Study on a Fast and Accurate Control Loading Device

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Abstract. A fast accurate control loading device is studied, which is mainly used by the metrological department for calibration and verification of motor vehicle weighing instrument and overload system. By way of control algorithm and the servo motor that drives lifting mechanism, the device is employed to perform a fast and accurate calibration and verification of weighing equipments, such as motor vehicle axle (wheel) weighing instrument and curb weight tester, resulting in higher working efficiency and lesser labor intensity.

Keywords: Fast and accurate control; Loading device; Control.

1. Introduction

Weighing equipment (which is such as motor vehicle axle (wheel) weighing instrument, loading automobile brake tester, etc.) must be required in vehicle safety inspecting. These equipments shall be verified and calibrated once a year in accordance with the verification regulation or calibration specification, the validity period is one year.

During the verification and calibration, the inspector need to install the loading portal frame on weighing equipment at the scene, and loads on the weighing machine body by mechanical jack, checks its accuracy. For example, according to the verification regulation JIG 1014-2006 special axle (wheel) load scale for motor vehicle test, “During verification, it shall be ensured that the pressure ACTS vertically through the axis of the force sensor on the load carrier of motor vehicle weighing instrument under test. Weighing points are generally not less than three, including 10% maximum weighing points, 50% maximum weighing points (or common weighing points) and maximum weighing points (or close to maximum weighing points)”, the loading points of motor vehicle weighing instrument are four (include 0,10%, 50%, 100%), the inspector loads and records the data at each point, and calculates the error of indication, and determines whether performance requirements are met. It can be seen that multiple points within the full range need to be verified. Current verification and calibration methods have these problems. First, they are inefficient, loading and data recording depends on manual, the whole process is time-consuming. Second, the labor intensity is large, the inspector need to manually loads to the maximum load of 25t; thirdly, the accuracy of the data is poor, during manual loading, it is not easy to keep the data on the weighing point that needs to be loaded, and there are operational errors in the recorded data.
1. loading portal frame 2- loading device 3- motor vehicle axle (wheel) weighing instrument

Figure 1. Calibration diagram.

Therefore, it is necessary to study a device that can load quickly and accurately and record loading data automatically, so as to improve verification efficiency and reduce labor intensity.

2. Development of Loading Device

The loading device consists of mechanical part, electronic control part and software system, as shown in figure 2. The mechanical part is the executive part of the device that is responsible for loading, load reduction, stop and other actions in accordance with the instructions. The electronic control part plays the role of connecting link between the preceding and the following, converting the analog signal of the sensor into digital signal and uploading it to the software system, the instructions of the software system are converted into executable instructions and executed. The software system is a human-computer interaction system, which can be converted into executable instructions of the system, and monitored whether the execution is in place.

2.1. Mechanical Part

The mechanical part includes force sensor, lifting mechanism, planetary gear reducer, servo motor, etc., as shown in figure 3. The servo motor is powered by AC220V, with a maximum speed of 3000RPM, and is connected to the planetary gear reducer with a speed ratio of 1:40 to improve the transmission torque. Lifting mechanism includes leading screw, feather key, guide sleeve, screw nut, gear transmission mechanism, body, etc. The gear transmission mechanism is a straight-tooth transmission mechanism with a transmission ratio of 1:2. The pinion is installed on the output shaft of the planetary gear reducer, and the large gear is connected with the leading screw. The gear transmission mechanism and the planetary gear reducer constitute two stages of deceleration to increase the output torque. The leading screw is sawtooth thread, and converts rotary movement to linear lifting movement, the sawtooth thread is a kind of commonly used thread that transfer axial force, which has the advantages of large transmission force and self-locking. The leading screw adopts 45 # material that has a certain strength and toughness after quenching and tempering. The screw nut adopts cast tin bronze ZCuSn10P1, which has good gluing resistance and abrasion resistance, and has low friction coefficient with steel screw. The screw nut and the guide sleeve are fixed as one. There is a guide groove on the guide sleeve, and a feather key is installed on the body. Both of them enable the guide sleeve to move up and down. A
The force sensor is installed above the guide sleeve, which can be removed when the loading device is transported to prevent sensor damage. The force sensor is a high-precision sensor with a measuring range of 25T and a precision of C3. It can meet requirements of the metrological department verification and calibration.

The strength and life of all mechanical parts have been calculated to meet the service requirements, and the total weight of the whole mechanical part (excluding the force sensor) is 20kg, which can be used as the weight.

2.2. Electronic Control Part

The electronic control part includes control box, limit sensor and various cables. The control box is equipped with servo driver, power supply, digital module, touch screen, power switch and various line ports, as shown in figure 4.

The servo driver has three control modes: position, speed and torque. The device adopts position control mode in lifting height control and speed control mode in load control. The power supply of the servo system is AC220V, and the servo system is controlled by the host computer (touch screen) with RS485 communication. Power supply provides dc power for digital module, limit sensor, servo driver and touch screen. The digital module converts the sensor analog signal into a digital signal and uploads it to the host computer (touch screen) with RS485, the digital module has a 24-bit acquisition accuracy and a sampling frequency of 100Hz, which meets the requirements of accuracy and control. The limit sensor is installed in the limit position of the lifting mechanism to protect it from damage which caused by overtravel of the screw nut and leading screw. The electrical structure is shown in figure 5.
prevent space interference, a shielding case is designed on the digital module, the circuit carefully designs power isolation and signal conditioning, these effectively prevent internal and external interference, and ensure the normal operation of the system.

![Figure 5. Electrical control structure.](image)

2.3. **Software System**

The software part is the core of the loading device, including various operational interfaces, signal acquisition and control algorithms, the operation interface includes the main interface, calibration, parameter setting and other interfaces.

As shown in figure 6, the main interface can be used for manual and intelligent control of lifting height and loading force. When lifting height is intelligently controlled, the inspector inputs the height in the target height box, the system automatically reaches the preset position according to the current height. During load control, the inspector inputs the load in the target load box, or sets the total load, the system loads the specified load value in turn according to the percentage of the total load in the "preset" menu (as shown in figure 7) without manual intervention. During the loading process, the inspector records or the system automatically records the load value when the value of the loading point is stable, so as to verify the performance of the verified equipment. It is worth noting that in the whole loading process, there can be no load reduction phenomenon, similarly, in the process of load reduction, there can be no loading phenomenon. When the inspector needs manual control, click the "fine adjustment" and "coarse adjustment" button in the manual control bar to increase or decrease the load or lifting height.

Parameters such as sensor measuring range and device protection limit can be set in the parameter setting interface, and the system will run according to the set parameters. In the calibration interface, the load can be calibrated to ensure the accuracy of the load displayed by the device.
Signal acquisition algorithm and control algorithm are the core of the software system. It is necessary to design various algorithms to achieve fast and accurate control. The purpose of the signal acquisition algorithm is to process the true and the false through the algorithm, that is, to retain the real signal and filter out the interference signal. This loading device adopts the least square method for analog signal processing, and the system collects data at a frequency of 100Hz, that is, one data is collected every 10ms, considering the power supply frequency of 50Hz, every four data is treated as a group according to the least square method as shown in figure 9, so as to obtain the real data.

The main purpose of the control algorithm is to ensure that the loading device reaches the target value quickly and accurately according to the current load and lifting height. When the lifting height is controlled, the servo motor is in the position control mode. The host computer calculates the distance to be run according to the difference between the current height and the target height, which are converted into the pulse value recognized by the servo system. The host computer sends out the operation instructions and pulse number. The servo system which is a set of feedback control system, feedbacks the current position in real-time during operation, and reaches the target value quickly and accurately according to the control instructions. When the load is controlled, the servo motor is in the speed control mode. The loading device should be quickly and accurately controlled to reach the target value. The developer needs to consider a variety of influencing factors. In the design, the developer integrated the influence of external loading portal frame strength on control accuracy, and carefully
designed the loading and unloading strategy. In the initial stage of loading, there is an empty stroke. The loading device should run quickly to the loading point, so as to save loading time. When the real-time load value changes, in order to accurately control the target value, the load is controlled in sections, and different load change rate \( k \) (load change per unit time) is set for each section. At the beginning of the load control, the \( k \) value is set to a larger value, and the servo motor is set to a higher speed. The loading device can run quickly and reach the load change point. In the process of the real-time load value approaching the target load value, the \( k \) value decreases in turn, and the servo motor speed decreases in turn, the purpose is to prevent beyond the target load value. In the last stage of control, system setting: \( k = 1 \text{ kg/S} \), servo motor speed: \( " n = 2 \text{ RPM}" \), the servo motor running at low speed, gradually close and stop to the target load, in this way, the system can accurately control lifting height and load quickly. Load change rate \( k \) is shown in Table 1.

| Loading section, kg | Load change rate(k), kg/s | \( k \) permissible error,\% | Servo speed, rpm |
|---------------------|---------------------------|---------------------------|---------------|
| current load < 0    | -                         | -                         | 3000          |
| current load ≥ 10–(target load-2000) | 1400 | 5 | 1500 |
| (target load-2000)–(target load-800) | 400 | 5 | 500 |
| (target load-800)–(target load-200) | 100 | 5 | 100 |
| (target load-200)–(target load-50) | 20 | 5 | 50 |
| (target load-50)–(target load-20) | 4 | 5 | 10 |
| (target load-20)–(target load-10) | 3 | 5 | 4 |
| (target load-10)–(target load-5) | 2 | 5 | 3 |
| (target load-5)–target load | 1 | 5 | 2 |

3. Testing and Validation
After the completion of the loading device, a large number of tests, including intensity difference loading portal frame loading test, external disturbance test, power adaptability test, environment temperature and humidity test, etc, are conducted. Through the analysis of multiple groups of test data, the control error is calculated, and the range method is used to calculate the repeatability, the load control error is not more than 0.2kg, and the repeatability is not more than 0.1kg. The control time from start to finish is not more than 40s, the loading device reached the development requirements. The reliability and accuracy of the device are verified by experiments. Compared with mechanical loading device, the efficiency of the whole system is increased by 50% and labor intensity is greatly reduced.

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