Minimizing the mechanical cross-couplings in a KAGRA suspension system

Ryohei Kozu[a], Y.Arai[a], E.Capocasa[b], E.Tapia[b], F.Peña[b], K.Izumi[c], M.Barton[b], N.Hirata[b], N.Ohishi[b], S.Yoshioka[d], T.Kajita[a]
[a]ICRR The University of Tokyo, [b]NAOJ, [c]JAXA, [d]Unicersity of Toyama

Abstract

KAGRA requests high level sensitivity to detect the Gravitational wave[1] and to reach the sensitivity, we made two filters to minimize the longitudinal and pitch coupling of Test Mass in Beam Splitter(BS). One minimizes the cross-coupling when we push the Intermediate Mass and another does when we push the TM. After setting this filter, the output signal became 1/10 times to 1/5 times smaller(it depends on the frequency).

1. Introduction

KAGRA is a large scale cryogenic gravitational wave telescope which is a variant of the Michelson interferometer. All the core optics are suspended by wires or fibers in order to attenuate the effect of seismic vibration which would confuse the detector output if unaddressed. In order to keep the interference condition to maximize the detector sensitivity, the longitudinal position of the suspended mirrors must be precisely locked to an appropriate position by applying longitudinal forces. However, such longitudinal forces are known to result in undesired misalignment of the optics via a mechanical cross-coupling.

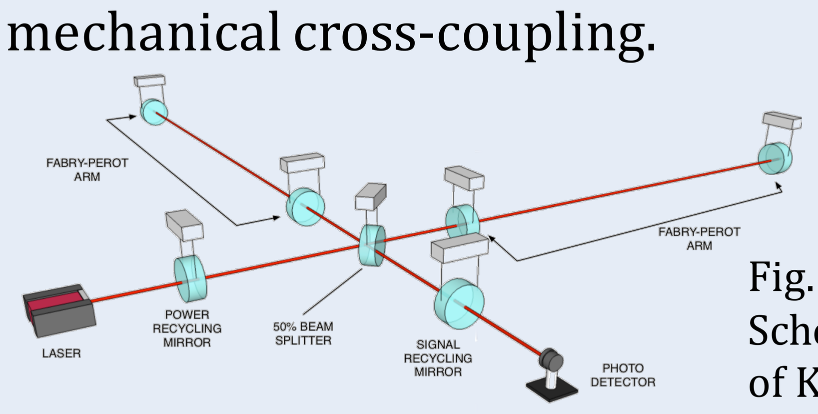


Fig. 1: Schematic model of KAGRA

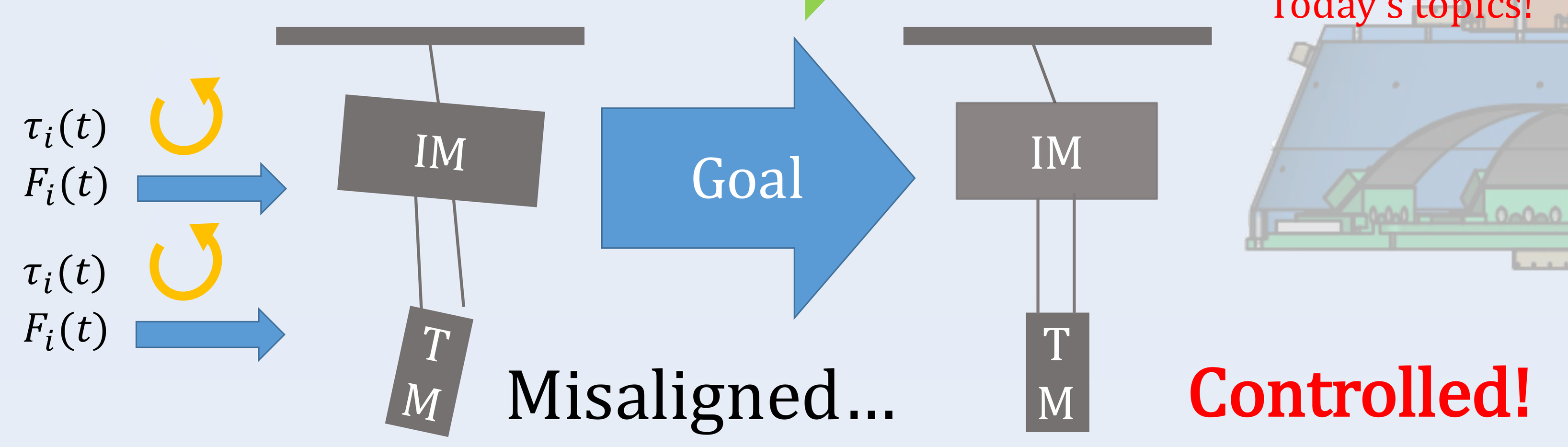
Fig. 2: Beam Splitter(BS)

2. Mechanical cross-coupling

The BS suspension as well as the other suspensions inevitably show the mechanical cross-coupling which is caused by the fact that the clamping points of the piano wires are vertically offset from the center of mass at each pendulum stage by design. (F,τ) are requested values and (x,θ) are resulting values which mean the position of IM/TM and the rotation of IM/TM. For simplicity, we only consider this pendulums as rigid bodies[2]. As we apply longitudinal forces, the BS optic acquire pitch rotation via $M_{\theta x}$. This is the coupling that we would like to minimize.

$$\text{EOM}: \begin{matrix}(\boldsymbol{x}(t),\boldsymbol{\theta}(t))\\(\boldsymbol{F}(t),\boldsymbol{\tau}(t))\end{matrix} \xrightarrow{\text{L.T.}} \begin{pmatrix}\tilde{x}(\omega)\\\tilde{\theta}(\omega)\end{pmatrix} = \begin{pmatrix}M_{xx} & M_{x\theta}\\M_{\theta x} & M_{\theta\theta}\end{pmatrix}\begin{pmatrix}\tilde{F}(\omega)\\\tilde{\tau}(\omega)\end{pmatrix}$$

Today's topics!



3. Minimizing the coupling

To minimize the cross-coupling, we apply torques to the mirror simultaneously in order to cancel the resulting misalignment. In this method, one must take into account the frequency responses for the longitudinal-to-pitch coupling $M_{\theta x}$ and the pitch-to-pitch coupling $M_{\theta\theta}$ to obtain a good cancellation. Therefore this method boils down to a set of transfer function measurements and designing of cancellation filters. One is L2P which represents the response between the input Longitudinal of IM/TM and the output pitch of TM. Another is P2P which represents the response between the Pitch of IM/TM and the output pitch of TM.

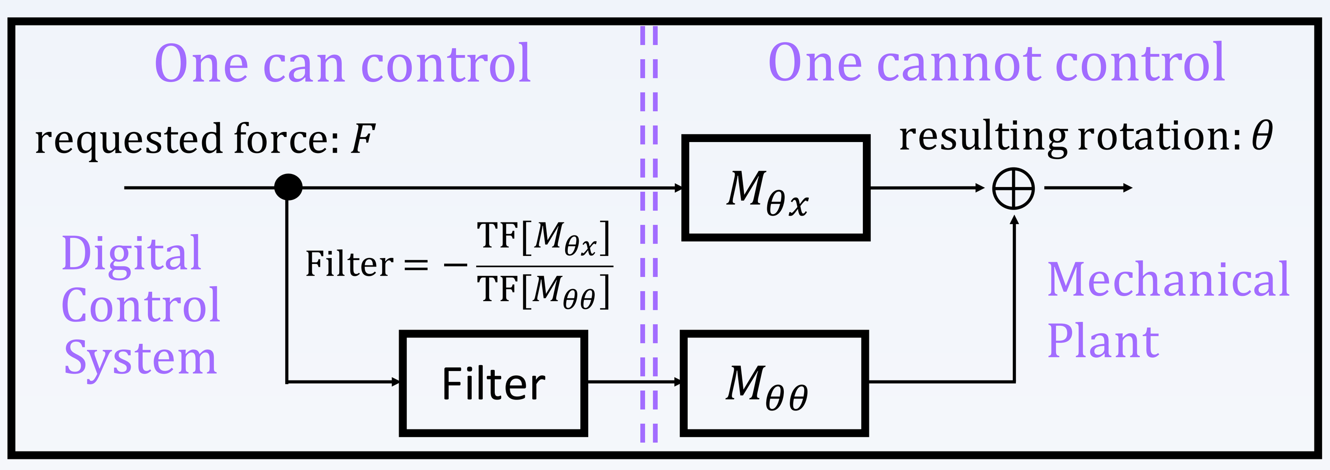


Fig.3: Digital System & Mechanical Plant

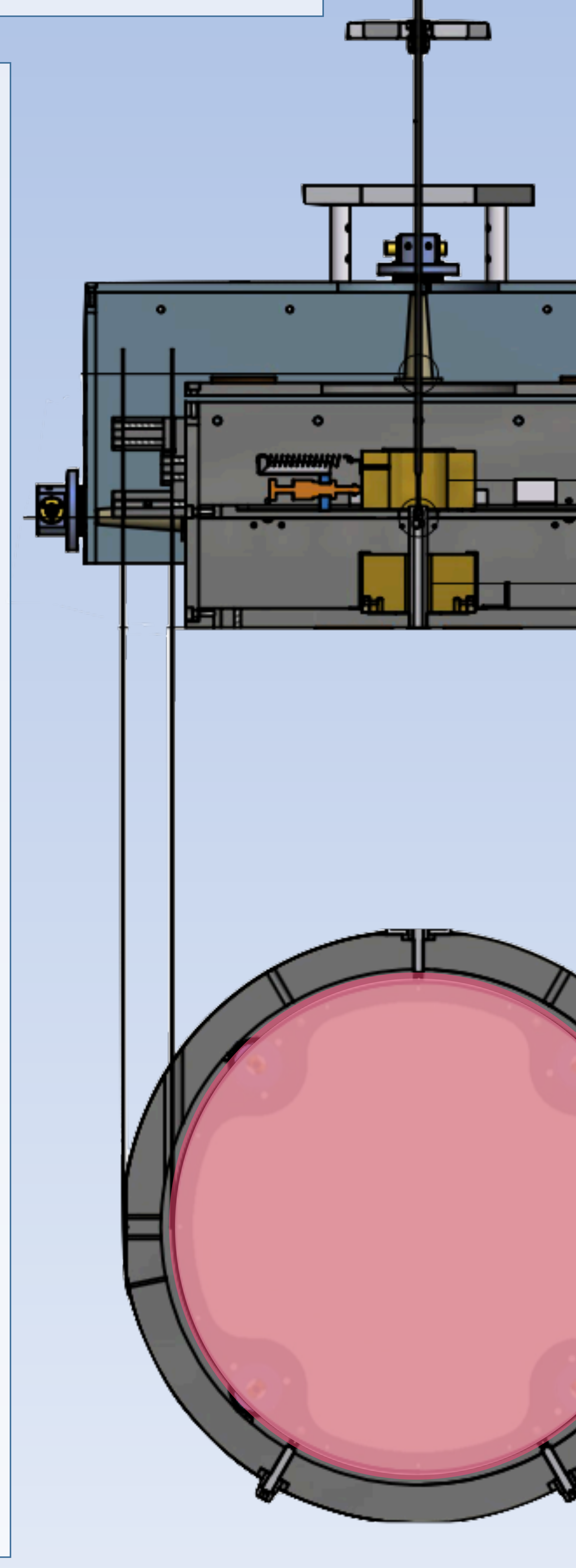


Fig.0: BS of KAGRA

4. Result

From the measured TFs, we made two new filters which decouple the input L-signal of IM/TM and the output P-signal of TM. There are the digital system of KAGRA, the TFs, new filters below.

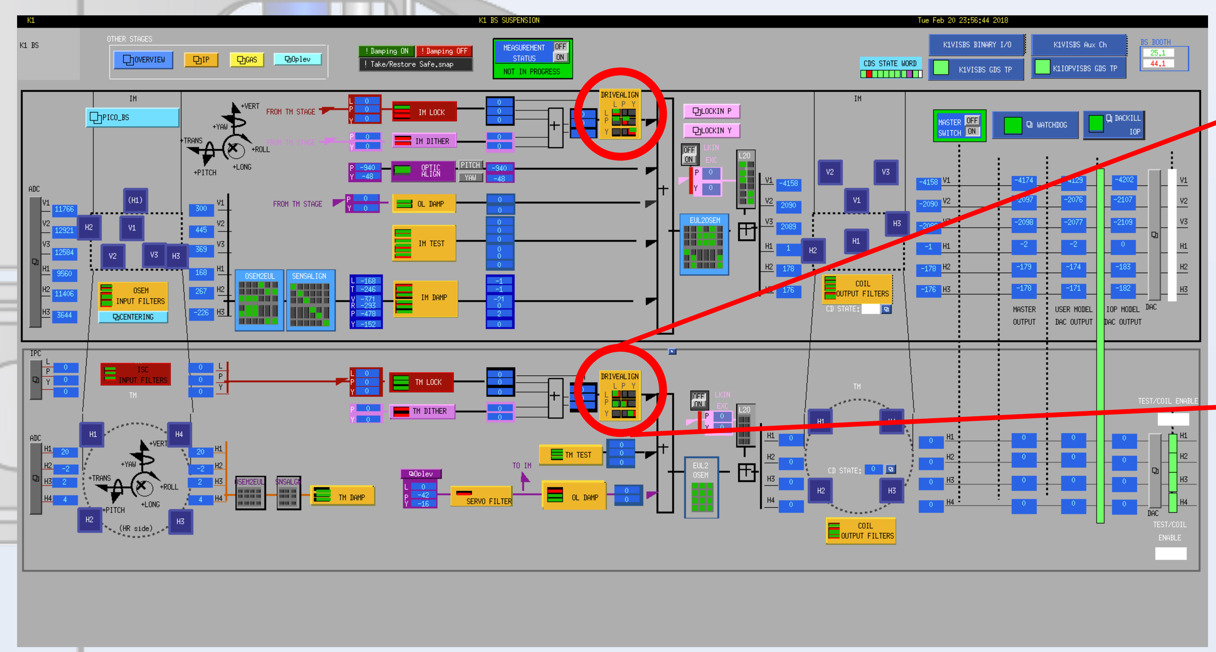


Fig.5: Digital system of BS payload

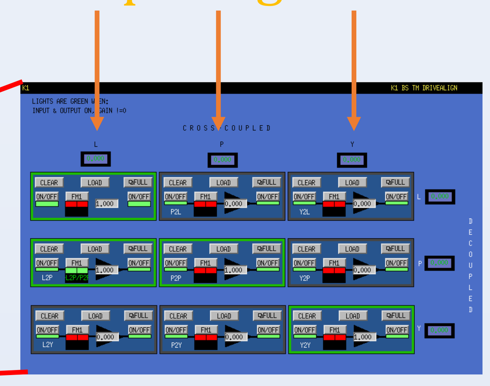


Fig.4: New filter screen

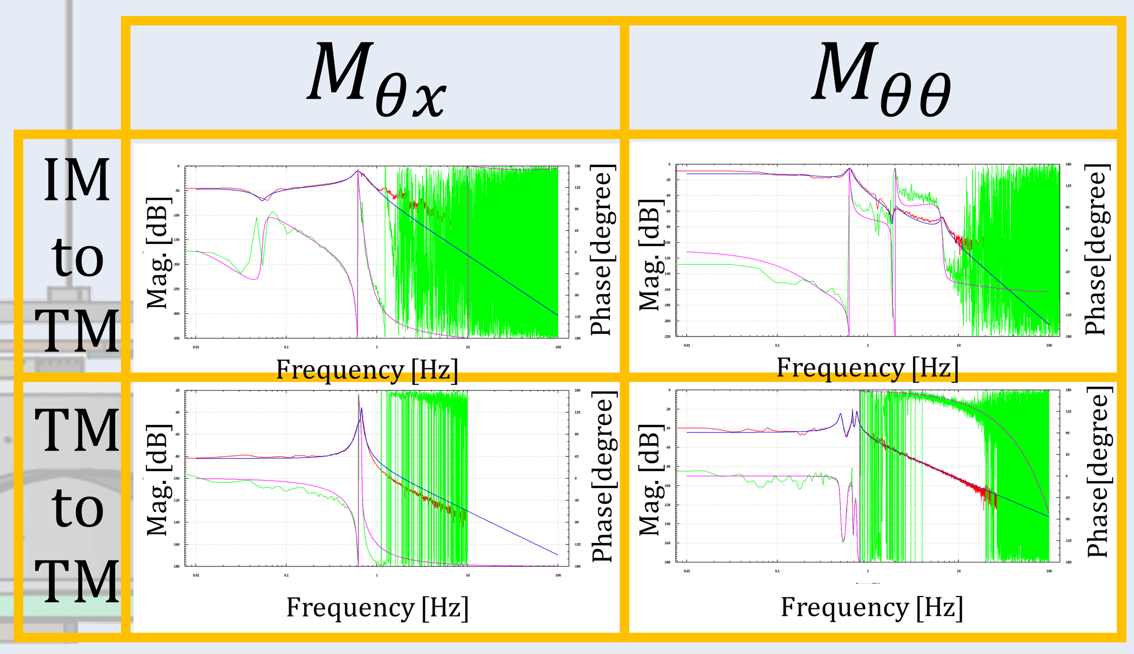


Fig.6: TFs of $M_{\theta x}$ & $M_{\theta\theta}$ from IM/TM to TM

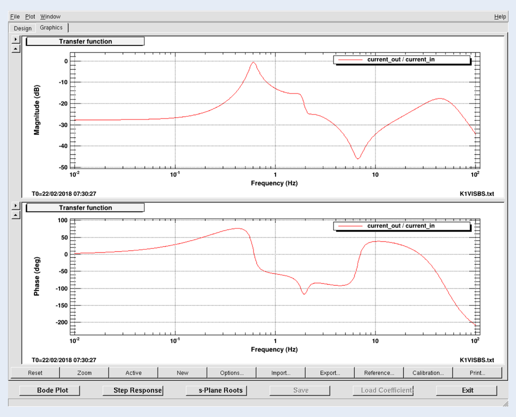


Fig.7: Filter for IM to TM

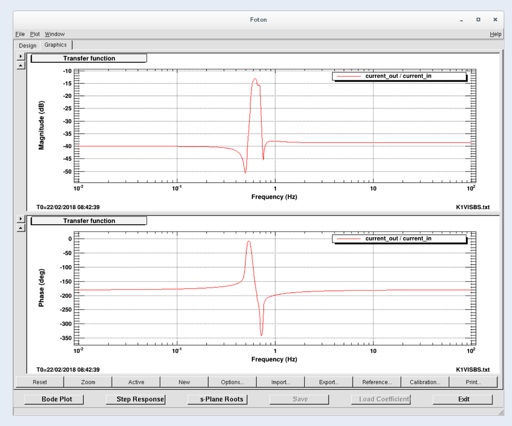


Fig.8: Filter for TM to TM

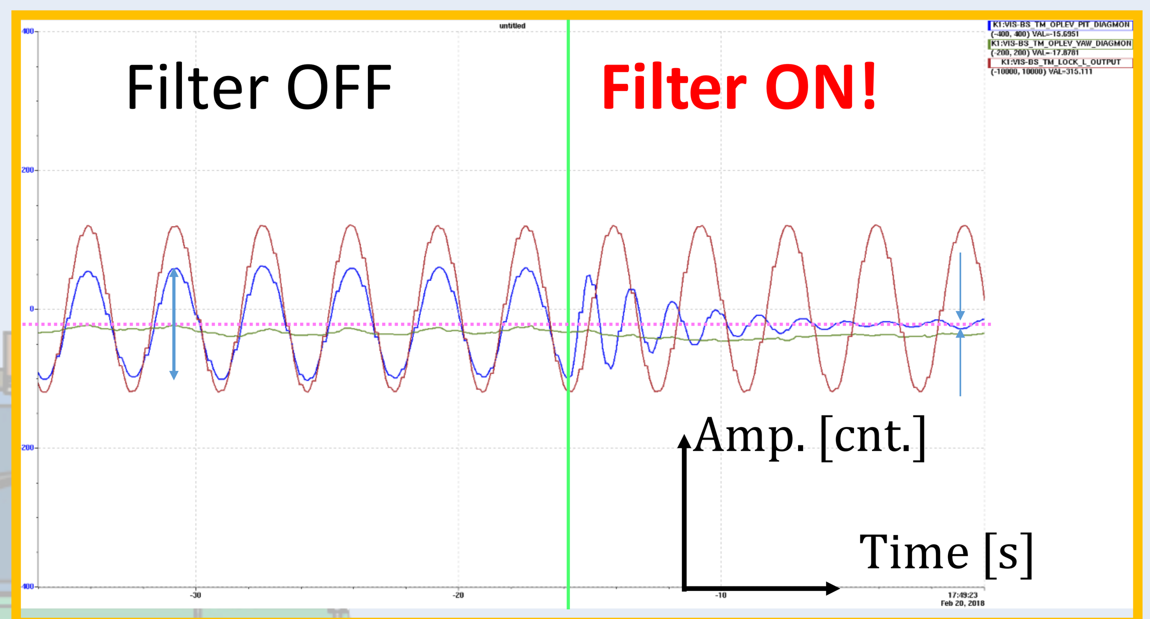


Fig.9: Frequency vs. TM pitch(Blue) & Input Excitation Force(Brown).
$M_{\theta x}$ of TM to TM, $f = 0.3$Hz, 1/10 times smaller

5. Conclusion

We can minimize the cross-couplings 1/10 times to 1/5 times smaller and this shows that we succeeded reducing! This is for the first time the cross-couplings in KAGRA suspensions, these consequences encourage us that this approach meats the requirements and we can use the same way to other suspensions like Signal Recycling(SR) and Power Recycling(PR). On the other hand, around the Resonance Frequency, the Amplitudes of resulting signal don't behave well. So we need to improve the filters furthermore.

Gallery

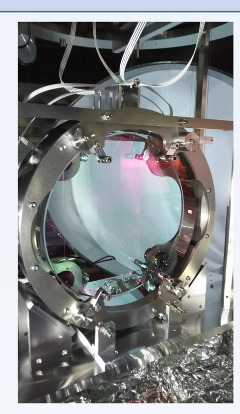


Fig.G1: BS mirror

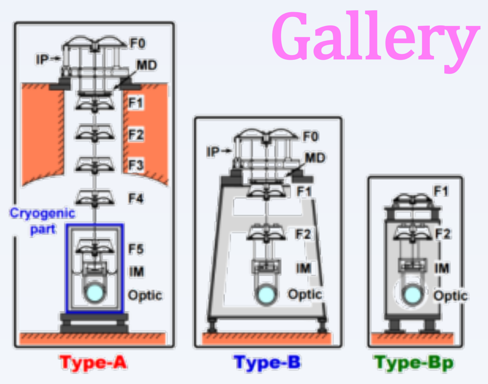


Fig.G2: Suspension type

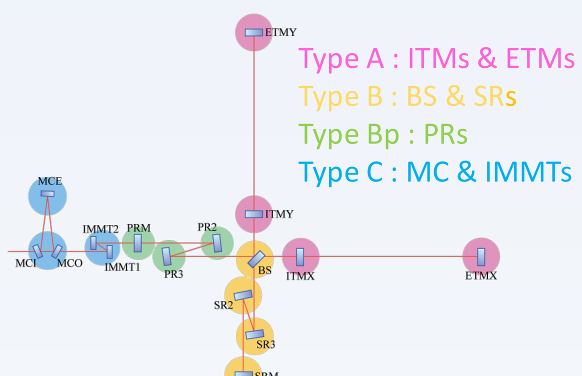


Fig.G3: Optics

Reference
[1]: http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/KAGRA
[2]: "Wire attachment points and flexure Corrections" M.Barton, N.Robertson LIGO-T080096-00-K https://dcc.ligo.org/