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

Ziying Wu
Department of mechanical engineering, Xi’an University of Technology, Xi’an, China, Zip: 710048, E-mail: ziyingwu@tom.com

Hongzhao Liu
Department of mechanical engineering, Xi’an University of Technology, Xi’an, China, Zip: 710048, E-mail: liu-hongzhao@163.com

Lilan Liu
Department of mechanical engineering, Xi’an University of Technology, Xi’an, China, Zip: 710048, E-mail: lilanliu@tom.com

Pengfei Li
Department of mechanical engineering, Xi’an University of Technology, Xi’an, China, Zip: 710048, E-mail: lipengfei@163.com

Daning Yuan
Department of mechanical engineering, Xi’an University of Technology, Xi’an, China, Zip: 710048, E-mail: daningyuan@163.com

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 \( \theta \), its inertia by \( J \), and the friction torque by \( f \). The viscous plus coulomb memoryless model is adopted in this paper, i.e.,
\[
f = K_c \dot{\theta} + K_v \text{sgn}(\dot{\theta})
\]
where, \( K_c > 0 \) is the viscous parameter, and \( K_v > 0 \) is the coulomb parameter. According to the Newton’s second law, the free vibration differential equation of a SDOF rotor system is
\[
J \ddot{\theta} = -f
\]
In this paper only the rotational speed decrement movement of the rotor at initial angular velocity is studied. So the sign function \( \text{sgn}(\dot{\theta}) \) is omitted. According to the equation \( \dot{\theta} = v \), the Eq. (2) is transformed to
\[
J \ddot{v} + K_v v + K_c = 0
\]
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
\[
v = (v_0 + K_v / K_c) e^{-K_v / J} - K_c / K_v
\]
The expressions of coulomb and viscous parameters are obtained by the least square method:
\[
K_v = \sum_{i=1}^{n} \left( \frac{K_v}{J} e^{K_v / J} - v_i \right) / \left( \frac{K_v}{J} e^{K_v / J} - v_i \right) / \sum_{i=1}^{n} (1 - e^{-K_v / J})
\]
\[
\sum_{i=1}^{n} \left( \frac{K_v}{K_c} e^{K_v / J} - K_c \right) \left( \frac{K_v}{K_c} e^{K_v / J} - K_c \right) / \left( \frac{K_v}{K_c} e^{K_v / J} - K_c \right) = 0
\]

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):

\[
V(s) = (sJ_0 - K_v)(Js^2 + K_v s)
\]

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

\[
V(j\omega) = -K_v + j\omega h_0]/(-\omega^2 + j(K_v \omega)) = \sum\omega^k\omega^k
\]

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

\[
E = \sum_{k=0}^{M} [V_k(j\omega_k)D^*(\omega_k) - N^*(j\omega_k)]^2
\]

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

\[
K_c = \sum_{k=0}^{M} (R_k J_0 \omega_k^2 + K_v I_k \omega_k) / M
\]

\[
K_v = \sum_{k=0}^{M} (I_k \omega_k^2 + R_k \omega_k^2) - \sum_{k=0}^{M} \left[ \sum_{k=0}^{M} I_k \omega_k \right] / I_k \omega_k
\]

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

SIMULATION

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

<table>
<thead>
<tr>
<th>Physical parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moment of inertia</td>
<td>J=0.17kgm²</td>
</tr>
<tr>
<td>Viscous friction coefficient</td>
<td>Kv=0.01203Nms/rad</td>
</tr>
<tr>
<td>Coulomb friction moment</td>
<td>Kc=0.0017Nm</td>
</tr>
<tr>
<td>Initial velocity</td>
<td>V0=10rad/s</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>SNR (dB)</th>
<th>Friction parameters</th>
<th>TDM Relative error (%)</th>
<th>FDM Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>Kc</td>
<td>4</td>
<td>8.6e-3</td>
</tr>
<tr>
<td></td>
<td>Kv</td>
<td>8.3e-2</td>
<td>6.4e-6</td>
</tr>
<tr>
<td>60</td>
<td>Kc</td>
<td>21.9</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Kv</td>
<td>0.17</td>
<td>2.2e-3</td>
</tr>
<tr>
<td>20</td>
<td>Kc</td>
<td>93.1</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>Kv</td>
<td>28.2</td>
<td>5.1e-3</td>
</tr>
</tbody>
</table>

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.

REFERENCES