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CHAIN FAULT DETECTION OF ESCALATOR USING HANDRAIL VIBRATION

Hiroyuki Tsutada[1], Takashi Hirai [1], Yutaka Itoh[2] and Satoshi Shiga[2]

[1]Advanced Technology R&D Center, Mitsubishi Electric Corporation
Tsukaguchi-Honmachi, Amagasaki, Hyogo, 661-8661, Japan
[2]Mitsubishi Electric Building Techno-Service Co., LTD.
Hishimachi, Inazawa, Aichi, 492-8161, Japan
Tsutada.Hiroyuki@ak.MitsubishiElectric.co.jp (email address of lead author or presenter)

Abstract

This paper proposes a new method of chain tension fault detection for escalators. In the conventional method, the handrail chain tension was checked manually by overhauling the escalator. However, the proposed method can detect the loose tension in the chain automatically using an accelerometer attached to the handrail without overhauling the escalator, which is effective for maintenance. First, the transitional pattern of the handrail vibration when starting up the escalator in the reverse direction was studied. The first pattern involves more high frequency vibration generated by starting up the upper sprocket, and the second pattern involves more low frequency vibration generated by starting up the handrail. When tension of the chain that transmits the rotational power of the upper sprocket to the handrail is loose, the time delay between the first pattern and the second patterns, called the “start up delay time”, is increased, because the power transmission from the upper sprocket to the handrail is delayed. Therefore, the loose tension of the chain can be detected by the start up delay time. Based on these characteristics, this paper proposes a method of detecting the start up delay time automatically using signal processing techniques. A chain fault detection system including a single axis accelerometer, a data logger and a wireless communication device was produced, and system tests were conducted to evaluate the performance for several loose tension conditions using real escalators. The test results showed that the start up delay time increased in proportion to the looseness of the chain tension. Therefore, it is possible to detect chain tension faults using the proposed method.

1. INTRODUCTION

Service quality and reliability have become more and more important in escalators, and customers require effective maintenance work with the minimum stoppage time for escalators [1]. Recent studies have suggested a method of evaluating the condition of escalators using sensors and optimizing the maintenance work based on the quantitative condition [2]. In this paper, we present a new method of chain fault detection for escalators.

In the conventional method of escalator maintenance, the tension of the handrail chain was checked every month [3]. This work requires overhauling the escalator manually, which takes about 30 minutes. On the other hand, the proposed method can detect loose chain tension automatically using acceleration sensors on the handrail when starting up. This method minimizes the maintenance time compared to the former method, because it estimates the tension level of the chain without overhauling the escalator.

First, an overview of the target system and analysis results of the handrail chain behavior when starting up escalator are described in Section 2. It is also proposed that the "start up delay time" is a key factor in this research. Next, the calculation method of the start up delay time using the handrail acceleration is described in Section 3. Finally, the experimental results showing whether it is possible to perform fault detection based on the start up delay time calculated by the proposed system are given in Section 4.

2. CHAIN BEHAVIOR WHEN STARTING UP ESCALATOR

2.1 Overview of Target System

An overview of the handrail driving unit is shown in Figure 1.

When starting up the drive unit, the upper sprocket starts to rotate and the drive chain begins to circulated. The step chain and the first handrail chain wind around the upper sprocket. So, when the upper sprocket begins to rotate, the step chain with the movement of the step, and the first handrail chain with the rotation of the handrail drive main axle begin to circulate. The second handrail chains wind around the handrail drive main axle. So, when the main axle starts to rotate, the second handrail chains circulate with the rotation of the handrail drive roller. The rotation of the roller makes the handrail move because the roller is pressed against the handrail. Though only one side of the second handrail chain is illustrated in Figure 1, the second handrail chains are attached on both sides around the main axle in real escalators.

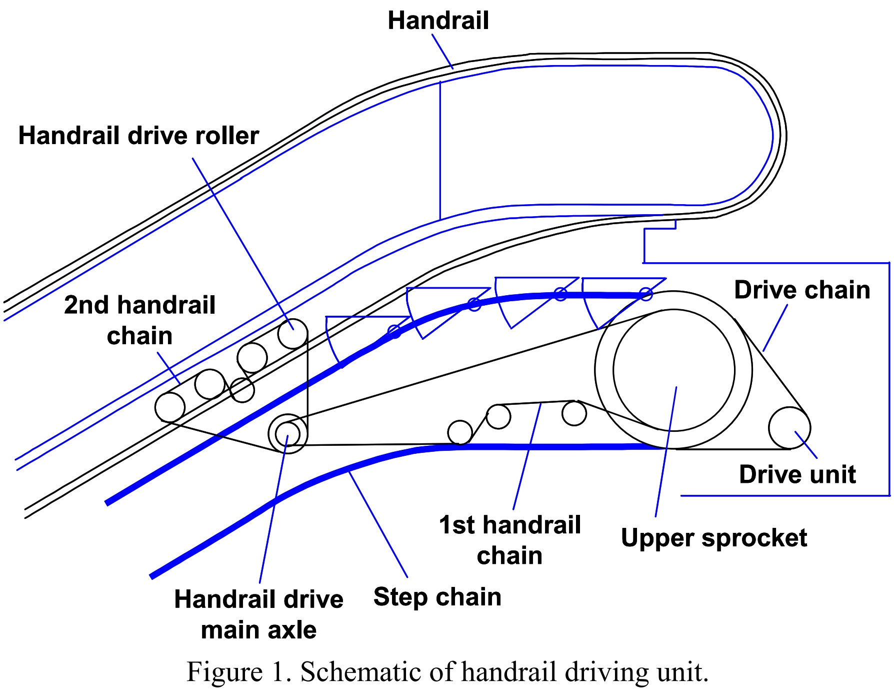

Figure 1. Schematic of handrail driving unit.

By the way, an extremely handrail chain tension is a serious fault, causing, for example, an abnormal sound generated by the chain touching the truss, extreme abrasion of the sprocket, jumping and cutting of the chain, and stopping the handrail. It is therefore important that the signs of loose handrail chain tension are detected during maintenance work. The purpose of this study is to detect the loose tension of the handrail chain without overhauling the escalator.

2.2 Start Up Delay Time

In this section, the chain behavior when starting up the escalator is investigated and the start up delay time is defined. The behavior when the first handrail chain tension is loose is shown in Figure 2.

When the escalator operates downward, state (1) in Figure 2, the first handrail chain circulates with loose tension on the upper side. After the operation is stopped, state (2) in Figure 2, the chain keeps the loose tension on the upper side. When the escalator operates in the reverse direction, in other words upward, state (3) in Figure 2, the upper sprocket starts to rotate, and the loose tension on the upper side in the first handrail chain is first wound in. While the loose chain is winding, the handrail drive main axle and the handrail are stopped. After the loose chain is completely wound in, the main axle and the movement of the handrail starts to rotate, state (4) in Figure 2.

The start up time difference between the upper sprocket and the handrail in the reverse operation defined as the "start up delay time". It is estimated that the start up delay time is increased as the chain tension is looser. So it is possible to detect the loose tension of the handrail chain if the start up delay time can be measured numerically.

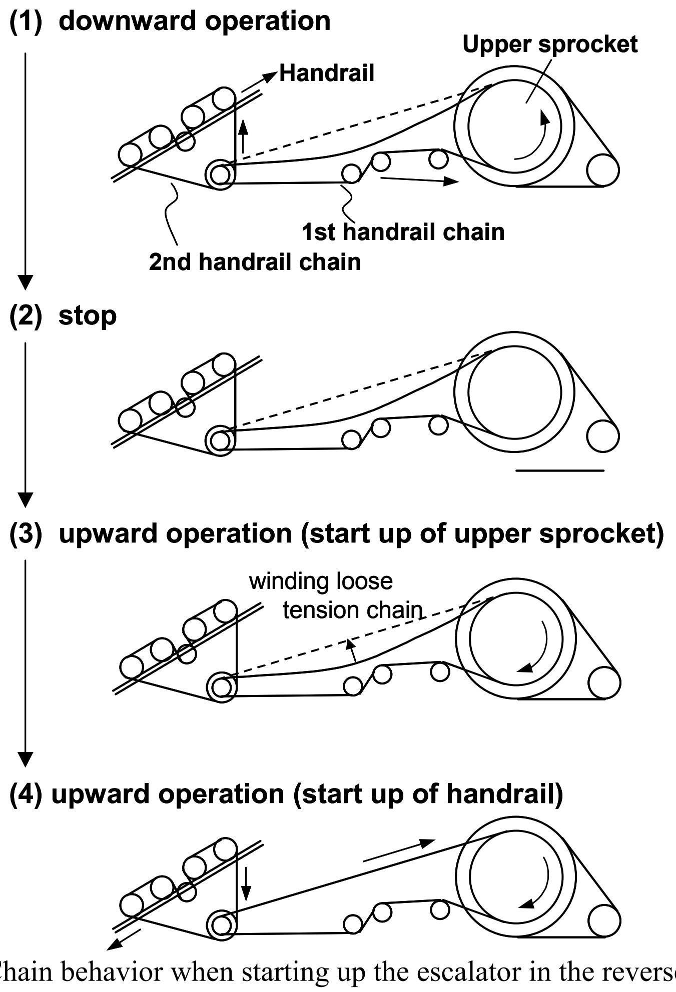

Figure 2. Chain behavior when starting up the escalator in the reverse direction.

3. CALCULATION OF START UP DELAY TIME USING HANDRAIL ACCELERATION

In this section, a method of calculating the start up delay time using the acceleration on the handrail is proposed.

3.1 System Configuration

The configuration of the chain fault detection system is shown in Figure 3. The system includes a data logger that measures acceleration on the handrail, a receiver that receives the measured data from the data logger and a PC that evaluates the measured data. The data logger consists of a single axis acceleration sensor, a main board including a signal acquisition and recording function, a wireless communication module, a 2.4 GHz antenna, and a battery. The sensor is attached so as to measure the acceleration towards the direction of movement of the handrail. The amplitude range of the sensor is from -1.7 G to +1.7 G, and the frequency range is from DC to 2.5 kHz. A CR filter whose cutoff frequency is 100 Hz is inserted in the input channel, and the sensor data is acquired at 1k sample/sec. The inspection time including attaching and removing the data logger is only a few minutes, because the data logger has the attachments that are easy to install on the handrail.

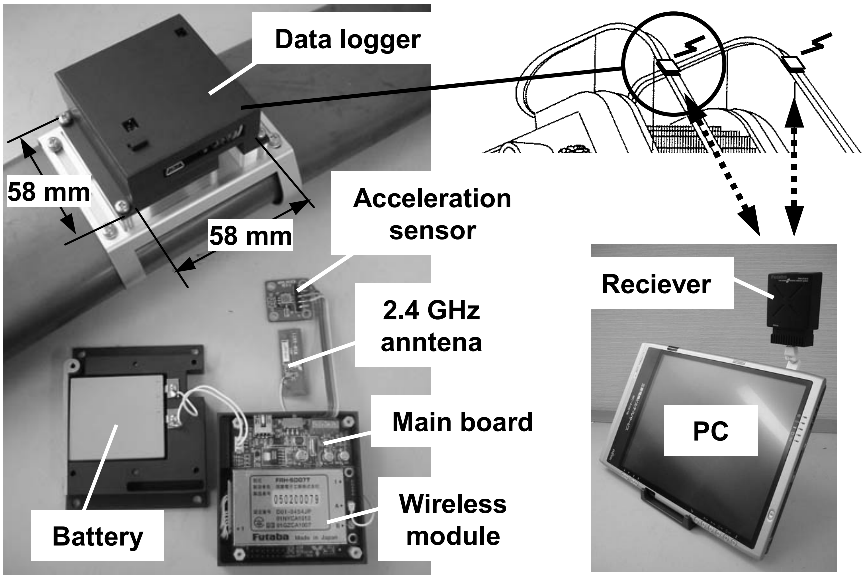

Figure 3. System configuration of the chain fault detection system.

3.2 Calculation Method of Start Up Delay Time

An example of the signals measuring the acceleration on the handrail during the reverse operation is shown in Figure 4.

It was found that the measured signals have two types of transitional vibration pattern. The first vibration pattern occurring from t_1 is a small vibration whose amplitude is about 20 mG, and involves more high frequency components ranging from 20 Hz to 100 Hz. It is considered that this vibration pattern is generated by the circulation of the step chain with the movement of the steps.

On the other hand, the second pattern which occurring from t_2 is a comparatively large vibration whose amplitude is over 100 mG, and involves more low frequency components ranging from DC to 20 Hz. It is considered that this vibration pattern is generated by the movement of the handrail, and indicates the acceleration of the handrail itself. The frequency component of the second pattern is lower than that of the first pattern because the main material of the handrail is rubber, and the high frequency components are damped.

As a result of comparison with the real start up behavior of a handrail driving unit and the acceleration signal using a video camera and several sensors, it was found that t_1 is the start up time of the upper sprocket, and t_2 is the start up time of the handrail. Therefore, it is confirmed that the acceleration signal on the handrail includes information about the start up delay time.

Next, the signal processing method of detecting t_1 and t_2 automatically, and the method of calculating the start up delay time using the acceleration signal are described.

To detect t_1, the dc offset of the acquired acceleration signal is removed, and the high frequency noise of the signal is also removed using a digital low-pass filter whose cutoff frequency is set to 100 Hz [4]. Then t_1 is determined as the instant when the filtered signal exceeds the threshold based on the amplitude of the signal in the stationary state.

To detect t_2, the velocity of the handrail is calculated by integrating the acquired acceleration signal. Then t_2 is determined as the instant when the velocity exceeds the threshold, which is set to 1% of the constant velocity. Determining the threshold using the acceleration of the handrail is difficult because the maximum amplitude of acceleration depends on the loose tension level of the chain, the installed condition of the escalator, and so on. On the other hand, determining the threshold using the velocity of the handrail is easy because the maximum velocity of the handrail is a constant value. Therefore, it is possible to detect the instant t_2 becomes stable using the velocity of the handrail.

Finally, the start up delay time is calculated from $(t_2 - t_1)$.

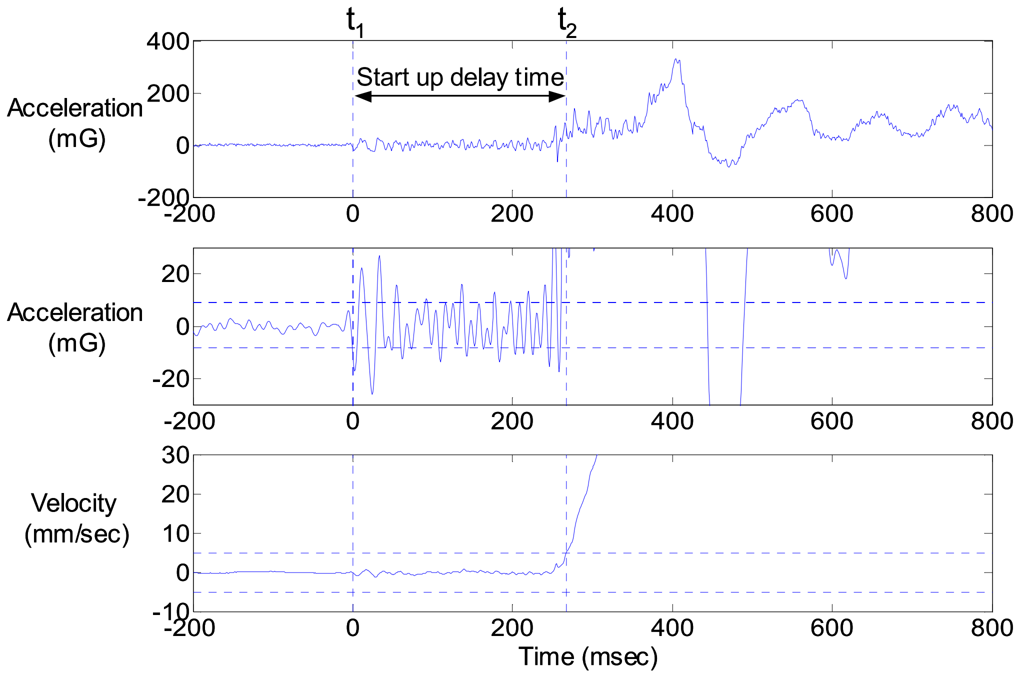

Figure 4. Sample data measured from escalator.

4. FAULT DETECTION TEST

In this section, experiments using real escalators examine whether it is possible to detect the loose tension of the handrail chain based on the start up delay time calculated by the proposed system.

4.1 Experimental Setup

The acceleration signals of the right and left handrails were acquired using the system shown in Figure 3. The start up delay times of the right and left handrails were calculated using the acceleration signals in a downward operation after an upward operation. The data logger was positioned on the handrails around the upper side of the handrail drive roller when starting the down operation.

The experiments were conducted using two cases. In Case (a) the tension of the first handrail chain was varied, and in Case (b) the tension of the second right handrail chain was varied. The level of tension of the chain was adjusted by changing the alignment bolt of the chain tension, and was measured as the maximum swing width of the chain by a gauge. The start up delay times were measured three times for each condition.

4.2 Results

Examples of the measured acceleration signals on the handrail for normal tension and loose tension are shown in Figure 5. The maximum swing width of the second handrail chain in the upper graph is 23 mm (normal tension), and the width in the lower graph is 95 mm (loose tension). Calculation results of the start up delay time are superimposed on the graph. It is confirmed that the calculated start up delay time increases when the tension of the chain is decreased.

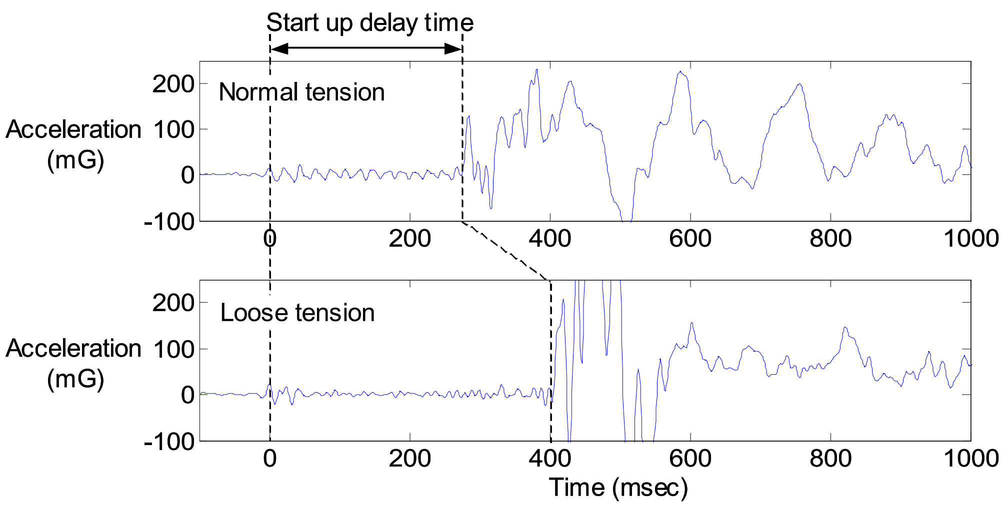

Figure 5. Comparison of measured signal for normal and loose tensions.

Next, the variation in the start up delay time caused by changing the tension level is plotted in Figure 6. The plot points indicate the average value of the start up delay time for each condition.

Figure 6(a) indicates the results when changing the tension level of the first handrail chain. The results show that the calculated start up delay time of the right and left handrails is in proportion to the maximum swing width of the first handrail chain. Based on this result, it is confirmed that it is possible to detect the loose tension of the first handrail chain using the calculated start up delay time.

Figure 6(b) indicates the results when changing the tension level of the second right handrail chain. The result show that the calculated start up delay time of the right handrail is in proportion to the maximum swing width of the second right handrail chain. Based on this result, it is also confirmed that it is possible to detect the loose tension of the second handrail chain using the calculated start up delay time.

Moreover, these graphs show that both sides of the start up delay time are increased when the tension of the first chain is loose, and that one side of the start up delay time is increased when the tension of the second chain is loose. These results show that it is possible to estimate a faulty chain position.

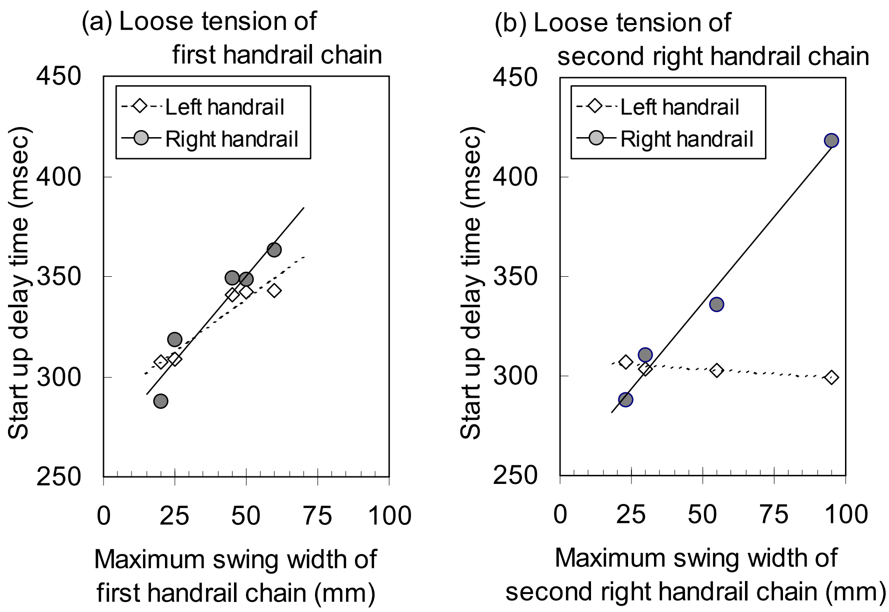

Figure 6. Variation of start up delay time by changing the tension of the first and second handrail chains.

5. CONCLUSIONS

This paper has presented a method of detecting the loose tension of handrail chains by calculating the start up delay time using the acceleration on the handrail when starting the reverse operation of an escalator. The results of the system tests indicated that the system can detect the tension level of the first and second handrail chains without overhauling the escalator. This system can reduce the maintenance work time to 10% compared to the former method.

In the future, field tests will be conducted to acquire data from various types of escalator, and the effectiveness of this system will be verified using statistical analysis.

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