A NOVEL DISTURBANCE OBSERVER DESIGN FOR MAGNETIC HARD DRIVE SERVO SYSTEM WITH A ROTARY ACTUATOR

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***Abstract* ---This paper presents a novel disturbance observer design for the magnetic hard drive servo systems with rotary actuators to improve the access time. One of the major drawbacks of the conventional disturbance observer design is that the disturbance rejection rate is increased at the cost of increased amplification on high frequency system noise, and consequently, system stability. To improve the disturbance compensation capability without affecting the system stability, a novel disturbance observer design is proposed in this paper. The idea is to replace the constant controller gain in the conventional disturbance observer with a first order filter. Compared with the conventional disturbance observer design, the proposed disturbance observer is shown to decrease the settling time by 40% and increase high frequency measurement noise attenuation by 10db, respectively. The proposed design has been implemented on a test stand with a 3.5" hard drive. Both simulation and experimental results have validated the claim.**

Keywords: hard disk drive servo, disturbance observer

I. INTRODUCTION

The concept of a disturbance observer was introduced in [1]. Since then, the disturbance observer has been widely used in disk drive servo control systems to compensate for system disturbances and un-modeled dynamics [2-4]. Due to system stability and the presence of measurement noise, the disturbance rejection rate of the conventional disturbance observer is limited. Although faster disturbance observer poles give better disturbance force rejection and consequently better position accuracy, the stability margin of the closed loop system and the measurement noise attenuation are inversely affected by the faster observer poles [5, 6].

To improve the disturbance compensation capability without affecting the system stability, a novel disturbance observer design is proposed in this paper. The basic idea is to replace the constant controller gain in the conventional disturbance observer with a higher order filter, e.g. a first order digital infinite impulse response filter. The proposed scheme adds extra degrees of freedom to the disturbance observer design. Therefore high disturbance objection rate is achieved without compromising the measurement noise attenuation.

The paper is organized as follows. Section II derives the disturbance observer model proposed. Section III shows the simulation and experimental results on a 3.5" hard disk drive servo system. The conclusion is given in Section IV.

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II. DERIVATION OF ADVANCED TYPE OF DISTURBANCE OBSERVER

A schematic block diagram of a closed loop disk driver servo system including a disturbance observer is shown in Fig. 1, where r is the reference input, w_0 is the disturbance input, y is the position output, v is the measured velocity signal, n is the measurement noise on v. A proposed disturbance observer structure is shown in Fig. 2, where the plant to be controlled is represented as $G(s)=P(s)/s$, $P_n(s)$ is the nominal value of $P(s)$.

The generalized disturbance observer architecture shown in Fig. 2 actually subsumes the conventional velocity type of disturbance observer appearing in the literature [2]. Consider a conventional velocity type of disturbance observer appearing in Fig. 3. A single block diagram reduction results in Fig. 2, which is easily seen to have the form of Fig. 2 by considering $P_n(s)=1/M_n s$, $g(s)=g$, $P(s)=1/(Ms+D)$.

The equivalent closed loop block diagram of Fig. 1 is depicted in Fig. 4, assuming that the nominal plant is a good model of the actual plant. It is seen that the disturbance observer provides pre-filtering to both the disturbance and the measurement noise. The resulting pre-filter of the disturbance input and the measurement noise by the disturbance observer, however, are different. Compromises must be made in designing the disturbance observer when considering system stability, fast disturbance rejection and good attenuation on measurement noises.

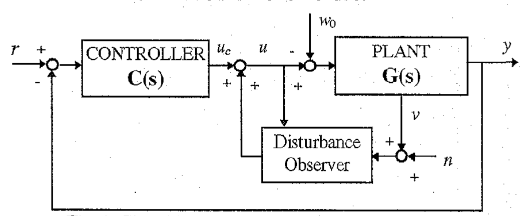

Fig. 1. Closed loop system with disturbance observer

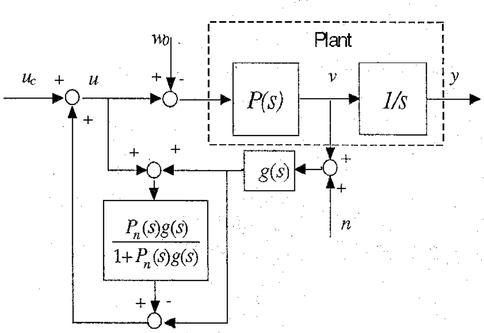

Fig. 2 Block diagram of proposed disturbance observer

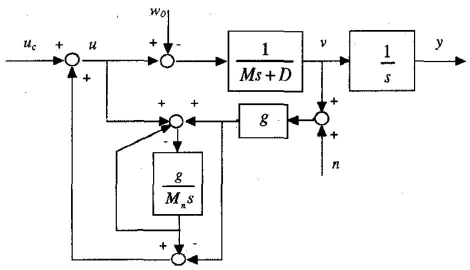

Fig. 3 Conventional velocity type of disturbance observer

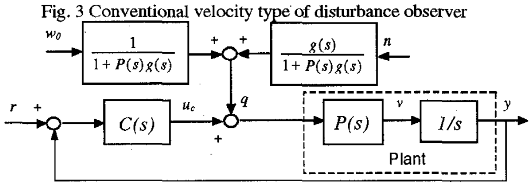

Fig. 4 Equivalent closed-loop block diagram with disturbance observer

Note that the filtered signal q of the disturbance input and the noise input is determined only by the plant dynamics $P(s)$ and the observer function $g(s)$. The function $g(s)$ is to be selected for both good steady state accuracy and transient response to a constant disturbance. Simultaneously, it should be designed for good noise rejection.

In the conventional velocity type of disturbance observer design, the observer function $g(s)$ is only a constant g. From Fig. 4 it is shown that the only way to reduce the steady state error in q in the conventional design is to increase g. The larger gain may cause instability of the system. Furthermore, the increase of gain will also increase the bandwidth of the measurement noise input. Even when a selected gain satisfies the stability requirement, the amplification of the measurement noise may still make the design impractical.

The problem of improving transient response for the conventional disturbance is similar. The poles are determined by the roots of the characteristic equation $1+gP(s)=0$, and this structure limits how far into the left half plane the dominant poles can go, if the relative degree of $P(s)$ is greater than 1.

The problem of improving the transient response and disturbance rejection of the conventional disturbance observer can be solved with the advanced disturbance observer design. By introducing disturbance observer functions $g(s)$ other than a constant gain, it is possible to obtain simultaneously both higher disturbance attenuation in the low frequency range and better rejection on measurement noise in the high frequency range, without compromising the system stability.

III. Simulation and Experimental Results

In this section, the advanced disturbance observer is applied on a disk drive servo system. The experiments are carried on a test stand with a 4 Gig byte 3.5" hard drive. The advanced disturbance observer is designed by replacing the constant gain in the conventional disturbance observer with a first order filter with a single stable pole and no zeros.

A. Design I. Case of high measurement noise

The first design is for a system which is subject to high measurement noise. The frequency responses of the pre-filter as the results of both the conventional and advanced disturbance observer are shown in Fig. 5. Note that while the magnitude response of the advanced disturbance observer is about 6dB greater than that of the conventional velocity disturbance observer at 200Hz, it is better than the conventional design at frequencies above 800Hz where measurement noise rejection is most needed.

The frequency responses from the disturbance input to the position output shown in Fig. 6 show that the advanced disturbance observer provides about 5dB more suppression on the disturbance input in the low and mid frequency range than the conventional disturbance observer does. For a constant disturbance, the advanced disturbance observer is therefore expected to have better positioning accuracy and faster disturbance rejection rate.

Fig. 7 shows the experimental as well as the simulation results of the closed loop system response to a step disturbance input with the advanced disturbance observer. The step input disturbance causes a maximal half track deviation of the head from the desired track center. Fig. 8 shows the results with the conventional disturbance observer under the same disturbance. Comparison between Fig. 7 and Fig. 8 shows that with the advanced disturbance observer design, the settling time of the step response has been improved by 43% under the present disturbance.

B. Design II. Case of fast disturbance rejection

In the second design, the observer gain of the conventional disturbance observer is doubled from that in Section 3.1 in an effort to improve the disturbance rejection rate. The advanced disturbance observer design remain the same as that in Section 3.1. With the increased observer

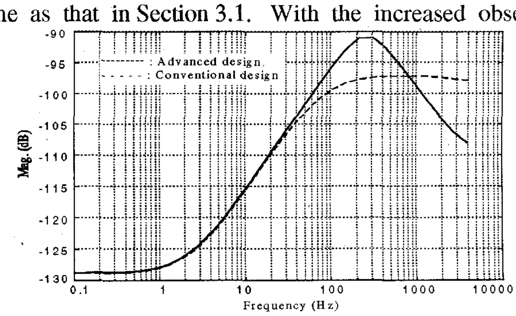

Fig 5. Frequency response of the pre-filter on measurement noise

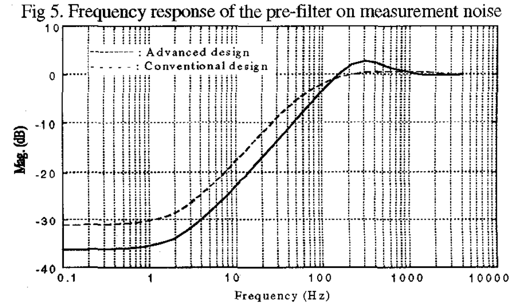

Fig 6. Frequency response of the pre-filter on disturbance input

gain, the conventional disturbance observer design now has a similar disturbance rejection ratio in the low and mid-frequency range as that of the advanced disturbance observer design, as shown in Fig.10. Therefore, settling time should be nearly the same for a step disturbance input is expected for both designs.

The time response for a step disturbance input is shown in Fig. 11. The system with the conventional disturbance observer with higher observer gain still has 10% longer settling time than that with the advanced disturbance observer. Note that the improvement in settling time is obtained at the cost of the degraded performance in noise rejection. Fig. 9 shows that the conventional disturbance observer amplifies the measurement noise more than 10dB than the advanced disturbance observer for frequencies above 1000Hz.

IV. Conclusion

A novel disturbance observer design is proposed in this paper. From the performance point of view, the difficulty with a conventional disturbance observer is to maintain high disturbance rejection, measurement noise attenuation, and sufficient stability margin. With the added degrees of design freedoms by the proposed disturbance observer structure, all three concerns can be addressed simultaneously.

Both simulation and experimental results on a hard disk drive servo system demonstrate that the advanced disturbance observer of this paper is capable of providing as much as 43% reduction in settling time of the step disturbance input, as well as 10dB increase in high frequency measurement noise rejection, at the cost of only minimal increases in complexity. The proposed disturbance observer can be used as a direct replacement of the conventional disturbance observer used on existing disk drive servos without redesigning the main control loop.

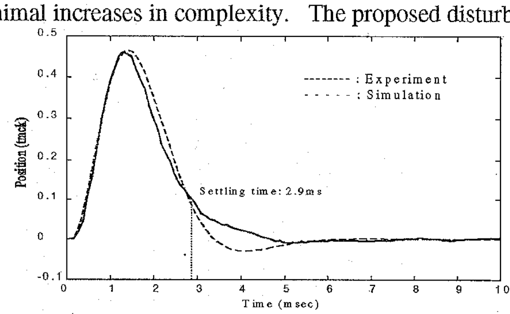

Fig. 7 Step response with advanced disturbance observer

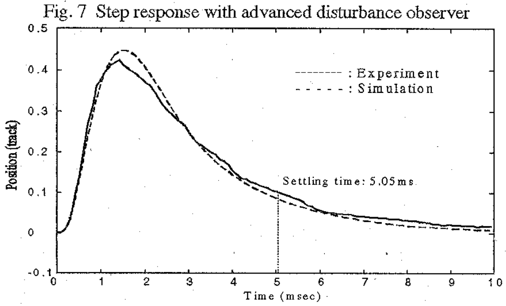

Fig. 8 Step response with conventional disturbance response

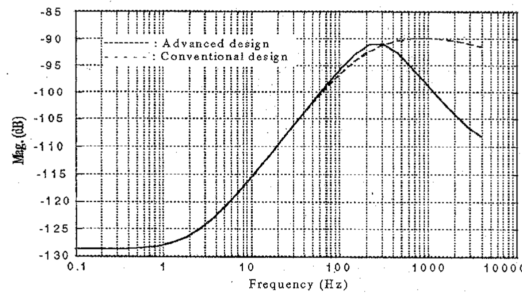

Fig. 9 Frequency response of the pre-filter for measurement noise

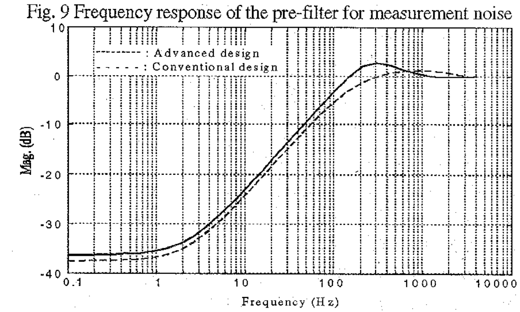

Fig. 10 Frequency response of the pre-filter for disturbance input

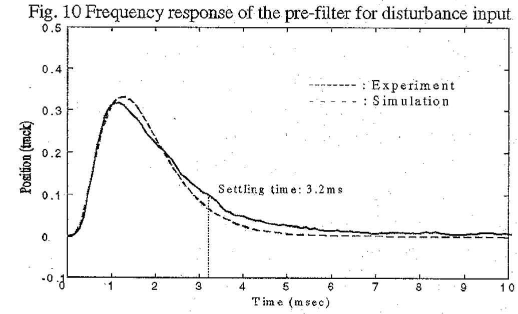

Fig. 11 Step response with conventional disturbance observer, large poles

V. Reference

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