Virtual Research Presentation Conference

Compact Optical Fabry-Perot Etalon for Space Application

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Program: Innovative Spontaneous Concept

Assigned Presentation RPC-141

Jet Propulsion Laboratory
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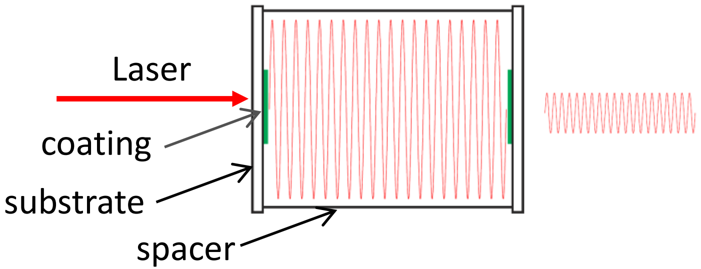
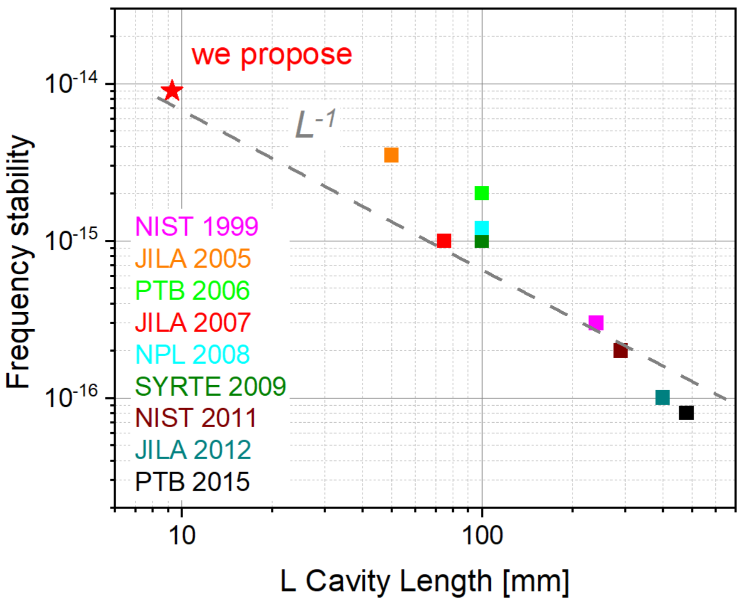
Tutorial Introduction

Abstract

a) Stable laser based on Fabry Perot etalon:
Laser frequency is referenced to cavity length $\Delta \upsilon / \upsilon = -\Delta L / L$



b) Highly stable optical frequency is critical in a variety of advanced research direction: optical atomic clock, gravational wave detection, very long base line interferometry, geodesy…



c) Better stability needs longer cavity, L^{-1} trend
Thermal noise (determined by the materials of coating, substrate and spacer) induced frequency noise is normalized by cavity length

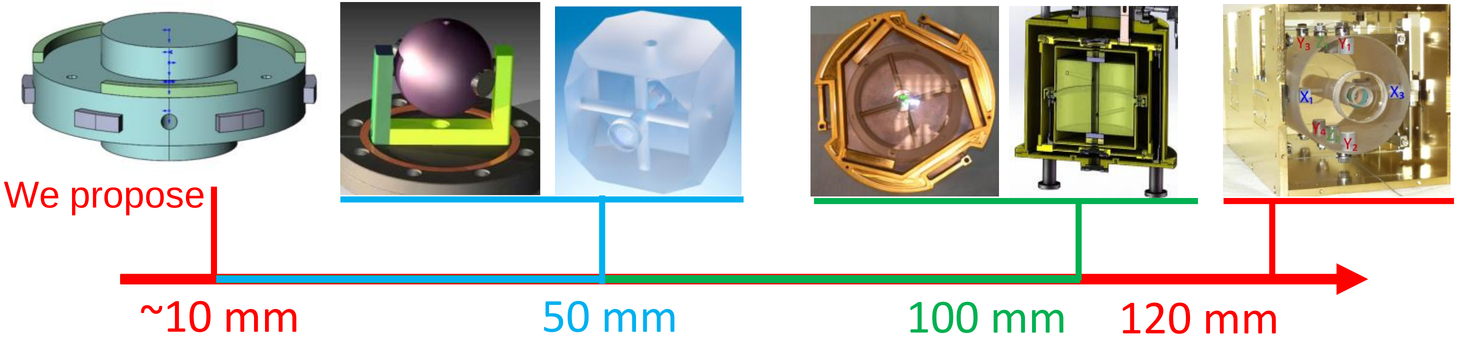
d) Cavity sits in highly isolated lab environment high vacuum, vibration isolation
Why: e.g. if cavity length = 1 meter, frequency stability = 1×10^{-16}, length change=1×10^{-16} meter. Size of nucleus 1×10^{-14} meter
Besides the fundamental thermal noise, technical noise are:

1. Temperature induced length change through coefficient thermal expansion
2. Vibrations induced length change through vibration sensitivity *length change=vibration noise × vibration sensitivity*

Problem Description

a) Sub Hz laser linewidth have been demonstrated, most of them are sitting in lab environments, and comprised of relatively large size, weight and power consumption (SWaP). All these factors are not optimized for space application.

b) State of the Art: There has been significant effort on portable cavity systems in which the method of rigid support cavity is primary consideration. But the cavity size is 50 mm to > 100 mm to implement the rigid mounting strategy, so SWaP of the entire system is still unsolved



c) We propose a cavity made by ultra low expansion glass, with compact size about 10 mm in length, and a novel rigid support system, sufficiently simple and cost effective design for space application

d) Relevance to NASA and JPL

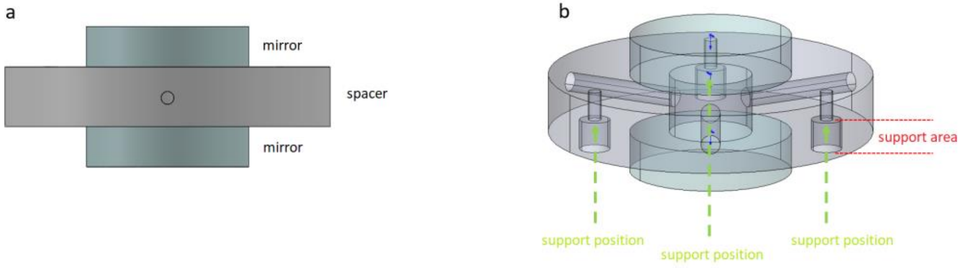
Narrow laser linewidth ~2Hz optical atomic clocks, broadband spectrometers, and GRACE-FO

Low drift rate < 0.1Hz/s high precision calibration for beam path control in HabEX

Methodology

a) Approach (NTR 51769)

1. We propose ~10 mm cavity which vertically supported by three counterbored holes which are evenly distributed
2. Vibration insensitive cavity design based on finite elements analysis: the deformation of one mirror due to vibration is compensated by the other mirror, so the cavity length is constant, leading to stable optical frequency
3. Cavity sits on a rigid support structure. Vertical and horizontal constrains are applied on the cavity

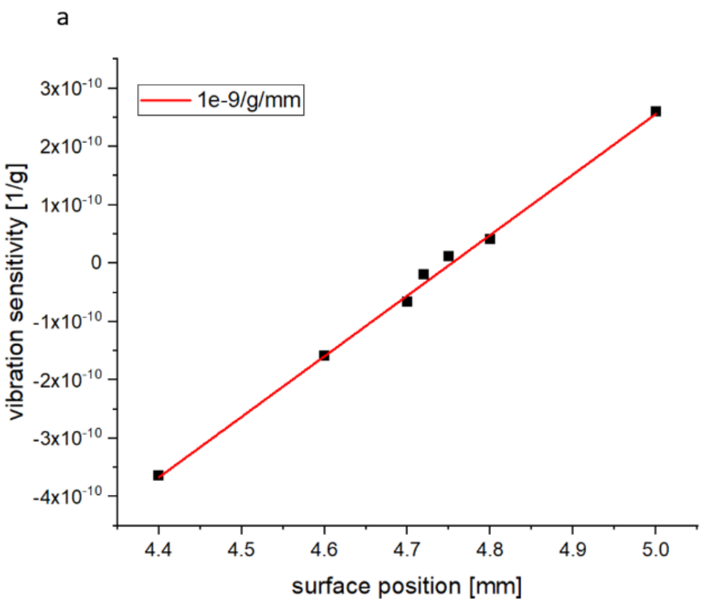


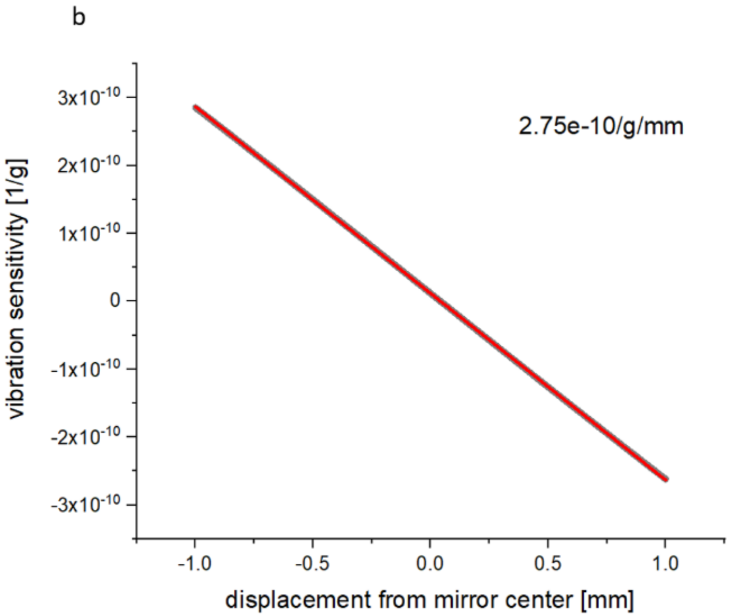
b) Innovation

1. We explore the compact cavity geometry and figure out a vibration insensitive support position
2. Cavity rigid support is design to decouple the temperature induced deformation and stress
3. The positions where the constrains are applied are optimized to minimized the force induced mirror deformation

Results

1) Cavity vibration insensitive design: shifting the vertical position of the support surface in the counterbored holes, vibration sensitivity has a zero-crossing at about 5 mm and slope is 1e-9/g/mm. The slope of the sensitivity in the horizontal plane is 2.75e-10/g/mm. These numbers are suitable for cavity stabilized laser system





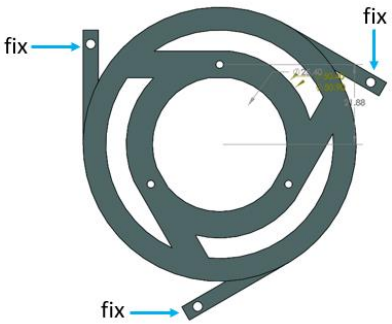
Results

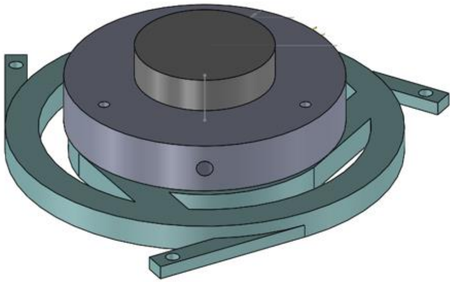
2) The cavity sits on a rigid support which has dual ring shape.

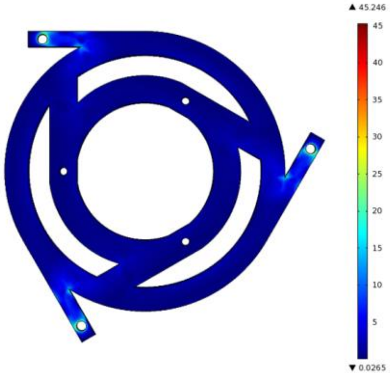
a. The ring is made by Invar, and outer ring is bolted down to the vacuum chamber. The inner and outer beam size is optimized by FEA to minimized the stress and deformation of the inner ring induced by the temperature fluctuation coupled from outer ring.

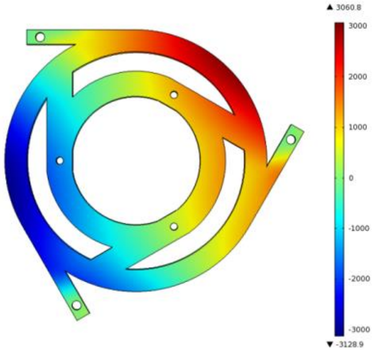
b. When the outer ring experience 50 Kelvin temperature change (293 K to 343 K), the stress is 40 MPa on the fix holes on the outer ring, and 1 MPa on the three holes on the inner ring which are used to support the cavity. Considering the yield stress of Invar is 300 MPa, the temperature induced stress on the dual ring rigid support is negligible.

c. The displacement with 50 K temperature change on the cavity support holes is 1.5 um, and there is no impact on the cavity vibration sensitivity.









Results

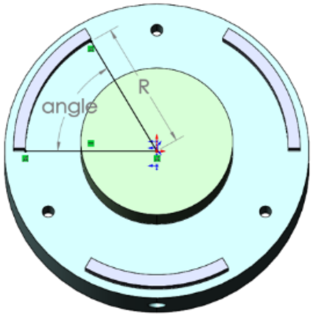
3) Constrain for vertical direction

a) Using three curved bars on top of the spacer surface. The force is applied on the bar and the direction is along the gravity. Together with the rigid support, the cavity is hold.

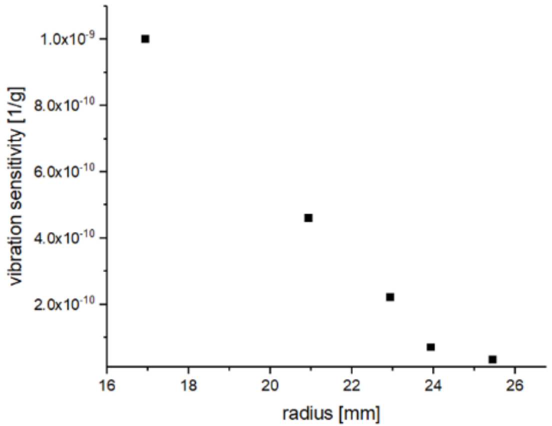
b) The position (R) and length (angle) of these three curved bars are optimized to minimize the force impact on the cavity deformation.

c) 1 N force, corresponding to 2g acceleration, lift the vibration sensitivity by 3e-12/g along vertical direction. In the assumption that the radius of the bar is 1 mm smaller than the optimized design and angle is 10 degree mismatch, the force induced vibration sensitivity is still below 1e-10/g determined by the cavity design.

a



b



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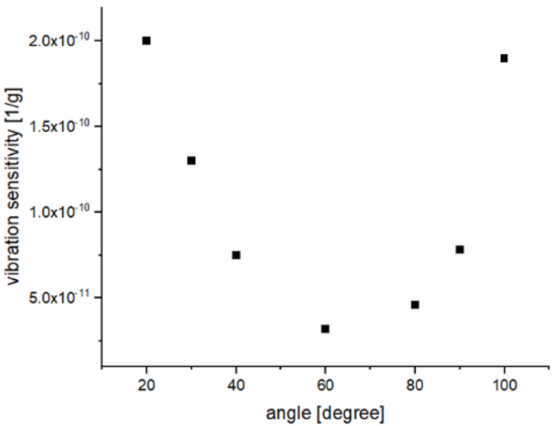


Results

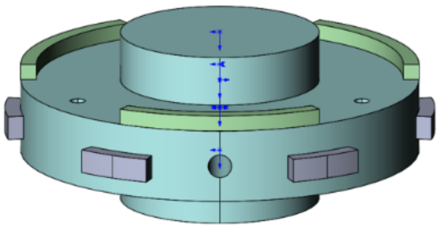
4) Constrain for horizontal plane

a) using six curved bars touching on the spacer side, and force on each of them is on the horizontal plane and pointing to the geometry center

b) adjusting the angle between two bars to minimize the force impact

c) 1 N force change vibration sensitivity 3.8e-13/g. The angle can be varied from 30 degree and the vibration sensitivity is 5e-13/g, which is still negligible comparing to the vibration sensitivity determined by the cavity spacer

a



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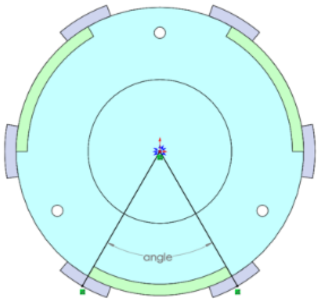

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