Preliminary results of the analysis and of the optimization dedicated to the final focus stabilization

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The aim of this brief report is to summarize the work which has been done on the final focus stabilization. This study is based on the development made by D. Schulte [1] and the report written by J. Pfingstner [2]. The first part is dedicated to the analysis of the first method that has been developed and the second part attempts to compare this method with standard controllers that use a parametric optimization.

1. Analysis of the previous development :

The context :

For instance, we consider a very basic process:

- The displacement of the beam (Δy) which needs to be controlled can be obtained using the beam position monitor located after the interaction point.
- The disturbance (X) is the mechanical excitation of the QD0 magnet
- The transfer function between the mechanical displacement of this QD0 magnet and the beam can be modelled by a constant matrix.
- The noise of the sensor (W) is added to the displacement beam..
- The action (k_b) meant to reduce the motion of the beam (or the offset between the two beams at the interaction point) is done by a kicker which is located just next the QD0 quadrupole. The obtained displacement of the beam is proportional to the injected current of the kicker.
- The dynamic of the system is due to the frequency of the beam train, so the process can be treated as a first approach as a delay with a gain at a sampling period T_e equal to 0,02 s.

Next, the process is represented in the figure 01 with these different components.

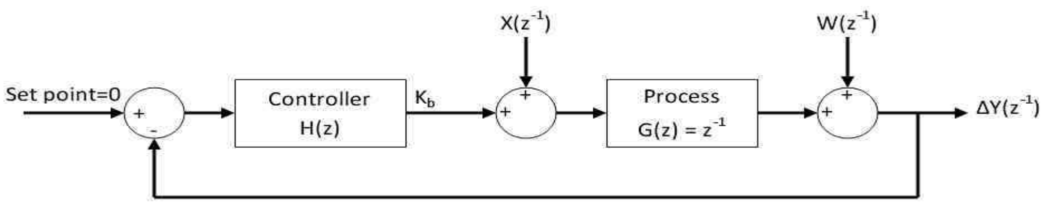

Fig 01 : Feedback scheme of the considered system

The closed loop transfer functions taken into account are:

1 – The transfer function between the beam displacement and disturbance:

$$\frac{\Delta Y}{X}=\frac{G}{1+GH}=F(z^{-1})$$

2 – The transfer function between the beam displacement and sensor noise:

$$\frac{\Delta Y}{W}=\frac{1}{1+GH}$$

It is important to note that, as G is a pure delay, the effect of the closed loop is the same, in term of amplitude, for the disturbance input or for the sensor noise input.

The analysis:

The first corrector developed by D. Schulte is:

$$k_b(n)=g_i k_b(n-1)+g_p\frac{\Delta y(n)}{a}+g_d\frac{\Delta y(n)-\Delta y(n-1)}{a}+g_{d2}(k_b(n-1)-k_b y(n-2))$$

Note that we have removed in the original equation the delay introduced in the recursive equation (we use $\Delta y(n)$ instead of $\Delta y(n-1)$)

Using the back shift operator z^{-1} :

$$z^{-1}\Delta y(n)=\Delta y(n-1)$$

And the notations below:

$$\Delta y(n)=\Delta y\,,k_b(n)=k_b$$

the following transfer function of the corrector can then be considered:

$$\frac{k_b}{\Delta y}=H(z)=\frac{g_p+g_d-g_d z^{-1}}{1-g_i z^{-1}-g_{d2}(z^{-1}-z^{-2})}=\beta_1\frac{1-\beta_2 z^{-1}}{(1-\alpha_1 z^{-1})(1-\alpha_2 z^{-1})}$$

Which can be seen as a lead (or lag) compensator ($H_1(z)$) plus a first order filter($H_2(z)$):

$$\frac{k_b}{\Delta y}=\beta_1 H_1(z)H_2(z)\quad \text{With}\quad H_1(z)=\frac{1-\beta_2 z^{-1}}{(1-\alpha_1 z^{-1})},H_2(z)=\frac{1}{1-\alpha_2 z^{-1}}$$

Using the given set of parameters: g_i=1.0, g_p=1.0, g_d=0.5, g_{d2}=1.0, we impose the denominator = $(1-z^{-1})^2$ which leads to a double integrator in the controller and a great attenuation at low frequency.

2. **Optimization with classical controller neglecting sensor noise:**

In the previous analysis, one or two integrators were imposed into the corrector. In the following, we do no more imposed an integrator but we only impose to reduce RMS at 0 frequency. The parameters of the corrector are only deduced from this only consideration, neglecting influence of sensor noise.
In order to obtain a more realistic simulation, a real measurement of the ground motion was used, thanks to Guralp geophone [3].
The only things we have to choose is the structure of the controller. Due to previous analysis the controller structure is the following:

$$H(z)=\frac{b_0+b_1 z^{-1}+b_2 z^{-2}}{1+a_1 z^{-1}+a_2 z^{-2}} \quad (1)$$

Tuning the controller parameters:

The goal is to reduce the RMS(0) (at 0 frequency) of $\Delta y(z^{-1})$
In order to find the best controller that minimize RMS(0), we have used the following steps :

- estimation of the PSD of the measured ground motion signal $X(z^{-1})=Z(x(t))$
- scanning the parameter space of the controller
- computation of the PSD of the obtained output using:
- $PSD(Y(j\omega)=|F(j\omega)|^2 PSD(X(j\omega)))$
- we keep the parameter set of the controller that gives the minimum RMS(0)

The optimized parameters are :

$$a_1=-0{,}125 \quad , \quad a_2=-0{,}875 \quad , \quad b_0=0{,}375 \quad , \quad b_1=1{,}1625 \quad , \quad b_2=0.1875$$

These parameters injected in (1) let appear a single integration at the denominator, as 1 is root of it, but it wasn't imposed, it is only a result of the optimization.

It is important to note that these parameters depend on the PSD of the input disturbance. (The previous set of parameters has been computed for the PSD of ground motion coming from the L.A.P.P. site). If this signal is changed in term of PSD (other site, or thanks to a passive/active isolation), then the optimization will produce another set of parameters.

The transfer function F , also called the sensitivity transfer function, has an important property :

$$\int_0^{\omega_e/2} \log|F(j\omega)|\, d\omega=0 \quad \text{with} \quad \omega_e T_e=2\pi$$

It follows that lowering effects of disturbances at low frequencies will increase effects of disturbances at high frequencies. And, if we use the above optimization procedure for a pure white noise disturbance, the result is a controller with a transfer function equal to 0.

Results:

The figures 03 and 04 represent the PSD and the integrated RMS displacements which were obtained with the initial algorithm and the developed one.

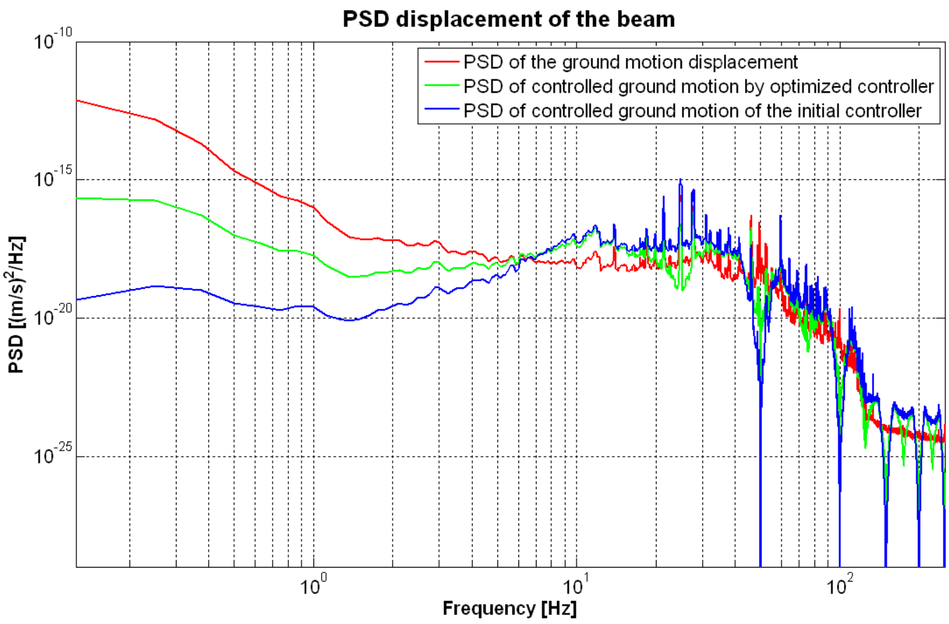

Fig 03 : PSD displacement of the beam with a real disturbance

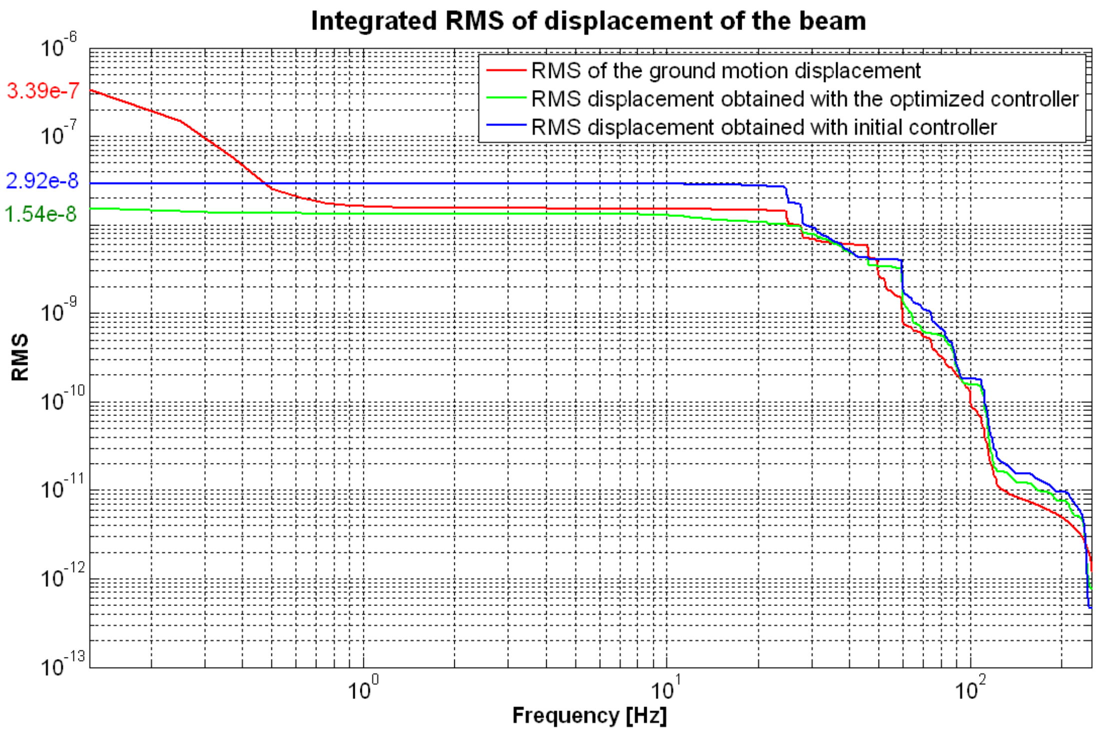

Fig 04 : Integrated RMS displacement of the beam with a real disturbance

One can notice that the optimization technique has allowed the decrease of the RMS (0). Note that the observed displacement at very low frequencies is lowered regarding to the real displacement due to the fact that the used sensor has the following transfer function :

$$C(s)=\frac{s^3-159s^2}{s^3+50{,}05\,s^2+2{,}36\,s+0{,}06}$$

The figure 05a represents the bode diagram of this sensor and one can notice the attenuation at low frequencies.

The next stage was to compare these 2 methods by using as disturbance a displacement measurement on an industrial active table [4] instead of the displacement of the ground motion. The figure 05b represents the Guralp sensor placed on the TMC table. The aim is to simulate the fact that the QD0 magnet will be placed on an active table.

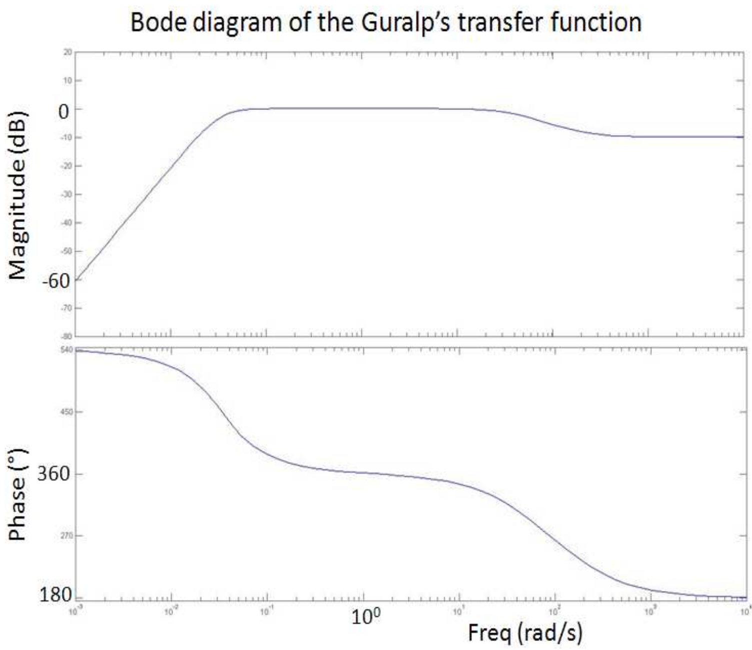

Fig 05a: Bode diagram of the Guralp's transfer function
Fig 05b: Measurement set-up with a Guralp sensor placed on the active table

As the PSD of the disturbance signal has changed, we have to optimized the controller. If we keep the previous parameter set, the RMS is not minimized.

The new parameter set is then :

$a_1=-2$, $a_2=1$, $b_0=-0{,}1$, $b_1=0.8$, $b_2=-0{,}6$

We can see that the optimization technique leads to a double integrator in the controller. The figures 06 and 07 represent the PSD and the integrated RMS displacements which were obtained with a perturbation which is a real displacement measurement on an active table.

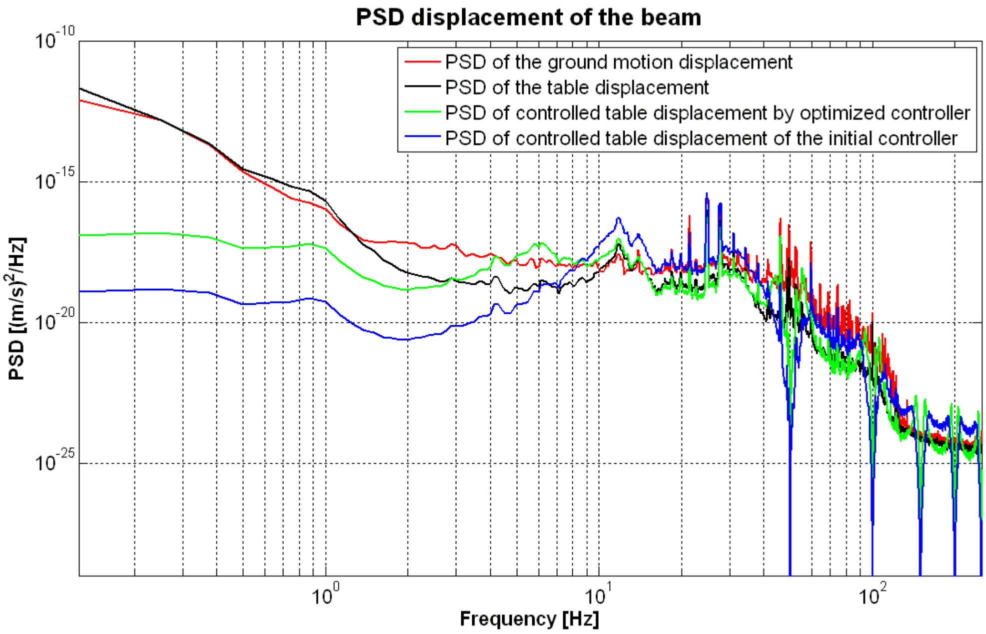

Fig 06 : PSD displacement of the beam excited by the measured displacement on an active table

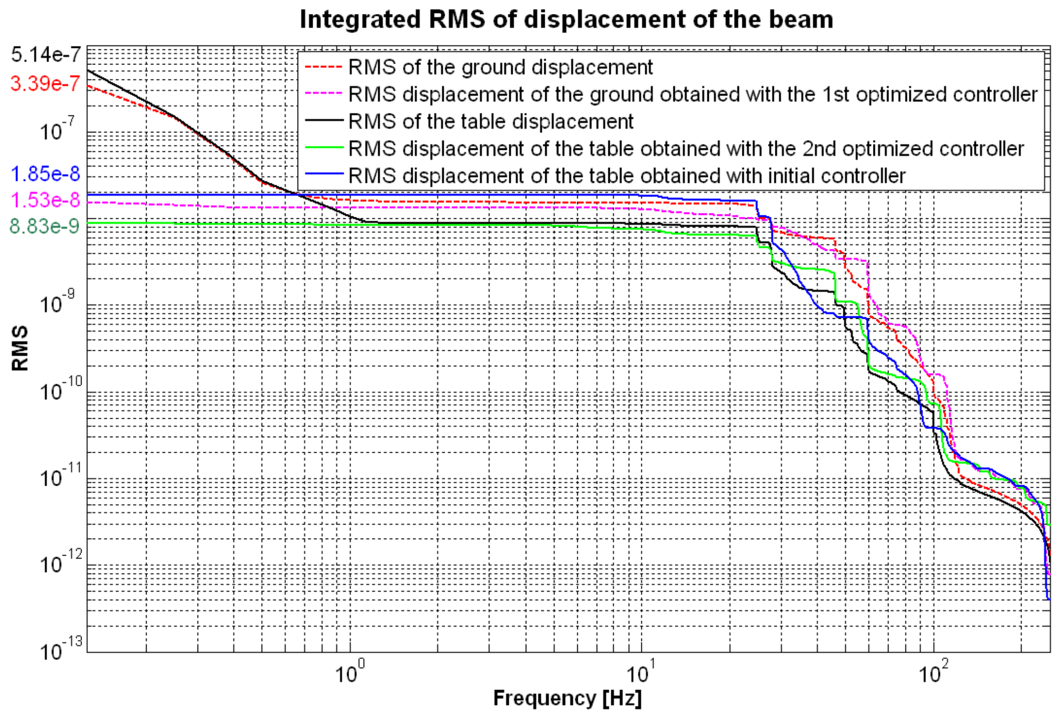

Fig 07: Integrated RMS displacement of the beam excited by the measured displacement on an active table

It is important to note that the values obtained in the above illustration depend on the PSD of the ground motion which depend on the measurement site as well.

3. Optimization with classical controller and sensor noise considerations:

As explained above, the magnitude of the transfer function between sensor noise and the output is the same. The following plot is a zoom for the above optimized controller (optimized for a disturbance without TMC table).

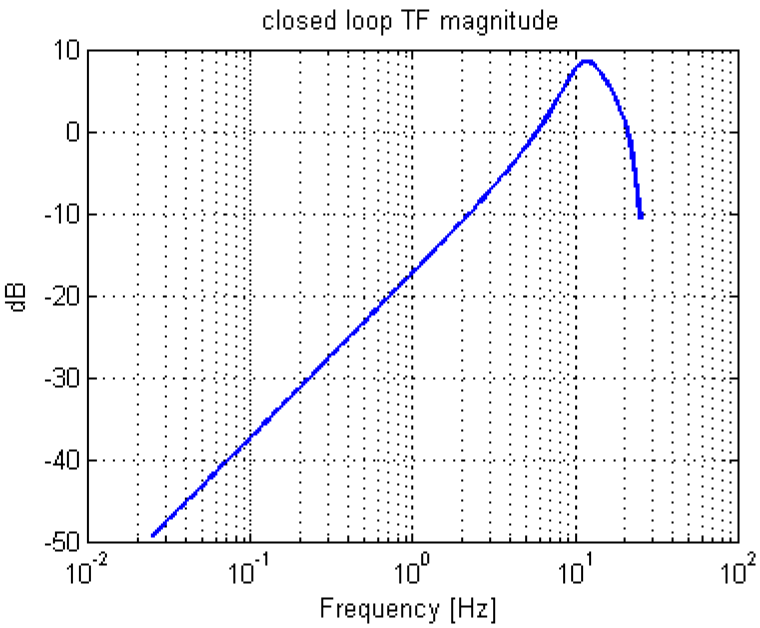

Fig 08: effect of the closed loop on the sensor noise

It is clear that the sensor noise is amplified by a factor 3.5 (or 9.5 dB) around 11 Hz. In order to lower this amplification, we use the same procedure as above for the optimization but we keep the controller that produces a maximum amplification of 1.2 (or 1.5 dB).

In that case, we obtain the following parameters set :

$a_1 = -1.8$, $a_2 = 0.8$, $b_0 = 0{,}3$, $b_1 = -0.2$, $b_2 = 0$

that gives a RMS at 0 equal to $2.25 \cdot 10^{-8}$, greater than previous optimized controller.
Note that the optimization technique scans the parameters with a step equal to 0.1, this could be refined. The following figure compares the amplification of the noise in the two cases.

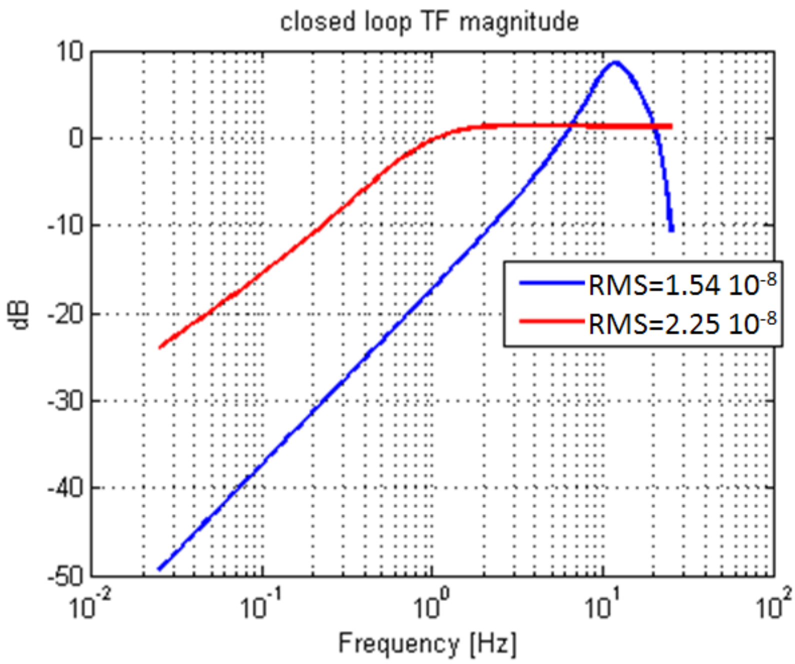

Fig 09: noise amplification : comparison of two controllers

As expected, the sensor noise is less amplified with the last controller around 11 Hz. But without other considerations, we are not able to say that this last controller is better than the previous one. On the other side, it is shown that we can have some action on the amplification of the noise.

4. Conclusions

The proposed method to tune the controller is able to obtain the minimum of the RMS at 0 with a given input disturbance. It is important to note that it is not possible to lower more RMS(0) by the mean of a feedback with a Linear Time Invariant controller after the proposed optimization. Thus, in order to lower RSM at 0 of the output, there are two possibilities :

- minimizing the input disturbance by adding more mechanical filters : statically or dynamically
- adding a feed-forward controller with an estimation of the input disturbance

It is also important to note that the attenuation of the input disturbance has to be done in the frequency range were the feedback is not efficient (i.e. were there is no disturbance attenuation and more obvious were there is an amplification) clearly above 10 Hz.

We also have investigated the effect of the loop on the amplification of the sensor noise. It is shown that there is always an amplification at high frequency, this amplification can be minimized but the counterpart is a raise of the RMS at 0.

5. Bibliography

[1] D. Schulte and al, “Some Comments on feedback and feedforward at the IP”
[2] J. Pfingstner, “Ground motion control problems for CLIC”
[3] B. Bolzon, “Etude des vibrations et de la stabilisation à l'échelle sous-nanométrique des doublets finaux d'un collisionneur linéaire”, Thesis, Université de Savoie, 2007, p. 145-146, also as LAPP-T-2007-05.
[4] TMC Company, “TMC STATIS 2000 stable active control isolation system”, Users manual, Document P/N 96-26690-02 Rev. D, Novembre 2002