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Comparing Two Voltage Observers in a Sensorsystem using Repetitive Control

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Abstract: In sensor systems one of the most crucial issues is represented by the insensibility of the sensors with respect to the disturbances to obtain precision in the detected measurements. This paper proposes two different observers to identify an input voltage disturbance in sensors for ferromagnetic particle monitoring. The disturbance is identified together with the state variables which can be used for a controller. Because of a sinusoidal function being chosen to be the reference signal of the sensor, the repetitive controller is proposed to make robust this periodic work function of the sensor. The tracking of this working point is realised using a classical feed-forward control, which is made robust using a resonant control loop. The resonant control loop provides not only for the robustness but in the meantime minimises the energy needed for the sensor. The resonance is maintained by using the repetitive controller. In this sense the resonance region of the system guarantees a structural robustness and optimality. The repetitive control provides a tracking throughout the cycles. Computer simulations are devoted to compare the obtained results and conclusion closes the paper.

Keywords: Repetitive control, Resonance control, Observers, Sensor

1. INTRODUCTION

The paper proposes two techniques to identify disturbances. The proposed techniques improve the disturbance rejection of a detector system and thus their reliability in a harsh industrial environment. The industrial application is based on a sensor for ferromagnetic particle monitoring. The main idea is to use an integration between a state observer and a disturbance one to estimate the non measurable state.

In the past three decades, research on the geometric approach to dynamic systems theory and control has allowed this approach to become a powerful and thorough tool for the analysis and synthesis of dynamic systems as presented in Katsura et al. [2008]. Over the same time period, mechanical systems used in industry and developed in research labs have also evolved rapidly. Mobile robotics is a notable case of such evolution Mansur et al. [2013]. In the field of the control of actuators and observers are largely used. For instance in Mercorelli [2012a] the author implemented a switching extended Kalman filter to observe with a switching dynamics, and in Mercorelli [2012b] a cascade Kalman filter is proposed as an observer to estimate the state in sensorless control for an actuator.

The main contribution of this paper is to realise a stable working point of sensor system using a classical feed-forward control, which is made robust with a resonant control loop. The resonant control loop provides not only for the robustness, but in the meantime minimises the energy needed for the sensor.

The paper is organised in the following way: Section 2 presents the measuring system and its possible model of the detector for ferromagnetical particle monitoring. The repetitive controller for setting the sensor around a sinusoidal function is presented in section 3. Section 4 shows two possible voltage disturbance state observers for the application. Section 5 is devoted to the simulation and discusses the obtained results based on numerical computer simulations considering real data of the system. Finally, conclusions close the paper.

The main nomenclature

C_0:	Nominal capacity of the system
$d_u(t)$:	Voltage disturbance
$\hat{D}(t)$:	Observed disturbance variable
$i(t)$:	Current of the system
$\hat{i}(t)$:	Observed current of the system
L_0:	Nominal inductance of the system
R_0:	Resistance of the system
T_p:	Period of reference signal
$u(k)$:	Discrete input voltage of the system
$u_C(t)$:	Capacitive voltage
$u_{\text{in}}(t)$:	Input voltage
$u_L(t)$:	Inductance voltage
$\hat{u}_L(t)$:	Observed inductance voltage
$\hat{u}_{L_{\max}}$:	Maximal output voltage of the system
$u_{\text{out}}(t)$:	Output voltage of the system
$\rho(t)$:	Error vector

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2. THE MEASURING SYSTEM AND THE MODEL OF THE DETECTOR

The induced terminal voltage of the detector can be described as

$$u_L(t) = -N\frac{\mathrm{d}\Phi(t)}{\mathrm{d}t} = -NA\frac{\mathrm{d}B(t)}{\mathrm{d}t}, \tag{1}$$

with the number of windings N and inner surface A in which the magnetic flux Φ permeates. With integration of (1) the relationship of the magnetic flux density $B(t)$ with $B(0) = 0$ and the induced terminal voltage $u_L(t)$ can be formulated as

$$B(t) = -\frac{1}{N\ A}\int_0^t u_L(\tau)\ \mathrm{d}\tau. \tag{2}$$

In Fig. 1 the general schematic of the operational amplifier is depicted. The output voltage is realised by an inverter, so that

$$u_1(t) = -R_N\ \frac{u_L(t)}{R_1}. \tag{3}$$

Considering the transfer function of the subsequent integrator which is combined with (3), the following expression

$$u_{\mathrm{out}}(t) = -\frac{1}{C_1\ R_2}\int_0^t -R_N\ \frac{u_L(\tau)}{R_1}\ \mathrm{d}\tau, \tag{4}$$

with $u_{\mathrm{out}}(0) = 0$ is obtained. According to (2) and (4) it results that

$$u_{\mathrm{out}}(t) = -N\ A\ \frac{R_N}{R_1\ R_2\ C_1}\ B(t). \tag{5}$$

Thus, a linear relationship between the magnetic flux $\Phi_1(t)$ of the detector of the receiving side and the output voltage $u_{\mathrm{out}}(t)$ of the operational amplifier are evident. Let us finally have a look on magnetic coupling and the maximum output voltage of the detector of the receiving side. Assuming that the detector is disturbed by a sinusoidal magnetic flux of

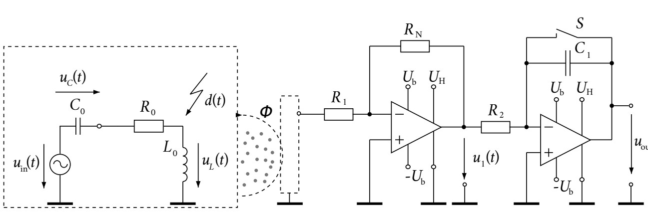

Fig. 1. Schematic of the detector and its components

$$\Phi_1(t) = \Phi_{\max}\ \sin(\omega\ t), \tag{6}$$

which is included in (1), it follows after differentiation that the maximum output voltage is

$$\hat{u}_{L_{\max}} = N_1\ \Phi_{\max}\ \omega. \tag{7}$$

The detector can be modeled using a linear system of the second order which represents a RLC circuit as follows

$$\begin{bmatrix} \frac{\mathrm{d}u_c(t)}{\mathrm{d}t} \\ \frac{\mathrm{d}i(t)}{\mathrm{d}t} \end{bmatrix} = \begin{bmatrix} 0 & \frac{1}{C} \\ -\frac{1}{L} & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} u_c(t) \\ i(t) \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{L} \end{bmatrix} u_{\mathrm{in}}(t) + \begin{bmatrix} 0 \\ \frac{1}{L} \end{bmatrix} d_u(t), \tag{8}$$

in which the informative state is represented by voltage $u_c(t)$ and the controlled state is current $i(t)$ and indirectly inductance voltage $u_L(t)$. Moreover, signal $d_u(t)$ represents the voltage disturbance one respectively

$$i(t) = [0\ \ 1]\begin{bmatrix} u_c(t) \\ i(t) \end{bmatrix} \tag{9}$$

and

$$u_L(t) = [-1\ \ -R]\begin{bmatrix} u_c(t) \\ i(t) \end{bmatrix} + u_{\mathrm{in}}(t). \tag{10}$$

3. REPETITIVE CONTROL FOR SETTING THE SENSOR AROUND A SINUSOIDAL FUNCTION

In Fig. 2 a schematic block diagram is shown in which a repetitive controller is proposed due to the input periodic reference signal. It is known that a repetitive controller is characterised by the following transfer function

$$G_r(s) = K\frac{e^{-T_p s}}{1 - e^{-T_p s}}. \tag{11}$$

The parameter T_p represents the period of the periodical signal to be tracked and parameter K represents a constant to be designed. It is known that, using Taylor expansion, the following relation is obtained

$$G_r(s) = K\frac{e^{-T_p s}}{1 - e^{-T_p s}} \approx K\left(\frac{1}{sT_p} - 1\right). \tag{12}$$

Considering the current of the model represented by (8)

$$I(s) = \frac{sC}{s^2CL + sCR + 1}U_{\mathrm{in}}(s). \tag{13}$$

Considering the approximated repetitive control represented by (12), the following closed loop transfer function is obtained

$$\frac{I(s)}{I_R(s)} = \left(1 + \frac{CK}{T_P}\right)\frac{sCKT_P - CK}{s^2\frac{LCT_p}{1+\frac{CK}{T_P}} + s\frac{(RC-CK)}{1+\frac{CK}{T_P}} + 1}, \tag{14}$$

where $I_R(s)$ is the reference current. For the asymptotical stability of the closed loop system it is necessary that the condition $K < R$. It is important to be noticed that the closed loop transfer function is a non-minimum phase one and in the proposed control structure parameter K and T_p are decisive for the stability. From (14) according to the standard notation the following two relations can be considered

$$\omega_n = \sqrt{\frac{1 + \frac{CK}{T_P}}{CL}}, \qquad \frac{2\zeta}{\omega_n} = \frac{C(R-K)}{1 + \frac{CK}{T_P}}. \tag{15}$$

For a given T_p which represents, as already explained, the period of the reference signal, and for a given damping factor $0 < \zeta < \frac{1}{\sqrt{2}}$ an optimal control strategy is to work in resonance, then the parameter K can be calculated such that the sensor works in the resonance condition. It is considered that

$$\omega_r = \omega_n\sqrt{1 - 2\zeta^2}, \tag{16}$$

where ω_r is the desired resonance frequency, which is the frequency of the reference signal. So once ζ is fixed, ω_r is obtained. Considering ω_n in (15), it follows

$$K = \frac{T_p(1 - 2\zeta^2) - \omega_r^2 T_p CL}{2C\zeta^2 - C}. \tag{17}$$

To complete the control structure, a possible idea is to consider a feed-forward control which can compensate the amplitude reduction and the phase delay. In this way a