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Application of PQ Method to Dual Stage Instrumented Suspension

Rudy J. M. Oosterbosch and Raymond A. de Callafon
University of California, San Diego
Dept of Mechanical and Aerospace Engineering
9500 Gilman Dr, La Jolla, CA 92093-0411

I. INTRODUCTION

The objective of disk drive control is to move the read-write head of the desired track as quickly as possible so that data can be read/written quickly and reliably. To achieve this a dual stage suspension is introduced. Here two actuators act in parallel. A Voice Coil Motor (VCM) does the low-frequent large stroke tracking and the second high-frequent short stroke actuator, a piezoelectric micro-actuator (MA), can be used for the high-frequent tracking. For higher-throughput data transfer larger rotational speeds are desired and this causes additional high frequent disturbances. One way to suppress these additional disturbances is to make use of a dual stage suspension with an additional sensor instrumented on the suspension. This sensor is of a piezo-resistive material and is used for measuring the additional high frequent disturbances and yields an Instrumented Suspension Signal (ISS), which can be used for active damping of the high frequent disturbances as is done in [1].

II. MODELING OF THE DUAL STAGE SYSTEM

A standard Prediction Error (PE) estimation technique [2], [3], is used to model the dynamics of the system and the effect of windage on a Hard Disk Drive. These results are presented in [1] and contain models of the dynamics of the Voice Coil Motor (*Pvcm*), Micro-Actuator (*Pma*) and Instrumented Suspension (*Pi*). Furthermore there are estimated noise models, which describe the spectral contents of the windage vibrations (*e*) on the MA and Instrumented Suspension by *Hma* and *Hi* respectively. A block diagram of the system is showed in figure 1.

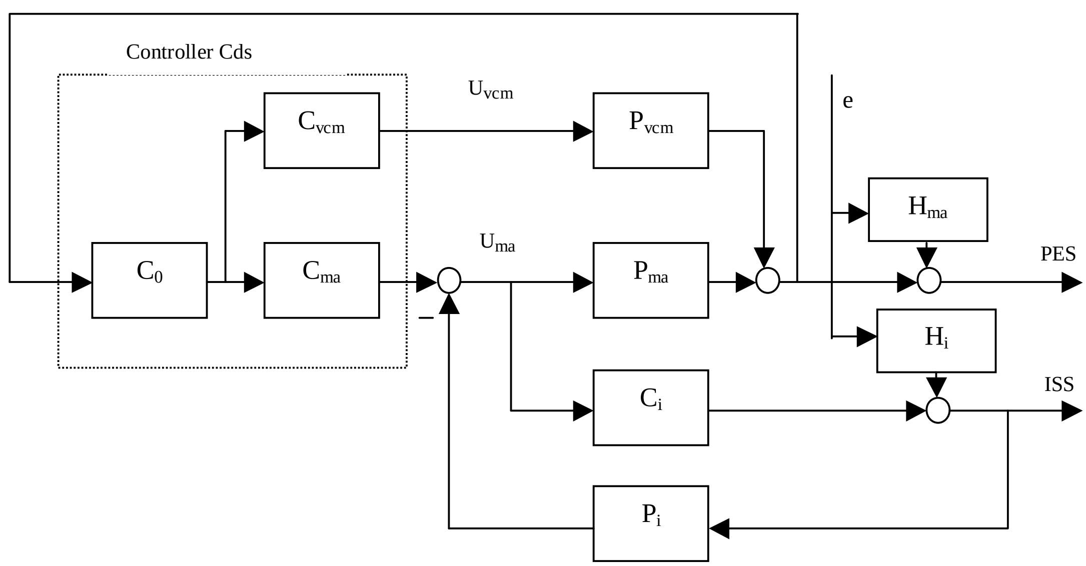

Figure 1: Block Diagram of the system

For controlling the system the Position Error Signal (*PES*) and the Instrumented Suspension Signal (*ISS*) are measured. For active damping of the suspension by measuring the ISS is done before in [1] by designing a controller (*Ci*). First the PQ method [4] will be used for designing a controller (*Cds*) for the hard disk drive system without taking in account the high frequent disturbances. Second, the controller *Ci* will be taken in account for compensating the high frequent induced vibrations in an additional control loop.

III. PQ DESIGN METHOD WITHOUT COMPENSATING FOR HIGH FREQUENT DISTURBANCES

For the design of a Single Input Dual Output (SIDO) controller (*Cds*) here is made use of the PQ Method. For the PQ method the transfer functions *P(s)* and *Q(s)* are defined as

$$P(s) = \frac{P_{vcm}(s)}{P_{ma}(s)},$$

$$C(s) = \frac{C_{vcm}(s)}{C_{ma}(s)}.$$

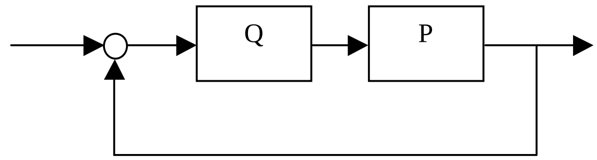

Figure 2: PQ feedback system

By using the PQ method the poles of the PQ feedback system, as depicted in figure 2, are the zeros of the Single Input Single Output system *Gsiso*, as depicted in figure 3. Here *Gsiso* is defined as

$$G_{siso}(s) = C_{vcm}(s) \cdot P_{vcm}(s) + C_{ma}(s) \cdot P_{ma}(s).$$

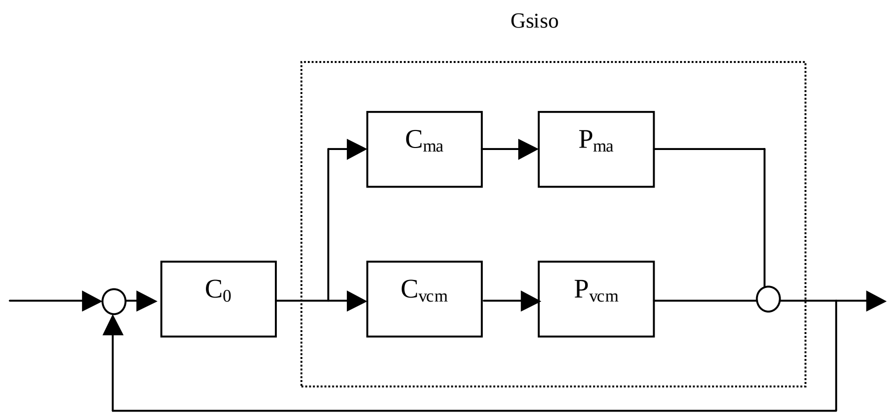

Figure 3: Gsiso

So designing *Q(s)* to stabilize the PQ feedback system ensures that Gsiso will have stable zeros. The first part of the PQ method is the design of a controller *Q(s)* for the system *P(s)*. For a fast response and a stable closed loop system as possible it is desired to have the zeroes of the closed loop system as far as possible into the left half of the complex plane and with conservation of robustness. Since the controller is the ratio of the two controllers, *Cvcm* and *Cma*, it can be used for a frequency separation between the two parallel systems. It is desired for the VCM that it will work primarily, and with a high disturbance reduction, at low frequencies and for the MA it is desired to work not at that low frequencies. The desired transfer function *Cvcm* will be an integrator.

$$C_{vcm}(s) = k \cdot \frac{\tau_d s + 1}{s}.$$

Designing *Q(s)* with an increase in the phase at the crossover frequency and with no contribution of *Cma* at low frequencies, the transfer function of *Q(s)* will be a lead compensator along with two differentiators

$$Q(s) = k \cdot \left(\frac{\tau_d s + 1}{s}\right)^2 \cdot \frac{\tau_1 s + 1}{\tau_2 s + 1}.$$

With *Cvcm(s)* and *Q(s)* like mentioned before *Cma(s)* results in

$$C_{ma}(s) = Q^{-1}(s) \cdot C_{vcm}(s) = \frac{s}{\tau_d s + 1} \cdot \frac{\tau_2 s + 1}{\tau_1 s + 1}$$

Now the second part of the PQ method can be done and is the design of a controller *C0* for plant *Gsiso* to establish the overall performance of the closed loop system. It is desired to have a stable system and the bandwidth as high as possible for optimal tracking. So *C0* is designed as a gain along with 2 second order low-pass filters to decrease the magnitude at higher frequencies and along with an lead filter to increase the phase at the crossover frequency.

$$C_0(s) = k \cdot \frac{1}{\tau_1^{\,2} s^2 + 2\beta_1 s + 1} \cdot \frac{1}{\tau_2^{\,2} s^2 + 2\beta_2 s + 1} \cdot \frac{\tau_3 s + 1}{\tau_4 s + 1}.$$

Because of the stability the bandwidth is limited till 1250 Hz and as final result of the controller design the disturbance reduction and the control energy of both the *Cvcm* and *Cma* is observed. The results are given in figure 4 and 5. In figure 4 *Hma* is the noise model with the spectral contents of the windage vibrations on the MA and H is the transfer function between the windage vibration and the Position Error Signal. In figure 5 *Uvcm* and *Uma* represent the control input on the VCM and MA respectively.

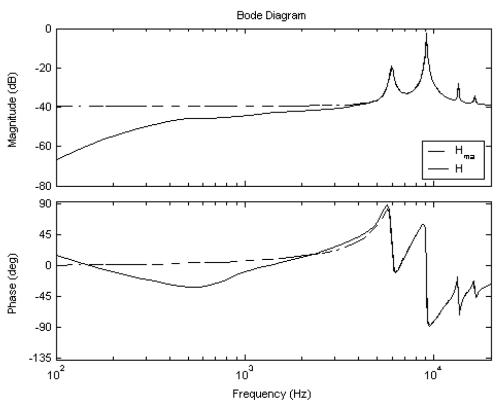

Figure 4: Disturbance reduction

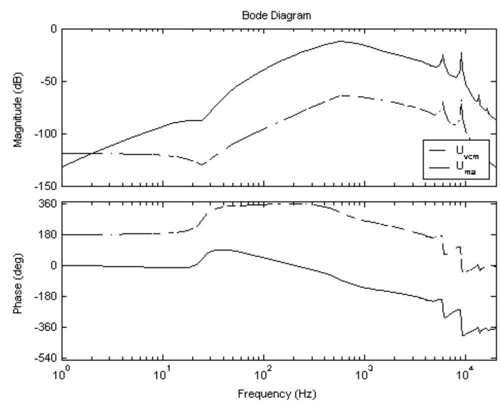

Figure 5: Control Inputs

IV. PQ DESIGN METHOD INCLUDING FEEDBACK SYSTEM *CIPI*

Now the feedback system *CiPi*, as designed in [1], is included in the feedback system *C0Gsiso*. The transfer function *P(s)* of the PQ method will be

$$P(s) = \frac{P_{vcm}(s)}{\dfrac{P_{ma}(s)}{1 + C_i P_i}}$$

Further the definition of *Q(s)* will be the same and therefore *Gsiso* results in

$$G_{siso}(s) = C_{vcm}(s) \cdot P_{vcm}(s) + C_{ma}(s) \cdot \frac{P_{ma}(s)}{1 + C_i P_i}.$$

Again the first part of the PQ method is the design of a controller *Q(s)* for plant *P(s)* with the same transfer function as before but only the time constants are a little bit different. In the second part of the PQ method *C0* is designed as a gain along with a lag filter to decrease the phase at the crossover frequency.

$$C_0(s) = k \cdot \frac{\tau_1 s + 1}{\tau_2 s + 1}$$

Now the bandwidth of the system reaches 2800 Hz and no low pass filters are needed to achieve stability. Again the disturbance reduction and the control inputs of both the *Cvcm* and *Cma* is observed and given in figure 6 and 7.

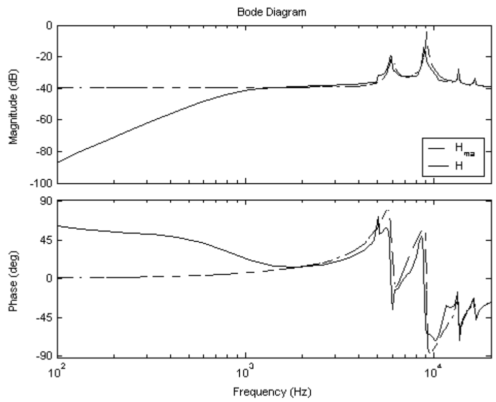

Figure 6: Disturbance reduction with Ci

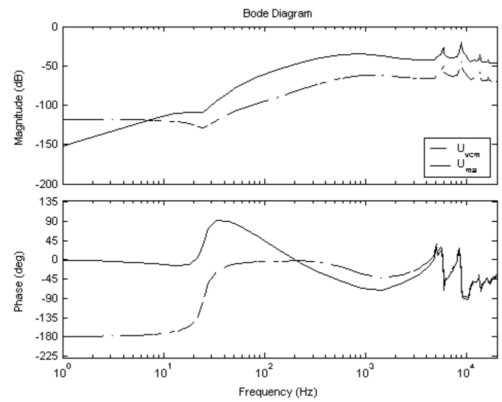

Figure 7: Control Inputs with Ci

V. CONCLUSION

Due to the implementation of the additional instrumented sensor on the suspension and the high frequent control with controller *Ci*, much better disturbance reduction at the high frequencies is achieved. Further by more accurate frequency separation between the VCM and MA the control inputs are better divided, the VCM and the MA has a higher input for respectively the low frequencies and the high frequencies. Together with the more simple shape of the controller, implementation of an additional instrumented sensor improves the performance of the hard disk system.

REFERENCES

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