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# Identification of slide valve dynamics with errors in variables

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**Abstract.** This paper proposes an algorithm for identifying the dynamics of a slide valve with errors in variables. Estimation of nonlinear parameters of exponential functions in the presence of noise is associated with known difficulties. The paper proposes a transition from a nonlinear in the estimated parameters of the static model to a linear in the parameters of the dynamic model. The estimation of the parameters of the dynamic model is carried out on the basis of the solution of the bias normal system of algebraic equations. The biased normal system of algebraic equations is often ill-conditioned. The paper proposes estimating parameters with a method based on equivalent extended systems. In testing algorithms, it was found that when there were errors in measurements related to the rod, the proposed algorithm yielded more accurate parameter estimates as compared with the least-squares technique. The proposed algorithm for estimating the parameters of slide valve will increase the accuracy of the control systems, as well as can be used to control the serviceability of slide valve.

## 1. Introduction

The widespread use of hydraulic drives in various machine-building industries such as machinery and construction, road, agricultural, and transportation equipment is due to the substantial benefits that hydraulic drives have over other types of drives. The benefits include high energy capacity, compactness, low response time, ease of operation, and the possibility of providing efficient arrangement and high gear ratios [1].

The hydraulic drive makes it possible to proceed with creating highly automated machines, robot and hydraulic-pulse systems, and other new equipment. Developing methods for making mathematical models for hydraulic-drive systems with experimental data is a relevant problem.

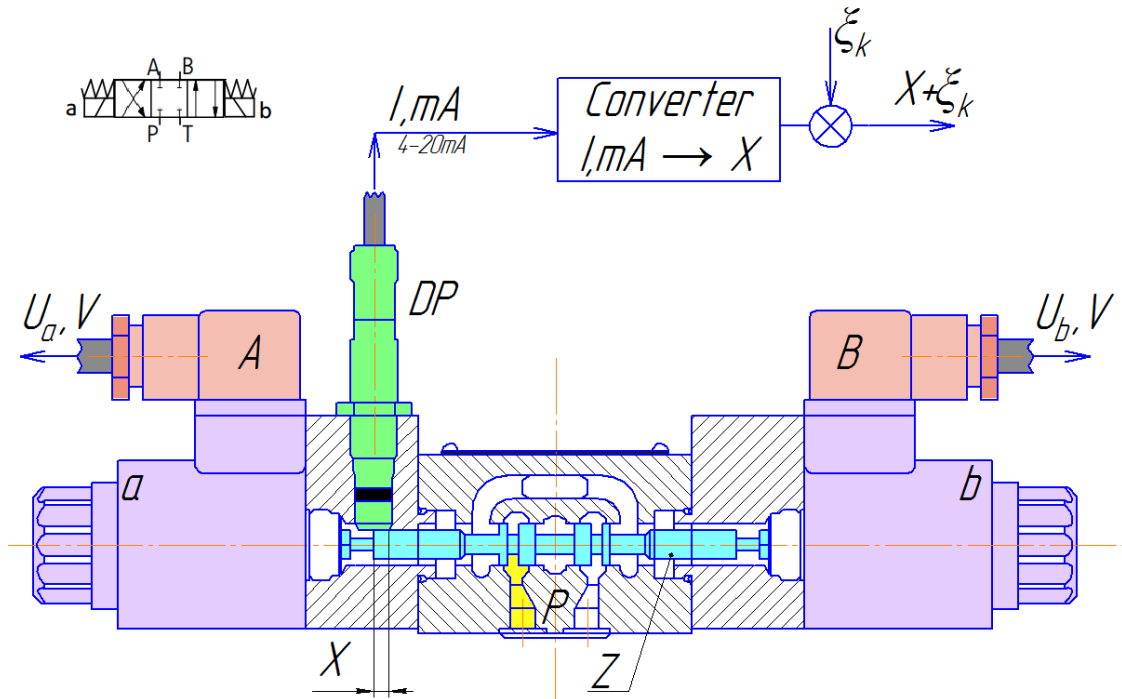
The key component of a hydraulic drive is a slide valve. Slide-valve models with a priori known parameters are treated in [2–5]. Reference [6] proposes a model with parameter identification. [7] proposes models with a small number of parameters. One of the models proposed in [7] is based on identifying parameters for an exponential function.

None of the papers deals with the effect that noise has on estimation accuracy. This paper addresses model identification [7] in the presence of observation noise on the basis of extended systems [8].

## 2. Materials and methods

The figure 1 shows and measuring the shift of the valve rod of 4/3 of the spool-type electro-hydraulic distributor.





**Figure 1.** 4/3 of the spool-type electro-hydraulic distributor.

The figure 1 shows 4/3 of the spool-type electro-hydraulic distributor, in which are indicated: “Z” is control spool; “A” is the coil of the electromagnet “a”; “B” is electromagnet coil “b”; “A” is the connector of the electromagnet coil “a”; “B” - the connector of the electromagnet coil “b”; “DP” is an inductive position control sensor. The redistribution of the distributor occurs when exposed to electromagnetic radiation (a, b). Return to the middle position (without current) produce control springs. The position of the spool is controlled by a sensor (DP), which generates a current signal (4-20mA) with interference, after which it becomes a normalized interleaving signal (X).

### 3. Identifying the dynamics of a slide valve

The shift of the valve rod at constant current under zero initial conditions in the range of  $x^{\min} \leq x_k \leq x^{\max}$  is given by:

$$x_k = A(1 - \exp(-\lambda T_k)), \quad (1)$$

where  $T_k = k \cdot \Delta t$ ,  $\Delta t$  is a sampling interval.

The delay  $\tau = 1/\lambda$  is obtainable from (1).

As the parameter  $\lambda$  enters equation (1) nonlinearly, the parameter is difficult to estimate. The traditional approach, which involves taking the logarithm of (1), does not yield sufficiently accurate estimates when there are measurement errors.

This is due to the following:

1. It is assumed that noise enters the model multiplicatively:

$$x_k = A(1 - \exp(-\lambda T_k)) \cdot \exp(\xi_k),$$

$\xi_k$  is an independent arbitrary value with the zero mean and the dispersion  $E(\xi_k) = \sigma_\xi^2$ .

The logarithm method cannot be used when noise is additive:

$$y_k = x_k + \xi_k.$$

2. The expression  $\exp(\xi_k)$  makes the nature of the stochastic component heteroscedastic.

3. Minimizing the logarithm of an error function is not always equivalent to minimizing the error function itself.

An alternative approach involves expressing equation (1) with a difference equation. Since expression (1) contains a constant coefficient, we will write a difference equation in relation to first-order differences for  $k > 2$ :

$$\begin{aligned}\Delta x_k &= b\Delta x_{k-1}, \\ \Delta y_k &= \Delta x_k + \Delta \xi_k,\end{aligned}\tag{4}$$

where  $b = \exp(-\lambda \cdot \Delta t)$ ,

The forecast error for model (4) can be written as:

$$\begin{aligned}\varepsilon_k &= \Delta y_k - b\Delta y_{k-1}, \\ \varepsilon_k &= \Delta \xi_k - b\Delta \xi_{k-1} = \xi_k - (1+b)\xi_{k-1} + b\xi_{k-2}.\end{aligned}\tag{5}$$

The use of the classical least-squares technique does not allow valid parameter estimates to be obtained for equation (4) because of the autocorrelation in the forecast error  $\varepsilon_k$ . Let us determine error dispersion for  $\varepsilon_k$ :

$$E(\varepsilon_k^2) = \sigma_\xi^2 + \sigma_\xi^2(1+b)^2 + \sigma_\xi^2 b^2 + \sigma_\xi^2 c_2 = 2\sigma_\xi^2(1+b+b^2).$$

Unbiased coefficient estimates are obtainable from the minimum condition for the criterion:

$$\min_b \frac{\sum_{i=1}^N (\Delta y_k - b\Delta y_{k-1})^2}{1+b+b^2}.\tag{6}$$

The criterion minimization (6) can be based on a solution to a biased normal system.

$$\hat{b} = (\Phi^T \Phi - \sigma^2)^{-1} (\Phi^T Y + \sigma^2),\tag{7}$$

where  $Y = (\Delta y_3, \dots, \Delta y_N)^T$ ,  $\Phi = (\Delta y_2, \dots, \Delta y_{N-1})^T$ ,

$\sigma = \sigma_{\min}(\Phi, Y)$  is the minimal singular value for the matrix  $(\Phi, Y)$ .

Reference [9] reports that the summand  $(-\sigma^2)$  in expression (7) makes it impossible to calculate  $\hat{b}$  with efficient numerically stable methods that do not involve first forming the matrix  $\Phi^T \Phi - \sigma^2$ .

Reference [8] proposes using an extended system that is equivalent to the biased normal system:

$$\bar{\Phi} \bar{b} = \bar{Y},\tag{7}$$

or

$$\begin{pmatrix} I & 0 & \Phi \\ 0 & I & j\sigma \\ \Phi^T & j\sigma & 0 \end{pmatrix} \begin{pmatrix} r \\ r_\xi \\ \hat{b} \end{pmatrix} = \begin{pmatrix} Y \\ 0 \\ -\sigma \end{pmatrix}.\tag{8}$$

System (8) is solvable with standard methods for solving linear algebraic equation systems—for example, with LU decomposition [10].

Using the estimate of  $\hat{b}$ , we can find an estimate for  $\hat{\lambda}$ :

$$\hat{\lambda} = -\frac{1}{\Delta t} \ln(\hat{b}),$$

then

$$\hat{\tau} = -\frac{\Delta t}{\ln(\hat{b})}.$$

#### 4. Simulation results

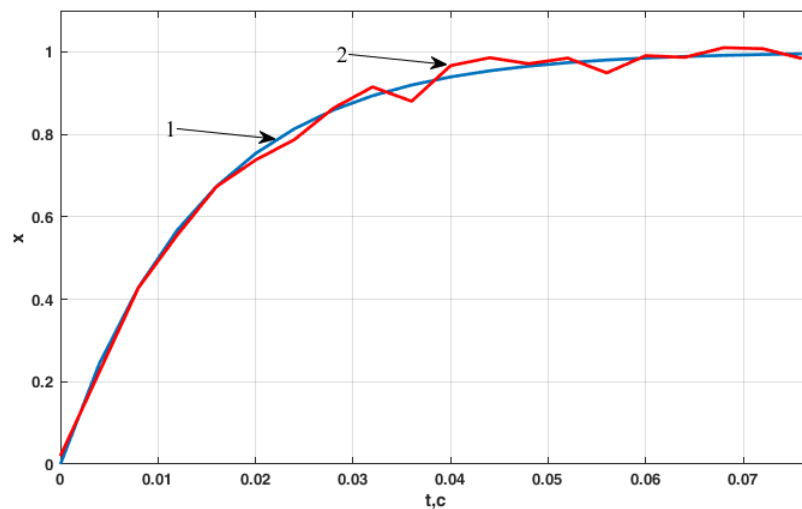
As a test example, we used the model:

$$y_k = 1 - \exp(-70 \cdot T_k) + \xi_k.$$

The number of observations:  $N = 20$ .

The sampling time:  $\Delta t = 0.004$  s.

Figure 2 shows a true model of transient response and model with measurement errors.



**Figure 2.** Transient responses of slide valve dynamics: 1 – true model of transient response, 2 – model with measurement errors.

We used the relative mean-square error of parameter estimation as a quality indicator for the model:

$$\delta b = \sqrt{\frac{\|\hat{b} - b\|^2}{\|b\|^2}} \cdot 100\%.$$

Table 1 shows parameter estimation errors for Least Square and proposed algorithm.

**Table 1.** Parameter estimation errors

$\sigma_{\xi} / \sigma_x$	$\delta b$ for LS (%)	$\delta b$ for criterion (8) (%)
0.001	2.62	1.51
0.002	3.81	2.12
0.003	5.77	2.64
0.005	9.36	4.62

The obtained results confirm the high accuracy of the proposed identification algorithm as compared with the least-squares technique.

#### 5. Conclusion

This paper proposed an algorithm for identifying the dynamics of a slide valve with errors in variables on the basis of extended systems. The simulation results showed that the proposed algorithm is superior in accuracy to the least squares method. The proposed algorithm for estimating the parameters of slide

valve will increase the accuracy of the control systems, as well as can be used to control the serviceability of slide valve. Further research will focus on testing the algorithm on actual slide valves and on generalizing results for the case of colored noise [11, 12].

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