IMEKO 2010 TC3, TC5 and TC22 Conferences
Metrology in Modern Context
November 22–25, 2010, Pattaya, Chonburi, Thailand

INFLUENCE OF AERODYNAMIC EFFECTS IN DEADWEIGHT MACHINES

Danilo Quagliotti [1], *Alessandro Germak* [2], *Fabrizio Mazzoleni* [3]

[1] Istituto Nazionale di Ricerca Metrologica (INRIM), Torino, Italy, D.Quagliotti@inrim.it
[2] Istituto Nazionale di Ricerca Metrologica (INRIM), Torino, Italy, A.Germak@inrim.it
[3] Istituto Nazionale di Ricerca Metrologica (INRIM), Torino, Italy, F.Mazzoleni@inrim.it

Abstract – In the evaluation of uncertainty of the forces generated by deadweight force standard machines, several contribution should be taken into the account. One of them, that normally is considered negligible, is the influence of aerodynamic effects. In the paper the theoretical analysis of this effect and the experimental measurements made on the INRIM deadweight FSM Galdabini 1 MN are presented.

Keywords: aerodynamics effects, force.

1. INTRODUCTION

The determination of the forces generated by a deadweight force standard machine (FSM) and of the relative uncertainty associated usually considers various influence factors such as mass, gravity acceleration, air buoyancy, etc.

Although in the related documents others effects are considered, like magnetic, electrostatic, mutual attraction among masses and aerodynamics, they are seldom considered in literature [1].

The effects of these influence factors are closely related to the individual realizations of FSM: capacity, type and size of machines can be substantially different and thus have different consequences.

Hence, after previous studies on mutual attraction among masses, we have faced new studies on the aerodynamic effects. So we have examined the effects due to the airflow at the INRIM force laboratory and acting on the masses of deadweight FSM Galdabini 1 MN (MCF1000).

2. AERODYNAMICS ANALYSIS

The MCF1000 extends in height from the ground floor to two basements, which are in a separate interior from ground floor. An opening of the floor allows the MCF1000 housing.

The masses of FSM are immersed in the air of the laboratory in which they are installed. The effect of air buoyancy is normally valued and corrected during the masses dimensioning.

However, thermal gradients and, above all, flows induced by the air conditioning systems could make the correction inadequate.

In fact, in the INRIM force laboratory, the air-conditioning surge emerging from the nozzles in basements get an outlet through the opening towards the ground floor, generating a consistent airflow.

Aerodynamic effects are due to the force exerted by the dynamic interaction of the generated air in motion onto the surface of the masses. In this case the flow direction is prevalent vertical so that the action on the masses can be compared to the effect of aerodynamic drag. In general, the calculation is dependent on the airflow profile but it can be represented schematically as

$$F = \frac{1}{2}\rho_a v^2 s\, c_d \qquad (1)$$

where ρ_a is air density, v is air velocity, s is the impact surface and c_d is the drag coefficient.

We have experimentally evaluated, under typical laboratory conditions (INRIM force laboratory) and using hot wire anemometry systems, the velocity of airflows that affects the masses of the FSM.

The examination was performed in different conditions of use, in order to observe all possible configurations.

From (1) and with appropriate geometric simplifications, we have valuated the threshold for the airflow velocity beyond which the effect can be considered significant, i.e. an equivalent contribution of relative uncertainty greater than 1×10^{-6}.

Replacing in (1) the values of ρ_a (1,17 kg·m^{-3}), s (1,13 m^2) and c_d (1,2 - typical for the so-called squat body) [3], [4], the speed limit was about 0,1 m·s^{-1}.

From this limit, we have examined the amount of airflow acting on the masses of the MCF1000, in the force INRIM laboratory, estimating the relative error in the generated force by a theoretical analysis, in the worst case.

Given the typical shape of the masses (cylinders with limited variations in diameter), the effect is more sensitive to the masses of small entities.

2.2. Measurement sessions

At first , we proceeded with a measurement session by means of an anemometer for a period of about four days and half, with a time acquisition of 5,6 s. The data collected are shown in Fig. 1.

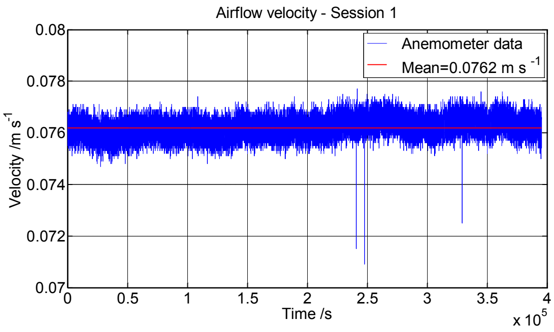

Fig. 1. Airflow measurement. First session, before the screening.

We have estimated an airflow mean velocity of about 0,076 m·s^{-1}. In the theoretical case, when the mass surface is normal oriented and completely exposed to the airflow direction, it corresponds to a relative error in the generated force slightly below 10^{-6}.

Considering this effect significant with respect to the uncertainty of the MCF1000, we decided to close the opening in the slab on the ground floor.

A second measurement session, with the same time acquisition and for about the same period of time, was repeated after the masses were screened and the opening reduced.

Fig. 2 shows that the air mean velocity was considerably reduced to 0,012 m·s^{-1}, reducing consequently the relative error of almost one order of magnitude.

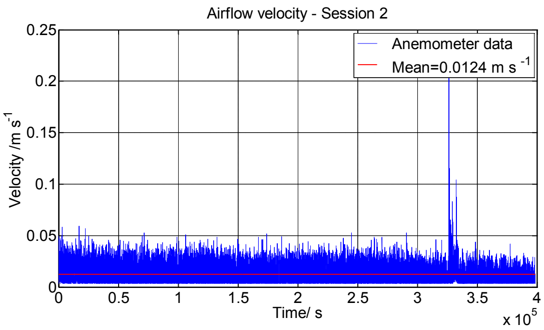

Fig. 2. Airflow measurement. Second session, after the screening.

The shields inserted into the base, that have minimized the opening between the ground floor and basement levels, have considerably reduced the vertical airflow and, consequently, the amount of vertical force applied, being proportional to the square of air velocity.

It should be noted that this factor can have a deceitful behaviour, depending not only on the shape and arrangement of the masses, but mainly from the flows that can be generated by thermal gradients and types of aeration systems. With appropriate precautions, this contribution can be entirely made negligible in the calculation of uncertainty.

4. CONCLUSIONS

The contribution examined should be carefully evaluated before being considered negligible in the budget of uncertainty. In this case, the aerodynamic effects were significant in normal conditions of air lifting between the underside, where the masses are located, and the work area above.

A theoretical analysis and experimental measurements led us to protect the masses of MCF1000 and to minimize the opening between the ground floor and the basements. The uncertainty contribution of airflow to vertical force applied was significantly reduced with this approach.

Since the results of the theoretical analysis demonstrate that this effect can be significant in the budget of uncertainty of dead-weight machines, the analysis should be more deeply studied in order to reach a sufficient uncertainty in its estimation. In fact, the calculation based on the analytical model is carried out with various simplifications which could overestimate this effect. In the perspective, it's necessary to compare these results with those obtained using alternative methods, such as finite elements simulation (FEM).

REFERENCES

[1] G. D'Agostino, A. Germak, F. Mazzoleni, D. Quagliotti, "Influence of the mutual gravitational attraction in a set of masses of deadweight machines", Proc. *XIX IMEKO World Congress*, Lisbon, 2009.

[2] C. Boffa, P. Gregorio, Elementi di Fisica Tecnica Vol. II, Levrotto & Bella, Torno, 1976.

[3] Norberg C., "Flow around rectangular cylinders - pressure forces and wake frequencies", *Journal of wind engineering and industrial aerodynamics*, Vol. 49, n. 1-3, Pagg. 187-196, 1993, ISSN: 0167-6105.

[4] Cakrawala A., Umemura A., "Experimental study on aerodynamic characteristics of a stepped-nose obstacle", *Transactions of the Japan society for aeronautical and space sciences*, Vol. 46, n. 154, Pagg. 238-245, Feb 2004, ISSN: 0549-3811.