DIAMOND LIGHT SOURCE BOOSTER FAST ORBIT FEEDBACK SYSTEM

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INTRODUCTION

The Diamond Storage Ring Fast Orbit Feedback (FOFB) system currently meets its requirements in terms of beam stability at Diamond. However new requirements for improved beam stability, either from users or as a consequence of operating with reduced electron beam height or a need to suppress new beam disturbances in the future would require improvements to the FOFB performance.

As part of the development of the Storage Ring controller optimisation, closed loop beam control has been applied on the Booster synchrotron by running the Booster as an electron storage ring at 100 MeV.

The Booster has the same hardware as the Storage Ring for beam position detection and control of the corrector magnets so the same FOFB control system can be used.

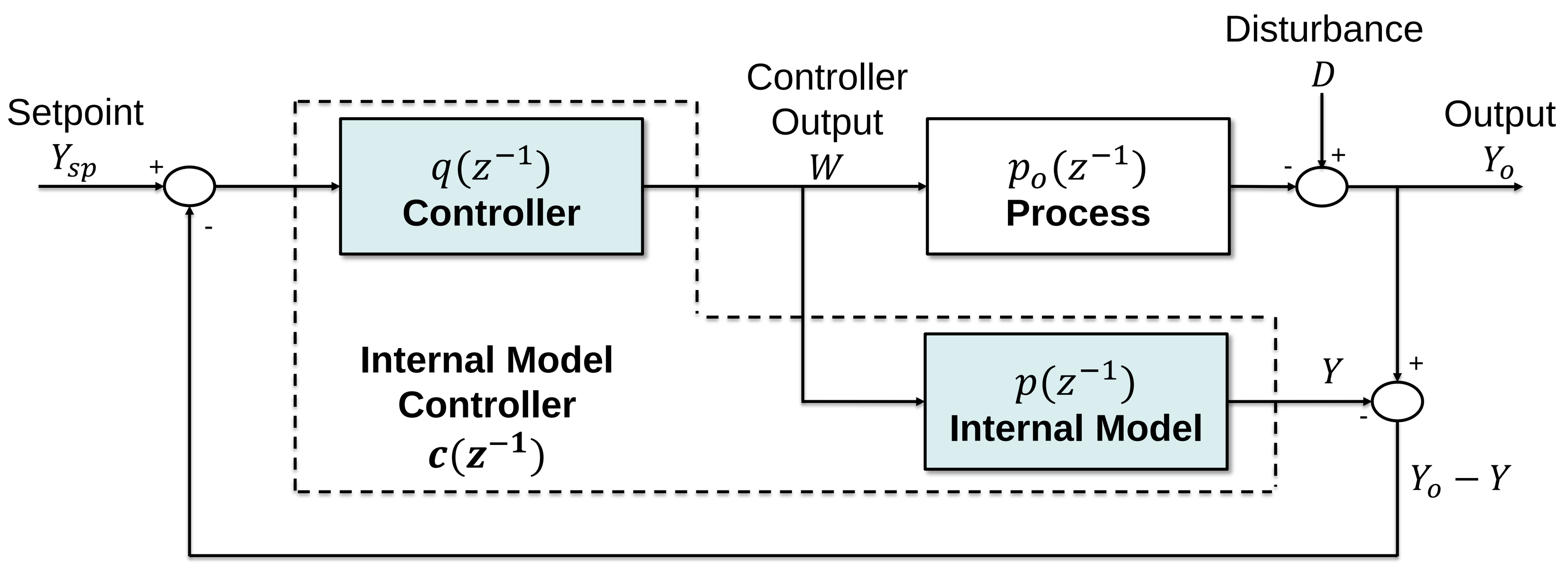

Fig 1. Structure of Internal Model controller

CONTROLLER DESIGN

The FOFB controller dynamics are designed using Internal Model Control (IMC) principles.

A process model $p(z^{-1})$ and the controller output W are used to calculate the model response Y. The model response is subtracted from the actual response Y_o and the difference is used as the input signal to the controller, $c(z^{-1})$.
The discrete time transfer function of the Booster IMC controller $\boldsymbol{C}(z^{-1})$ is

$$\boldsymbol{C}(z^{-1}) = c(z^{-1})\boldsymbol{C}$$

$$\text{where} \quad \boldsymbol{C} = \boldsymbol{V}\boldsymbol{D}\Sigma^{-1}\boldsymbol{U}^T$$

with $\boldsymbol{V}$ and $\boldsymbol{U}$ being derived from the Singular Value Decomposition of the steady state response matrix, $\boldsymbol{B} = \boldsymbol{U}\Sigma\boldsymbol{V}^T$ where Σ is a diagonal matrix containing the singular values and $\boldsymbol{D}$ is a diagonal matrix containing the controller gains. The controller dynamics, $c(z^{-1})$ takes the form

$$c(z^{-1}) = \frac{q(z^{-1})}{1 - p(z^{-1})q(z^{-1})}$$

where $p(z^{-1})$ is the dynamic response of the actuators and $q(z^{-1})$ is the pseudo plant inverse dynamics.

CONTROLLER PERFORMANCE

The controller design considers both dynamic (temporal) and modal (spatial) dimensions.

Low-order spatial modes demands little effort from corrector magnets to correct large distortions whereas high order modes demand large excursions from corrector magnets for correction of small disturbances.

The mode space colourmap of the average power of the underlying disturbance shows that the frequency distribution is concentrated below 50 Hz with a peak at 30 Hz especially at low order modes. There is also some variation at low frequencies present in all modes.

The aim of the control system is to reduce the effect of disturbances on the beam particularly for the low order modes for frequencies up to 100 Hz while at the same time attenuating low frequency disturbances in all modes.

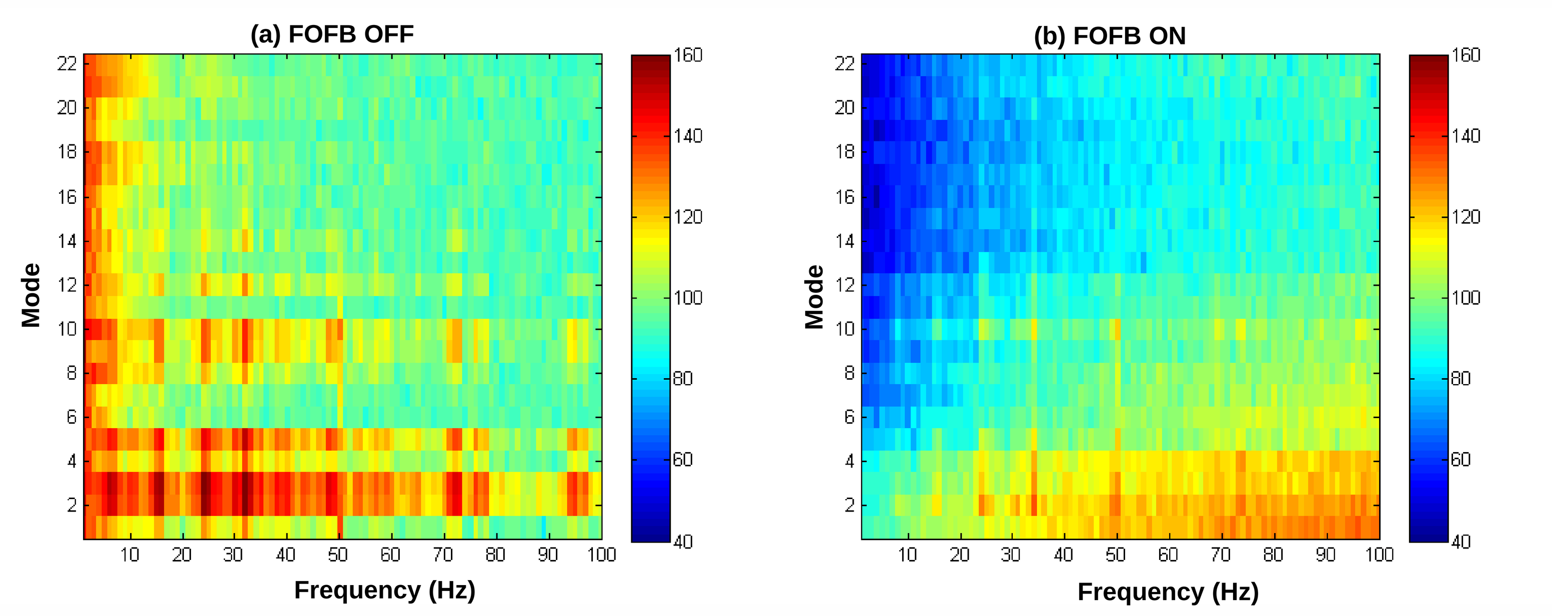

Fig 2. Colourmap of the average power (in dB) at each frequency in mode space for (a) FOFB off and (b) FOFB on. The total power in the output up to 100 Hz when FOFB off is 3.58 m²·Hz⁻¹ off compared to 0.46m²·Hz⁻¹ with FOFB is on.

TWO-DIMENSIONAL LOOP SHAPING

The sensitivity function is the transfer function from a disturbance to the output and can be used to analyse the behaviour of the closed loop system.

The bandwidth of the controller in the two-dimensional frequency domain can be defined as the contour in both temporal and spatial dimensions such that the magnitude of the sensitivity is $|S(n, e^{j2\pi\omega})| = 1/\sqrt{2}$ for all (n, ω) enclosed by the contour where n is the spatial mode and ω is frequency in rad.s^{-1}.

The temporal component of two-dimensional bandwidth can be shaped using the closed loop bandwidth of the controller, ζ, whereas the spatial component is affected by μ, the regularisation parameter applied to the singular values.

The sensitivity function can be designed on a mode-by-mode basis to fit the disturbance spectrum of each mode to achieve a specification on the residual power observed across all sensors.

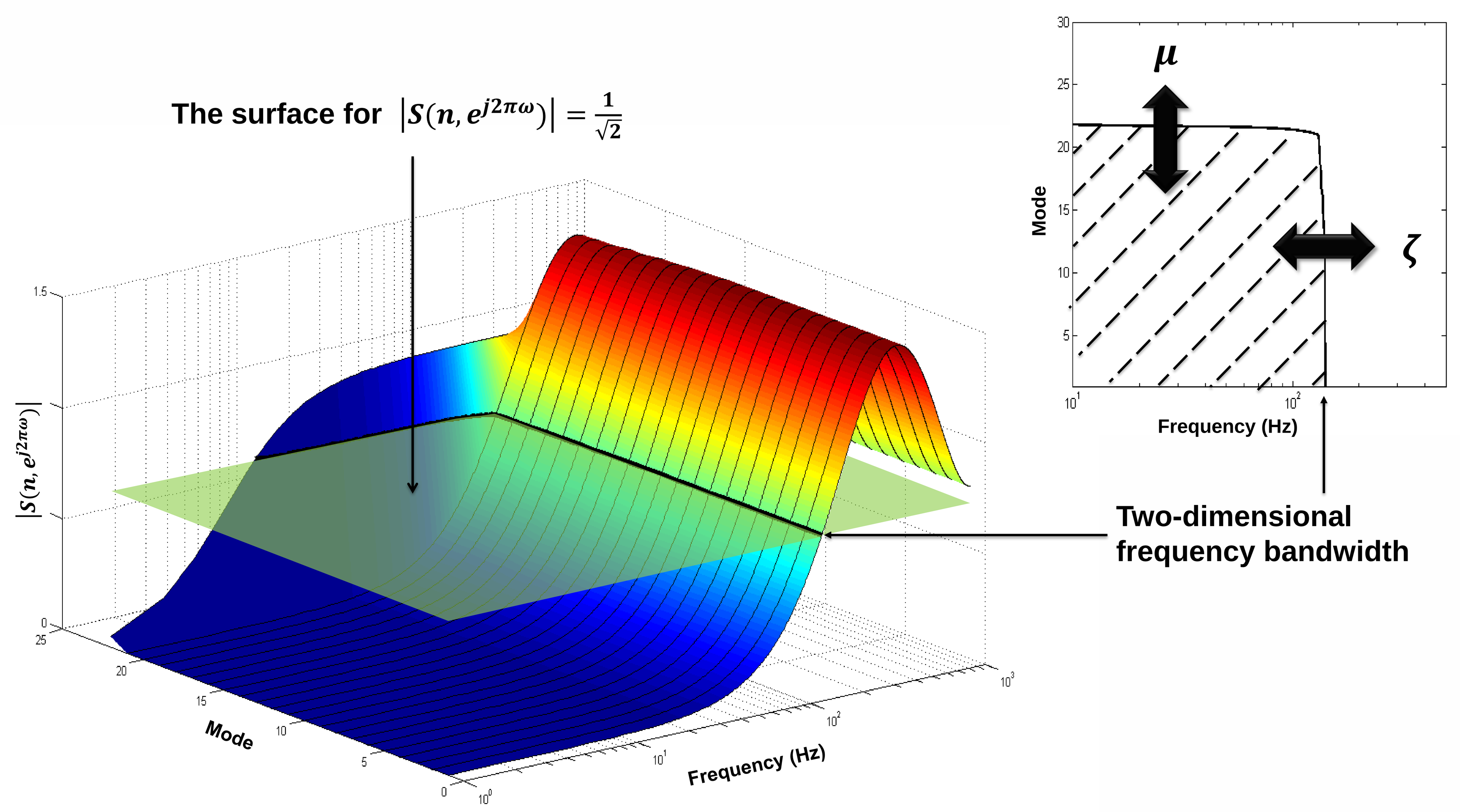

Fig 3. Magnitude of the sensitivity $|S(n, e^{j2\pi\omega})|$ for each mode against frequency in Hz. The plane for $|S(n, e^{j2\pi\omega})| = 1/\sqrt{2}$ for all (n, ω) and the two-dimensional contour (black line) are shown. The arrows indicate the effect of the controller closed-loop bandwidth ζ and the singular value regularisation parameter μ.

For more information please visit www.diamond.ac.uk

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