Effect of Friction on the Slide Guide in an Elevator System

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Abstract. The slide guide in an elevator moves in contact against the guide rail. This kind of surface contact exhibits a highly non-linear hysteretic friction behaviour which hampers greatly the riding quality of the elevator system. This paper presents an experimental investigation on this type of phenomenon through measuring the contact friction force between the interface of the slide guide and the rail under different combination of input parameters. The experiment shows frictional behaviours including pre-sliding/gross-sliding regimes, transition behaviour between them, time lag, and velocity (weakening and strengthening) dependence. In addition, it is found that different materials in contact, lubrications and friction duration have strong impacts on evaluation of the friction characteristics. The observations in the test provide an insight into relationships between different friction behaviours and can be used to validate the appropriate theoretical friction models.

Keywords: friction; experiments; lubrication; slide guide; elevator system

1. Introduction

The friction dynamics modeling and identification is gaining in importance in recent years. In the domain of elevator designing and manufacturing, it has been testified that the main source of lateral vibrations is coming from the unevenness of the rails. When the slide guide mounted with the pad is moving in contact along the rail, the vibration is apparent because of the friction induced by the interaction between the contact surface of slide guide/pad and the rail. Fig. 1 shows the sketch of a slide guide in an elevator when being in contact with the rail. The zoom at the upper right corner is the enlarged view depicting the details of the contact.

To reduce the friction induced vibration transmitted to the elevator, an accurate modeling on friction dynamics is therefore imperative. Although researches on the sliding friction characteristics in the field of elevator designing and manufacturing were not thoroughly examined in literature yet [1], similar studies on frictions in other engineering fields have been a hot topic for a very long time. Generally, the endeavors of the researches on the topic of frictions are spread out in two associated branches: experimental investigations and mathematical approaches. In a large extent, the research, analysis and findings of friction phenomena are based on experimental works. It is now well known that the friction reveals two regimes: the pre-sliding/micro-sliding regime and gross-sliding/macro-sliding regime. In addition the friction exhibits some interesting phenomena, such as stick-slip, velocity dependence, frictional lag and hysteretic behaviors, etc. [e.g. 2-4]. On the other hand, besides for dry friction, lubrication plays an important role in characteristics of friction. Gao [5] and Velde et
al. [6] conducted dynamic frictional analysis on slide guide way with oils. Muraki and Tominaga [7] investigated the frictional properties of some additives for sliding guide way lubricants. In a word, friction is in fact an experimentally driven knowledge. Experiments hide behind nearly all the equations, formulas and theories concerning frictions behaviors, which need to be treated carefully.

![Fig. 1 The plain view of a slide guide and guide rail](image)

The current paper first introduces in section 2 the experimental work on the dynamic characteristics of contact friction between slide guide/pad and the rail of elevator system. In section 3, the experimental observations of the contact friction between the slide guide and rail are provided. Some friction behaviors are analyzed and discussed. In addition, the influences of materials in contact, lubricants and friction duration are presented as well. Finally some appropriate conclusions are drawn in section 4.

2. Experimental work

2.1. Design and discussion of the test rig
The experiment was carried out on a hydraulic driven vibrator system. The test rig was shown in Fig. 2. It consists of two main parts: the driving part and the frictional part. The driving part includes a piece of rail which is mounted on the vibrator and moving along with it under specified input signals. The frictional part contains the pad, universal joint, force sensor and some connecting parts. The pad has the shape of flat flake which is detached from real elevator’s slide guide, and it is inlayed in the mounting frame which is fixed to the rigid base via the force sensor and the universal joint linking them together. The friction occurs on the interface between the pad and the rail driven by the hydraulic vibrator, and the friction contact surface lies in the center plane of the universal joint and the force cell which prevent the introduce of extra moment into the recording of the friction force as much as possible. In addition, the universal joint is used to set off the small vertical, lateral and rotational alignment errors caused by positioning the pad on the moving rail. The method of applying normal force is implemented by mounting the calibrated masses over the pad on the frame. In this way, the mass, mounting frame and universal joint are kept in still when the test is start-up. This method has an obvious advantage that the friction force recorded by the load cell will not be contaminated by the inertia effect. Practically, however, the absolutely standstill of the test rig is hard to be maintained. It is inevitable the test rig will move slightly. Fortunately the inertia caused by this minute movement can be subtracted by measuring the acceleration of the test rig which will be talked about in the following sections.
2.2. Measuring instrument and signal processing

The friction force, displacement, velocity and acceleration are the main variables needed careful attentions in the test. An Omron ZS-L laser displacement sensor is used to measure the relative displacement between the rail and the pad. The friction force is measured by the stress-strain force sensor with the range of 0-1000N. Velocity is estimated by numerical differential method. The acceleration is measured by a B&K piezoelectric accelerometer of type 4382. The input signal is guaranteed by the hydraulic vibrator (Servo Valve Actuator EVH-50-100-3). All these dynamic signals are collected simultaneously by LMS SCADAS III data acquisition system.

There is one thing need to be taken care of that, in the channel setup panel of the data acquisition system, the coupling method for the channel connecting the force sensor should not be AC but DC mode because of the characteristic of the friction force. It is known that the friction is velocity dependent, which means the friction force keeps unchanged when velocity is constant when other parameters are neglected. While AC mode means the data acquisitor will only record alternatively changing signals and treat the constant ones as “zero”, which is the routine method to record experimental signals such as accelerations. So if the relative speed of the friction is near constant, which is common in the frictional test such as in the gross-sliding regime of friction, the selecting of AC mode in the acquisition system will omit the real varying value of the friction force and record only small force near “zero” instead. Fig. 3 is the comparison of the friction force under AC mode and DC mode. We can see in Fig. 3 that the friction force measured in AC mode decreased rapidly (dash line) which differs dramatically with the correctly measured friction force via DC mode (full line), indicating the importance of selection of correct coupling method.

2.3. Experimental parameters
The tests were run in ambient atmosphere with humidity 50~80% and room temperature 15~30℃. The rail is the sample product of an elevator company, and the pad is made of nylon and plastic respectively. The specimen and the pad were cleaned in the acetone, before each test, when in the condition of dry frictions. In the case of lubricated ones, the lubricant used is Mobil Vactra Heavy Oil series with the viscosity 11.0. The input frequency and amplitude are ranging from 0.1 to 5 Hz and 0.1 to 5 mm respectively in the form of sine and triangle wave. The normal loads varies in the range of 20~300N. The vibrator can produce sine and triangular waves. The triangular wave is especially useful in that the velocity keeps constant in one stroke during triangular input. So we can evaluate the velocity dependent characters of friction.

3. Experimental Results and discussion

3.1. Hysteretic behavior and pre-sliding regime
The hysteresis is generally defined as the phenomenon whereby changes in some property of a physical system lag behind changes in the phenomenon causing it [8]. In the case of friction, it is said that the changing of the friction force drops behind that of the displacement/velocity, or the output (the friction force) depends on the history of the input (displacement/velocity).

Fig. 4 The time history of the friction force and displacement: (a) A=0.5mm, f=0.5Hz, normal load=150N, steel & nylon; (b) A=0.5mm, f=0.5 Hz, normal load=100N, steel & plastic

Fig. 4 is the time histories of the friction force and displacement. All the friction force cited in this paper is denoised in advance using EMD (Empirical Modal Decomposition) method [9]. It is clearly seen that the friction history can be divided into two different but relative regimes: pre-sliding and gross sliding regimes. At small displacement around velocity reversal points (e.g. in Fig. 4a, from point A to point B), asperity junctions between two surfaces deform plastically like nonlinear springs. Thus the adhesive forces are dominant and the friction forces behave as a function of displacement rather than the velocity. This is the pre-sliding regime. In the stage from point B to C, the junctions break and the friction transfers into the gross sliding regime where the velocity dependence on friction manifests itself.

3.2. Transition behavior, friction overshoot and time lag
The complete of pre-sliding regime will eventually result in the subsequent gross sliding phase. The transition between these two phases is of importance which will lead the dependence of friction from the displacement dependence to the velocity dependence and vice versa. The friction overshoot is also observed at the end of this transition progress. After velocity passes through the reversal point where velocity is zero, the friction force increases up to its maximum value, namely, the break-away force [10]. Then the friction will evolve into gross sliding phase where the velocity dependent characteristic
will manifest itself, and the friction force will also drop to a relative low value. The phenomenon of the falling of friction force from a higher value to a lower one in the transition from pre-sliding to gross sliding is called the Friction Overshoot. Generally the falling of friction force between the end stage of the pre-sliding and the initial stage of the gross sliding includes at least two obvious components. One is coming from the breaking of the asperity junctions which is the intrinsic characteristic of the friction. Another is the inertia force of the test rig which could be subtracted from the signal by measuring the mass of the test rig and its acceleration. Take Fig. 5 for example, which represents the friction force as the function of the time. We can clearly see the friction force overshoots with the value of 3.02N when the force is positive and 3.71N when negative. While the inertia force according to the multiplication of the mass of test rig and relative acceleration is not more than 0.11N (from test results), which holds only a very small portion of the total friction force overshoots, indicating that the friction characteristic dominates the force overshoots.

![Friction Force vs Time](Fig. 5 The effect of friction force overshoot (A=0.5mm, f=0.5Hz, normal loads=150N, steel & nylon)

The time lag, or the so called frictional lag, is the phenomenon which happens in the gross sliding phase. To examine this transition phenomenon, the system is excited by a harmonic displacement signal with different value of amplitudes and frequencies, and some relations are obtained. Fig. 6 is the friction force as the function of the velocity selecting from the test records. Among them, Fig. 6a is the case of dry friction, while Fig. 6b is the lubricated friction (with other test parameters such as normal force, frequency, etc. keeping unchanged). From the diagram, it is clearly seen that the friction force in the stage of acceleration (from point A to B) is higher than that in the deceleration stage (from B to C) which means the time lag exists in both the cases of lubricated and dry frictions. Please note the little difference between Fig. 6a and 6b. In Fig. 6a, the friction force climbs up from point A to B with the increasing of velocity, and drops along the route from point B to C with the decreasing of velocity. While in Fig. 6b, situation happens in an opposite direction. From A to B, the friction force decreases with the increase of velocity, and from B to C, the force grows up with the falling of velocity. This difference reveals two things: (1) the friction force is affected by the lubricated condition of the contact surface; (2) the friction force is velocity dependent in the gross sliding phase. This will be discussed in the next few subsections.

3.3. Velocity dependence of friction

It is now known that the friction force is relative to velocities when the velocities are constant, which means different stable velocities corresponds to different friction forces, the so called Striebeck curve. It is not easy to get the value of friction force in different velocities not only because of the stick-slip motion [10] but the difficulty of maintaining steady velocity. In the current experiment, a hydraulic vibrator is used which can produce triangular wave forms (which means a steady velocity in one stroke) to assess the dependence of friction on velocities. First, under different combinations of
amplitudes and frequencies, we can get different steady input velocities (in one stroke). Then by measuring the friction force corresponding to these velocities, the Striebeck curve is obtained. Fig. 7 is the experimentally observed curves using different frictional material configurations and under different lubrication conditions. From Fig. 7 we can see clearly that the characteristics of the stribeck under different situations present a completely diversity. This reminds us that the friction is also relevant to the material configuration, lubrication and other factors which will be spread in the next paragraph.

Fig. 6 The friction force as the function of velocity. (a) refers to dry friction; (b) is the lubricated friction.

Fig. 7 The coefficient of friction as the function of velocity under different combinations of materials and lubrications
3.4. Dependence on materials, lubrication conditions and time

The contact friction happens between different surfaces, so the property of materials of the surfaces in contact and the lubrications play an important role on determining the friction characteristics. Generally the friction force is largely reduced compared to the dry friction condition, by introducing a thin lubrication film into the contact surfaces. Literatures on these topics can be found in the field of machine tools [5, 7] and other areas. In the design and manufacturing of elevator’s rail systems, related papers are very rare. In the current paper, in order to investigate the influence of the material, lubrication and time on the characteristic of velocity dependent friction, two material configurations (nylon-steel and plastic-steel) which are common in elevator systems are used. The lubricant used in the test is Mobil Vactra Heavy Oil series with the viscosity 11.0. In figure 7, it is seen that: (1) the coefficient of friction for the lubricated case decreases dramatically compared to the dry friction in one material configuration (taking Fig. 7a and 7c for example); (2) different material configurations have an great impact on the friction. Comparing Fig. 7a with 7b, we noticed that both material configurations exhibit a same velocity weakening effect (which means the friction force decreases with the increasing of the velocity). While for the lubricated cases between Fig. 7c and 7d, situations are getting changed. With the increasing of the velocity the steel/plastic configuration (Fig. 7c) first decreases and after reaching a minimum value, it builds up (observed as well by Muraki in [7]). For steel/nylon configuration (Fig. 7d), it presents a velocity strengthening effect, showing that the property of velocity dependent friction is subjected to not only the material combination, but the lubricating conditions; (3) even for the same friction material configuration, the changing trends on the coefficient of friction under different lubrication conditions are also difficult to identify. For steel/nylon configuration (Fig. 7b and Fig. 7d), the changing trends are opposite to each other (velocity weakening versus velocity strengthening). For steel/plastic configuration, it is more complicated (Fig. 7a and 7c).

Except for the influence of the friction materials and lubrication conditions, the duration of friction affects the test results as well. In the test we found that the friction force increased automatically in a few hours since the starting of the friction without changing any other parameters. One possible reason for this kind of gradually increasing phenomenon on friction force may be originated from the micro crumbs created in the contact surface during the friction, which alters the state of the two surfaces in contact and finally changed the behavior of the friction force. The research on the quantitative analysis on the influence of the time variance is rarely reported in the literature by now and it is out the scope of the current paper. In order to reduce the influence of the time variance on friction to the minimum, we cleaned the contact surface carefully with the acetone since the beginning of each test and keep the running time of each test as short as possible. In a word, the frictional materials, lubrications and time variance have dramatic influences on the determination of friction characteristics, and the influences of these parameters are coupled deeply, which are not easy to be separated from each other. From the current literatures there is no single friction model which could consider all these factors in one equation which lead to this an open topic and is need to be developed.

4. Conclusions and future works

With the persisting demands on a more comfortable riding quality on elevator systems, the characteristics of the friction of the rails and slide guide are of very importance which needs people’s concentration. Motivated by this aim, this paper examined the properties of the friction contact between the interface of the slide guide and rail of elevator systems through experimental endeavors. Under different input combinations of parameters (amplitudes, frequencies, normal loads, materials in contact and lubrications, etc.), some phenomena related to friction are observed, including (i) the existence of pre-sliding and gross sliding regimes and their transferring behavior between each other, (ii) friction dependence on velocity (weakening and strengthening effect), (iii) time lag, and (iv) frictional overshoot. Moreover, the characteristics of frictional dependence on materials, lubrications and durations were discussed as well. The test has proven to be a good approach to investigate friction behaviors. The observations of the test provide an insight into relationships between different friction
behaviors and can be used to validate the proposed friction models which will be the future subject of works.

**Acknowledgment**

The authors gratefully acknowledge the support from National Nature and Science Foundation of China (No. 10502032) and program of Introducing Talents of Discipline to Universities (No.B06012).

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