Design for 2 MN dead-weight and build-up hybrid force standard machine

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Abstract. Based on the requirement for high accuracy and large range DWM in China. The paper describes a design of the 2 MN dead-weight and build-up hybrid force standard machine, which would be established by Fujian Province Institute of Metrology, Fuzhou, China. The design has covered 1) main specifications; 2) main construction; 3) Finite Element Analysis (FEA) of key units, etc. It solves the technology defects of counter-force phenomenon existing in traditional DWM through rational weights combination and independent loading of each weights. Setting up a servo control method to ensure the loading speed of the weights is controllable, so as to enhance the accuracy of the machine. The build-up system in the DWM is designed to preload and calibrate the dynamometer less than class 0.05. Besides the auxiliary systems designed make the machine more intelligent and convenient.

1. Introduction
With the advancement of science and technology, the demand for higher accuracy and larger range in force measurement in industry and in research is increasing. At present, the maximum range of dead-weight standard force machine (DWM) is 1 MN ($U_{rel} =0.002\%, k=2$) in China. Larger than 1 MN dead-weight force standard machine is still blank in China, compared with other countries in the world establishing lager than 1 MN, which includes 4.45 MN in NIST/USA, 2 MN/1 MN in PTB, 1.2 MN in NPL/UK, 1 MN in NRiM, 1 MN in NPL/India [1][2][3].

Hundreds of sensor-related enterprises and aerospace, defense industry, intelligent control, traffic construction and other related industries in China is desperately in need 2 MN DWM to provide national traceability in the calibration of reference standards with high precision. However, there are some technology defects affecting the measurement results in current DWM, such as weights exchanging (counter-force phenomena), loading/unloading speed is not controllable, lacking of loading status monitoring, etc. Therefore 2 MN dead-weight force standard machine has been designed by Fujian
Province Institute of Metrology (FJIM) of China, who built up successfully the largest range force standard machine -60 MN BM in the world.

2. Main specifications of the 2 MN DWM

The machine is divided into two parts, of which one is the build-up part used for preloading in order to improve work efficiency, the other one is the dead-weight part for normal calibrating and testing. The main specification is listed in table 1.

| No. | Title                        | Dead-weight | Build-up  |
|-----|------------------------------|-------------|-----------|
| 1   | Apply force direction        | Tension and compression | Compression |
| 2   | Range                        | 20 kN-2 MN  | 20 kN -2 MN |
| 3   | $U_{rel}(k=2)$               | 0.005%      | 0.05%     |
| 4   | Indication error             | 0.005%      | 0.05%     |
| 5   | Repeatability                | 0.002%      | 0.05%     |
| 6   | Loading period for each step | <30s        | <60s      |

3. Main construction

The profile of the machine is shown in figure 1. The machine consists of six main systems as following: 1) Top working parts, including 4 top columns, ball screw rod, moving beam and upper beam; 2) A main frame covering 9 columns, middle and bottom supported plate; 3) Hanging system, which is the most important parts in this machine, is consist of reverse, center boom and 63 pieces of weights; 4) Loading and unloading control system for weights in unattached way; 5) Loading status monitor system; 6) Build–up system for preloading.

![Figure 1. Profile of 2 MN DWM](image1.png)  
![Figure 2. Schematic diagram of 2 MN DWM](image2.png)
4. Weights hanging system

4.1 Reverser design

The reverser using double-beam and three-column structure, is made of stainless steel, with a removable structure between the column and the upper and lower beams. The reverser weight is 20 kN, acting as the first step load for the machine. As a result of the three-column structure design, the reverser loading and locating points are set at the bottom to avoid the possible instability of the dual column reverser, so as to improve the ability to withstand abnormal loads.

The reverser should be optimized with the constraints of weight and strength. So this paper optimizes the reverser with the method of continuum topology optimization, the FEA results shown in figure 3. Both the weight and strength meets the design requirements. The deformation of three-column are less than 2 mm at 2 MN loading.

![Stress cloud of before optimization](image1)

![Stress cloud of after optimization](image2)

Figure 3. FEA results of reverser

4.2 Center boom

Center boom structure, shown as in figure 2, is hollow structure, the weight of which is equal to 10 kN, acting as the secondary step load of the machine. All the tray are equipped with triple spherical positioning device. It is designed by Morse taper for connection between the every neighbor boom, in order to ensure the accuracy of vertical positioning. The connection between reverser and center boom is by means of spherical positioning, and they can be separated for loading respectively. Keep this mind, it can realize the first step loading of 20 kN.

There are totally 63 pieces of weights, 39 groups of weights, constituting 2 MN. Triple spherical positioning are used for positioning between weight and weight, weight and tray, as shown in figure 4, which is able to achieve self-aligning for weights. The positional accuracy of this method is better than the traditional conical positioning form.
4.3 Loading and unloading control system

The loading and unloading control system is drove by servo motor, and it can realize that the hanging system is loaded at any preset speed. The weights are controlled by the displacement sensor signal and the reference force sensor feedback signal. All the hanging and the weights are loaded independently and accurately, to achieve none weights exchanged in counter-span process, and solve the counter-force phenomenon completely in the process of loading.

5. Build-up system

The build-up system is designed to preload for improving work efficiency, and calibrate the transducer less than class 0.05.

6. Other systems

In addition, loading status monitor system is established to monitor the levelness, position and displacement of the weights hanging system in case of abnormal conditions. Weights auxiliary disassembling and assembling system is designed to disassemble the weights automatically and conveniently when they would be calibrated.

7. Conclusion

The design of 2 MN dead-weight and build-up hybrid force standard machine has been done, which is almost finished being manufactured at this time. The counter-force phenomenon of the machine is completely solved in the process of loading or unloading with the method of rational weights combination and independent loading of each weights. Setting up a servo control method to ensure the loading speed of the weights is controllable, so as to enhance the accuracy of the machine. The build-up system in the DWM is designed to preload and calibrate the dynamometer less than class 0.05.

8. Reference

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