TEST-BENCH MEASUREMENT OF POWER-SUPPLY, MAGNET, AND VACUUM-CHAMBER BANDWIDTH AT NSLS-II

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Abstract

In 2019, the NSLS-II fast orbit feedback (FOFB) system was upgraded by reducing BPM and Cell Controller latency, increasing the closed-loop bandwidth from about 250 Hz to 400 Hz. The dynamic behavior of the power supply, magnet, and vacuum chamber, however, had not been directly measured and was treated as a lumped delay. To provide baseline parameters for the NSLS-IIU upgrade, we developed a dedicated test bench and remeasured these components. The existing fast-corrector power supplies show bandwidths of about 4.5 kHz horizontally and 1.5 kHz vertically, while the magnet and chamber responses are near 10–15 kHz with an overall response time of about 10 µs. We also characterized a newer power-supply regulator design and tuned it to achieve a 6 kHz bandwidth in both planes for use in the upgraded FOFB system. Incorporating these measurements into a physics-based model yields good agreement with observed system behavior. These results provide the first full experimental characterization of the fast-corrector chain at NSLS-II and establish the baseline for designing next-generation hardware for NSLS-IIU.

INTRODUCTION

Fast orbit feedback (FOFB) systems require high closed-loop bandwidth to suppress beam motion. At NSLS-II, the FOFB system was upgraded in 2019 by reducing latency in the BPM and cell controller, increasing the closed-loop bandwidth from approximately 250 Hz to 400 Hz in the horizontal plane [1]. Despite this improvement, the dynamic behavior of key components, including the power supply, fast corrector magnet, and vacuum chamber, was not directly measured and was instead treated as a lumped response. This limits the ability to accurately model the system and to identify bandwidth bottlenecks for further upgrades. To address this, a dedicated test bench was developed to measure the transfer function and latency of these components and to provide baseline parameters for the NSLS-IIU upgrade. The system response is described using a physics-based model that relates the transfer function to the power-supply and vacuum-chamber dynamics, digital processing effects, and total system latency,

$$G(s) = \frac{1}{(s+p_{\mathrm{ps}})(s+p_{\mathrm{chamber}})}\left(\frac{1-e^{-sT_{\mathrm{avg}}}}{s}\right) \times \left(\frac{1-e^{-sT_{\mathrm{zoh}}}}{s}\right) e^{-sT_{\mathrm{latency}}} H_{\mathrm{PID}}, \tag{1}$$

where p_{ps} and p_{chamber} represent the power-supply and vacuum-chamber poles, T_{avg} is the averaging time, T_{zoh} is the zero-order hold, T_{latency} is the total system latency, and H_{PID} is the controller response. The measured parameters are incorporated into this model to predict closed-loop performance and to evaluate upgrade scenarios for the FOFB system [2].

TEST-BENCH SETUP AND MEASUREMENT METHOD

A dedicated test bench was developed to characterize the dynamic response of key components in the fast orbit feedback system. The setup consists of a function generator used to excite the system over a range of frequencies and an oscilloscope to measure the input and output signals. A spare fast corrector magnet and vacuum chamber were used to represent the system under realistic conditions, as shown in Fig. 1.

Pickup coils were designed to measure the magnetic field response of the magnet and chamber. Different coil geometries and numbers of turns were evaluated to optimize signal sensitivity and bandwidth. The coils were mounted using a custom 3D-printed holder to ensure repeatable positioning during measurements. The transfer function of each component was obtained by applying a sinusoidal excitation over a range of frequencies and measuring the corresponding response. The amplitude and phase were extracted from the input and output signals to construct the frequency response. Latency was determined from time-domain measurements by applying a step-like input signal and measuring the delay between the input and output responses. This procedure was applied consistently to the power supply, vacuum chamber, and fast corrector magnet to enable direct comparison.

RESULTS

The latency of the fast-corrector power supply was measured using time-domain step excitation, as shown in Fig. 2. The delay between the input signal and the magnetic field response is approximately 10 µs. The transfer function of the power supply was then measured, as shown in Fig. 3.

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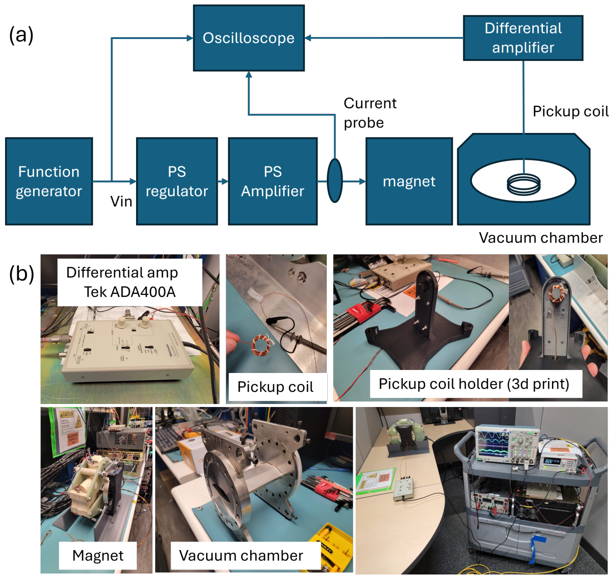

Figure 1: Test-bench setup: (a) schematic diagram of the excitation and measurement chain; (b) photograph of the implemented setup with function generator, oscilloscope, pickup coils, and test magnet.

The existing system exhibits bandwidths of approximately 4.5 kHz in the horizontal plane and 1.5 kHz in the vertical plane. A newer power-supply regulator, currently under development and based on a design modified from the ALS-U power supply, was also evaluated and tuned to achieve a bandwidth of approximately 6 kHz in both planes, which is sufficient to achieve a closed-loop bandwidth in the 1 kHz range based on the model.

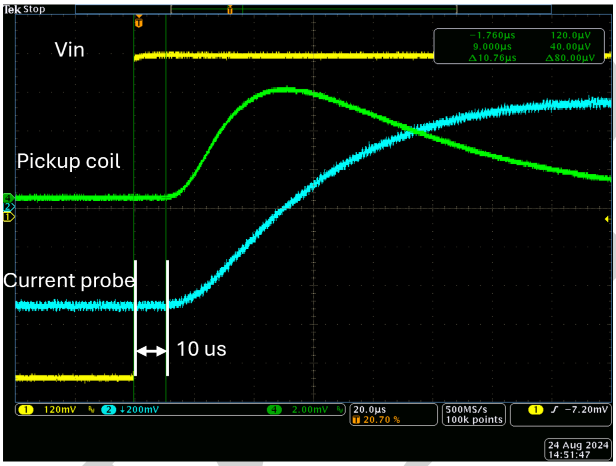

Figure 2: Example latency measurement using step excitation. The delay between the input signal (Vin) and the magnetic field response (pickup coil and DCCT) is approximately 10 µs.

The transfer function of the vacuum chamber is shown in Fig. 4. The response is not captured exactly by a single-pole model, but the measured behavior is bounded reasonably well by one-pole responses in the range of 10–15 kHz. Among these, a 13 kHz one-pole model provides the closest overall approximation and is used as a practical estimate for the chamber response. Compared to the power supply, the chamber introduces a higher bandwidth limitation and therefore has a secondary impact on the overall system performance.

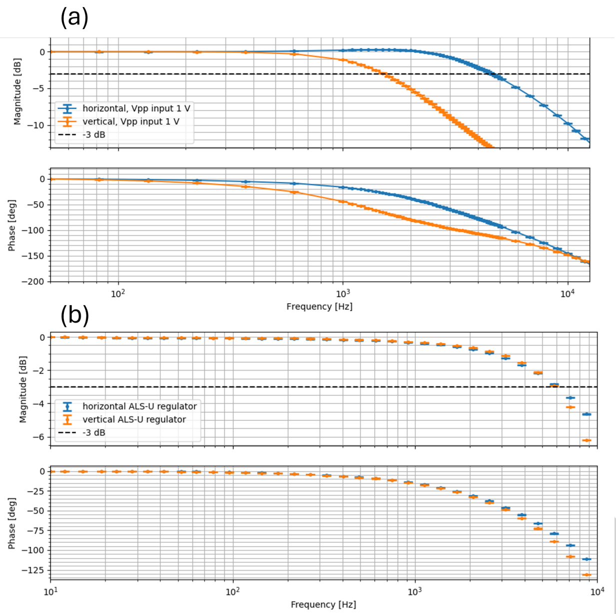

Figure 3: Measured transfer function and latency of the fast-corrector power supply: (a) existing system in the horizontal and vertical planes; (b) upgraded regulator demonstrating ∼6 kHz bandwidth.

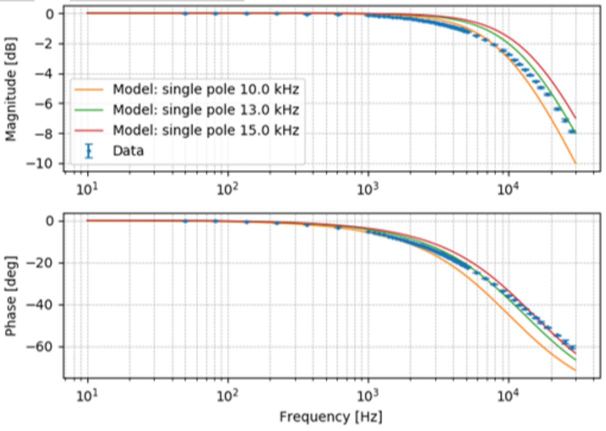

Figure 4: Measured transfer function of the vacuum chamber, compared with one-pole models from 10 to 15 kHz. A 13 kHz one-pole response provides the closest overall approximation.

The fast corrector magnet exhibits a flat response over the measured frequency range due to its air-core design, indicating negligible bandwidth limitation. Its contribution to the overall system dynamics is therefore small compared to the power supply and vacuum chamber, and it is not considered a limiting factor in the model.

MODEL VALIDATION

The measured transfer functions and latency were incorporated into the system model described in Section 1. The predicted closed-loop response was calculated and compared with experimental measurements under different controller settings, as shown in Fig. 5.

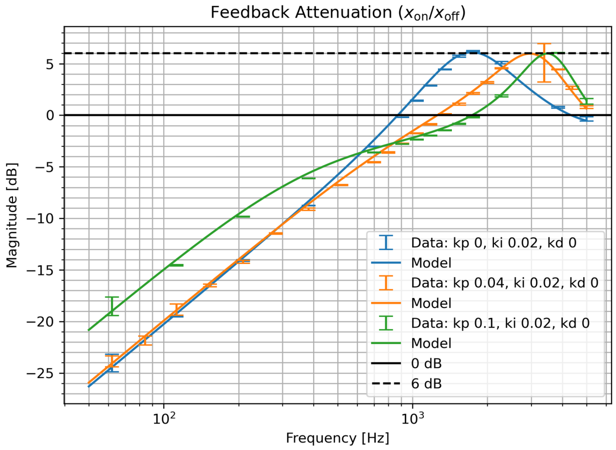

Figure 5: Comparison of measured and modeled closed-loop feedback response for different controller gains, showing good agreement in magnitude and bandwidth. Results reported in [2].

Good agreement is observed between the model and measurement across the frequency range of interest. The model captures the overall shape of the response and the shift in bandwidth with varying controller gain. The dominant system behavior is well described by the measured power-supply and vacuum-chamber characteristics. The validated model provides a practical tool for predicting system performance and evaluating upgrade scenarios.

SUMMARY

A dedicated test bench was developed to characterize the dynamic response of key components in the NSLS-II fast orbit feedback system. The transfer function and latency of the power supply, vacuum chamber, and fast corrector magnet were measured. The results show that the power supply is the dominant limitation in both bandwidth and latency, while the vacuum chamber provides a secondary effect and the magnet contribution is negligible. The measured parameters were incorporated into a physics-based model, which shows good agreement with the measured closed-loop response. The validated model provides a practical framework for identifying system limitations and evaluating upgrade strategies. These results establish a baseline for the design and development of next-generation FOFB hardware for NSLS-IIU.

REFERENCES

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