System for the Control and Stabilizing of OK-4/Duke FEL Optical Cavity[1]

I. V. Pinayev, M. Emamian, V. N. Litvinenko,
S. H. Park, and Y. Wu

FEL Laboratory, Department of Physics, Duke University
P. O. Box 90319, Durham, NC 27708-0319

Abstract. The control system of an optical cavity is described. Usage of the piezoelectric actuators and position sensitive photodetectors in this system allows us to reach a resolution at a submicroradian level and to suppress mirror vibrations below 50 Hz.

INTRODUCTION

The OK-4/Duke free electron laser (FEL) has one of the longest optical cavities (53.76 m) among the existing FELs and the optical beam waist in the undulators is about 300 μm. This implies that the optical cavity control system should have a resolution better than a few μrad and be capable of keeping mirrors in the desired position with the same accuracy. Because the OK-4/Duke FEL has an almost concentric optical cavity with mirror radii of curvature of 27.27 m, it requires a resolution better than 1 μrad.

The previously used optical cavity control system, with an SL20A gimbal mirror mount (manufactured by Microcontrole) with 0.1 μm stepper motor actuators, had sufficient resolution. The existing tables supporting the mirror system, however, did not suppress vibrations down to the required levels. Also they had a long-term drift caused by the changing of the static load on the floor nearby (see Fig. 1).

It is possible to suppress high-frequency vibrations using passive damping, but the low-frequency vibrations and drift are still a problem for such systems. Therefore, we decided to replace the control system with a new one using active suppression of the mirror vibration and drift.

---

[1] This work is supported by Office of Naval Research Contract #N00014-94-1-0818 and AFOSR Contract #F49620-93-1-0590.

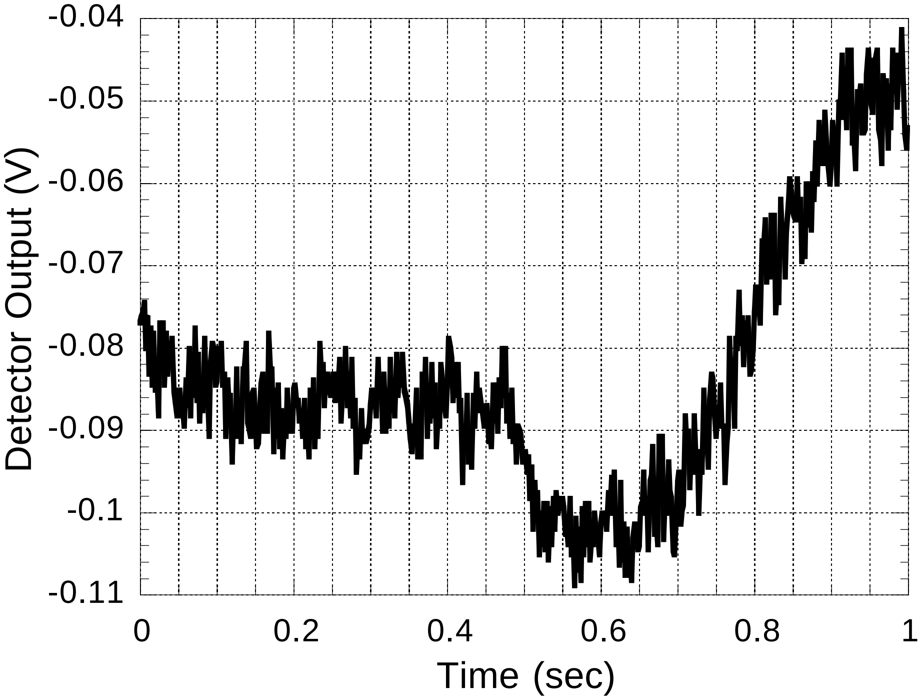

FIGURE 1. The changing of the mirror mount's tilt angle caused by the variation of static load on the table (10 mV=0.4 μrad).

GENERAL LAYOUT

The general layout of the optical cavity control system is shown in Figure 2. The mirror mount's tilt angle is measured with help of an auxiliary concave mirror (R=5.7 m) rigidly fixed on the mount. A small semiconductor laser installed inside the ring room is used as a reference. The three-foot concrete slab supporting the storage ring has pillars going down to the bedrock which provide a significantly more stable environment. Light emitted by the laser passes through the 0.6 mm diameter pinhole to the auxiliary mirror. Distance between the mirror and pinhole is equal to the radius of curvature of the auxiliary mirror. The image of the pinhole is focused on the two-dimensional position sensitive photodetector (PSD) S2044 manufactured by Hamamatsu. The pinhole diameter is chosen not only to provide a point-like light source but also to reduce the photon flux so that the PSD current does not exceed the maximal rating. This configuration has the advantage of being insensitive to the angular position of the laser beam. To prevent refraction caused by the airflow and to exclude the influence of ambient light, the entire optical path lies inside a sealed plastic tube.

The signal from PSD is processed by the analog unit shown in Figure 3 which provides output voltages proportional to the distance between the centers of the light spot and detector. The analog divider/multiplier AD734 is employed to normalize the signal and to make it insensitive to the variations of the laser power.

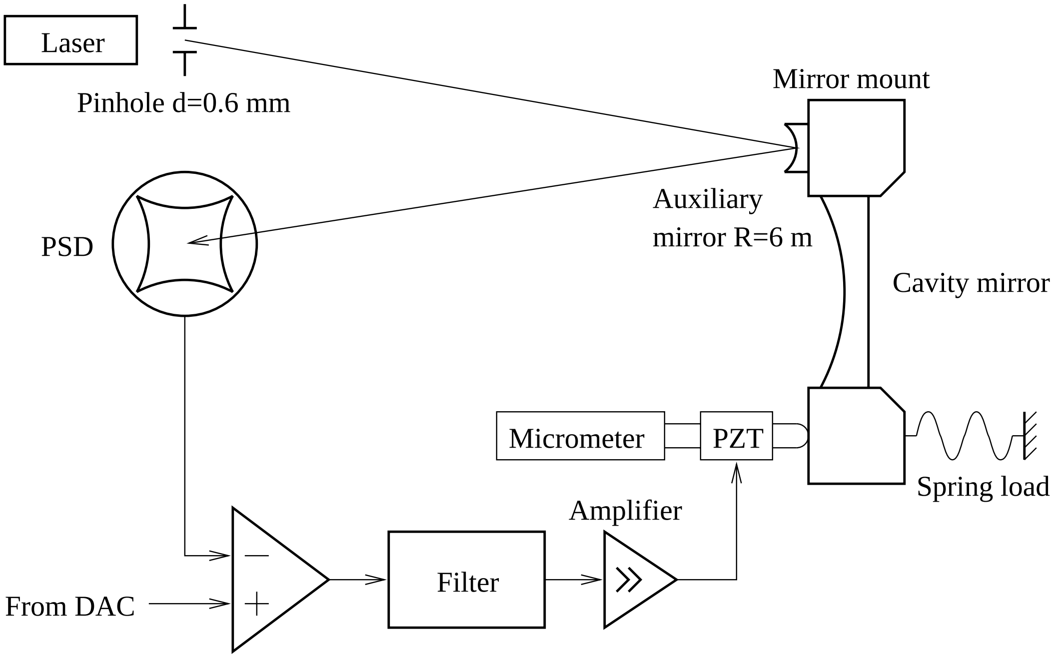

FIGURE 2. the mirror control and stabilization system for the OK-4/Duke FEL.

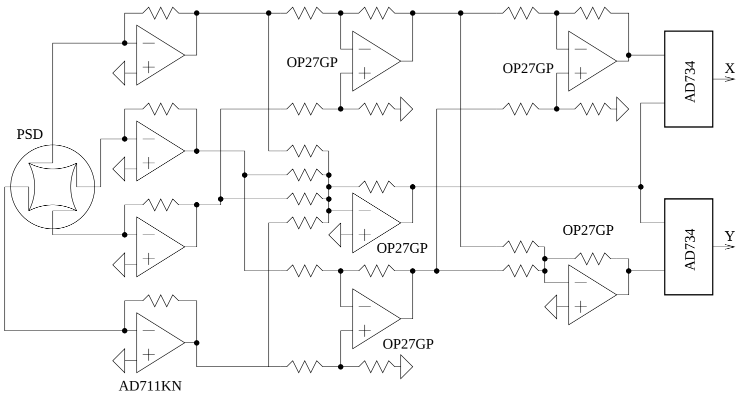

FIGURE 3. The operating circuit for two-dimensional PSD.

The precision of the mirror control system is defined by the PSD spatial resolution and the accuracy of the electronics. The main source of errors in the electronics is the bias current and offset voltage of the operational amplifiers being used. To minimize these errors, the precision operational amplifiers AD711 and OP27 are used. The electronics provide a geometrical accuracy better than 1 μm, assuming maximal values for the PSD dark current, bias currents, and offset voltages. According to the manufacturer's specifications, the PSD has a resolution better than 2.5 μm. The accuracy of the control system can be easily calculated to be better than 0.5 μrad. It should be mentioned that, as a result of the distortions, the PSD has a nonlinear response to the position of light spot. The typical deviation from linearity does not exceed 40 μm.

The S2044 PSD has a 0.3 μsec rise time and the analog chips in the electronics have a unity gain at a frequency of few MHz. The wide frequency band eliminates the influence of the position-sensitive detector on the gain-phase characteristics of the feedback loop.

We have chosen 30 μm P-830.20 piezotranslators manufactured by Polytec PI for our system. They are designed to withstand high loads and have a maximal operational voltage of 150 V. The small displacement range of the piezotranslators requires that the initial position of each mirrored be set by two manual micrometers. Fine adjustment of the mirrors is controlled by four 16-bit digital-to-analog converters (DACs). The signal from PSD is compared with the control voltage from the DAC and the error signal is amplified to change the voltage on the piezoelectric actuator.

Testing of the prototype feedback system with HP4194A Impedance/Gain-Phase Analyzer showed that the cutoff frequency is much lower than was estimated using the piezotranslator stiffness and the mirror mount inertia. We found a set of mechanical resonances of mirror mount itself. The strongest resonance which has the lowest frequency of about 100 Hz is caused by the ball bearing support (see Fig. 4). To provide a higher cutoff frequency with a substantial phase margin for stability we use a correction filter installed before the power amplifier. Its circuitry and characteristics are shown in Figure 5 and Figure 6, respectively. Each filter is tuned individually for better performance. This allows us to increase the cutoff frequency from 1 Hz to 50 Hz. The correction filter also integrates the error signal, which provides a much higher long-term stability. The gain-phase characteristics of the corrected feedback system are shown in Figure 7. The high-frequency vibrations are suppressed by mechanical absorbers incorporated into the table supports.

The optical cavity control system is brought under the EPICS storage ring control system. It provides individual mirror positioning as well as the control of the optical cavity axis. Observation of the output of the PSD electronics which has a sensitivity of 40 nanoradians per millivolt showed that the mirror vibration level is below 100 nanoradians with a negligible drift.

The system was used for two successful runs for lasing in the the wavelength ranges of 345–413 and 226–255 nm.

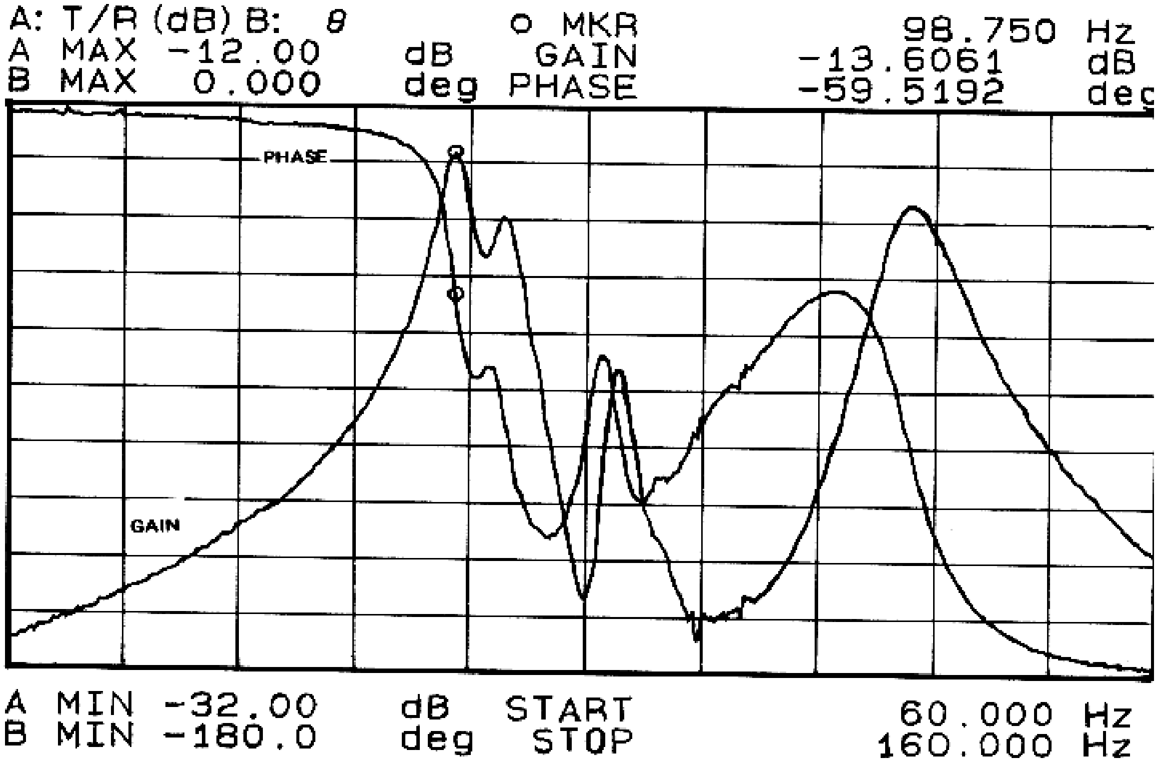

FIGURE 4. Amplitude-phase characteristic of the 100 Hz mirror mount mechanical resonance.

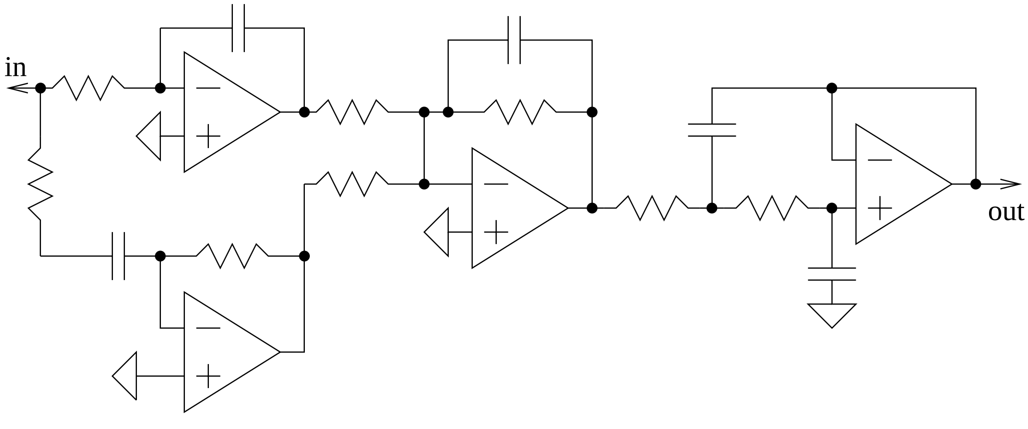

FIGURE 5. Circuitry of the correction filter.

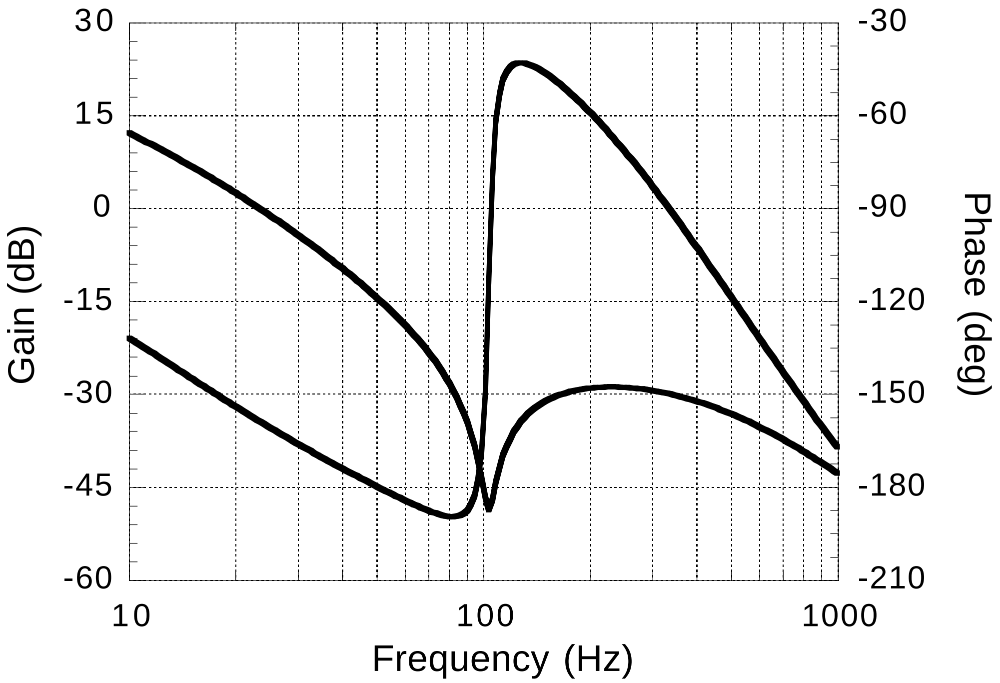

FIGURE 6. Gain-phase characteristic of the correction filter.

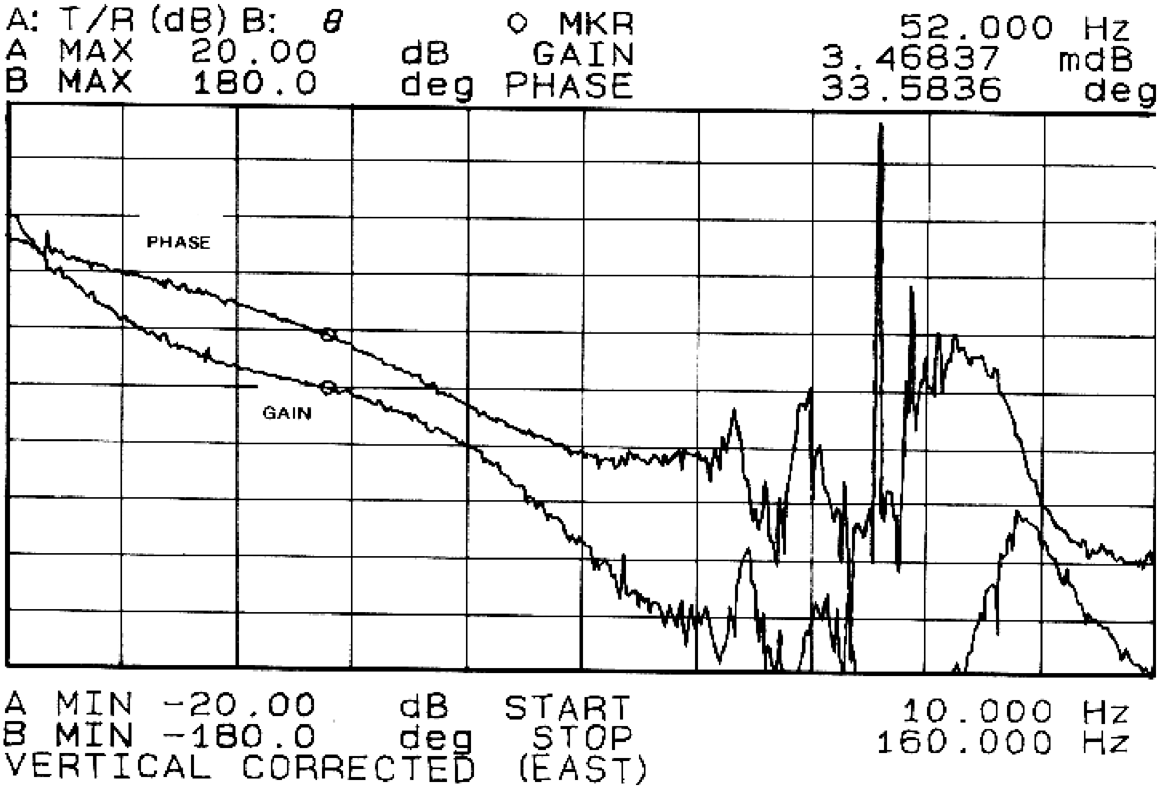

FIGURE 7. Gain-phase characteristics of the feedback system.

FUTURE IMPROVEMENTS

In the near future we plan to:

1. Replace the existing control system with a new system in which the PSD is moved with stepper motor driven translation stages. This will give us greater tuning range and will eliminate PSD non-linearities, which will be used as a zero position detector.
2. Design and manufacture a new gimbal mount for the optical cavity mirrors. This should allow us to eliminate low-frequency resonances and increase the frequency range of the feedback system.

We are also considering the possibility of replacing existing analog electronics with a digital system processing board for flexibility and higher accuracy.