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DESIGN OF AN EQUIPMENT FOR MEASUREMENT OF SAG AS AN EFFECT OF CORIOLIS FORCES

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Abstract: *The paper aims to present a study, on the small-scale, remodeling of a device that performs a relative motion and to highlight the resulting sag, as an effect of the Coriolis force. The remodeling of the equipment has as a starting point of the dimensions of an elastic rod. This bends gives an sag (f), as well as the frame in which it is mounted, of course followed by calculations of strength, sizing and design of other elements of their assembly such as: frame, shaft transmits the movement from the motor through the belt, it is fixing the shaft to the frame of the equipment etc.*

Key words: *rod, effect Coriolis, basic elements, secondary elements.*

1. INTRODUCTION

The aim of the paper is to study an existing, large device that highlights the Coriolis effect [1], [2]. It desires to redesign it, to smaller dimensions, both as a size and as a mass [1]. We mention that the Coriolis effect appears in the mechanisms that execute relative movements; this can have in time, negative effect on the components due to the appearance of the Coriolis acceleration and implicitly of the Coriolis force, and all this leading to a sag resulting from the bending of an elastic steel rod. This leads to the phenomenon of fatigue and implicitly to its break.

It is important to establish that, this phenomenon in terms of time, leads to wear of the rod (parts) under the effect of Coriolis.

1.1 NOTIONS REGARDING THE CORIOLIS FORCE

The reshaping of the equipment through redesign, with its advantages and disadvantages, in the end, must lead to the visibility of the Coriolis effect (sag (f) which is obtaining by the appearance of the Coriolis acceleration, respectively the Coriolis force from the relative movement).

Thus, the operating principle of the equipment will be briefly explained (Fig. 1):

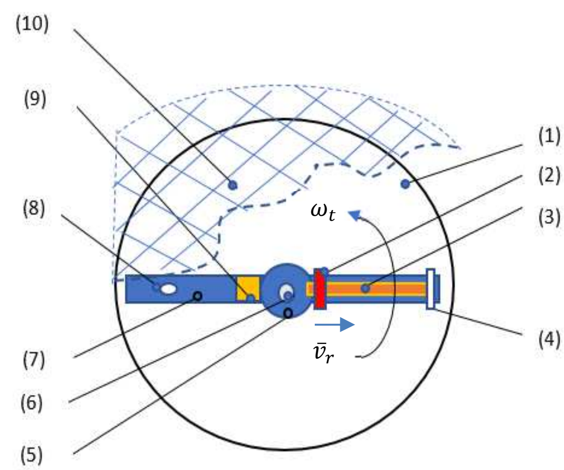

Fig. 1 Basic elements necessary in the design of the equipment.

It will consist in the appearance of the relative movement [3], movement composed of a rotational movement of the rod (3) around the motor axis (absolute rotational movement with respect to the frame having the angular speed ω_a). Also, and a relative movement that is produced by releasing of the pill (4) in the electromagnet, making a rectilinear movement

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along the rod (3) (at velocity v_r), and if we refer to the transport movement, it follows a circular trajectory with the angular speed ω_t, as if the pill is fixed to the rod (3), rotating with it.

The vector equation of relative motion [3], [4], [5] is:

$$m \cdot \bar{a}_r = \bar{R} + \bar{R}_l + \bar{F}_{jt} + \bar{F}_{jc} \qquad (1)$$

where: $m =$ pill mass [kg]

$\bar{a}_r =$ acceleration in relative motion $\left[\frac{m}{s^2}\right]$

$\bar{R} =$ the resultant vector of active forces [N]

$\bar{R}_l =$ the resulting vector of binding forces [N]

$\bar{F}_{jt} =$ inertial transport force [N]

$\bar{F}_{jc} =$ inertial Coriolis force (rel. 1) [N]

Whose scalar relation is:

$$F_{JC} = 2mv_r\omega_t = 690 \text{ N} \qquad (2)$$

where: v_r – relative velocity of the pill [m/s]

ω_t – angular velocity of the rod [rad/s]

From relation (2) it could see that the Coriolis force depends on ω_t, so there must be a circular motion and a relative speed v_r.

The direction of the Coriolis force is in the plane of the frame, it is perpendicular to the plane formed by (v_r and ω_t) for this reason it will deform the rod.

2. CLASSIFICATION OF THE ELEMENTS NECESSARY FOR THE DESIGN OF THE DEVICE

In the following, we will define the component elements [9] of the designed equipment, mentioning that in its design, the diameter of the frame, respectively the length of the rod, will be impose, and a calculation that is reproducing in the following according to [2].

In addition, apart from the reduction of the dimensions of the equipment, the reduction of its mass was take into account, respectively the materials chosen and the assembly of the components improved, compared to the existing ones. It has been improved, especially the method of assembling the components on the shaft of the rod, movement transmitted through the belt from the engine, all of which are detailed in the following.

In this case (Fig. 1), by a brief description, we speak of a rotational movement given by the rod (3), on which is fixed a body called the pill (2) which can perform a rectilinear motion along the rod (3).

The device includes the **basic elements** (Fig. 1) such as those that highlight the sag given by the Coriolis force:

- frame (1) in which the elements are fixed;
- the pill / body (2) necessary to perform the rectilinear movement;
- stem (3);
- graduated ruler (4) and,

the **secondary elements** (Fig. 1, Fig. 2) but, particularly important in terms of mounting the basic elements such as:

- *upper steering* (5) wheel driven axle;
- *shaft (6)* on which the basic elements of the device are fixed;
- *flat plate* (7) for fixing the rod;
- *counterweight* (8);
- *electromagnet* (9) trigger of the rectilinear movement of the *pill* (3);
- user *protection wire* (10) important in terms of protection of the person handling the equipment;
- frame support *legs* (11);
- *bearings, wedges* and *bolts* / fastening *nuts* (12) of the elements as a whole etc.;
- *flywheel* (13) with the role of driving wheel, which takes over through the belt the movement from the engine shaft;
- *belt* (14);
- *engine* (15);
- device *switch* (16);
- etc.

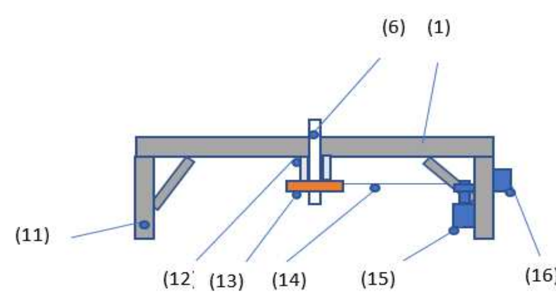


Fig. 2 Secondary components of the equipment.

2.1 Recalculation of rod length

In order to be able to resize the equipment frame [10], [11], respectively redesign the equipment, the formula of the theoretical arrow (f^{teor}) was used, where its value and the other dimensions, less the length of the rod [3], were imposed, this resulting from the calculations [2] and later taken as the basis of the design of the equipment frame.

$$f^{teor} = \frac{16\pi}{675} \frac{n^2 m l_1^2 \sqrt{x^2 - x_0^2}(2l_1+3l_2)}{Ed^4} \text{ [mm]} \qquad (3)$$

In relation (3), in conformity with relation (1), we have:

$d = 0.05$ m,
$n = 600$ RPM, $l_1 = 0.300$ m, $l_2 = 0.04$m,
$x = 0.30$m, $x_0 = 0.065$m
$m = 0.3$ kg, pill mass/mobile weight (3).
d/l – diameter/rod length (2)
l_1, l_2 – the distances from which the pill starts and stop
x_0, x – the initial distances of the pill due the clamping elements on the shaft
n – frame shaft rotation
E – longitudinal elasticity module from steel (Young module) = 2.1×10^{11} N/m^2.

From (3) resulted a value of the rod length imposed according to [2] and recalculated for the values given by the study of:
$f = 0.015$ m (15mm) - the imposed sag on the rod (2) and $d\_rod = 0.005$ m (5 mm) - the diameter of the rod.

Therefore, the calculated frame diameter is:
$D\_frame = 0.32$ m, the minimum diameter calculated to check the sag.

Because, constructively, the frame with diameter $D\_frame = 0.32$ m would be too small, although the rod with l = 0.15 m would check the imposed sag. It optimize upwards, to obtain $D\_frame = 0.60$ m, which means that: length $l\_rod = 0.28 – 0.29$ m with the same $d = 0.005$ m and we will probably get an sag (f^{teor}) greater than 0.015 m.
Thus, the diameter of the frame was constructive IMPOSED:

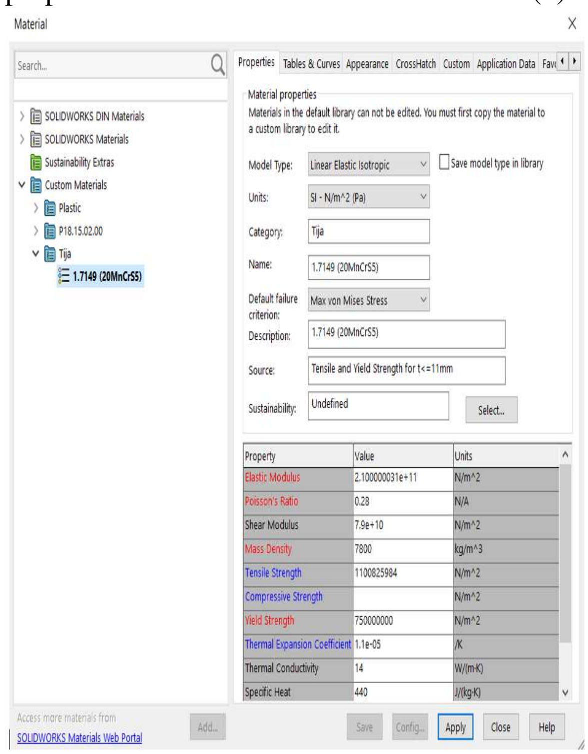
$D\_frame = 0.60$ m.

Returning to relation (3) with the value $D\_frame = 0.6$ m, which implies the recalculation of the lengths l_1 and l_2 according to [2], a $f^{teor} = 0.030$ m will result (much more visible). The purpose of the redesign, as previously specified, is that the reduction of the device, respectively the reduction of the rod (3), should not lead to a reduction of the Coriolis effect so that the theoretical arrow is not observing, and the calculations and values imposed on D_frame demonstrated what we wanted to highlight.

2.2 Modeling of the rod subject to bending

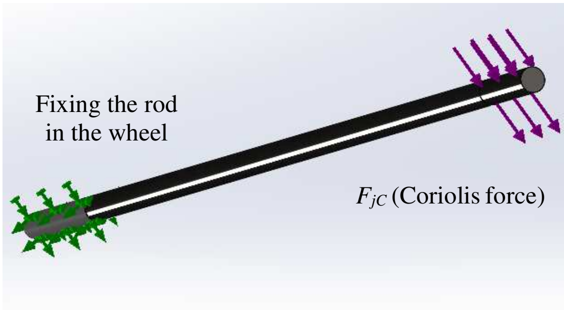
It is impetuously necessary to check if the rod resists bending under the effect of the Coriolis force. In order to model the rod and verify its bending, an FEA analysis of the device rod was perform using SolidWorks software.

Tab. 1 Settings regarding the choice of properties in the FEA simulation of the rod (2).

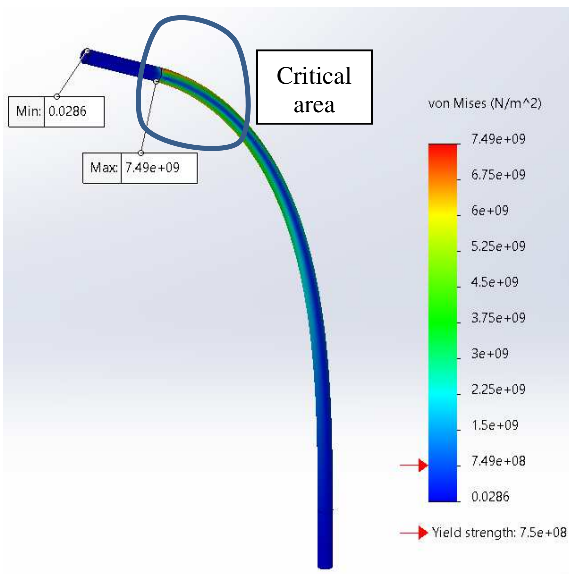


The material selection regarding the simulation is equivalent to that of the device design and are show in the table 1. FEA simulations for bending and deflection are performing in a preliminary form starting from theoretical formulas.

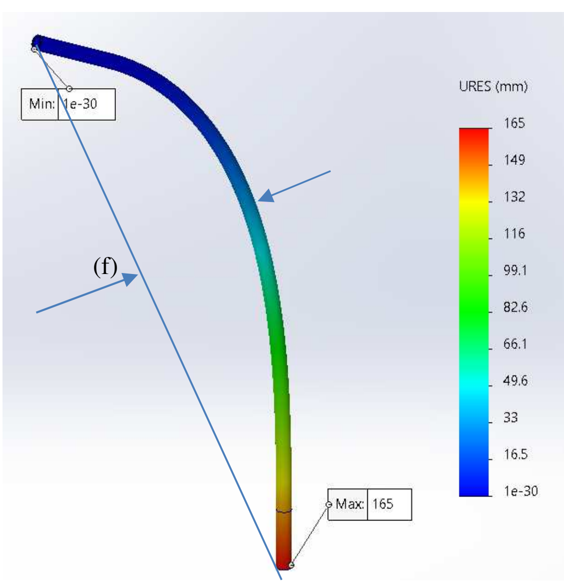
FEA Analyzed Requests:



a. Catching the rod (2) in the steering wheel [1].



b. Bending.



c. Sag.

Fig. 3 Rod (imposing conditions during FEA simulation).

It is observing in the table 1 and figures 3a and 3b how the properties of the rod subjected to the Coriolis force are set, which in the end, under the action of the bending stress, will produce the sag (*f*) (Fig. 3c).

The value of the Coriolis force is given by relation (2), namely F_{jc} = 690 N so that its value could be imposed in setting the simulated properties from table 1, and its deformation direction results in the plane of the frame (thank) perpendicular to the plane formed by v_r and ω_t.

Thus, figure 3a shows the static fixation of the positioning characteristics of the rod (3), in its threaded area, and on its end, due to the relative movement, the Coriolis force appears. This bends the rod (3) under the sag (*f*) in figure 3c, a dangerous red zone is observing at the exit of the rod from the wheel where it is screwing, which proves that the steel rod can break due to fatigue.

This fact was also demonstrated by practice, in the already existing device, a fact that later required the manufacture of the protective net shown in figure 1.

Fixation of the rod in the wheel is giving by screwing, unlike the existing one that was fixe with tightening.

3. FUNCTION DESCRIPTION OF THE EQUIPMENT

Developing the appearance of the relative movement through the prism of the designed components, we will be able to state that:

The principle of operation of the device studied and shown schematically in figure 4 is that it produces a sag (*f*) only if there is a Coriolis force, and it occurs only in the case of relative motion.

The relative motion will consist of a rotational motion of a rod (3) together with an engine shaft and at the same time a relative motion produced by the release of a pill (4) from an electromagnet (9), this making a rectilinear motion along rod (3) (with relative velocity (v_r)).

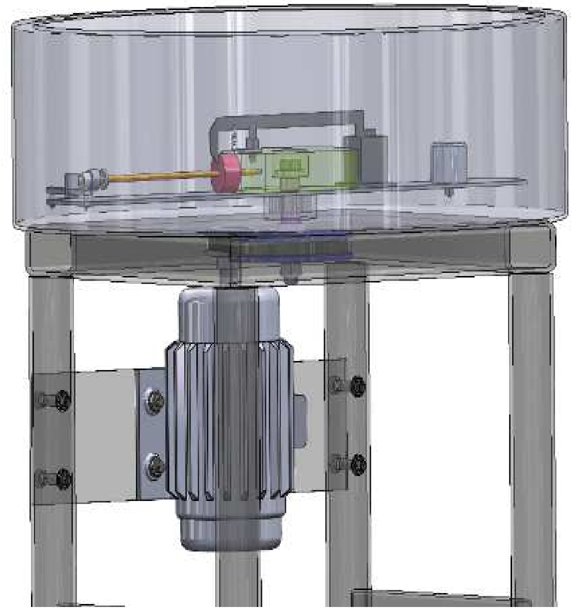
At the beginning of the movement, the cursor will be set to zero, on the ruler (4) which shows the sag given by the Coriolis force. The engine (15) is the triggering factor of the rotational movement, of course when actuating the switch (16). The engine will transmit through the belt (14) a rotational movement of the driven flywheel (13), which will transmit the movement of the main shaft (6) of the frame (fixing it with bearings, shoulder bushes, wedges etc.). The shaft it will rotate together with the flywheel (5) by which the rod (3) is attached. By operating the electromagnet (9), the body (2) will execute a rectilinear movement along the rod (3).

When the device is stopped, the position of the cursor on the ruler (4) is observed, which is no longer in the zero position, this means that the rod (3) which was initially supported in the zero position of the cursor, during the operation of the device was deformed with a sag (f). The sag is give it by this movement of the cursor on the ruler (4).

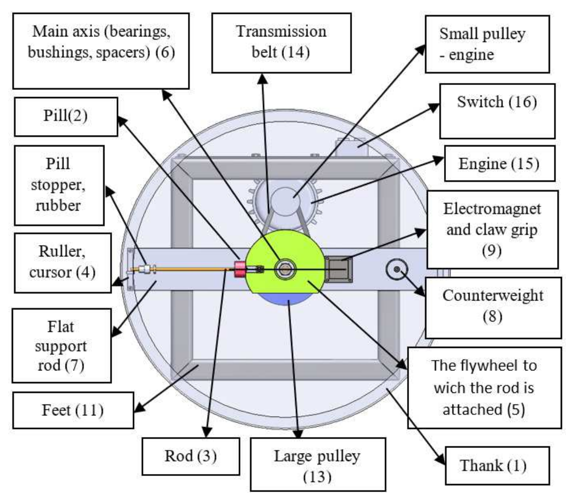
4. IMPROVING THE DESIGN EQUIPMENT COMPONENTS OF POINT OF VIEW OF DIMENSIONS AND MATERIALS

The design of the device components (Fig. 4) will design with SolidWorks 2022 software and it turned out that, in the construction of the equipment there are components without which the Coriolis effect cannot visualized, components still called basic elements, but of course accompanied by secondary components without which the equipment could not work, hereinafter referred to as secondary components. Thus, in the figure 3 show the basic and secondary components (top view) that make up the designed device.

A basic component of the device (Fig.5), and which occupies a special place in this study, has the elastic rod (3), which must be determinate in a first phase, all the overall dimensioning of the equipment starting from this calculation. Thus, in addition, to its sizing and strength calculations [2] and which study another paper. The rod as the main effect, in terms of strength is bent, but the resulting displacement (sag (*f*)) is also analyzing).



a. Ensemble equipment [1].



b. Equipment top view.

Fig. 4 Diagram of the functional designed elements of the equipment.

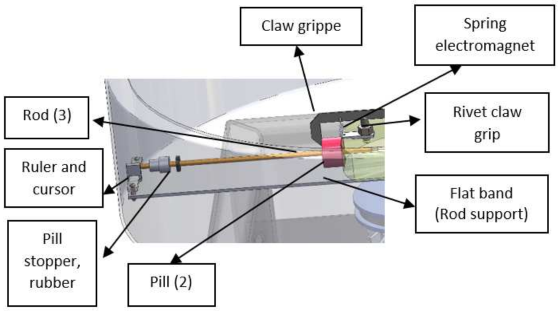
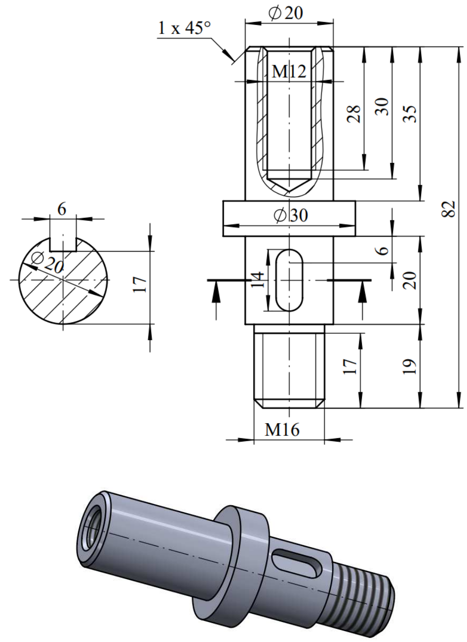
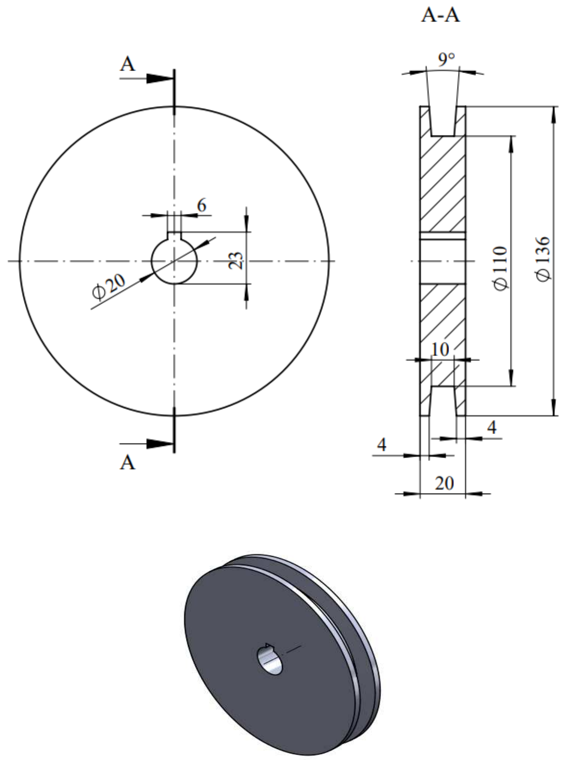


Fig. 5 Breaking the catch of basic components.



a. Main axis of rotational transmission in the frame.



b. Large pulley.

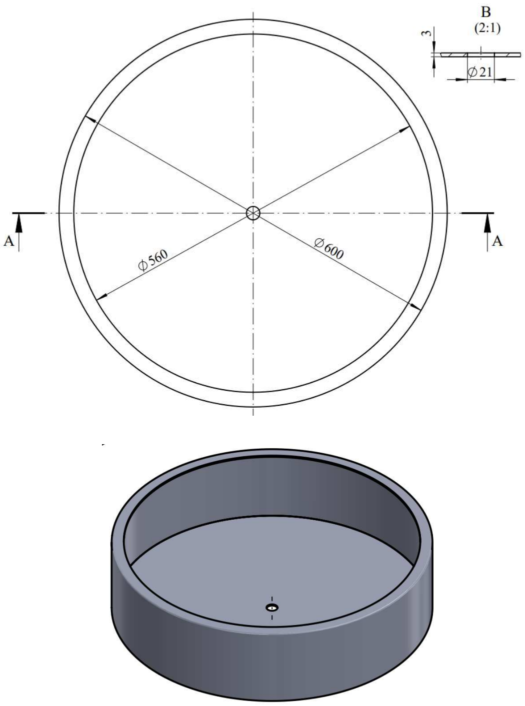
The components shown in figures 4 and 5 will give in the following paragraphs and briefly described [7], [8], [9]. Such, the shaft is of the steel and the road is fixe in them. Unlike the existing equipment that had a rolled steel rod (OL37), the redesign make with elastic steel (20MnCrS5).

The shaft has a length of 82 mm and diameter of 20 mm, and the final it is final screw thread of M16 (Fig. 6a), smaller than the existing one that had a length of 110 mm, the one that resulted from the calculations [2] and in this way saving material, respectively reducing the size and mass of the device.

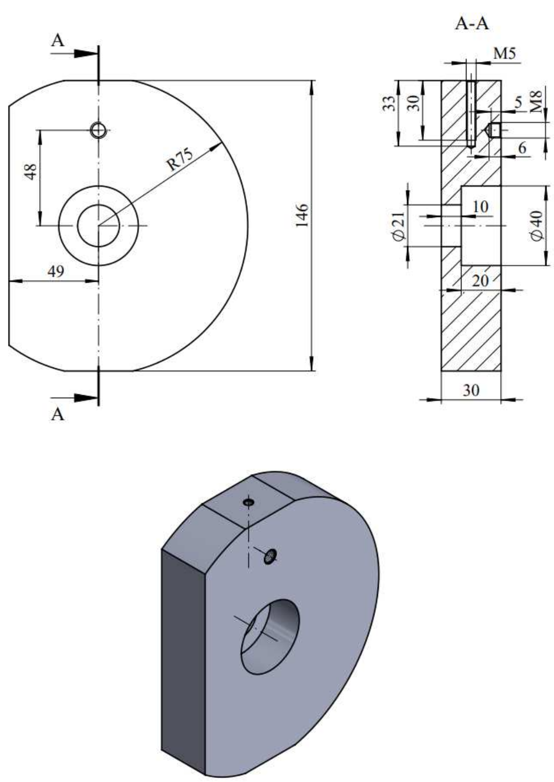
The wheeler (Fig.6d) that drives the large pulley has the role of reducing the engine velocity from 1500 RPM to 600 RPM and is made of steel (S235JR), and on which is wound a trapezoidal transmission belt (standard) that transmits the rotational movement from the pulley's engine.

The pulley has an outer diameter of D = 136 mm (Fig. 6b). This choose starting from the diameter of the shaft section on which it is mounted, other parts depending on the engine velocity, and the pulley is assembled on the shaft with the help of a parallel wedge.

The old frame or frame (1) is make of 3 mm thick of S185 steel, in comparison with existing frame that has a think of 5 mm and a diameter of 60 mm (Fig. 6c), the last is resized diameter. As can be seen, the thickness of the frame had reduced, which leads to a reduction in the mass of the device, without affecting the studied Coriolis phenomenon.



c. Frame



d. Wheel[1].

Fig. 6 Functional components of Coriolis equipment.

CONCLUSIONS

The paper achieved its goal in terms of component design so that, it managed to achieve what it set out to do, and reduce the overall dimensions of the studied device, while managing to maintain the effect given by the Coriolis force. We mention that all this was possible starting from the calculation of the rod length (3) imposing the value of the theoretical sag [2] so that, from here resulted the overall dimension of the tank (1), taking into account that the rod (3) performed a rotational movement as space for movement in this frame.

It is also necessary to mention some aspects regarding the way of redesign different from the existing one when mounting the secondary components on the movement shaft, without which the relative movement could not have taken place. For example, the rod (3) is mounted in the wheel (5) by screwing, also the wedge element that fixes the shaft (6) to the wheel (5) etc.

The paper also highlights how equipment based on the Coriolis force could designing and built [1]. As advantages of the Coriolis effect we mention its use in the construction of high-performance gyroscopes [6], and the disadvantages are the wear of parts of mechanisms that due to the phenomenon of fatigue, they break over time.

Using the FEA (Finite Element Analysis) module in SolidWorks software provides the tools needed to quickly test projects and read them intelligently providing accurate and reliable results.

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Proiectarea unui dispozitiv cu scopul măsurării săgeții ca efect al forței Coriolis

Rezumat: Lucrarea doreşte să prezinte un studiu privind remodelarea la dimensiuni reduse a unui echipament care efectuează o mişcare relativă şi evidențiază săgeata unei tije, ca efect al forței Coriolis. Remodelarea pornind de la dimensiunile tijei şi implicit cuva în care aceasta este fixată. Bineînțeles că, acest calcul este urmat de proiectarea altor elemente de asamblare ale echipamentului precum: cuva în care este evidentiată mişcarea, axul care transmite mişcarea de la motor prin curea, fixarea axului de cuva echipamentului etc.

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