Modelling Convex-Concave Ultra-Stable Optical Cavity

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***Summary*—We have designed an optical cavity with a large beam spot diameter on the mirror's surface to reduce a thermal noise stability limit connected with mirror reflective coatings. We propose an optical cavity in a concave-convex configuration.**

Keywords—component; Optical Cavity, ultra-stable cavity, laser, Gaussian beam, narrow line, big spot size.

I. Introduction

Ultra-stable, high-Q optical cavities of narrow-linewidth lasers are essential for optical atomic clocks [1]. One of the fundamental limits that affect the stability of the lasers is the thermal noise of the cavity components. Possible mitigation includes longer cavity spacers [2-3], cryogenic temperatures [4], and reflective materials with low mechanical losses [5]. Unfortunately, all those methods come up with disadvantages. For instance, cryogenic temperature brings vibrations due to the technical limitations of the cooling system and long cavities have problems with supporting structure. Therefore, we have decided to design an optical cavity with a concave-convex configuration that can have a big light spot radius on both mirrors' surfaces. This design will not only increase the stability of the cavity but can be economically beneficial.

II. Method and Results

Thermal noise of an optical cavity can be computed using the fluctuation-dissipation theorem (FDT) [6]. The noise power spectral density of mirrors' coatings is proportional to the square of the beam spot radius. The size of the light beams on the cavity mirrors depends on the mirrors' radius of curvature (RoC) and the cavity length. Since the RoC of commercially available mirrors is limited, to increase the beam spot radius the length of the cavity can be increased. To avoid a long cavity we chose instead the convex-concave configuration. Due to manufacturing limitations, we have limited the range of RoC between 1 m and 20 m. In our calculation, we have considered different factors, e. g. stability condition for resonators, the spot size of the light beam on mirrors, and the higher order modes which may appear close to the fundamental mode. Moreover, we have considered possible misalignment in the assembling of the cavity and tolerances during the manufacturing of the cavity.

III. Simulation and Results

The numerical simulations were performed in MATLAB. Fig. 1 shows the stable region for different combinations of RoC between 1 m to 20 m. The lower stability parameter (g1g2) results in better stability conditions for the resonator. Fig. 2 presents that by increasing the RoC of both mirrors we can increase the beam spot size. In addition, results depicted in Fig. 3 reveal the areas where the first higher order mode appears close to the fundamental mode, and, the color bar shows which number of the higher order modes are in the region.

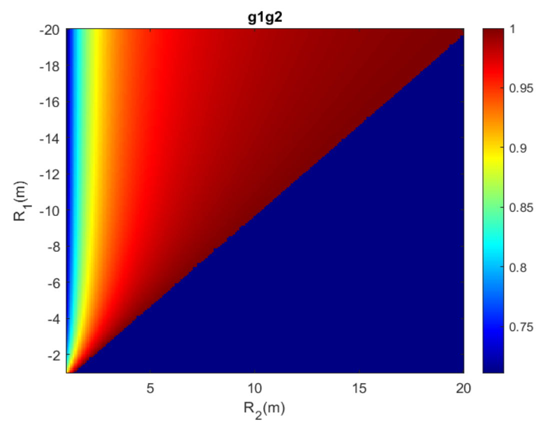

Fig. 1. The stability condition for different RoC (1- 20 m).

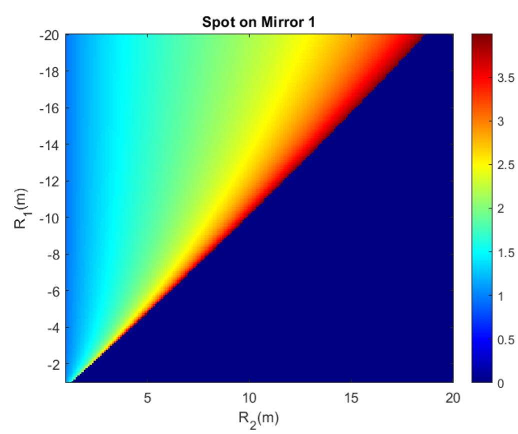

Fig. 2. The diameter (in mm) of the beam spot on mirror.

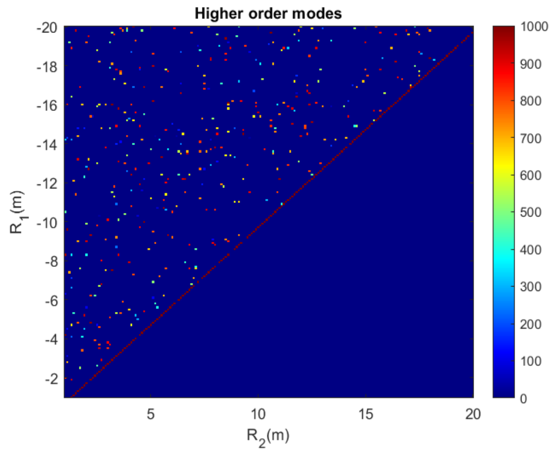

Fig. 3. The safe regions where there are no higher order modes close to the fundamental mode for different configurations of RoC.

IV. CONCLUSIONS

We report the design of the ultra-stable cavity with big beam spots size on the mirrors to reduce mirrors' substrates and reflective coating thermal noise contribution.

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