IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference
11 – 13 October 2022, Cavtat-Dubrovnik, Croatia

THE DEVELOPMENT OF DEADWEIGHT FORCE STANDARD MACHINE OF 500 kN WITH WEIGHT EXCHANGE CONTROL SYSTEM

Xu Yinjie[1], Tang Yun[2], Huang Weijun[3], Zhao Xinghua[4]

National Institute of Measurement and Testing Technology, Chengdu, China
[1] 8803676@qq.com, [2] 13880414879@163.com, [4] 1641164079@qq.com
GTM China Office, Shanghai, China, [3] william.huang@gtmchina.cn

Abstract:

Based on the "force standard machine weights exchange method and weights exchange device" patent technology, a deadweight force standard machine (DWM) of 500 kN was developed. Benefited by the weights exchange control system with eight weights and load frame, this machine can load/unload any load level equally with the minimum increment of 10 kN, in 10 kN to 500 kN range, and the load history curve is basically the same. Eliminating the counter-force phenomenon in traditional DWM, it meets the technical requirements of OIML R 60 international recommendations for loading equipment.

Keywords: deadweight force standard machine; weights exchange; counter-force phenomenon; weights exchange control system; weights exchange control method

1. INTRODUCTION

According to Newton's second law, DWM generated standard force by the gravity of a weight of known mass. Because of limited numbers of weights, DWM needs to generate the load level by different combinations of weights. The phenomenon, the load decreases in the increases loading process and the load increases in the decreases loading process, is called counter-force phenomenon. To eliminate this phenomenon, a DWM of 500 kN has been designed. And it is also applied by the "force standard machine weight exchange method and weight exchange device" patent technology [1]. This machine could generate any load level equally with the minimum increment of 10 kN, in 10 kN to 500 kN range, by the effect of eight sets of independent servo-closed-loop loading system work together, equipped under each weights. In all condition, loading increase or decrease progress, loading/unloading one or more pieces of weight, and whatever the weights exchanging or not, the loading history are all almost the same.

2. THE WORKING PRINCIPLE AND OPERATIONAL SOFTWARE OF 500 kN DEADWEIGHT FORCE STANDARD MACHINE

This DWM of 500 kN's schematic is shown in Figure 1, it has eight weights: 1 × 10 kN, 2 × 20 kN, 1 × 50 kN and 4 × 100 kN, from bottom up, and the load frame, having a nominal value of 10 kN. It has 510 kN nominal value totally, by the case of the load cell testing program, when the load frame as the minimum dead load, there is still 500 kN load value for use. Each weights equipped a set of servos loading system, could complete the weight loading/unloading in 25 s. At operating platform, the test space (tension and compression) can be adjusted by the movable crossbeam and cooperated by servo lifting device equipped on top beam, the calibration task can be completed automatically.

The test program could run automatically by the software, which developed by our software team, as showed in Figure 2. Classified by load cell and force transducer, the software provides two test programs, could run pre-load test, load test, creep test automatically according to the requirements of OIML R 60 [2], ISO 376 [3], ASTM E74 [4], JJG 144 etc., and recorded the absolute time by the requirement of OIML R 60 in load cell test program.

3. THE WEIGHTS EXCHANGE CONTROL SYSTEM AND CONTROL METHOD

3.1. The Weights Exchange Control System

With the purpose of the weight loading and unloading process controllable, we designed a set of servo-closed-loop loading system for each weight. Figure 3 shows one of three loading devices under each weight. The system was consisting of servo motor, lifting gear, monitoring sensor and spring instrument. The deformation of spring instrument extended the process that the load of each weight transferring between the loading frame and the loading system.

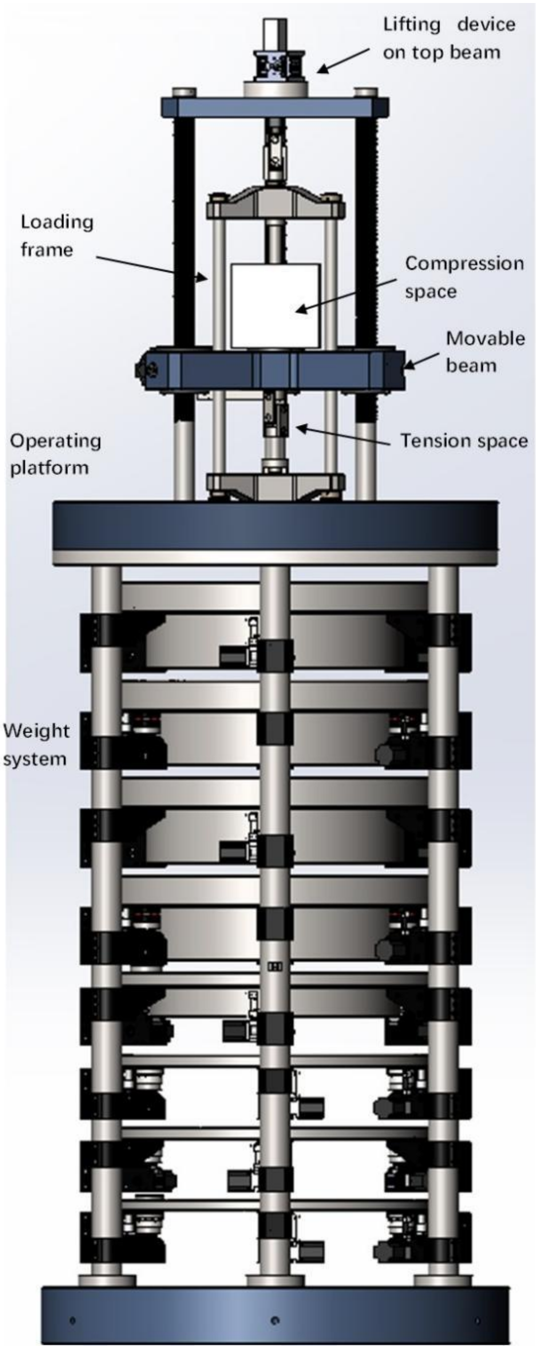

Figure 1: The schematic of the machine

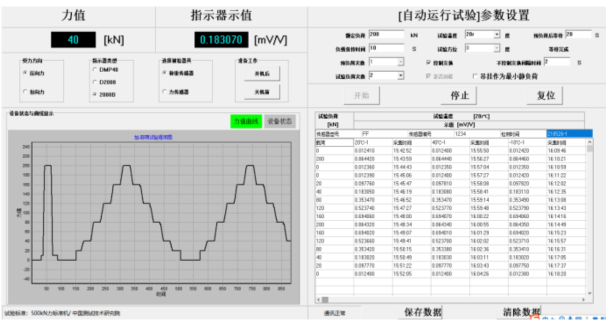

Figure 2: The operational program of machine

In the loading progress, according to the signal feedback by the monitoring sensor, the key information of weights exchange: when the weight comes into contact with the load frame, when the weights were completely loaded, loading speed, and the value of each weight transferring between the load frame and the loading system etc. can be obtained by the controller, and then adjust the status of the weights quickly.

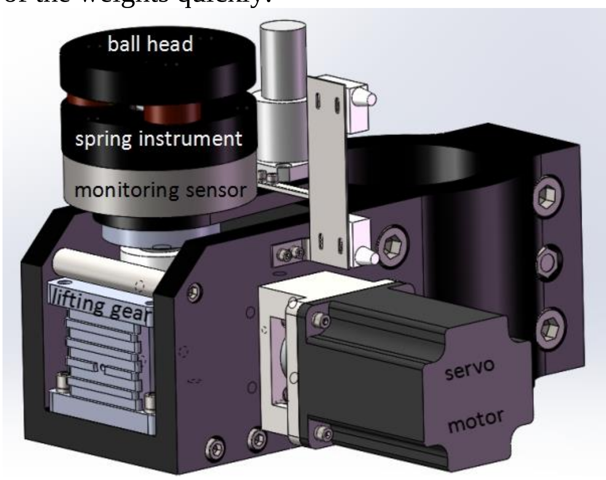

Figure 3: The model of weight loading system

3.2. The Control Method of Weights Exchange

Based on the servo-closed-loop loading system, we designed the control method of weights exchange to avoid the counter-force phenomenon. The basic principle of the control method of weights exchange, is to complete weights unloading in the loading progress and vice versa. Taken the load level that need to load one weight and meanwhile, unloading another weight, in increase loading progress, for example, as shown in Figure 4.

1. The loading weight moves fast, until it contacts the load frame, then slows down (in a minimum loading speed), wait the loading system contact the weight need to unload;

2. When the control system gets the signal that the loading system contact the weight need to unload, then give the commands that loading/unloading the weights in pre-set speed (in increase loading progress, the unloading weight move faster at this step, which means the loading system complete the unloading weight unload earlier);

3. When the weight completely unloads from the load frame, speed up the loading weight until progress is complete. And then, complete the loading progress of this load level.

Follow these three principles could ensure that, in loading increase progress, the start line of the weight unloading is later than the weight loading, but the end line is earlier.

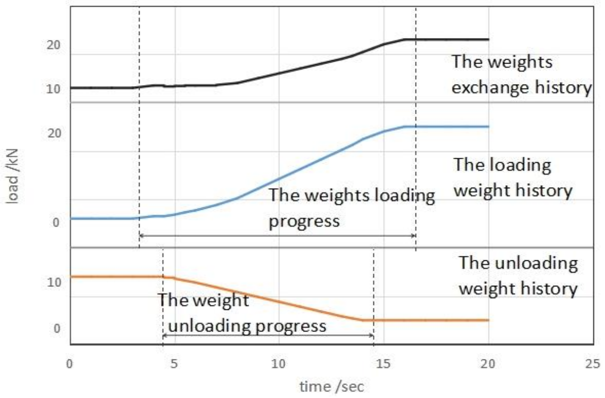

Figure 4: The schematic of weights exchange control

Figure 5 shows a complete load history in the calibration process of a 200 kN load cell, in the test sequence, the load level 40 kN to 80 kN, 80 kN to 120 kN, 160 kN to 200 kN need to carry out 1 vs 2, 2 vs 2, 1 vs 1 weights exchange. The load history drawn by the real-time information feedback by the monitoring sensors under the eight weights, shows that each stage of the loading process is basically the same, which means the counter-force phenomenon has been eliminated. Figure 6 shows the detail of the test sequence of the load level 80 kN to 120 kN. In this load stage, the DWM needs to unload 50 kN weight and 20 kN weight, by the meanwhile, load 100 kN weight and 10 kN weight. The loading history shows that, with the weights control system and control method, the counter-force phenomenon basically has been eliminated. When the DWM conducts the calibration task, the same loading history for each load level could reduce the error introduced by creep effect, to a great extent.

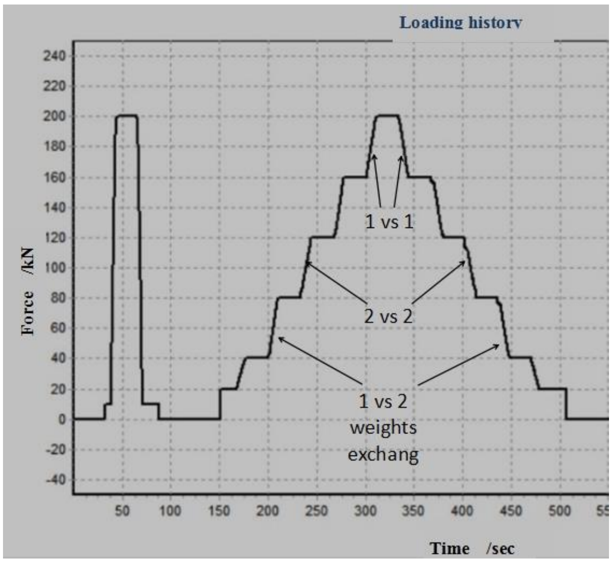

Figure 5: The loading history drawn by operational software

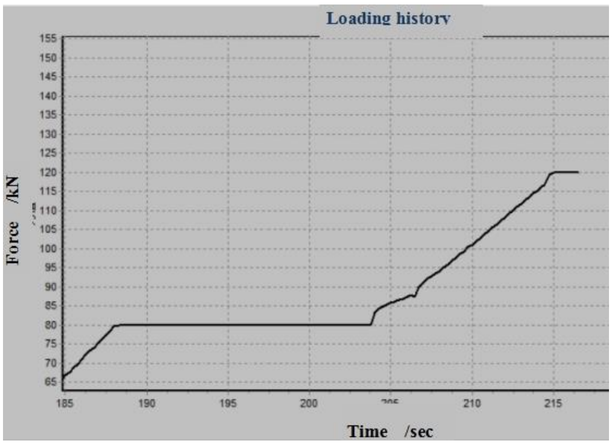

Figure 6: The detail of 80 kN to 120 kN loading history

4. THE METROLOGICAL CHARACTERISTICS

The DWM machine was designed for a transducer manufacturer, in Ningbo city, Zhejiang province, China. The design uncertainty of the DWM is less than 0.003 %, the error of mass measurement of each of the eight weights and the loading frame on the machine is less than 0.000 5 %. At the DWM installation site, the acceleration due to gravity measured by absolute gravimeter, the error is less than 0.000 1 %. The result of force comparison (10 kN, 50 kN, 100 kN, 250 kN, 500 kN) with primary standard verified that the force deviation is less than 0.002 %, the comparison results extend the uncertainty is less than 0.003 % (k = 2), which met the design requirement, as shown in Table 1.

Table 1: The comparison test data

Reference standard	**Force / kN**	$\boldsymbol{\delta_r}$ **/ %**	$\boldsymbol{U_c}$ $\boldsymbol{k = 2}$ **/ %**
Transducer 10 kN	10	0.000 7	0.002 2
Transducer 100 kN	50	0.000 8	0.002 2
Transducer 100 kN	100	0.001 8	0.002 2
Transducer 500 kN	250	0.001 6	0.002 2
Transducer 500 kN	500	0.001 3	0.002 2

5. SUMMARY

The 500 kN DWM weights exchange control system has achieved the following results:

1. The 500 kN DWM could carry out the calibration automatically according to the requirement of ISO 376 and OIML R60.
2. The weights exchange control system and the control method eliminate the counter-force

phenomenon effectively.

3. The uncertainty of force value produced by 500 kN DWM is less than 0.003 % (k = 2) and has been verified by comparison.

6. REFERENCES

[1] Y. J. Xu, Y. Tang, C. Q. Tang, "Force standard machine weights exchange method and weights exchange device", National Institute of Measurement and Testing Technology, Chinese patent, China National Intellectual Property Administration, ZL 3013 1 0379554.2.

[2] OIML R 60, "Metrological Regulation for Load Cells Part 1: Metrological and Technical Requirements, Part 2: Metrological controls and performance tests".

[3] ISO 376, "Metallic materials - Calibration of force-proving instruments used for the verification of uniaxial testing machines", 2011.

[4] ASTM E74, "Standard Practice of Calibration of Force-Measuring Instruments for Verification the Force Indication of Testing Machines", 2018.