Balance Control by Weighting and Tensiometric Measurements of Bucket Wheel Excavators

MARIN SILVIU NAN, IOSIF KOVACS, FLORIN DUMITRU POPESCU
The Machine and Installation Department
University of Petroşani
Str. Universităţii, Nr.20, Petroşani
ROMÂNIA
mnan@upet.ro, ikovacs@upet.ro, fpopescu@gmail.com
http://ime.upet.ro/mi/index.html

Abstract: - An essential element when establishing the balance of a bucket wheel excavator is the determination of the barycentre, the best results being thus obtained by weighting after having installed all the components. The problem, on which emphasis is laid, is how to maintain the stability and equilibrium of bucket wheel excavators or any other extraction machinery during operation, the main machinery of a technological extracting system employed for coal mining. The balance survey, respectively that of the stability of these machineries is compulsory because the bearing surface is rather small compared to the other building sub-systems outside the range of the surface, onto which much higher forces operate. The lack of correct balance for bucket wheel excavators determines their operation in an inadequate dynamic mode, or in extreme cases, there is the danger of losing stability by tilting over the excavator respectively suffering huge material and human loss. It is compulsory to verify for the correctness of the position and mass value of balance because there might be substantial error sources leading to compromise the operation. One of the most popular methods is that of weighting the entire equipment from the superior platform of the excavator. The weighting process implies the lifting of the excavators in three spots with hydraulic cylinders, the measurement of the forces, as well as the measurement of pressure inside the cylinders and of the stroke of each cylinder. The data measurement and rehashing installation is destined to determine the dimensions that finally define the weighting process of excavators or other operating machineries to which the balancing and control of stability is imposed. Thus, two types of data measurement and rehashing installations depending on the nature and type of the transducer used will be presented. For the first type, only analogical signals are transmitted to a numerical computer, and for the second type only digital signals are transmitted.

Key-Words: - Barycentre, Tensiometric bridge, Excavator, Force Transducer, Pressure Transducer

1 Generalities

Generally working machineries inside quarries and mainly rotor excavators have a rather small bearing surface, and the building parts, which are influenced by great forces, stretch towards the exterior of the surface.

The balance problem of such bearing structures is of utmost importance, because the resultant of all the forces which act on the structure is not allowed to touch or to overpass the perimeter of the bearing surface, consequently leading to the instability of the structure.

The problem is much more difficult because the centre of mass of the rotor excavator is higher than the bearing structure as well as the point where all the exterior forces act on the excavator.

Figure 1 schematically represents the superior part of a rotor excavator.

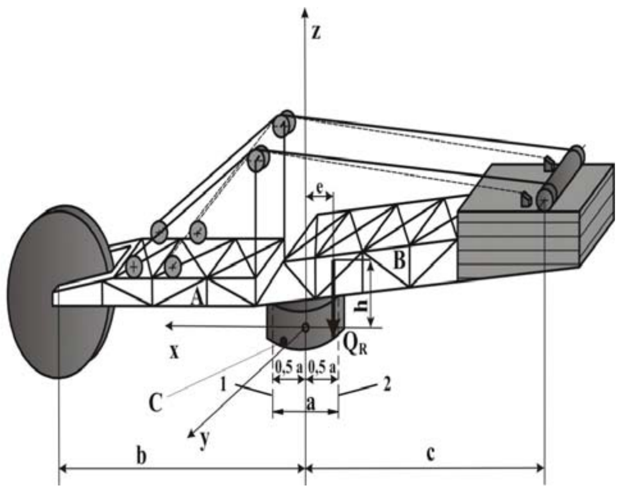

Fig.1 Specific elements of the balance and stability of the superior rotary platform of the rotor excavators

A – rotary arm;
B – counterweight arm;
C – rotary crown of the superior part;
1 and 2 – limits of the bearing perimeter of the superior part.

The limits of the bearing perimeter are represented by the numbers 1 and 2, are situated on a distance of 0,5×a from the axis of revolution of the superior part to the axis z of the reference system.
The distance between the two bearing perimeters "a" is small compared to the rotor "b" and of the counterweight "c".

The centre of mass of the superior part's weight QR is shifted by the extension "e" towards the arm, depending on "z", at a height "h" from the perimeter of the bearing surface.

These two measures "e" and "h" are not constant and depend on the height where the rotor is lifted, thus "e" is minimum when the arm of the rotor is in horizontal position and once the arm is lifted it rises, and "h" is minimum when the arm is lowered and rises as the arm of the rotor is lifted.
In horizontal position of the working machine, respectively the rotor excavator, and the resultant pierces the bearing surface to a distance "e" and an axis z. When the machinery is tilted, the point where the resultant pierces the bearing surface is shifted, and according to the direct tilt, the distance to the axis may be greater or smaller than "e".

2 Theoretical and Technical Considerations Regarding the Balance and Stability of Working Machinery

The vertical forces that act over the rotor on the axis (-z) shift the intercrossing point of all the forces toward the bearing perimeter 1, and the horizontal forces which act over the rotor on the axis (-x), only if this is situated under the plane of the bearing surface, producing the same effect.

The forces that act inside the rotor on the (+z) axis, respectively the forces inside the counterweight arm on the (-z) axis, shift the intercrossing point of all the forces toward the the bearing perimeter 2, and the horizontal forces which act inside the rotor on the (+x) axis, only if they act under the plane of the bearing surface and the forces on the (-x) axis producing the same effect if they act above the plane of the bearing surface.

An absolute operation of the excavator is possible only if the intercrossing point of the resultant of all the forces is situated inside the bearing surface delimited by 1 and 2.

Even in the most unfavourable situations of external forces manifestation, forces which might occur during operation, the intercrossing point of the resultant is not allowed to overpass the bearing perimeter, because otherwise not only the machinery might turn over, damaging the excavator, but also endangering the lives of human operators.

In order to tackle with the problem of stability, subsidiarily that of balance, the forces that act on the rotor excavator may be divided into two groups:

- All the forces which act continuously and constantly on a construction are part of the first group;
- All the forces which do not act continuously (i.e. all the exterior forces), and also the forces determined by the tilt of their own weight, are part of the second group.

The forces comprised in the first group are forces created by the weight of each component on the (-z) axis. For this kind of forces, the place of the centre of mass can be found out with the masses of the building parts in composition. Thus, some errors might turn up due to a high number of components which may not have an exact mass. It is recommended for the position of the centre of mass, given by the own mass, to be determined after having installed all the components by weigh in and only then to establish the necessary mass of the counterweight because it is interdependent to the position of the centre of mass. In order to be able to modify the mass of the counterweight from construction it is recommended to take into account for the design phase of a variation domain of ±10 % for the mass of balance determined theoretically. Due to the utmost importance of the size of the mass for the operation of the excavator, this has to be clearly specified in its technical documentation. Its size has to be clearly and visibly written on the exterior of the construction. The forces comprised in the first group are forces that give stability, due to their not modifying the size and position and continuously act on the (-z) axis. Due to these forces on the bearing surface the stability moments tend to appear.

The forces comprised in the second group are forces that tend to tilt over the machinery, developing around the bearing surface the moments, which may be theoretically calculated out of the individual forces. It is still in this group that the forces that appear due to the blocking of the rotor in the massif or due to the rotor's suspension on the slope.

Be it the case of suspension of the superior platform onto a ball bearing the perimeters are clearly being determined by the centre line of the rolling surface of the bearing. A clear improvement of safety can be obtained with the help of catch hooks (rams), between the superior rolling surface and the inferior rolling surface of the bearings.

Be it the case of special constructions for the rotary platforms, which can undertake traction forces, the edges of the bearing surface are situated outside the centre line of the rolling surface of bearings and is oriented in such a way that it is able to undertake moments trough the rotary platform.

If it is necessary to ensure similar conditions to the ball bearing normal rotary platforms it can be made only with the help of a construction with catch hooks that is able to undertake and transmit high traction forces between the superior and the inferior rotary part.

Such constructions with catch hooks operate only after the platform has already tilted, that is why its operation in combination of charges where no rotary movement will take place has to be limited.

On the machineries where the superior part of the rotary structure is fixed on a revolving base plate by spherical articulations, which permits the tilt, it is necessary to obtain a certificate of stability for the plane of the articulations.

Due to the fact that the articulations of tilt in most of the cases are closer to the rotary axis than the exterior perimeter of the bearing trajectory the certificate of stability is no longer necessary for the plane of the rotary binding.

For the plane of the fulcra of the inferior construction on the crawler belt system, depending on the rolling system, different forms of supporting perimeters may exist. In figures 2, 3 and 4 different forms of support types can be seen.

The inferior construction offers a constant value in order to determine the moment M_S, while for the superior part the different rolling positions need to be analysed.

Also for the moments M_r the most unfavourable position of the rolling part confronted to the bearing perimeter of the inferior part.

The inclination forces have an acute tilt effect because the bearing plan is situated lower, under the barycentre of the masses, respectively that of the rolling platform.

Mainly the weights of the building ensemble of the crawler belts does not have to be used for determining the safety to tilt in the supporting points of the inferior part because in most of the cases the building of the supporting points of the inferior part cannot undertake high traction forces. Only one stabilizing force of the supporting point of the inferior part can be taken into consideration, and which can be transferred through extension from the building of the supporting point to the building of the crawler belts.

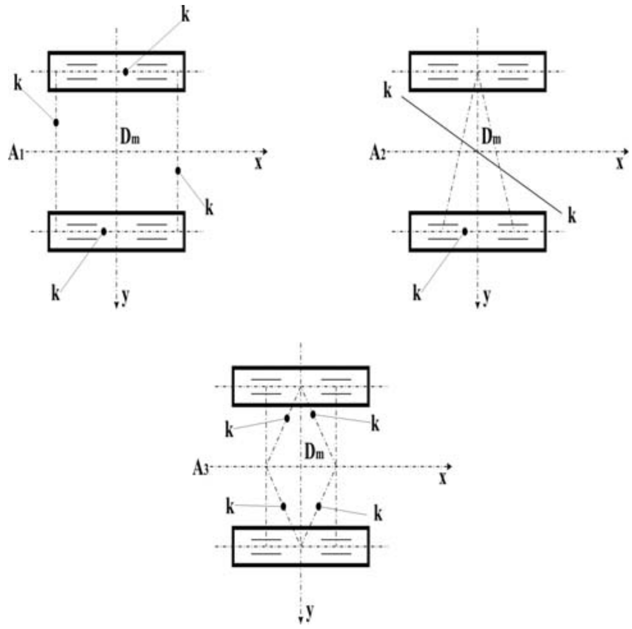

Fig.2 Support types for the rolling system with 2 crawler belts.

k – supporting perimeter;
A_1 – rolling system with 2 rigid crawler belts; guidance tilt roller;
A_2 – rolling system with 2 crawler belts; a immobile crawler belt and a revolving one;
A_3 – rolling system with 2 revolving crawler belts; balanced guidance rollers (compensating)

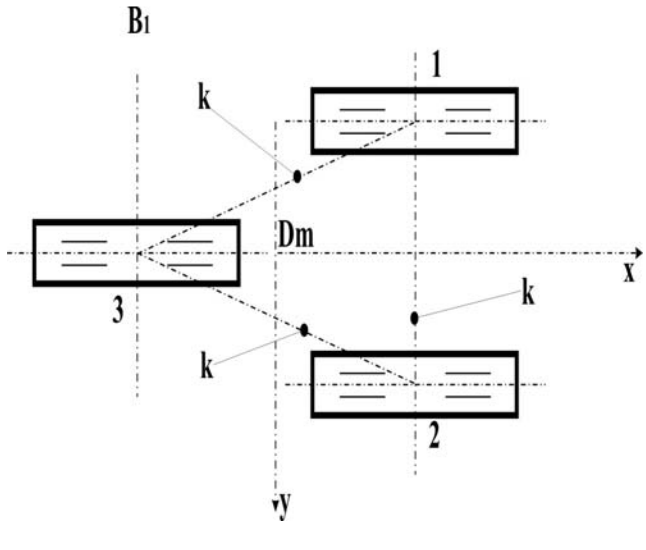

Fig.3 Support types for rolling systems with 3 crawler belts.

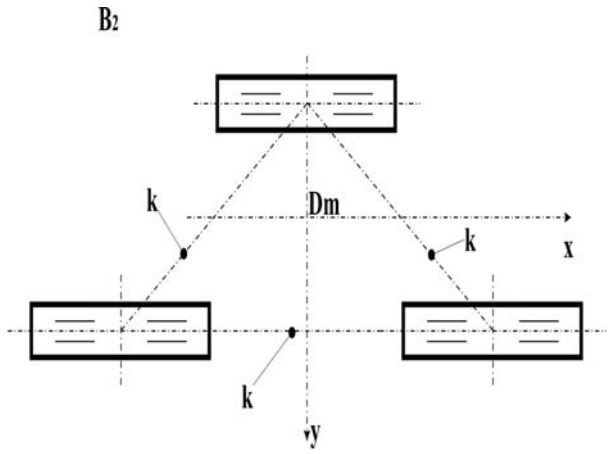

Fig.4 Support types for rolling systems with 3 crawler belts.

B_1 – rolling system with 3 controlled crawler belts; compensated guidance rollers;
B_2 – rolling system with 3 crawler belts, 2 controlled crawler belts; compensated guidance rollers.

Because the position of the barycentre may be influenced by the masses situated on the arm of the rotor and on the counterweight arm it has to be taken into consideration that the heavy objects which are not part of the construction of the excavator but which are necessary for repair works not to be left there when the excavator is in operation and to be discarded after these works have been done. If there is the need for some of these elements to be installed afterwards either on the arm of the rotor or on the counterweight arm then the weight of these elements needs to be balanced through a corresponding correction. This kind of corrections for the counterweight, need to be mentioned into the technical documentation of the machinery.

Be it the case of repair works where large masses are discarded, e.g. dismantling the operation of the rotor, stability measures need to taken (e.g. discarding a counterweight part, or butting it).

For the deposit or interchanging machineries, stability researches need to be done similar as for the rotor excavators. Both for the excavators as well as for the interchanging machinery, both the horizontal impulse as well as the supplementary vertical charge, need to be taken into consideration when calculating the stability.

3 Excavator analogical weighting system

The term analogical refers to the analogical signals sent by the transducers to a computer through an A/D data acquisition card (figure 5).

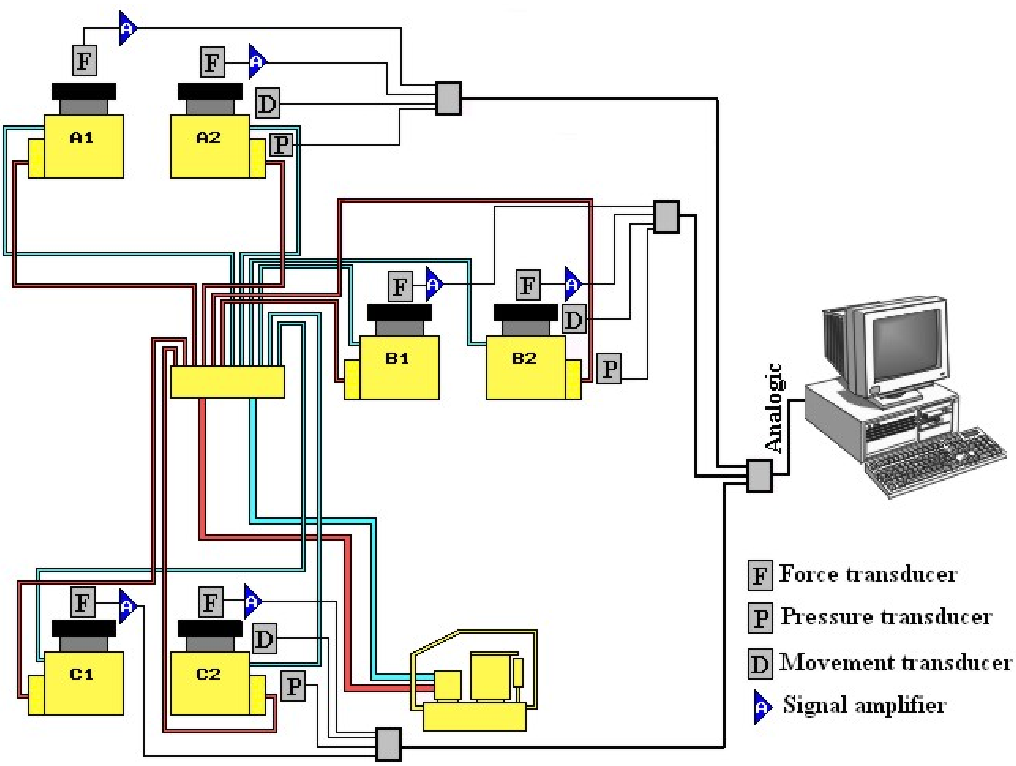

Fig. 5 Transmitter data collection system – analogical signal

The tensions provided, by the transducers in each lifting point are accepted by the A/D data acquisition card through connection cables. This type of card is installed on the main board of a numerical computer. In order to be able to monitor the process, a language C software has been developed, which will allow to read, interpret, compare and record all the pieces of information obtained by the I/O card.

Force, pressure and location transducers are used, the construction details of which are presented in the following paragraphs by briefly describing the construction and the operation, the technical characteristics, the conditions of installation, connection, etc.

3.1. Force transducer

The force transducers are destined to determine the level of the elevation force developed by each hydraulic cylinder. Six C6A force transducers are used (figure 6) manufactured by Hottinger Baldwin Messtechnik GmbH.

Fig.6 The C6A Force Transducer

These measurement devices represent the resistive transducers to determine the compression and extension forces in a static or dynamic regime. Regarding their usage, they don't need excessive maintenance and may be installed in places hard to reach. The electrical signal provided by this type of transmitter may be broadcasted to a certain distance in order to measure, rehash, display and record it.

The operating principle of such a transmitter is based on the proportional variation of the calibrated tensiometric element ohmic resistance, being deformed under such a force. This type of ohmic resistance variation, generates the imbalance of the Wheatstone bridge, thus, supplying the bridge with power, an output signal (tension) proportional to the ohmic resistance variation and consequently proportional to the compression force is determined.

3.2 Pressure transducer

The three P6A pressure transmitters (figure 7) are manufactured by Hottinger Baldwin Messtechnik GmbH.

The requirements of the installation impose the selection of a P6A Pressure Transmitter, the P6A-500B-D with connector, with a measurement range of 10 to 500 bar, and which is destined to measure static and dynamic pressures in the range mentioned earlier.

Fig.7 The P6A pressure transducer with connector

3.3 Movement transducer

For the analogical weighting system we will consider a Microsonar UT-212 (figure 8) movement transmitter with ultrasonic.

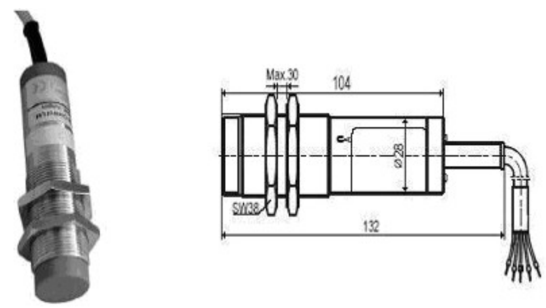

Fig.8 Ultrasound transducer Microsonar UT-212

The experiments were made using transducers Microsonar UT-212, which were installed on a plate surface, which allows to change the distance in order to set up their transfer characteristic. In Figure 9 it is shown the transducer transfer characteristic MicrosonarUT-212, as well as its transfer equation.

The equation was used in an application which allows to measure the distance to the target.

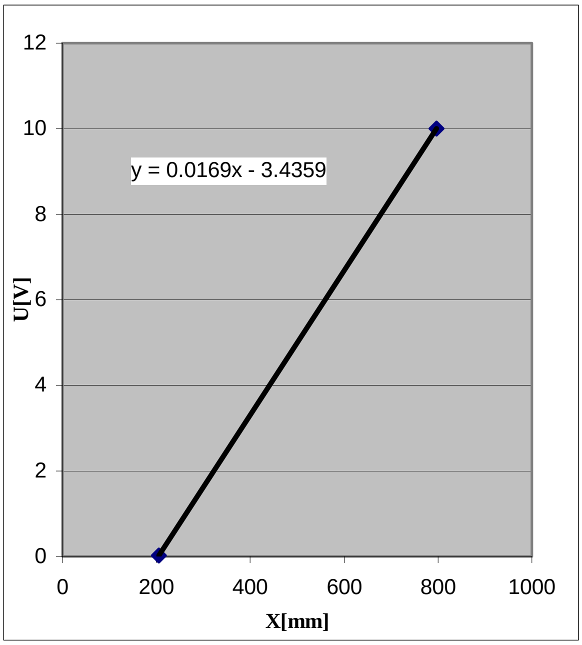

Fig.9 Transducer transfer characteristic

3.4 Signal Amplifiers

If the distance between the resistive transmitters and the measurement amplifier is greater than 3m, in order to ensure the safety and precision of transmitting the signal from the transmitters, signal amplifiers will be used.

Fig.10 Signal Amplifier for resistive and inductive transmitters

For resistive transmitters we will use MC3 signal amplifiers, and for the inductive transmitters we will use MC2A signal amplifiers. Both types of amplifiers are manufactured by Baldwin Messtechnik GmbH (figure 10).

4. Excavator Digital Weighting System

This type of system is detailed in figure 11.

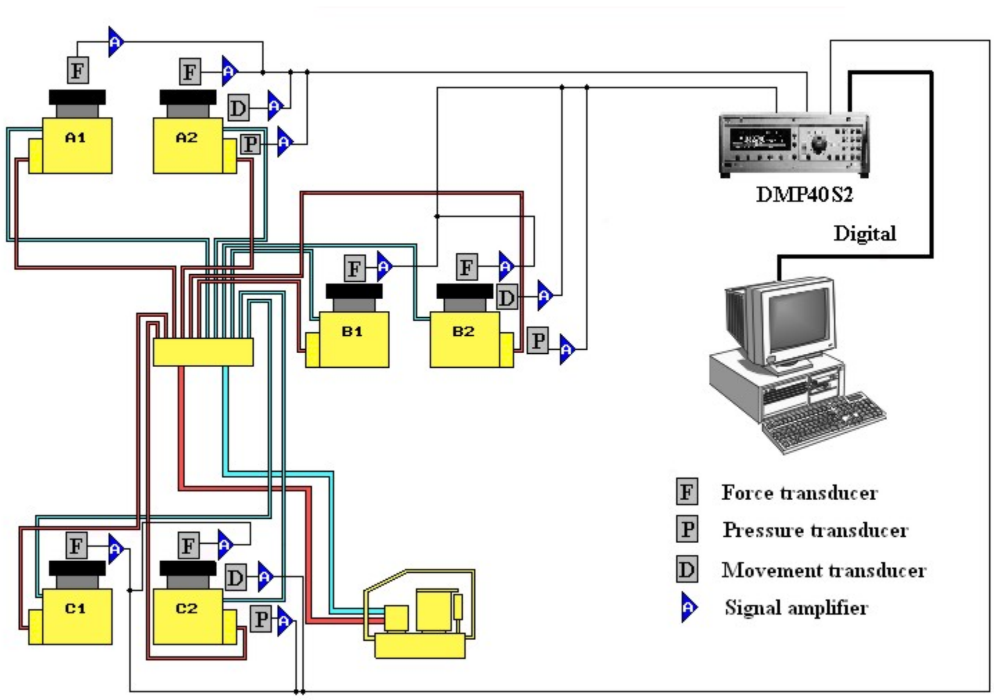

Fig.11 Data collection system – digital signal

The digital notion refers to the fact that analogical signals broadcasted by the transmitters are sent to a measurement amplifier which interprets them and sends them further to a computer through a serial protocol.

In this case, the information is received in digital format by the computer, the role of interpreting the electrical values (tensions) being that of digital measurement amplifier.

The same type of force and pressure transducers will be used as well as signal amplifiers as the ones presented in the previous paragraphs (3.1, 3.2 and 3.4), in conclusion, the same as for the analogical weighting system.

Using the digital measurement amplifier we may focus on the problem of determining the tension inside different components of the metallic structure of the excavator with the help of strain transducers.

4.1 DMP40S2 Digital Precision Measurement Amplifier

This type of equipment (figure 12) manufactured by Hottinger Baldwin Messtechnik GmbH allows the simultaneous connection of 16 transmitters and broadcast to a numerical computer through a serial protocol the real values of the measured values.

Fig.12 Digital Precision Measurement Amplifier

The block diagram for the operation of the DMP40S2 device is detailed in figure 13 where all 16 channels of the device may be observed.

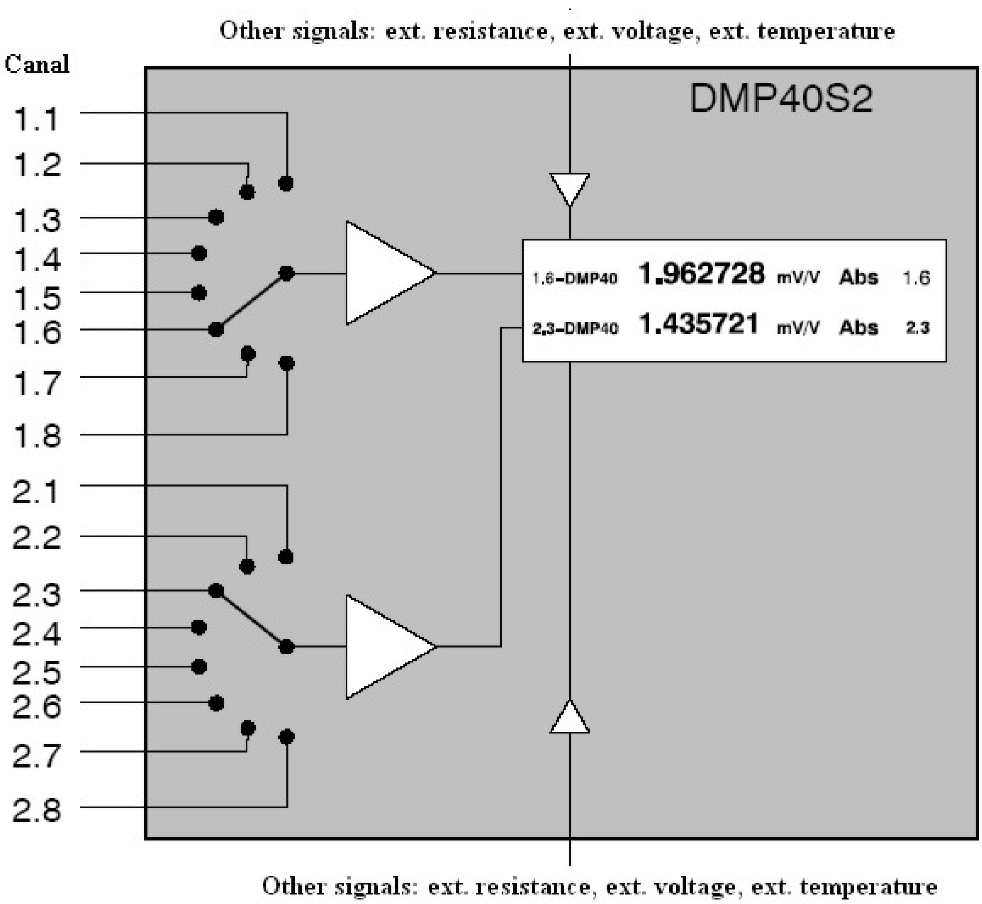

Fig.13 The Operational Block Diagram of the DMP40S2 Measurement Amplifier

4.2. Position Transducer

As a position transducer for this type of weighting, the WA type transducer is chosen. This type of transducer is presented in figure 14 and is manufactured by Baldwin Messtechnik GmbH. For the given operation conditions, the K-WA-500W-32K-K1-LB-2-2 transducer may be used.

Fig.14 WA Inductive Transducer

4.3 Strain Transducers

In order to determine tensions and efforts we propose the use of SLB-700A/06 resistive strain transducers (figure 15), manufactured by Hottinger Baldwin Messtechnik GmbH.

Fig.15 SLB-700A/06 Resistive Strain Transducer

Depending on the necessities, other types of strain transducers may be used by directly applying them to the area to be studied.

5. Software for Monitoring the Weighting Systems

In order to monitor the weighting system we propose a software, developed in C language, which will allow data for both types of measurement systems (analogic and digital).

For the analogical type, the software will have the following functions:

- It will receive from the ultrasonic transmitters, through the IO card, the tension corresponding to each position of the hydraulic cylinder in all three support points;
- It will receive from the ultrasonic transmitters, through the IO card, the tension corresponding to the pressure of three of the lifting cylinders;
- It will receive from the 6 force transmitters, through the IO card, the corresponding tension for the compression force (F_{mas});

For the digital case, the software application realises the following function: it reads on a serial basis the information sent by the DMP40S2 Measurement amplifier;

For both of the proposed systems, the software will take the following common steps:

- Determines the calculated value of the lifting force (F_{calcul}) depending on the measured pressure and the section area of the hydraulic cylinder;
- Compares the values of the forces for each supporting point, signalling any difference that passes over 1 %;
- Determines the coordinates of the barycentre;
- Writes the measured and calculated values onto a file for future editing.

The two types of weighting of bucket wheel excavators represent both advantages as well as disadvantages. The analogical type is one that implies a reduced amount of money regarding the equipment, unlike the digital type.

Regarding the software, the analogical type is more laborious because the application needs to collect and practically measure the values broadcasted by the transducers, which are merely tensions. As previously detailed in Chapter 1 paragraph 1.6 the ensemble Computer – Software has the role of a measurement device, implying as well the calibration of the transducers.

For the digital type, this function is taken by the measurement amplifier, the software having only to collect, analyse and display the values.

Figure 16 represents a print screen of the monitoring result of the weighting process.

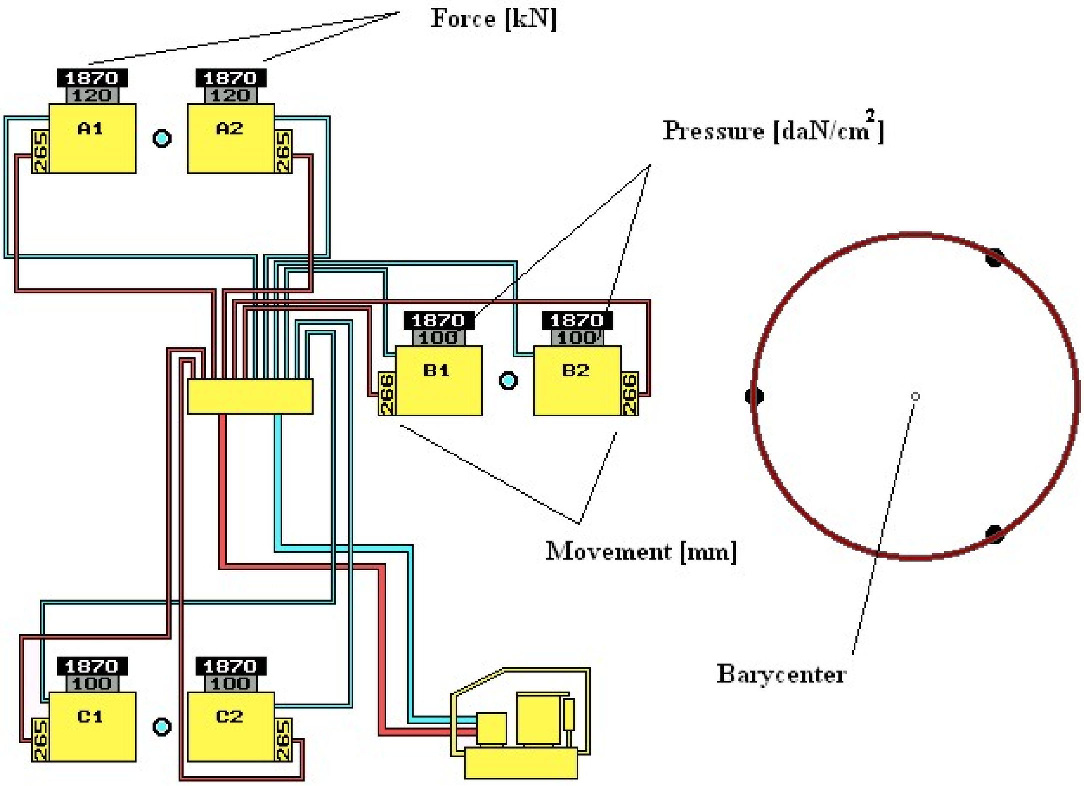

Fig.16 Print Screen of the Monitoring Process

6. Conclusions

Emphasis is laid on the problem of balance and stability not only of the rotor excavators, which represent the main machinery in a coal mining technological system, but also of other machineries employed in excavations.

The balance survey, respectively that of the stability of these machineries is compulsory because the bearing surface is rather small compared to the other building sub-systems outside the range of the surface, onto which much higher forces operate. The lack of correct balance for the rotor excavators determines their operation in an inadequate dynamic mode, or in extreme cases, there is the danger of losing stability by tilting over the excavator respectively suffering huge material and human loss.

Thus, these excavators have a mass of balance theoretically measured during the production process. It is compulsory for the correctness of the position and mass value of balance to be checked because there might be substantial error sources leading to compromise the operation. In order to solve this problem there are several methods, one of them based on the weighing the entire equipment installed on the superior part of the excavator.

It is obviously necessary to lift the entire platform with the help of linear motor hydraulic force elements (hydraulic cylinders) and to determine the value of the developed forces on the points where these devices are installed. Taking into consideration the forces developed and the points of installation of the force elements by a calculus method the place and the weight value of the excavator may be determined (as a vector). In present there is the tendency to use either a simpler hydraulic system manually operated construction lifting device, or more complex centralized command lifting devices fitted with measurement devices, i.e. force transmitters, emplacement transmitters, the centralization and rehash of the information being made with the help of computers based on special software.

The study regarding the theoretical aspects of balancing the bucket wheel excavators, emphasises the classical mechanical theory regarding the balance of machineries and the compulsory conditions to be met in order for the machineries to be balanced when operating in practical work conditions. It is obvious that the bucket wheel excavators are still weighted according to a methodology with the help well known equipment, but the proposed solution represents a step forward, meaning the modernisation by using a computer fitted with adequate means and software on one hand, and on the other hand the introduction of the computer and of the specialized software to permanently control the position of the barycentre inside the pre-established area of balance (visible on the computer's display). If the tendencies of shifting out of the defined balance area are perceived, then, operations to bring the machinery into the position which ensures it a sure mechanical stability are necessary.

Theoretical and experimental research lead to the development of the concept called "Laboratory for weighing and strain gauge measurements", representing a modern and accessible solution in order to perfect balance and the control of stability of excavators in brown coal mines, in order to enhance mining performances, respectively their degree of use. This mobile laboratory may provide services in this field of expertise, including the determination of tension inside the metallic construction for other potential beneficiaries.

References:

[1] X1. Abdullah Al-Mamun, Zhen Zhu, Prahlad Vadakkepat and Tongt Heng Lee, *Path Following Controller for Gyroscopically Stabilized Single-Wheeled Robot*, Proceedings of the 9th WSEAS International Conference on Automatic Control, Modeling & Simulation, Istanbul, Turkey, May 27-29, 2007

[2] X1. Diana Cotoros, Dumitru Nicoara, Mihaela Baritz, Anca Stanciu, *Upon the Solutions Trajectories of an Euler Type Gyroscope*, Proceedings of the 2nd IASME / WSEAS International Conference on Continuum Mechanics (CM'07), Portoroz, Slovenia, May 15-17, 2007

[3] X1. Krishnamurthy Bhat, Chayalakshmi C.L., *Tilt angle measurement using accelerometer IC and CAN protocol implementation for data transmission*, Proceedings of the 7th WSEAS International Conference on Applied Informatics and Communications, Athens, Greece, August 24-26, 2007

[4] X1.Florin Dumitru Popescu, *Examinations regarding the possibility to continuously control the balance of rotor excavators with an inclinometer*, 9th WSEAS International Conference on AUTOMATION and INFORMATION (ICAI'08), Bucharest, Romania, June 24-26, 2008

[5] X1. Florin Dumitru Popescu, Marin Silviu Nan, *Possibility to continuously control the tilt of excavators with an inclinometer*, WSEAS TRANSACTIONS on SYSTEMS and CONTROL, Manuscript received Jan. 9, 2008; revised Apr. 2, 2008

[6] X2. Căprariu V., *Ghid de utilizare Turbo C 2.0*, Editura Micro Informatica Cluj-Napoca, 1991

[7] X2. Iliaş Nicolae, *Maşini miniere, exemple de calcul*, Editura Tehnică Bucureşti, 1993

[8] X2 Kovacs Iosif, Iliaş Nicolae, Nan Marin Silviu, *Working operation of the mine cutters*, Universitas Publishing House, Petrosani, 2000

[9] X2. Magyari Andrei, *Instalații mecanice miniere*, Editura Didactică şi Pedagogică Bucureşti, 1990

[10] X2. Nan Marin Silviu, *Capacitatea sistemelor de transport*, Editura Universitas Petroşani, 2000

[11] X2. Popescu Florin, *Calculatorul numeric în industria extractivă*, Editura Universitas Petroşani, 2004

[12] X2. Popescu Florin, *Programarea şi utilizarea calculatoarelor*, Editura Sigma Plus Deva, 2002