finesse of recycling cavity	27.6	133.7	91.9	419
13	Recycling cavity dewiggling factor	15.7	76	52.3	238.6
14	$\epsilon(f)$ $Hz^{-1/2}$	$7.4 \cdot 10^{-6}$	$3.3 \cdot 10^{-7}$	$2.2 \cdot 10^{-7}$	$4.8 \cdot 10^{-8}$
15	Angular wiggle $rad \cdot Hz^{-1/2}$	$6.7 \cdot 10^{-11}$	$3 \cdot 10^{-12}$	$2 \cdot 10^{-12}$	$4.4 \cdot 10^{-13}$
16	Lateral beam displacement $m \cdot Hz^{-1/2}$	$1.3 \cdot 10^{-7}$	$5.9 \cdot 10^{-9}$	$4 \cdot 10^{-9}$	$8.6 \cdot 10^{-10}$
17	Beam pulsation $Hz^{-1/2}$	$7.4 \cdot 10^{-6}$	$3.3 \cdot 10^{-7}$	$2.2 \cdot 10^{-7}$	$4.8 \cdot 10^{-8}$

Table 1: Acceptable beam wiggle levels inside the recycled system (lines 6-9) and between the main mode cleaner and the recycling mirror (lines 14-17). The other lines contain the data from which the wiggle levels have been derived, as explained in the text.

- Line 1 contains the frequencies for which the wiggle levels have been estimated. 10 Hz is considered the lowest frequency at which the seismic isolation can be made good enough to allow a substantial sensitivity; 50 Hz is the frequency with the highest expected sensitivity for bursts; 215 Hz is the lower limit of the frequency band where one expects the highest sensitivity for periodic signals; and 1000 Hz is an arbitrarily chosen higher frequency. These data are taken from Appendix A of the December 1987 Proposal.

- Line 2 indicates the tipe of signal corresponding to each column.

- Line 3 lists the spectral density of strain noise equivalent to the highest sensitivities expected from the advanced later stage detectors, as described in Appendix A of the December 1987 Proposal.

- Line 4 contains the optimized storage times corresponding to the sensitivities in Line 3. For burst signals, $\tau = (4\pi f)^{-1}$. For periodic signals, τ is half the period of the signal.

- Line 5 gives the finesse values corresponding to the storage times on Line 4: $\mathcal{F} = \pi c\tau/l$.

- Line 6 lists the acceptable power spectral density of time varying higher transverse mode amplitudes[4], in the presence of a static higher mode amplitude of 0.3. ϵ's are estimated by using $\delta l/l = \delta\nu/\nu$, Eq. (8) (Appendix 1) for $N = 1$ and $\mathcal{F}$ from Line 5.

- Lines 7-9 translate ϵ from Line 6 into angular wiggle, lateral displacement of the beam and beam pulsation, by use of Eqs. (5,3,7) (Appendix 3), respectively. The appropriate beam radius is 1.8 cm.

- Line 10 lists the transmission of the 4 km cavity input coupler corresponding to the finesse $\mathcal{F}$ given in Line 5, by using $T_c \sim 2\pi/\mathcal{F}$ (mirror losses are disregarded).

- Line 11 contains the loss L_I which the light incures by interacting with the 4 km cavities, calculated by using the transmissions from

[4]at the input of the 4 km cavities

Line 10, a sum of mirror losses $L_c + L_h = 100\ ppm$ and: $L_I = 1 - [(T_c - L_c - L_h)/(T_c + L_c + L_h)]^2$, where "c" stands for "coupler" and "h" stands for "high reflector".

- Line 12 lists the finesse of the recycling cavity (defined in Appendix 2): $\mathcal{F}_R = 2\pi/(\Theta + L_I)$, where Θ is the transmission of the recycling mirror which is assumed to have negligible loss. The recycling factor is maximized by $\Theta = L_I$, thus $\mathcal{F}_R = \pi/L_I$.

- Line 13: the dewiggling effect of the recycling cavity is estimated by use of $\mathcal{F}_R$ from Line 12 and Eq. (10) (Appendix 1), for $N = 1$.

- Line 14: multiplying the ϵ's from Line 6 by the dewiggling factors from Line 13 yields the acceptable higher mode amplitudes at the input to the recycling mirror.

- Lines 15-17: the higher mode amplitude ϵ from Line 14 is converted to angular wiggle, lateral beam displacement and beam pulsation by use of Eqs. (5,3,7) (Appendix 3). These are the values which should not be exceeded at the input to the recycling mirror.