

APPLUS+ AND IMGC DEADWEIGHT FORCE MACHINES INTERCOMPARISON BY USING THE IMGC SIX-COMPONENT DYNAMOMETERS

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ABSTRACT

Two IMGC multicomponent dynamometers were used to measure the parasitic components generated by the APPLUS+ 0,5 MN deadweight force standard machine. Results are presented which indicate that they are of a very low level. Measurements of the dynamic components during weight changes and free suspension of the system are also presented.

1. INTRODUCTION

The results of several comparisons of force standard machines show uncertainties in force determinations higher than can be expected on the basis of the uncertainties with which mass and gravity acceleration values are determined.

The main sources of the differences are parasitic effects caused by undesirable components (side forces and moments) generated by asymmetry in machine structure, non-symmetric deformations of the loaded machine, faulty load cell positioning on the machine and machine-load cell interaction [1]. In order to improve primary force standards as well as to understand anomalies and optimise calibration methods, it is essential to measure the effect of different parameters on the parasitic components [2].

In June 2003, IMGC's six-component dynamometers were used to measure the parasitic components of APPLUS+'s 0,5 MN deadweight machine. The results are reported here, together with measurements of the influence of different weight combinations, dynamic effects on these components and the long term stability of the parasitic component by using the 100 kN IMGC six-component dynamometer, as a complete metrological characterization with this six-component dynamometer had been carried out in 1994 and the main tests were repeated on 2003

2. THE APPLUS+ 500 kN DEADWEIGHT STANDARD MACHINE

The APPLUS+ deadweight machine, has the following characteristics: maximal capacity, 500 kN; lowest load 10 kN; loading frame: four columns. It has different types of weight pieces, the first being the loading frame of 10 kN. The machine is normally kept at (20 ± 1) °C.

3. THE IMGC SIX-COMPONENT DYNAMOMETERS

In the early 1980s, IMGC designed and constructed a 100 kN six-component dynamometer [3] to measure parasitic components. Ten deadweight force standard machines around the world have since been evaluated with this dynamometer [2]. The ability to monitor all six components in real-time, during both load changes and free oscillation of the system, proved to be a valuable tool in the identification of loading anomalies. Following the success of this work, the European Union

commissioned IMGC to design and construct a 500 kN six-component dynamometer [4]. Both dynamometers are composite load cells consisting of six uniaxial load cells arranged to measure the orthogonal forces, bending and twisting moments. Decoupling between the load cells is provided by the use of elastic flexures. Both dynamometers were used to characterise the APPLUS+ machine.

They are two assembled balances with six elementary load cells. The 100 capacity IMGC six-dynamometer (fig. 1) is 450 mm high, diameter 390; and its weight is 150 kg; the 500 kN dynamometer is 780 mm high and with a diameter of 420 mm, it is 550 kg heavy (fig 2).

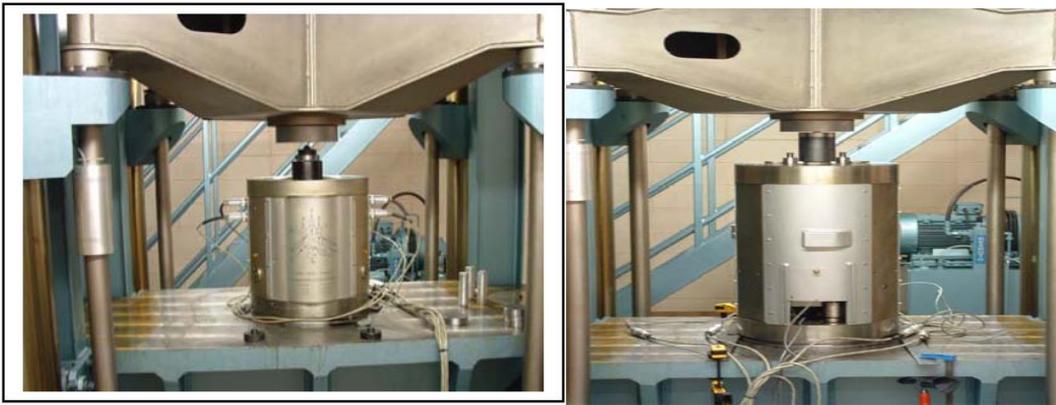


Fig 1 IMGC – 100 kN six component dynamometer and APPLUS+ 500 kN DWM

Fig 2: IMGC – 500 kN six component dynamometer and APPLUS+ 500 kN DWM

The versatility characteristics of the two dynamometers and the measurement method adopted make it possible to study dynamic phenomena of the machine/dynamometer system, which are understood both as load-application transients and as free oscillations of the system under constant load. Real-time diagrams of the evolution of the force tensor applied to the dynamometer are a very useful tool to detect anomalies that otherwise would be difficult to locate.

4- MEASUREMENT PROCEDURE

The tests were designed to measure three aspects of the performance of the 500 kN machine:

- the effect of axial load value on parasitic component values;
- the influence of different weight combinations on component values;
- the dynamic components generated by the machine during both weight changes and steady state operation.

The 100 kN dynamometer was used in the range from 20 kN to 80 kN and the 500 kN dynamometer was used from 100 kN to 500 kN.

Each dynamometer is connected to an AC digital indicator (HBM DK38 S6 with 10 nV/V resolution).

5 EXPERIMENTAL RESULTS AND ANALYSIS

Measurements were repeated with the dynamometers at four different angular positions relative to machine axes (0° , 180° , 90° , 270°), and were made at a temperature of $(19.9 \pm 0,5)^\circ\text{C}$.

The orientation of the dynamometer in the machine defines two orthogonal horizontal axes (X, Y). The dynamometers measure the vertical force (F_z), the two horizontal forces (F_x , F_y), the two

bending moments about the horizontal axes (M_X , M_Y), and the twisting moment about the vertical axis (M_Z).

At each orientation, three preload cycles of rated load applied for two minutes followed by zero load for five minutes were performed.

Measurements were taken at incremental loads only, with readings taken two minutes after load application or removal

5.1 100 kN six-component dynamometer measurement

Parasitic components

a) Side components (X, Y)

With load ranging from 20 kN to 80 kN the average values of the component X, covering all the dynamometer positions indicated in Table I, varies from $-2,1$ N to $-10,9$ N. The average values range from $-2,6$ N at 20 kN to $-10,43$ N at 80 kN. The maximum deviation is 0.9 N with $Z = 20$ kN. The average values of the component Y, covering all the dynamometer positions indicated in Table II, varies from $-0,2$ N to $-3,1$ N. The average values range from $-0,48$ N at 20 kN to $-2,51$ N at 80 kN. The maximum deviation is 0.9 N with $Z = 20$ kN (Fig. 3)

b) Twisting moment N

The values of twisting moment N resulted to be lower than 0.6 N m so that this moment can be considered negligible .

The twisting moment was not affected by different weight-piece oscillation amplitudes. Variation N remained, as a rule, within ± 0.5 N m.

c) Bending moments L, M

As a rule, bending moment L resulted smaller than 2 N m, with $Z = 80$ kN; bending moment M was about 3 N m at the same load level (Fig. 4).

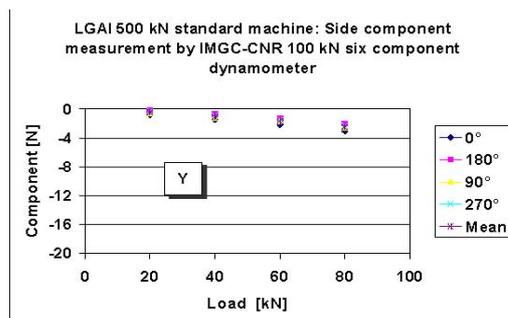


Fig 4 Bending moment measurement by IMGC- 100 kN six-component dynamometer

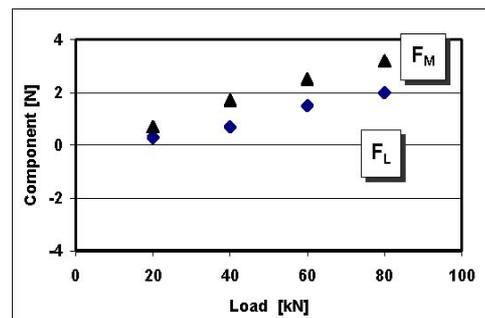


Fig 3: Y-component measurement by IMGC 100 kN six-component dynamometer

Long term stability

In the 1994 campaign with load ranging from 20 kN to 80 kN, the average X values covering all the dynamometer positions range from -2.5 N to -9.6 N. Component Y varies from -0.9 N to -3.2 N. The maximum deviation, Δ , is 1 N with $Z = 80$ kN.

The values of parasitic components measured in 2003, are in agreement with those obtained in '94 with the IMGC 100 kN dynamometer, and confirm the high stability of the APPLUS+-500 kN-DWM over a period of about ten years.

5.2 500 kN six-components dynamometer measurement

Preliminary tests carried out before to start for measurements:

Influence of loading transient

The continuous recording of the signals from the three horizontal load cells (H1, H2, H3) makes it possible to evaluate if any anomalous load levels arise during the load application transient, for increasing and decreasing load, from 0 up to 500 kN. In fig 5 an example of continuous recording signals.

Influence of different weight-piece oscillations

The continuous recording of the signals from the three horizontal load cells (H1, H2, H3) was analysed during the reading time (60 s) in order to check at any load level, the different amplitudes of weight piece oscillations. Fig. 5, as an example, clearly shows the peaks occurring in transients of weight-piece application on the carrier which give rise to dynamic components in the machine-dynamometer interface.

Between two successive peaks there can be seen the free oscillations of weight pieces. Fig. 6 shows the free oscillations at 20 kN.

The values appearing in the figures do not reveal significant differences for side components X and Y. This means that the weight pieces oscillate freely, so that no particular effects were observed in the machine-dynamometer coupling, when changing load

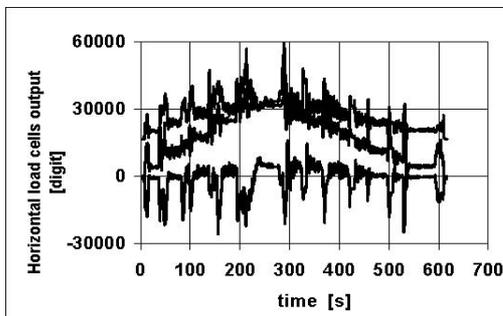


Fig 6: Recording of the three horizontal load cells output data reading (20 kN load level)

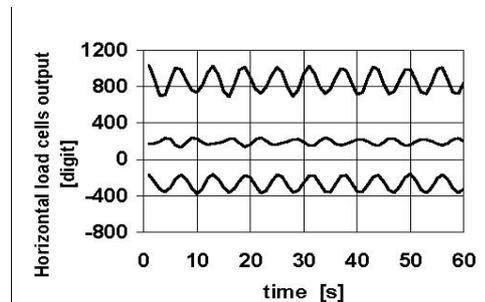


Fig 5 Continuous recording of the three horizontal load cells output during load application from 100 kN up to 500 kN

Parasitic component

a) Side components (X, Y)

With load ranging from 100 kN up to 500 kN the average values covering all the dynamometer angular positions range from -11 N to -43,5 N (Fig. 8). The maximum deviation, Δ , is 1,2 N with $Z = 300$ kN, and 0,5 N with $Z = 500$ kN. Component Y varies from -3,0 N to 15,5 N at 0° , and the average values range varies from -2,6 N to -16,75 N. The maximum deviation, Δ , is 2,2 N with $Z = 300$ kN and 0,5 N with $Z = 500$ kN, for the four angular positions (Fig. 8).

The above results indicate that the APPLUS+ 500 kN deadweight machine produces only small side forces (X, Y) and that these components vary linearly with axial load Z. The X/Z ratio is about $8.5 \cdot 10^{-5}$; the Y/Z ratio is about $3,4 \cdot 10^{-5}$.

b) Twisting moment N

The values of twisting moment N resulted to be lower than -0.6 N m so that this moment cannot influence the value of the vertical load. (Fig. 7).

The twisting moment was not affected by different weight-piece oscillation amplitudes. Variation N remained, as a rule, within ± 0.3 N m.

c) Bending moments L, M

As a rule, bending moment L resulted smaller than -7 N m, with $Z = 500$ kN; bending moment M was about 12 N m at the same load level. This means that the reproducibility of the load application point was better than $\Delta y = L/Z \leq \pm 0.02$ mm and than $\Delta x = M/Z \leq \pm 0.025$ mm at rated load, with the dynamometer at different angular positions.

Influence of different weight piece combinations

The observed differences ($\Delta X \leq 1$ N; $\Delta Y \leq 1$ N at 500 kN) were very small and did not affect the machine behaviour.

Also the axial load ($\Sigma V_i = V_1 + V_2 + V_3$) was not affected by the different weight-piece combinations. The relative deviation between the two values obtained at 500 kN with and without the mass of 50 kN was always less than $1 \cdot 10^{-5}$.

5.3 Six-component dynamometers overlapping

Fig 8 resumes the final results (X and Y components) obtained by using the 100 kN six-component dynamometer and the 500 kN six component dynamometer.

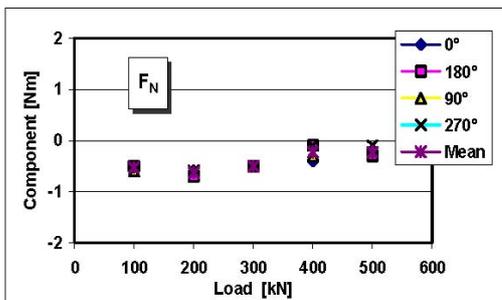


Fig 8 Side components measurement by IMGC- 100 kN and 500 kN six-component dynamometers

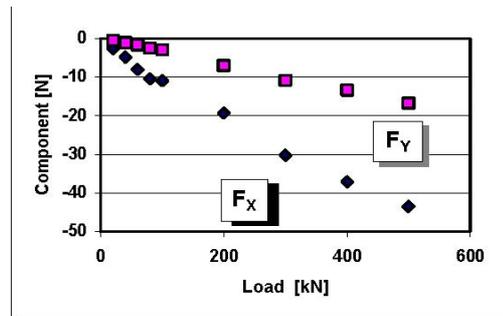


Fig 7: Twisting moment measurement by IMGC- 500 kN six-component dynamometer.

6. CONCLUSIONS

The tests carried out on the APPLUS+ 500 kN machine, as regards the measurement of parasitic components and the influence of several parameters on the values of such components, allow the following main conclusions to be drawn:

Side force components, F_x and F_y , are small, proportional to axial load, and independent of weight combination.

It is thought that the components mainly result from the initial inclination of the lower platen. They correspond to a maximal inclination of the main frame lower than 10^{-4} rad ($X \leq -50$ N; $Y \leq -20$ N). The lack of quadratic dependence on axial load indicates that no significant distortions of the machine frame occur under load. Linearity of side components (X, Y) vs axial load indicates that those components mainly depend on how the machine has initially been settled (initial inclination β) and that, consequently there occur no distortions or rotations of the loading or main frames with variations of the applied load: in fact sizable quadratic effects would otherwise be introduced

High reproducibility of side components X, Y values vs axial load for different angular positions of the dynamometer in respect of the machine axis Z.

This implies good reproducibility of the vectorial forces (axial force and side components) generated by the APPLUS+ standard deadweight machine; and a very low effect of machine-dynamometer interactions (rotation effects).

The twisting moment M_z is small, indicating that there is no contact between the suspended weights and the machine frame.

The bending moments, M_x and M_y , very small up to rated load, show an eccentricity lower than 0,1 mm of the load application line to the axis of the dynamometer. This is thought to be due to the method employed for centralising devices in the machine.

The parasitic components were independent of weight combination, indicating good vertical alignment of the weights. The values of the components measured by the two six-component dynamometers show a very good overlapping effect

The dynamic assessment of the machine shows that the parasitic components generated during weight changes are of similar magnitudes to those measured statically, and that the suspended mass is free to oscillate.

The parasitic components of the APPLUS+ 0,5 MN deadweight force standard machine have been successfully measured. The results indicate that their effect on the calibration of compression load cells and other compression force transfer devices is likely to be insignificant. The values of these parasitic component are in agreement with those obtained in 1994 with the IMGC 100 kN dynamometer, and confirm the high stability of the APPLUS+-500 kN-DWM over a period of about ten years

6. BIBLIOGRAPHY

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