Research on a general approach to the balance coefficient of unloaded elevator

Xiaozhou Tang, Guoqing Pan*, Shu Chen, Dongdong Hu, Yu Wang and Huipin Lin
Hangzhou Special Equipment Inspection and Research Institute, Hangzhou, Zhejiang, China

*Corresponding author: gq.guoqing.pan@gmail.com

Abstract. The traction machine can suffer a motor power loss due to friction. Therefore the influence of the frictional force cannot be ignored in the measurement of the elevator balance coefficient. To overcome the shortcomings of the current method, a new general way of measuring the balance coefficient has undergone studies by following the definition of balance coefficient, and the fact that static friction is always against movement tendency. Here the feasibility of the method is demonstrated.

1. System principle
The counterweight is the component that balances the mass of the car in a traction system, the weight of which is:

\[ W = P + K \times Q \]  \hspace{1cm} (1)

where \( P \) is the mass of the car, \( Q \) is the mass of the load, and \( K \) is the balance coefficient. Therefore, the balance coefficient \( K \) is:

\[ K = \frac{(W-P)}{Q} \]  \hspace{1cm} (2)

Theoretically, as long as the difference between masses of the counterweight and the unloaded car is known, the balance coefficient can be inferred. While in reality, it is not practical to measure the masses. Besides, the frictions that come from gearbox or rails can lead to inaccurate measurements [1]. Here a new method to measure the balance coefficient is proposed, which considers frictions. As shown in figure 1, the core measurement parts beneath the counterweight consist of a pressure sensor and a jack [2-4].
a. Counterweight lifting measurement  

b. Counterweight lowering measurement

**Figure 1.** Measurement principle diagram of universal unload elevator balance coefficient test system

While the counterweight is moving up and down with a constant speed, the pressure sensor can measure weights that are necessary for a complete measurement [6]. From the mechanical analysis, weights measured by the sensor can be inferred as [7]:

\[
C_1 = W \cdot g - P \cdot g + f \tag{3}
\]

\[
C_2 = W \cdot g - P \cdot g - f \tag{4}
\]

Where \(W\) is the mass of counterweight, \(P\) is the mass of the car, and \(f\) is the friction. Because the elevator system is a fixed complete set of equipment, the absolute value of the frictional force \(f\) does not change whether the car goes up or down. The difference \(C\) between masses of the counterweight and the unloaded car is then inferred as:

\[
C = \frac{C_1 + C_2}{2} \tag{5}
\]

According to Formula 2 and Formula 5, the value of the balance coefficient \(K\) can be calculated.

2. **Overall architecture of the balance coefficient measurement system**

The measuring system consists of both hardware and software. The hardware handles movement, data collection, and communication. A removable power supply and other auxiliary devices are attached to guarantee that the system functions. While the software, installed on a host computer, is mainly responsible for the human-computer interaction and data processing. See Figure 2 for more information about sub-modules.

**Figure 2.** Overall architecture of the system
3. Construction of balance coefficient measurement system

3.1. Pressure Sensor
The pressure sensor (Figure 3) collects the weight difference between the counterweight and the car. Resistance strain sensor has the advantages of small size, small weight, excellent dynamic characteristics, high accuracy, and high sensitivity, thus making it suitable for all kinds of scenarios. A resistance strain sensor works as the data acquisition device in the test system. For a system where there is a passenger elevator weighted between 630kg and 2000kg, the maximum weight difference between the car and the counterweight is around 1000kg. As a result, the resistance strain sensor used in the prototype of the measuring system has a range of 0-2000kg. Considering that the rigid collision between the counterweight and the sensor may be harmful to the reliability of the whole system, dampers are there for protection.

3.2. Motion device
According to the system design, the motion device has to lift and lower the counterweight and pressure sensor at a constant speed. The prototype utilizes a double-acting hydraulic oil pump as the motion device which works like a jack. The pump, model number YBC80L4 (Figure 3), has features such as two-way oil supply, 15ml/s output flow, 35mm cylinder radius, and 52s full-running time. It can collect the required data within 30 seconds.

3.3. Main control unit and data acquisition and processing
The central control unit adopts the STC89C52RC single-chip microcomputer (MCS51 architecture) developed by Taiwan Acer Technology (Figure 3). This single-chip microcomputer has features such as fast speed, low power consumption, excellent stability, and high environment adaptability. Designed with a maximum frequency of 80Mhz, 8k bytes of memory space, and an integrated 512-byte random access register, the unit can control the motion of the jack by controlling the oil supply to the pump.

The voltage level of the microcontroller serial port is different from that of the host computer. The high level of the TTL level output of the microcontroller is higher than 2.4V, the low level of the output is less than 0.4V. In contrary, computer's RS-232 logic 1 is ranged from -3V to -15V, while logic 0 is ranged from +3V to +15V. Therefore, a conversion chip with model SP3232EEN (Figure 3) works as a conversion device.

The pressure sensor C8051F350 (Figure 3) fully integrates the microcontroller of the single-chip composite signal system. With 21-bit 8-channel ADC and 8-bit 2-channel DAC, combined with high-precision analog data converter and a high-throughput 8051 CPU, it is ideal for analog and calculation-intensive applications. C8051F350 has a fully differential 24-bit analog-to-digital converter. Thus it is used to handle analog number conversions.
3.4. Design of error correction module and human-computer interaction software

The position of measurements is where the counterweight reaches the lowest. At this point, masses of the wire rope, compensation chain, and the cable rack surely contribute to the system error of measurements, which can be described as

\[ C' = n \ast (n_1 \ast m_1 \ast H - n_2 \ast m_2 \ast H - n_3 \ast m_3 \ast \frac{H}{2}) \]  

(6)

where \( n \) is the traction ratio, \( n_1 \) is the number of suspension devices, \( m_1 \) is the mass of the unit suspension device, \( H \) is the lifting height, \( n_2 \) is the number of compensation devices, \( m_2 \) is the mass of compensation devices, \( n_3 \) is the number of traveling cables, and \( m_3 \) is the quality of accompanying cables.

As shown in Figure 4, the human-computer interaction software designed for Windows OS is based on Microsoft .Net Framework with C#, the backend of which is an SQLite database. Before measurements, the initialization requires descriptions about the elevator and values used for error correction. In case of drifting, zero values are necessary. Collected data is transmitted to the host computer through a wireless USB network adapter. The software also handles printing after completed measurements. For batch view, measured data can be exported and saved to local disk.
4. Experimental results
With 800kg related load, 1.0m/s moving speed, 6 meters lifting height, an elevator with a declared balance factor of 0.4 was measured with two methods.

![Diagram of elevator system software interaction design]

**Figure 4. System software interaction design**

With a standard weight of 25kg as the related load, the intersection point of up curve and down curve implies that the balance coefficient is 0.4292.

![Prototype of universal no-load elevator balance coefficient test]

**Figure 5. Prototype of universal no-load elevator balance coefficient test**
Figure 6. Balance factor current method

Figure 7. Measurement of the balance factor of a universal unloaded elevator

While as a comparison, five sets of test values obtained from the general no-load elevator balance coefficient measurements studied in this paper are shown in Table 1. The balance coefficient curve shown in Figure 7 is calculated based on equations 2 and 5. The average value, 0.4045, is the measured balance coefficient, which is very close to the declared value.

| Test number  | 1   | 2   | 3   | 4   | 5   | Average value |
|--------------|-----|-----|-----|-----|-----|---------------|
| Uplink       | 325.86 | 326.26 | 326.45 | 325.47 | 325.36 | 325.88 |
| Downward     | 321.21 | 320.22 | 322.22 | 321.81 | 321.56 | 321.40 |

In conclusion, the general method of measurement of the no-load elevator balance coefficient is feasible.
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