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RESEARCH ON THE IDENTIFICATION METHODS OF FRICTION IN KINEMATICAL JOINTS OF MECHANICAL SYSTEMS

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ABSTRACT

This paper describes two approaches for the simultaneous identification of the coulomb and viscous parameters in kinematical joints. One is a time-domain method (TDM) and the other is a frequency-domain method (FDM). Simulation shows that both of the two methods have good performances in identifying friction at high SNR (90dB). But at low SNR (20dB), the estimation accuracy of the frequency-domain method is higher than that of the time-domain method. A field experiment employing a linkage mechanism driven by motor is also carried out. The experimental results obtained by the two approaches are almost identical under different experiment conditions. It has been concluded that the presented identification methods of friction in kinematical joints are correct and applicable.

INTRODUCTION

Kinematical joint is an absolutely necessary structural connection in mechanical systems. The kinematical joint is responsible for transferring energy to a remote site, and may change the type of motion, as needed. The characteristics of kinematical joints have been studied in many papers [1,2]. Friction is an inevitable and complicated phenomenon in kinematical joints when the system works. Many friction models have been presented for friction identification, such as the viscous plus coulomb memoryless model [3,4], the stick-slip model [5] and LuGre model [6] etc. When the system runs stably, these friction models tend to be the same friction model, i.e., the viscous plus coulomb memoryless model [3]. Therefore, it is important to study the viscous plus coulomb friction model in mechanical systems.

METHODS

1 The time-domain method

We denote the rotor angular position by θ, its inertia by J, and the friction torque by f. The viscous plus coulomb memoryless model is adopted in this paper, i.e.,

$$f = K_v\dot{\theta} + K_c \operatorname{sgn}(\dot{\theta}) \tag{1}$$

where, $K_v > 0$ is the viscous parameter, and $K_c > 0$ is the coulomb parameter. According to the Newton's second law, the free vibration differential equation of a SDOF rotor system is

$$J\ddot{\theta} = -f \tag{2}$$

In this paper only the rotational speed decrement movement of the rotor at initial angular velocity is studied. So the sign function $\operatorname{sgn}(\dot{\theta})$ is omitted. According to the equation $\dot{\theta} = v$, the Eq. (2) is transformed to

$$J\dot{v} + K_v v + K_c = 0 \tag{3}$$

The initial angular velocity of the rotor is v_0 at time $t = 0$ in Eq.(3). The analytic solution of Eq.(3) based on the ordinary differential equation theory is

$$v = \left(v_0 + K_c / K_v\right)e^{-K_v t / J} - K_c / K_v \tag{4}$$

The expressions of coulomb and viscous parameters are obtained by the least square method:

$$K_c = \sum_{i=1}^{n}(v_0 e^{-\frac{K_v}{J}t_i} - v_i)(K_v - K_v e^{-\frac{K_v}{J}t_i}) / \sum_{i=1}^{n}(1 - e^{-\frac{K_v}{J}t_i}) \tag{5}$$

$$\sum_{i=1}^{n}\left(\left(v_0 + \frac{K_c}{K_v}\right)e^{-\frac{K_v}{J}t_i} - \frac{K_c}{K_v} - v_i\right)\left(-\frac{v_0 t_i}{J}e^{-\frac{K_v}{J}t_i} - \frac{K_c t_i}{JK_v}e^{-\frac{K_v}{J}t_i} - \frac{K_c}{K_v^2}e^{-\frac{K_v}{J}t_i} + \frac{K_c}{K_v^2}\right) = 0 \tag{6}$$

The viscous parameter can be got by substituting Eq.(5) into Eq.(6). But Eq.(6) is a nonlinear equation about the parameter K_v. The analytic solution is difficult to obtained. Therefore, the search method is applied to Eq.(6) for solving the parameter K_v.

2 The frequency-domain method

The Laplace transformation is taken to Eq.(3):

$$V(s) = (sJv_0 - K_c)/(Js^2 + K_v s) \tag{7}$$

Then the frequency characteristic function is obtained by substituting $s = j\omega$ into Eq.(7):

$$V(j\omega) = [-K_c + j(\omega J v_0)]/[-J\omega^2 + j(K_v\omega)] = N^*(j\omega)/D^*(j\omega) \tag{8}$$

The weighted least square method is adopted for parameter estimation. $D^*(j\omega_k)$ is a weighted factor, and the quadratic sum of the errors is obtained by

$$E = \sum_{k=0}^{M} \left| V_e(j\omega_k) D^*(j\omega_k) - N^*(j\omega_k) \right|^2 \tag{9}$$

The coulomb and viscous parameters are obtained through partial derivation about K_c, K_v in Eq.(9):

$$K_c = \sum_{k=0}^{M} (R_k J\omega_k^2 + K_v I_k \omega_k)/M \tag{10}$$

$$K_v = \frac{M \sum_{k=0}^{M} R_k J v_0 \omega_k^2 + \sum_{k=0}^{M} \left[\left(\sum_{k=0}^{M} R_k J \omega_k^2 \right) I_k \omega_k \right]}{M \sum_{k=0}^{M} \left(I_k^2 \omega_k^2 + R_k^2 \omega_k^2 \right) - \sum_{k=0}^{M} \left[\left(\sum_{k=0}^{M} I_k \omega_k \right) I_k \omega_k \right]} \tag{11}$$

The parameters R_k and I_k are the real and imaginary parts of the frequency characteristic fuction $V_e(j\omega_k)$ at frequency point ω_k, i.e., $V_e(j\omega_k) = R(j\omega_k) + jI(j\omega_k) = R_k + jI_k$. Thus, the viscous and coulomb parameters can be obtained by means of the Nyquist plot of the frequency characteristic function of the investigated system.

SIMULATION

A SDOF rotor system is designed to verify the correction of the presented methods. The physical parameters of the system are shown in Table 1.

Table 1 Basic physical parameters and values

Physical parameters	Values
Moment of inertia	J=0.01kgm^2
Viscous friction coefficient	Kv=0.01203Nms/rad
Coulomb friction moment	Kc=0.0017Nm
Initial velocity	V_0=10rad/s

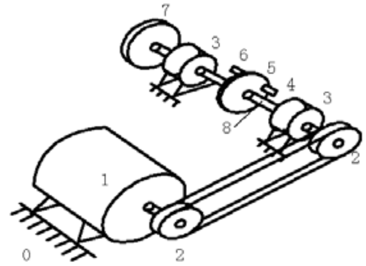
The friction parameters under different SNR 90dB、60dB and 20dB are identified. The relative errors between the identified and the true values are shown in Table2.

Table 2 Simulation results

SNR (dB)	Friction parametes	TDM Relative error (%)	FDM Relative error (%)
90	Kc	4.9	8.6e-3
	Kv	8.3e-2	6.4e-6
60	Kc	21.9	2.6
	Kv	0.17	2.2e-3
20	Kc	93.1	6.4
	Kv	28.2	5.1e-3

EXPERIMENT AND RESULT

An experimental system is designed as shown in Fig.1.



1-motor 2-V type belt wheel 3-rolling bearing body 4-light source
5-code disc 6-photosensitive diode 7- wheel 8- drive shaft

Fig.1 The schematic diagram of the experimental system

In the experiment, the system decays at two different initial rotational speeds (72r/min and 60r/min). The experiment system is equivalent to a DOF rotor system. The equivalent moment of inertia is 0.13kgm^2. The aim of this part is to study the viscous and coulomb parameters in the rolling bearings. The identified results are shown in Table3.

Table 3 Experimental results

Studied system	Initial speed	Friction parameters	TDM	FDM
motor and drive shaft	72r/min	Kv (Nms/rad)	0.0114	0.0096
		Kc (Nm)	1.186	1.207
	60 r/min	Kv (Nms/rad)	0.0128	0.0104
		Kc (Nm)	1.193	1.201

It has been seen from Table 3 that: the identified values of the viscous and coulomb parameters are almost identical at the speeds of 72r/min and 60r/min.

CONCLUSIONS

Two approaches for the simultaneous identification of the coulomb and viscous parameters in kinematical joints are presented. The accuracy and validity of the two methods are illustrated by simulation. The experimental results show that the two methods have good repeatability under different experimental conditions. The methods for friction identification described in this paper can be applied to practical engineering.

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