LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY - LIGO -CALIFORNIA INSTITUTE OF TECHNOLOGY MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Technical Note	LIGO-T1100602-v2-	2013/01/31				
Beam Splitter / Folding Mirror Suspension (BSFM) Actuation Ranges						
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1 Introduction

This document defines the maximum range of the actuators on an Advanced LIGO (aLIGO) Beam Splitter / Folding Mirror Suspension (BSFM), given the final design of its respective actuation chains. The range is calculated explicitly at DC in tabular form in section 3. Because the range depends on the actuator driver's frequency response which are different at each stage, the single actuator force is shown as a function of frequency in section 4. The mechanical response to longitudinal force, and pitch and yaw torques are shown in 5. Finally, the magnitude of test mass displacement as a function of frequency for high(est)-range and low(set)-noise configurations is shown in section 6.

2 Calculating the Maximum Force

The maximum (peak) differential drive voltage, V_{max} , from an aLIGO Digital-to-Analog Converter (DAC), a General Standards PCIe66-18AO8, 18-bit, DAC card, is 10 $[V_p]$ [1].

Though the BSFM is a triple suspension with optic forming the final suspended stage (M3), it only has actuators on its upper two stages (Top, Intermediate or Middle, henceforth abbreviated as M1 and M2 respectively) [3, 9]. For the those stages, the force is calculated by multiplying each component of the linear actuation chain,

$$F = \eta T_{CD} G_{AI} V_{DAC} \tag{1}$$

where V_{DAC} is the applied DAC voltage, G_{AI} is the gain of the anti-aliasing chassis (assumed to be unity), T_{CD} is the transconductance of the coil driver (in [A/V]), and η is the OSEM arrangement's coil-magnet force coefficient (in [N/A]). Each isolation stage's driver circuit transconductance produces frequency-dependent current, and this frequency dependence is switchable such that the driver can meet both actuation range and output noise requirements. Table 1 summarizes the frequency response of each driver configuration for each stage. The assumed-frequency-independent, force-per-current coefficient for a given OSEM arrangement is then applied to determine the force produced in the actuator basis.

For both stages, the frequency-dependent, single-actuator, maximum force is converted to the Euler basis using the number of actuators and lever arm for each degree of freedom, which is then propagated through the aLIGO production BSFM Matlab model [7] transfer functions between drive each stage's Euler degree of freedom and test mass displacement in the same degree of freedom.

Table 1: Frequency response for each state of the two actuator driver types. Maximum range states are marked with \dagger , low-noise states are marked with \diamondsuit . TTOP is a Triple Top Coil Driver, TACQ is an (unmodified) Triple Acquisition Coil Driver.

V						
Driver	Drawing $\#$	State Name	(zeros):(poles) [Hz]			
TTOP	D0902747-v4	acq †	(31):(0.9)			
		lp \diamond	(10, 31): $(0.9, 1)$			
TACQ	D0901047-v4	acqOff lpOff	(9):(82)			
		acqOn lpOff †	(1.05):(46)			
		acqOff lpOn \diamond	(9, 11, 21):(1, 82, 210)			
		acqOn lpOn	(1.05, 11, 21):(1, 46, 210)			

3 Maximum Displacement at DC

Design Onlines (Carld Mission Oversesion (OOCM)												
(Beam Splitter / Fold-Mirror Suspension (BSFM)												
Details of OSEMS, Magnets, Coil Driver	s and maximum DC	drive range at e	each stage									
T1100602-v2												
Jeff Kissel and Norna Roberston												
31st January 2013												
Max DAC Voltage		opropo the Dive o	nd Minua logo)									
	(Dillerential voltage	acioss life rius a	nu minus iegs)									
10	1											
			Magnet Size	Coil Magnet	Coil Magnet							
Suspension Stage	OSEM Type	Magnet Type	diameter x	Actuation	Actuation							
			thickness	Strength	Strength							
Units	[]	[]	[mm]	[N/A]	[N/mA]							
Top (TOP M1)	BOSEM	NdFeB	10 x 10	1 694	0.001694							
Intermediate Mass (MID_M2)	BOSEM	SmCo	10 x 5	0.963	0.000963							
Optic (ROT M3)	DODE	none	n/a	n/a	0.000000 n/a							
	TIONE	TIONE	11/d	11/a	11/a							
				DC Current								
	DC	DC Max	DC Current	DC Current	Frequency							
Coil Driver	Transconducance	Current Output	Range	Range	Range							
	Hanooonaabanoo	ourione output	rtango	Requirement	rtango							
				[(mA_p) or								
Units	[mA/V]	[mA p]	[mA pp]	(mA rms)]	[Hz]							
				60 (p),	f < 1 Hz, 1							
Triple TOP (D0902747-v4)	11,919	119.19	238.38	200 (rms)	$H_{Z} < f < 100 H_{Z}$							
Triple Acc. (D0901047-y4)	0 32635	3 2635	6 527	M2: 2.5 (n)	f < 1 kH7							
Thpic Acq. (20001047-44)	0.02000	0.2000	0.021	WIZ. 2.0 (p)	7 5 1 1012							
Modified Triple Acr. (L1200226 v2)	2 0204	20 204	56 569	2/2	n/o							
Woullieu Thpie Acq. (L1200220-v2)	2.0204	20.204	50.506	II/d	l l/d							
	2 1	DC Compliance			DC Compliance	DC Max Disp.	DC Max Disp. from	DC Disp. Range	DC Disp. Range			
Degree of Freedom (DOF)	Stage	at Mass	Lever Arm	# OF USEMS	at Coll Driver	from Coil Drive	Coil Drive	from Coil Drive	from Coil Drive			
		at maoo			Output		0011 21110					
		[(m/N) or			[(m/mA) or	[(m_p) or	[(um_p) or	[(m_pp) or	[(mm_pp) or			
Units	[]	[(m/N) or (rad/N.m)]	[m]	n	[(m/mA) or (rad/mA)	[(m_p) or (rad_p)]	[(um_p) or (urad_p)]	[(m_pp) or (rad_pp)]	[(mm_pp) or (mrad_pp)]			
Units Longitudinal	[] M1	[(m/N) or (rad/N.m)] 0.001528	[m] 1	[]	[(m/mA) or (rad/mA) 5.177E-06	[(m_p) or (rad_p)] 6.171E-04	[(um_p) or (urad_p)] 617.07	[(m_pp) or (rad_pp)] 1.234E-03	[(mm_pp) or (mrad_pp)] 1234.142			
Units Longitudinal	[] M1	[(m/N) or (rad/N.m)] 0.001528 0.137720	[m] 0.055	[]2	[(m/mA) or (rad/mA) 5.177E-06 1.283E-05	[(m_p) or (rad_p)] <u>6.171E-04</u> 1.529E-03	[(um_p) or (urad p)] 617.07 1529.37	[(m_pp) or (rad_pp)] <u>1.234E-03</u> <u>3.059</u> E-03	[(mm_pp) or (mrad_pp)] 1234.142 3058.743			
Units Longitudinal Pitch Yaw	[] M1 M1 M1	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.152080	[m] 0.055 0.104	[] 2 1 2	[(m/mA) or (rad/mA) 5.177E-06 1.283E-05 5.359E-05	[(m_p) or (rad p)] <u>6.171E-04</u> 1.529E-03 6.387E-03	[(um_p) or (urad p)] 617.07 1529.37 6386.88	[(m_pp) or (rad_pp)] <u>1.234E-03</u> <u>3.059E-03</u> 1.277E-02	[(mm_pp) or (mrad_pp)] 1234.142 3058.743 12773.757			
Units Longitudinal Pitch Yaw Longitudinal	[] M1 M1 M2	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.152080 0.003691	[m] 0.055 0.104	[] 2 1 2 4	[(m/mA) or (rad/mA) 5.177E-06 1.283E-05 5.359E-05 1.422E-05	[(m_p) or (rad p)] 6.171E-04 1.529E-03 6.387E-03 4.640F-05	[(um_p) or (urad p)] 617.07 1529.37 6386.88 46.40	[(m_pp) or (rad_pp)] 1.234E-03 3.059E-03 1.277E-02 9.281F-05	[(mm_pp) or (mrad_pp)] 1234.142 3058.743 12773.757 92.807			
Units Lonaitudinal Pitch Yaw Lonaitudinal Pitch	[] M1 M1 M2 M2	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.152080 0.003691 0.303950	[m] 0.055 0.104 1 0.0707	[] 2 4 4	[(m/mA) or (rad/mA) 5.177E-06 1.283E-05 5.359E-05 1.422E-05 8.278E-05	[(m_p) or (rad p)] 6.171E-04 1.529E-03 6.387E-03 4.640E-05 2.701E-04	[(um_p) or (urad p)] 617.07 1529.37 6386.88 46.40 270.14	[(m_pp) or (rad_pp)] 1.234E-03 3.059E-03 1.277E-02 9.281E-05 5.403F-04	[(mm_pp) or (mrad_pp)] 1234.142 3058.743 12773.757 92.807 540.283			
Units Longitudinal Pitch Vaw Longitudinal Pitch Vaw	[] M1 M2 M2 M2	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.152080 0.003691 0.303950 0.329090	[m] 0.055 0.104 1 0.0707	[] 2 4 4 4	[(m/mA) or (rad/mA) 5.177E-06 1.283E-05 5.359E-05 1.422E-05 8.278E-05 8.962E-05	[(m_p) or (rad p)] 6.171E-04 1.529E-03 6.387E-03 4.640E-05 2.701E-04 2.925E-04	[(um_p) or (urad p)] 617.07 1529.37 6386.88 46.40 270.14 292.49	[(m_pp) or (rad pp)] 1.234E-03 3.059E-03 1.277E-02 9.281E-05 5.403E-04 5.850E-04	[(mm_pp) or (mrad pp)] 1234.142 3058.743 12773.757 92.807 540.283 584.971			
Units Longitudinal Yaw Longitudinal Pitch Yaw Longitudinal	[] M1 M2 M2 M2 M2 M0DM2	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.152080 0.003691 0.329090 0.0329090	[m] 1 0.055 0.104 1 0.0707 0.0707 1	[] 2 1 2 4 4 4 4 4	[(m/mA) or (rad/mA) 5.177E-06 1.283E-05 5.359E-05 1.422E-05 8.962E-05 1.422E-05	[(m_p) or (rad p)] 6.171E-04 1.529E-03 6.387E-03 4.640E-05 2.701E-04 2.925E-04 4.022E-04	[(um_p) or (urad p)] 617.07 1529.37 6386.88 46.40 270.14 292.49 402.17	[(m_pp) or (rad pp)] 1.234E-03 3.059E-03 1.277E-02 9.281E-05 5.403E-04 8.502E-04 8.6043E-04	[(mm_pp) or (mrad_pp)] 1234,142 3058,743 12773,757 92,807 540,283 584,971 804 334			
Units Consitudinal Pitch Yaw Longitudinal Pitch Viau Longitudinal Longitudinal Longitudinal	[] M1 M1 M2 M2 M2 M2 M0DM2 M0DM2	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.152080 0.003691 0.303950 0.329090 0.003691 0.202050	[m] 0.055 0.104 1 0.0707 0.0707 0.0707	[] 2 4 4 4 4 4	[(m/mA) or (rad/mA) 5.177E-06 1.283E-05 5.359E-05 1.422E-05 8.278E-05 8.962E-05 1.422E-05 8.972E-05 8.972E-05	[(m_p) or (rad p)] 6.171E-04 1.529E-03 6.387E-03 4.640E-05 2.701E-04 2.925E-04 4.022E-04 2.341E-02	[(um_p) or (urad p)] 617.07 1529.37 6386.88 46.40 270.14 292.49 402.17 2341.05	[(m_pp) or (rad pp)] <u>1.234E-03</u> 3.059E-03 <u>1.277E-02</u> 9.281E-05 <u>5.403E-04</u> 5.850E-04 <u>8.043E-04</u> 4.822E.02	[(mm_pp) or (mrad_pp)] 1234.142 3058.743 12773.757 92.807 540.283 584.971 804.334 4692.500			
Units Longitudinal Pitch Yaw Longitudinal Pitch Yaw Longitudinal Pitch	[] M1 M1 M2 M2 M0DM2 M0DM2	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.152080 0.0303950 0.329090 0.003691 0.303950 0.303950	[m] 0.055 0.104 1 0.0707 0.0707 1 0.0707 0.0707	[] 2 4 4 4 4 4 4 4	[(m/mA) or (rad/mA) 5.177E-06 1.283E-05 5.359E-05 1.422E-05 8.962E-05 1.422E-05 8.278E-05 8.278E-05 0.002E 05	[(m_p) or (rad p)] 6.171E-04 1.529E-03 6.387E-03 4.640E-05 2.701E-04 2.925E-04 4.022E-04 2.341E-03 0.525E-05	[(um_p) or (urad p)] 617.07 1529.37 6386.88 46.40 270.14 292.49 402.17 2341.25	[(m_pp) or (rad pp)] 1.234E-03 3.059E-03 1.277E-02 9.281E-05 5.403E-04 5.850E-04 8.043E-04 4.683E-03	[(mm_pp) or (mrad pp)] 1234.142 3058.743 12773.757 92.807 540.283 584.971 804.334 4682.509			
Units Lonaitudinal Pitch Yaw Lonaitudinal Lonaitudinal Pitch Yaw Longitudinal Pitch Yaw Longitudinal Pitch Yaw	[] M1 M2 M2 M2 M2 M0DM2 M0DM2 M0DM2	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.03691 0.303950 0.329090 0.03691 0.303950 0.329090	[m] 0.055 0.104 1 0.0707 0.0707 1 0.0707 0.0707	[] 2 4 4 4 4 4 4 4 4 4 4 4 4	[(m/mA) or (rad/mA) 5.359E-05 5.359E-05 1.422E-05 8.962E-05 8.962E-05 8.962E-05 8.962E-05	[(m_p) or (rad p)] 6.171E-04 1.529E-03 6.387E-03 4.640E-05 2.701E-04 2.925E-04 4.022E-04 2.341E-03 2.535E-03	[(um_p) or (urad p)] 617.07 1529.37 6386.88 46.40 270.14 222.49 402.17 2341.25 2534.90	[(m_pp) or (rad pp)] 1.234E-03 3.059E-03 1.277E-02 9.281E-05 5.403E-04 8.043E-04 4.663E-03 5.070E-03	[(mm_pp) or (mrad_pp)] 1234.142 3058.743 12773.757 92.807 540.283 584.971 804.334 4682.509 5069.804			
Units Longitudinal Pitch Yaw Longitudinal Pitch Pitch Yaw Yaw	[] M1 M1 M2 M2 M2 M0DM2 M0DM2 M0DM2	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.052080 0.003691 0.303950 0.329090 0.329090	[m] 0.055 0.104 1 0.0707 0.0707 1 0.0707 0.0707	[] 2 4 4 4 4 4 4 4 4 4 4	[(m/mA) or (rad/mA) 5.177E-06 1.233E-05 5.359E-05 1.422E-05 8.962E-05 8.278E-05 8.962E-05	[(m_p) or (rad p)] 6.171E-04 1.529E-03 6.387E-03 4.640E-05 2.701E-04 2.925E-04 4.022E-04 2.341E-03 2.535E-03	[(um_p) or (urad p)] 617.07 1529.37 6386.88 46.40 270.14 282.49 402.17 2341.25 2534.90	[(m_pp) or (rad pp)] 1.234E-03 3.059E-03 9.287E-02 9.281E-05 5.403E-04 8.8043E-04 4.683E-03 5.070E-03	[(mm,pp) or (mrad pp)] 1234.142 3058.743 12773.757 92.807 540.283 584.971 804.334 4682.509 5069.804			
Units Consitudinal Pitch Yaw Longitudinal Pitch Yaw Longitudinal Pitch Yaw Longitudinal Pitch Yaw	LI M1 M1 M2 M2 MODM2 MODM2	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.052080 0.003691 0.303950 0.0329090 0.003691 0.303950 0.329090	[m] 1 0.055 0.104 1 0.0707 0.0707 1 0.0707 0.0707	[] 2 4 4 4 4 4 4 4 4 4 4 4 4	[(m/mA) or (rad/mA) 5.177E-06 1.283E-05 1.422E-05 8.962E-05 1.422E-05 8.962E-05 8.962E-05	[(m_p) or (rad p)] 6.171E-04 1.529E-03 6.387E-03 4.640E-05 2.701E-04 2.925E-04 4.022E-04 2.341E-03 2.535E-03	[(um, p) or (urad p)] 617.07 1529.37 6386.88 46.40 270.14 292.49 402.17 2334.25 2534.90	[(m_pp) or (rad pp)] 1.234E-03 3.059E-03 9.281E-05 5.403E-04 5.850E-04 8.043E-04 4.683E-03 5.070E-03	[(mm,pp) or (mrad pp)] 1234.142 3058.743 12773.757 92.807 540.283 584.971 804.334 4082.509 5069.804			
Units Longitudinal Pitch Yaw Longitudinal Pitch Pitch Pitch Yaw References	II M1 M1 M2 M2 M2 M0DM2 M0DM2 M0DM2	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.03691 0.303950 0.329090 0.03691 0.303950 0.329090	[m] 1 0.055 0.104 1 0.0707 0.0707 1 0.0707 0.0707	[] 2 4 4 4 4 4 4 4 4 4 4 4 4	[(m/mA) or (rad/mA) 5.177E-06 1.283E-05 5.399E-05 1.422E-05 8.962E-05 1.422E-05 8.962E-05 8.962E-05	[(m_p) or (rad p)] 6.171E-04 1.529E-03 4.640E-05 2.701E-04 4.022E-04 4.022E-04 4.022E-04 2.341E-03 2.535E-03	[(um, p) or (urad p)]	[(m_pp) or (rad pp)] 1234E-03 3.055E-03 1.277E-02 9.281E-05 5.403E-04 8.043E-04 4.683E-03 5.070E-03	[(mm_pp) or (mrad_pp) 3058 743 12773.757 92.807 540.283 584.971 804.334 4682.509 5069.804			
Units Longitudinal Pitch Yaw Longitudinal Pitch Yaw Longitudinal Pitch Yaw References DAC Voltage	11 M1 M1 M2 M2 M0M2 M0DM2 M0DM2	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.03850 0.03950 0.320900 0.003691 0.303950 0.329090	[m] 0.055 0.104 0.0707 0.0707 1 0.0707 0.0707	[] 2 1 2 4 4 4 4 4 4 4 4 4 4 4	[(m/mA) or (rad/mA) 5.177E-06. 1.283E-05 5.359E-05 1.422E-05 8.962E-05 8.962E-05 8.962E-05 8.962E-05	[(m_p) or (rad p)] 6.171E-04 1.529E-03 6.387E-03 4.640E-05 2.701E-04 2.925E-04 4.022E-04 2.341E-03 2.535E-03	[(um.g)) or (urad p)] 617.07 6386.88 46.40 2701.44 2701.44 2202.49 402.17 2341.25 2534.90	[(m_pp) or (rad pp)] 1.234E-03 3.059E-03 1.277E-02 9.281E-05 5.403E-04 8.043E-04 4.683E-03 5.070E-03	[(mm,pp) or (mrad pp)] 1234.142 3058.743 12773.757 92.807 564.0283 584.971 804.334 4682.509 5069.804			
Units Longitudinal Pitch Yaw Longitudinal Pitch Yaw Longitudinal Pitch Yaw Longitudinal Congitudinal References DAC Voltage OSEM and magnet details	II M1 M1 M1 M2 M2 MODM2 MODM2 T1200311-v1 M0900034-v4	[(m/N) or (rad/N.m)] 0.001528 0.1377200 0.137200 0.0303950 0.33950 0.33950 0.33950 0.33950 0.33950 0.33950	[m] 0.055 0.104 1 0.0707 0.0707 0.0707 0.0707	[] 2 4 4 4 4 4 4 4 4 4 4 4 4 4	[(m/mA) or (rad/mA) 5.177E-06 1.283E-05 5.359E-05 1.422E-05 8.962E-05 1.422E-05 8.278E-05 8.962E-05	[(m_p) or (rad p)] 6.171E-04 1.529E-03 6.387E-03 4.640E-05 2.701E-04 2.925E-04 4.022E-04 2.341E-03 2.535E-03	[(um,p) or (urad p)] 17,000 1529,37 6386,88 46,40 270,14 292,49 402,17 2341,25 2534,90	[(m_pp) or r(rad pp)] 1234E-03 3.055E-03 1.277E-02 9.281E-05 5.403E-04 8.043E-04 4.683E-03 5.070E-03	[(mm_pp) or (mrad_pp)] 3058 743 12773 757 92 807 540,283 584.971 804.334 4682,509 5069,804			
Units Lonaitudinal Pitch Vaw Lonaitudinal Pitch Vaw Lonaitudinal Pitch Yaw Lonaitudinal Pitch Yaw References DAC Voltage OSEM and magnet details OSEM collAbaret Actuation Strengths	II M1 M1 M1 M2 M2 MODM2 MODM2 MODM2 MODM2 T1200311-v1 M00034-v4 T1000164-v3 M004-v3	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.135720 0.03691 0.33950 0.329090 0.03691 0.33950 0.329090	[m] 0.055 0.104 1 0.0707 0.0707 0.0707 0.0707	[] 2 1 2 4 4 4 4 4 4 4 4 4 4 4	[(m/mA) or (rad/mA) 1.282-05 5.3598-05 1.422E-05 8.2728-05 8.2728-05 8.278E-05 8.962E-05	[(m_p) or (rad p)] 6 171E-04 1 529E-03 6 387E-03 4 640E-05 2 701E-04 2 925E-04 4 022E-04 2 341E-03 2 535E-03	[(um.g)) or (urad p)] (urad p)] (ura	[(m_pp) or (rad pp)] 1.234E-03 3.055E-03 1.277E-02 9.281E-05 5.403E-04 8.043E-04 4.683E-03 5.070E-03	[(mm_pp) or (mrad pp) 3058,743 12773,757 92,807 540,283 5840,283 6844,971 804,334 4682,509 5069,804			
Units Longitudinal Pitch Yaw Longitudinal Pitch Yaw Longitudinal Pitch Yaw Longitudinal Congitudinal Congitudinal Collidage OSEM Act Magnet details OSEM Actionages for long/bitch/vaw	II M1 M1 M1 M2 M2 MODM2 MODM2 T1200311-v1 M0900034-v4 T1000164-v3 T1000164-v3	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.1520801 0.003691 0.329900 0.003691 0.329900 0.003691 0.329900	[m] 1 0.055 0.104 1 0.0707 0.0707 1 0.0707 0.0707 1 0.0707 1 0.0707	11 2 11 2 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	[(m/mA) or (rad/mA) 1.283-06 1.283-05 5.359E-05 1.422E-05 8.962E-05 8.962E-05 8.962E-05 8.962E-05	((m_p) or (rad p)) 6.171E-04 1.520E-03 6.387E-03 4.640E-05 2.701E-04 2.925E-04 4.022E-04 4.022E-04 2.341E-03 2.535E-03	[(um,p) or (urad p)] 617.07 6386.88 46.40 270.14 292.49 402.17 2341.25 2534.90	[(m_pp) or 1234E-03 3.055E-03 1.277E-02 9.281E-05 5.403E-04 8.043E-04 4.883E-03 5.070E-03	[(mm_pp) or (mrad_pp) 1234.142 3058.743 12773.757 92.807 540.283 584.971 804.334 4682.509 5069.804			
Units Lonaitudinal Pitch Vaw Lonaitudinal Pitch Vaw Lonaitudinal Pitch Yaw Lonaitudinal Pitch Yaw References DAC Voltage OSEM and magnet details OSEM Coil/Agnet Actuation Strengths DC Compliances for long/pitch/yaw	II M1 M1 M1 M2 M2 MODM2 MODM2	[(m/N) or (rad/N.m)] 0.001528 0.157200 0.03691 0.303950 0.329090 0.03691 0.303950 0.329090 0.03691 0.33950 0.329090	[m] 1 0.055 0.104 - 1 0.0707 0.0707 - 0.0707 0.0707 - - - - - - - - - - - - -	1 2 1 2 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	[(m/mA) or (rad/mA) 1.283-05 1.282E-05 1.422E-05 8.278E-05 8.422E-05 1.422E-05 8.422E-05 8.422E-05 8.422E-05 8.422E-05 8.962E-05 8.962E-05	[(m_p) or [rad p]] (a b)] (a b)] ([(um.g)) or (urad p)] (129.37)) (129.37 (129.37)) (129.37 (129.37)) (129.37) (129.37)) (129.37) (129.37)) (129.37) (129.37))	[(m_pp) or 1.234E-03 3.055E-03 1.277E-02 9.281E-05 5.403E-04 8.043E-04 4.683E-03 5.070E-03	[(mm_pp) or (mrad pp) 3058,743 12773,757 92,807 540,283 5840,283 6844,971 804,334 4682,509 5069,804			
Units Longitudinal Pitch Yaw Longitudinal Pitch Yaw Longitudinal Pitch Yaw Longitudinal DiscreteS DAC Voltage OSEM and magnet details OSEM CollMagnet Actuation Strengths DC Compliances for long/pitch/yaw	II M1 M1 M1 M2 M2 MODM2 MODM2 MODM2 MODM2 T1200311-v1 M0900034-v4 T1000164-v3 Model: Parameters: Model:	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.033950 0.033950 0.329900 0.033950 0.329900 0.33950 0.329900	[m] 1 0.555 0.0104 1 0.0707 0.0707 1 0.0705 1	L1 2 1 2 4 4 4 4 4 4 4 4 4 4 4 4 4	[(m/mA) or (rad/mA) 1.283-06 1.283-05 5.359E-05 1.422E-05 8.962E-05 8.962E-05 8.962E-05 8.962E-05 8.962E-05	((m_p) or (rad p)] 6.171E-04 1.520E-03 6.387E-03 4.640E-05 2.701E-04 2.925E-04 4.022E-04 4.022E-04 2.341E-03 2.535E-03	[(um,p) or (urad p)] 6386.88 46.40 270.14 292.49 402.17 2341.25 2534.90	[(m_pp) or r(rad pp)] 1234E-03 3.055E-03 1.277E-02 9.281E-05 5.403E-04 8.043E-04 4.883E-03 5.070E-03	[(mm_pp) or (mrad_pp) 1234.142 3058.743 12773.757 92.807 540.283 584.971 804.334 4682.509 5069.804			
Units Lonaitudinal Pitch Yaw Lonaitudinal Pitch Yaw Lonaitudinal Pitch Yaw References DAC Voltage OSEM and magnet Actuation Strengths DC Compliances for long/pitch/yaw	II M1 M1 M1 M2 M2 MODM2 MODM2 MODM2 MODM2 MODM2 MODM2 MODM2 MODM2 MODM2 MODM2 MODM2 MODM2 Parameters: DC compliance =	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.152080 0.033691 0.333950 0.329090 0.03691 0.333950 0.329090 0.03691 0.33950 0.329090	[m] 1 0.055 0.104 10.0707 0.0707 0.0707 1 0.0707 0.0707 1 1 1 1 1 1 1 1 1 1 1 1 1	1 2 1 2 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	[(m/mA) or (rad/mA) 1.283-06 1.283-05 1.422E-05 1.422E-05 8.278E-05 8.422E-05 1.422E-05 8.422E-05 8.422E-05 8.422E-05 8.962E-05 8.962E-05	[(m_p) or [rad p]] (a b)] (a b)] ([(um.g)) or (urad p)] (urad p)] (urad p)] (urad p)] (urad p)] (urad p)] (urad p) (urad p) (urad p) (urad p)] (urad p	[(m_pp) or (rad pp)] 1.234E-03 3.055E-03 1.277E-02 9.281E-05 5.403E-04 8.043E-04 4.683E-03 5.070E-03	[(mm_pp) or (mrad pp) 3058,743 12773,757 92,807 540,283 5840,283 6844,971 804,334 4682,509 5069,804			
Units Longitudinal Pitch Yaw Longitudinal Pitch Yaw Longitudinal Pitch Yaw Longitudinal References DAC Voltage OSEM and magnet details OSEM CouliMagnet Actuation Strengths DC Compliances for long/pitch/yaw Coil driver remultements	II M1 M1 M1 M2 M2 MODM2 MODM2 T1200311-v1 M0900034-v4 T1000164-v3 Model: Parameters: DC compliance == DC compliance == DC compliance ==	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.033950 0.033950 0.320900 0.033950 0.320900 0.333950 0.329900 caltech.edu/svn/sus/ ssmake3MBf bsfmopt_metal.m Transfer function frc	[m] 1 0.055 0.0104 1 0.0707 0.0707 1 0.0707 0.0707 1 0.0707 1 0.0707 0.0	11 2 11 2 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	[(m/mA) or (rad/mA) 1.283-05 5.359E-05 1.422E-05 8.278E-05 8.962E-05 1.422E-05 8.962E-05 8.962E-05 8.962E-05 8.962E-05	[(m_p) or [rad p]] 6.171E-04 1.520E-03 6.387E-03 4.640E-56 2.701E-04 2.925E-04 2.341E-03 2.535E-03	[(um.p) or (urad p)] 6386.88 46.40 270.14 292.49 402.17 2341.25 2534.90	[(m_pp) or (rad pp)] 1234E-03 3.055E-03 1.277E-02 9.281E-05 5.403E-04 8.643E-04 4.683E-03 5.070E-03	[(mm_pp) or (mrad_pp) 1234.142 3058.743 12773.757 92.807 540.283 584.971 804.334 4682.509 5069.804			
Units Lonaitudinal Pitch Vaw Lonaitudinal Pitch Pitch Pitch Yaw Longitudinal Pitch Yaw References DAC Voltage OSEM and magnet Actuation Strengths DC Compliances for long/pitch/yaw Coil driver requirements	II M1 M1 M1 M2 M2 MODM2 MODM2 DC ampliance == T060065-v1	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.152080 0.033691 0.333950 0.329090 0.03691 0.333950 0.329090 0.03691 0.33950 0.329090	Iml 1 0.055 0.104 0.107 0.0707 0.0707 0.0707 1 0.0707 1 0.0707 1 0.0707 1 0.0707 0.0707 0.0707 1 0.0707 1 0.0707 0.0707 0.0707		[(m/mA) or (rad/mA) 1.283-05 1.2832-05 1.4222-05 8.2782-05 8.4222-05 8.4222-05 8.4222-05 8.4222-05 8.4222-05 8.4222-05 8.4222-05 8.9622-05 1.4222-05 8.9622-05	[(m_p) or [rad p]] 6,171E-04 1,520E-03 6,387E-03 4,640E-05 2,2701E-04 2,225E-04 2,241E-03 2,535E-03	[(um.g)) or (urad p)] (urad p)] (urad p)] (urad p)] (urad p)] (urad p)] (urad p) (urad p) (urad p) (urad p) (urad p)] (urad p)	[(m_pp) or (rad pp)] 1.234E-03 3.055E-03 1.277E-02 9.281E-05 5.403E-04 8.043E-04 4.683E-03 5.070E-03	[(mm_pp) or (mrad pp) 3058,743 12773,757 92,807 540,283 5840,283 6844,971 804,334 4682,509 5069,804			
Units Longitudinal Pitch Pitch Vaw Longitudinal Pitch Vaw Longitudinal Pitch Vaw Coliditional OSEM and magnet details OSEM ColiMagnet Actuation Strengths DC Compliances for long/pitch/yaw Colid driver requirements Colid driver requirements Colid Drive PO Transportations	II M1 M1 M1 M2 M2 MODM2 MODM2 T1200311-v1 M000034-v4 T1000184-v3 Model: Parameters: DC compliance == T080065-v1 Informed by	[(m/N) or (rad/N.m)] 0.001528 0.137720 0.152080 0.003691 0.303950 0.320900 0.003691 0.303950 0.320900 0.303950 0.329090 0.329090	[m] 1 0.055 0.0104 1 0.0707 0.0707 1 0.0707 0	II 2 11 2 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 0 0 10 0 0 0 10 0	((m/mA) or (rad/mA) 1.283-05 5.359E-05 1.422E-05 8.278E-05 8.962E-05 1.422E-05 8.962E-05 8.962E-05 8.962E-05 8.962E-05 8.962E-05	[(m_p) or [rad p]] 6.171E-04 1.520E-03 6.387E-03 4.640E-05 2.701E-04 4.602E-04 4.022E-04 4.022E-04 2.341E-03 2.535E-03	[(um.p) or (urad p)] 6386.88 46.40 270.14 292.49 402.17 2341.25 2534.90	[(m_pp) or (rad pp)] 1234E-03 3.055E-03 1.277E-02 9.281E-05 5.403E-04 8.643E-04 4.683E-03 5.070E-03	[(mm_pp) or (mrad_pp) 1234.142 3058.743 12773.757 92.807 540.283 584.971 804.334 4682.509 5069.804			
Units Lonaitudina Pitch Yaw Longitudinal Pitch Yaw Longitudinal Pitch Yaw References DAC Voltage OSEM and magnet Actuation Strengths DC Compliances for long/pitch/yaw Coil driver requirements Coil Driver DC Transconductance	II M1 M1 M1 M2 M2 MODM2 MODM2 MODM2 MOD	[(m/N) or (rad/N.m)] 0.001528 0.152080 0.03691 0.303950 0.329090 0.03691 0.33950 0.329090 0.03691 0.33950 0.329090	Iml 1 0.055 0.104 0.104 0.0707 0.0707 0.0707 1 0.0707 0.0707 0.0707 rev1891 rev2005 registrate redw121G caltech.edu/aLIG php?callRep=449		[(m/mA) or (rad/mA) or (rad/mA) 1.2832-05 1.4222-05 1.4222-05 8.2782-05 8.4222-05 1.4222-05 8.4222-05 8.4222-05 8.4222-05 8.4222-05 8.4222-05 8.4222-05 8.4222-05 8.4222-05 9.42	((m_p) or (rad p)) 6,171E-04 1,520E-03 6,387E-03 4,640E-05 2,2701E-04 2,255E-04 2,241E-03 2,535E-03	[(um.g)) or (urad p)] (urad p)] (urad p)] (urad p)] (urad p) (urad	[(m_pp) or 1.234E-03 3.055E-03 1.277E-02 9.281E-05 5.403E-04 8.043E-04 4.683E-03 5.070E-03	[(mm_pp) or (mrad pp) 2334.142 3058.743 12773.757 92.807 540.283 584.0283 584.071 804.334 4682.509 5069.804			

Figure 1: Explicit actuation range calculation at DC for aLIGO BSFM Suspension. As this calculation is prone to erroneous factors of two everywhere (differential vs. single ended, peak vs. peak-to-peak, etc.), the calculation is shown explicitly from both the maximum displacement (peak) and displacement range (peak-to-peak). Note that maximum, peak values are denoted with subscript "p," and range, peak-to-peak values are denoted with subscript "p." Similar results from the previous version of this table against the peak-to-peak range.

4 Single-Actuator Actuation Strength

4.1 High-Range Configuration



4.2 Low-Noise Configuration











6 Frequency-dependent Maximum Displacement



6.1 High-Range Configuration

LIGO-T1100602-v2-







6.2 Low-Noise Configuration

LIGO-T1100602-v2-





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