Development of Identification Algorithms in Frequency Domain for Friction-Based Servo Drives Technology

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***Abstract* - In this paper, nonlinearities, such as friction, backlashes, and saturations are commonly exists in servo drive systems in industry. Specifically, friction exists in servo motor control systems. The friction effects are undesirable in servo applications because they disturb the system performance. So it is required to know or identify the friction in servo systems. In this thesis, binary test signals are used to perform identification, thus simplifying the behaviour of friction. An identification method using the Identification Toolbox in MATLAB/SIMULINK is proposed in this analysis.**

***Keywords* - Simulation, Friction Compensation, Identification Algorithms, System Identification MATLAB.**

I. INTRODUCTION

The identifications system is to extract mathematical models from physical systems. A properly identified model can explain the details of a system and estimate its behaviors under specified inputs by means of computer simulation. The increasing needed for precision machining and processing of semiconductors, optoelectronic elements, and high-density magnetic memory devices has increased the demand for high-accuracy machining at the level of submicrometers.

A problem of general identification system, is characterized by three components: a class of models, a class of input signals and an identification criterion. The class of models should be appropriate and the set of signals should have the property of persistent excitations relative to the class of models. A recursive criterion is usually adopted to extract target parameters from the I/O data. Successful system identification, therefore, depends on careful consideration of the previous entities.

The classical theories of frequency response only apply to linear systems. Most nonlinear systems have to be linearized around a specific operating point such that a linear model can be derived. Typical identification procedures include spectrum estimation techniques based on covariance and Fourier transform analyses.

The existence of nonlinearity, such as friction, backlashes, and saturations, in practical systems is usually not modeled and is ignored in the identification process

In this paper, a frequency-domain system identification method is proposed for DC servo motor with friction. The major advantage of this approach is its application of differential binary signals to system excitations, by means of which the commonly seen nonlinear distortions due to friction can be successfully decoupled.

II. SERVO SYSTEMS WITH FRICTION

A typical servo system usually consists of a plant (such as a slider table), an actuator (such as a dc motor), and some driving circuits as shown in the block diagram in Fig. The slider table is modeled as a second-order transfer function and is driven by a dc motor that is also modeled as a second order system. The position of the slider table can be measured by means of a motor encoder or directly by means of a position sensor (such as an optical position sensor) attached to the table. To obtain semi position feedback, the rotating angle of the motor is derived by transforming the encoder readings into position readings by multiplying by a constant l/2π, l where is the pitch of the ball–screw driving the slider table. Since the table position is not directly read out, there are always errors on the order of several micrometers in the position readings which comprise semi position feedback.

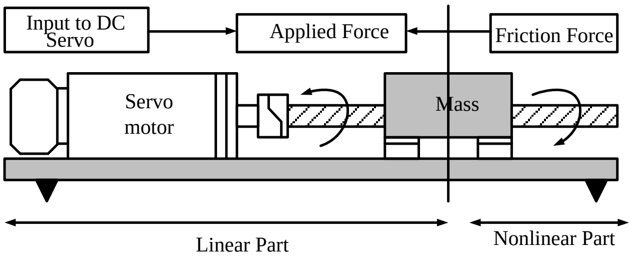


Fig. 1 Separated Block Diagram of Servo System

Most of the previous studies on friction with dc servo systems can be mentioned with a system model. In such kind of system, friction is not included in the servo system [5]. By adding the friction term, the system becomes as shown in Fig.1. As shown in this figure, there are three parts:

1. Input voltage to DC servo motor
2. Applied force/torque to the mass and
3. Friction force opposing the motion of the mass.

The input voltage and applied force are usually known from time domain system identification procedure. In this thesis, the system model of a servo system with friction will be identified in frequency domain. And the effect of friction will also be considered in the identification process.

III. SERVO SYSTEM MODEL

A DC motor is a torque producer that converts electrical energy into mechanical energy. It is also a power actuator device that delivers energy to a load.

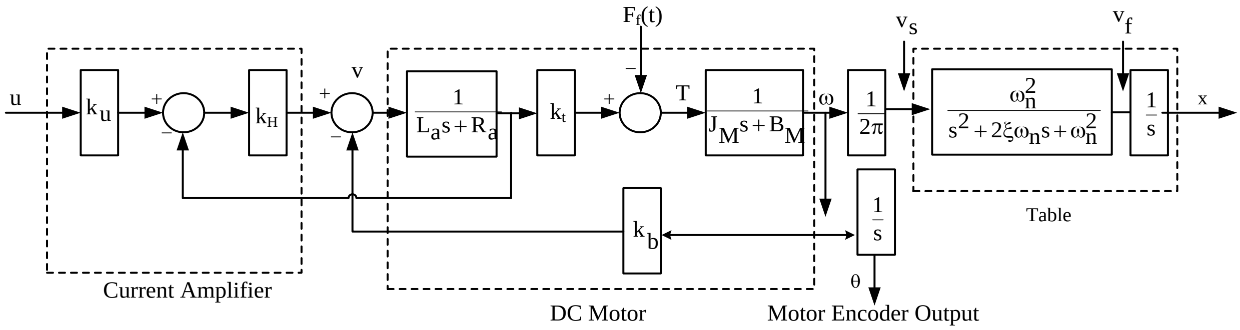


Fig. 2 Block Diagram of a Servo System

A sketch of the basic components of a DC motor is shown in Fig. 3. The non-turning part (stator) has magnets or, for small motors, permanent magnets. The rotor is wound with wire, and through this winding (armature winding) a current i_a is forced through the (stationary) brushes and the (rotating) commutator. The transfer function of the DC motor will be developed for a linear approximation to an actual motor, and second-order effects, such as hysteresis and the voltage drop across the brushes, will be neglected.

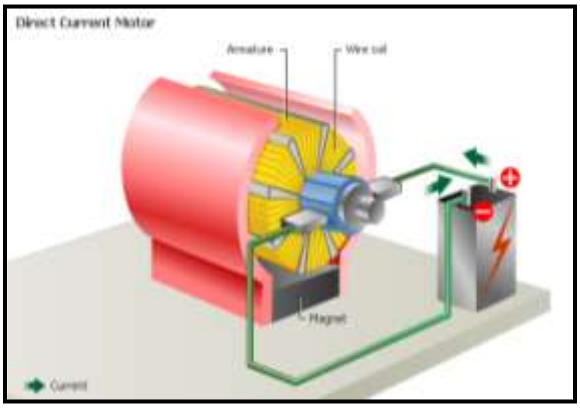


Fig. 3 Simulation Model for Satellite Communications System

A servo motor is a dc, ac, or brushless dc motor combined with a position sensing device (e.g. a digital decoder) In this section, discussion will be focused on the three-wire DC servo motors that are often used for controlling industrial machines.

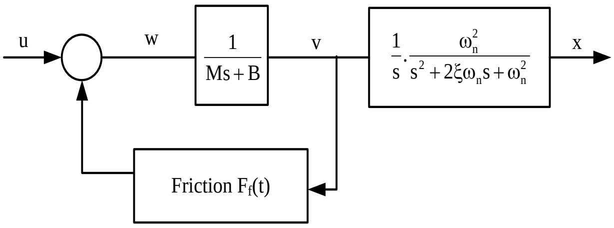


Fig. 4 Simplified System Block Diagram

A three-wire DC servo motor incorporates a DC motor, a gear train, limit stops beyond which the shaft cannot turn, a potentiometer for position feedback, and an integrated circuit for position control. With these overall simulation parameter values established, now attention to the simulation models for the transmitter, the filters, the nonlinear amplifier, the demodulator, and the semianalytic estimator.

The function of the current amplifier is to keep the motor armature current i proportional to the input command u, independent of the motor back electromotive force (EMF) $k_b.\omega$. The gain k_{ii} is usually very large in the dynamic range of the mechanics, the current loop gain can be considered as a constant k_i; therefore, the transfer function from input to the equivalent transversal speed of the motor axis is written as

$$G_\omega = \frac{1}{2\pi}\frac{k_i k_u}{J_M s + B_M} \qquad (1)$$

To increase resolution to the submicrometer level, full-position feedback is utilized by directly measuring the table position. The transfer function for full position feedback can be described by

$$G_{\omega F} = \frac{1}{2\pi}\frac{k_i k_u}{J_M s + B_M}\cdot\frac{\omega_n^2}{(s^2+2\xi\omega_n s+\omega_n^2)} \qquad (2)$$

By letting $M=2\pi J_M/lk_ik_u$ and $B= M=2\pi B_M/lk_ik_u$, Equation (1) can be simplified to obtain

$$G_{\omega s} = \frac{1}{(Ms+B)}$$

In addition, Equation (2) can be simplified to obtain

$$G_{\omega s} = \frac{1}{(Ms+B)}\cdot\frac{\omega_n^2}{(s^2+2\xi\omega_n s+\omega_n^2)} \qquad (3)$$

Most of the previous studies on friction with dc servo systems have started with a system model like that in Equation (3). By adding the friction term (as shown in Fig. 2, the dynamical equation is obtained as follows

$$M\frac{dv}{dt}+Bv = u(t)-F_f(t) \qquad (4)$$

Where v is the velocity variable and $F_f(t)$ is the friction force. The full position feedback system described in Equation (4) is presented by the block diagram in Fig.4.

IV. IDENTIFICATION PROCEDURE

In order to identify friction elements of a servomechanism through the proposed method, an accurate linear element model should be obtained in advance. In reality, it is difficult to obtain an accurate linear element model of a servomechanism because the inherent nonlinearity, friction, degrades the accuracy of the identification process. To reduce this effect, specially designed input signals are devised for the identification of the linear element.The method of system identification by differential binary excitation (SIDBE) procedure proposed in this paper is shown in Fig. 5.

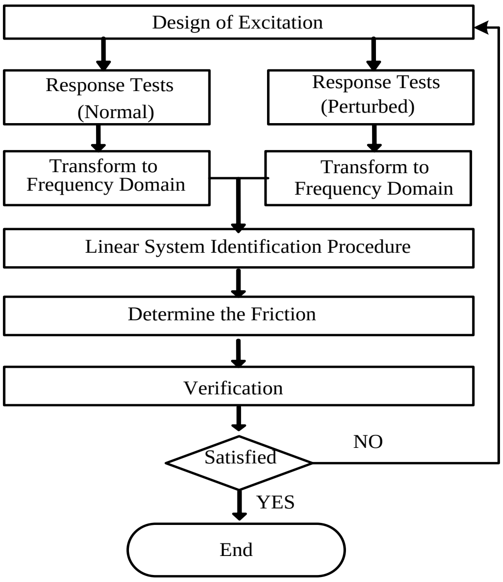


Fig. 5 Procedure for Frequency Domain Identification

The steps in the procedure are listed as follows.

1. Design the input excitation u_1 with specified frequency contents; then construct u_2 with the same frequency components and slightly smaller magnitude. Both of inputs of u_1 and u_2 are composed of multi frequency components. However, the same components are applied to both of u_1 and u_2. The difference of u_1 and u_2 will result in a signal which has the same frequency components as u_1 and u_2.
2. Apply the inputs u_1 and u_2 to the system and collect the output data v_1 and v_2, respectively.
3. Transform the collected Input/Output pairs into the frequency domain and derive the required differential Input/Output pair. In that case, the applied u_1 and u_2 are firstly designed in time domain. And both of v_1 and v_2 are also collected in time domain. Those signals in time domain are transformed into frequency domain.
4. Apply estimate of linear system to perform linear block identification
5. Determine the Coulomb friction in both directions.
6. Verify the result by means of simulation. If the verification result is not satisfactory, go to Step (2) to increase the excitation magnitude, or go to Step (1) to redesign the excitations with a different frequency spectrum.

V. CONCEPT OF SYSTEM IDENTIFICATION WITH FRICTION

The static and Coulomb friction are assumed to be different constants according to their different directions.

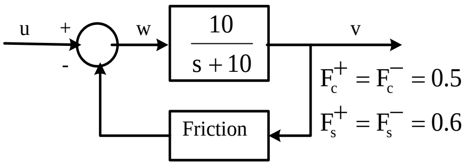


Fig. 6 Simple Servo System with Friction

VI. FLOWCHART OF IDENTIFICATION PROCEDURE

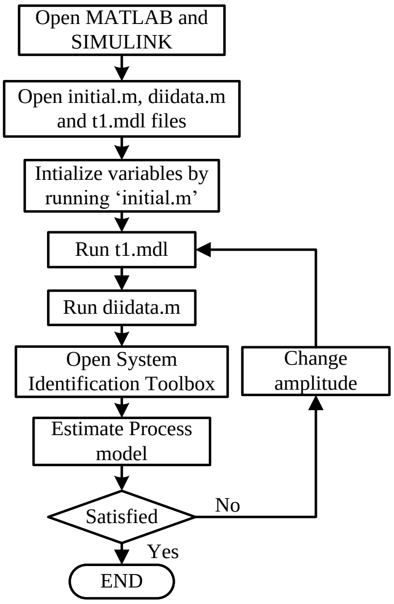


Fig. 7 Flowchart for Identification in MATLAB/SIMULINK

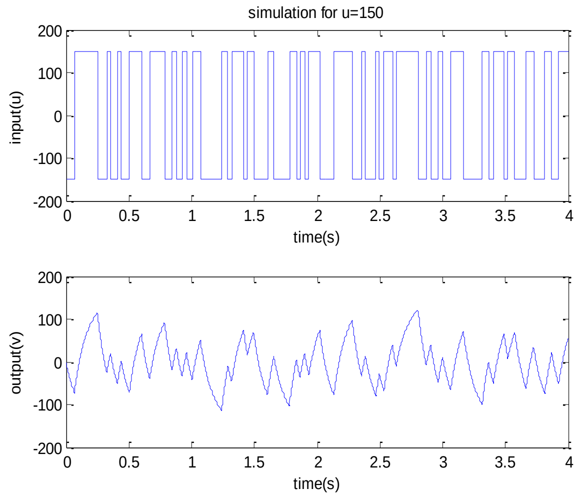
A flowchart of the program is shown in Fig. 7.There are three files involved with the initialization of the simulation. One, 'initial.m', is simply all the constants involved with the servo system such as mass, DC gain, number of poles and friction constants. The second file, 'diidata.m', creates the object file for the system identification toolbox and this data is imported into MATLAB workspace. The third file 't1.mdl' is SIMULINK model of servo system. 'initial.m' can be regarded as the input file to the model and 'diidata.m' is used to save the outputs of the model.

The initialization involves creating the variables and gains of the servo system by inserting from 'mat' file into workspace in MATLAB. Next, the SIMULINK model of the system is run. These values are saved as identification data object using 'iddata' command from MATLAB. This data object is imported into MATLAB Identification Toolbox using 'ident' command in MATLAB Command Window. These steps are repeated until the estimated transfer function of the simulation is satisfied.

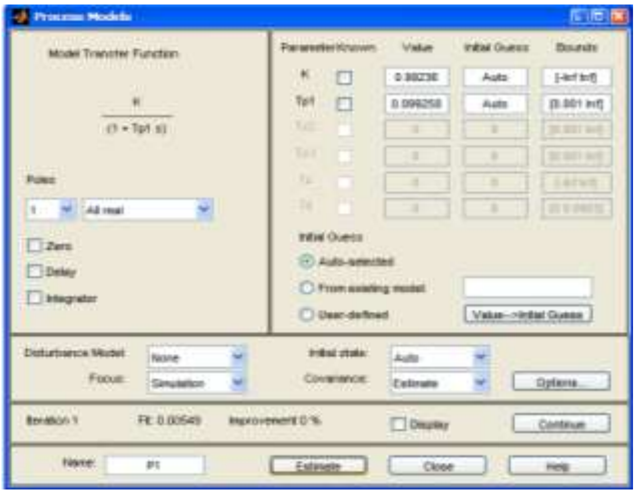
A procedure for system identification algorithm for servo system with intrinsic friction, SIDBE, has been developed and Matlab implementation is described. The key feature that distinguishes SIDBE from conventional frequency-domain identification is the design of the differential binary excitation. In order to derive an accurate model of the linear block as well as the Coulomb friction, the linear part from the nonlinear feedback friction are decoupled and modeled in SIMULINK. In addition, the use of System Identification Toolbox is also described in details.

VII. SIMULATION RESULTS

The simulation results for the identification system are shown, The estimated parameters of system object to each kind of input are compared and analyzed. Three kinds of inputs are applied to the same system and the amplitudes are also changed.



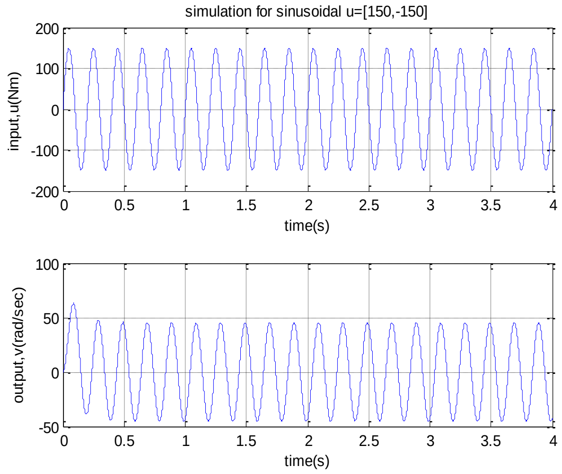
(a)



(b)

Fig. 8 (a) Simulation Result and (b) Result Transfer Function Window of Identifcation for Square Wave Input

The simulation results for square wave input with the input velocity of (-150,150)Nm. If higher amplitude of binary input is used for simulationthe estimated variables are very close to the real parameter value 'Sampled sine' option 'Signal Builder' block is used to determine the desired input.

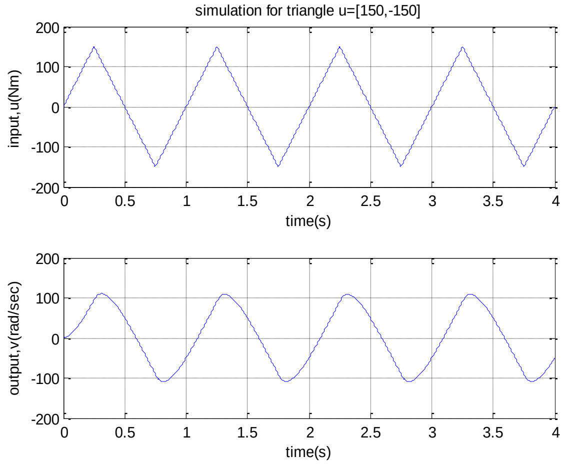


(a)

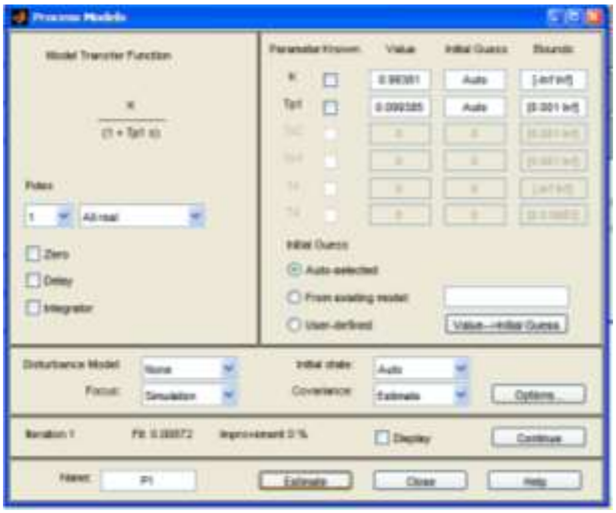
(b)

Fig. 9 (a) Simulation Result and (b) Result Transfer Function Window of Identifcation for SineWave Input

50 samples are calculated per one period of sine wave. Frequency of sine wave is 5Hz. Offset is set to zero so that binary values are able to be developed. Simulations are run for 4 seconds. Fig.9 is the simulation results for sine wave input with the input velocity of (-150,150)Nm and Fig.10 is the simulation results for triangle wave input with the input velocity of (-150,150)Nm.



(a)



(b)

Fig. 10 (a) Simulation Result and (b) Result Transfer Function Window of Identifcation for TriangleWave Input

TABLE I
IDENTIFICATION RESULTS FOR SINE WAVE INPUT

	Pole	Constant	DC-gain
Real Value	-10	10	1
Input=[-1,1]	-35.0116	6.7432	0.1926
Input=[-60,60]	-10.2805	9.9365	0.96651
Input=[-150,150]	-10.0767		0.98616

VIII. CONCLUSIONS

In this system, open-loop constant velocity experiments are carried out to measure a friction-velocity map. Herein, the friction torque, measured as the averaged control output, is given as a function of the rotational velocity. This friction-velocity map shows a small viscous friction component at high velocities. An open-loop sinusoidal input is applied to the system and the applied torque, friction torque and velocity are measured. It is found that the velocity signal cannot be used for system identification purpose because this signal is significantly affected by friction and zero values are presented in the signal.

Based on the observations of these identification simulations, a friction model is chosen. Because coulomb and viscous friction effect is considered, it is chosen to model the friction using classic model from literature. This model is preferred above other dynamic models, because of the limited amount of friction model parameters that need to be identified. The parameters of this model are adopted from literature.

Results show that the system behaves irregularly when the sinusoidal input is applied to the system. However, a square wave excitation input results in a nonzero velocity signal. So, binary inputs are conducted to investigate the signal phenomena in more detail. As in the sinusoidal experiments, an open-loop binary input is applied to the system.

However, in some binary input experiments, the velocity is ramped down to zero again, affected by friction. From these experiments, it can be observed that the system is sensitive to input excitation type and magnitude of input.

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