Section 10

Appendix 7: Controls Analysis

7 Controls Analysis

7.1 BSM Control System Analysis B.Stobie UKATC 23/06/01

7.1.1 SCOPE

This analysis describes the control system for the SPIRE Beam Steering Mirror (BSM).
The BSM is a two-axis device, using flex-joint supports to give a negligible friction control of the axes, allowing high accuracy positioning.
The description concentrates on the Chop axis, as the Jiggle axis has exactly the same control scheme, with parameters changed to suit the larger inertia and flex-joint spring rate. However some Jiggle modelling results are included.

7.1.2 LINEAR ANALYSIS

As the lowest BSM structural resonance has been estimated at around 800 Hz by FE modelling, The BSM axes can be modelled for the purposes of control as a simple spring-mass-damper system, using the flex-joint spring rate.

The mechanism can be represented by the second-order system

$$G(s) = \frac{w_n^{\ 2}}{s^2 + 2*d*w_n*s + w_n^{\ 2}}$$

where the system natural frequency

$$w_n = \sqrt{\frac{Ks}{J}}$$

with Ks = flex joint spring rate, 0.047 Nm/rad Chop and 0.37 Nm/rad Jiggle
J = axis inertia. 1.7e-6 Kgm^2 Chop and 45.0e-6 Kgm^2 Jiggle
d = flex joint damping 2.3e-5 Nm/rad/sec

The Chop step specification requires a sinusoidal step profile to be achieved in less than 20mS. With a design target of 15 mS, a nominal system risetime of about 5mS is required to closely follow the externally generated profile.

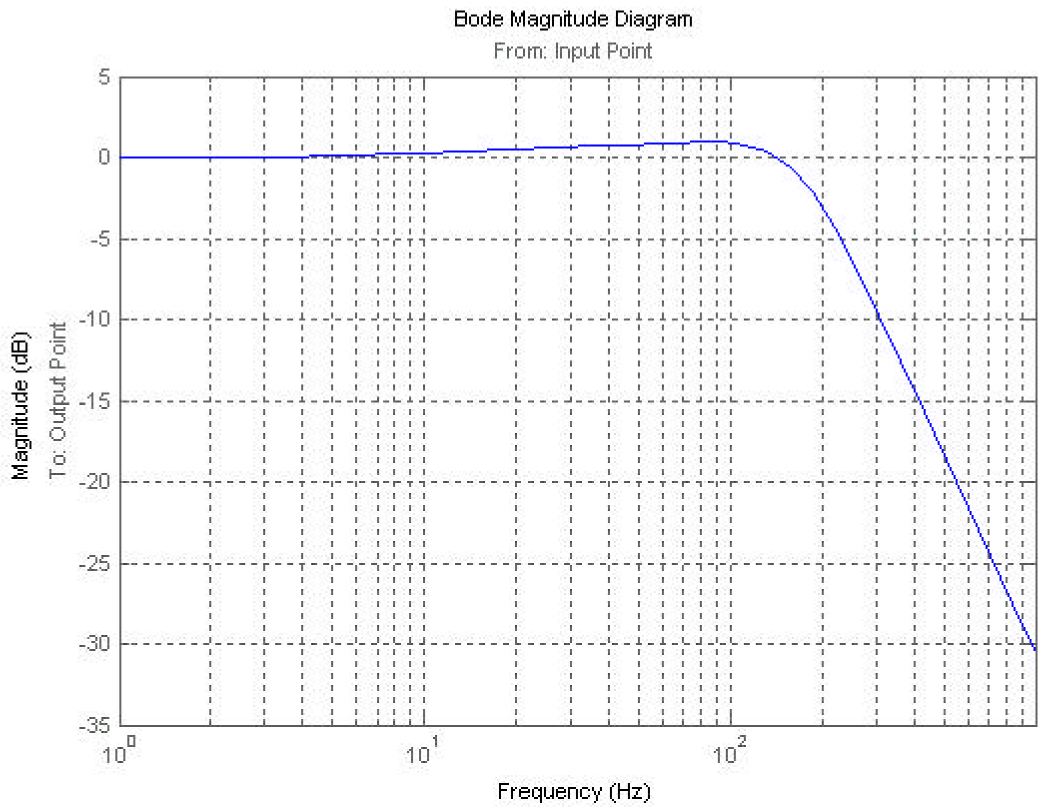
A second order linear system has a 2% settling time of 4 time constants, or $\frac{4}{d*w_n}$. With d = 0.707, this becomes $\approx \frac{5.7}{w_n}$. This requires a bandwidth of approximately 200 Hz to meet the design target.

A linear frequency-domain model was constructed to evaluate a standard nested velocity and position loop control system.
All linear elements in the mechanism, motor power amplifier and position sensor were included in the model. An acceleration loop was included to limit the system acceleration, as the slew rate of the electronic power amplifier may produce instability for large step demands.

The following control parameters were used. Note that the position loop integrator is of the form (1 +s*t) / s .

Parameter	Description
position sensor gain	100
position loop gain	21.9
position loop integrator time constant	0.013
rate loop feedback gain	2.66
Acceleration loop feedback gain	0.5e-3

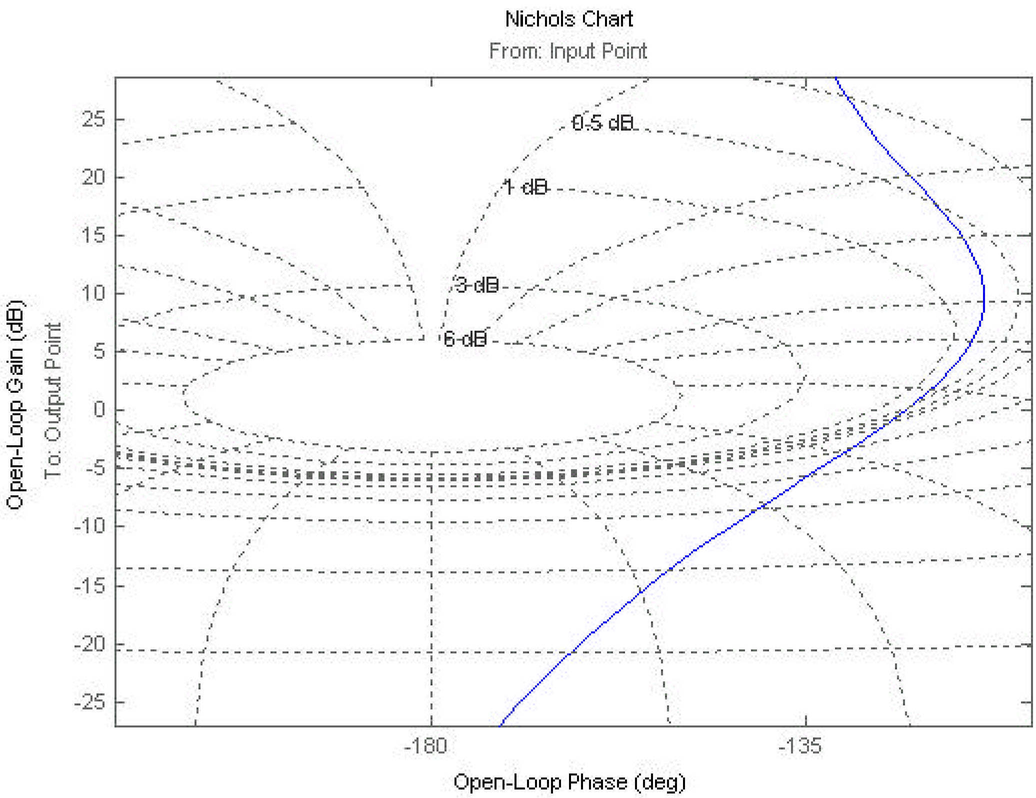
Figure 1 Chop Axis Closed-Loop Bode Diagram



It can be seen from the above closed-loop Bode plot that the –3dB bandwidth is approximately 200 Hz.

The loop stability can be evaluated using the Nichols chart, which plots open-loop response with overlaid closed-loop contours.

Figure 2 Chop Axis Nichols Chart



The gain margin is 33dB and the phase margin is approximately 57 degrees.

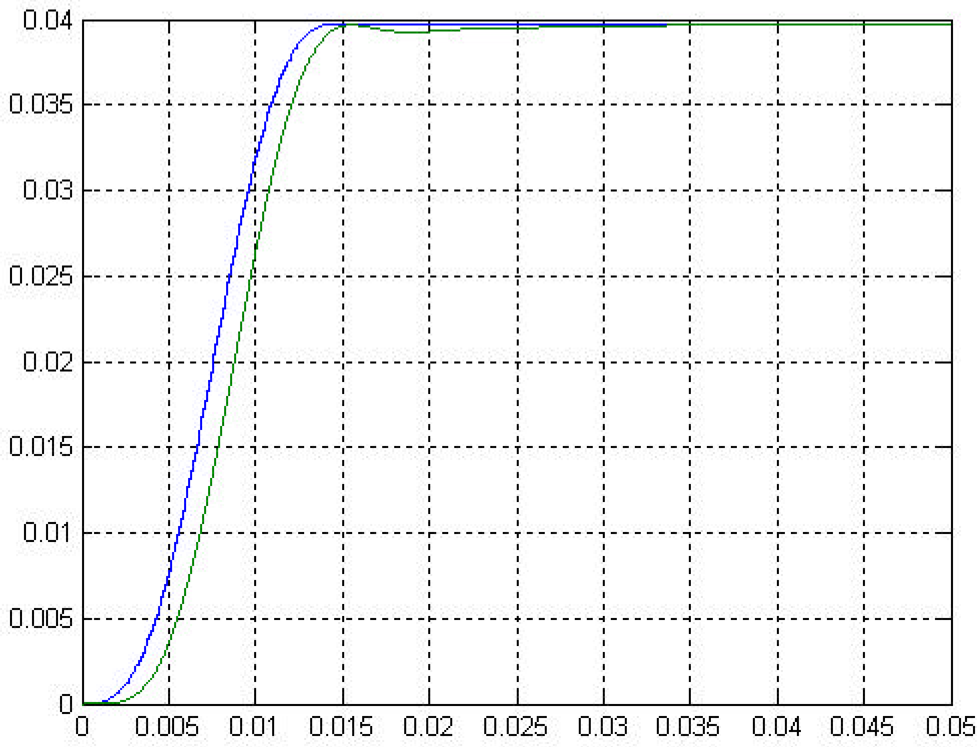
7.1.3 NON-LINEAR SIMULATION

Though the foregoing analysis gives a good guide to general performance, there are a number of significant non-linearities present in the system, particularly the voltage limits of the power amplifier. More significantly, the control system will be implemented entirely in software, apart from the power amplifier and the position sensor preamplification. Standard linear analysis cannot handle the sampling effects and quantisation in a simple manner.
There is also the assumption in the above modelling that rate and acceleration signals were available for feedback, however the system uses only a magnotorestive position sensor. Therefore the required signals need to be estimated from the existing information. A standard method of achieving this is using a state observer, which employs a basic model of the system, and uses feedback from the available system signals to correct any errors in these estimates due to, for example, incorrect estimates of system parameters such as inertia and spring rate. This method also copes with variations in parameters such as the spring rate. However, the calculations can only be done accurately by a processor and associated software.

For these reasons, a detailed time domain non-linear simulation of the BSM axes control system has been created using matlab-Simulink, an industry standard tool.
This model is described in detail in the SPIRE BSM Design Description document, however, some results are presented here for convenience.

The following figure shows the demanded sinusoidal position step demand (blue) for the Chop axis, and the system response (green).

Figure 3 Chop Axis Step Response (non-linear simulation)



Note that the simulated performance meets the original design target step response of 15 mS.

Finally, as power dissipation is an important parameter to be minised for the BSM, as it is in a cryogenic environment, the non-linear simulation enables the calaculation of dynamic power dissipation. It is interesting to note from the following figure that the peak motor power required to slew the axis is approximately the same as that required to hold the axis at a fixed angle.
Indeed over time, the dominant power dissipation requirement for the BSM mechanism is that required to hold the axes against the flex joint spring forces – this is the trade-off for almost zero friction during axis rotation.

Figure 4 Chop Axis Motor Power Dissipation (at 4 deg.K)