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MODELLING THE DYNAMIC BEHAVIOUR OF A DRY FRICTION-TYPE MECHANICAL SHOCK INDICATOR

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ABSTRACT

This paper presents the development and validation of a mathematical and numerical model that fully characterises the behaviour of a dry friction-type mechanical shock detector device that uses the displacement of a magnet to detect excessive accelerations. Modelling friction with a unary coefficient was found to have shortcomings and a more sophisticated approach to predict the effects of friction was developed using an adaptation of the Stribeck friction model. The numerical model was validated by producing a variety of excitation motions using a programmable actuator.

Keywords: dry friction, stiction, Stribeck, nonlinear, numerical model.

INTRODUCTION

In order to minimise product damage during transportation, passive shock indicators are used to establish if excessive shocks have been experienced. One such device uses the deflection of a magnet that slides on a plastic base. Preliminary work showed significant variation in trigger threshold with pulse duration as well as some departure from the specified trigger threshold curves. To enable further investigation and gain a better understanding toward designing more reliable devices, a mathematical model of the device was developed using a series of constitutive equations of motion that were then used in a numerical model to predict the displacement response of the free magnet due to a pre-determined excitation motion. This involved the establishment of the device's dynamic parameters by experimental means. The numerical model was validated by comparing results from numerical predictions to those from physical experiments undertaken on a sample of the device.

Validation experiments were carried-out with a programmable servo-hydraulic actuator controlled by a shock controller. The motion of the free magnet relative to the device body was measured using a high-speed camera and specially-developed software to analyse the captured images. The measured free magnet displacement response was compared with that of the numerical model by feeding the shock function into the (Simulink®) differential equation solver. In the first instance, a series of experiments were carried out using the unary friction coefficient model which, for most cases showed some discrepancy between predicted and observed displacements. The model was then altered to include an adaptation of the Stribeck friction model (Andersson et al, 2007) shown in (1) where Δv is the relative velocity and F_f and F_N the friction and formal forces respectively.

$$F_f = \left\{ \mu + (\mu_s - \mu)\exp\left(\left|\frac{\Delta v}{v_t}\right|\right) sign(\Delta v) \right\} F_N \tag{1}$$

The main aim of the validation experiments was to establish the accuracy of the mathematical model and to determine the values of the Stribeck break-out friction coefficient, μ_S, and the velocity threshold, v_t.

RESULTS AND CONCLUSIONS

The response of the free magnet due to a series of half-sine pulses of varying durations and amplitudes were evaluated with typical results shown in Figure 1 which reveals good agreement with measured values and a significant improvement on the unary friction model.

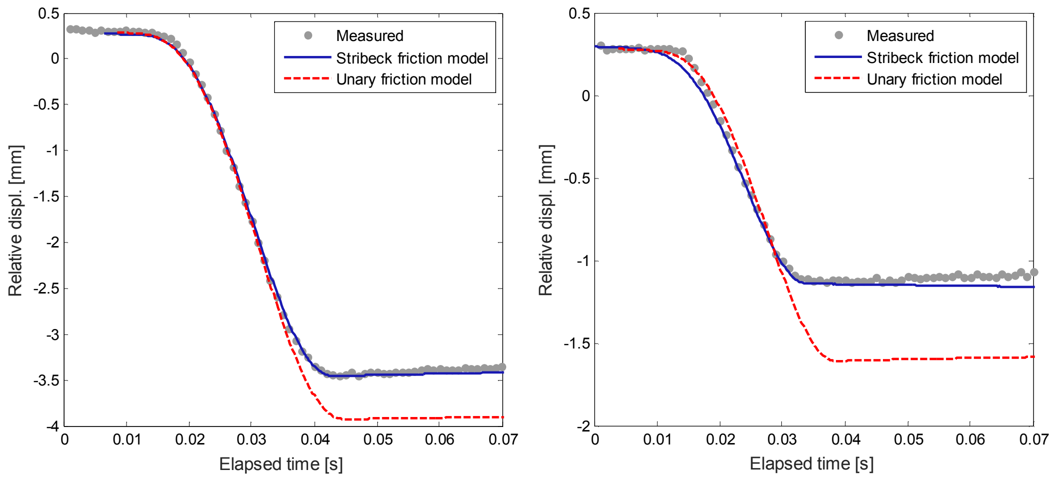

Fig. 1 - Free magnet response to 30 ms half-sine pulse of 25 m/s^2 (left) and 15 m/s^2 (right).

Overall, the results reveal good agreement between the numerical model (Stribeck friction) and observed response. It is clear that the unary friction model is too simplistic to accurately represent the complex interaction between the surface of the magnet and that of the moulded plastic body especially at low relative velocity when stiction-like motion can occur. The tribology of such devices has, inherently, an element of volatility related to temperature and spatial variations over the surface of the device that is made of moulded plastic. Furthermore, the complex magnetic fields that exist between the two magnets may apply a torque to the free magnet as it moves away from its home position thus affecting the way it makes contact with the device's body. This, it is expected, contributes to the limitations of the current model. The majority of the discrepancies between observed and measured values occur when the relative velocity of the magnet is small corresponding to the initial, non-linear portion of the Stribek friction curve. It must, however, be pointed out that the model is reasonably accurate for predicting the downward motion of the free magnet for a range of shock pulse types and durations and is therefore useful in predicting whether the device will trigger given a particular excitation. These results show that the model can be used to enable further investigation into the behaviour of the device (namely its trigger threshold) when subjected shock excitation of varying duration and of more complex shapes (as is often the case in real-life impacts) without having to perform difficult and time-consuming experiments.

REFERENCES

[1]-Andersson S., Söderberg A., and Björklund S. Friction models for sliding dry, boundary and mixed lubricated contacts. Tribology International, 2007, 40(4), p 580-587.