The Pre-stabilized Laser Reference Cavity

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ABSTRACT

Material describing the PSL reference cavity is enclosed in this collection of notes. The first in hopefully a series that will cover the PSL.

1. THE REFERENCE CAVITY – A PHYSICAL DESCRIPTION

The PSL reference cavity, shown in Figure 1, is a linear Fabry-Perot cavity consisting of a 203.2 mm long fused silica spacer with two mirrors that are optically contacted to each end of the spacer. The spacer is a right cylinder with an outer diameter of 50.8 mm and an inner diameter of 12.7 mm. Each end of the spacer is polished to a surface figure of 10-5 and flat to $\lambda/20$. In addition a 1.27 mm $\times$ 45° chamfer exists at each end. In the middle of the spacer is a 6.35 mm diameter vent hole which is bored from the outside of the spacer body through to the inner bore. 38.1 mm in from each end is a 90°$\times$ 0.508 mm deep groove for the wires used to suspend the cavity. The spacer is made from either Corning 7940 or Dynasil 1100.

The concave mirrors used are 25.4 mm diameter, 6.35 mm thick with a wedge angle of 30 minutes, and a radius of curvature of 500 mm. The mirrors are specified to have a transmission of 300 ± 30 ppm, a loss of less than 30 ppm and a back surface that is anti-reflection coated such that the reflectivity is less than 500 ppm for a wavelength of 1064 nm. The mirror substrate material is Dynasil 1101.

2. REFERENCE CAVITY PARAMETERS

2.1. Cavity Length

Because the reference cavity mirrors are curved, the cavity length is not the length of the spacer. A small correction must be applied in order to get the correct cavity length. Figure 2 shows the geometry of the correction.

For the reference cavity, a is taken to be 6.35 mm and R is 500 mm. In fact the reference cavity mirrors have a small annulus polished on them, so a is really less than 6.35 mm. The segment x is half the correction to the spacer length in order to get the cavity length. Simple geometry gives the following expression for x

$$x = R - \sqrt{R^2 - a^2}$$

Substitution of the above values gives x to be $40\,\mu$m. The cavity length is therefore 203.3 mm.

2.2. Beam Waist and Location

The beam waist and location of the beam waist is given by[1]

$$w_0^2 = \frac{\lambda}{\pi}\,\frac{R\sqrt{d\,(2R-d)}}{2R + d\,(n^2-1)}$$

and

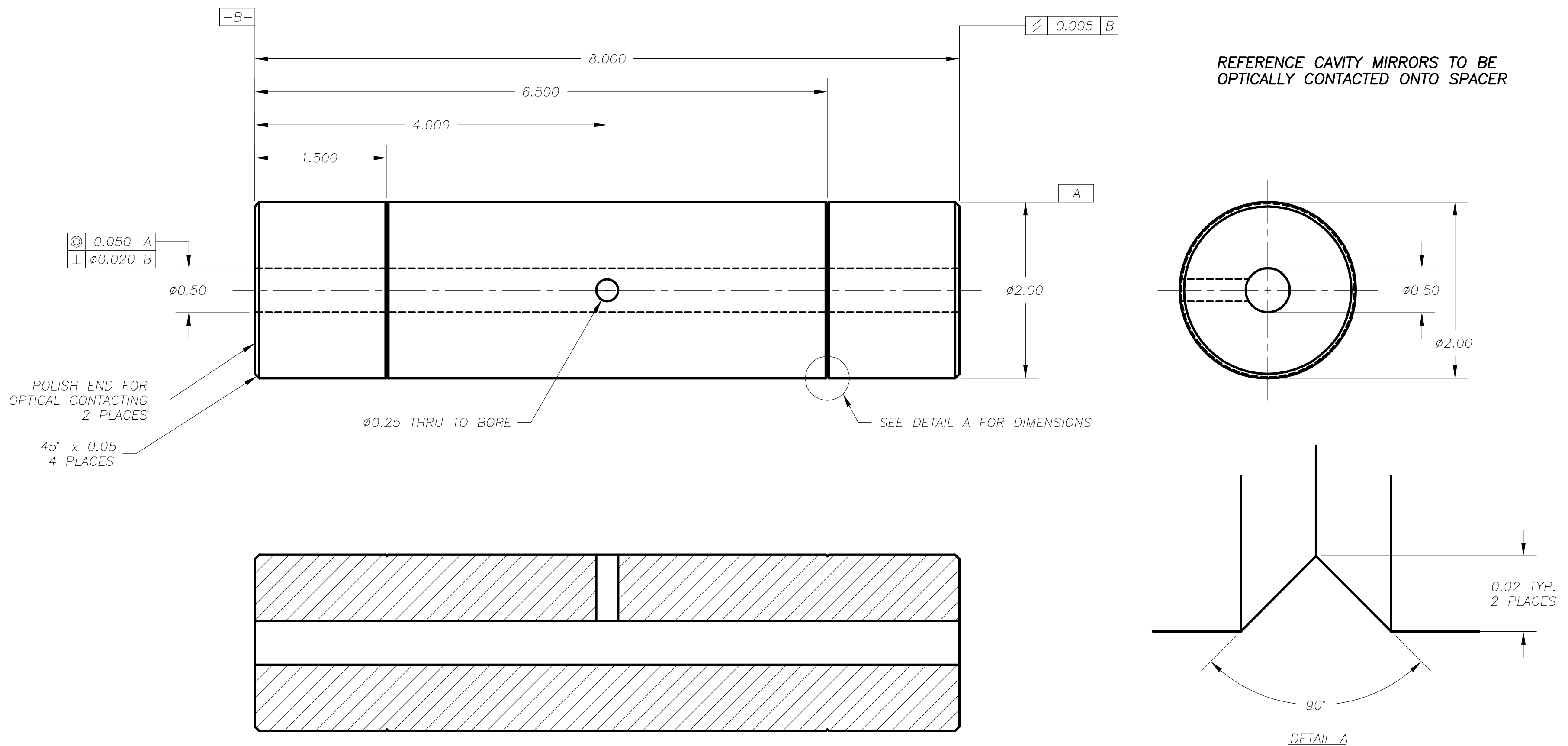
$$t = \frac{n\,d\,R}{2R + d\,(n^2-1)}$$

respectively, where n is the refractive index of the mirror substrates, R is the radius of curvature of the cavity mirrors and d is the distance between the back surfaces of the cavity mirrors. The geometry is shown in Figure 3. Assuming that the refractive index of the mirror substrates is 1.45 then

$$w_0 = 237\,\mu\text{m}$$

and

$$t = 126\,\text{mm}$$



UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES

TOLERANCES:
FRACTIONAL ±
ANGULAR ± 1°
ANGULARMACH ± BEND ±
TWO PLACE DECIMAL ± 0.030

THREE PLACE DECIMAL ± 0.005
FINISHED SURFACE RMS
BREAK CORNERS IN: OUT:
REMOVE ALL BURRS

MATERIAL: FUSED SILICA
HEAT TREAT:
FINISH:
USED ON:
NEXT ASS'Y:

DWG. NO. | DESCRIPTION

REFERENCE DRAWINGS

REV	DESCRIPTION	DCC	SYS	DET	CDS	VE	CC	BT	CHECK	DRWN	DATE
00	PRE-RELEASE									P. KING	06/10/97

ISSUE DESCRIPTION

LIGO CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PRE-STABILIZED LASER
REFERENCE CAVITY SPACER

CAD FILE: D970002-RC.dwg
SIZE: B
DWG. NO. D970002-RC
SCALE: NTS
SHEET: 1 OF 1

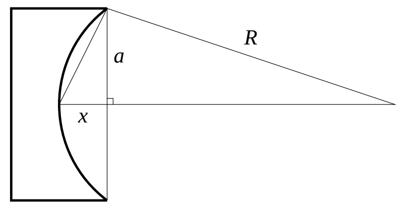


Figure 2. Geometry for correcting for the curvature of the reference cavity mirrors. The scale is exaggerated for clarity.

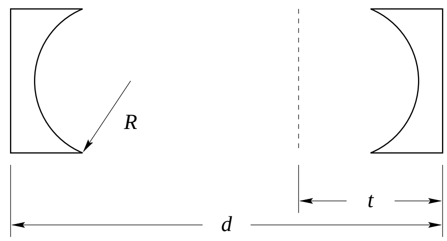


Figure 3. The geometry used in calculating the beam waist and its location.

2.3. Free-spectral Range

The free-spectral range (FSR) of a cavity, of length L, is given by

$$FSR = \frac{c}{2L}$$

For the reference cavity the FSR is calculated to be 736.5 MHz.

2.4. Cavity Finesse

The cavity finesse $\mathcal{F}$ is given by

$$\mathcal{F} = \frac{\pi\sqrt{R}}{1-R}$$

where R is the reflectance of the mirror. Note that $R+T+L=1$ where T is the transmittance and L is the total loss. Substituting in the appropriate values gives a value for the finesse of

$$\mathcal{F} = 9\,518$$

The full-width-half-maximum bandwidth of the cavity $\Delta\nu_{FWHM}$ is given by

$$\Delta\nu_{FWHM} = \frac{FSR}{\mathcal{F}}$$

The bandwidth is handy to know when it comes to calculating the slope of the so-called Pound-Drever discriminator slope. The calculated bandwidth is 77.4 kHz.

2.5. Cavity Storage Time

The cavity storage time is given by

$$\tau_p = \frac{1}{FSR}\,\frac{1}{1-R_1R_2}$$

where R_1 and R_2 are the reflectances of the cavity mirrors. The cavity storage time is therefore calculated to be 2.06 μs.

mirror diameter	25.4 mm
mirror thickness	6.35 mm
mirror wedge angle	30 minutes
mirror transmittance	300 ± 30 ppm
mirror absorptance	< 30 ppm
mirror back surface reflectance	< 500 ppm
cavity length	203.3 mm
beam waist	237 μm
beam waist location	126 mm from back surface of mirror
free-spectral range	736.5 MHz
finesse	9518
bandwidth (FWHM)	77.4 kHz
storage time	2.06 μs

Table 1. Summary of the reference cavity parameters.

3. AT A GLANCE

REFERENCES

1. H. Kogelnik and T. Li
   Laser Beams and Resonators
   Appl. Opt. **5**, 1550–1567 (1966).