SMEC Mechanism Control System and GSFC Prototype Test Report

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1 INTRODUCTION

The purpose of this document is to describe and analyze the control system used for the SMEC Mechanism of SPIRE Instrument and to present results in control loop operation of the GSFC mechanical prototypes which are the mechanical baseline design for the SPIRE SMECm .

2 PROCESS DESCRIPTION

The process to be controlled comprises:

- a mechanism assembly
- a moiré fringes optical encoder
- a voice coil motor
- analog electronics
- a digital controller around a 21020 Digital Signal Processor

Note: in case of optical encoder failure, a short range +/- 3.2 mm LVDT is implemented in the control for degraded mode operation. This sensor could be used together with the encoder signal during normal operation.

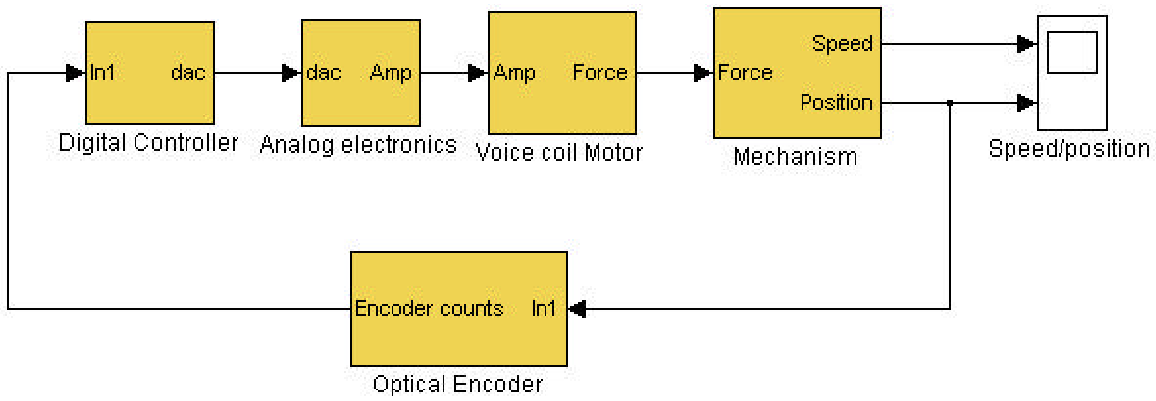
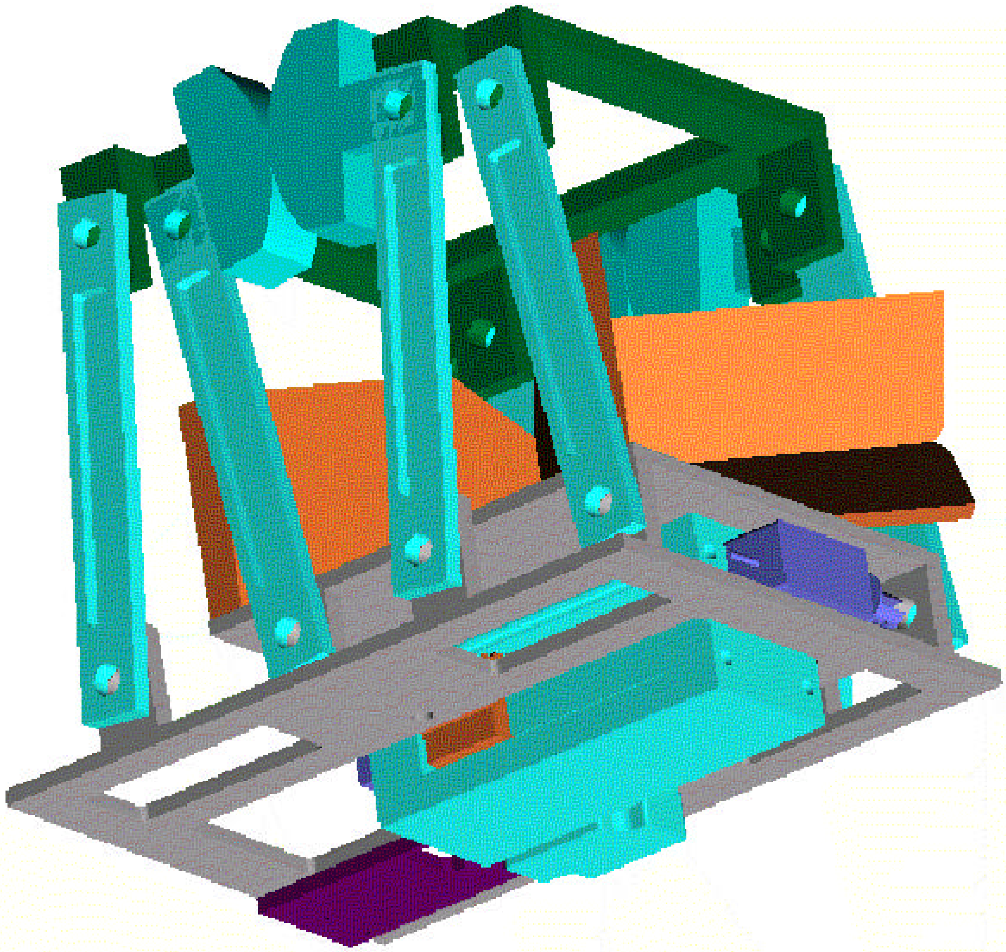


Figure 1: SMEC Process model

2.1 Description of the mechanism

The mechanism comprises a double stage parallelogram with 16 flexible pivots.
The motion is kept linear by mean of a compensation stage on the top of the mechanism.



2.1.1 Frequency response of the mechanics

Globally, and after a first frequency identification, the frequency response of the system shows a main stiffness at about 0.5 Hz followed by a resonance around **30 Hz for Prototype 1 (50 Hz for Prototype 2).**
This resonant frequency is due to poor stiffness of the frame.

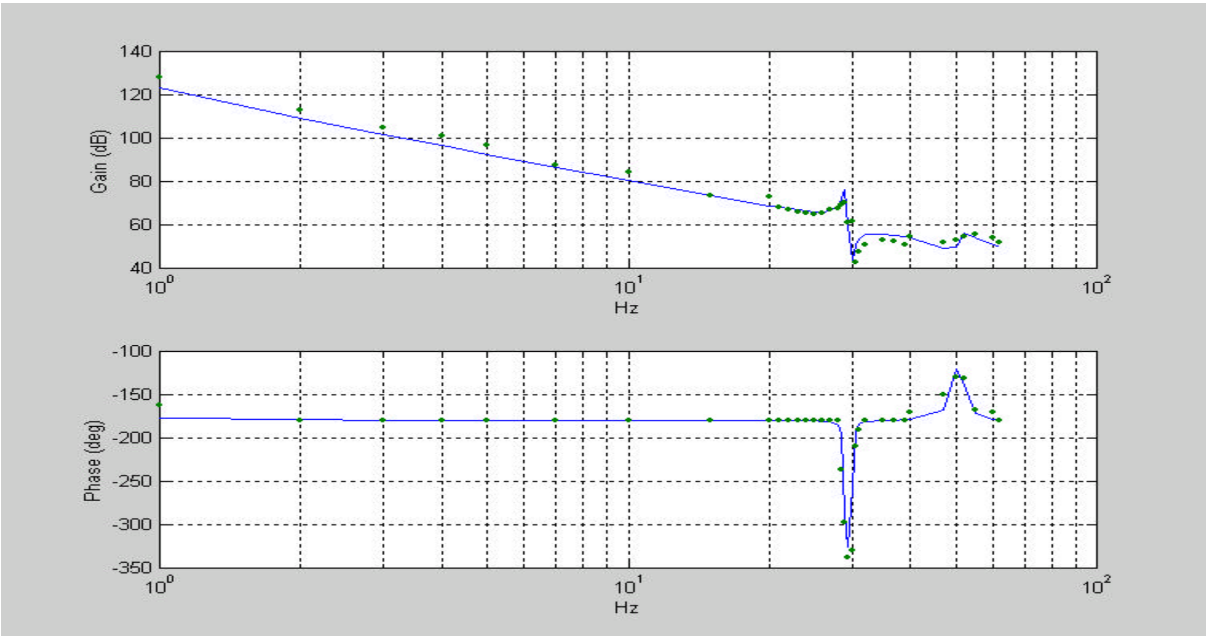


Figure 2: Frequency response of GSFC Mechanics Prototype 1 (up to 100 Hz)

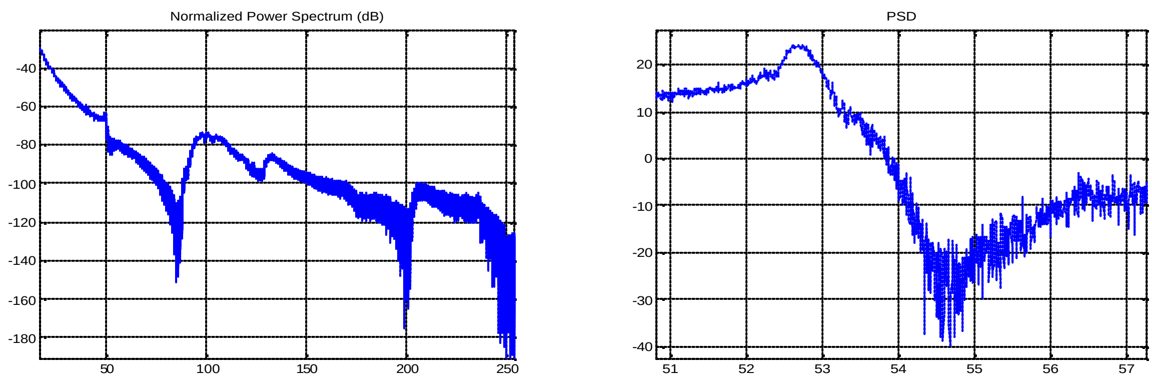
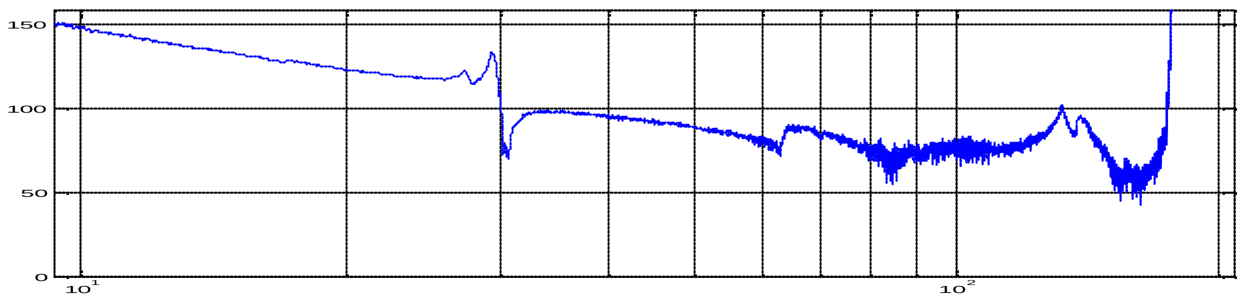


Figure 3: Frequency response of GSFC Mechanics Prototype2

Chirp response 0.3 indac sine amplitude chirpp2_10300

2.1.2 Disparity of the mechanical response

The measurements at various carriage position show a disparity in the frequency and the damping of the main modes, as shown on next figures (harmonic responses from GSFC Prototype 1)



Chirp5200.mat

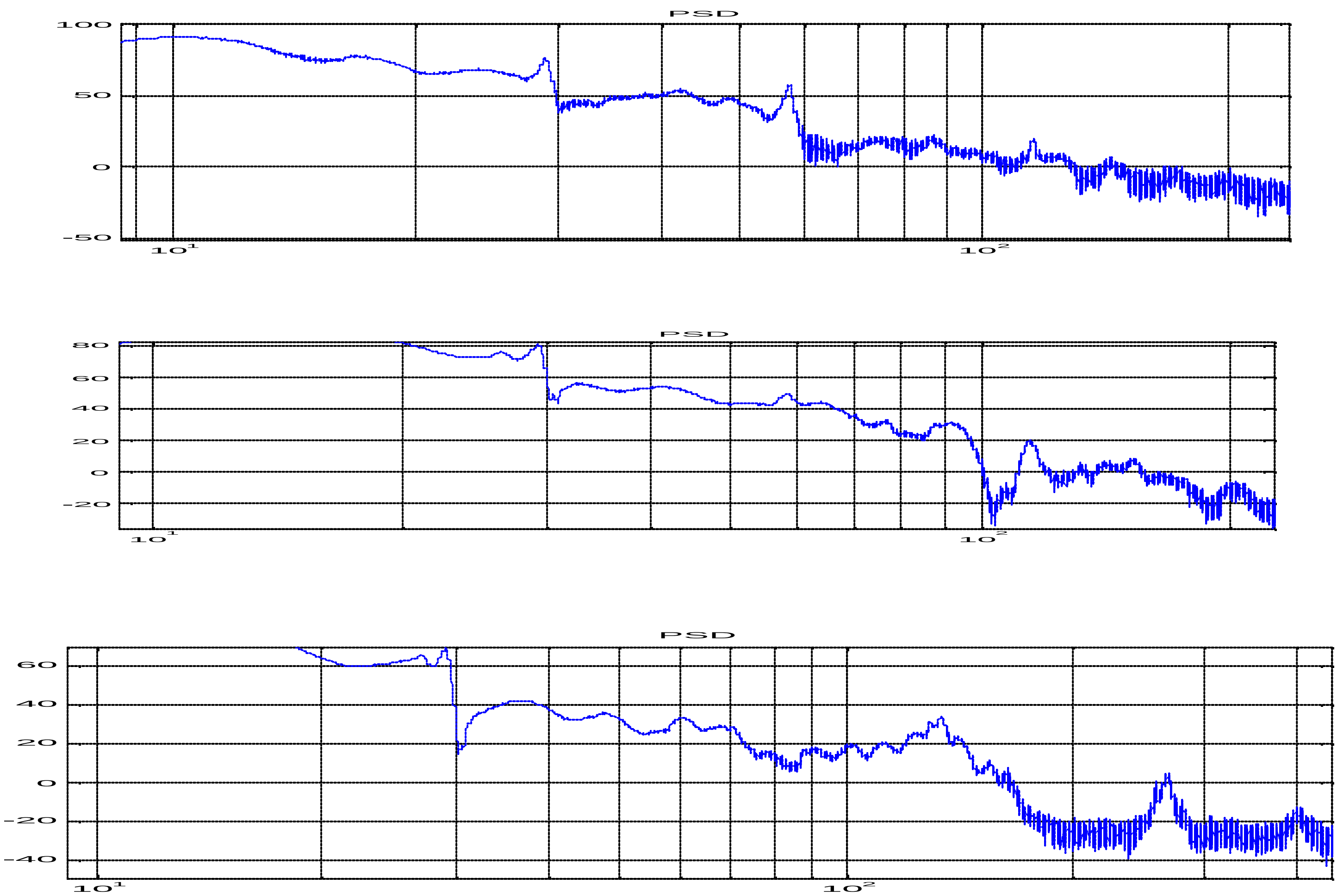


Figure 4 Mechanical modes depending on experiment conditions

2.2 Non linear effects in the frequency response

The 30 Hz (50Hz for prototype 2) resonant-anti resonant mode damping is not linear, depending on the level of the sine stimulus, i.e. it appears only after a threshold of stimulus. This level could be explained by the friction existing at compensation level which damps the 30 Hz for low signals. For very low sine stimulus, the 30 Hz does not appear as a resonance with a 180 degree phase shift. Then the phase shift between the stimulus and the encoder signal appears and increases when applying an increasing stimulus. The following figures show the response at 30Hz depending on the level of the stimulus, due to non linear effects.
In these conditions it shall not be possible to compensate exactly the modes by notching. It is the reason why the notching shall be very large only to insure closed loop stability, but without the possibility to damp the modes which shall be visible with residual effect in closed loop operation.

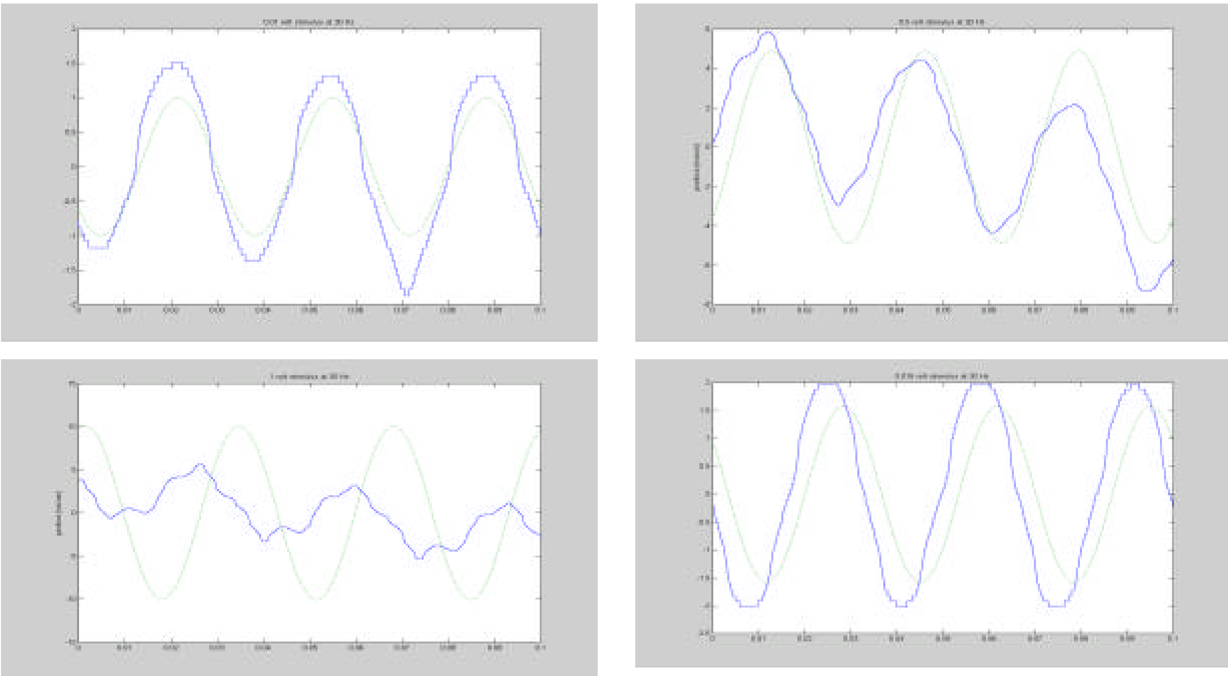


Figure 5: Responses at 30Hz at various stimulus amplitude

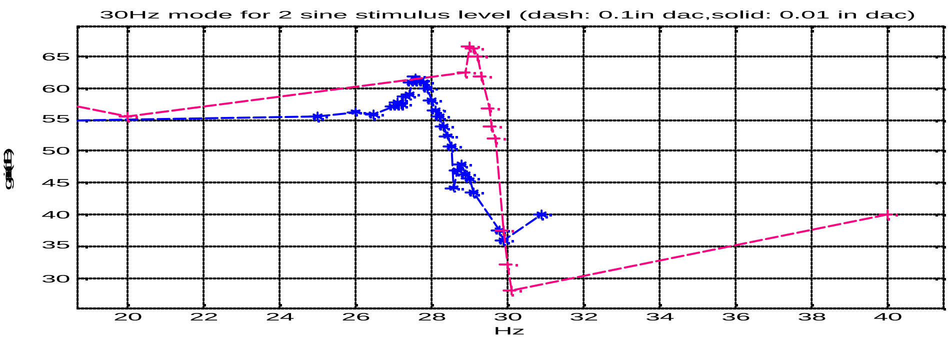


Figure 6 : 30Hz mode disparity vs stimulus amplitude

2.3 Model of the mechanics

The 50 Hz mode is due to the frame longitudinal deformation (deformation of the parallelogram). This deformation is composed with a 2 mass spring system which induces a resonance/ non resonance effect. The 2 mass-spring model can be explained by the fact that there are 2 semi pendulum with intermediate mass.

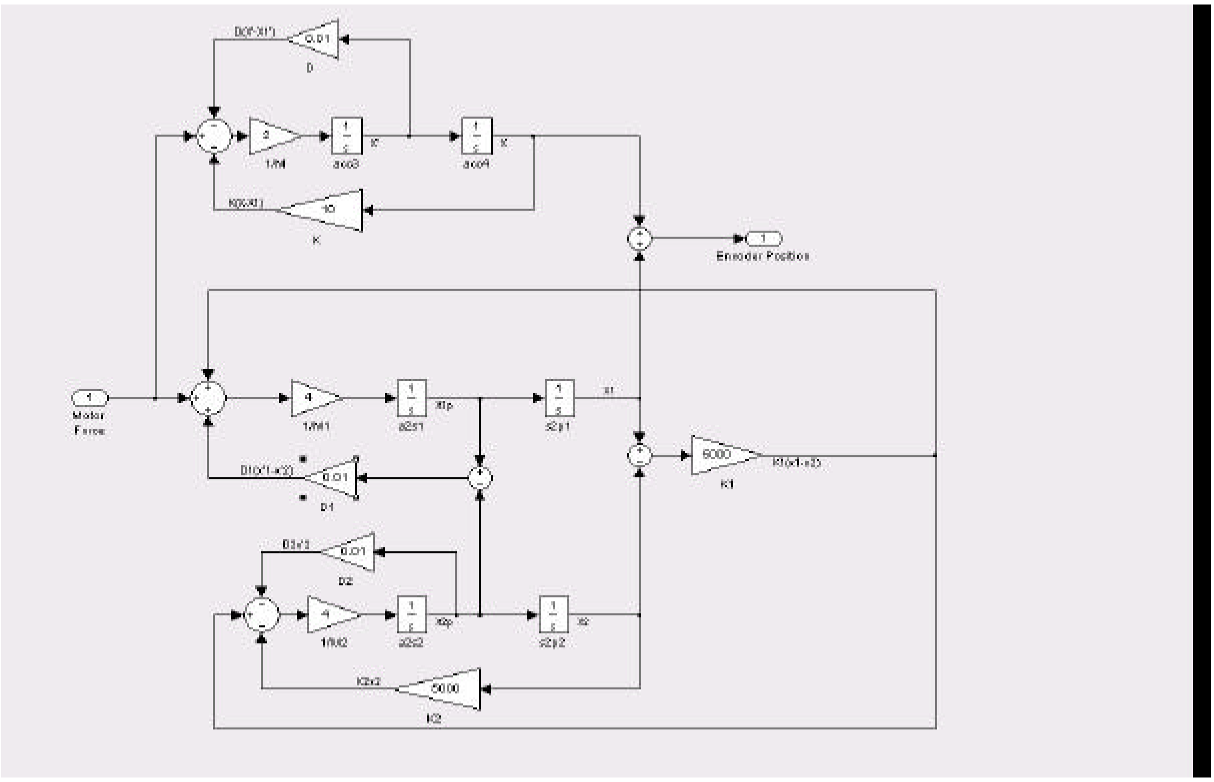


Figure 7: Mechanism model

The following figure shows the related frequency response of the mechanics. This model shall be used for the controller synthesis.

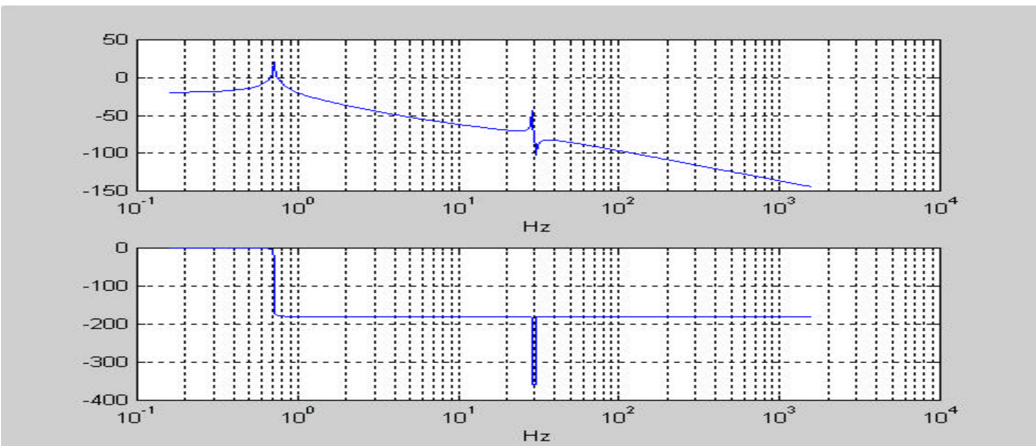


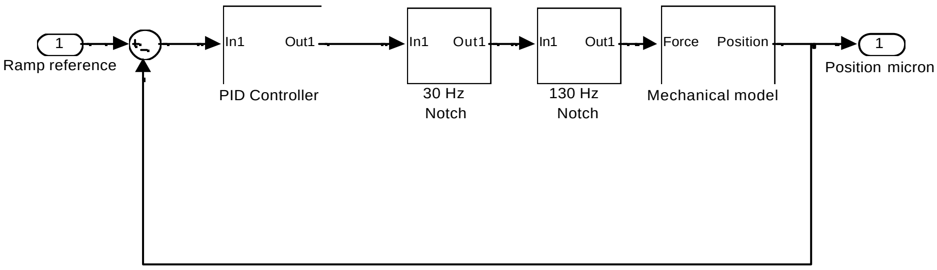
Figure 8: frequency response of the mechanical model

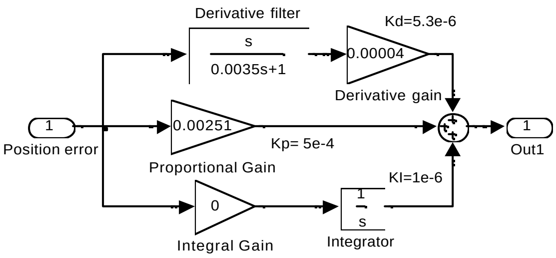
(here on the basis of a 30 Hz mode as measured on GSFC Prototype 1)

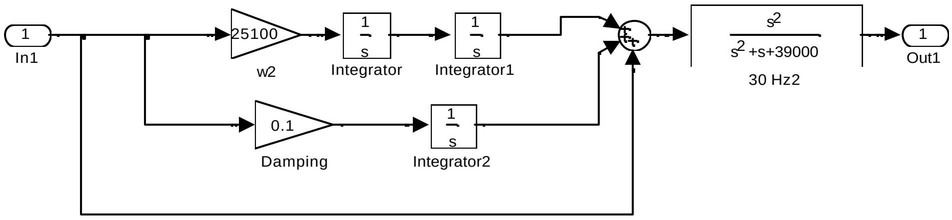
3 CONTROL OF THE MECHANISM

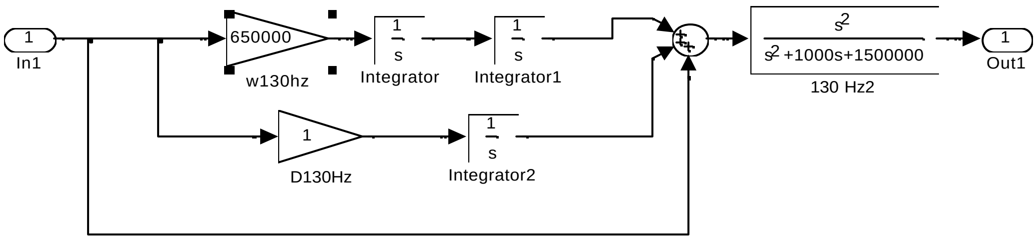
3.1 Controller model

The control loop is closed using a PID controller with a notching at 30Hz (or 50Hz for prototype 2)and 130 Hz.









3.2 Simulation of the FTS on MATLAB

3.2.1 Control time response and bandwidth

The closed loop is tuned to yield a 50 ms time response, but with a no damped mode at 30 and 60 Hz. (linear combination of the 2 resonant frequencies). About the 30 Hz, we are limited by the torsion effect and not really by the longitudinal displacement. Indeed, in the former case, the motor can not control the mode since the motor can not counter act in rotation. In the case of the longitudinal displacement, we can damp the mode closing the loop at a higher frequency (in this case we try to avoid the torsion mode). Due to the non linearity of the 30 Hz behavior, the notching is not achieved precisely.

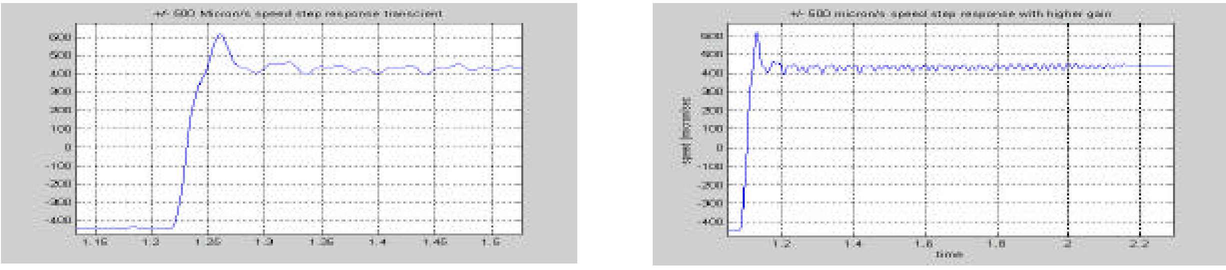
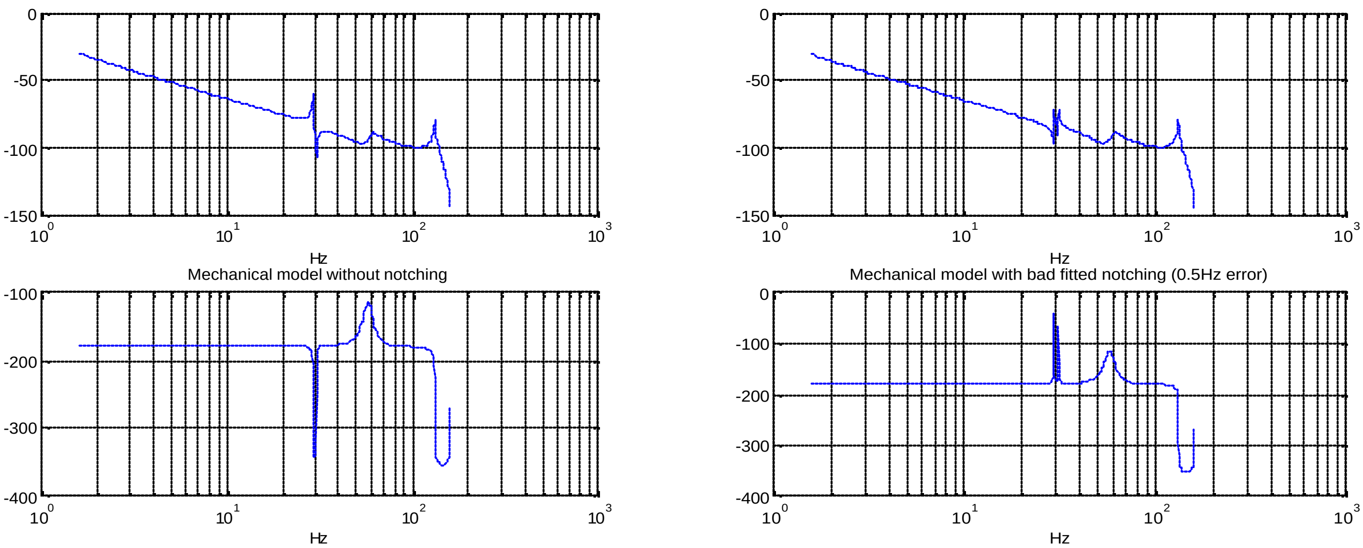


Figure 9: Time response of the control with two set of PID parameters

3.2.2 Effect of a bad notching

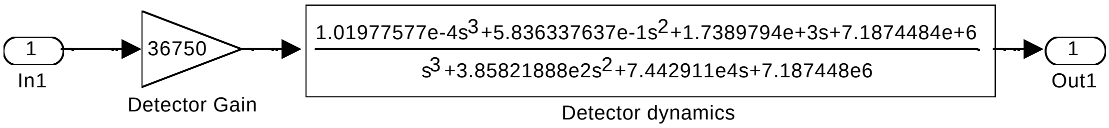
We see hereafter the consequence of a bad notching. If the resonance frequency moves, the notch induces a parasitic resonance. The notch effect is efficient over a very narrow frequency range (<<0.5 Hz) due to the very high proximity of the resonant/anti-resonant frequencies associated with a very low mechanical damping of the modes.



3.2.3 Stability of the speed control

3.2.3.1 Specification of speed stability

It is required that the speed shall not fluctuate more than 10 µm/s rms over the scan, after detector filtering. The detector filtering consist of a 3rd order filter with a 29 Hz cut-off frequency. The model shown hereafter is deduced from JPL detector data.



The detector response is shown on the following transfer function plots.

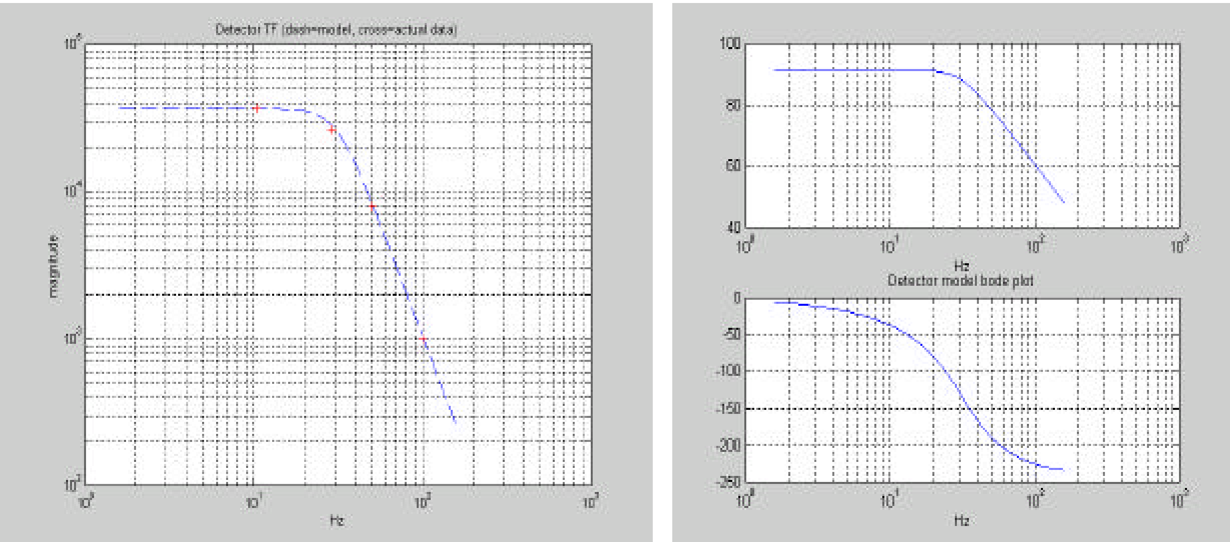


Figure 10: Spire detector frequency response

4 GSFC PROTOTYPES CONTROL PERFORMANCES RESULTS

4.1 Position jitter

4.1.1 Prototype 1 position jitter

The position jitter, i.e. the difference between the ideal position ramp and the actual position provided by the 0.1 µm encoder pulses, was about **+/- 0.4 mm** peak using the GSFC Prototype 1 control.

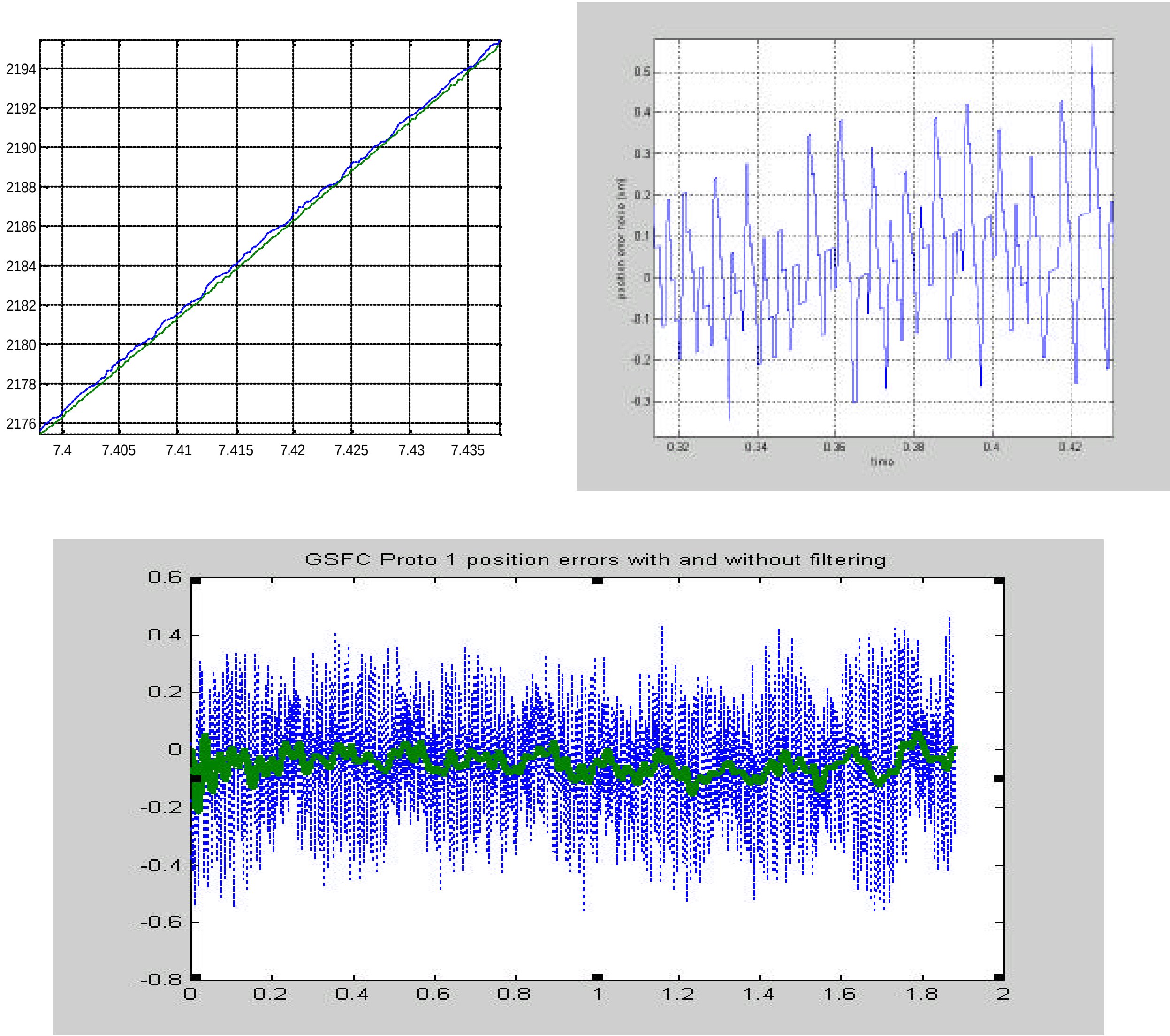


Figure 11: Position fluctuations during a 500 mm/s scanfor the Proto 1

4.1.2 GSFC Prototype 2 position jitter results

Due to a better mechanical stiffness, the control shows better results with a **+/- 0.15 μm** peak position jitter. The effect of encoder quantization of **0.1 μm** becomes a limitation in the control loop performance and yields some non linear limit cycle effects due to quantization. This implies a better interpolation for the encoder electronics (up to now the electronics is an Heidenhain interpolator by 5 giving 2µm/(5x4) = 0.1 um resolution)

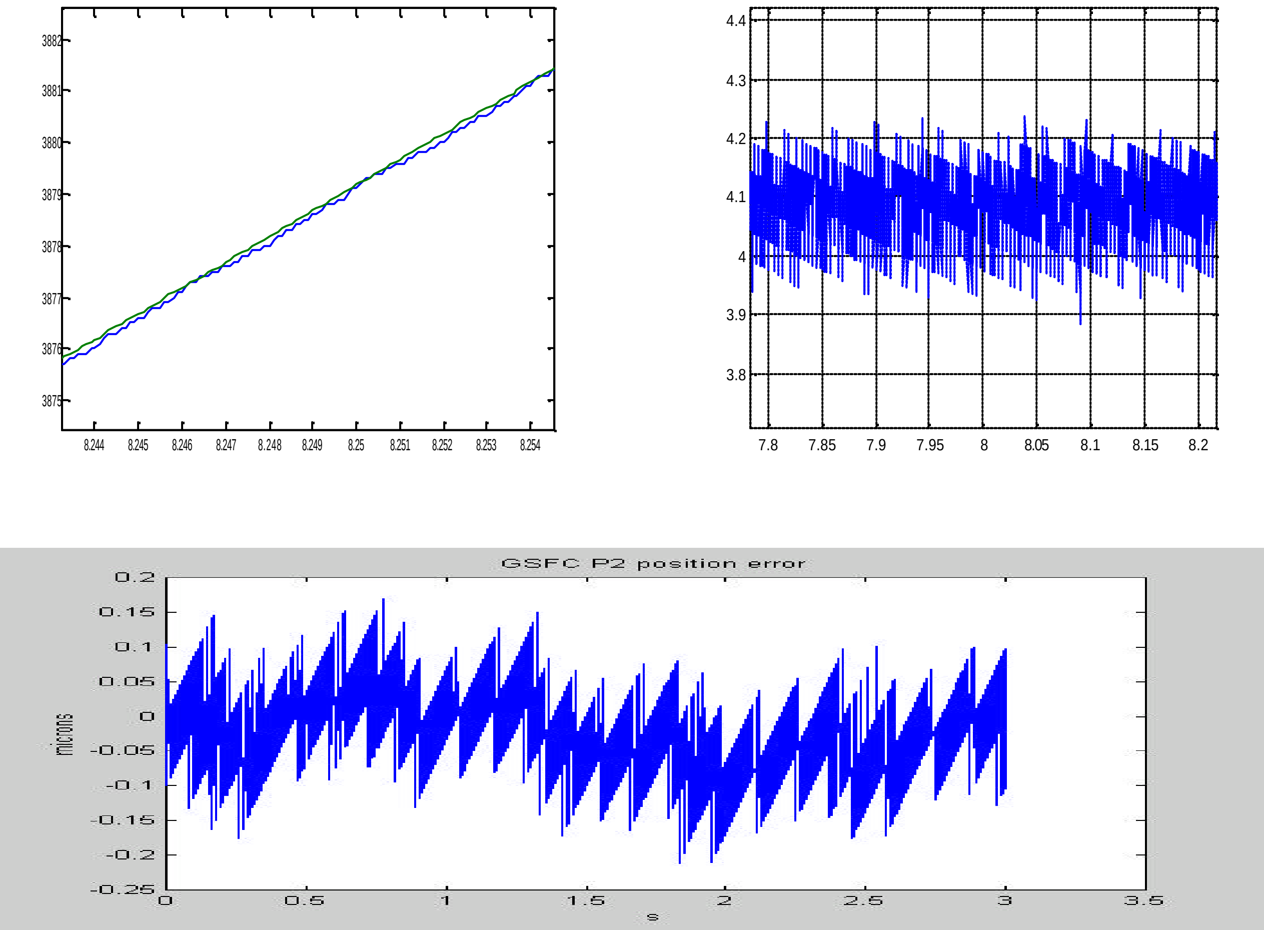
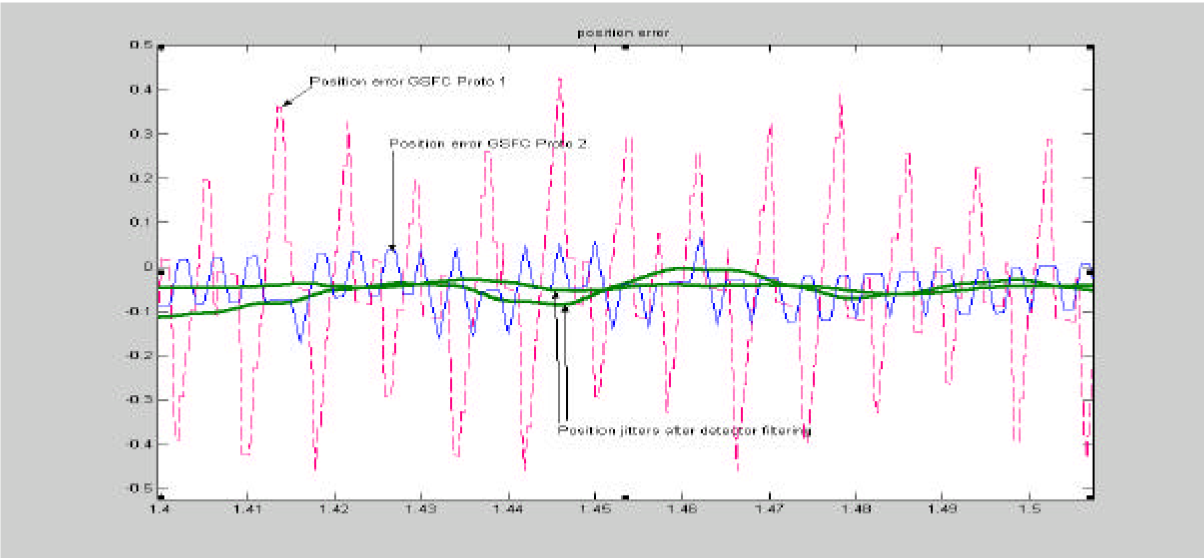


Figure 12: Position fluctuations during a 500 μm/s scan for the Proto 2

4.1.3 Comparison of the 2 position jitters



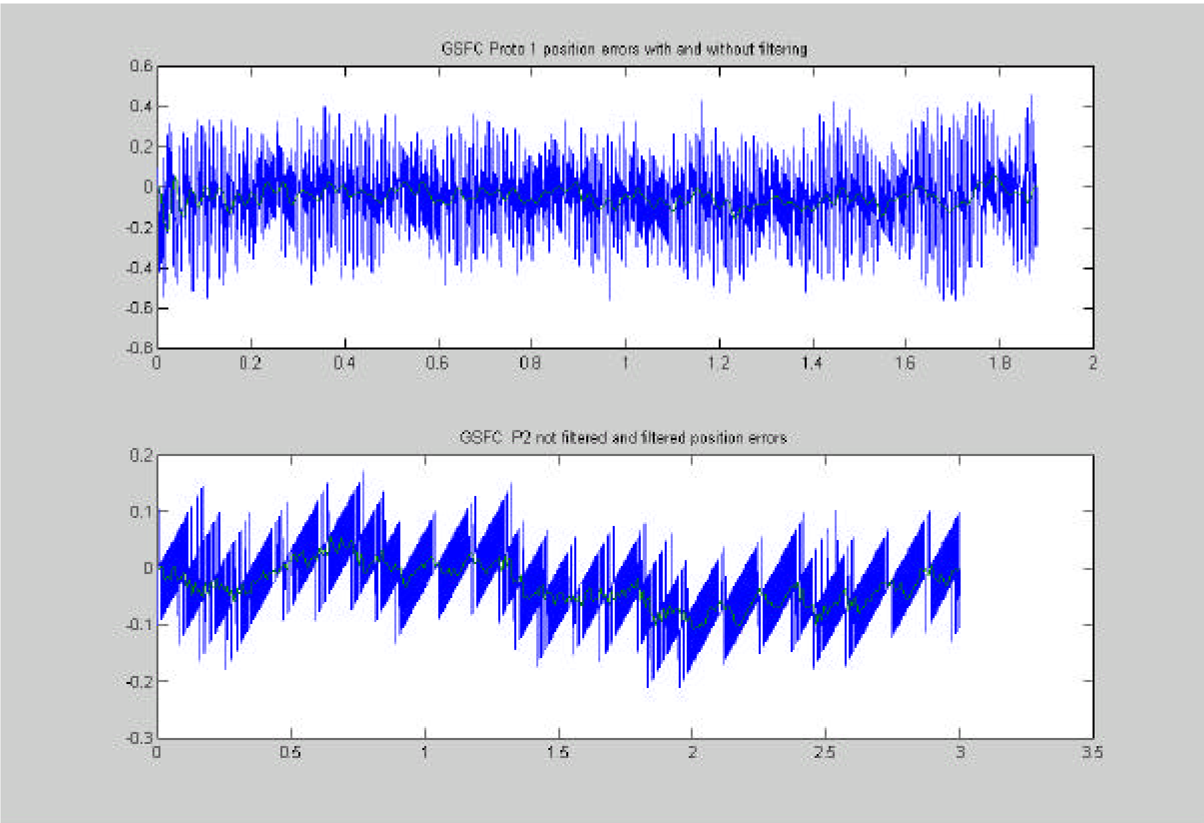


Figure 13: comparison of GSFC P1 &P2 position errors

4.2 Position error spectra

On the next figure we plot the normalized spectrum (i.e. a sine with amplitude A shall have a spectral line equal to A) of the 2 position jitters of proto 1 and proto 2 with and without detector filtering.

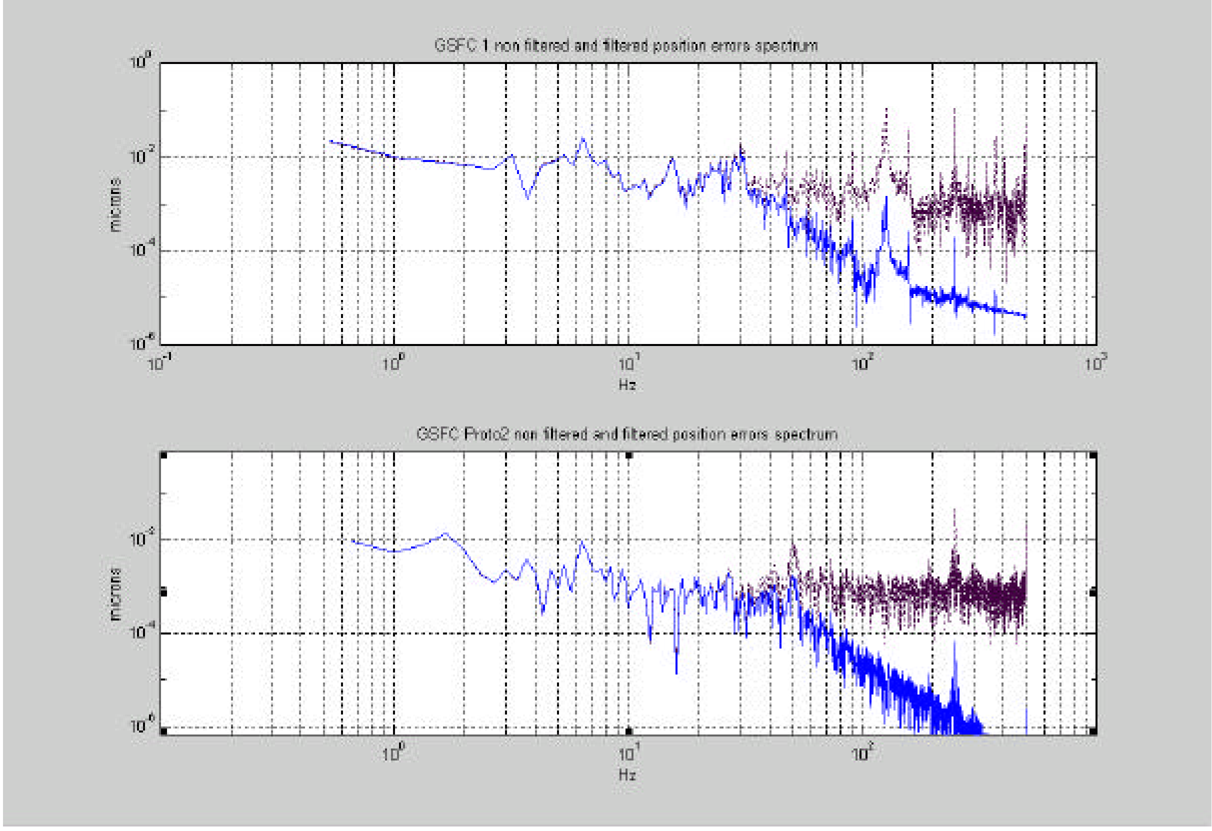
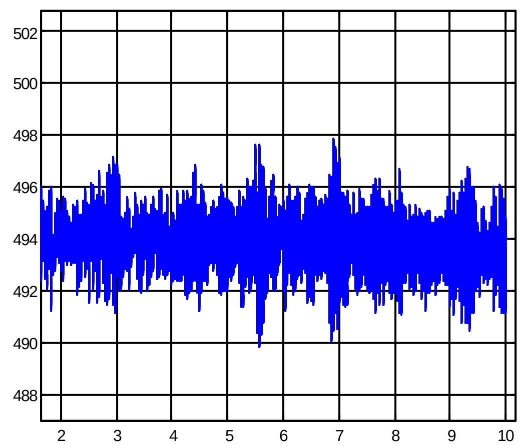
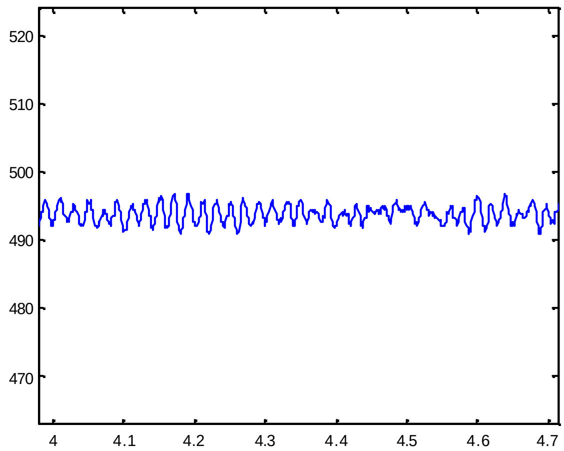


Figure 14 : Spectra of position errors

4.3 SMEC Speed jitter

We derive the position jitter(filtered one) to obtain the velocity jitter. The different figures are shown for various positions of the scan mechanism. Globally we obtain around **2mm/s rms** velocity jitter at SMEC level. Figure top right shows the velocity jitter computed in real time on MATLAB/dSpace where the position counts are derived and then filtered.





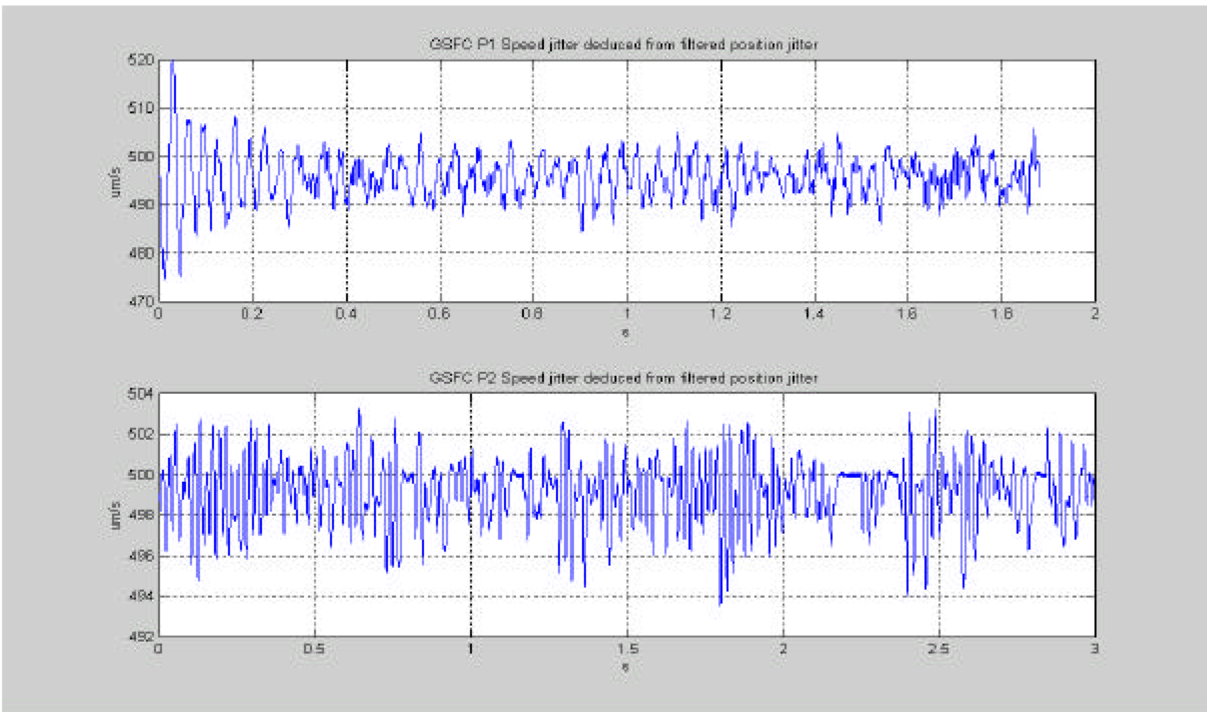


Figure 15: SMEC Velocity for GSFC P1 & P2

4.4 OPD Speed jitter

We multiply by 4 the SMEC speed vector to obtain the velocity at OPD level. This is to be compared with Bruce Swinyard simulations in the document 'Simulation of GSFC Prototype Mechanism performances in the Spire FTS'. We see a significant difference due to computation methodology. This point is to be clarified since these simulations have a crucial impact on the official requirement on the speed stability of the SMEC defined as a 10 µm/s rms jitter afeter JPL Detector filtering.

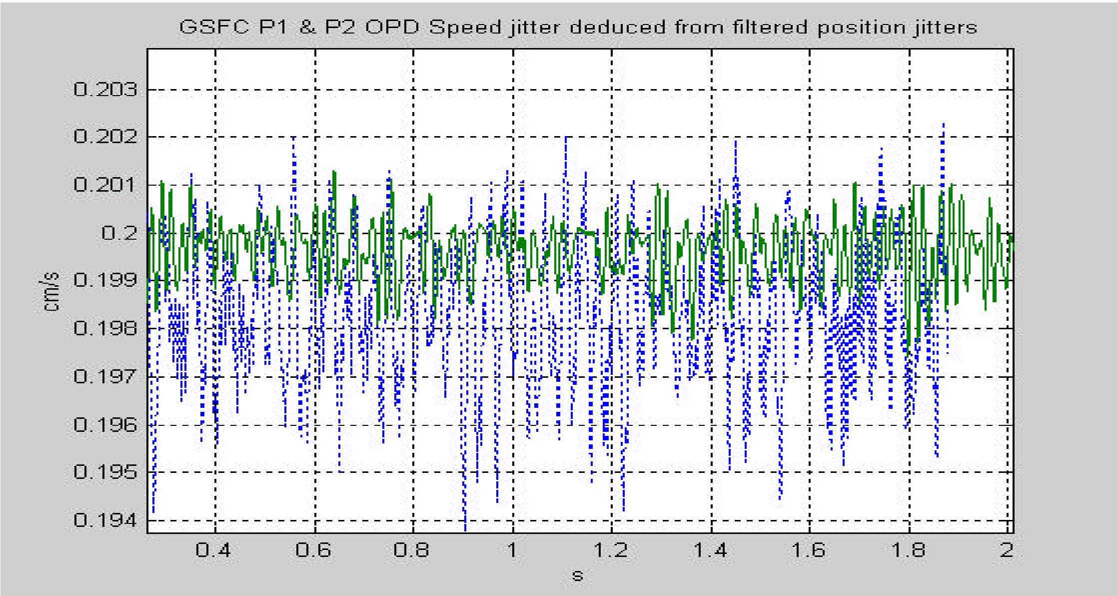


Figure 16 : OPD Velocity simulation for GSFC P1 & P2

4.5 SMEC Speed jitter vs. scan position

The mechanism geometry varies according to the scan position. In particular, the frame does not yield the same stiffness if the mechanism is vertical or inclined. Consequently, the mode frequencies and damping varies according to the scan. Since the control is tuned for a dedicated position, the notching does not fit the mechanical modes along the complete trajectory, and since, the speed jitter level is not the same for all scan positions. The following table gives an example of speed jitter depending on the scan position for the prototype 1. The results for GSFC prototype 2 are twice better.

Scan position (cm)	Filtered Speed fluctuation (um/s)
0.1	8.6
0.2	6.3
0.3	6.5
0.4	4.3
0.5	4.1
0.6	6.9
0.7	7.6
0.8	8.2
0.9	6.1
1.0	6.8
1.1	8.2
1.2	9.6
1.3	10.3
1.4	10.2
1.5	14.5
1.6	17.4
1.7	9.1
1.8	6.2
1.9	4.8
2.0	5.5
2.1	5.3
2.2	6.2
2.3	4.5
2.4	4.2
2.5	5.1
2.6	3.3
2.7	3.2
2.8	3.4
2.9	3.7

Table 1: Filtered speed fluctuation rms values vs. scan position
(GSFC Prototype 1)