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DETERMINING THE POSITION OF THE CENTER OF GRAVITY BY TENSIOMETRIC MEASUREMENTS FOR THE MACHINES WITH BUCKET WHEELS USED TO REMOVE COAL FROM DEPOSITS

Răzvan Bogdan ITU[1], Florin VÎLCEANU[2], Gheorghe Bogdan URDEA[3]*

[1]University of Petrosani, Romania, razvanitu@upet.ro
[2]University of Petrosani, Romania
[3]University of Petrosani, Romania

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Abstract: *The machines with bucket wheels used to remove and to put coal in deposits are intended to dump and remove coal from quarries and power station deposits. The paper presents how to determine the gravity center of a machine with bucket wheels used to remove coal from deposits, by tensiometric measurements, in various positions of the arm of the bucket rotor (wheel). The machine with bucket wheel used for taking out from deposits is within Arcelor Mittal Galați. The measurements have been made in limit positions of the arm of the bucket wheel, horizontally and vertically, respectively, and have been made because of determining an additional weight that should be added in the ballast box of the equilibrium arm, if appropriate.*
Keywords: *removal and depositing machine, center of gravity*

1. Introduction

Machines with bucket wheels for removing and depositing are part of the technological machinery used in quarries, machinery used for transport and dumping, from the simplest (bucket excavators, truck hauling) to the most up-to-date and sophisticated ones (rotor excavators, heavy transporters, depositing machines, reloading bridges, direct dumping bridges). Removal and dumping machines belong to the category of depositing machinery. They are intended to dump and remove coal from the quarry, power station, or iron-and-steel works deposits. Coal deposits, either from the power station precincts, or from mines, are manipulated with the help of depositing machines, removal machines, or mixed, because of consumption, or loading coal in means of conveyance. Similarly, there may be machinery in the deposits that homogenize coal, for a certain requirement of the consumer (specifically power stations) [1].

Fig. 1. Removal machine from deposits with bucket wheels

In a way, the dumping machines in deposits can be assimilated to the dumping machines in wastes, as a principle of forming piles, and the removal machines to bucketwheel excavators.

The bucket wheel machine, meant to remove coal, which is the object of this paper, operates in the Iron-and-steel Works Galati, (officially Liberty Galati, previously Arcelor Mittal Galati and Sidex Galati, which is the largest Iron-and Steel Works in Romania. (Fig. 1).

[*] Corresponding author: Itu Răzvan Bogdan, assoc.prof. Ph.D. eng., University of Petrosani, Faculty of Mechanical and Electrical Engineering, Department of Mechanical, Industrial and Transport EngineeringPetrosani, Romania, Contact details: University of Petrosani, 20 University Street, razvanitu@upet.ro

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The removal (and depositing) machine with bucket wheel, is part of the heavy machinery for the exploitation and manipulation of coal at the surface, as with the rotor excavator and the dumping machines, have a relatively small support base, and the constructive parts, over which great forces act, extend much towards the exterior.

For such structures, stability is a critical issue, since the resultant of all the forces acting, should not reach or exceed the outline of the support surface, because that might lead to flipping the support structure over.

The problem is more difficult since the center of gravity of the machinery's own mass is much above the support structure and so is the point in which exterior forces act on the machinery.

2. Removal and dumping machine in deposits

Machines that remove and dump from and in deposits, with bucket wheels on track, are part of the family of the machinery of coal households, intended to dump and take over coal to and from the coal deposits of quarries, power stations, or iron-and steel works.

The load-bearing structure of the machinery has the following sub-units (Fig. 2):

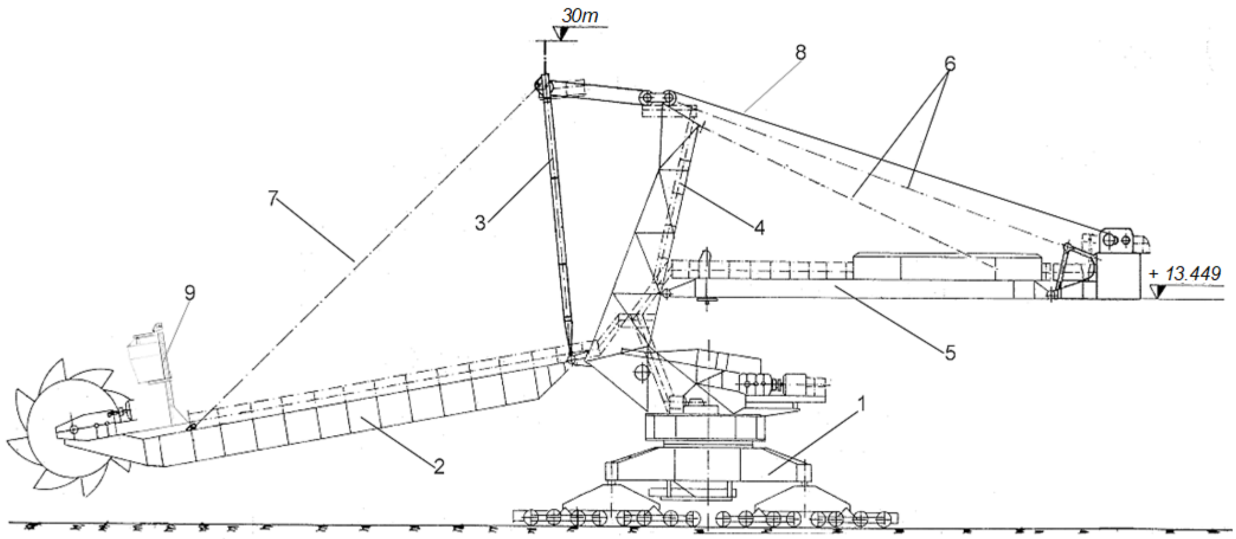

Fig. 2. Construction sub-units

1–tripod and rotating platform (travel mechanism); 2 - boom (arm of the bucket wheel); 3–articulated mast; 4–fixed tower; 5– balance arm; 6–balance anchor arm tie-bars (secondary); 7- boom anchor tie-bars (principal); 8–boom lifting-lowering cables; 9–control cabin

A tripod (lower load-bearing structure or basic chassis) is a triangular metal construction, placed above three pairs of balances of the marching mechanism, which travels by the running wheels on a railway track.

On the basic chassis, the lower ring (running track) of the rotating bearing is mounted, with a toothed crown, interlocked with threaded screws to the basic chassis. Above the bearing, the pivoting load-bearing metal construction is assembled, made up of the rotating platform, the tower, the balancing arm and the wheel arm with buckets (boom) with articulated pillar.

The rotating platform is found above the basic chassis and can rotate through the support bearing and the toothed crown, the movement being given by the rotation mechanism (motor – brake- reduction gear – attack pinion).

The arm of the wheel with buckets-boom is a special metal construction, rigidized for torsion, that works in the console. It is made up of two longitudinal sections, and a third lateral section, in console. At the end of the console, the bucket wheel is found and its driving mechanism. The second end of the bucket wheel arm is articulated to the tower through two axes (boom rotation center). Each of the two axes is applied by bearings at one end by a set of annular fixing wedges. On the arm of the bucket wheel, the conveyer belt is mounted (reversible), which conveys the excavated material to the receiving funnel that is found above the rotating platform, and/or the material coming from the conveyer belt (for depositing regime of the machine).

The mast rests on the bucket wheel arm and attaches with the help of the tie-bar the arm part in the console. The arm of the bucket wheel, the part up to the console articulated to the tower, the mast, and the principal tie-bars (front) make up special triangles, which cannot be distorted, that take over the special forces from the chipping and conveying process.

The tower is the principal part of the fixed metal construction, which rests directly on the rotating platform, and in the upper part there is the block with the cable guiding rollers of the lifting mechanism of the bucket wheel arm. Of the metal construction of the tower, which is a spatial lattice girder, the balancing arm is rigidly fixed, ending with the ballast box.

The balancing arm (counterweight arm) is a spatial rigidized metal construction, on which the cabin with control and monitoring apparatus is found, as well as the electrical transformer. At the end of the balancing arm, the tiltable ballast box is found. On the ballast box the lifting mechanism of the arm–wheel–tie–bar–mast unit is mounted.

The anchor tie-bars of the balancing arm connect the balancing arm and the tower. Their role is to support the balancing arm. They are part of the safety and load-bearing elements of the machinery.

Anchor tie-bars are principal elements helping in lifting and lowering the bucket-holder arm vertically.

Boom lifting – lowering cables – using the pulley battery, they lift and lower the bucket-holder arm.

Control cabin is on the bucket wheel arm, being the machinery control point.

The machinery can function in a *depositing regime* – takes over the coal of the conveyer belt (the rotating mechanism of the superstructure and of the arm lifting ensures homogeneity, plus the matching mechanism ensures depositing along the entire length of the deposit); *take over regime*–from the deposit piles; *direct regime*–the machine is in functioning – stationary regime [2].

3. Determining the center of gravity

Determining the center of gravity of the machinery can be done by weighing or by tensiometric measurements.The classic method of determining the center of gravity by 'weighing', lies in lifting the superstructure on hydraulic cricks with static determinations for certain distinct situations.

For this, the machinery must be on horizontal ground, with good and safe carrying capacity in time. The difference between the levels of the three resting points is maximum 15 mm (we use a theodolite). Again, the machinery's conveyer line is empty of material. The arm of the bucket wheel and the bucket wheel are cleaned (in the inside too). The stairs, catwalks, metal constructions, mechanisms, etc. are cleaned, the possible tools, parts that by falling could lead to accidents are removed.

The electric supply is cut off. Measures are taken to avoid accidental turning on the voltage.

The machinery structure is rotated as to the basic structure, so that the points on the chassis and on the rotating platform, marked for mounting the hydraulic presses (cricks), would match. These points should overlap as exactly as possible. The bucket wheel is left at 0,5 m above the floor.

The points of application of the hydraulic presses are specified in the documentation regarding the distances between them and to the rotation center of the upper platform (superstructure). Groups of presses by two are used. In mounting the groups of presses in view of even distribution of lifting forces, both in the upper part, and in the lower part of the presses, one metal beam will be interspersed between the lifting points and the group of presses, for each. The presses will be symmetrically positioned to the lifting points marked on the base chassis close to one another. Each group of presses is hydraulically coupled between them, for evenly lifting from all the marked points, for even distribution of the forces of the presses in the groups, to be able to measure the lifting force on each of the points of application of the marked presses, to measure the lifting height in the marked points.

For the verification of the lifting forces, whence conclusions are drawn regarding the position of the center of gravity of the excavator superstructure, for each group of presses, a manometer, previously checked metrologically before use, is mounted.

From a constructive point of view, the machinery is supported by three travel mechanisms. The weight of the machinery is supported by the group of the three mechanisms loaded by means of spherical bearings, which form in the horizontal plane, an equilateral triangle *ABC*, the center of the circle circumscribed in, and inscribed outside, being situated on the vertical rotation axis in the horizontal plane of the superstructure (Fig. 3).

Through these bearings, pressures are transmitted to the travel mechanisms, and further to the ground.

The R_A, R_B and R_C reaction values being known, measured in *A*, *B*, and *C* supports, the weight of the superior rotative platform and the position of the superior platform's center of gravity projection, in *ABC* triangle plane, can be determined.

We consider two systems of reference, a mobile *Oxyz* reference system, attached to the upper platform with *Ox* axis along the arm of the bucket wheel and with the positive sense towards the wheel, and a fixed reference system $O_1x_1y_1z_1$ with O_1x_1 axis, passing through point *A* and perpendicular on *BC*, with the positive sense of the axis towards point *A*. Axes *Oz* and O_1z_1 of the two reference systems coincide, and the origins *O*

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and O_1 of the two reference systems coincide among them and coincide with the rotation center as well, situated in the ABC triangle plane, on the vertical rotation axis.

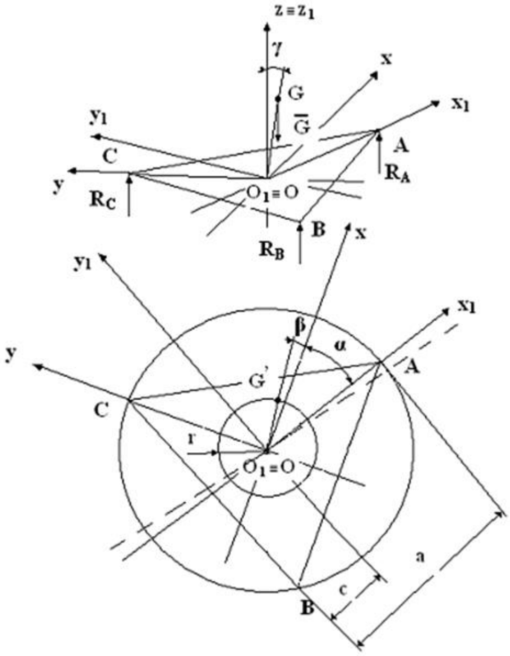

Fig. 3. Scheme of the machinery support

If we reduce the applied forces, and all the connection forces related to point *O* (sum of the resultants and sum of the resultant momentums), we obtain the elements of the reduction torsor. From the necessary and sufficient equilibrium conditions, known from mechanics, these elements equal zero.

Projecting the vectorial relationships on the axes of the coordinate system (reference system), equilibrium equations are obtained for the rigid body actuated by a particular system of forces, as in the case considered, parallel forces in space, and, respectively, 3 scalar equations, an equation of projections from the resultant (on *Oz* axis), and two projection equations from the resultant moment on *Ox* and *Oy* axis). It results that the support on the three spherical bearings is statically determined.

Solving the system of equations leads to obtaining expressions of R_A, R_B and R_C reactions from bearings, function of αandβ angles, and reactions that have two components each, one constant and one variable. Variable components are a function of the α position angle of the arm and are harmonic, de-phased between them with 120°.

Since these components are harmonic forms, the corresponding signal of a sensor placed at one of the bearings, will have a proportional form of variable signal [3].

3.1. Location of the measuring point

In order to determine the variation of the position of the gravity center of the upper rotating platform (mass unbalance of the excavator), it is sufficient to process the signal of a single sensor placed in the vicinity of the bearing on the connecting beam.

Resistive transducers have been applied in the middle of the translation mechanism on the principal beam, as per Fig. 4

Fig. 4. Positioning of transducers on the beam

Fig. 5. Beam calibration

One can notice that one of the transducers is longitudinally applied on the beam, and the second is transversally applied on the beam.

In view of measurements, the following stages have been applied:

1. The beam has been calibrated to determine the position of the initial center of gravity. The calibration has been made with a hydraulic crick of 200.000 N, and with a tensiometric transducer of 100.000 N, as per Fig. 5

2. In order to determine the position of the center of gravity, in horizontal position the arm rotated from left to right, from 0 degree to 180 degrees, Fig. 6. Angle Φ represents the position of the arm and is in the range of 0 – 180 degrees, and β represents the center of gravity as to the machine arm, OC_g represents the radius at which the center of gravity is.

3. To determine the position of the center of gravity in the case in which the arm moves in extreme positions, namely, *-9°...9°*, the beam has been brought to *0°* position, that is, on the bearing where the transducers are placed.

The measurement apparatus is a SPDER 8 tensiometric amplifier with 8 channels, Hottinger Baldwin Messtechnik made. To record the value of distortions in dynamic regime, the amplifier is connected to a PC using an analogous -digital convertor. Electroresistive transducers have the following characteristics:

3/120 LP 21 type- Hottinger Baldwin Messtechnik made;

Ohmic resistance R=120Ω;

TER factor k=2,01;

Manufacturer series V-13202/21 Lot Nr: Y-5.

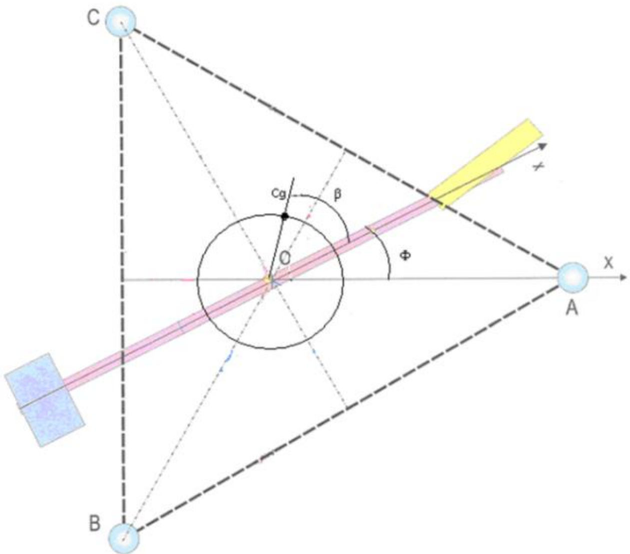

Fig. 6. Plane scheme of the machine

Transducers have been applied with X60 type adhesive, lac protector de tip PU120 type protective lacquer, made by Hottinger Baldwin Messtechnik.

The measurement apparatus is heated under voltage for 30 minutes, after which all the measurement points are balanced and recordings are made in a dynamic regime [4].

3.2. Measurement results and their interpretation

As a result of calibration, force diagrams have been recorded (given force captor) – distortion (given by eletroresistive transducers), Fig. 7. Following the calibration, the constant resulted. The recorded values have been analyzed by collinearity correlation and c=51965 constant resulted, with which specific distortion, mass conversion will be done, Fig. 8.

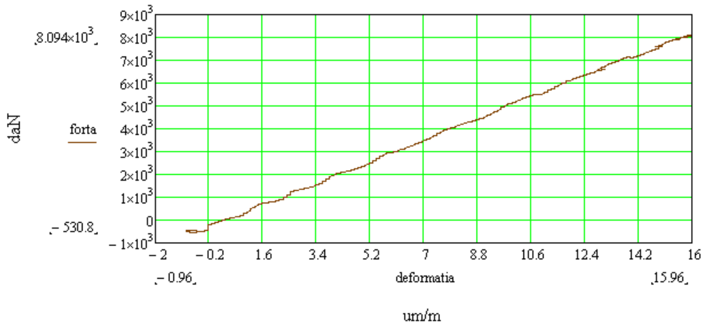

Fig. 7. Force–distortion diagram

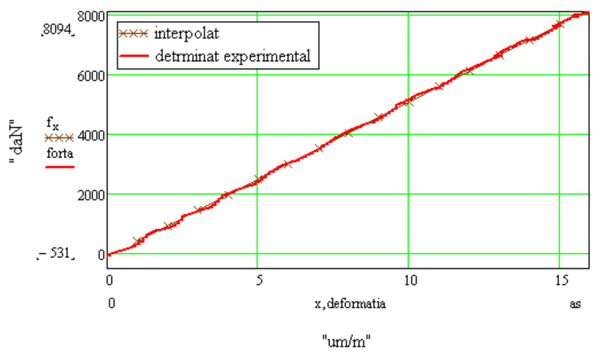

Fig. 8. Results interpolation

The results of the center of gravity position calculated based on the measurements undertaken are shown in Table 1, and the diagrams from below, OC_g and β as per Fig. 6.

Table 1. Measurement results

Rotation	**OC_g [mm]**	**β [degrees]**
Rotation 1	488	5,9
Rotation 2	482	4,8
Rotation 3	485	5,64
Rotation 4	493	9

Fig. 9 shows the signals recorded in the case of rotation of the arm in trigonometric sense, from bearing A (see Fig. 6), zero point, to a 180-degree domain, Fig. 6. The signals presented are: recorded signal and filtered signal to avoid possible perturbations. The diagrams presented are in specific distortion, *μm/m*, function of the rotation angle of the arm.

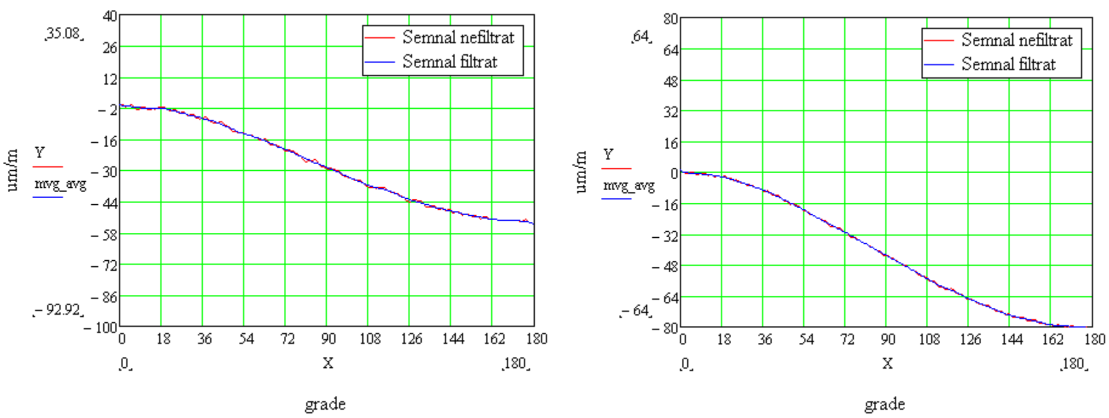

Fig. 9. Recorded signals [unfiltered signal, filtered signal]

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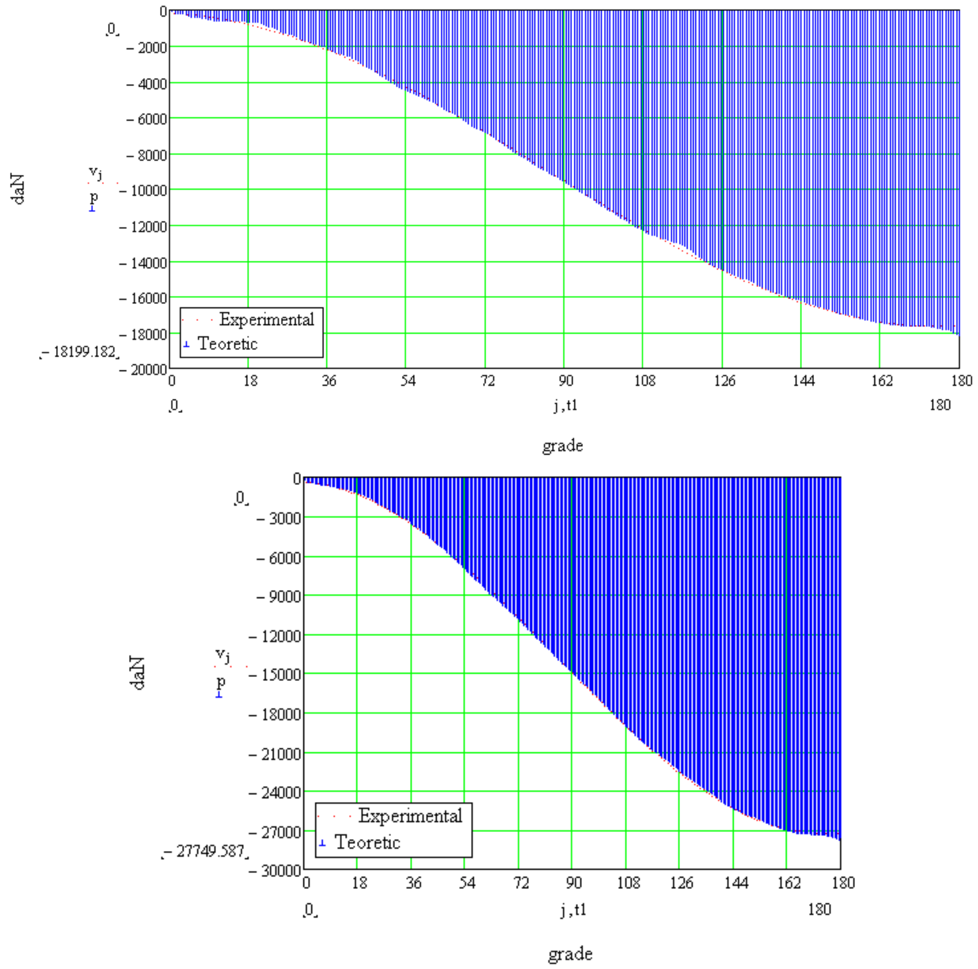

Fig. 10. Force variation on A bearing, function of the rotation angle of the arm

Fig. 10 shows the force variation, function of the rotation angle. Diagrams are determined on theoretical and experimental principles.

Fig. 11 shows the variation of specific distortion on bearing *A*, function of the vertical position of the arm, -9° ... 9°. Analyzing the diagram, a 178 mm oscillation resulted, compared to OC_g eccentricity.

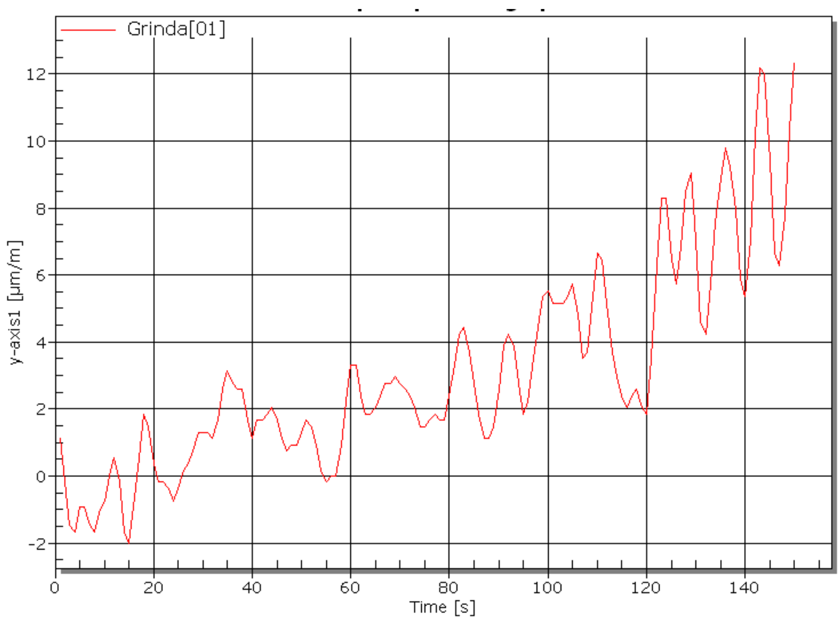

Fig. 11. Force variation on A bearing, function of the descending angle of the arm

4. Determining the additional mass

With the following data:

l = 17800 mm, the distance between the ballast box and the rotation center;

m = 197081 kg, superstructure mass;

OC_g=485 mm, eccentricity value, Table 1

additional mass is determined:

$$m_a = \frac{mr}{l} = \frac{197081 \cdot 485}{17800} = 5370$$

5. Conclusions

Following the system calibration, 519,65 constant resulted.

Following the arm rotation in a horizontal position, the following eccentricities resulted 488 mm, 482 mm, 485 mm and 493 mm. All these eccentricities are towards the rotor, angle β< *90* grade.

In the case of lifting the arm from -9 to 9 degrees, the position of the center of gravity has a deviation of 178 mm.

In the case of the machine at which the ballast box is at l= 1780 mm to the rotation center, and the superstructure mass is m= 197081 kg it resulted that 5370 kg should be added to the ballast box [5].

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