Examinations regarding the possibility to continuously control the balance of rotor excavators with an inclinometer

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Abstract: -For the machineries and installations that have a small bearing surface compared to their height, an efficient control of balance can be done only if the angle of tilt of the superstructure is known, and if the angle does not exceed certain values. The limit values of the angle of tilt are determined by one condition, i.e. the composite force of both the interior and the exterior forces should pierce the plan, which is bounded by the props of the machinery. In order to continuously measure the angle of tilt of the superstructure, in any direction possible, recent studies highlight the possibility of using inclinometer to be able to control the balance and respectively the stability of rotor excavators. By measuring the angle of tilt for a structure considered rigid with the help of inclinometers, we are looking to evaluate the movement of the center of gravity toward the interior of the bearing surface, which may have consequences on the stability of the machinery. Thus a continuous control using computers over the tilt of the structure can be made considering the two perpendicular directions, so as the limit value of the angle of stability is not exceeded.

Key-Words: - Barycentre, Inclinometers, Data acquisitioning card, Artificial horizon, Excavator

1 Generalities

The scope of measuring the angle of tilt of a structure considered rigid is to evaluate the movement of the barycentre towards the interior of the bearing surface, which may have consequences on the stability of the machinery (Figure 1).

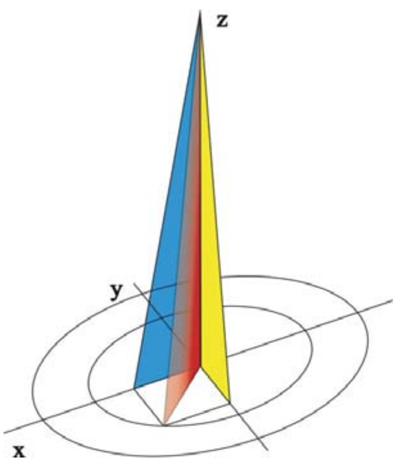

Fig.1 Top view of the angle of tilt
Red – Structure's angle of tilt, blue, yellow – axes projection of the angle of tilt

Thus, taking into consideration the facts presented above, if the value of the angles of tilt with the vertical inside both a longitudinal (x) and a transversal (y) plane are known, then the determination of the movement of the barycentre of the structure towards the interior of the bearing surface is possible, ordered by the bearing system. Figure 2 represents a simplified angle of tilt with one of the considered axis.

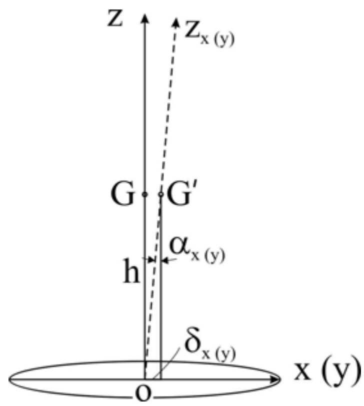

Fig.2 Projection movement of the barycentre

Where:
x – longitudinal axis;
y – transversal axis;
z – vertical axis;
G – barycentre;
G' – displaced barycentre;
G" – barycentre projection on the bearing surface;

h – barycentre height over the bearing surface;
α_x – angle of tit in longitudinal plane;
α_y – angle of tilt in transversal plane;
δ_x – barycentre project displacement in longitudinal plane;
δ_y – barycentre project displacement in transversal plane.

$$\delta_x = h \cdot \sin \alpha_x \tag{1}$$

$$\delta_y = h \cdot \sin \alpha_y \tag{2}$$

Taking into consideration the two displacements, δ_x and δ_y, we are able to calculate the barycentre's projection inside the bearing surface, as shown in figure 3.

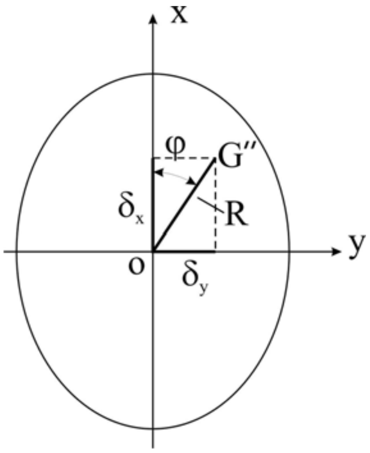

Fig.3 Barycentre's projection inside the bearing surface

Thus, the coordinates for the projection of the barycentre inside the bearing surface are the following.

$$R = h\sqrt{(\sin \alpha_x)^2 + (\sin \alpha_y)^2} \tag{3}$$

$$\varphi = \operatorname{arctg} \frac{\sin \alpha_y}{\sin \alpha_x} \tag{4}$$

Inclinometer devices are being used in order to measure the angle of tilt with the vertical of the surface; depending on the solution we are trying to find and the precision of the measurement, the sensors of the device will be set in the following technologies: accelerometer, electrolytic, quicksilver, gas bubble, and pendulum.

2 H4 Inclinometer

In order to measure the angles of tilt inside the planes X-Y, 2, type 4 Rieker inclinometers will be used (Figure 4); these devices are single axis inclination type inclinometers, metallically manufactured, with a IP66 protection degree, and a range of +/- 30^{o}.

Fig.4 H4 Series Inclinometer

Depending on the chosen measurement device, the output may be either analogue (0 – 5V) or digital (transmitted through a serial port). One specification should be made when using an analogue type, i.e. the module NV8 for signal filtering and conditioning is necessary. A computer has to be also preset in measuring design, computer which will have connected to its COM1 and COM2 serial ports the 2 inclinometers. The installation of the 2 devices will be made with the help of a metallic cube, in order for the axes of the devices to parallel with the longitudinal axis of the machinery, respectively with its transversal axis. Such an installing device can be seen in figure 5, used to hold 3 sensors (3 axes).

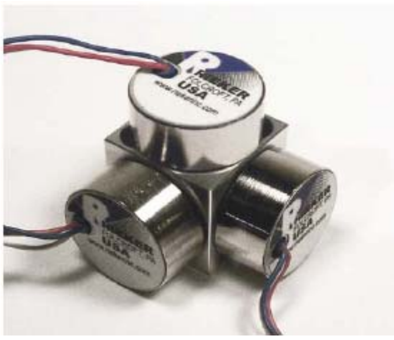

Fig.5 Device for 3 sensors

The technical characteristics of such a transmitter are presented in the table 1.

Table 1

Input Parameters	
Measuring Range	+/- 30°
Measuring Axes	1
Power Supply	8-30V DC
Output Parameters	
Non Linearity	< 0.5% of the Measuring Range
Null Repeatability	0.05°
Transverse Sensitivity	< 1° at a 30° tilt
Sensitivity	< 300mS
Optional Temperature Compensation Drift	< +/- 1.0° over full operating temperature
Operating Temperature	-40°C ... +85°C
Analog Output (0... 5V)	
Zero offset	2.5V
Analog Voltage Output	0 ... 5V DC
Voltage Sensitivity	66.7mV/°
Temperature Compensation	< +/- 0.5°
Resolution	< 0.02°
Current Consumption	10mA
Digital Output	
Temperature Compensation	< +/- 0.5°
Resolution	< 0.02°
Current Consumption	10mA typical
Output Format	ASCII decimal
BAUD rate	9600
DATA bits	8
PARITY	none
STOP BITS	1

3 Experimental research

As shown in the paragraphs above, if the value of the angles of tilt with the vertical inside both a longitudinal (x) and a transversal (y) plane are known, then the determination of the movement of the barycentre of the structure towards the interior of the bearing surface is possible. This means the installation of two inclinometers, which will measure the corresponding tilt of the two axes. Thus, one of the inclinometers will measure the tilt along the longitudinal axis of the excavator, and the other one will measure the tilt along the transversal axis or as put in other words front / back and tilt left / right.

For realizing a soft application the Analogical Output H4 Type Inclinometer has been taken as model. The power supplied, by this type of inclinometer was accepted by a numerical calculator through a data acquisitioning card (Figure 6).

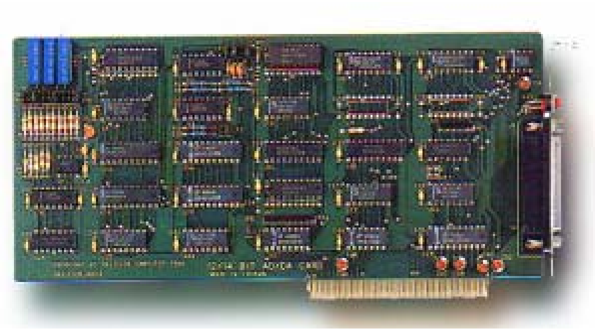

Fig.6 A/D – D/A 12 bits Card

This type of card allows 2 digital-analogical outputs (unipolar and bipolar) and 16 analog-digital simple inputs or 8 analog-digital differential inputs, all of these having a 12 bits resolution. The Technical data of this card are the following:

D/A

– resolution	12 bits;
– number of channels	2;
– power output:	
- unipolar output	0 at 2,5 V, 0 at 5 V, 0 at10 V;
- bipolar output	-2,5 at 2,5 V, -5 at 5 V, -10 at 10 V;
– conversion time	< 2 μs ;
– output impedance	> 2 kΩ ;

A/D:

– resolution	12 bits;
– power input	
- unipolar input	0 at 2,5 V, 0 at 5 V, 0 at 10 V;
- bipolar input	-2,5 at 2,5 , -5 at 5 V, -10 at 10 V;
– conversion time	< 22 μs (for each channel);
– maximum power allowed	12 V.

The reading, interpreting and display of monitored values program was realized in C language on a DOS platform. Monitoring the angles of tilt (front/back and left/right) was materialized with the help of an artificial horizon. The Figures 7 and 8 represent two print screens representing different situations referring to the tilt of an excavator.

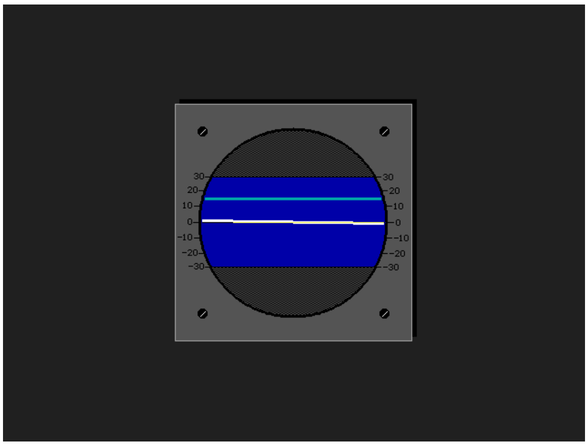

Fig.7 Front tilt – Left/right null

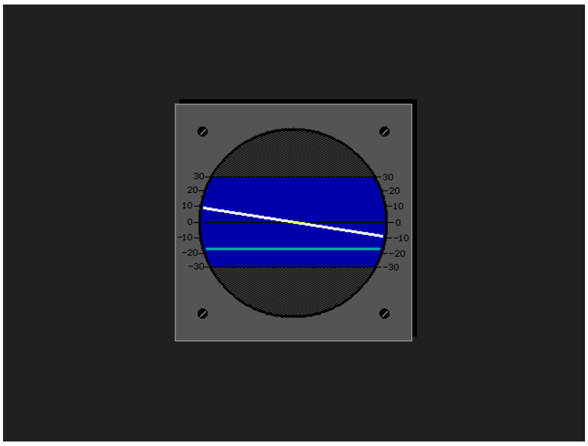

Fig.8 Back tilt – right tilt

4 Conclusions

Analyzing the paragraphs above we have reached the conclusion that the stability (equilibrium) may be monitored correctly with the help of inclinometers which will measure the angles of tilt front / back respectively left / right. As a solution to the experiment we have chosen the analogical output H4 Type Inclinometer.

The soft application allows the measurement of tilt through an artificial horizon. Both the front / back tilt and the left / right tilt can be measured simultaneously. The display of the tilt being intuitive for the operator of the excavator, thus allowing him to take immediate and efficient action in order to avoid a dangerous tilt which might lead to a malfunction or in some extreme cases to a possible overturn f the excavator.

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