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BRAWAL 1611 AND BRAWAL 4011 ENERGY-ECONOMICAL HYDRAULIC EXCAVATORS WITH THE ARTIFICIAL INTELLIGENCE ELEMENTS.

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Abstract

The Brawal excavators have original proprietary structure protected by numerous patents. The sliding working accessories enable optimization of the parameters of cutting and of additional functions, for example exact scarping. Energy-recuperation system decreases the cost of operation and temperature of the hydraulic oil, thus increasing the machine's capacity to work in tropical conditions. The excavator can be equipped with the so-called U.S.E.B system of monitoring and automation, which enables monitoring of several dozen of machine's parameters and automation of various cutting processes. It also contains protection systems.

1. PARAMETERS AND MAIN ADVANTAGES

The BRAWAL excavators with sliding accessories, produced by Polish companies, are ranked among the new generation excavators thanks to the advantages incomparable to the excavators currently produced around the world. The excavators have passed through a full cycle of laboratory and exploitation tests in various soil and climatic conditions in Europe, Asia and Africa. The BRAWAL machines have shown their technical and operational merits, including high capacity and energy conservation, as well as extraordinary technical parameters. The structure of the BRAWAL excavator has been accommodated for work with various attachments and for easy construction of related machines, including machines adapted for scarping, mining, and loading. The following attachments can be mounted on the BRAWAL excavator: drag attachments, buckets (clamshell attachments), line attachments and cranes. The three-circuit hydraulic power system enables the installation of various tools, including crushers, cutters, face milling cutters, demolition attachments, etc. ensuring simultaneity of all the working movements, including motion.

Table 1. Main parameters of excavators

Parameters	Units	BRAWAL 1611	BRAWAL 4011
Weight [t]	t	32	65
Power [kW]	kW	132	264
Capacity of the backhoe bucket according to SAE 1:1	cu. m	1.8	5
Capacity of the front shovel	cu. m	2.5	7

The main advantages of the excavator are:

- smaller weight (by about 25%) in relation to the size of the bucket and achieved capacity,
- decrease of the cutting resistance by over 30% which leads to a decrease of energy consumption during excavation,
- possibility of achieving of maximum forces in the whole working area,
- the BRAWAL excavators are adapted to work in the most difficult soil conditions, they can work in up to category VI ground conditions, and not as it is the case with the currently produced excavators only up to the category IV ground conditions, without any danger of damage, thanks to the shock absorber located in the accessory sliding system,
- new kinematics of the accessories enable precise scarping of the slopes and obtaining of a flat bottom of an excavation,
- excavators are equipped with energy recuperating equipment. Energy accumulated in the lifted accessories is recuperated in the so-called recuperator after lowering of the accessory and is re-used in the working cycle.
- excavators are designed in order to enable the installation of additional systems in customized versions, including:
    - electronic controls with microcomputer with the artificial intelligence elements for monitoring and automation,
    - remote control system with a wire connection or using radio waves.

The advantages of the excavator have been achieved through novel solutions covered by patents, as illustrated in Fig. 1-7.

2.DISCUSSION OF STRUCTURAL SOLUTIONS OF BRAWAL EXCAVATORS.

Hydraulic excavators with the hitherto existing structure have working attachments mounted in a fixed manner to the superstructure frame. In the BRAWAL excavators, the attachments are mounted to a slidable cart placed in a way enabling sliding on a beam (guide bar) mounted to the superstructure, as is illustrated by Fig. 1.

The cart is moved with the use of hydraulic cylinder. The hydraulic cylinder is equipped with proper valves and constructed in such a way that at the same time it serves as an overload absorber, when an attachment encounters an obstacle.

2.1 Backhoe attachment with new kinematics

Backhoe attachment with a Mono type (single element) boom has different proportions and kinematics. The Boom is supported by cylinders on a big arm, and this enables conveying of maximum forces of cutting in any configuration of the arm. The bucket has properly designed angles of revolution, so as to, on the one hand, ensure optimum angle of cutting along repetitive paths, and on the other hand to ensure transport of the excavated material for optimum distances.

Fig. 1 presents the kinematics of the backhoe attachment of a traditional excavator. The excavator cuts by means of three circular motions performed by the bucket, arm and

boom. Practically every furrow-slice is different, and so the directions of the cutting forces and the angles of cutting forces are different.

Due to such process, the furrow-slices are torn out from the borrow pit, and so there are large losses of energy resulting from the fact that the cutting resistance increases geometrically in relation to the thickness of the furrow-slice being cut. Additionally, the directions of the forces often have unfavorable direction when they work along arms that are long in relation to the point of overturning, which fact leads to the loss of stability already when the forces are significantly smaller than the maximum force. Circular motion of the accessories does not allow the bottom of the excavation to be precisely finished, and this in turn causes the necessity of a manual work in the excavation.

The kinematics of the attachments for the BRAWAL excavators introduce new technology of cutting consisting of cutting with regular furrow-slices, as is shown by Fig.1.

After lowering the attachments to the excavation, the attachment is moved back with the cart by a distance equal to the thickness of furrow-slice (g), and then cut with a circular motion. The forces working on the teeth run near the support and do not cause the loss of excavator's stability, and thus they can reach maximum values in the working area.

Horizontal shift of the attachments by means of the cart facilitates flat cutting, parallel to the base (bed), is scarping, while the cylinder of the cart guards the attachments against overload. Scarping is achieved in the following way: while shifting the attachments on the cart with a speed of v, we lower the boom with a set speed depending on the assumed angle of the slope of a scarp.

2.2 Drive, hydraulic system and energy recuperation system

The drive consists of three variable capacity hydraulic pumps with a fixed power automatic device for all three pumps. The third pump of a proper size is connected to the main power system, and can be simultaneously used for precise control of the thickness of a furrow-slice during digging and scarping, or can be used for powering of the system of automatic scarping. The maximum pressure with which the hydraulic system works is 30 MPa. The boom cylinder is equipped with a cut-off valve enabling stopping of the attachments in case when a hydraulic hose breaks. The cut-off valve is equipped with a pressure valve safe-guarding against maximum growth of pressure at the moment of stopping.

Along the line of lifting and lowering of the boom, between the boom cylinder and the divider, there is a device for energy storing, as it is shown in Fig. 5 and 7.

This device, so-called recuperator, consists of an inertial wheel powered by a hydraulic engine. During the phase of lowering of the boom the oil from under the cylinder piston flows to the hydraulic engine of the recuperator and accelerates the inertial wheel. The energy of the falling attachments and the energy of the combustion engine, which in the course of powering the pumps puts load on the hydraulic cylinder, are stored in the inertial wheel.

Energy stored in the recuperator is transferred to the system during the phase of lifting of the attachments during 3-4 seconds, with an average power of about 70% of the combustion engine power. Thanks to the above mentioned device, the excavator has two power systems making up the so-called hybrid power unit, due to which in the selected stages of work the excavator possesses big summary power, and this cuts the time of the working cycle and

allows for minimization of the energy consumption in relation to the amount of excavated material.

The BRAWAL excavator, thanks to the new kinematics of the accessories and new structure, allows for easier installation of the automatic system. High capacity of the excavator in relation to its weight, energy-saving hydraulic system and energy-saving process of cutting, accommodation of the excavator to work in the heaviest soils, the maximum powers in the whole working area, and whole range of other qualities make the BRAWAL excavator a pioneer of new generation of excavators. What is noteworthy is a fact that the BRAWAL excavators won gold medals during the International Poznań Fairs in 1992 and 1993, got the "Mister Eksportu" title, and in 1993 the BRAWAL 1611 excavators was ranked among the prize winners in the "Teraz Polska" (Now Poland) competition for the best Polish products.

3. U.S.E.B. SYSTEM OF MONITORING AND AUTOMATION OF BRAWAL EXCAVATORS WITH ELEMENTS OF ARTIFICIAL INTELLIGENCE

The monitoring and automation system of the BRAWAL excavators enables monitoring of several dozen parameters, such as: pressure, temperature and level of working fluids and also warns the operator if the permissible levels are exceeded. It serves the role of load limiter and of the weighing and summing system. It continuously follows the position of the attachments and on operator's order repeats the executed working cycle. It enables optimization of the cutting parameters, as well as scarping.

The control system consists of a microcomputer, set of electronic sensors for registration of the angles of location of elements of attachment and of the excavator itself, of an ultrasonic sensor for positioning of the cart, of pressure gauges and tensometers for measurement of forces. For diagnosis of parameters the excavator is equipped with temperature indicators, indicators of the level of fluids and inductive tachometer. Among the control equipment there are electronic controls cooperating with proportional valves. The TS-200E microcomputer used in the BRAWAL excavators, together with the description of the programs and indicators, are presented in Fig.6.

4 GENERAL CONCLUSIONS

Tests of BRAWAL 1611 excavator with the U.S.E.B. system have proved that the excavator has in-built elements of artificial intelligence. The excavator takes over many working functions, diagnoses the working situation by itself, analyses it and makes proper control decision without engaging the operator while assessing the work using optimum parameters, which are:

1. The hydraulic system of the excavator senses the magnitude of the cutting forces and accommodates the speed of movement of the bucket teeth in such a way so as to make full use of a constant power of the engine N = const.

2. The hydraulic system of the excavator senses the size of movement resistance and automatically accommodates the speed of movement so as to make full use of a constant power of the engine.

3. The excavator senses the beginning of lowering of the attachment and automatically stores the potential energy of the attachment in so-called recuperator.

4. The excavator senses the neutral gear of the engine during lowering of the attachment and stores its energy in the recuperator while the toxicity of the exhaust fumes is decreased thanks to constant speed of the engine.

5. The excavator senses the lifting of the attachment and automatically directs at it the stream of energy gathered in the recuperator, thus aiding the lift.

6. The excavator, "taught" by the operator, automatically stops the attachment on the required depth and turns on the shift of the cart, thus establishing the assumed thickness of the layer being cut, and in the final movement of the cart it starts advanced cutting with the arm.

7. During the work cycle the excavator senses the force applied to a tooth and in case of its low value, it undertakes the decision about increasing of the thickness of the furrow-slice by moving the cart with attachment.

8. In case of the maximum force which may lead to opening of safety-valves, the excavator makes the decision about decreasing of the furrow-slice being cut by moving the cart with the attachment, but only to the bottom limit of the programmed pressure.

9. The excavator, in the course of scarping, follows the speed of falling and lifting of the attachment Vy and the speed of cart Vx, and compares them with the speed which ensures the required angle of scarping, and in the work phase it undertakes a decision correcting the Vy speed so as to maintain angle μ.

10. The excavator, during performing the tasks with the loader attachment senses the beginning of the loss of stability and makes the decision about shifting the cart and attachment forward in order to create a horizontal force at the blade of a tooth which returns the machine to the position of full contact of the chassis with the ground, and enables achieving the maximum cutting force on the blade of a tooth.

11. The excavator, in the course of work with the backhoe attachment senses the beginning of the loss of stability and makes the decision about shifting the cart and attachment forward in order to decrease the cutting force which causes the loss of stability of the excavator. The movement of the cart stops when the excavator returns to ground.

12. Taught (programmed) excavator stops the movement of the cart in a desired point so as not to exceed a safe reach with an excessive load.

13. The excavator senses the level of the oil in the tank and signals the operator when the level decreases below minimum.

14. The excavator senses the temperatures of the hydraulic oil and of the combustion engine and signals them when the critical temperature is exceeded.

15. The excavator senses the level of the coolant and signals falling of the level below the critical level.

16. The excavator senses the slope of terrain and signals at critical angles.

5. BIBLIOGRAPHY

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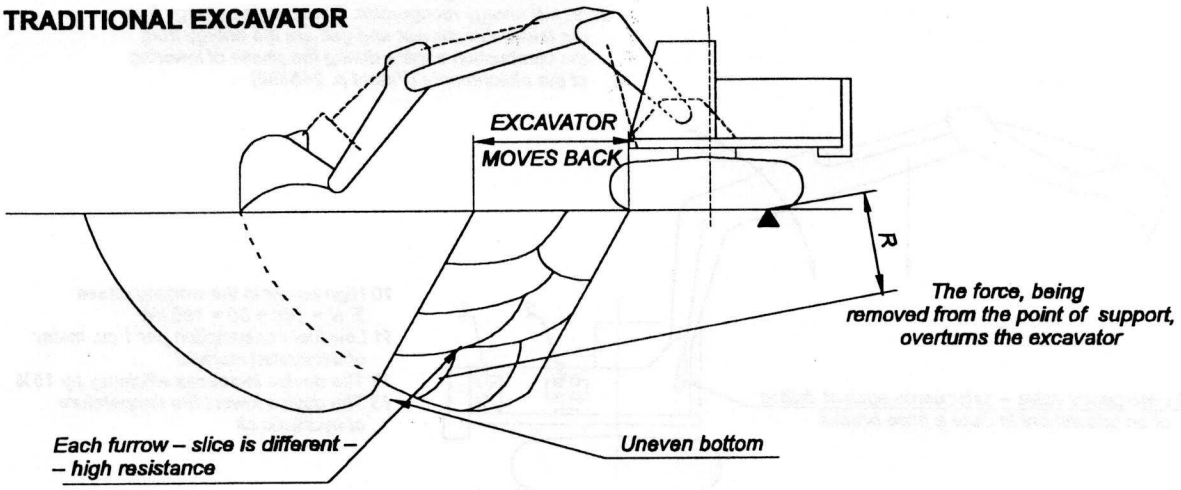
COMPARISON OF THE PROCESS OF CUTTING WITH THE USE OF BACKHOE ATTACHMENT



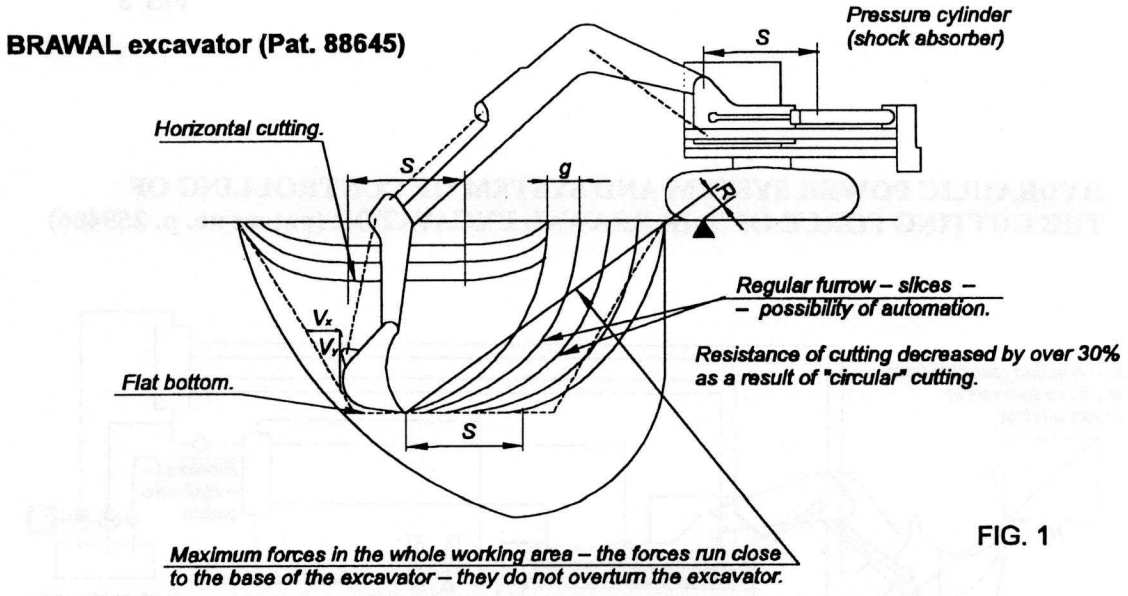


FIG. 1

THE PRINCIPLE OF ADAPTING THE BRAWAL EXCAVATOR TO WORK IN ROCKS

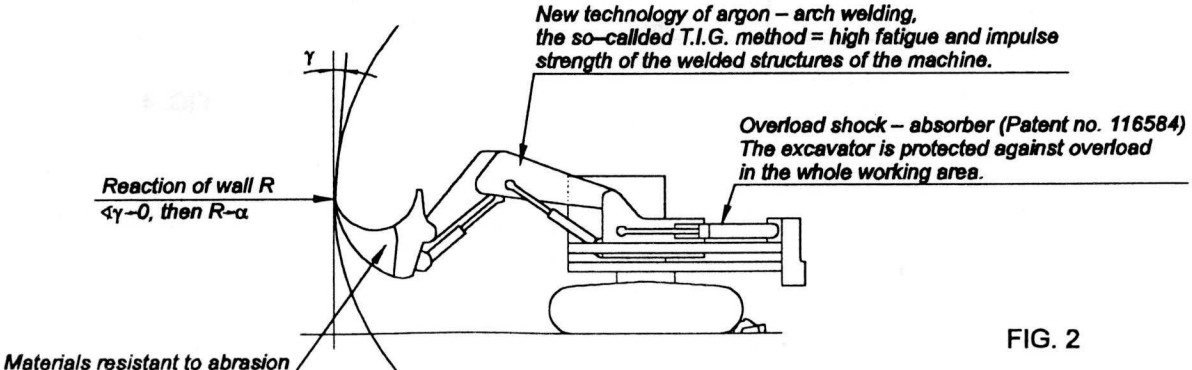


FIG. 2

EXCAVATOR'S HYBRID DRIVE WITH ENERGY RECUPERATION

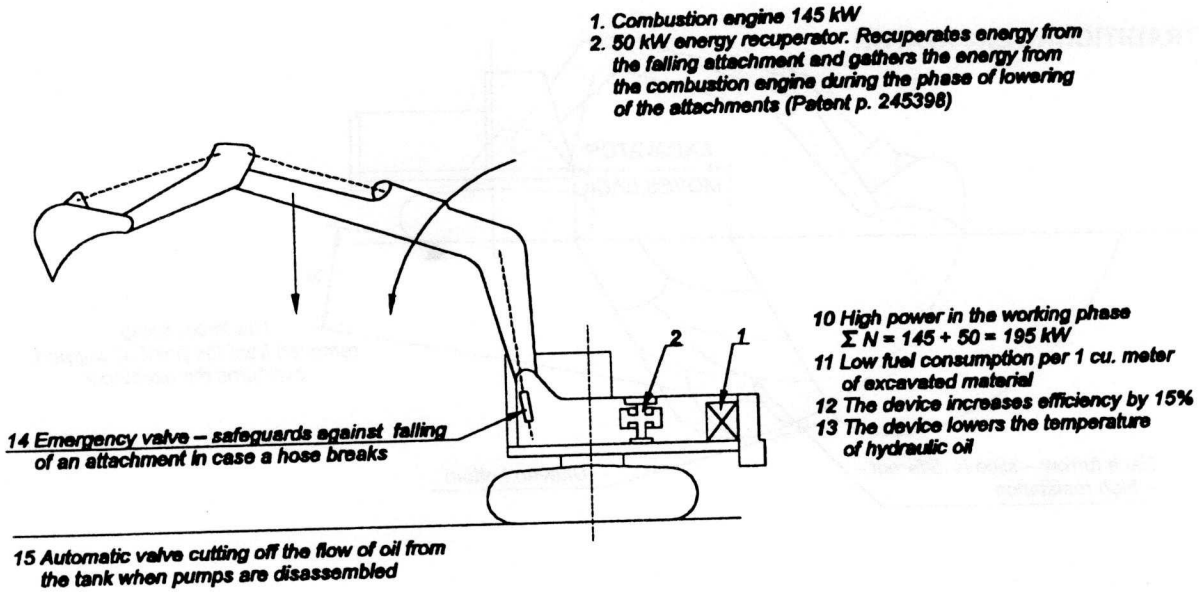


FIG. 3

HYDRAULIC POWER SYSTEM AND SYSTEM OF CONTROLLING OF THE CUTTING FORCE OF THE BRAWAL EXCAVATOR (patent no. p. 259486)

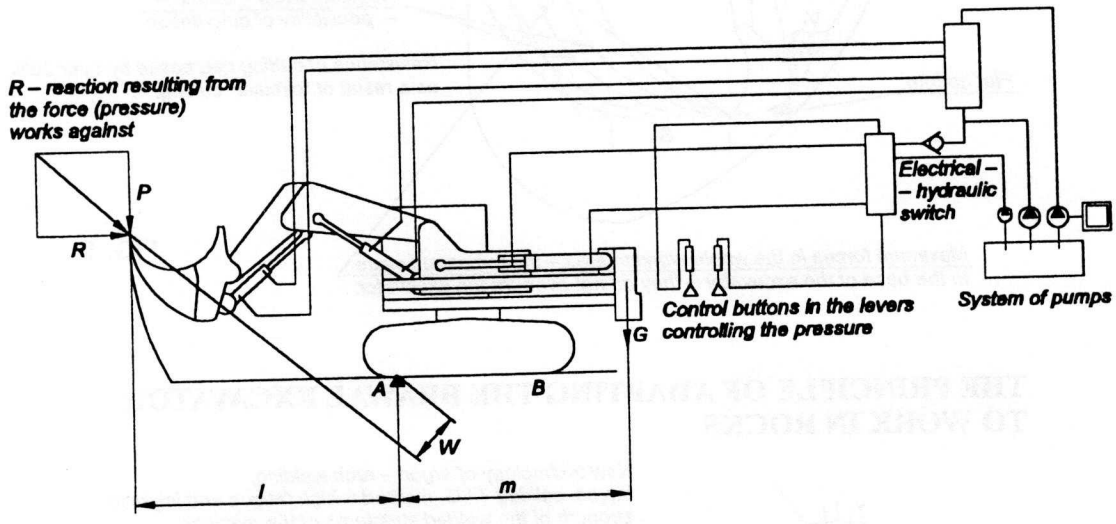
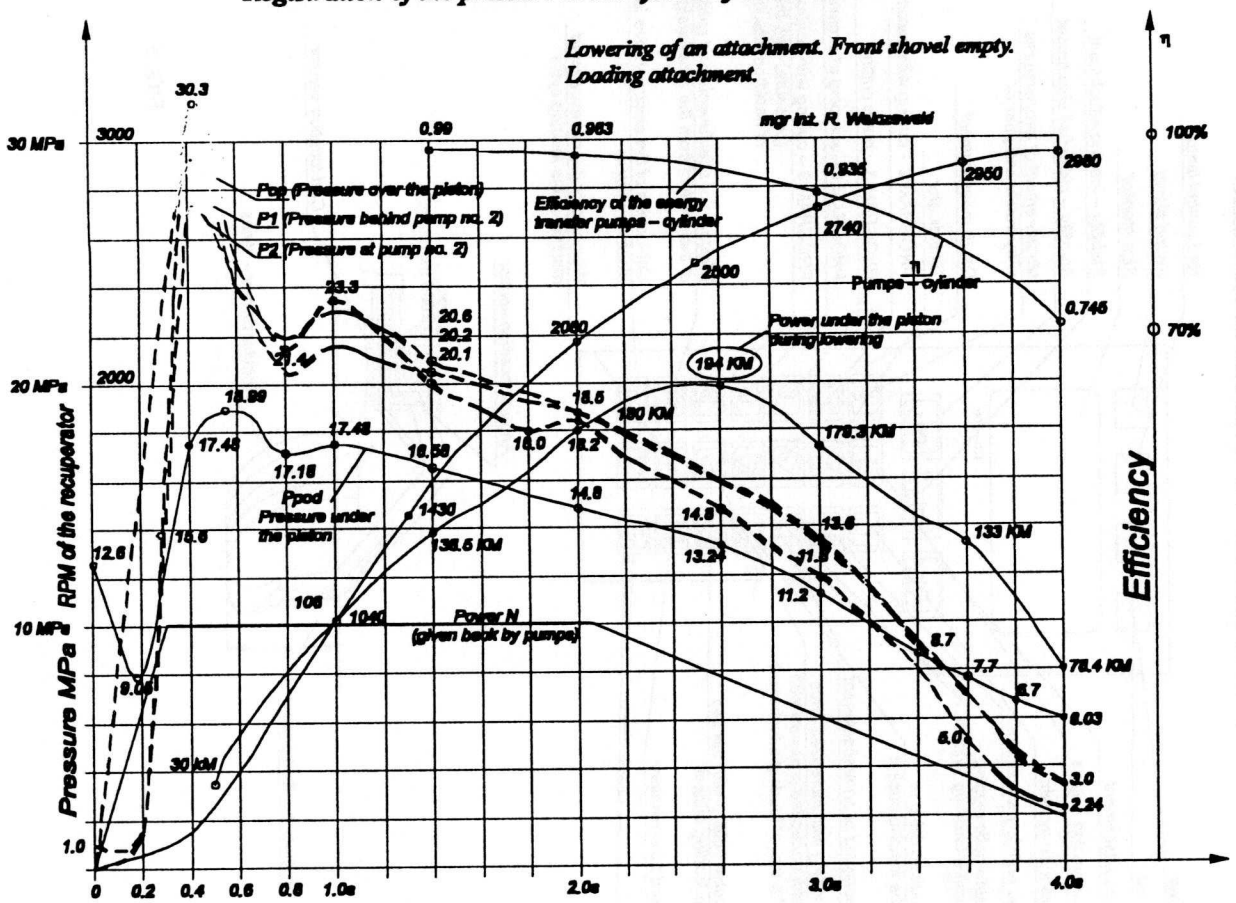


FIG. 4

Values of pressure, RPM and power in the recuperator system in the function of time during lowering of the attachments. Registration of the pressure in the system of boom drive.



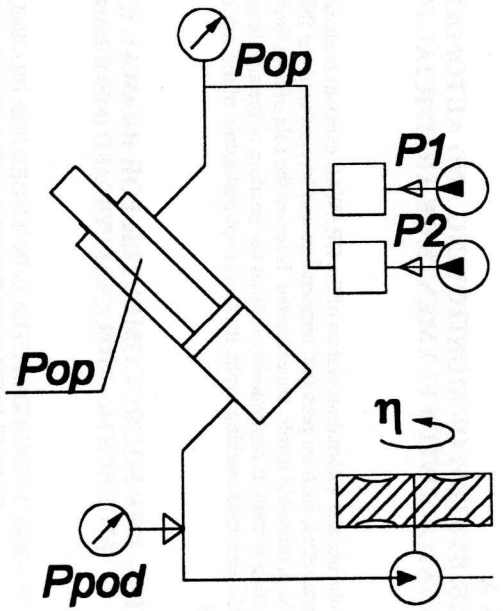


FIG. 5

TYPE A
U.S.E.B. SYSTEM OF MONITORING AND AUTOMATION OF BRAWAL EXCAVATORS WITH ELEMENTS OF ARTIFICIAL INTELLIGENCE

The monitoring and automation system of the BRAWAL excavators enables monitoring of several dozen parameters, such as: pressure, temperature and level of working fluids. It warns the operator in case the permissible levels are exceeded. It serves the role of load limiter and of the weighing and summing system. It continuously follows the position of the attachment and on operator's order repeats the executed working cycle. It enables optimalizatoin of the cutting parameters, as well as scarping

TS – 200E MICROCOMPUTER FOR BRAWAL EXCAVATORS
WITH SIGN MONITOR AND KEYBOARD (MEMBRANE – TYPE)

TS – 200E MICROCOMPUTER IS INTENDED FOR BRAWAL EXCAVATORS WITH ELECTRONIC CONTROLLERS/PROGRAMMERS

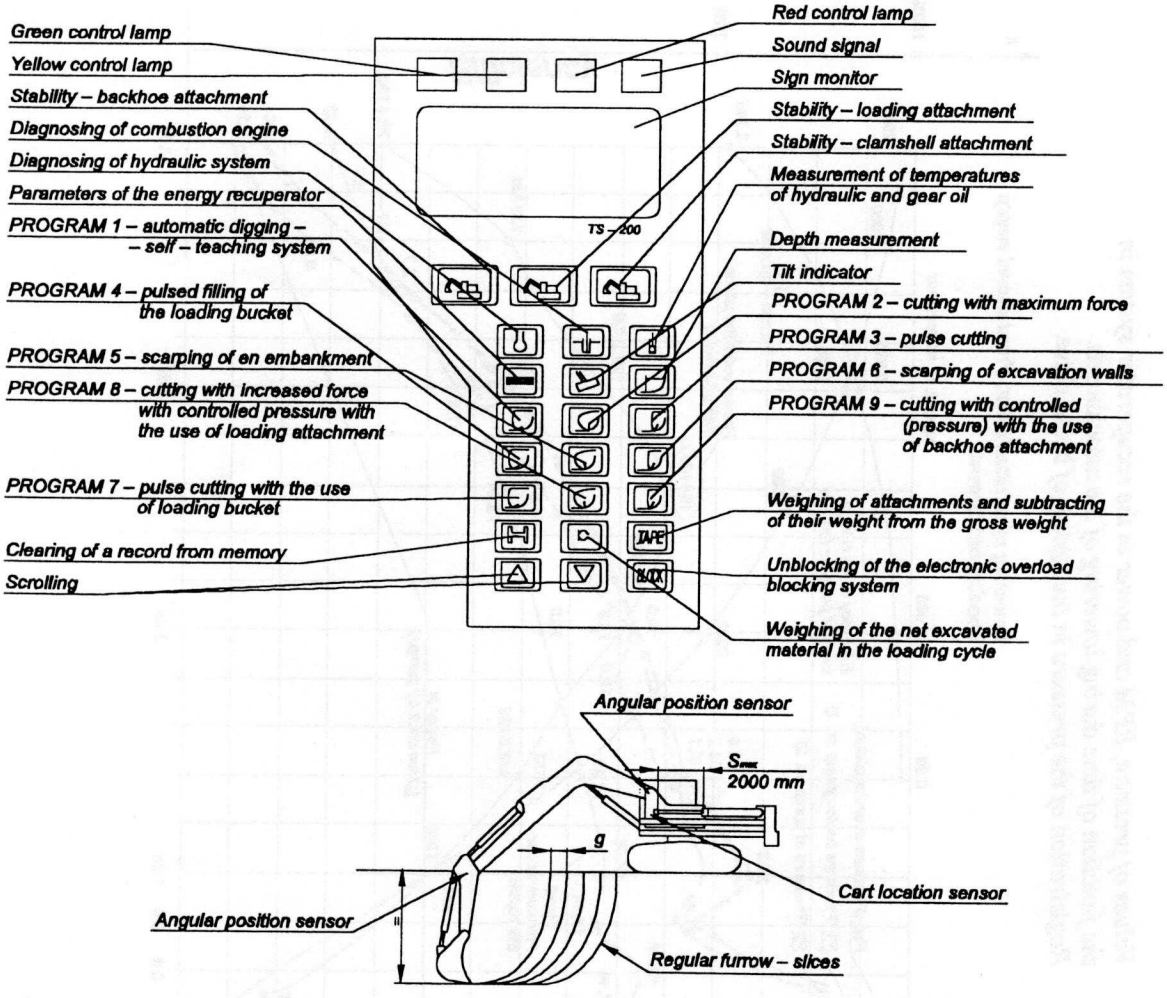


FIG. 6

RECUPERATION OF ENERGY IN THE BRAWAL 4011 EXCAVATOR
WITH LOADING ATTACHMENT
AND IN THE BRAWAL 1611 EXCAVATOR

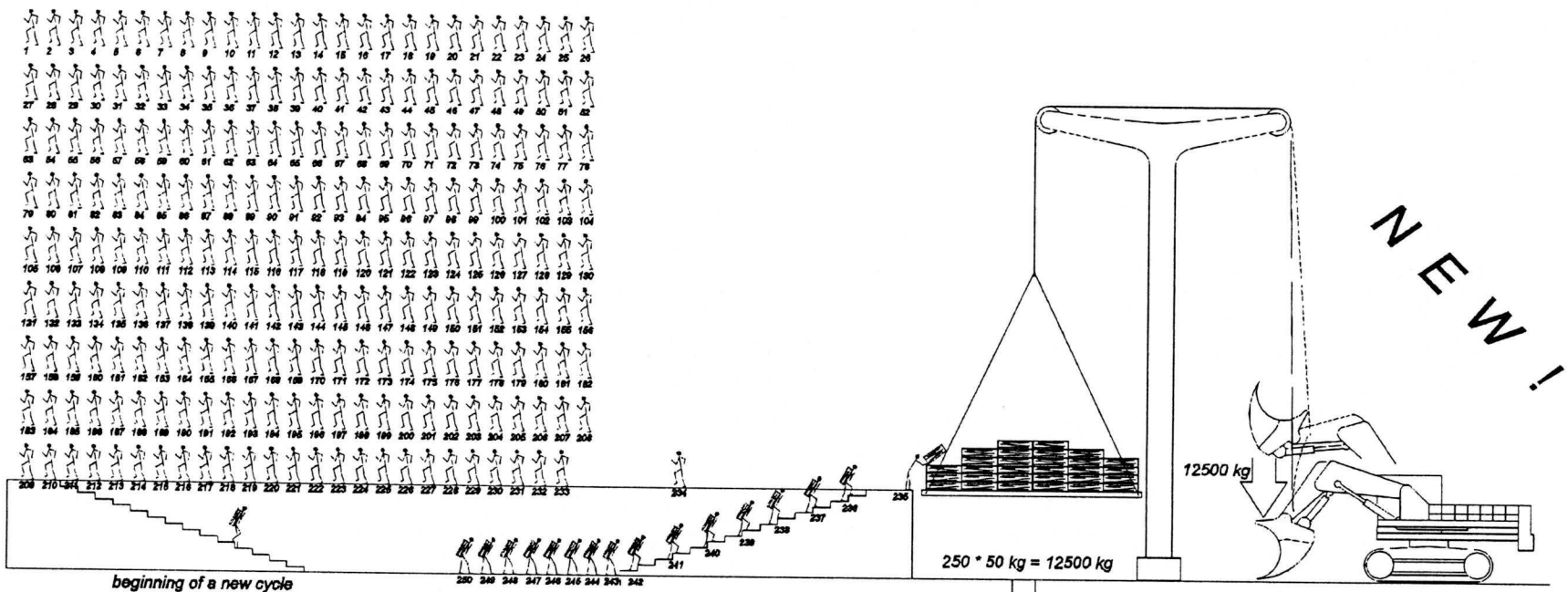


FIG. 7

WORK NECESSARY TO LIFT THE ATTACHMENT IN EACH CYCLE OF WORK CONVERTED INTO HUMAN WORK IS:

- *Mass of the loading attachment – 12.500 kg*
- *Height of lifting of the center of gravity – 2.8 m (1st floor)*
- *Duration of a cycle – 18–25 s*
- *Mass per 1 man assumed in analysis – 50 kg*

Number of people necessary to load a mass of 12.500 kg

$$A = \frac{12\,500}{50} = 250 \text{ people}$$

Explanation:

The drawing shows a grup of 250 people who every 20 seconds load bags with cement weighing 50 kg onto the platform located at the height of the first floor. The loaded platform causes the excavator's attachment to the lift.
The figure pictures the potential energy which is stored in the phase of falling of the attachment in the recuperator and then used in the cycle of work.
In an excavator which is not equipped with recuperator this energy is lost and converted into heat.

USE ONLY EXCAVATORS WITH ENERGY RECUPERATION YOU WILL MAKE GREAT SAVINGS IN TERMS OF COSTS OF OPERATION

The energy recuperated in working cycle substitutes the work of 250 people carrying 50 – kilogram bages onto the first floor.