Mechanical Q factor measurement of Type-Bpp SAS in iKAGRA

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Contents

1 Overview

iKAGRA における PR3 に用いられた懸架装置： Type-Bpp Seismic Attenuation System (Type-Bpp SAS) の Mechanical Q factor の測定結果をまとめた。この測定の目的は、地震などの外乱によって大きな振動が励起された際に、その励起された振動を、Calm-down phase における Damping control によってどれだけ早く低減させることが出来るかを確認することである。なお、Calm-down phase における制御では、$1/e$ decay time が 1 min. 以下であることを requirement としている。

2 Glossaries

BF : Bottom GAS Filter
IR : Intermediate Recoil Mass
IM : Intermediate Mass
RM : Recoil Mass
TM : Test Mass

L : Londitudinal
T : Transversal
V : Vertical
R : Roll
P : Pitch
Y : Yaw

3 Controls in the calm-down phase

3.1 Servo design

3.2 Mechanical Quality factor measurement

The investigation of the mechanical Q factors, for the type-Bpp SAS with and without control in the calm down phase, is summarized. The Q factor is expressed by $Q = \frac{1}{2}\,\omega_0 T_e$, where ω_0 is a resonance frequency and T_e means $1/e$ mitigation time of its vibration. In this work, we obtain the damping time of the mechanical resonances by exciting the system using appropriate actuators and measuring decay signals using implemented sensors. Also, only modes with resonance frequencies below 20 Hz are measured because of the difficulty in exciting the system above 20 Hz with actuators on the SAS. The results is shown in Figure 3. The observed decay signal is fitted by one exponential-decay sine wave function:

$$f(t) = A \exp\left(-\frac{t}{\tau_e}\right) \sin\left(2\pi f_0 t\right) + x_0 \tag{3.1}$$

Sometimes, it is difficult to excite only one resonant mode and beating signal is measured, because there exsists other mechanical resonances with close to eigen frequencies. In such a case, the signals is fitted by two decay sine wave function:

$$f(t) = A_1 \exp\left(-\frac{t}{\tau_{e,1}}\right) \sin\left(2\pi f_1 t\right) + A_2 \exp\left(-\frac{t}{\tau_{e,2}}\right) \sin\left(2\pi f_2 t\right) + x_0 \tag{3.2}$$

(In the table , Q and T_e show the measured value.) All eigen modes, predicted by 3 dimensional rigid body model simulation, are shown in the table 1.

table 1: Simulated eigen mode list of Type-Bpp SAS for iKAGRA[1]

#Mode No.	Frequwncy [Hz]	Mode shape	Note
#1	0.161	YIM, YRM, YTM	wire torsion mode
#2	0.334	RIM, RRM, RTM	IM Roll
#3	0.376	PIM, -PRM, -PTM	IM Pitch
#4	0.440	VIM, VRM,VTM	GAS filter
#5	0.513	TIM,...	main pendulum
#6	0.514	LIM,...	main pendulum
#7	0.658	LTM,...	TM-RM pendulum
#8	0.659	TTM,...	TM-RM pendulum
#9	0.823	PTM,...	TM Pitch
#10	1.030	YIR	IR Yaw
#11	1.034	-YIM, YRM, YTM	TM Yaw
#12	1.099	TIR	IR Pendulum
#13	1.099	LIR	IR Pendulum
#14	1.201	TIM,...	IM Pendulum
#15	1.202	LIM,...	IM Pendulum
#16	1.399	YIM,...	RM Yaw
#17	5.376	PRM,...	RM Pitch
#18	11.33	VTM,...	TM Vertical
#19	15.52	RTM,...	TM Roll
#20	51.80	...	IM Vertical
#21	71.77	...	IM Roll
#22	98.14	...	IR Roll
#23	101.5	...	IR Pitch
#24	124.9	...	IR Vertical

[1] In the colounm of each "Mode shape", main vibrations, whose amplitude are larger than others, are written in.

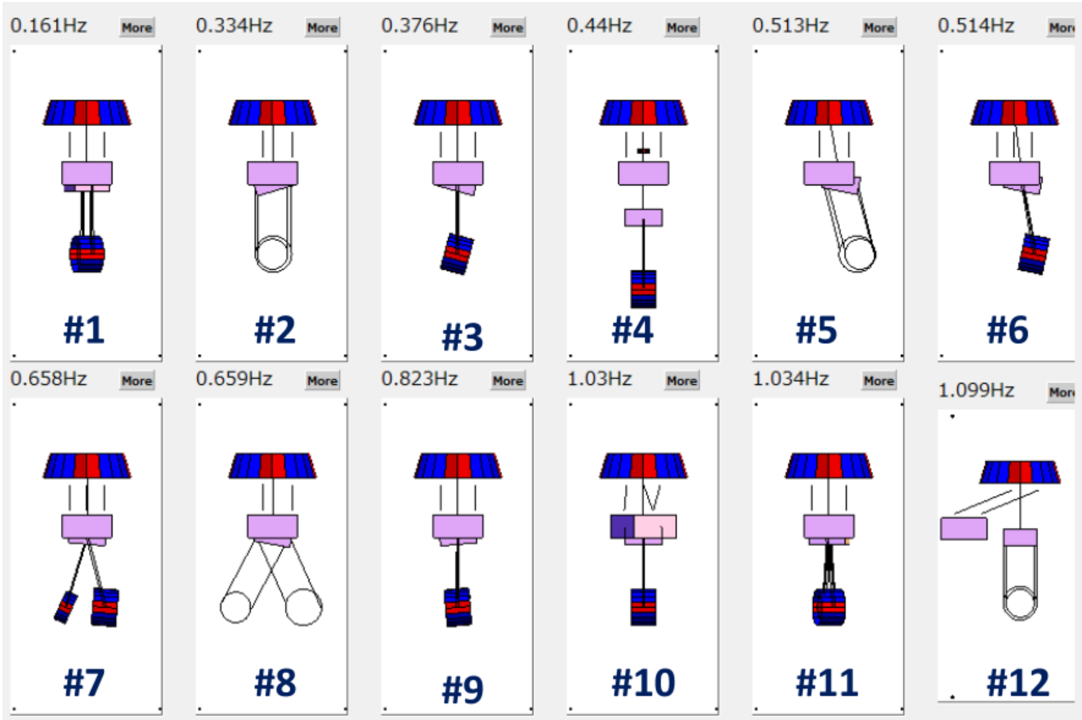

Figure 1: Eigen mode shapes of Type-Bpp SAS, predicted by SUMCON(a)

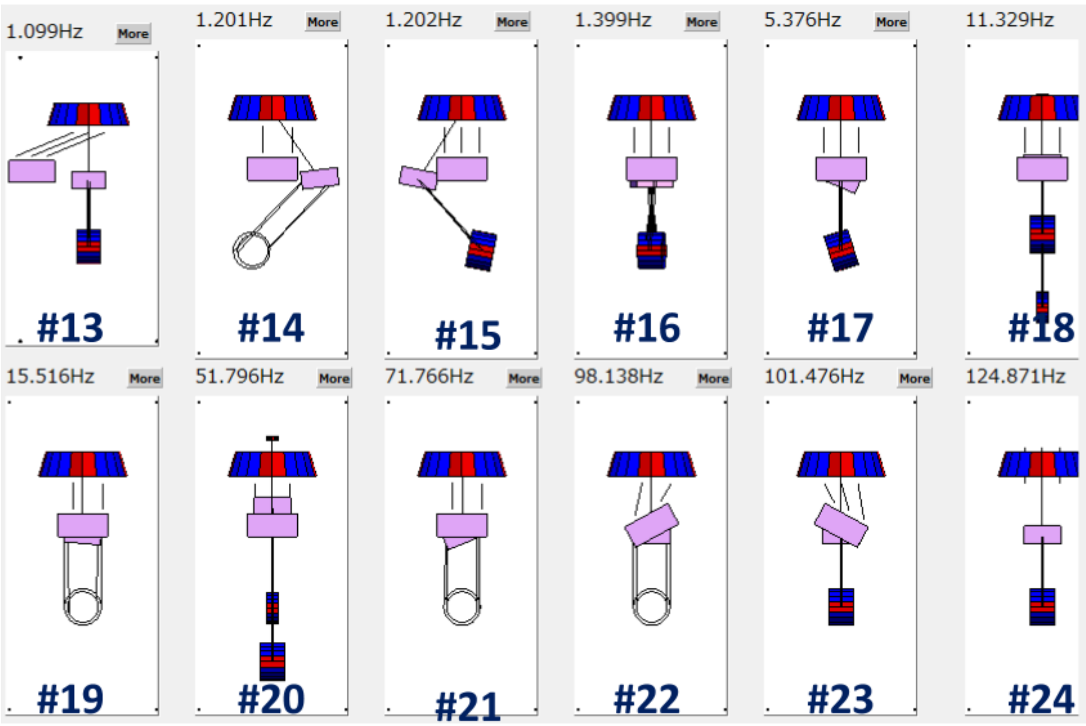

Figure 2: Eigen mode shapes of Type-Bpp SAS, predicted by SUMCON(b)

table 2: Without damping control

#Mode Number	Frequency [Hz] Simulated	Fitted	Difference [%]	decay time [sec]	Q factor	exc. point
#1	0.161	0.143	11	645	289	YIM
#2	0.334	0.427	28	43	58	RIM susp.point!
#3	0.376	0.464	23	71	103	LIM
#4	0.440	0.681	55	16	35	VBF freq!
#5	0.513	0.517	0.8	222	361	TIM
#6	0.514	0.526	2.1	91	150	LIM
#7	0.658	0.661	0.4	268	557	LTM
#8	0.659	0.661	0.2	214	445	RIM
#9	0.823	0.825	0.2	121	313	PIM
#10	1.030	0.980	4.8	698	2150	YIM
#11	1.034	1.000	3.3	398	1251	YIM
#12	1.099	1.069	2.8	219	735	TIM
#13	1.099	1.077	2.0	199	673	LIM
#14	1.201	1.110	7.6	366	1275	TIM
#15	1.202	1.110	7.6	357	1245	LIM
#16	1.399	1.342	4.1	1104	4655	YIM
#17	5.376	4.556	15	73	1051	PIM
#18	11.33	11.32	0.1	37	1324	VIM decay time!
#19	15.52	15.77	1.6	57	2826	RIM decay time!
#20	51.80	X	X	X	X	X
#21	71.77	X	X	X	X	X
#22	98.14	X	X	X	X	X
#23	101.5	X	X	X	X	X
#24	124.9	X	X	X	X	X

table 3: With controls

#Mode Number	Frequency [Hz] undamped	damped(fitted)	difference [%]	decay time [sec]	Q factor	exc. point
#1	0.143	0.140	2.0	5	2.1	YIM
#2	0.427	0.447	4.6	1.1	1.5	RIM
#3	0.464	0.470	1.5	4	6.4	PIM
#4	0.681	0.705	3.5	2.6	5.8	VBF
#5	0.517	0.538	4.0	12	20.5	TIM
#6	0.525	0.510	2.9	12	19.4	LIM
#7	0.661	0.661	0	129	268	LTM
#8	0.661	0.655	0.9	24	50.1	RIM
#9	0.825	0.831	0.7	9.8	25.6	PIM
#10	0.980	0.994	1.4	2	6.2	YIM
#11	1.000	0.998	0.2	174	546	YIM
#12	1.069	1.057	1.1	1	2.5	TIM
#13	1.077	1.053	2.2	1.0	3.46	LIM
#14	1.110	1.115	0.5	1	3.7	TIM
#15	1.110	1.190	7.2	0.8	2.96	LIM
#16	1.342	1.341	0.01	9.2	38.9	YIM
#17	4.556	4.562	0.13	24	350	PIM
#18	11.32	11.33	0.04	53	1889	VIM
#19	15.77	15.76	0.01	37	1846	RIM
#20	X	X	X	X	X	X
#21	X	X	X	X	X	X
#22	X	X	X	X	X	X
#23	X	X	X	X	X	X
#24	X	X	X	X	X	X

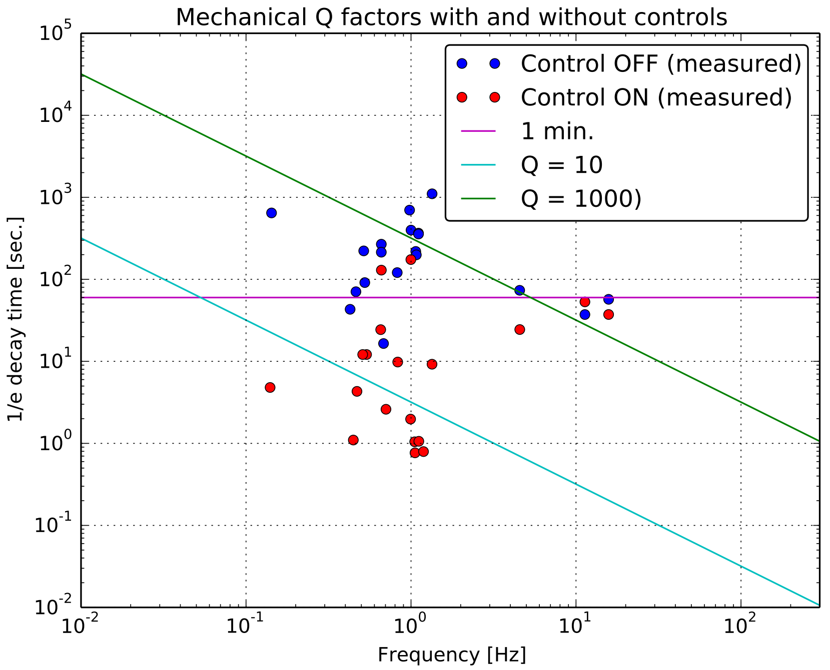

Figure 3: Measured result

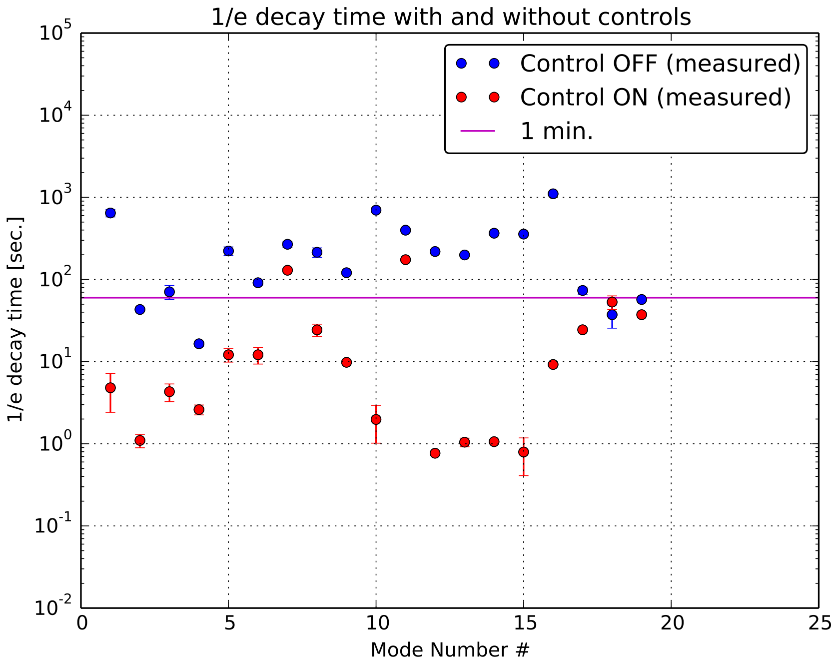

Figure 4: Measured T_e vs. mode number

- #2,3,4 → mechanical model 要変更。IM suspension point, GAS resonance frequency.

- #10,19 without controls, #12,14,19 with controls → error bar 大。

- 今回の測定で、requirememt である 1 min を超えたのは mode 7, 10 であり、これらはともに TM-RM の振動に寄るものある。今回は TM-RM 間の damping control は切っていたため、要求値を満たすことはできなかったが [2]、TM の振動を読みとるセンサー [3] と、TM-RM 間には actuator が配置されればダンプ出来るモードと考えられ、この二つの共振モードの減衰時間は requirement の 1min. 以下に抑制することがでいるはずであるため、問題はないと思われる。

[2]TM-OSEM での damping を用いると長くて十数秒で damp できることは確認済み。
[3]bKAGRA では OSEM-shadow sensor ではないが

A TM transfer function from TM-OSEM to TM sensor

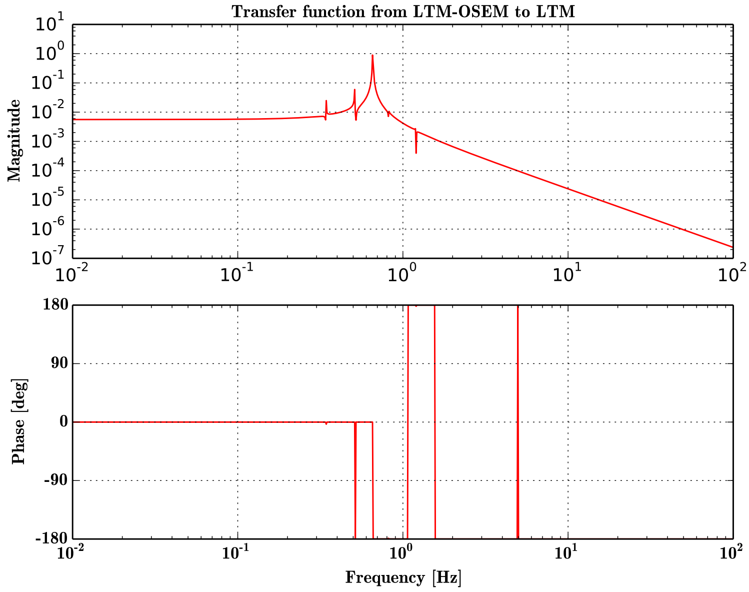

Figure 1: Transfer function from LTM-OSEM to LTM sensor

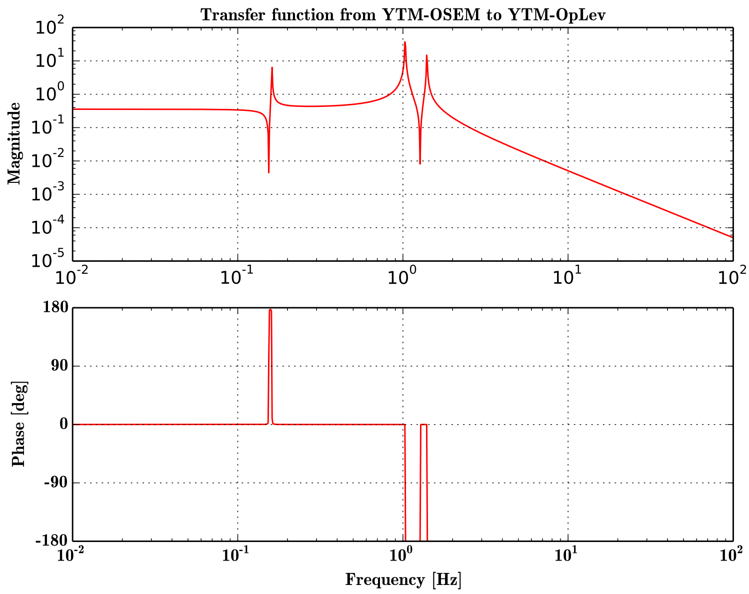

Figure 2: Transfer function from YTM-OSEM to YTM sensor

B Result in Type-B1 proto

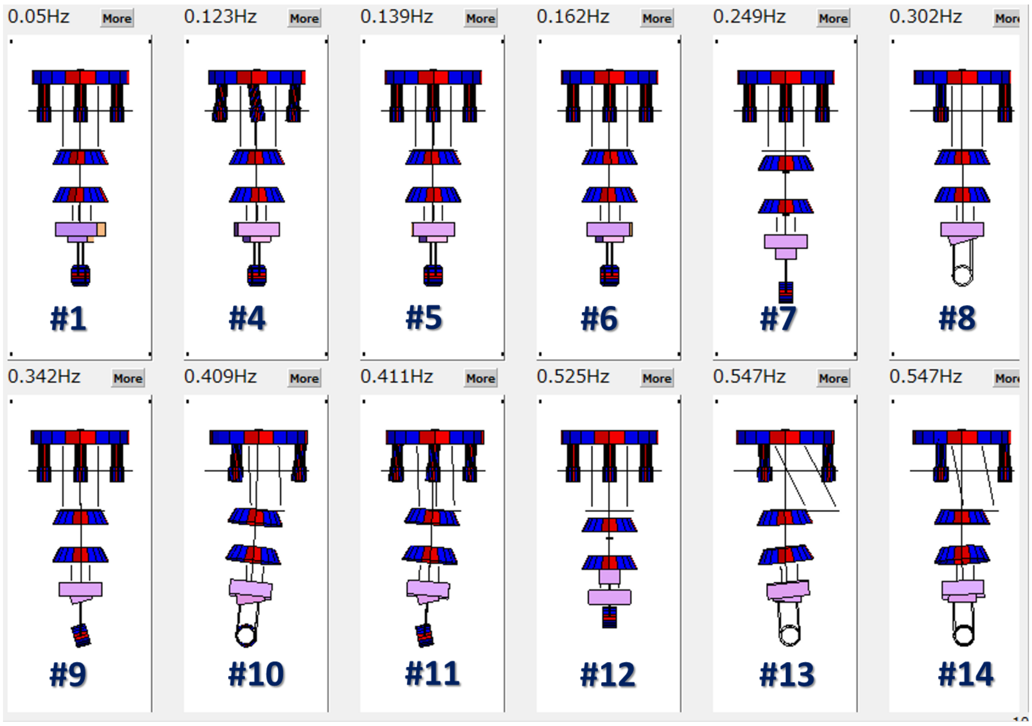

Figure 1: Eigen mode shapes of Type-B1 proto SAS, predicted by SUMCON(a)

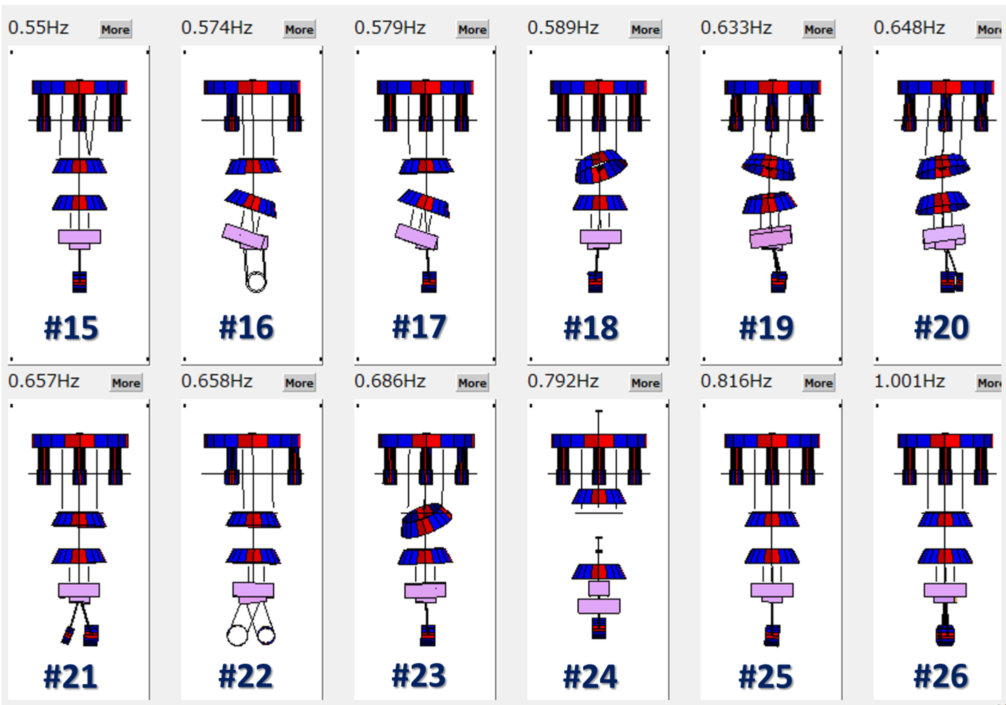

Figure 2: Eigen mode shapes of Type-B1 proto SAS, predicted by SUMCON(b)

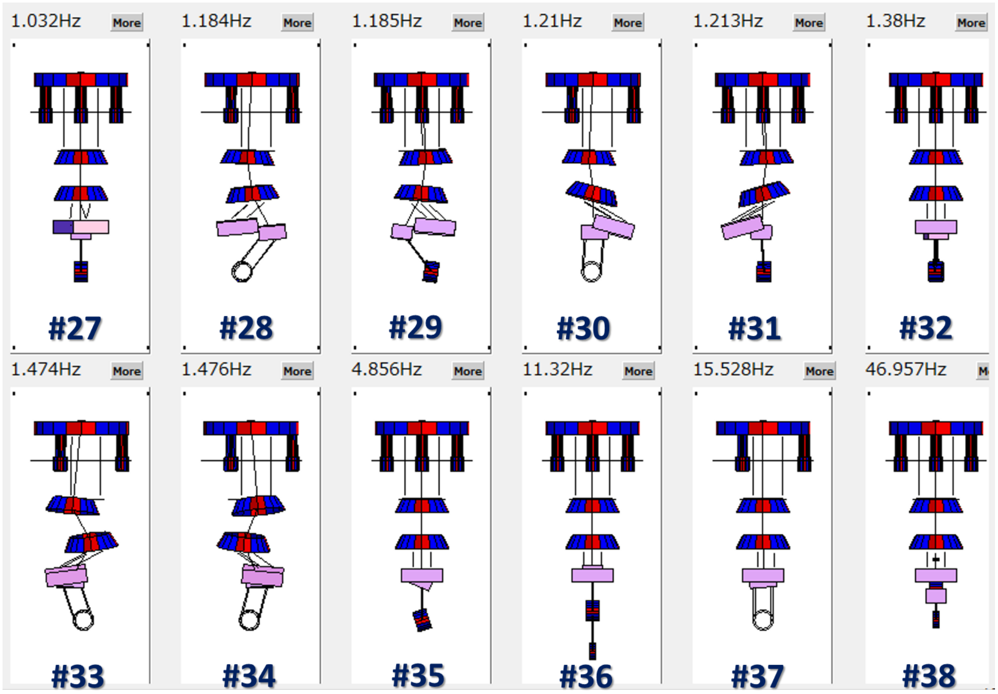

Figure 3: Eigen mode shapes of Type-B1 proto SAS, predicted by SUMCON(c)

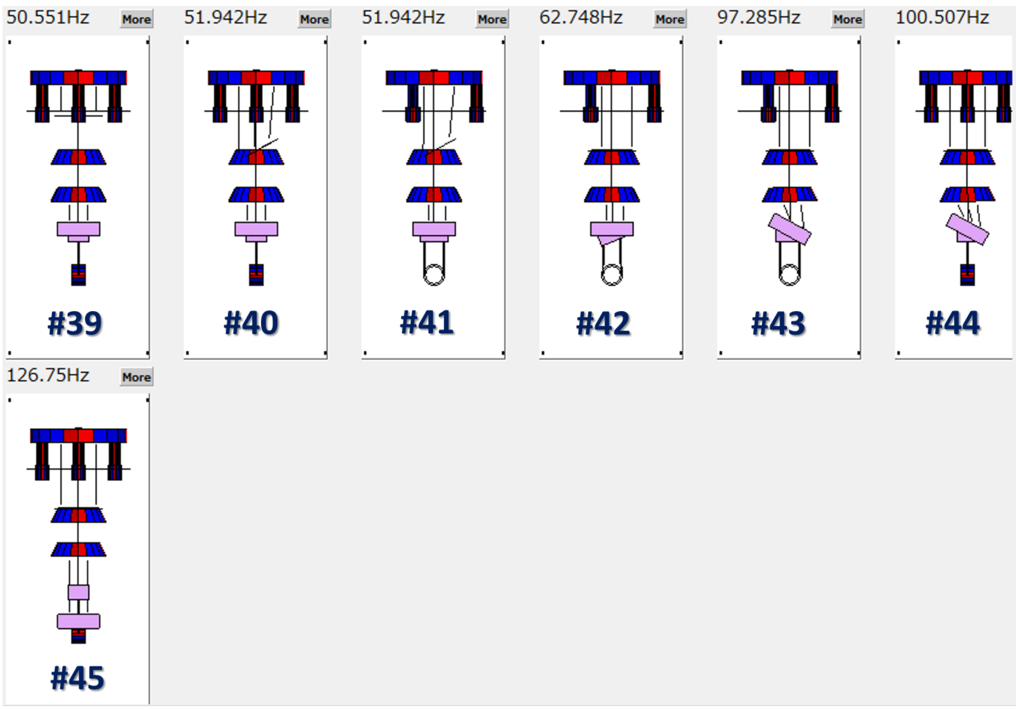

Figure 4: Eigen mode shapes of Type-B1 proto SAS, predicted by SUMCON(d)

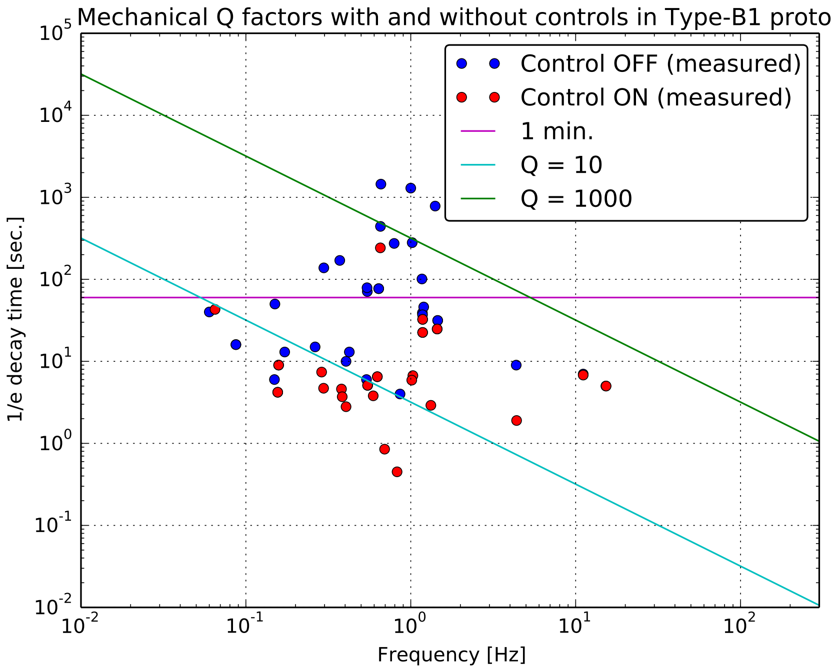

Figure 5: Measured result

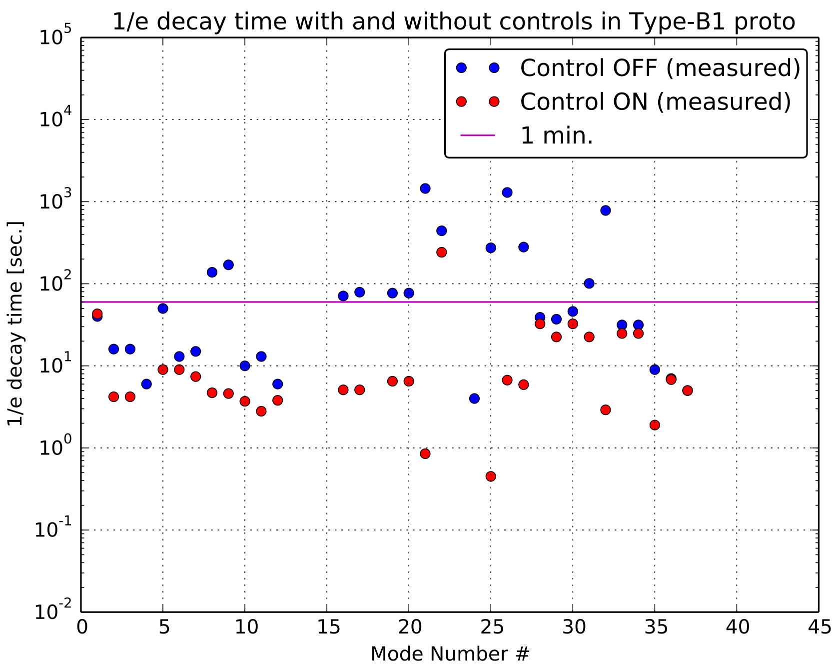

Figure 6: Measured T_e vs. mode number