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THE STUDY OF THE 1MN LEVER-AMPLIFIED FORCE STANDARD MACHINE WITH TRAVELING WEIGHT AND DOUBLE LEVERS

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Abstract: The paper described the study of the traveling weight, double levers force standard machine, which the maximum load is 1MN. First, the double levers system keep the main lever balance when the displacement of the traveling weight is zero; second, traveling weight is driven by the coordination of some components: ball screws, beam for loading. Displacement transducer and semi-closed loop control are applied to monitor and control the movement of traveling weight and main lever. The machine can apply load according to the displacement of the traveling weight, which is different from deadweight stack with individual mass disk. The experiment data are analysis, and the machine had the advantages of wide measurement range, higher control precision, higher accuracy and better efficiency.

Keywords: force, force standard machine, lever, traveling weight.

1. INTRODUCTION

The lever-amplified force standard machine (in short, LM) is a kind of standard machines, which scale up the gravity of the standard weight as load cell. One way to amplify is the single lever, which has fixed lever amplification-ratio, and a deadweight stack with individual mass disk. The capacity of the kind of machine depends on the ratio and the combination forms of the disk. The mechanism of deadweight stack is complicated and expensive; there is a new kind of mechanism, which the lever amplification-ratio is variable, such as 25 kN jockey-weight force calibration machine of GTM [1, 2].

2. MECHANICAL PRINCIPLE

The 1MN LM introduce some new techniques: the first, traveling weight mechanism realize the variable force arm; the 2nd, double levers mechanism keep main lever initial balance; the 3rd, precise screw drive take close control on the movement of the traveling weight and hence the amplification-ratio; the last, hydraulic drive system keep precise control on load cell. Fig.1 is the schematic diagram of mechanism.

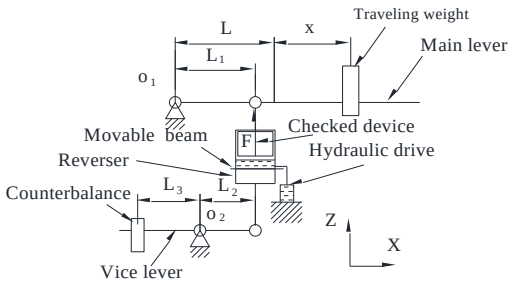

Fig.1 Schematic diagram of the system

In Fig.1, o_1 is the hinge point of the main lever; o_2 is the hinge point of the main lever.

The mechanism is simplified as: all members is rigid body and not considers the effect of deformation, Equations (1) and (2) describe the balanced system. In the balanced system, the sum of all moments is zero, so:

$$\sum M = (F - F_0) \cdot L_1 - Q_1 x = 0 \quad (1)$$

$$F_0 = Q_3 + (Q_1 L + M_1)/L_1 - (Q_2 L_3 - M_2)/L_2 \quad (2)$$

With:

Q_1: the result force of traveling weight (included gravity and air buoyancy) [N]

Q_2: the result force of counterbalance (included gravity and air buoyancy) [N]

Q_3: the result force of reverser (included gravity and air buoyancy) [N]

M_1: the result torque of the main lever (included air buoyancy) [N•m]

M_2: the result torque of the vice lever (included air buoyancy) [N•m]

F: the load of the checked device [N]

L: the force arm of the main lever [m]

L_1: the force arm of beam for loading on main lever [m]

L_2: the force arm of beam for loading on vice lever [m]

L_3: the force arm of counterbalance [m]

x: the displacement of traveling weight on main lever [m]

From equations (1) and (2), if the displacement of traveling weight on main lever is zero (x=0), the main lever keeps balance by counterbalance on vice lever, also known as the initial balance. When the main lever balance, the load of the checked device is the function of x:

$$F = Q_1 x / L_1 \quad (3)$$

3. CONSTRUCTION OF THE DEVICE

3.1 Basis of the design

Based on above mechanical principle, the 1MN LM system construct by some module, including mechanical construction, control module, hydraulic module, the HMI module and so on.

3.2 Mechanical Construction.

The mechanical construction of the 1MN LM system is shown as Fig.2 including the double lever mechanism, loading mechanism, and fixed framework etc.

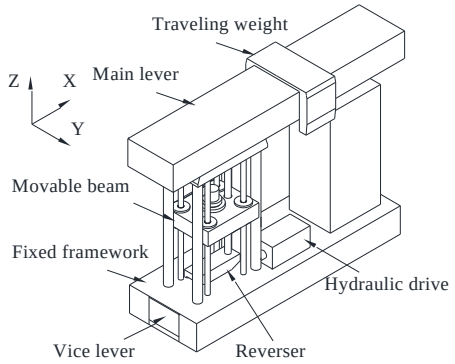

Fig.2 mechanical construction diagram

The fixed framework is the base of the LM, fixed on the base where surrounding layout shockproof ditch. The frame levelled precisely. The double lever mechanism includes the main lever and the vice lever; the hinge of the lever is knife-edge bearing. According to the equation (1) and (2), the function of the counterbalance is to keep the initial balance, and if the mass of the counterbalance is finished, the mass will not change unless the load of the lever system has been changed.

For a given LM, the result force of traveling weight (Q_1) and force arm(L_1) are constant, so the displacement of the traveling weight is the only important influence parameter, based on equation (3), which means that the displacement of the traveling weight deserve close attention.

The beam for loading is composed of the mover beam and the hydraulic drive. Fig.3 is the arrangement diagram of the beam for loading. At work, the movable beam translates along the ball screw until the checked device approach reverser. Then the locking devices are activated, the movable beam fixe on the ball screw. The hydraulic drive starts for precision loading. At work, tension device fixed under the movable beam and compression device above the beam

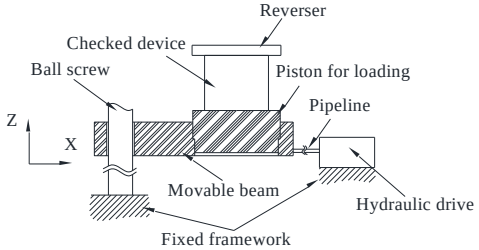

Fig.3 arrangement of the beam for loading

3.3 Control System.

The control system includes the motor control system, hydraulic system, Data Acquisition and Processing System (in short, DAPS). The target of the system is the balance of the main lever and the following parameters are under real-time monitor: displacement of the main lever, the movement of the traveling weight, the indicator of the checked device, the pressure and displacement of the hydraulic system etc.

LVDT（Linear Variable Differential Transformer）is applied to monitor the displacement of the main lever. Two ways are applied to keep the movement precision and smoothness: the first, high precision ball screws and rails; the second, semi-closed loop control based on high-precision resolver encoder. Equation (4) is the displacement resolution of the traveling weight:

$$\delta x = d / f(\alpha, i) \qquad (4)$$

With:

d: helical pitch of ball screws

$f(\alpha, i)$: transfer function of encoder's resolution and transmission ratio of motor-driven mechanism

The data capture card sum up the data and submit to PC programme. The programme analyse the system status and issue instruction to traveling weight drive and hydraulic drive, Fig.4 is the communication diagram, the arrows are the data transfer direction.

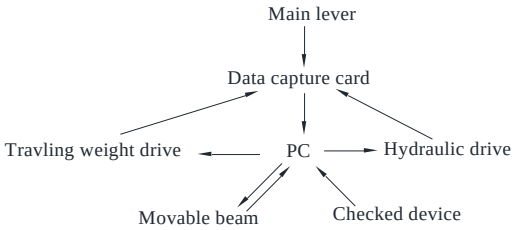

Fig.4 communication diagram

3.4 Software system

The software system is compatible with most of the amplifier for strain-gauge transducers in Chongqing region, such as Type 2000, Type 6000 and HBM DMP40. The soft use RS232/845 protocol and programme based on verification regulation of domestic related specifications [4]. Take account in the information level of the checked device, the system has some modes to improve efficiency: calibration mode, automatic mode, semi-auto mode, manual mode. When the system is under verification, the calibration mode is used. Under Automatic mode, the programme set the load, the load compute the position of the traveling weight, equation (3), then hydraulic drive module start to balance the main lever, at last the programme record the indicator of the checked device automatically. The different between the semi-auto mode and the auto-mode is that the data record manually under semi-auto mode. The manual mode apply the load, the balance of main lever and record the reading manually. The HMI have real-time display the working module and its correlated parameters. Fig.5 is the main interface.

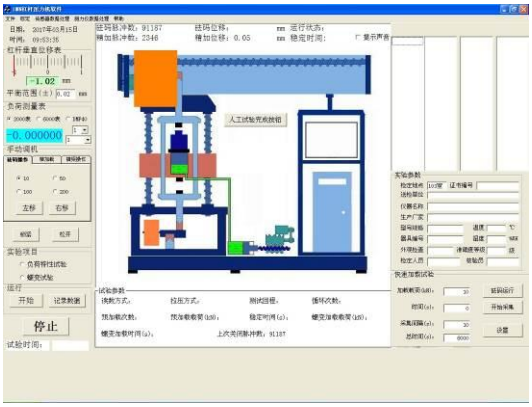

Fig.5 screenshot of HMI

4. MEASUREMENTS.

The 1MN LM, after assemble and debug, is as Fig.6.

Fig.6 1MN LM

The machine has passed the verification from National Institute of Measurement and Testing Technology, China (in short NT), from 2014 to 2015. The measurement standard used in the verification is Class 0.01 standard dynamometer (HBM C3H3-1MN), which can be traceable to China National Standards of Measurement. Since 2016, the machine had verified by local force measurement standard. The measurement standard used in the verification is the Class 0.01 standard dynamometer (HBM C4-1MN), which also can be traceable to China National Standards of Measurement. The ambient temperature is (23±1)℃, the relative humidity is (70±5)%. To minimize the uncertainty associated with the indicating instrument, HBM DMP40, was used in the tests, which passed calibration at NIT, from 2014 to 2016.

The standard dynamometer was placed at three symmetrically rotation positions relative to the axis of the piston for loading (0°, 120°, 240°). Prior to start of a measurement cycle, the standard dynamometer was loaded with max load three times at the 0° position, returning to zero after each maximum load application.

Fig.7 and Fig.8 show the comparison graphs of repeatability error and reproducibility error of 1MN standard dynamometer. As it seen in these figures, that repeatability and reproducibility errors are very close to each other measured by different standard dynamometer.

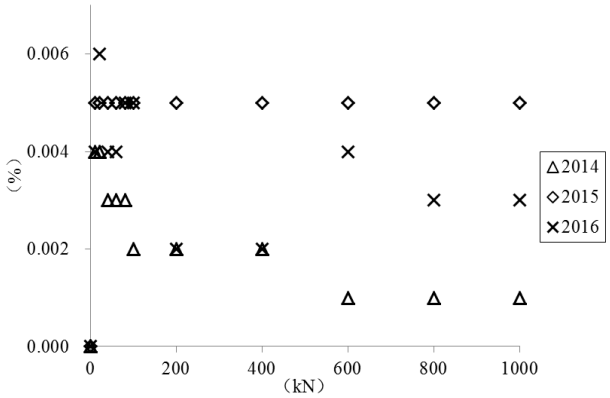

Fig.7 Force repeatability error

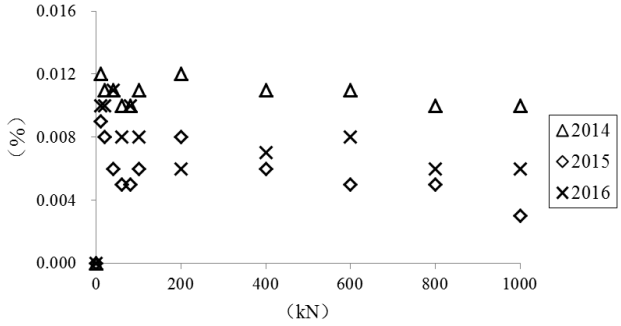

Fig.8 Force reproducibility error

5. CONCLUSION.

The repeatability error and reproducibility error measured by the NIT standard from 2014 to 2015, over a range of 0 N to 1MN was compared with the result measured by local standard. The results of comparison show that the agreement between NIT 1MN Class 0.01 standard dynamometer and local Class 0.01 standard dynamometer. Repeatability error of the LM is less than 0.005% and reproducibility error is less than 0.015% for over a range of 0 N to 1MN. Because of that, 1MN traveling weight, double levers force standard machine can be used as Class 0.02 measuring instrument according to JJG376-2001.

The systems realize the force calibration standards of NIT and Local department in the stated range. The newly designed and manufactured 1MN traveling weight, double levers force standard machine can give service to measurement traceability system, at Chongqing area.

ACKNOWLEDGMENTS

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