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CYLINDER WITH DIFFERENTIAL PISTON FOR MASS MEASUREMENTS

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Abstract

The paper presents a cylinder with differential piston, adapted for measuring the weight of fixed objects such as: fuel tanks (regardless of their capacity), bunkers and silos for all kind of materials, or mobile objects such as: automobiles, trucks, locomotives and railway cars. Although, the cylinder with differential piston is used on a large scale in hydraulic drive or hydraulic control circuits, till now it was not used as constituent part for weight measurements devices. The novelty of the present paper is precisely the use of the device for such purposes. Based on a computation algorithm, the paper presents the general design (assembly), of the device used for weighing important masses (1...100 tones). The fundamental idea consist in the fact that, a mass over 10 tones may be weighted with a helicoidally spring subjected to an axial force between 0 and 3000 N, with a deflection of about 30 mm. Simultaneously with the mechanical part, the electronic recording system is also described. The great advantage of the presented device consist in the fact that it can be used in heavy polluted atmosphere or difficult topographic conditions as a result of both the small dimensions and the protection systems adopted.

Key words: *cylinder hydraulic with differential piston, hydrostatic pressure, measuring devices*

1. INTRODUCTION

In the technical literature, the cylinder with differential piston is mentioned in the schemes of hydraulic control or driving [1], [2], [3], [4], for various actuating systems (such as transport and hoisting devices, adjusting mechanisms for hydraulic turbines, actuating systems for lock gates, etc. The novelty of our studies was the use of differential pistons for measuring the weight of fixed objects, such as: fuel tanks (regardless of their capacity), bunkers and silos for all kind of materials or mobile ones, such as: automobiles, trucks, locomotives and railway cars. In this way a mass over 10 tones may be weighted with a helicoidally spring subjected to an axial force between 0 and 3000 N, with a deflection of about 30 mm. At the ground idea of the paper (for which it was obtained also the patent A00307/10.05.2006) there are the considerations regarding the devices having cylinders with differential pistons: simple and robust construction, great sensibility and precision. Such devices are not influenced by some corrosive environments in which there are used. Supplementary, the use of microelectronics allows obtaining a modern product, competitive and easy to employ. It is characterized by: low acquisition price (it is three times cheaper than similar other products) and favorable maintenance costs.

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2. DESCRIPTION OF THE SYSTEM

The weighing system has two components: a mechanical one, which includes the differential cylinder and an electronic one for the digital display of the measured mass.

2.1 The mechanical system

The assembly of the mechanical system is presented in Figure 1. It is composed from the cylindrical main part 1 continued by the cylindrical body 8, which separate the lower part, maintained under the oil pressure, from the upper one, where is formed a tight space under atmospheric pressure. In this tight space, the elements displaying the value of the measured mass are placed.

The piston 3, placed at the cylinder bottom is put in contact with the body that must be measured. Through the elastic membrane 4, a hydrostatic pressure is produced in the working fluid. Depending on the value of the measured mass this pressure ranges between 0 and 100 daN/cm^2. As a result of the communication orifices existing in the differential piston, the pressure will be equal on both sides of the piston. Because the working areas of the piston are different, the acting forces will be also different. As a result the piston rod will be pushed upward, into a translation motion. This translation will be converted into a rotation motion of the disk 9.

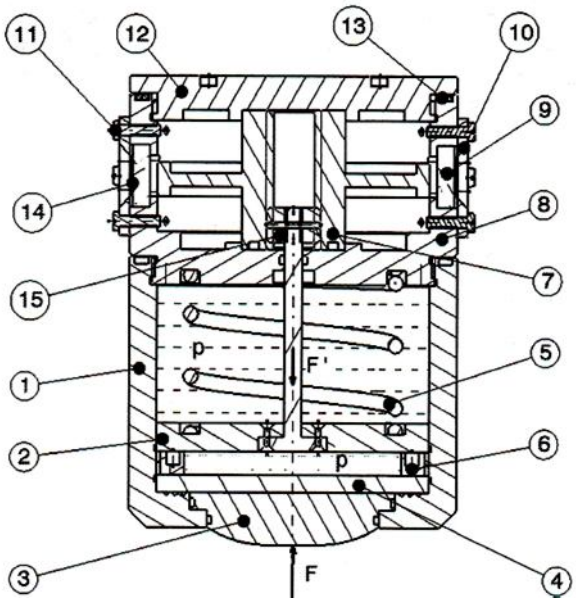


Figure1. The mechanical part of the device (axial cross section)

Considering that the hydrostatic pressure p has the maximum value (100 daN/cm^2), the force F acting on the inferior side of the piston will be [1], [5]:

$$F = S \cdot p = \frac{\pi \cdot D^2}{4} \cdot p \cong 5026 \text{ daN}$$

and the force F' acting on the upper side of the piston will be:

$$F' = S' \cdot p = \frac{\pi \cdot (D^2 - d^2)}{4} \cdot p \cong 5006 \text{ daN}$$

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The difference between the forces acting on the piston is:

$$F\text{-}F' = 20 \text{ daN}$$

The force acting on helicoidally spring being $F_{sp} = F\text{-}F'$, with a deflection of 30 mm the approximate constant of the spring will be:

$$k_{ap} = \frac{F - F'}{f} = \frac{200}{30} \cong 6.667 \text{ N/mm}$$

Choosing the following parameters for the hydraulic cylinder and the spring:

d_{sp} = 4.3 mm, the diameter of the spring wire,

D_{sp} = 60 mm, the wrapping diameter of the spring,

d = 5.05 mm, the piston rod diameter,

f = 30 mm, the spring deflection equal with the piston stroke,

p = 100 bar, the maximum pressure in the cylinder,

n = number of the spring whirl,

the actual constant of the spring becomes:

$$k = \frac{G \cdot d_{sp}^2}{8 \cdot n \cdot D_{sp}^3} = 6.648 \text{ N/mm}$$

Taking into account the actual parameters, the force developed by the spring is:

$$F_{sp} = k \cdot f = 199{,}44 \text{ N} \cong F\text{-}F'$$

and the force reduction of the device:

$$i = \frac{F}{F - F'} = \frac{50260}{199.44} = 252.00562$$

The stroke of the differential piston 2 is 30 mm and is put into correlation with the pitch of trapezoidal thread (Tr 18x30) of the nut 7 and the disc 9 so that at the end of the stroke, the indicatory disc rotates itself with 360º. This represents a good accuracy being 140 N for each degree.

The proposed solution offers the following advantages:

- allow the weighing of large and extra large masses in every place where such necessity occur, regardless if the objective is stationary or mobile;
- for mobile objects (cars, lorries, locomotives, railway cars, etc.) is sufficient a single device, over which every axle pass successively. Finally the total mass is computed by adding the successive values;
- for stationary objects, the measuring cylinders will be placed in those parts that sustain the objectives. The devices will remain there for the entire life of the objective.

In the figures 2 and 3 there are presented images of the cylinders and the complex device manufactured for the measurement of light vehicles masses. The assembly for measurements in the light variant comprises the following elements: the cylinder with differential piston 1, the central

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frame 2 and the access platforms 3. These platforms facilitate the mounting and descending of the vehicle wheel, on the central frame that include the cylinder with differential piston.

The central frame consists of two plates (the lower and the upper) pressed in heated conditions (deep drawing), between them being placed the cylinder 1. The upper plate sits on the cylinder (Figure 4) and transmitted the whole load towards the piston 3. It is important that the displacement of the two plates forming the central frame take place only on the vertical direction. To fulfill this condition, there were placed four plugs, for guiding and centering.



Figure 2. Cylinders with differential piston (measuring transducers)

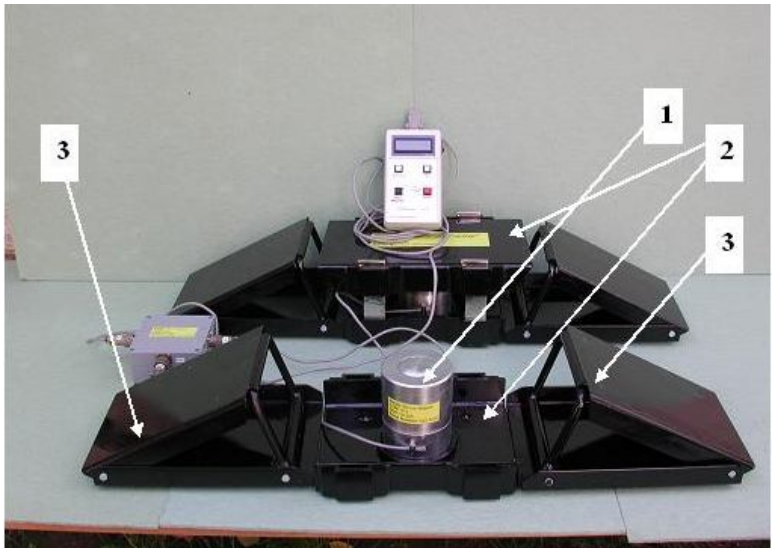


Figure 3. Prototype used for the mass measurement of light vehicles

For realizing a weighing, two such devices are needed so that the entire front axle, with both the left and right wheel, passes in a single movement, over the weighing cylinder. The operation will be

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repeated also for the rear axle (or rear axles, if the vehicle has multiple rear axles). The values read on the disk 7 will be totalized and the whole mass of the vehicle is found. It is possible to use a single device by passing successively the left wheels and the right ones (the errors are small but the weighing time is a little longer). For easing the handling and transportation of the frames the weighing device can be folded and dismounted.

The device for measuring very heavy masses, this is the case for lorry trailers, or lorry trailers combination, is similar to that presented in Figure 3 but between the two plates (the upper and the lower) of the frame 2, there were placed two differentials weighing cylinders. For this variant, the central frame must be longer, because here must be placed two weighing cylinders, but also because the rear part of a heavy lorry is provided with 2 axles. Because the mass is very great the load of each wheel is taken by two weighing cylinders.

For this variant, the two plates composing the central frame have a single degree movement (namely translation in the vertical direction), the oscillations and tilting are prevented by the tree pairs of plugs.

It must be mentioned that for weighing a heavy lorry, for the front axle, provided with a single axle, it is sometimes possible to use the light-weighing device, but for the rear axle in all cases it must be used the heavy weight device. Also in this case the central frame is composed from individual elements that can be assembled in the indicated place and the two frames may be folded and dismounted.



Fig. 4. The mass measuring of an automobile front axle

In order to maintain the alignment of the three elements, composing the frame, during the vehicle climbing, the lower plates are provided with elements preventing the plates to slide.

2.2 The electronic system for picking-up and displaying the measured values

Sometimes the reading of the measured values, mechanically displayed, encounter difficulties because the cylinder are placed in very low positions. For such situations it was conceived an electronic telemeter system for displaying the measured values. The electronic system maintains the high precision and the reading may be done easy at distances till 10 m, from the measuring cylinder.

The electronic system is composed from two devices:

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- the measuring device (two pieces)-MD;
- the displaying and control device-DCD.

The two MD are permanently in communication with the DCD through a RS 232 interface.

2.2.1 The measuring device MD

The measuring devices (Figure 5) are used for obtaining the mass of the vehicle on each wheel and to transmit this information to the displaying and control device.

The good working of the MD is supervised by a microcontroler. A piston that has a displacement proportional with the vehicle mass, play the role of transducer. This displacement is converted in voltage by a potentiometer transducer. At his turn the voltage is transmitted to an interface circuit. This circuit assures the calibration of the mass measuring transducer. The voltage is converted in a digital magnitude by the analogical/digital converter of the microcontroler. The digital magnitude processed by the microcontroler is transmitted through a RS232 interface.

The feeding of the measuring device is provided by five batteries of the type "AA". The other parts of the measuring device are:

- a supervision circuit of the fed voltage, which signalize through a led, the discharge of the batteries:
- an "ON/OFF" switch.



a) Measuring device of type 1 b) Measuring device of type 2 c) Measuring device of type 3

Figure 5 The electronic measuring devices (MD)

2.2.2. The displaying and control device-DCD

From a constructive point of view, this device is a portable console (Figure 6). This device displays the information obtained by the measuring devices upon a LCD with 2x16 characters.

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a) displaying and control device-DCD (front view) b) displaying and control device-DCD (rear view)

Figure 6 The displaying and control device-DCD

The displaying and control device-DCD has the following buttons:

- "ON/OFF";
- "RESET" for entering in the measuring menu;
- „MEASUREMENT" for performing a measurement;
- "M+" for adding the measured masses in order to obtain the vehicle mass;
- "STOP MEASUREMENT" to end the measurement process.

The feeding of the displaying and control device is done by five "AA" type batteries. The DCD contains also a circuit for signalizing discharge of the battery.

The running parameters of the electronic device are:

- Type of feeding: 5 "AA" type batteries;
- Number of measuring devices: 2;
- Maximum number of measurements for a vehicle: 8;
- Measurement precision for a measuring device: ± 25 kg;
- Displayed precision: ± 0.5%;
- The measuring unities: tons (T);
- The maximum measured mass for a single device: 10.0 tons;
- The dimensions of "DCD": (90x170x40) mm;
- The dimensions of "MD": Φ100 – 135 mm.

2.2.3 Description of the measuring process

For putting into operation the device, the DCD must be connected to the two MD with the proper cables. The button "ON/OFF" of the first „MD" is pushed in the position "ON". If the green led is continuously burning, the supplying voltage is in normal limits, if the led is intermittently burning, the supplying voltage is under the normal value and the battery must be replaced. The second "MD" must be proofed in the same way. The button "ON/OFF" of the DCD is pushed in the position 'ON'. On the LCD display the following messages appear (there are illustrated in the Figure 7):

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- the message "DISCHARGED BATTERY", if the voltage is under the normal value. If this message is seen, the batteries must be replaced and the procedure must be repeated (Figure 7a);
- the message "TRANSDUCER ERROR" appears if there is a communication lack between the transducers. If this message is seen, it means that there are transducers deficiencies or the connecting cable is damaged. At first, the connecting cable must be verified and if it is in order than all the transducers must be verified. After the defective part is repaired, the putting into function procedure must be repeated (Figure 7b);
- the message "READY FOR MEASUREMENTS" signifies that the installation is functioning (Figure 7c).

To obtain the vehicle mass, the following procedure must be applied:

The first axle of the vehicle is mounted on the two measuring devices and after that, the button „MEASURE" of the DCD is pushed. On the LCD display appears the message „THE MASS OF AXLE 1: xx.xT" on the first row, and the message „TOTAL MASS: zzz.zT" on the second row (Figure 8a). The figure 1 represents the axle number and is displayed intermittently and "xx.x" represents the mass of the axle. The device remains in measuring state for 50 ms. The measured value is displayed every 0.5 s. If the operator wants to memorize the measured value the button "+M" must be pushed. On the LCD appear the following messages, on the first row "THE AXLE MASS1: xx,xT" and on the second row "TOTAL MASS: zzz.zT" (Figure 3). The "TOTAL MASS" displayed value is equal with the measured value. The axle number "1" is continuously displayed, which means that the mass value is memorized.



a) "DISCHARGED BATTERY"



b) The message "TRANSDUCERS ERROR"



c) The message "READY FOR MEASUREMENTS"

Figure 7 Messages displayed

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In order to fulfill the following measurement, the vehicle is mounted with the adequate axle on the two measuring devices and the button "MEASURE" of the DCD is pushed. On the LCD appears the message „THE MASS OF AXLE 2: yy.yT" on the first row, and the message „TOTAL MASS: www.wT" on the second row. The figure 2 represents the axle number and "yy,y" represents the measured axle mass. The axle figure is intermittently displayed. The device remains in measuring state for 50 ms. The measured value is displayed for 0.5 s. If the operator wants to memorize the measured value the button "+M" must be pushed. On the LCD display appear the following messages, on the first row "THE AXLE MASS2: xx,xT" and on the second row "TOTAL MASS: zzz,zT". The "TOTAL MASS" displayed value is equal with the current measured value added with the mass previously measured. The axle number "2" is continuously displayed, which means that the mass value is memorized. If the vehicle has only two axles and the measurement is finished, the button "STOP MEASUREMENTS" must be pushed. On the LCD appears the message: "AUTO MASS: aaa.aT". The DCD goes out from the measuring state and pushing any of the buttons 'MEASURE", "+M", "STOP MEASURING" remains without effect. In order to perform another cycle of measurements the button "RESET" must be pushed. On the LCD will appear the message "READY FOR MEASURE" and the procedure presented previously must be repeated.

If a vehicle has more than two axles, the measurement procedure for the other axles are similar as for the axle 2, the number of the axle being 3, 4 till 8. If the number of measurements goes beyond eight, on the display appears the message "ERROR: TO MANY MEASUREMENTS" (Figure 15). In this situation the "reset" button must be pushed, on the display appears the message "READY FOR MEASURE" and a new cycle of measurements can begin.



a) Display "TOTAL MASS": 0xx,xT' b) Display "ERROR TO MANY MEASUREMENTS"

Fig. 8 Messages displayed

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The homologation tests were accomplished in the following way:

- In traffic for a small weight vehicle (a DACIA car), as can be seen in Figure 16;
- By loading the devices with a 10 tons hydraulic press, available at the I. M. S. T. Faculty of the Bucharest Polytechnic University, considering that in the traffic loading the forces will be similar with those offered by the hydraulic press. Such a loading was necessary to see if heavy vehicles can be measured but also to verify if undesirable leakage may occur.

Each device was tested six times with different loadings and all the results were excellent.

The presented measuring system can be used for:

- **mobile objectives**: cars in traffic to see if it is loaded or empty, to verify the momentary mass, without deviating the vehicle from its moving direction, towards a weigh platform. The system allow the weighing of the vehicle in a short delay of time, just on the place were it was stopped;
- **fixed objectives (**bunkers, silos, tanks etc.). These objectives may be permanently observed and on there entire life. Sometimes this information is important for those, which administrate such objectives. Of course, the reduction of the content under an inferior limit may be announced by acoustic or optic means;
- **protection of fixed objectives** (protection against overloading). For example, the weight of lorries can be measured when acceding on some bridges. When the weight goes beyond some reference value, an optic or acoustic signal is released.

3. CONCLUSIONS

The presented system, which uses a differential hydraulic cylinder, is a new procedure in weighing systems. It allow to measure heavy and very heavy loads, easy, with high precision, from distances till 10 m, regardless if the objective is fixed or mobile.

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