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## 10 MN BUILD-UP FORCE STANDARD MACHINE DEVELOPED IN CHINA

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**Abstract** - The paper describes a 10 MN Build-up force standard machine developed in China. The BM has capacity of 10 MN compression, relative expanded uncertainty of 0.05% (k=2, probability being about 95%) which has been evaluated based on characteristics of three load cells as reference as well as on force comparison with 20 MN hydraulic amplification force standard machine established at NIM being relative expanded uncertainty of 0.01%(k=3), force fluctuation of less than  $\pm 0.002\%$ , etc. The BM is driven by a hydraulic system with a technology patented in China, which makes loading speed quicker and much stable as well as unloading. The force measuring system is similar to the other BM such as 9 MN BM established by LNE/France, and one by INRIM/Italy, etc.

**Key words:** build-up force standard machine, build-up measuring system, relative uncertainty

### 1. INTRODUCTION

Since 1950's China has established series of force standard machines including deadweight machines with ranges of 10N–1.1MN, lever amplification machines with ranges of 1kN–1MN, hydraulic amplification machines with ranges of 10kN - 20MN and force comparators/build-up machines (FC/BM) with ranges of several kN - 30MN. With requirements of constructions such as express roads, high speed railways, high buildings, it needs to establish more large capacity force machines in China. It is known that the FC/BM has advantages, for instance, lower cost, smaller room, easier control and maintain. At the same time, the relative combined uncertainty becomes quite less based on that the load cells as reference have much better characteristics as well as

the build-up measuring systems and hydraulic driving and controlling [1][2][3][4]. The paper describes construction, specifications, uncertainty evaluation, etc.

### 2. CONSTRUCTION

The 10 MN BM consists of four units including a framework (see fig.1), build-up measuring system (see fig.2) which is similar to 9 MN BM developed by LNE/France as well as INRIM/Italy, hydraulic driving and controlling system (see fig.3), data acquiring and processing system. The table 1 shows main specifications of the machine.

In order to obtain high stability of load generated, there are two servo-motors (see 4-1, 4-2 in fig.3), which controls two pumps (see 3-1, 3-2 in fig.3). One pump is used to control oil interring into the cylinder, while the other one for oil going out of the cylinder. It makes threshold of the force generated being as much smaller as 0.01kN (0.0001%FS), the servo-motors and two pumps are working at ideal ranges, and making oil-leakage of the cylinder stable, which makes the force fluctuation as better as  $\pm 0.002\%$  of load generated on the range of 1-10 MN.

### 3. UNCERTAINTY EVALUATION

There are two methods to evaluate the combined uncertainty of the force generated, of which one called "direct method" is based on calibration results of the three load cells as reference standard, the other one called "in-direct method" on comparison with the 20 MN hydraulic amplification force standard machine (HM) established in NIM being relative expanded uncertainty of 0.01%

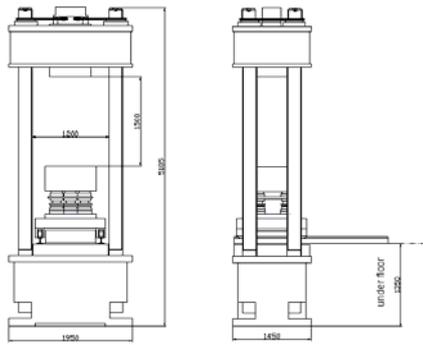


Fig.1 10 MN BM framework

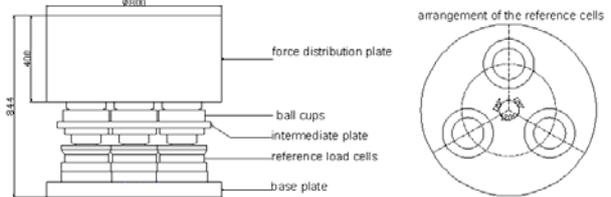


Fig.2 Build up Force measuring system

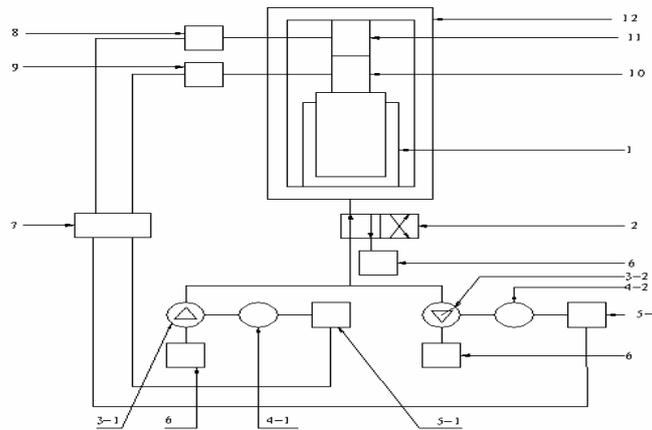


Fig.3 Block-figure of control system for the BM

(1) cylinder, (2) valve to alternative direction, (3-1,3-2) two pumps, (4-1,4-2) two servo-motors, (5-1,5-2) two servo-controllers, (6) a tank, (7) acquire-control system, (8) indicator for a transducer(11) under calibration, (9) indicator for the reference transducers(10), (12) main framework, etc.

Table 1 main specifications of 10 MN BM

Force range	Compression 1~1 0MN
Classification	0.05
Room for compression	1200x1500mm (width x height), being four columns
Controlling	Half automatic
Height of BM (m)	5.18
Width of BM (m)	1.95
Weight of BM (t)	48
Numbers of load cells as reference	3; HBM RTNC3 330T
Fluctuation of force generated	±0.002% of a load generated for range of 1-10 MN
Rel. expanded uncertainty, k=2	0.05% of a load generated for range of 1-10 MN

**3.1. direct method**

The three load cells were calibrated with the 5 MN HM established in NIM being relative expanded uncertainty  $W_{HM}$  of 0.03% (k=3), of which each one was carried out at  $0^{\circ}$  position for three increasing cycles on ranges of 0.3, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.3 MN and one decreasing cycle, as well as at  $90^{\circ}, 180^{\circ}$  and  $270^{\circ}$  positions for one increasing cycle and one decreasing cycle.

Based on the calibration results, it has been calculated that repeatability R, reproducibility  $R_{of}$ , hysteresis H, zero recovery  $Z_r$ , threshold  $R_{es}$  of the outputs for each cell. After considering long-term stability  $S_b$ , temperature effect  $S_t$  on rated output and interpolation error  $I_p$ , relative combined uncertainty  $W_x$  of the

output for each cell on increasing loads could be calculated by equ.(1)

$$w_x = \sqrt{(W_{HM}/3)^2 + (R/(1.69\sqrt{3}))^2 + (R_{ot}/(2.06\sqrt{4}))^2 + (R_{es}/(2\sqrt{3}x))^2 + (Z_r/(x_n\sqrt{3}))^2 + (I_p/\sqrt{3})^2 + (S_i\Delta t/2/\sqrt{3})^2 + (S_b/\sqrt{3})^2} \quad (1)$$

Where  $x_n$  - rated output of a cell concerned

$\Delta t$ - maximum deference of temperature while it is calibrated by the HM, and used on the BM.

Finally the relative combined uncertainty  $w_x$  of the output for each cell on increasing loads are less than or equal to 0.024%, 0.022% and 0.022% separately.

Since each cell is calibrated by the same 5 MN HM, there is correlation amount of three outputs of the cells[5] when considering combined uncertainty of sum of the three outputs while they are connected serially, or of average of three outputs while they are connected parallely. Since then, the relative combined uncertainty of a force generated by the BM is always equal to the average of three relative combined uncertainties for the three cells as reference. It is shown at equ.2.

$$w_x = u_x / x \cong (w_1 + w_2 + w_3) / 3 \quad (2)$$

In fact, it is also suitable to more cells used at a BM. At final result, the relative expanded uncertainty of a increasing force generated by the 10 MN BM for the range of 1-10 MN is 0.05% (k=2, probability being about 95%). It is almost same to the decreasing force generated by the 10 MN BM.

**3.2. Indirect method**

The 10 MN BM has been compared with the 20 MN HM using a load cell of LY-CM-10 MN made in China, and evaluated on the relative combined uncertainty with indirect method.

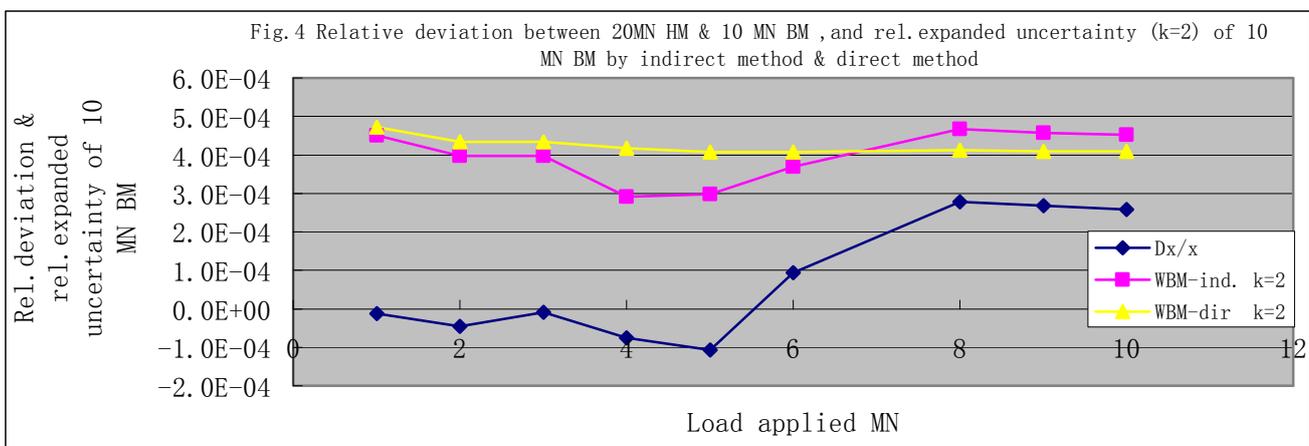
The cell has been calibrated by the 20 MN HM, which is similar to

the method mentioned above except that there are no decreasing loads applied. Relative combined uncertainty  $w_{x1}$  of output was calculated based on  $R_1, R_{ot1}, Z_{r1}, R_{es1}, I_{p1}$  and  $W_{HM}$ , which are less than 0.02% for the range of 1-10MN. The relative deviation between the 10 MN BM and 20 MN HM is less than  $\pm 0.03\%$  for the same range.

When it is considered that the 10 MN cell is used to calibrate the 10 MN BM, the relative combined uncertainty of the output of the cell is evaluated based on  $R_2, R_{ot2}, Z_{r2}, R_{es2}, I_{p2}$  obtained

from the cell calibrating the 10 MN BM, and  $w_{x1}$  above,  $S_{t1}$  of the cell, which is less than 0.022%. The relative expanded uncertainty (k=2) of the force generated by the 10 MN BM is less than 0.047% for the range of (1-10) MN while the relative deviation has been concerned as contribution, which is quite agreement with the results obtained by “direct method” on paragraph 3.1.

There is fig.4 showing relative deviation between 20MN HM & 10 MN BM, and relative expanded uncertainty (k=2) of 10 MN BM evaluated by the indirect method & direct method.



**4. Conclusion**

Since there are two servo-motors and pumps used to control oil volume in the cylinder as well as oil-leakage, it makes force

generated by the 10 MN BM quite stable being fluctuation as better as  $\pm 0.002\%$ . The relative expanded uncertainty (k=2, probability being about 95%) evaluated by the two methods has

good agreement being less than 0.05%.

It is protected that if the three force transducers as reference have better characteristics than these used here, relative expanded

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uncertainty ( $k=2$ , probability being about 95%) of force generated by a BM would be as better as 0.03%.

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