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An Industrial Model Based Disturbance Feedback Control Scheme

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Abstract: This paper presents a model based disturbance feedback control scheme. Industrial process systems have been traditionally controlled by using relay and PID controller. However these controllers are affected by disturbances and model errors and these effects degrade control performance. The authors propose a new control method that can decrease the negative impact of disturbance and model errors. The control method is motivated by industrial practice by Fuji Electric. Simulation tests are examined with a conventional PID controller and the disturbance feedback control. The simulation results demonstrate the effectiveness of the proposed method comparing with the conventional PID controller.

*Keywords**:** Disturbance feedback control*, *Model based control, PID*

1. INTRODUCTION

Unitary control such as relay control and PID control have been widely applied to industrial process systems. For a long time engineers have used relay and PID controllers because it is possible to implement those even with limited knowledge, information and low cost. However, these controllers have issues for disturbance, mutual interference, and model errors.

For disturbance problems, Two-Degree-of-Freedom PID control gives better performances than conventional One-Degree-of Freedom PID, both w.r.t. set point and disturbance response (Horowitz, 1963; Araki and Taguchi, 2003).This controller also make possible to improve both set-point and disturbance response by tuning new parameters α and β. However, the parameter gives the engineer an additional task, because these parameters are not tuned independently on control performance w.r.t. set point and disturbance response. More tuning parameters make it more complicated for the engineer.

Multivariable control also has been applied to industrial systems in order to solve the following control issues. Model predictive control (MPC) has been applied to overcome mutual interference by minimize objective function (Maciejowski, 2000). Examples of such methods are given in e.g. (Kawai, 2007; Larsen, 2004). However MPC originally does not consider disturbances. Thus, we need to improve and modify the MPC algorithm as needed (Tange, 2009, 2012). Furthermore, multivariable control design normally needs advanced and expensive hardware, as well as, much time and cost for model and control design, which makes a barrier for this to be in wide use.

This paper proposes a new control method in order to attenuate the impact of disturbances and model errors. The control method is motivated by industrial practice for instance used for speed control of motor drives as shown in Fig.1 (Nishida, 1997; Miyashita, 2000). The advantage of the proposed method is examined by simulation tests by using two example models.

2. THE MODEL BASED DISTURBANCE FEEDBACK CONTROL METHOD

A block diagram for the proposed method is shown in Fig.2, where r is the reference input, u is the control input ($u = u_1 + u_d$), y is the control output, d is the disturbance, G is the controlled object, K is the feedback controller, G_n is the nominal plant, L is the gain of disturbance feedback, y_n is the output of the nominal plant, $\varepsilon = y_n - y$ is an estimate of dG. The block diagram shows that the proposed method compensates the disturbance using u_d.

This control method compensates the error between y_n and y including the effect of disturbance and mutual interference. For this reason, the proposed method is an effective technique to reject disturbance, mutual interference and model error for various systems.

The closed loop transfer function is obtained as follow:

$$y = \frac{GK(1+G_nL)}{(1+GK)+GL(1+G_nK)}r + \frac{G}{(1+GK)+GL(1+G_nK)}d. \quad (1)$$

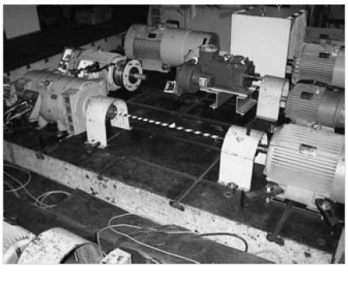

Fig.1. Example for a motor speed control by Fuji Electric.

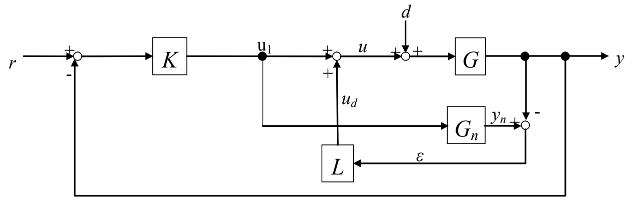

Fig. 2. A block diagram of the disturbance feedback control.

When G=G_n, namely nominal plant is equal to controlled object completely, then Equation (1) gives

$$y = \frac{GK}{(1+GK)} r + \frac{G}{(1+GK)} \frac{1}{(1+GL)} d. \tag{2}$$

Equation (2) describes that L can attenuate the disturbance.

Furthermore, L can be tuned independently for disturbance response, and L will have no impact at the set-point response.

2.1 Stability condition of disturbance feedback control

Consider the second term of Equation (2). This part gives

$$\frac{y}{d} = \frac{G}{(1+GK)(1+GL)}. \tag{3}$$

For example, G and K are defined as follows:

$$G(s) = \frac{G_s}{(1+T_1 s)(1+\sigma s)}. \tag{4}$$

$$K(s) = K_p \frac{1+sT_1}{sT_1}. \tag{5}$$

Where, G_s is the process gain, T_1 and σ are time constants, $T_1 > \sigma$, K_p is proportional gains. The long-time constant T_1 is dominant in G. The long time constant T_1 of the process is cancelled by the zero in the PI controller.

From (3), (4), and (5) we have

$$\frac{y}{d} = \frac{G_s T_1 s(1+\sigma s)}{\left[(1+\sigma s)T_1 s + G_s K_p\right]\left[(1+\sigma s)(1+T_1 s) + G_s L\right]}. \tag{6}$$

From the (6), the characteristic equation is written as

$$\left(\sigma T_1 s^2 + T_1 s + G_s K_p\right)\left[\sigma T_1 s^2 + (T_1+\sigma)s + (1+G_s L)\right] = 0\,. \tag{7}$$

When a real part of a solution is negative value, then the system is stable. Stability condition of Equation (7) is given by the following inequalities:

$$-T_1 + \sqrt{T_1^2 - 4T_1 \sigma G_s K_p} < 0\,.$$

$$-(T_1+\sigma) + \sqrt{(T_1+\sigma)^2 - 4T_1\sigma(1+G_s L)} < 0\,. \tag{8}$$

Therefore, if K_p and L satisfy (9), the system is stable.

$$G_s K_p > 0, \; L > \frac{-1}{G_s} \tag{9}$$

2.2 An implementation method of the disturbance feedback control by a Two-Degree-of-Freedom structure

The disturbance feedback control can be changed equivalently to Two-Degree-of-Freedom (2DOF) control.

As an advantage this equivalent transformation can be implemented in the device of two-degree-of-freedom PID without having to provide a new controller for disturbance feedback control.

However, since this control device has been designed based on the disturbance feedback control method, it can be designed independently of the suppression of the disturbance unlike two-degree-of-freedom PID control.

Fig.3 shows an example of a 2DOF PID control system, which is a set-point filter type, because it is obtained by inserting a filter in the set-point path of the conventional PID controller.

Thus, the disturbance feedback control is categorized as a 2DOF control system and the controller can be treated as a PID controller. The disturbance feedback control also can be changed to other equivalent 2DOF representations such as feed forward type, feedback type, and loop type expression as shown in Fig.4, Fig.5 and Fig.6 (Araki and Taguchi, 2003).

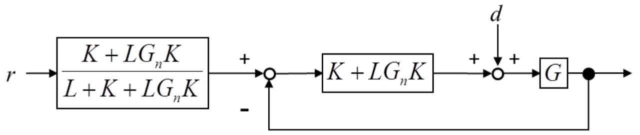

Fig.3. A set-point filter type representation.

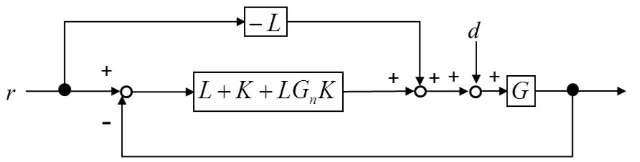

Fig.4. A feed forward type representation.

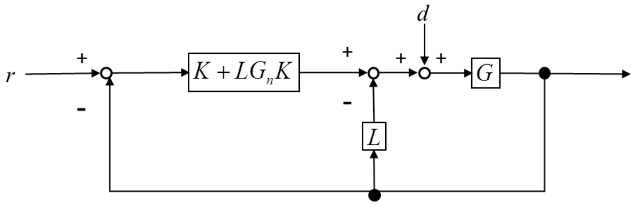

Fig.5. A feedback type representation.

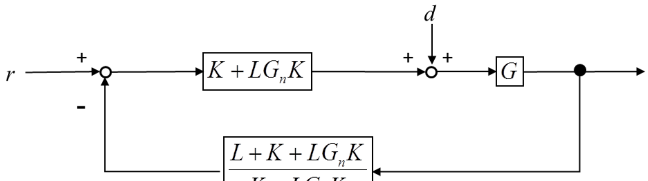

Fig.6. A loop type representation.