DEVELOPMENT OF A 0.1 N – 100 N FORCE STANDARD MACHINE

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Abstract − Centro Español de Metrología (CEM) is developing a new force standard machine. This new force standard machine operates in a working range from 0.1 N up to 100 N. The designed machine consists of a suspended – fulcrum arm, a main body, a set of individually loaded masses and a control system that will be able to operate it automatically almost in full.

Keywords: Deadweight force machine, small forces.

1. INTRODUCTION

CEM has been working in the development and maintenance of the force unit since 1996. The realization of this unit has been made through three deadweight force standard machines with capacities 500 kN, 20 kN and 1 kN [1], and two hydraulic force standard with capacities 2 MN (compression) [2] and 10 MN (both in tension and compression) [3], which allow generating reference force values both in tension and compression.

This set of force standard machines allows the generation reference force values, both in tension and compression from 10 N up to 10 MN.

The new development of this new standard machine will provide measurement capabilities in force from 100 N up to 0.1 N, both in tension and compression.

The new working range of this standard machine includes very low forces. As a consequence, several new factors had to be considered if compared with high range force standard machines. A careful research in the state of the art in low force measurements was performed in order to decide which operating principle should be used for this new standard machine. Finally, the operating principle chosen for the new development was deadweight force machine. Several designs were considered in order to be able to minimize the disturbances that could affect the loads, which had a very low nominal value.

2. DESCRIPTION

The final design of the deadweight machine is based on a virtual development, using CAD/CAM tools (SolidWorks, Pro-Engineer and Ansys), which enables a numerical analysis and modelling.

A structural model was developed for the main elements of the machine (arm, frames, mass positioning system, etc.). In order to reduce every possible future disturbance, some of the parts of a typical deadweight standard machine were reviewed and improved.

In Figure 1 an overview of the structural parts is given. In Figure 2 the principal components of the machine are numbered. These components are described in detail along this paper.
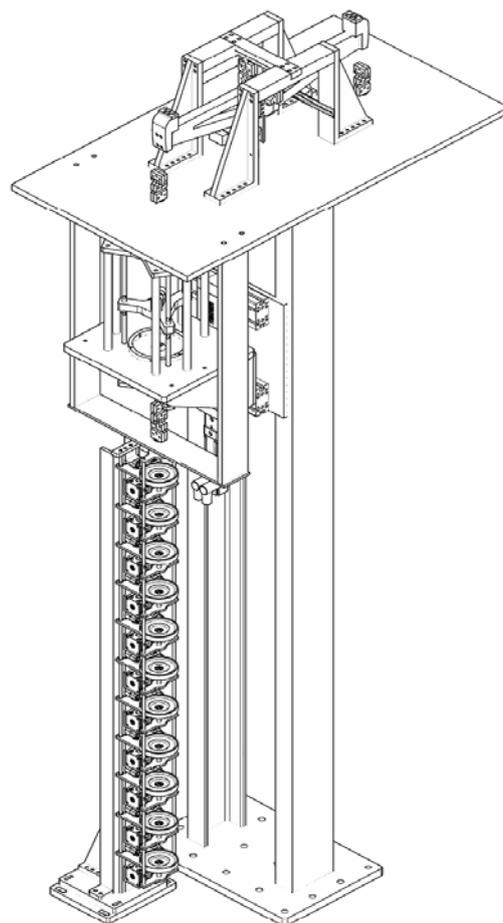

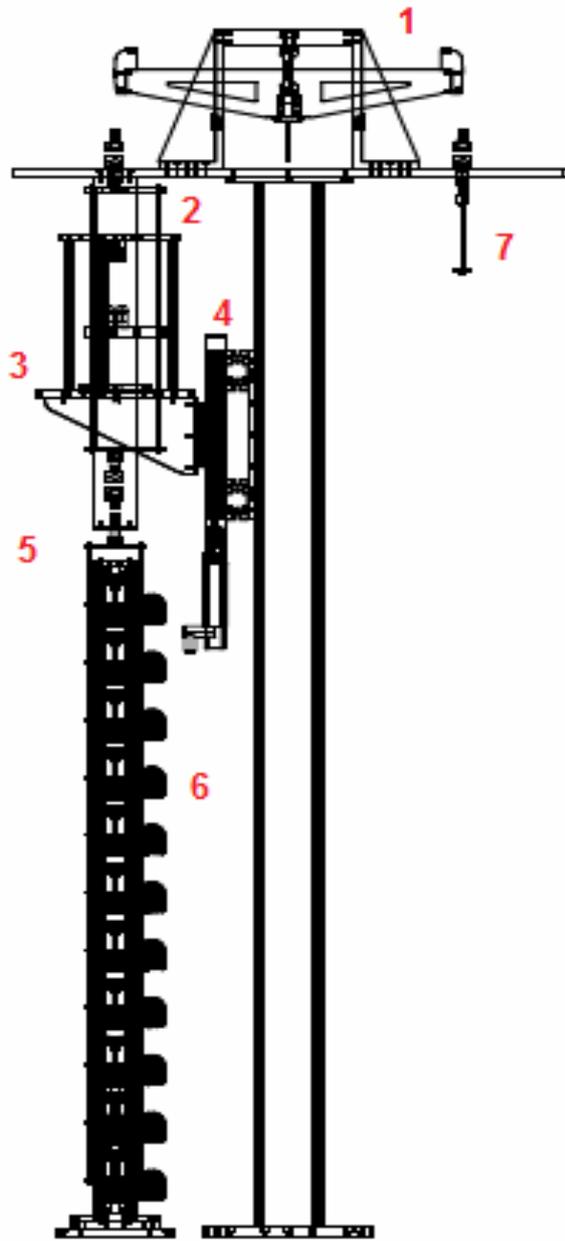Fig. 1. Overview of the force standard machine design.

Fig. 2. Components of the new force standard machine (1) arm and suspended fulcrum support, (2) upper support for tension tests, (3) bottom support with alignment system, (4) positioning unit, (5) load line, (6) load positioning system and (7) counterweight load line.

2.1. Arm and suspended fulcrum support. Tare weight compensation.

The small forces that are included in the working range of the machine require very good accuracy in the transducer positioning during the tests. On the other hand, a counterweight is required to compensate the weights of supports and load lines. That is the reason why a positioning system is required.

In classical deadweight standard machines the tare weight compensation is made through a balance, supported by metallic wedge-shaped part and controlled using capacitive sensors. However, this support has friction losses and the positioning accuracy is not reliable enough in the working range of the new force standard machine.

For this reason, the balance system was replaced by a lever arm, similar to those used in primary torque standard machines, which supports the whole load line.
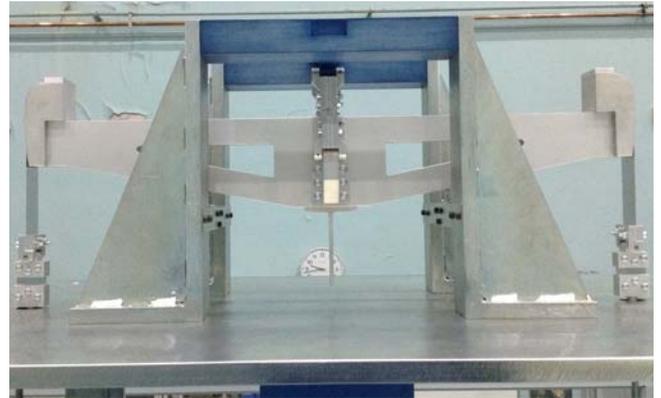

Fig. 3. Lever arm

The design of this arm includes two important innovations.

Firstly, a suspended-fulcrum system has been designed for supporting the arm. Instead of being supported by a wedge-shaped part, the arm is hanging from a structure using two thin sheets of metal (foils), as it is shown in figures 3 and 4.

This method is friction-less and ensures the verticality of the arm, as it is hanging from the aluminum tap and cannot rotate. Similar designs have also been used by other NMI's with satisfactory results [4] [5].

The lever arm is made of a special aluminum alloy, which has good structural characteristics and lower density values than other materials. In order to reduce the weight of the lever arm, it was mechanized creating some internal geometry. Stress and strain analyses were carried out in order to ensure a good structural behaviour.
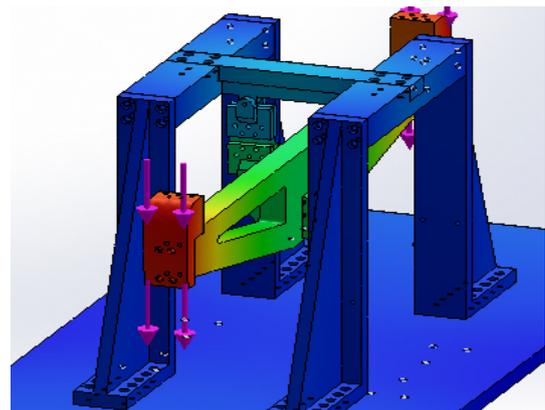

Fig. 4. Lever arm structural analysis

Structural analyses were also carried out in order to check that the foil will be able to support the weight of the structure and the loads applied during the tests.
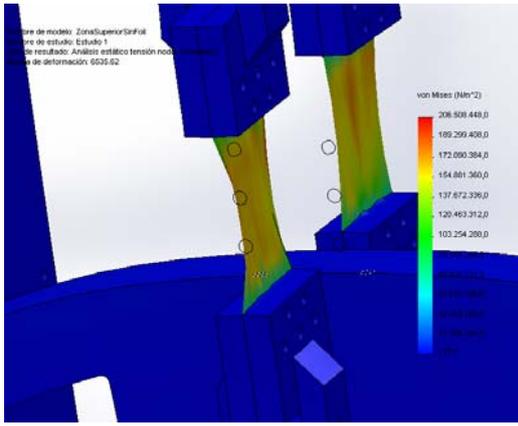
Fig. 5. Suspended-fulcrum structural analysis

Fig. 6. Detail of the suspended-fulcrum supporting system for the lever arm

Secondly, a laser system has been attached to the arm in order to detect whether the arm is in equilibrium or not. This laser detection system is much more accurate than other systems based on capacitive or inductive sensors.
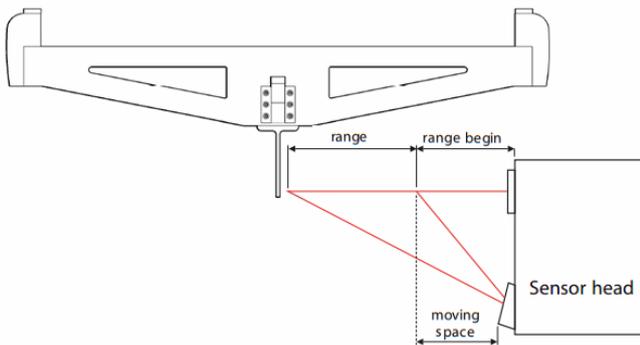

Fig. 7. Laser detection system

2.2. Upper support

The upper support is composed by three different axes, which avoid lateral loads and twists and provide more stability to the transducer positioning. This is an improvement of the new machine, as current deadweight force standard machine usually employ only 2 axes, which is a less stable configuration.
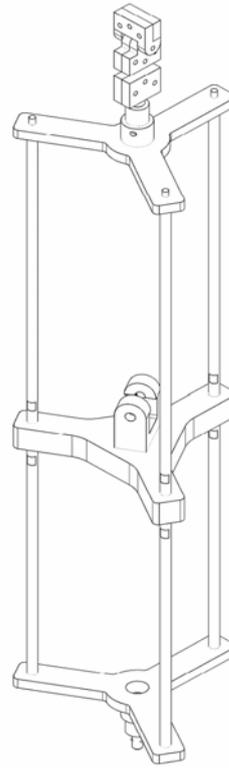

Fig. 8. Upper support.

This system helps to ensure the correct transmission of the forces generated by the machine to the transducer, minimizing any possible frictional losses.

2.3. Bottom support with alignment system

The bottom support is used to place the force transducer and it ensures the correct alignment with load line of the machine.
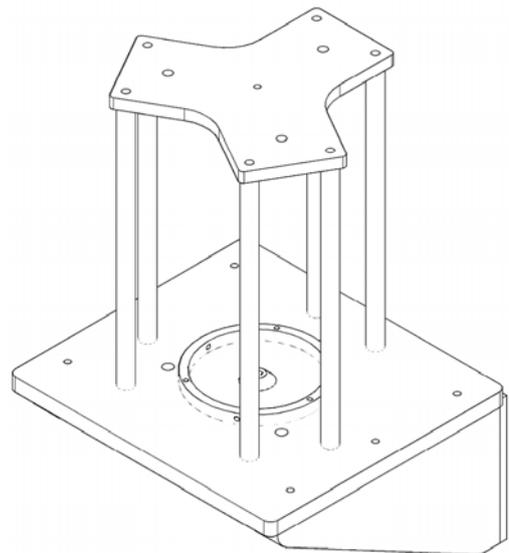

Fig. 9. Bottom support with alignment system.

The complete assembly of the upper and bottom support is shown in figure 10:

Fig. 10. Upper and bottom support assembly.

2.4. Positioning unit

The laser detects the position of the arm and sends the signal to the control unit of the system. This control unit actuates a linear motion system in order to equilibrate the arm.

This linear motion system is based on a ball screw drive, which provides a more accurate positioning of the bottom support than a trapezoidal screw drive.
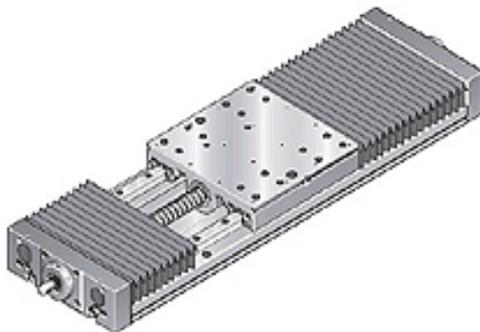

Fig. 11. Lineal motion system.

2.5. Load line

The load line is a new design that has never been used in deadweight machines.

Some conventional deadweight machines use a pile of masses that are move using a single platform, placing them in the load line always following the same sequence.

One of the requirements on this machine is that it has to be able to actuate each mass of the load line individually, both in manual and automatic operation. On the other hand, it has to be able to work with small loads

In order to achieve this goal it was necessary to have different supporting platforms. As a consequence, a new type of load line was designed that uses two axles to support each of the cones that are going to hold the loads during operation.

As the load line does not use a single axle it is possible to place supports for the loads between each holding cone of the load line, as it is shown in figure 12.

The load line is built in a special aluminum alloy in order to reduce the system weight.
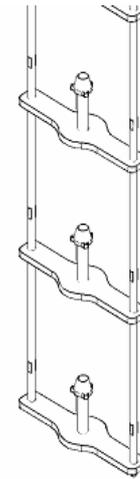

Fig. 12. Load line detail

This new load design is the reason why the sets of masses to be used in the new force standard machines have different shapes and sizes. All of them have an annular shape, but they are supported in different ways depending on their nominal value. The smallest masses are supported by 3 little flanges located in the load line cones.

Fig. 13. Set of masses detail

2.6. Load positioning system

The requirement of the individual operation for each load leads to a new design of a mass positioning system.

In this new system there is a platform for each of the 11 stages in the measuring range. Each platform is actuated by a motor and trapezoidal screw drive to convert the rotary movement into a linear displacement.

Loads are ring-shaped to make possible for the holding cone of the load line to go through them. However, the working range of the machine is too wide, so each load has different dimensions.

In order to be able to place any of the loads correctly aligned, a load support was designed and placed over each platform. This load support has been designed in order to fit the different sets of loads included in the working range.
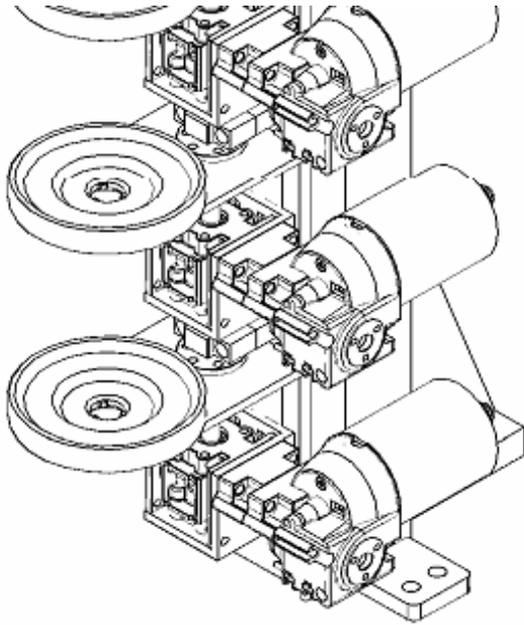
Fig. 14. Detail of the mass positioning system

Fig. 15. Load line and mass positioning system assembly

Fig. 16. Load line connection detail

2.7. Counterweight load line

The total weight of the system (supports, load lines…) has to be compensated to avoid its influence on the force generation.

This compensation is made using a counterweight which weight will be adjusted to compensate the influence.

4. CONCLUSIONS

CEM has designed a primary force machine that will be working in the range from 100 N up to 0.1 N.

The new force standard machine has already been assembled and placed at CEM's Force laboratory.

Fig. 17. The new force standard machine at CEM's force unit

It has been proved that the new design is robust enough to support the efforts of the load application process in force transducers calibrations.

The improvements implemented in the classical deadweight force standard machine design have been proved reliable in a mechanical and structural way.

Fig. 18. The new force standard machine at CEM's force unit
(including stairs and isolation)

This design has many advantages such as the possibility to operate each load individually and an accurate positioning system.

An estimation of possible uncertainty contributions was carried out in order to minimize the expanded uncertainty of the machine, which takes into account the weight of the load, the air buoyancy and the friction losses in the machine.

The maximum estimated value for the relative standard uncertainty of the machine is less than 2×10^{-5}.

Thanks to this new force standard machine, CEM will contribute to the current state of the art in force and will increase and improve its measurement capabilities.

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