Digital Control for Lock Acquisition

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Abstract

Study of the "guided lock acquisition" as an advanced locking technique for future ground based GW-detectors

Key wards; the guided lock

an intelligent servo which extrapolates the displacement of a mirror. It was proposed and demonstrated at old Caltech 40m in the 90's

We have done

Experiments of the guided lock using TAMA

Eventually we modified this method and succeeded in increasing the lock probability.

contents

contents

1. **Introduction**
2. The guided lock
3. Modified guided lock
4. Summary

1.1 Lock acquisition

1.2 PDH sensing

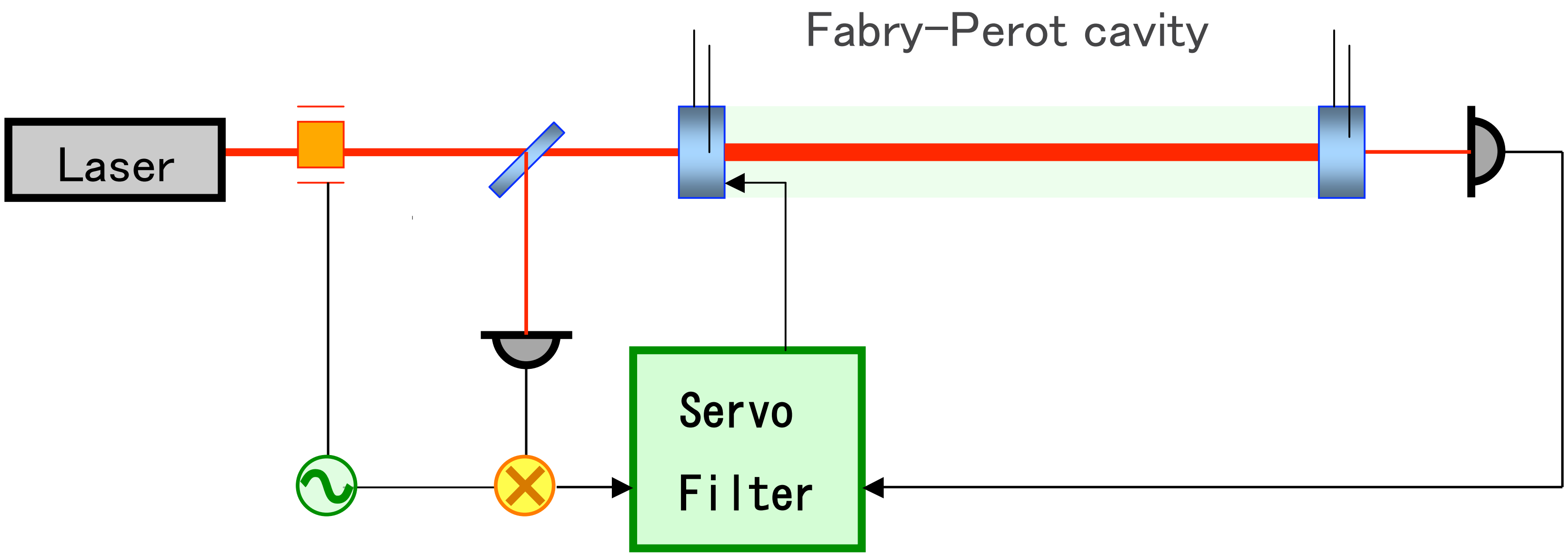
1.3 Locking condition

1.4 Difficulty in locking

1.1 Lock acquisition

The lock acquisition is to make the relative position of the mirrors
$L = n\lambda/2$ (n: integer)

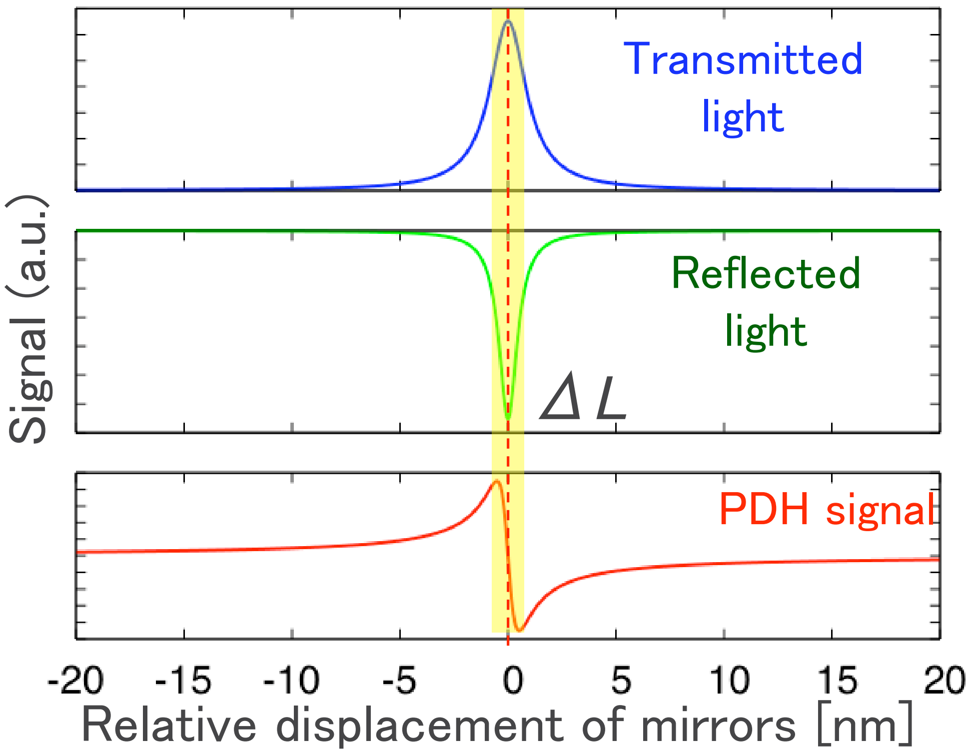
- initially mirrors swing in low frequency (〜1Hz)
- Pound Drever Hall (PDH) technique is used
- servo actuates the mirror



1.2 PDH sensing

PDH signal has a good sensitivity, but ···

provides us the cavity length in only narrow region



The order of the linear region

$$\Delta L \sim \frac{\lambda}{2\mathcal{F}} \quad ,$$

λ : laser wave length
F: finesse

In case of TAMA;
ΔL=1nm

1.3 Locking condition

Locking is not always achieved

3-component

- ▲ Mirror moves with a certain velocity
- ▲ Linear region of signal is narrow
- ▲ Max. actuator force is limited

In order to lock, in principle it is necessary to meet a requirements

(kinetic energy) < (work done by actuator)

$$\frac{1}{2} m v_0^2 \leq F_{\mathrm{max}} \Delta L$$

▲ ▲ ▲

1.4 Difficulty in locking

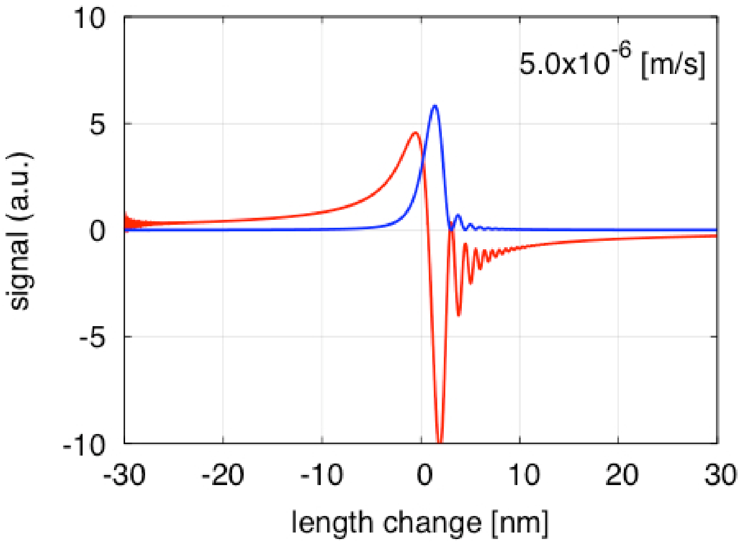
In the future interferometer, locking becomes more difficult

$$\frac{1}{2}mv_0^2 \leq F_{\rm max}\Delta L$$

F_{MAX} → weaker

ΔL → narrower (High finesse)

Moreover, complex dynamical response will easily appear



critical speed of mirror

$$v_{\rm cr} = \frac{\Delta L}{\tau_s} \approx \frac{\pi c \lambda}{4L\mathscr{F}^2}$$

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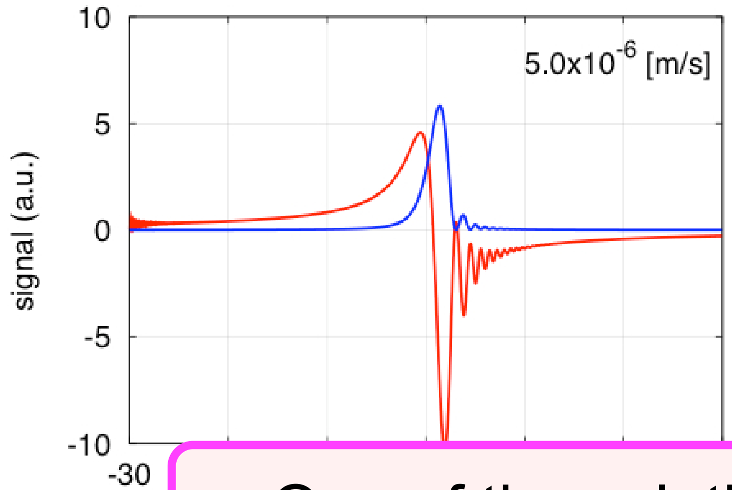


critical speed of mirror

$$v_{cr} = \frac{\Delta L}{\tau_s} \approx \frac{\pi c \lambda}{4L\mathscr{F}^2}$$

One of the solution is the guided lock

contents

1. Cavity lock

2. The guided lock

3. Modified guided lock

4. Summary

2.1 what is guided lock

2.2 experimental set up

2.3 velocity measurement

2.4 Uncertainty

2.5 Problem

2.1 What is guided lock?

proposed by J.Camp et al (1995)

An intelligent servo which extrapolates the displacement and actuates the mirror

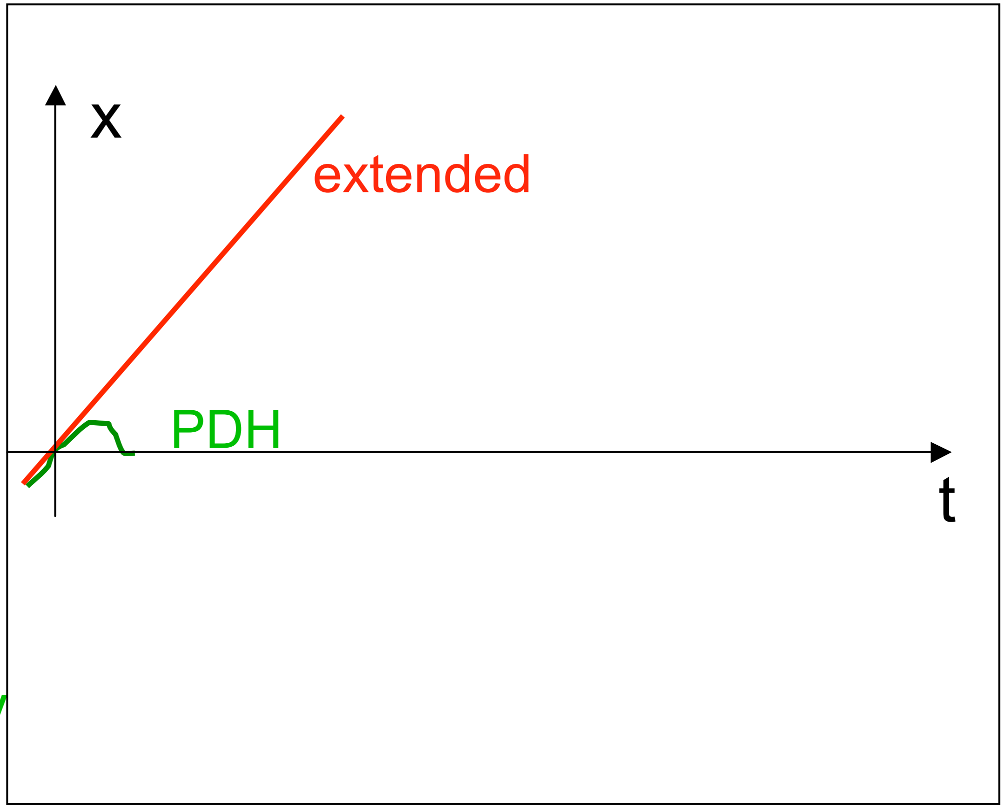
- - Assumption - -

Mirror moves with uniform velocity

$$\frac{1}{2} m v_0^2 \leq F_{\max} \Delta L$$

⇒extends ΔL effectively

⇒gets slower mirror



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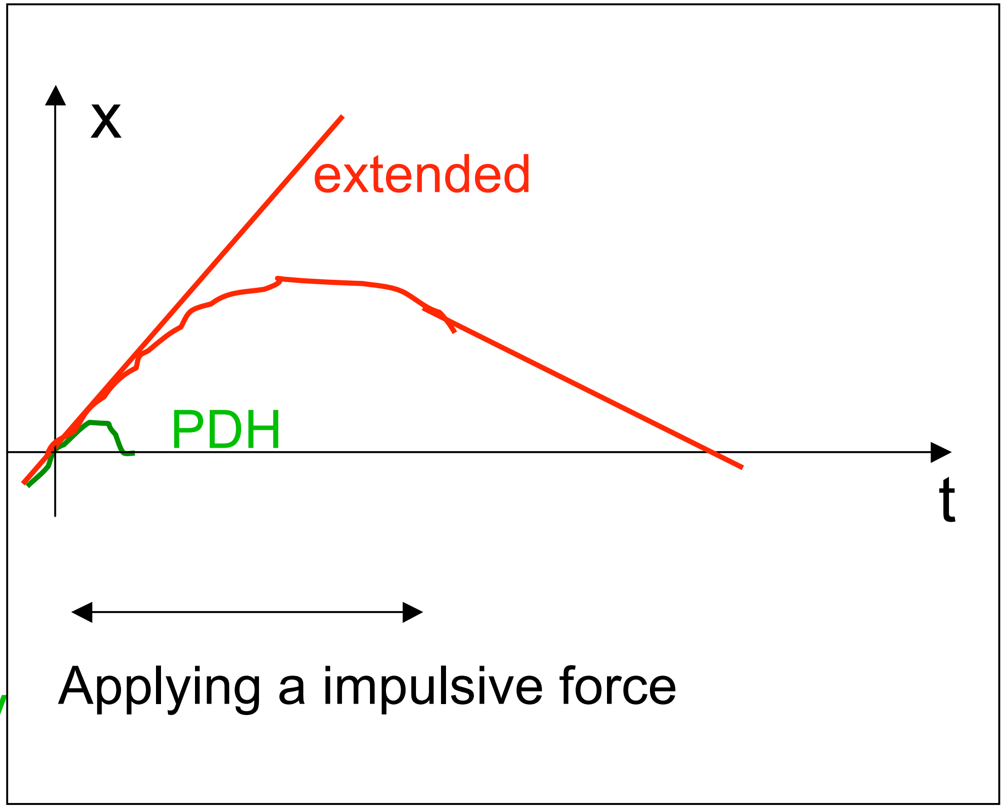
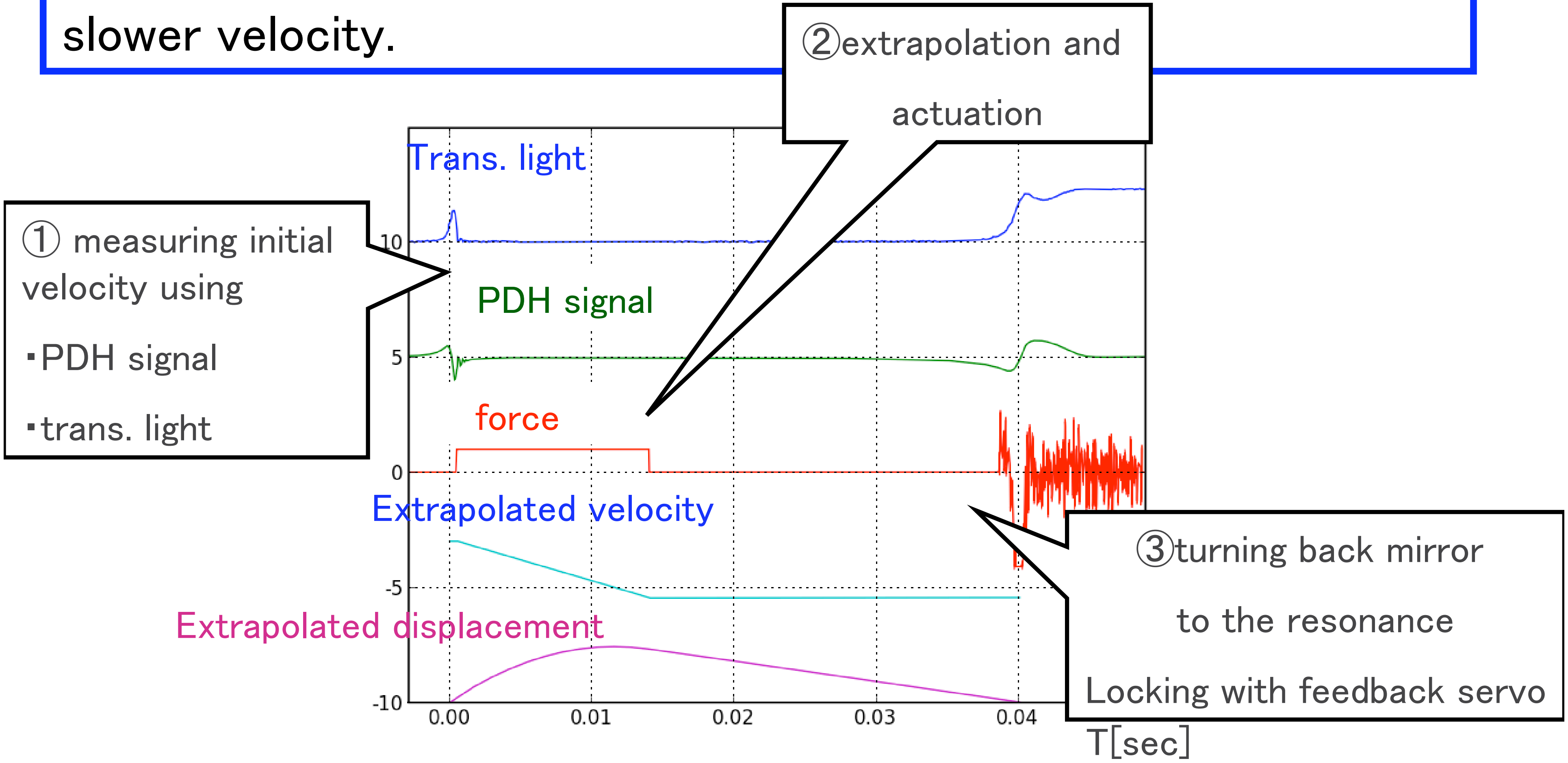


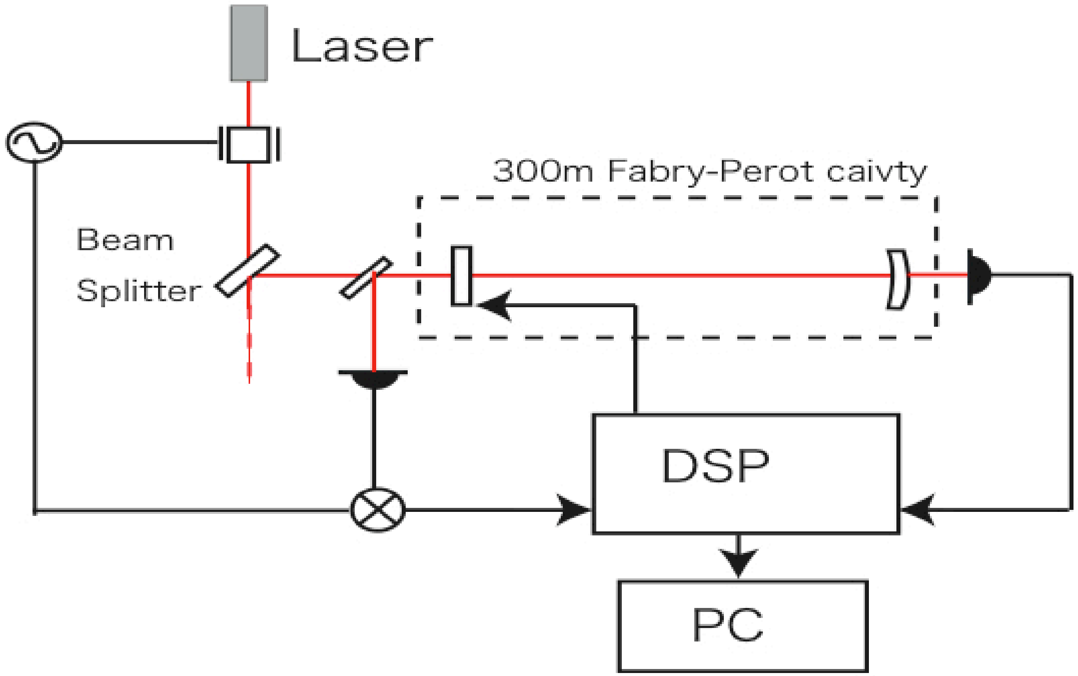
2.1 What is guided lock?

Based on the velocity obtained form a resonance, extrapolates the displacement and guides the mirror into the resonance with slower velocity.



2.2 Experimental set up

Fabry-Perot cavity in TAMA300



L=300 [m]
λ=1064 [nm]
finesse : 500
200kHzAD/DA-samp.

Transmitted light, PDH signal are inputted into DSP(Digital Signal Processor)

2.3 Velocity measurement

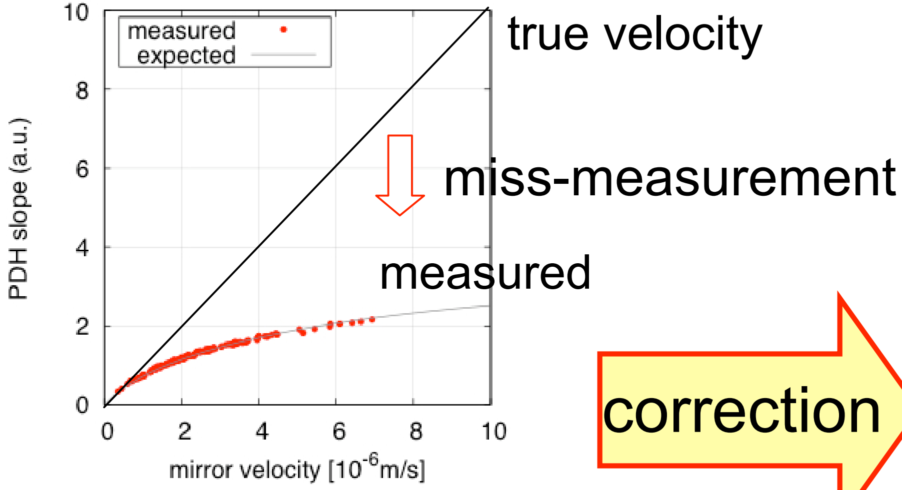
Measuring the Initial velocity is necessary for extrapolation

Slope of PDH + correction by trans. light

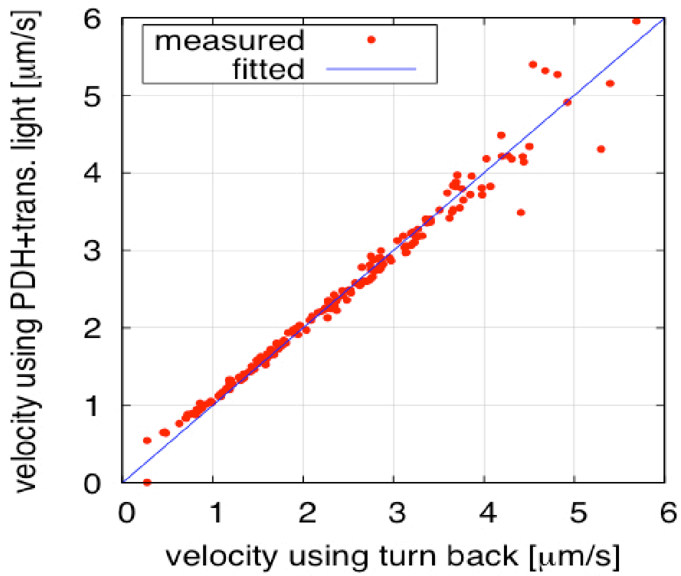
$$v = \frac{1}{H}\frac{dV_{\mathrm{PDH}}}{dt}\left(\frac{T}{T_0}\right)^{\Gamma}$$

(Γ=-1.4)

PDH slope   Trans. light

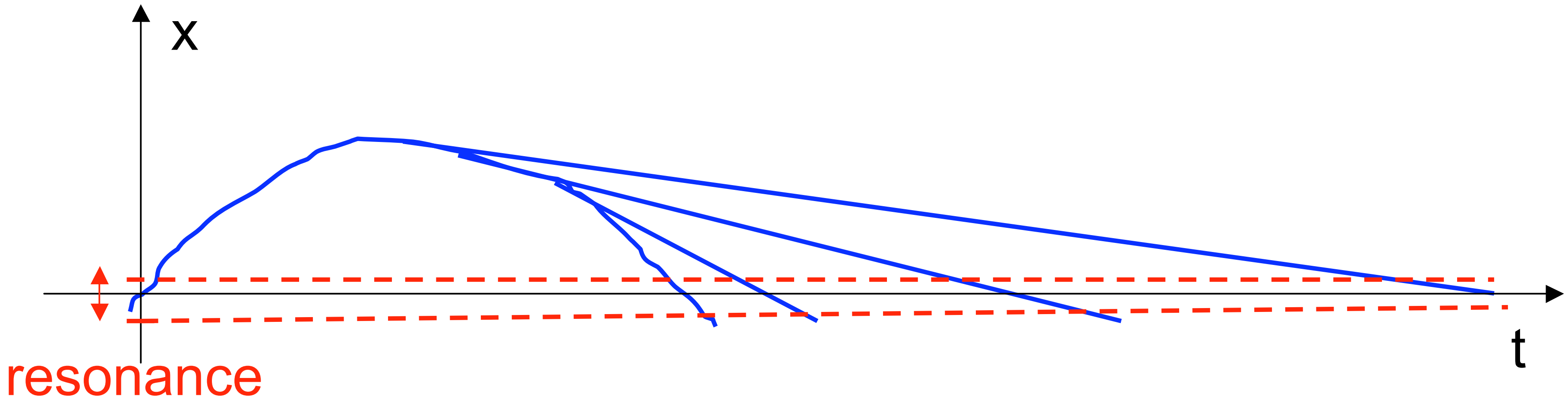


correction



Only PDH slope cause miss-measurement

2.4 Uncertainty

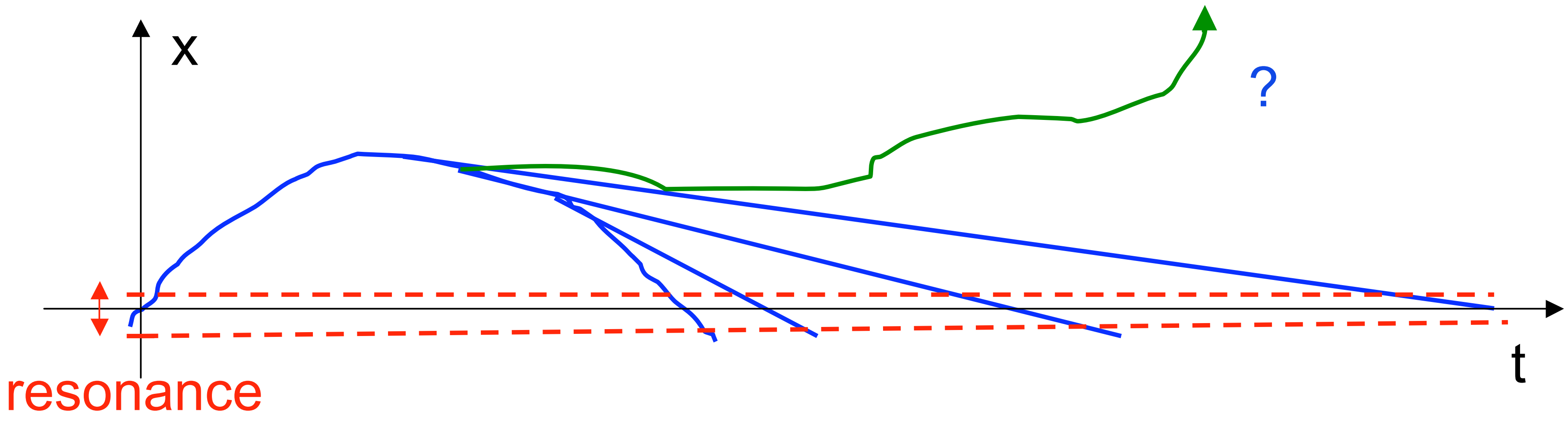


We can see signal only when in a resonance

Deceleration leads longer time to turn back the resonance.

=> Longer time accumulates bigger uncertainty.

2.4 Uncertainty



We can see signal only when in a resonance

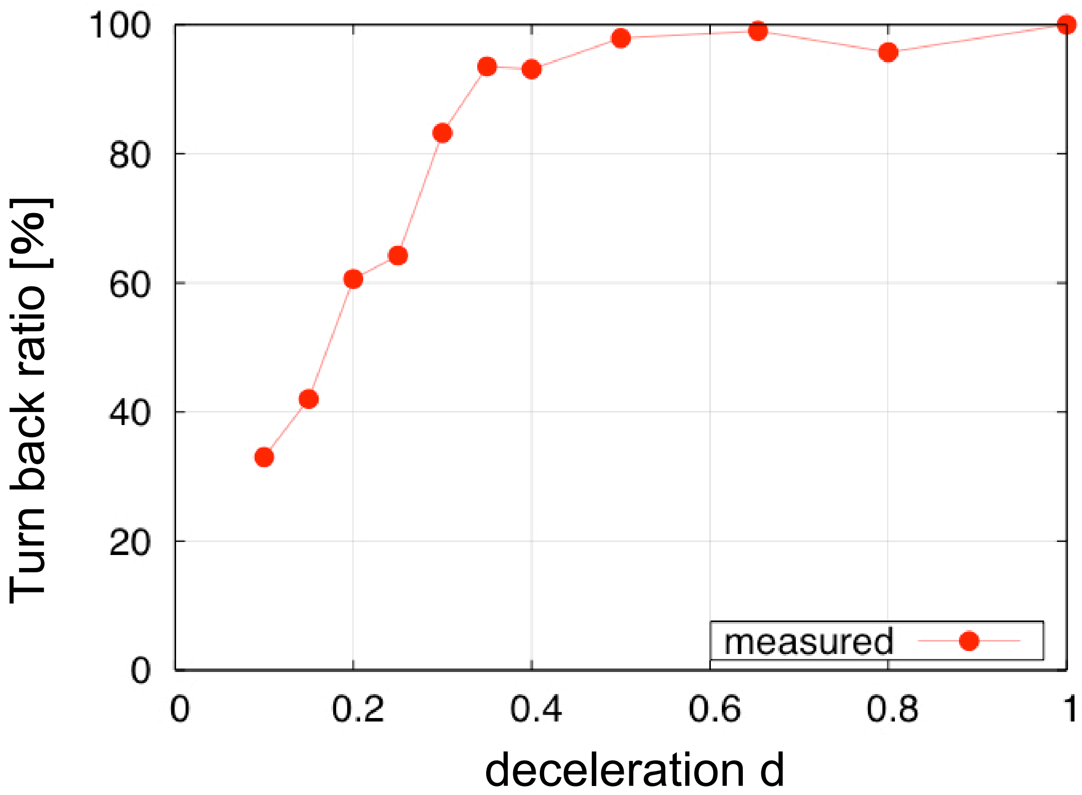
Deceleration leads longer time to turn back the resonance.

=> Longer time accumulates bigger uncertainty.

2.4 Uncertainty

Measurement about turn back ratio

If we try to make slower mirror , it decrease the event that mirror come back to the resonance.



Turn back ratio= [turn back event] / [total trial]

deceleration: $d = \left| \frac{v_{\text{after}}}{v_{\text{before}}} \right|$

2.5 Problem

review： what is guided lock?

- ○extrapolating the displacement as a uniform velocity
- ○based on the extrapolation, actuating mirror to the resonance

problem：

If we try to decelerate the mirror, turn back event gets fewer

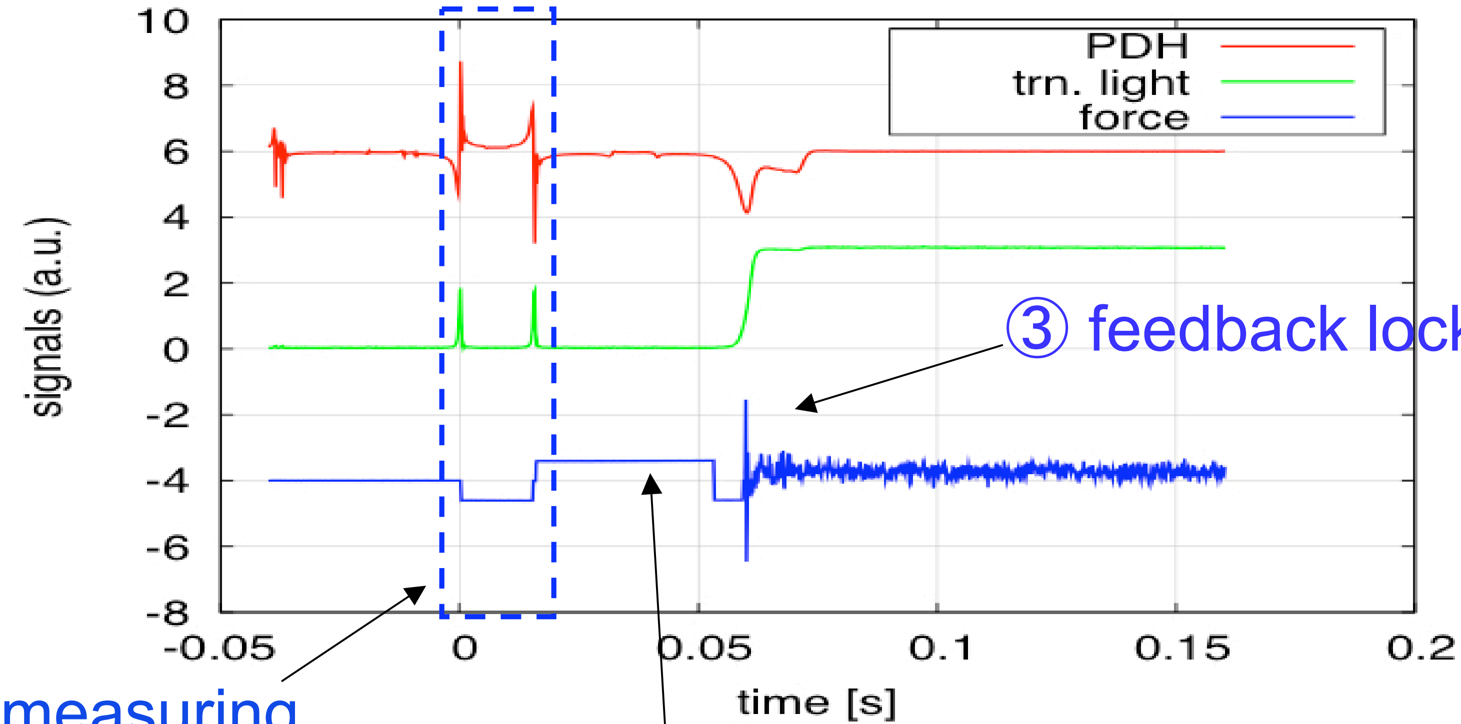
the assumption, uniform velocity motion, seems to be incorrect
We have to include acceleration effect

contents

3.1 Modifying

Acceleration is also considered

⇨ Extrapolation with uniform acceleration motion



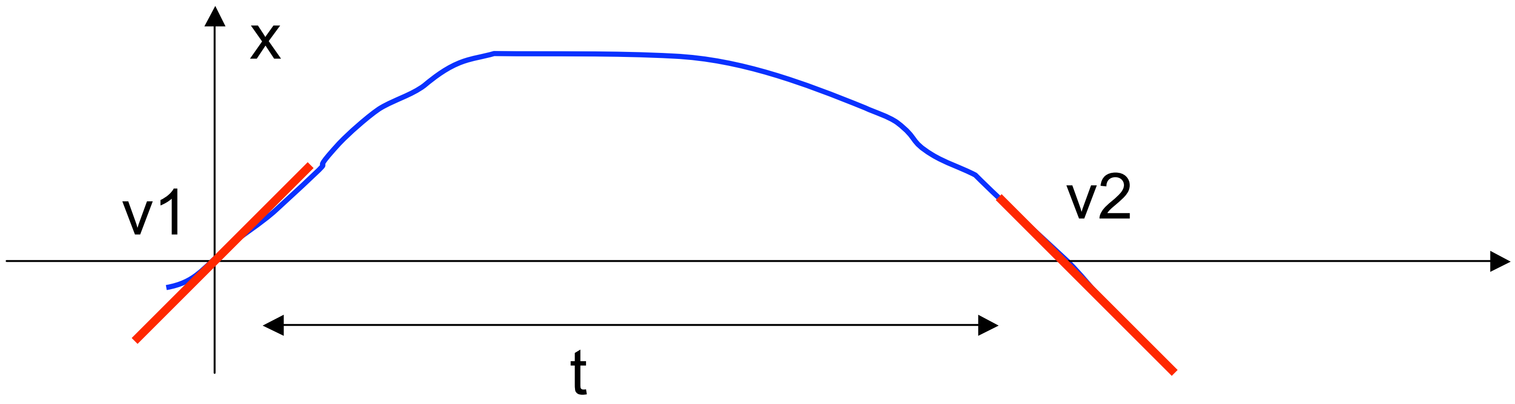
③ feedback locking

① measuring acceleration

② extrapolation of motion & actuation

3.2 Measuring acceleration

Generally, measurement of v1, v2 and t gives an acceleration



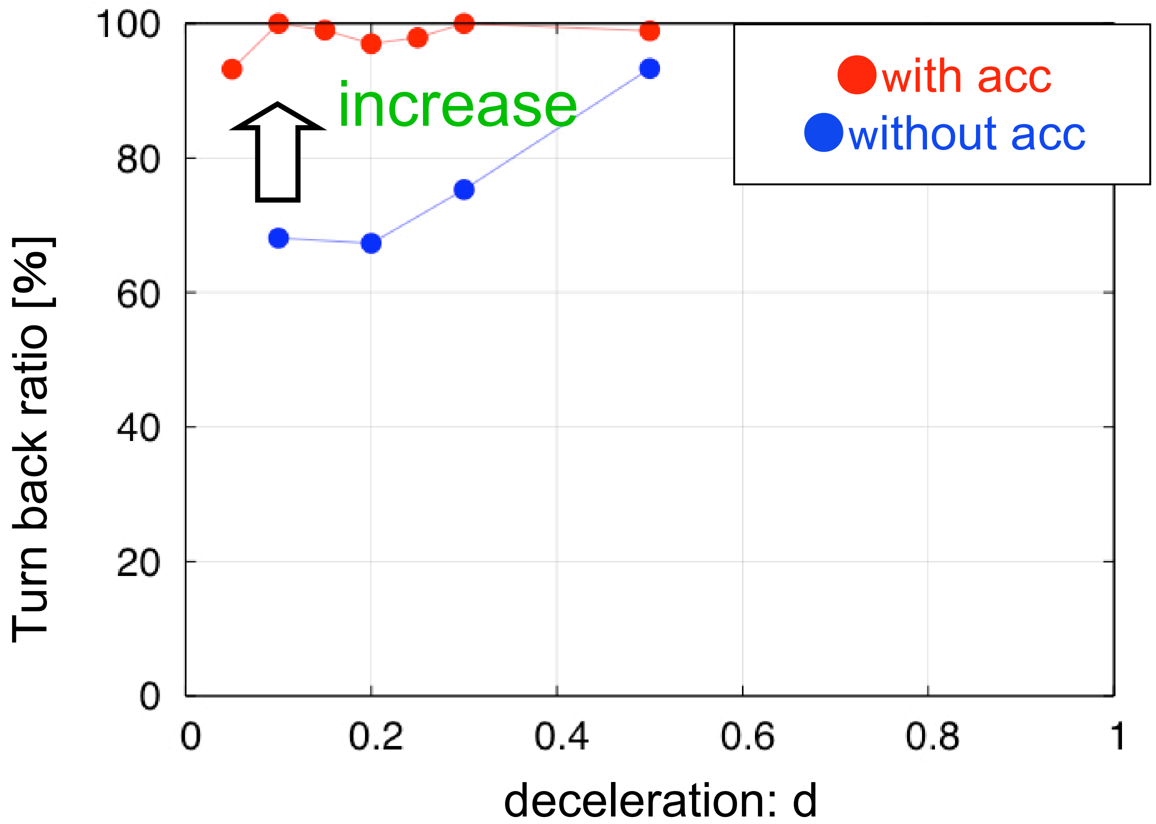
We have to use 2 fringes (the same resonance)

When mirror passes a resonance, we apply the constant force and turn mirror back to the same resonance

3.3 Turn back ratio

More than 90% came back !!

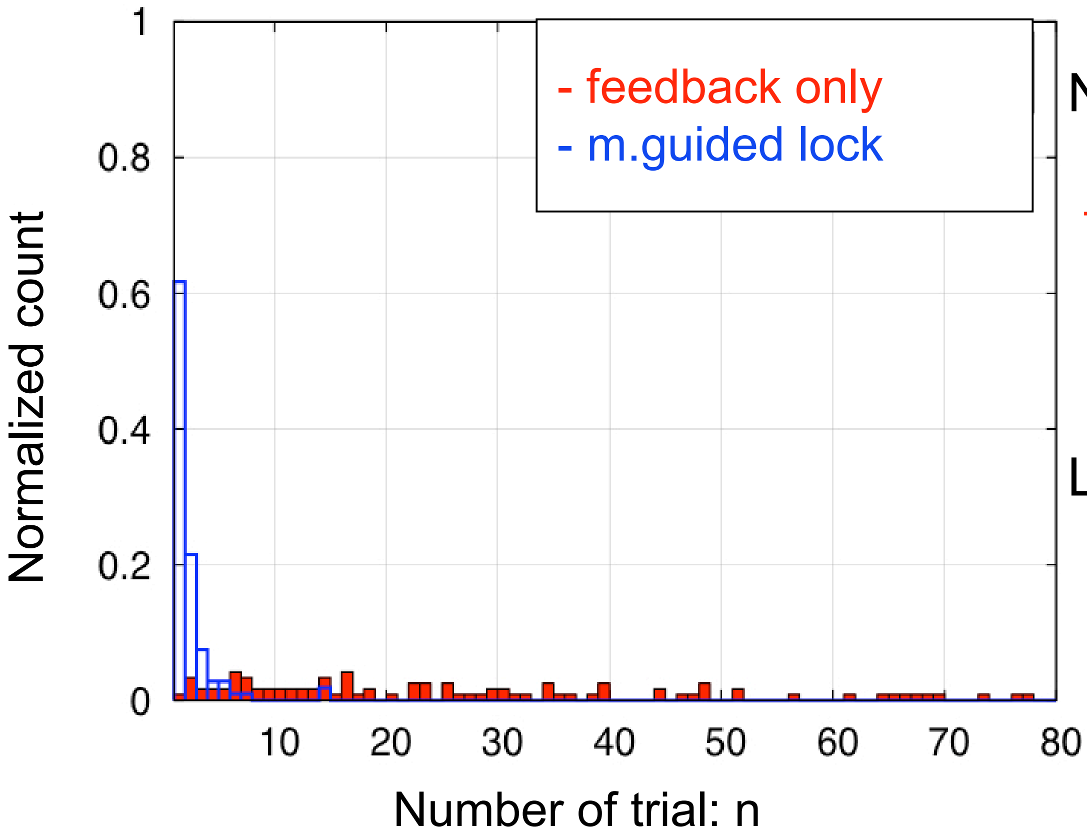
Considering acceleration is important



3.4 Lock probability

measurement about lock probability at d=0.1

Increasing lock probability about 35 times !



Number of trial（# of resonance）: n

feedback only : <n>=59

m. guided lock : <n>=1.7

Lock probability per fringe :1/< n>

feedback only : 1.7[%]

m.guided lock : 60[%]

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4. **summary**

4.1 Discussion

4.2 Summary

Discussion

How useful if we apply this method to LCGT?

assumption: our experimental results can be smoothly applied to LCGT

Lock probability per resonance

feedback only:	0.3%
guided lock:	2.4%
m.guided lock:	26% (d=0.1)

By using our technique in LCGT, we can improve the lock probability about 90 times !!

summary

Study of guided lock using 300-m Fabry-Perot cavity in TAMA.

★ the guided lock: limited by acceleration of mirror

⇒ Mirror can not come back to the resonance

★ modified guided lock: Acceleration is considered

=>Mirror can come back to the resonance and
increase locking probability from 1.7 to 60%

This technique can be good for future interferometers

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