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Open and Closed Loop Parametric System Identification in Compact Disk Players

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Abstract

By measuring the current through the coil of the actuators in the optical pick-up in a compact disk player, open loop parametric system identification can be performed. The parameters are identified by minimizing the least-squares loss function of the ARX model. The only parameter which cannot be identified in open loop is the optical gain. This is therefore estimated in closed loop. Practical results are analyzed and show very accurate estimates of the real parameters.

1 Introduction

Since the compact disk player was introduced in the market two decades ago, more products based in the same technology have been developed, as CD-ROM and DVD players. The trend is clear, towards higher storage capacity and data transfer rate. Even though improvements are observed in the storage capacity of the disk, little has been done to improve the optical pick-up performance and their parameter tolerances. The robustness requirements to the position controllers therefore have increased: due to the higher storage capacity the controllers must be more accurate and at the same time, they must also cope with considerable parameter tolerances. In order to alleviate the robustness requirements of the position controllers, parameter estimation can be performed. There has been made several studies where system identification of the optical pick-up is carried out in closed loop [1],[2]. In [1] it is pointed out that the characteristics of the position mechanism of a CD-player are very hard to measure in open loop. [3] measures the open loop characteristics by using a laser Doppler vibrometer. This paper proposes a simple, yet very accurate method to perform parametric system identification in open loop in CD-players by measuring the current through the actuators. Closed loop identification, is also performed in a simple way, which is necessary to measure the optical gain, the only parameter which cannot be measured in open loop.

This paper is organized as follows. In section 2, a 4th order model of the optical pick-up is presented. Closed loop system identification is described in section 3. In section 4 the open loop system identification is explained, where the model is reduced to 2nd order. The identification algorithm is briefly described in section 5. In section 6 and 7 the results are presented and discussed.

2 Model of the optical pick-up in a CD-player

The optical pick-up is a 2-axis device, enabling a movement of the lens in two axes: vertically for focus correction and horizontally for track following. Two coils, which are perpendicular to each other are suspended between permanent magnets. A current through a coil creates a magnetic field which repeals with the magnetic field from the permanent magnet and the coil and consequently the lens will move in the corresponding direction. The pick-up can be considered as two moving masses, see fig. 1. m_1[Kg] is the mass middle point of the lens, and m_2[Kg] is the mass middle point of the arms of the levers which the lens is suspended on. x[m] and x'[m] are their corresponding displacements from a fixed point of the optical pick-up. f_{el}[N] is the force applied to m_1[Kg] which is given by eq. 1,

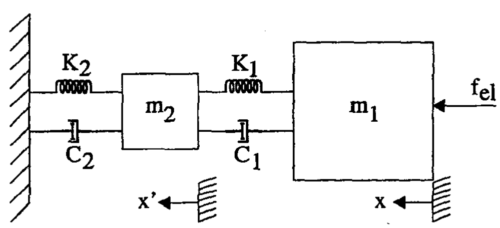

Figure 1: Translational diagram of the optical pick-up.

$$f_{el}(s) = \frac{-(Bl^2 \cdot x)s + Bl \cdot u}{R} \qquad (1)$$

where Bl[N/A] is the AC-sensitivity, u[V] the voltage applied to the coil, x[m] the displacement of the lens and $R[\Omega]$ the resistance of the coil. K_1[N/m] and K_2[N/m] are the spring modulus and C_1[N·s/m] and C_2[N·s/m] are the viscosity coefficients.

The transfer function from u[V] to x[m] is then given by,

$$F(s) = \frac{X(s)}{U(s)} = \frac{b_0 s^2 + b_1 s + b_2}{a_0 s^4 + a_1 s^3 + a_2 s^2 + a_3 s + a_4} \tag{2}$$

Table 2 shows the coefficients of the polynomials described in eq. 2

b_0	m_2Bl
b_1	$Bl(C_1 + C_2)$
b_2	$Bl(K_1 + K_2)$
a_0	Rm_1m_2
a_1	$Bl^2m_2+Rm_1C_1+Rm_1C_2+Rm_2C_1$
a_2	$Bl^2(C_1+C_2)+Rm_1(K_1+K_2)+Rm_2K_1+RC_1C_2$
a_3	$Bl^2(K_1+K_2)+Rm_1C_2+RK_2C_1$
a_4	RK_1K_2

Table 1: Coefficients of the optical pick-up.

The presented transfer function, in eq. 2 is valid for focus and radial actuators. In this paper it has been chosen to study the focus actuator only. Similar results however transfer immediately to the radial loop.

3 Closed loop system identification

Figure 2 shows the diagram which the closed loop system identification is based on. The absolute position of the focus point cannot be measured directly. The intensity of the reflected laser is measured by the photo-diodes and these produce a current, which in the linear area, is directly proportional to the distance between the focus point x, and the position of the signal layer ref, thereby the photo-diodes can be modeled by a constant gain K_{opt}. The focus error f_e, is fed into a PID controller, $K(z)$. The output of the controller is superimposed with an excitation signal u_{exc} which is fed into the CD-player.

The excitation signal is a harmonic with known amplitude and frequency, which starts at 100 Hz and increases with a step of 1 Hz up to 1kHz. Measurements above 1kHz can be extrapolated with high precision as the system rolls off with -40dB/dec. Extrapolation is though less accurate at frequencies below 100Hz and reliable measurements are not possible due to a poor signal-to-noise ratio.

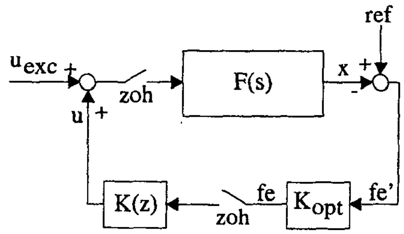

Figure 2: Focus closed loop.

In order to calculate the gain and phase of $F(s)$ between 100Hz and 1kHz, a discrete Fourier transformation of the input u_{exc} and output signal f_e is performed. If $\hat{f}_e(j\omega)$ and $\hat{u_{exc}}(j\omega)$ denote the discrete Fourier transforms of f_e and u_{exc} respectively, then the gain and phase are given by,

$$|F(j\omega)| = 20 \cdot \log \left| \frac{\hat{f}_e(j\omega)}{\hat{u_{exc}}(j\omega)} \right| \tag{3}$$

$$\text{Arg } F(j\omega) = \angle \frac{\hat{f}_e(j\omega)}{\hat{u_{exc}}(j\omega)} \tag{4}$$

where $\angle$ denotes the phase-shift between $\hat{f}_e(j\omega)$ and $\hat{u_{exc}}(j\omega)$. The disadvantage of this method is that the reliability of the measurements depends on the purity of the disk surface. A disk with scratches, finger prints and dirt will result in less accurate measurements. The controller must also keep the focus point in the linear area which is a few μm.

4 Open loop system identification

By inserting a known resistance in series connection with the coil of the focus actuator (in this case $r_m = 1.2\Omega$), the current through the coil can be measured. The advantage of the transformation from the SISO to this SIMO system is that the output u_m shown in fig. 3 can be directly measured in open loop,

where

$$F_{11}(s) = \frac{x(s)}{u(s)} = \frac{\frac{Bl}{m(R+r_m)}}{s^2 + (\frac{c}{m} + \frac{(Bl)^2}{m(R+r_m)})s + \frac{k}{m}} \tag{5}$$

which describes the movement of the optical pick-up according to the applied voltage.

$$F_{12}(s) = \frac{u_m(s)}{u(s)} = \frac{\frac{r_m}{R+r_m}(s^2 + \frac{c}{m}s + \frac{k}{m})}{s^2 + (\frac{c}{m} + \frac{(Bl)^2}{m(R+r_m)})s + \frac{k}{m}} \tag{6}$$

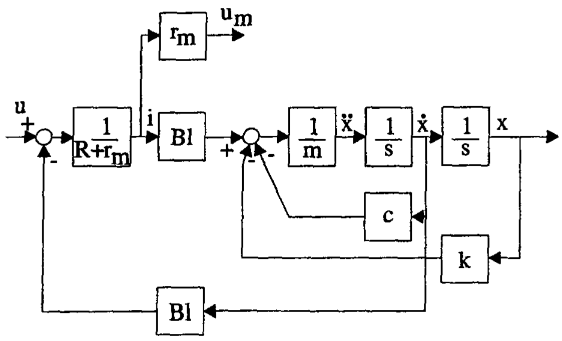

Figure 3: State space diagram of $F(s)$ (reduced order).

The model has been simplified to a second order model as only the dynamics below 100Hz are desired to be identified in open loop. This corresponds to merging the two masses m_1 and m_2 described above. (If desired the dynamics around 500Hz can be identified by the presented open loop method). This simplification requires the following three substitutions:

$$m = m_1 + m_2 \ , \quad K = K_1 + K_2 \quad \text{and} \quad C = \frac{C_1 + C_2}{C_1 C_2}$$

Due to the feedback from the velocity of the focus point through Bl to the voltage applied to the coil, all the parameters of F_{11} can be determined only by identifying F_{12}. F_{12} has the following rational structure:

$$A \cdot \frac{s^2 + a_1 s + a_2}{s^2 + b_1 s + b_2} \tag{7}$$

It is assumed that the mass of the optical pick-up has an inappreciable variation during production and along the life-time of the CD-player and that the measurement resistance, r_m is well-known. Moreover it is assumed that $a_2 = b_2$ which means that $F_{12}(j\omega = 0) = F_{12}(j\omega = \infty)$. Under these assumptions, the mechanical parameters, R, C, K and Bl, which are subject to change both in production and along the life-time of the CD-player, can be estimated by the following expressions:

$$R = \frac{r_m \cdot (1 - A)}{A} \tag{8}$$

$$C = m \cdot a_1 \tag{9}$$

$$K = m \cdot a_2 \tag{10}$$

$$Bl = \sqrt{m \cdot \frac{r_m \cdot (1 - A)}{A} b_1} \tag{11}$$

And thus, F_{11} has been determined indirectly.

5 Identification algorithm

The benefits of performing system identification in open loop are mainly that simple algorithms can be used. The least-squares loss function (see [4]), shown in eq. 12 is chosen which should be minimized when determining the parameters.

$$V(\theta, t) = \frac{1}{2} \sum_{i=1}^{t} (y(i) - \varphi^T(i)\theta)^2 \tag{12}$$

$y(i)$ is the output of the physical model obtained from experiments, in this case $u_m(t)$. $\varphi(i)$ are the regressors and θ are the parameters of the model to be determined, that is, the coefficients of the polynomials in eq. 6. As it can be observed in eq. 12 the estimated output $\hat{y}$ is given by $\hat{y} = \varphi^T(i)\theta$. Introduce the notations

$$Y(t) = (y(1)\ y(2)\ \dots\ y(t))^T$$
$$E(t) = (\varepsilon(1)\ \varepsilon(2)\ \dots\ \varepsilon(t))^T$$
$$\Phi(t) = (\varphi^T(1)\ \varphi^T(2)\ \dots\ \varphi^T(t))^T$$

where the residuals $\varepsilon(i)$ are defined by

$$\varepsilon(i) = y(i) - \hat{y}(i) = y(i) - \varphi^T(i)\theta \tag{13}$$

The loss function described in eq. 12 can be written as

$$V(\theta, t) = \frac{1}{2} \sum_{i=1}^{t} \varepsilon^2(i) = \frac{1}{2} \|E\|^2 \tag{14}$$

It can be proved that if the matrix $\Phi^T \Phi$ is nonsingular (excitation condition), the minimum is unique and given by

$$\hat{\theta} = (\Phi^T \Phi)^{-1} \Phi^T Y \tag{15}$$

Let the parametric model be described by the ARX model which corresponds to

$$A(q) u_m(t) = B(q) u(t - nk) + e(t) \tag{16}$$

where q is the forward shift operator, nk is the number of delays from input to output and $A(q)$ and $B(q)$ are the the output and input equations respectively. $e(t)$ is measurement noise considered as Gaussian white noise. The least-squares method together with the presented ARX model can be used to identify the parameters of the transfer function described in eq. 6.

6 Experiments

A laboratory rig consisting of a CD-player and a PC with a I/O card has been used to perform the experiments. Moreover some hardware was built in order to connect the CD-player to the I/O card. The sampling frequency was chosen to 35kHz, the processor limits of computation overload. The experiments were performed in 12 CD-players of the same model. As similar tendencies were observed in all the experiments only the results of one CD-player is shown in this paper. Figure 4 shows two curves. The solid curves are the measurement results of $F(s)$ using the closed loop method described in section 3 with a PID controller and a suitable u_{exc} amplitude. A little amplitude can be dominated by the presence of noise. On the other hand, a large amplitude will not keep the focus point in the linear area and an erroneous gain is calculated. The dashed curve is the fitted model using `fitsys` function in Matlab. The presented model in eq. 2 shows that it accurately describes the dynamics around 500 Hz. An additional pole was added to better fit the curve due to the influence of the anti aliasing analog filter.

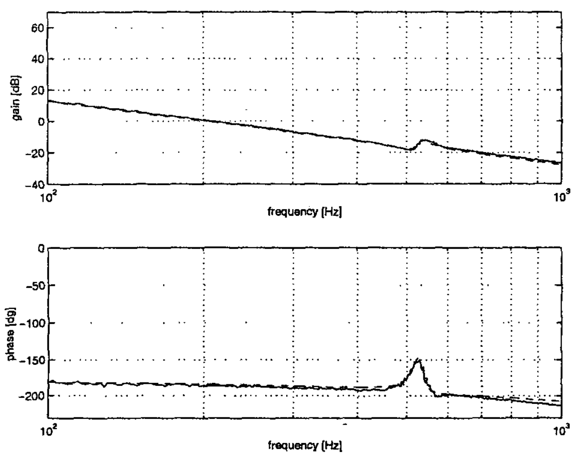

Figure 4: Measured (solid) and fitted (dashed) $F(s)$ transfer function.

Figure 5 shows the bode plot of $F_{12}(s)$. The solid curve is a gain and phase measurement using a similar u_{exc} as in the closed loop method. The frequency area is from 10Hz to 50Hz with a step of 0.1Hz. Very accurate measurements were achieved. The measured trace has though a lower gain at 10 Hz compared to 50Hz. As that experiment lasted over 30 min. the temperature of the coil may have increased, resulting in a lower resistance R and consequently in a higher gain of $F_{12}(s)$. The dashed trace was obtained by computing the least-square estimates of the ARX model.

As excitation signal a sweep signal from 10Hz to 50Hz was chosen, composed by one period for each frequency step of 1Hz. It can be observed that there are only insignificant differences between the traces. A transfer function was fitted to the solid trace in order to calculate the values of the actual CD rig, denoted fitted values in table 2.

The values calculated computing the least-square of the ARX model are the estimation values. The difference be-

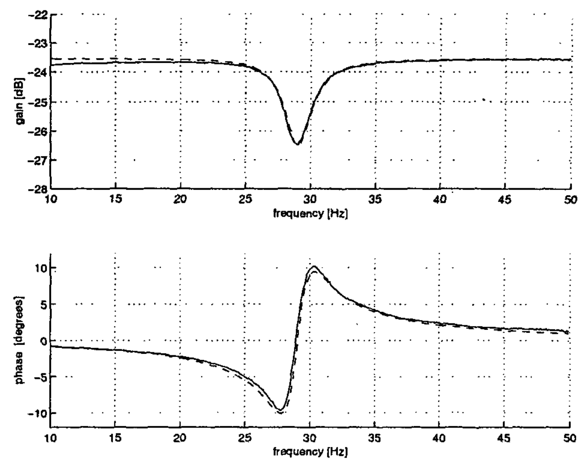

Figure 5: Measured (solid) and fitted (dashed) $F_{12}(s)$ transfer function.

Parameter	data sheet	fitted	estimation
R[Ω]	15.3-20.7	16.8660	16.8321
C[Ns/m]	(*)0.0021-0.0122	0.0074	0.0075
K [N/m]	(*)14.94-25.56	18.5667	18.6429
Bl[N/A]	0.2-0.3	0.2338	0.2347

Table 2: Coefficients of the optical pick-up.
(*) Indirectly calculated from the data sheet.

tween these two methods are inappreciable, less than 1.5% for each parameter. The data sheet values are included in the table to show whether the fitted and estimated values are realistic.

After realizing both the closed and open loop experiments, the higher order model, shown in fig. 6 is obtained by adding to $F_{11}(s)$ the dynamics around 500Hz estimated in the closed loop experiment.

Obviously there will be a DC-offset between the closed and open loop experiment, as the optical gain only can be calculated in the closed loop experiment. F_{11} is therefore DC rectified in order to include the optical gain K_{opt}.

7 Conclusions

By measuring the current through the coil of the actuators in the optical pick-up in a compact disk player, open loop parametric system identification is performed resulting in very accurate estimates of the real parameters. This method can easily be implemented in CD-players by adding only one additional measurement, namely the current through the actu-

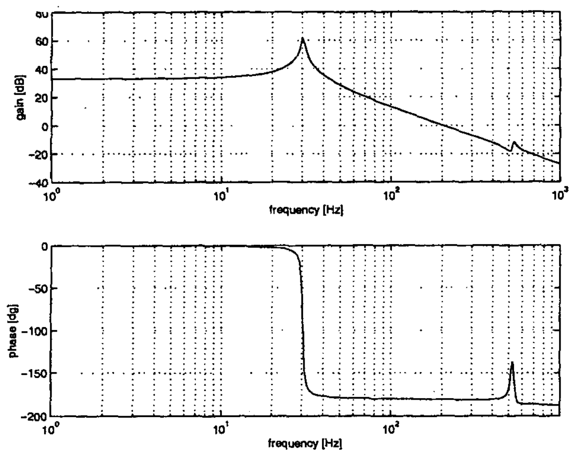

Figure 6: Focus actuator model (without anti aliasing filter).

ator coil. The only parameter which cannot be identified in open loop is the optical gain which is highly dependent on the reflection coefficient of the disk. This therefore has to be estimated in closed loop.

References

[1] R. Pintelon, P. Guillaume, Y. Rolain and F. Verbeyst (1992). Identification of Linear Systems Captured in a Feedback Loop. *9th. IEEE, pp. 14-20*

[2] Yeh, Ting-Jen and Pan, Yi-Chuan (2000). Modeling and Identification of Opto-mechanical Coupling and Backlash Nonlinearity in Optical Disk Drives. *IEEE Transactions on Consumer Electronics, Vol. 46, No. 1., pp. 105-115*

[3] Raymond A. de Callafon, Paul M.J. van den Hof, Maarten Steinbuch (1993). Control Relevant Identification of a Compact Disc Pick-up Mechanism. *32nd IEEE, Vol. 3, pp. 2050-2055*

[4] Karl J. Åström, Björn Wittenmark (1995). Adaptive Control, second edition. *Addison Wesley*