

Design of 60 MN Build-up Force Standard machine

Yao Jinhui¹, Li Qingzhong/Presenter², Xu Hang³, Chi Hui⁴, Lin jianhui⁵, Li Haigen⁶

¹, Fujian Province Institute of Metrology, Fuzhou, China, yaojinhui2000@126.com

², Fujian Province Institute of Metrology, Fuzhou, China, liqznim@126.com

³, Fujian Province Institute of Metrology, Fuzhou, China, fjil-xh@126.com

⁴, Fujian Province Institute of Metrology, Fuzhou, China, 11392326@qq.com

⁵, Fujian Province Institute of Metrology, Fuzhou, China, Linjianhui0928@126.com

⁶, Kente Mechanical & Electrical Co., Ltd, Shaoxing city, China, lihg286@163.com

Abstract: The paper describes a design of the 60 MN build-up force standard machine(60 MN BM), which would be established by Fujian Province Institute of Metrology, Fuzhou, China, at the end of 2014. The design has covered 1) main specifications; 2) main construction; 3) Finite Element Analysis (FEA) of key units; 4) uncertainty evaluation of the force generated, etc.

The 60 MN BM will generate vertical load of (4-60) MN, as well as lateral load of (120~2000) kN. The machine is employed to calibrate and test force transducers, load-boxes, hydraulic jacks, plastic supports, etc. The machine is divided into two parts, of which one part is used to generate reference load as a calibration machine, the other one is used as a normal testing machine to test the force apparatus as mentioned above.

Key words: build-up force standard machine, finite element analysis, uncertainty evaluation

1. Introduction

As it is more and more that construction of express roads, high speed railways, huge bridges, high buildings, nuclear powers, metallurgy and space, etc,

force calibration machines with large capacity have established in the world [1][2][3], which includes 54 MN BM in NIST/USA, 30 MN BM in UK, 16.5 MN HM in PTB/Germany, 20 MN HM in NMIJ/Japan[4]. At the same time, there are series of force calibration machines established in China, which covers 1 MN DWM as primer force standard constructed 30 years ago, 20 MN HM, 30MN BM, as well as quite more of 10MN BM, 5MN BM, 3MN BM, 2 MN BM, 1 MN BM, etc. In order to calibrate or test force transducers, load-boxes, hydraulic jacks, plastic supports, etc, the 60 MN build-up force calibration machine has been designed by Fujian Province Institute of Metrology, Fuzhou, China.

2. Main specifications of 60 MN BM

The machine is divided into two parts, of which one part is used to generate reference load as a calibration machine, the other one is used as a normal testing machine testing the force apparatus as mentioned above. The normal testing machine could generate not only vertical load of 60 MN, but also lateral force of 2 MN. The main specification is listed in table 1.

Table 1 Main specifications of the 60 MN BM

Title	Compression force as reference	Compression force as	Lateral force as
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			testing machine	testing machine
Range	(4~20)MN	(12~60)MN	(6-60)MN	(120~2000)kN
Expanded uncertainty (k=2)	0.05%	0.1%	1%	1%
Repeatability	≤0.03%	≤0.05%	≤0.5%	≤0.5%
Resolution	≤0.01%	≤0.02%	≤0.2%	≤0.2%
Fluctuation of force for 30s , better than	±0.01%	±0.01%	±0.2%	±0.2%
Load cells as reference	3x 7.5 MN	3x20 MN	12x5 MN	2 MN

3. Main construction

The profile of the machine is shown in fig.1. The machine consists of five parts as followings. 1) A main frame covering an upper beam, a moveable middle-beam, a base and columns (see fig.2); 2) A set of piston-cylinders (see fig.3), which includes a center one being internal diameter 1188mm, and max. pressure 20 MPa responsible load of 22.17 MN; 12 pieces of small ones, of which each diameter is 470 mm, and max. pressure 20 MPa responsible load of

41.64MN. The normal total load generated is 60 MN.

3) The load cells used as reference are listed in table 1, which were delivered by HBM/Germany exception of the 12 pieces of 5 MN and the 2 MN cells being local made. There is a transfer unit for reference load cells in fig.4. 4) An unit generating lateral load. 5) A servo-control part is shown in fig.5. One of most important technologies used here is the double-pump-servo controlling system, which makes load applied being stable and quick.

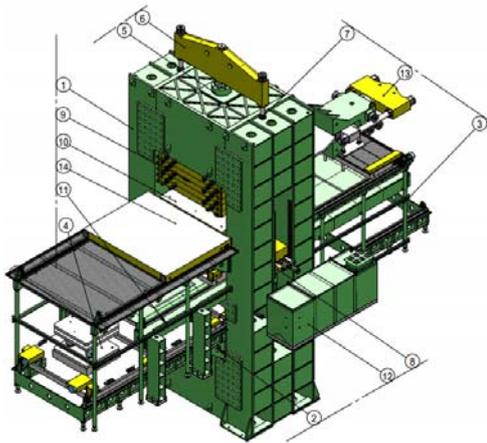


Fig.1 Profile of the 60 MN BM

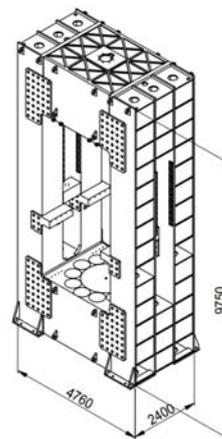


Fig.2 The main frame of the 60 MN BM

1- a sealed-main-frame of 200 ton; 2-a set of piston-cylinders generating the main load;3-a track rail for the lateral unit;4-a transfer unit for reference cells;5-a lift-piston-cylinder to transfer the plates(No.9);6~8- self-locking system for the plates(No.9);9-a set of plates;10- a plate under the reference;11-a moveable track-rail of the middle-beam; 12-a hydraulic system;13-a lateral loading unit;14-a transfer unit for cell under calibration.

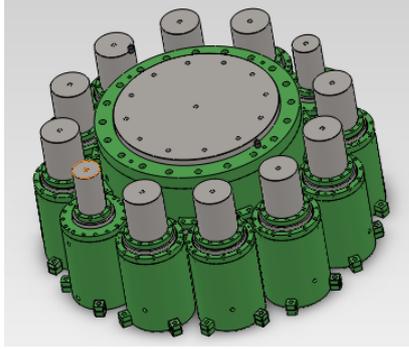


Fig.3 Main piston-cylinders

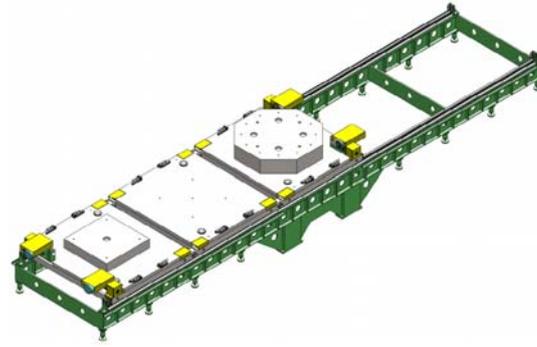


Fig.4 Transfer unit for reference cells

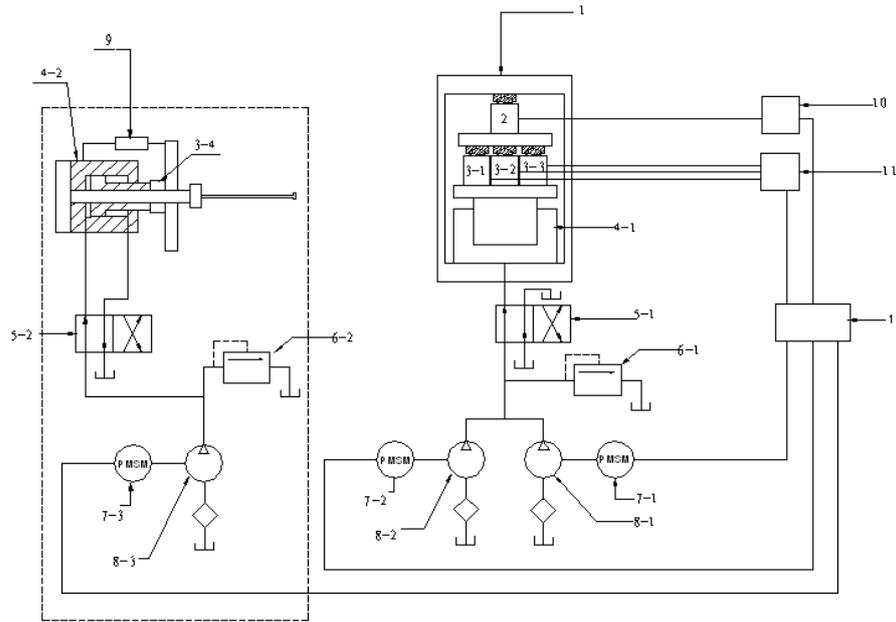


Fig.5 Scheme of the servo-control part

1- the main frame; 2-the load cell under calibration; 3-the load cells as reference(No.3-1,3-2,3-3), and lateral load cell (No.3-4); 4-1:the main piston-cylinders; 4-2: the lateral piston-cylinder; 5-the alternative valves; 6- the leak valves; 7- the servo motors; 8- the servo pumps; 9- a displacement transducer; 10- the measuring unit for load cell under calibration; 11- the measuring unit for reference; 12- a computer.

4. FEA of 60 MN BM

It has been done that the construction of the machine was analyzed by FEA with the software ANSYS, which covered the main frame of machine, the support-plates of 3×20MN cells, the lower-plate under the cells, and the lifting-part of cells, etc.

There are some figures as example, which includes

Fig.6a 3D model of the frame; Fig.6b FEA model of the frame; Fig.6c the stress cloud of the frame; Fig.7a FEA model of the plates for 3×20MN cells; Fig.7b the stress cloud of the plates for 3×20MN

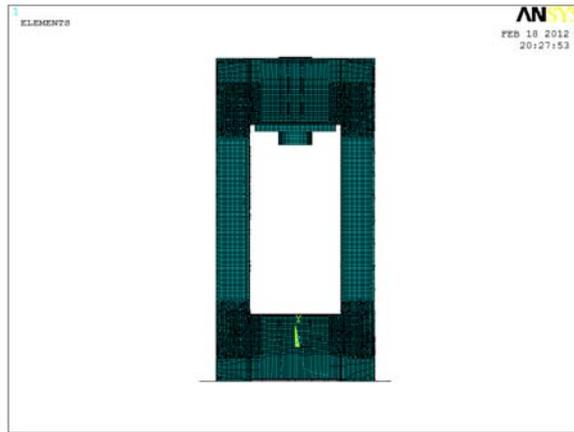
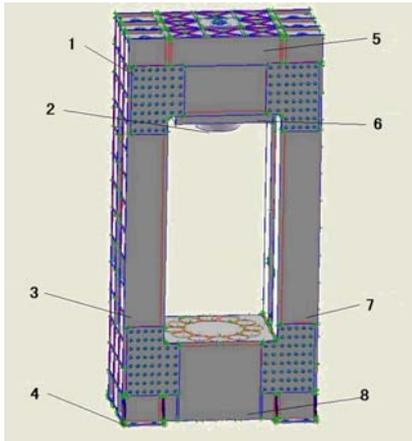


Fig.6a 3D model of the main frame sealed Fig.6b FEA model of the main frame sealed

1-a reinforced-plate; 2-an upper cap; 3-the left column;
 4-a base foot; 5-the upper beam; 6-a moveable plate;
 7-the right column; 8-the lower beam

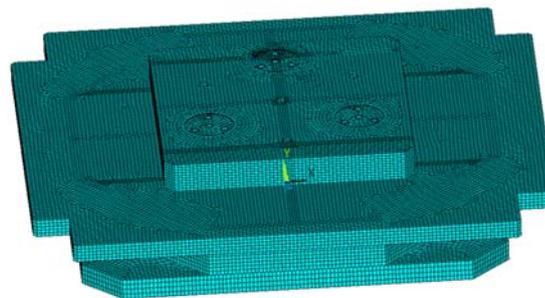
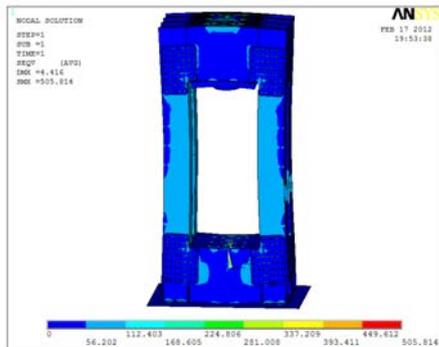


Fig.6c the stress cloud of the main frame

Fig.7a FEA model of the plates for 3x20MN cells

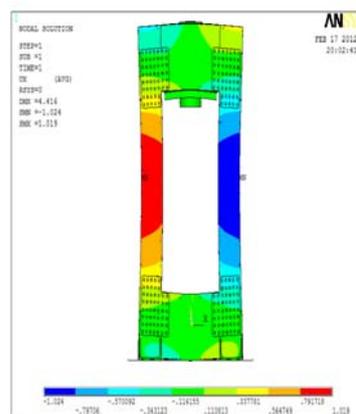
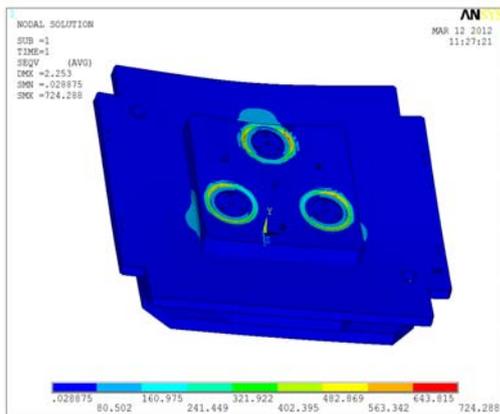


Fig.7b stress cloud of the plates for 3x20MN cells Fig.8 X-direction deformation of the frame

Table 2 has given maximum stress of varies parts column, the left column, the lower beam, the calculated by FEA. It was also calculated by FEA that reinforced-plate, the upper cap of a cell, of which all deformations of the main frame (see fig.8), the right deformations are less than 4.5 mm.

Table2 Sum of maximum stress of varies parts of the machine

No.	Title	Max. stress, MPa	Located
1	The main frame	506	At an inner corner sealed* between the right column and the base
2	The right column	459	
3	The left column	458	At an inner corner sealed* between the left column and the base
4	The upper beam	196	At connect point between reinforced-plate and lower-plate
5	The lower beam	191	At inner of convexity
6	The reinforced-plate	413	At an inner hole close to connect sealed* between the left column and upper-beam
Remarks	*The material used is the manganese-steel, JM-56 being yield intensity $\geq 560 MPa$		

5. Uncertainty evaluation

The combined uncertainty of the standard force generated by the machine has been evaluated by ‘direct method’, which is based on calibration results of the total cells including the repeatability, the reproducibility, the measuring resolution, the

temperature effect, the zero recovery, the long-term stability, the interpolation error, and the combined uncertainty of standard force generated by the 20 MN HM established in NIM, etc. [5][6]. Table 3 has given specifications of load cell 20MN No. 160340025, as well as their averages for each cell.

Table 3 Specifications of 20 MN cell No 160340025

Load MN	R	R _{ot}	H	Z _r mv/v	I _p	S _{b06-10}	w _{20MN-sb}
4	2.1E-05	1.2E-04	-1.6E-03	0.000074	5.5E-06	1.9E-04	1.4E-04
6	2.8E-05	9.6E-05	-1.4E-03	0.000074	-1.8E-06	1.3E-04	1.1E-04
8	1.0E-05	9.3E-05	-1.3E-03	0.000074	1.9E-05	1.0E-04	9.8E-05
10	1.7E-05	7.4E-05	-1.1E-03	0.000074	2.5E-05	9.4E-05	9.3E-05
12	6.9E-06	3.4E-05	-7.9E-04	0.000074	5.0E-05	6.0E-05	8.3E-05
14	1.8E-05	4.1E-05	-5.4E-04	0.000074	4.9E-05	6.5E-05	8.5E-05
16	5.2E-06	2.6E-05	-3.2E-04	0.000074	7.3E-05	3.1E-05	8.3E-05
18	9.2E-06	3.7E-05	-1.5E-04	0.000074	6.9E-05	4.4E-05	8.5E-05
20	1.2E-05	3.3E-05		0.000074	6.1E-05	6.5E-05	8.7E-05
R _{es} mv/v	0.00001	S _t /°C	0.001%	t	10	W _{fcm} k=3	0.01%
$w_{20MN-sb} = \sqrt{(W_{fsm} / 3)^2 + (R / 1.64 / \sqrt{3})^2 + (R_{ot} / 1.64 / \sqrt{3})^2 + (R_{es} / (2x_r \sqrt{3}))^2 + (s_r \Delta t / \sqrt{3})^2 + (Z_r / x_n / \sqrt{3})^2 + (I_p / \sqrt{3})^2 + (s_b / \sqrt{3})^2}$							
Cell _{xx-no} MN	Average for each cell						
cell ₂₀₋₂₃	7.9E-05	5.2E-05	-7.9E-04	0.000066	-1.0E-05	*	<u>1.0E-04</u>

cell ₂₀₋₂₄	3.0E-05	2.5E-05	-8.2E-04	0.000042	3.4E-05	*	<u>9.6E-05</u>
cell ₂₀₋₂₅	1.4E-05	6.2E-05	-9.0E-04	0.000074	3.9E-05	8.7E-05	9.6E-05
cell ₂₀₋₂₆	3.3E-05	3.7E-05	-8.6E-04	0.000086	-4.7E-05	*	<u>1.0E-04</u>
cell _{7.5-18}	6.7E-05	6.7E-05	-2.6E-04	0.000042	5.3E-06	*	<u>8.7E-05</u>
cell _{7.5-19}	1.8E-05	4.2E-05	-3.4E-04	0.000044	2.3E-06	*	8.2E-05
cell _{7.5-20}	8.1E-05	1.0E-04	-2.8E-04	0.000046	6.9E-06	*	<u>9.1E-05</u>
cell _{7.5-21}	5.9E-05	9.5E-05	-2.6E-04	0.000040	7.1E-06	-9.3E-05	1.0E-04
Remarks: *to be tested; The data with under line were estimated							

Since the total cells were calibrated with the 20 MN HM, there were correlation of calibration results between four cells of 7.5 MN as well as 20 MN cells. The relative combined uncertainty of 20 MN BM with 3x7.5 MN cells is equal to average of relative combined uncertainties of the three cells (taking No. 019,020 and 021), which has been estimated being 1.2×10^{-4} for increasing force or decreasing force, and its relative expanded ($k=2$) would be 2.4×10^{-4} for the force range of (4.5-22.5) MN.

It is similar as the 20 MN BM that 60 MN BM with 3x20 MN cells (taking No. 024,025 and 026) has been estimated, of which the relative expanded uncertainty ($k=2$) would be 2.2×10^{-4} for the force range of (12-60) MN for increasing force or decreasing force.

6. Conclusion

The design of 60 MN build-up force standard machine has been done, which includes main specifications and construction; Finite Element Analysis (FEA) of key units; uncertainty evaluation of the force generated, etc. The 60 MN BM will generate vertical load of (4-60) MN, as well as lateral load of (120~2000) kN. The relative expanded uncertainty ($k=2$) of the vertical force generated would be less than or equal to 5×10^{-4} for 20 MN BM, and 1×10^{-3} for 60 MN BM.

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