Optical characterization



Resonant modes in a cavity

One mode V_{mnq} = three parameters m, n, q - m, n = transverses modes





Fundamental mode and higher-order modes

Frequency of resonant higher-order modes:

$$\delta \nu = k \nu_0, \quad \nu_0 = \frac{c}{2d} \frac{1}{\pi} \cos^{-1} \left[\left(1 - \frac{d}{R_1} \right) \left(1 - \frac{d}{R_2} \right) \right]^{1/2}.$$

with k = m+n

FSR scans of the arm cavities



Analysis of 1 scan



Detection of the TEM00 as the tallest peaks detected

Restriction to interval between TEM00 for other modes and sidebands detection and removal of aberrent peaks Peak identification

Utility of FSR scans for characterization of the arm cavities



Zoom on one scan (duration ~60s)

Information obtained from FSR scan

- -> misalignment from TEM 00 and TEM 01 mode spacing
- -> mismatch is linked to height ratio of TEM02 and TEM00

(see Alignment of resonant optical cavities, Dana Z. Anderson for this link)

-> height of sidebands gives the depth of modulation

-> g factor computed for mode-spacing

-> evolution of g-factor from hot to cold interferometer, input/end mirror change RoC using mode spacing

ROC computation

$$\frac{d(\text{HOM-TEM00})}{FSR} = \frac{k}{\pi} \operatorname{acos}_{\sqrt{\left(1 - \frac{L}{R1}\right)\left(1 - \frac{L}{R2}\right)}}$$

- Cold ROC

Use one value for cold ROC (here: IM) to compute the 2nd cold ROC using mode-spacing fit when the ITF is cold $(t=\infty)$

- <u>Hot-to-cold change</u>

Assume an equal ROC change for EM and IM to compute ROC change using mode-spacing fit at unlock (t=0)

```
function calculate_ROC(d_0, d_inf, k, known_ROC)
%k order of mode
L=3000;
R1_inf = known_ROC;
syms R2 real
R2_inf = vpa(solve(d_inf ==k/pi*acos(sqrt((1-L/R1_inf)*(1-L/R2))), R2))
syms a %variation totale
R1_0 = R1_inf + a;
R2_0 = R2_inf + a;
a_value = vpasolve(d_0 == k/pi*acos(sqrt((1-L/R1_0)*(1-L/R2_0))),a)
fprintf("Cold ROC: R1 = %fm and R2 = %fm\t---\t " + ...
    "Hot ROC : R1 = %fm and R2 = %fm \n", R1_inf, R2_inf,R1_inf +a_value, R2_inf + a_value)
fprintf("Variation: R_0 = R_inf + a with a = %fm\n", a_value)|
end
```

Cold scans



Mode spacing : (position of HOM – position of TEM00) /FSR

Hot to cold scans



Overlay of scans

	Cold NE ROC (13/03) (m)	
TEM01	1677.2 +/- 0.4	
TEM02	1676.4 +/- 0.1	
TEM03	1679 +/- 2	
TEM04	1681.73 +/- 0.04	

	NA ROC change (m)	WA ROC change (m)
TEM01	3	1.5
TEM02	5	3.5
TEM03	3.5	2.5
TEM04	3.5	2.5



Mismatch and misalignment



Ring heater calibration

- Change of cold ROC following RH power change from 07/01/23 and 02/02/23 scans (see VIR-0544A-23)
- Recomputed values from 07/01 to use the same HOM as a basis for comparison
 - These cold RoC values all come from the extrapolation of hotto-cold ITF measurements Astigmatism very visible in 07/01 scans (more so on North arm than West arm) 3228 3230



Recomputed values are not as good as in January (see VIR-0038A-23) because more spread out (probably from using a different method for peak detection)

Ring heater calibration

Mirror, HOM considered, method for peak detection	NA (m)	WA (m)
IM RoC	1421	1422
EM RoC (07/01 scans, TEM02, find peaks)	1671.2 +/- 0.2	1673.1 +/- 0.1
EM RoC (02/02 scans, TEM02, find peaks)	1675.6+/-0.06	1676.4 +/-0.07
EM RoC (07/01 scans, TEM04, find peaks)	1676.5 +/- 0.1	1677.1 +/- 0.1
EM RoC (02/02 scans, TEM04, find peaks)	1680.70 +/- 0.05	1680.65 +/- 0.05

Total change of RH power :

NEM : RH power change of -1.14W WEM : RH power change of - 0.82 W

	NA (m/W)	WA (m/W)
Calibration using TEM02	-3.9+/-0.2	-4.0+/-0.2
Calibration using TEM04	-3.7+/-0.1	-4.3+/-0.2