@ Florentin

Did not edit response 2, since I don't get the idea you're trying to get at. You might also want to include a small 1-2 sentence primer on how coupling strength changes with FSR from c.c, or else a general reader will have no idea what the paper is talking about when you say "at x FSR from concentric". Also, all that "last stable point" stuff, you're going to have to deal with it.

Also, as a side note, I have never seen anyone else use the term "loosely locked".

Reviewer #2 comments

Dear reviewer #2,

Thank you for giving us the opportunity to submit a revised draft of our manuscript to RSI. We appreciate the time and effort that you have dedicated to providing your valuable feedback on our manuscript. Here is a point-by-point response to the reviewers' comments and concerns.

- **Comment 1:** *It is not clear from the paper at which cavity length (or critical distance d) the cavity is characterised. The sentence "This value is chosen as it ... will allow greater tip-tilt tuning as the cavity approaches concentricity" suggests that the cavity is or will not be operated at d = 7.8 um. As a consequence the following questions arise.*
  a. What is the expected cavity mode diameter at the mirrors for the cavity length that was used in this work / will be used to achieve the coupling strength quoted in the one before the last paragraph?
  b. Are there significant (with respect to the finesse) losses due to the finite mirrors size for the cavity at those lengths?
  c. Would there be significant change in those losses from the transversal mirrors displacement, measured in this work?
  d. See question 2.b

  Responding to all the parts in what essentially looks like a single paragraph looks very messy. There should probably be an empty row of space between the responses to each part.

Response: The value of $d \approx 7.8\,\mu\text{m}$ during the gluing of the mirrors is chosen such that it is half of the piezo's travel range. As the cavity approaches the concentric point (as d approaches 0), each piezo is able to travel $\sim 7.8\,\mu\text{m}$ in both directions, therefore increasing the cavity's tip/tilt adjustability. In this paper, the measurements were conducted for a critical distance of $d = 1.06(5)\,\mu\text{m}$, corresponding to 3 FSR from the concentric point. The specific critical distance value at which the measurements were conducted will be added to the manuscript.
At a critical distance $d = 1.06(5)\,\mu\text{m}$, the cavity beam waist at the mirrors is estimated at $w(z_{mirror}) \approx 0.37\,\text{mm}$. The clear aperture diameter of the mirrors is specified to be 7.4 mm from the manufacturer. Due to the large clear aperture provided, the finite mirror size and any transversal mirror displacements measured in this work do not significantly impact the losses.

- **Comment 2:** *Partially related to the last question. Authors state that "Close to the concentric point, transverse positioning noise will dominate the deviation of the cavity resonance from the atomic transition." This statement appears to be central for all that follows in the manuscript. I recommend authors substantiate that statement with a brief explanation or literature.*
  a. If the statement above is true and d is known it looks like the measured effective cavity length variation could be converted to the actual mirror displacement or tilt, a value that could be useful for a specialised reader.
  b. If the cavity was not characterised at the length that it is aimed to operate for the strong coupling, what will be the effective change dL, once the length of the cavity is increased to the operational one?
  Response: The closer to the concentric point, the more focused the cavity modes become, leading to higher transverse sensitivity. As an error signal can easily be obtained through the PDH technique for the

longitudinal axis of the cavity, it is possible to transfer the stability of the lock laser to the cavity. However, transverse locking schemes are not trivial and lack a clear way of defining an error signal for a possible lock. Therefore, any transverse displacement would provide higher change in cavity length than a longitudinal displacement, depending on the capability of the transverse locking scheme in place as well as the cavity susceptibility to transverse displacement. More information about the locking schemes, both longitudinal and transverse, can be found in one of our group previous paper [Nguyen et al., 2018]. Is it sufficient in terms of references?

Maybe you misunderstood the question? The question was "can you show why as we get closer to concentric, the transverse noise increases?", not "How can one correct for this noise?". The explanation given also doesn't make sense, the noise we talk about in this paper must be independent of the lock (which is exactly why we had to use a slow lock).

Our measured effective cavity length variation of $\delta L_{C,rms} = 0.36(2)\,\text{Å}$, at a critical distance $d = 1.06(5)\,\mu\text{m}$, would correspond to a mirror transverse displacement in one direction of $0.63\,\mu\text{m}$ How did you get this value?. We can add the evaluation of this transverse displacement when discussing the result of $\delta L_{C,rms}$.

The critical distance of $d = 1.06(5)\,\mu\text{m}$ is the target operation regime for our coming experiments. The last stable resonance of our cavity system is estimated at $d = 0.35\,\mu\text{m}$ and its effective length variation is estimated to be $\delta L_{C,rms} \approx 0.6\,\text{Å}$. A few points. First, I actually did not choose 3 FSR from concentric as the measurement location for the dip measurements presented on the poster. Also, interesting choice of 3 FSR from cc as the target, even though in the introduction and the conclusion, the last stable point kept being mentioned. There also isn't a reason given as to why 3 FSR from cc is the target (why not 4? or 2?). Finally, how did you estimate the noise at the last stable point? If you indeed have a model, it would do better than the current response in part a.

- **Comment 3:** *The method to characterise the cavity noise with the error signal of the laser that is locked to the same cavity raises several questions.*
  a. Authors state that the laser is "loosely locked" using integral feedback. I strongly recommend authors adding the information on the effective cutoff frequency of the feedback loop resulting from that particular integral controller. The interpretation of the Figure 6 is virtually impossible without the knowledge, in which part of the spectrum the lock is expected to track the cavity's length.
  b. The laser frequency noise is measured separately and presented in Fig. 6 (yellow curve), however authors do not clarify if this particular curve is measured while the laser is locked to the cavity under study. The answer to this question can significantly change understanding of Fig. 6.
  Response: Thank you for pointing this out. In this paper, we tuned the strength of the integral part down such that it has a sub-Hz cutoff frequency. We will make sure to include this in the paper.
  For the measurement of the laser noise, as stated it is measured independently from the NC cavity, therefore it is not locked to the cavity while its frequency noise is measured. The intention is to provide a baseline noise level for comparison with the cavity noise. Clarification will be made to not confuse the reader.

- **Comment 4:** *I find the notation "root mean square" to be more informative than "total noise", used by authors. In fact in the current version only the algebra index "rms" allows the reader to be sure what the "total noise" exactly means.*
  Response: Well noted, we will make the change.

- **Comment 5:** *As the authors characterise the mechanical vibrations, It would be useful for the other researchers if authors could specify at least roughly how the whole setup was mounted. In particular, was there any active or passive vibration isolation? Was the setup placed on a suspended optical table? Was additional care taken to damp resonances* *in the mechanical support and/or isolate the setup from the sources of the mechanical noise?*

Response: The measurements were conducted in an UHV environment. The cavity rests within a glass cuvette, mounted onto our main vacuum chamber which operates at 10^{-9} mbar. The vacuum chamber is placed on an optical table stabilized from external vibrations by pneumatic isolators (Newport I-2000). Due to space constraints in the glass cuvette, we did not mount the cavity on a passive isolation stage, thus the cavity is still coupled to vibrations from the vacuum chamber. Any components on the optical table that might introduce noise into the chamber (cooling fans, loose cables attached to the vacuum chamber) were switched off, removed from the table, or clamped down tightly.

We will add this information at the end of the "Cavity alignment" section to ensure clarity as suggested.

[Nguyen et al., 2018] Nguyen, C. H., Utama, A. N., Lewty, N., and Kurtsiefer, C. (2018). Operating a near-concentric cavity at the last stable resonance.