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Surface vectors for optics in local coordinates

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Detector

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1 ABSTRACT

The vectors describing the surfaces of the wedged optics are calculated in the LIGO global coordinate system and are then transformed into local coordinates.

2 KEYWORDS

wedge angles, surface vectors, global coordinates, local coordinates

3 VERSION HISTORY

10/30/97 - Preliminary version, no balancing data

6/21/00 - Final draft with balancing data

6/22/00 - Rev 00

4 OVERVIEW

Due to the curvature of the earth, the local vertical varies by around 0.6 mrad over the length of each arm. This is of the same order as the requirement for the initial pitch imbalance of the optics. The best method for levelling the optics has not been decided but it is likely to be convenient to level the optics relative to the local vertical. For this and other reasons, we need to know the surface vectors for the optics in local coordinates. These have been calculated in the Mathematica notebook `/home/mbarton/analysis/geometry/OpticGeometryV2.nb` and are summarised in this document.

Of particular interest are the vertical components of the HR (or BS) surfaces, which are used for balancing. These have been separated out and converted to degrees, minutes and seconds for ease of use.

5 SOURCES OF INFORMATION

5.1. Global to local conversion

The matrices of direction cosines relating the global and local coordinate systems are given in LIGO-T950004-B (Albert Lazzarini) for key points along the arms at Hanford and Livingston. When used to premultiply column vectors, the matrices are passive transformations from local to global coordinates. To go from global coordinates to local, the transpose (equivalent to the inverse for rotation matrices) should be taken.

5.2. Optic shapes and orientations

The wedge angles for the optics and the surface vectors for about half the faces are given in LIGO-T070091-00 (Dennis Coyne). Surface vectors for the remaining faces can easily be calculated from the information given.

5.3. Relationship to E000028

There is an independent calculation of the surface vectors in local coordinates by Dennis Coyne in "Core Optics Tilt Angles", E000028. The calculations agree to about one arcsecond and either can be used for balancing optics.

6 SURFACE VECTORS

Tables 1-2 are extensions of part of Table 3 in T970091-00. They omit the columns giving the centre position of the optic but add extra rows for surfaces not mentioned in T970091-00. The numbering scheme for the surface vectors conforms to T970091-00 for vectors mentioned there and to Dennis Coyne's working papers in all other cases. Note that the numbering is independent for the 2 km and 4 km interferometers.

Note also and especially the sign convention: all surface vectors point in the general direction of the optical path back to the laser. Thus half of the vectors point into the centre of the optic instead of outwards as might be expected. These are marked with an asterisk. For example, the surface vector for the HR (beamsplitter) side of the recycling mirror points toward the laser, not toward the beamsplitter and so is indicated by "n3*". To get an outward pointing version, reverse all three components.

Table 1: Surface vectors in global coordinates for a generic 4 km interferometer

Optic	*Surface*	*Vector*	$\hat{i}$	$\hat{j}$	$\hat{k}$
Global - 4 km					
RM	laser	n2	-0.998153	-1.36771E-4	6.07514E-2
	BS	n3*	-0.999821	-1.37E-4	1.88998E-2
BS	Y	n4	-0.70709	0.70709	6.89E-3
	X	n5*	-0.706897	0.706897	2.43409E-2
ITMx	BS	n6	-0.999793	0	-2.03608E-2
	cavity	n7*	-1.	0.	-2.62982E-8
ITMy	BS	n8	0	-0.999793	-2.03608E-2
	cavity	n9*	0.	-1.	-2.62982E-8
ETMx	cavity	n10	-1	0	0
	end	n11*	-0.999391	0.	3.48995E-2
ETMy	cavity	n12	0	-1	0
	end	n13*	0.	-0.999391	3.48995E-2

Table 2: Surface vectors in global coordinates for a generic 2 km interferometer

Optic	*Surface*	*Vector*	$\hat{i}$	$\hat{j}$	$\hat{k}$
Global - 2 km					
RM	laser	n2	0.998153	-2.04327E-19	6.07514E-2
	BS	n3*	0.999821	0	1.88998E-2
BS	X	n4	0.70709	-0.70709	6.89E-3
	Y	n5*	0.706897	-0.706897	2.43409E-2
FMx		n9	0.706756	0.70745	3.3158E-3
		n13*	0.706244	0.706937	3.82131E-2
FMy		n6	0.707125	0.707081	3.3196E-3
		n12*	0.706612	0.706568	3.82169E-2
ITMx	FM	n10	-0.999951	0	-9.89E-3
	cavity	n11*	-1.	0.	3.69433E-8
ITMy	FM	n7	0	-0.999951	-9.89E-3
	cavity	n8*	0.	-1.	3.69433E-8
ETMx	cavity	n16	-1	0	0
	end	n17*	-0.999391	0.	3.48995E-2
ETMy	cavity	n14	0	-1	0
	end	n15*	0.	-0.999391	3.48995E-2

Table 3: Surface vectors in local coordinates for the Hanford 4 km IFO

Optic	*Surface*	*Vector*	$\hat{i}$	$\hat{j}$	$\hat{k}$
Hanford 4 km IFO					
RM	laser	n2	-0.998115	-1.36248E-4	6.13692E-2
	BS	n3*	-0.999809	-1.36835E-4	1.95187E-2
BS	Y	n4	-0.707086	0.70709	7.32163E-3
	X	n5*	-0.706882	0.706897	2.47724E-2
ITMx	BS	n6	-0.999805	-1.71838E-7	-1.97419E-2
	cavity	n7*	-1.	2.65461E-9	6.18974E-4
ITMy	BS	n8	-1.26007E-5	-0.999793	-2.03522E-2
	cavity	n9*	2.63855E-9	-1.	8.5437E-6
ETMx	cavity	n10	-1.	-7.34449E-11	-8.57E-6
	end	n11*	-0.999391	2.99015E-7	3.48909E-2
ETMy	cavity	n12	-1.61147E-10	-1.	-6.19E-4
	end	n13*	2.16026E-5	-0.999412	3.42809E-2

Table 4: Surface vectors in local coordinates for the Livingston 4 km IFO

Optic	*Surface*	*Vector*	$\hat{i}$	$\hat{j}$	$\hat{k}$
Livingston 4 km IFO					
RM	laser	n2	-0.998133	-9.90691E-5	6.10649E-2
	BS	n3*	-0.999815	-1.25204E-4	1.92138E-2
BS	Y	n4	-0.707088	0.707094	6.67434E-3
	X	n5*	-0.70689	0.706912	2.41253E-2
ITMx	BS	n6	-0.999799	-1.2506E-5	-2.00469E-2
	cavity	n7*	-1.	9.73498E-8	3.13974E-4
ITMy	BS	n8	-6.29595E-6	-0.999805	-1.97419E-2
	cavity	n9*	9.73578E-8	-1.	6.18974E-4
ETMx	cavity	n10	-1.	-3.66047E-10	-3.14E-4
	end	n11*	-0.999402	2.16024E-5	3.45857E-2
ETMy	cavity	n12	-9.80132E-13	-1.	-8.57E-6
	end	n13*	1.09584E-5	-0.999391	3.48909E-2

Table 5: Surface vectors in local coordinates for the Hanford 2 km IFO

Optic	*Surface*	*Vector*	$\hat{i}$	$\hat{j}$	$\hat{k}$
Hanford 2 km IFO					
RM	laser	n2	0.99819	5.17989E-7	6.01335E-2
	BS	n3*	0.999833	1.59317E-7	1.82809E-2
BS	X	n4	0.707094	-0.70709	6.45837E-3
	Y	n5*	0.706912	-0.706897	2.39094E-2
FMx		n9	0.706758	0.70745	2.87225E-3
		n13*	0.706267	0.706937	3.77699E-2
FMy		n6	0.707127	0.707081	2.87583E-3
		n12*	0.706636	0.706569	3.77734E-2
ITMx	FM	n10	-0.999957	-8.21026E-8	-9.27103E-3
	cavity	n11*	-1.	2.65515E-9	6.19037E-4
ITMy	FM	n7	-6.11926E-6	-0.999951	-9.88143E-3
	cavity	n8*	2.6777E-9	-1.	8.60694E-6
ETMx	cavity	n16	-1.	-1.85988E-12	3.02E-4
	end	n17*	-0.99938	2.99087E-7	3.52013E-2
ETMy	cavity	n14	-6.52045E-10	-1.	-3.08E-4
	end	n15*	2.16021E-5	-0.999402	3.45917E-2

Table 6: Surface vectors in local coordinates for Hanford 2 km IFO

Optic	*Surface*	*Vector*	$\hat{i}$	$\hat{j}$	$\hat{k}$
Hanford 2 km IFO					
RM	laser	n2	0.99819	5.17989E-7	6.01335E-2
	BS	n3*	0.999833	1.59317E-7	1.82809E-2
BS	X	n4	0.707094	-0.70709	6.45837E-3
	Y	n5*	0.706912	-0.706897	2.39094E-2
FMx	BS	n9	0.706758	0.70745	2.87225E-3
	ITMx	n13*	0.706267	0.706937	3.77699E-2
FMy	BS	n6	0.707127	0.707081	2.87583E-3
	ITMy	n12*	0.706636	0.706569	3.77734E-2
ITMx	FMx	n10	-0.999957	-8.21026E-8	-9.27103E-3
	cavity	n11*	-1.	2.65515E-9	6.19037E-4
ITMy	FMy	n7	-6.11926E-6	-0.999951	-9.88143E-3
	cavity	n8*	2.6777E-9	-1.	8.60694E-6
ETMx	cavity	n16	-1.	-1.85988E-12	3.02E-4
	end	n17*	-0.99938	2.99087E-7	3.52013E-2
ETMy	cavity	n14	-6.52045E-10	-1.	-3.08E-4
	end	n15*	2.16021E-5	-0.999402	3.45917E-2

7 BALANCING DATA

Tables 7-11 give angle data for use in balancing. Tables 7 and 8 are for reference only and give the angles in global coordinates. Tables 9-11 give the values in the appropriate local coordinate system. The sign given in the last column is for the outward pointing vector, even in cases such as the RM HR surface and the ITMx/y cavity surface where Dennis Coyne's sign convention is inward pointing. Thus "up" means that the person doing the balancing has to raise the face of the optic and "down means that it should be lowered.

Table 7: Balancing data (in global coordinates) for a generic 4km IFO

Optic	*Surface*	*angle (mrad)*	*degrees*	*minutes*	*seconds*	*sign*
Global - 4 km						
RM	BS	-18.901	1	4	59	down
BS	Y	6.890	0	23	41	up
ITMx	cavity	0	0	0	0	flat
ITMy	cavity	0	0	0	0	flat
ETMx	cavity	0	0	0	0	flat
ETMy	cavity	0	0	0	0	flat

Table 8: Balancing data (in global coordinates) for a generic 2 km IFO

Optic	*Surface*	*angle (mrad)*	*degrees*	*minutes*	*seconds*	*sign*
Generic 2 km IFO						
RM	BS	-18.901	1	4	59	down
BS	X	6.890	0	23	41	up
FMx	BS	3.316	0	11	24	up
FMy	BS	3.320	0	11	25	up
ITMx	cavity	0	0	0	0	flat
ITMy	cavity	0	0	0	0	flat
ETMx	cavity	0	0	0	0	flat
ETMy	cavity	0	0	0	0	flat

Table 9: Balancing data for the Hanford 4km IFO

Optic	*Surface*	*angle (mrad)*	*degrees*	*minutes*	*seconds*	*sign*
Hanford - 4 km						
RM	BS	-19.520	1	7	6	down
BS	Y	7.322	0	25	10	up
ITMx	cavity	-0.619	0	2	8	down
ITMy	cavity	-0.009	0	0	2	down
ETMx	cavity	-0.009	0	0	2	down
ETMy	cavity	-0.619	0	2	8	down

Table 10: Balancing data for the Livingston 4km IFO

Optic	*Surface*	*angle (mrad)*	*degrees*	*minutes*	*seconds*	*sign*
Livingston - 4 km						
RM	BS	-19.215	1	6	3	down
BS	Y	6.674	0	22	57	up
ITMx	cavity	-0.314	0	1	5	down
ITMy	cavity	-0.619	0	2	8	down
ETMx	cavity	-0.314	0	1	5	down
ETMy	cavity	-0.009	0	0	2	down

Table 11: Balancing data for the Hanford 2 km IFO

Optic	*Surface*	*angle (mrad)*	*degrees*	*minutes*	*seconds*	*sign*
Hanford 2 km IFO						
RM	BS	-18.282	1	2	51	down
BS	X	6.458	0	22	12	up
FMx	BS	2.872	0	9	52	up
FMy	BS	2.876	0	9	53	up
ITMx	cavity	-0.619	0	2	8	down
ITMy	cavity	-0.009	0	0	2	down
ETMx	cavity	0.302	0	1	2	up
ETMy	cavity	-0.308	0	1	4	down