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On the Optimization of Resistance Projection Welding Process

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Abstract. The resistance projection welding process for weld nuts has several parameters to reach good joint quality. In this study, three welding parameters were chosen, such as electrode force, welding period and welding current to examine the process. Design of experiments was prepared to optimize the conditions. The three above mentioned parameters were changed systematically with Response Surface Method, where the linear and the quadratic effects of the parameters can be estimated. During the experiments three output parameters, such as ultimate torque, weld spatter and inspection of screw were determined, and optimization were performed for the resistance projection welding process of the weld nut.

Keywords: optimization, RSM method, DoE, welding

Introduction

Resistance welding, which can be classified in the group of press welding, is one of the oldest methods of welding, a group of processes in which a cohesive bond is created by the combined application of force and heat. In addition to spot, line and butt welding, the basic processes of resistance welding include bump welding derived from spot welding and foil line welding derived from line welding [1].

In resistance spot welding, with the increase in the number of welds (due to wear), the gradually increasing electrode tip size leads to a decrease in the size of the seam (due to the decreasing current density) and the pressure between the plates (sufficient to ensure optimal local contact), as a result of which the electrode head must be regulated at regular intervals; an additional problem is that the minimum distance between the point seams is limited due to the shunt effect. Therefore, bump welding was developed to eliminate these difficulties [1].

The process derived from spot welding usually works with less force and a shorter welding cycle than the bumpless version. The essential difference between the two can only be seen in the design of the electrodes (flat electrode head), which stems from their different tasks. While in spot welding, in addition to application of compressive force and current, the task of the electrodes is to concentrate force and ensure the current density necessary for melting, while in butt welding, application of compressive force and current are limited to what the task of the electrodes is [1]. The applied force and current are concentrated by the geometry formed on one of the workpieces, the so-called bump (hence the name of the procedure). The current density required to melt the materials to be joined is the result of contact on a relatively small surface (the bump), where in addition to the current density, the contact resistance also increases to the desired value [1].

The goal was to obtain as much information as possible about the butt-welding process with minimal cost (number of experiments) and time, regarding the effect of individual welding technological parameters (continuous independent variables) on the load capacity of the welded nuts, their distortion, and the spatter occurring during welding (dependent variables).

Due to the complex quality requirements, maximizing the load capacity of the butt-welded joint is not adequate, therefore we set the goal of optimizing the welding technological parameters according to three aspects.

1. Materials and methods

1.1. Experiments

The experiments were carried out on 50 × 50 × 4 mm plate-like test specimens made from the base material of the original product (S235JR) and its production technology. The aim was to ensure that the condition of the surface of the test specimens (various impurities, metal dust, surface oxide scale) is almost identical to that of the original part. During the experiments, M6 weldable nuts (DIN 928, [2]) were joined to these test specimens, and then these were also used for (destructive) break torque tests to determine the load capacity of the joint (Fig. 1). It was 23°C in the plant during the tests.

Fig. 1. – The prepared specimens before, after, and during the brake torque tests (from left to right)

The spatter that occurred during the execution of the series of experiments (which is practically unavoidable due to the surface oxide) was subjectively classified according to the categories defined in Table 1. With this, the goal is that although we cannot eliminate the root cause (the cracked surface resulting from the hot-rolled material quality, since the customer requests the product from such a material), it is necessary to reduce the spatter caused by it, which is harmful in many ways and dangerous for accidents.

Table 1. Definition of the categories of the splash

Defined weld spatter categories	*Value*
Small spatter: the bulk of the sparks reach to the operator's wrists and forearms.	0
Medium spatter: most of the sparks extend to the body line of the operator.	0.5
High spatter: the vast majority of sparks fly past the machine operator.	1

After welding the test specimens, the so-called go/no-go check is performed as well. It is scored 1 for those that could be folded into, and 0 for those that could not.

The break torque test is performed with a Beta 606/20 type torque limiter, control range: 30-200 Nm, accuracy: between ±4%. The measuring device was calibrated by the company shortly before the tests. The method of the break torque test is starting from 30 Nm and increasing in 1 Nm increments, the tightening torque of the torque wrench is checked on all welded joints. When the seam breaks, the set torque value is recorded with which the welded specimen is loaded.

1.2. Design of experiments

Design of Experiment (DoE) is an effective procedure for planning and analysing experiments, which allows drawing real and objective conclusions based on the obtained data [3-4].

The (continuous) factors are decisively determining the bump welding process (the heat input), i.e., the main welding parameters: the electrode force (F [kN]), the welding cycle time (t [period]) and the welding current (I [kA]). It is assumed that there would be at most a quadratic effect in the system, therefore non-linear (quadratic) effects are considered. To reduce the number of experiments to be performed, the Box-Behnken fractional factorial design was chosen from the Response Surface Method (RSM) [5]. With this experimental plan:

- the main effects (x_1, x_2, x_3),
- the quadratic effects (x_1^2, x_2^2, x_3^2), and
- the interactions ($x_1 \cdot x_2$, $x_1 \cdot x_3$, $x_2 \cdot x_3$)

can be considered.

The developed phenomenological model is as follows:

$$Y = b_0 + b_1 \cdot F + b_2 \cdot t + b_3 \cdot I + b_{11} \cdot F^2 + b_{22} \cdot t^2 + b_{33} \cdot I^2 + b_{12} \cdot F \cdot t + b_{13} \cdot F \cdot I + b_{23} \cdot t \cdot I + \varepsilon \quad (1)$$

where b_is are the coefficients of the regression model, Y is the value of the output parameter, ε is the experimental error. Using the Box-Behnken fractional factorial design, the former response function can be estimated, which is a multivariate linear regression model.

Each factor is examined at three levels, which means that each parameter can only have a high (+1), a medium (0) and a low (-1) value, and the recommended setting is placed in the design center (0). The size of the variation interval (Table 2) is determined in such a way that the experimental settings cover a sufficiently large range and result in welding that is feasible on the machine and does not endanger either it or its operator. It is also important to choose a sufficiently small range so that the correlations corresponding to the used model (Eq. 1) are true.

Table 2. The set values of the factors in natural units

Parameter	*(-1)*	*(0)*	*(+1)*
F [kN]	3	4.5	6
t [period]	4	6	8
I [kA]	9	11	13

The Box-Behnken design requires only 15 experimental settings shown in Fig. 2, compared to 27 settings for the full design, three of which are repetitions at the centre point (plan centre). The latter was used to check the adequacy of the model.

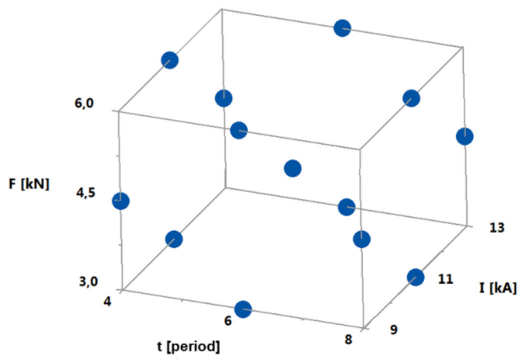

Fig. 2. – The set of Box-Behnken design

To estimate the effects more precisely, the welding was repeated three times, which meant a total of 45 tests. To eliminate unwanted effects (for example, some time-dependent factor that may be present in the system but neglected), the tests are performed in a random order generated by a random number generator.

1.3. Method of optimization

The expectation is that the break torque should be as high as possible, but at least 20 Nm (according to the specification), the nut should fulfil its function and the spatter should be as small as possible during welding. Table 3 contains a quantified formulation of these expectations.

Table 3 - Objective functions chosen for multivariate optimization of parameters

Dependent variable	*Objective*	*Minimum value*	*Maximum value*	*Target value*
Break torque [Nm]	Max.	36	84	84 (min. 20)
Go/ Not Go	Max.	0	1	1
Spatter	Min.	0	1	0

The requirements formulated in Table 3 contradict each other, because at maximum break torque the go/no-go is minimal and weld spatter is maximal. To perform multivariate optimization of the parameters, (different) dependent variables in Table 3 should be comparable to each other. Therefore, to map them, the desirability functions (d-function) were introduced shown in Fig. 3. The d_{Bt} shown in the Fig. 3 is relative to the brake torque, d_G and d_{Sp} belong to go/not go gauge and the splash rate, respectively. Each of these (based on fuzzy logic) has a desirability function value between 0 and 1, depending on the degree of function or, in other words, the degree of fulfilment of expectations, by which it can already be compared with each other [6].

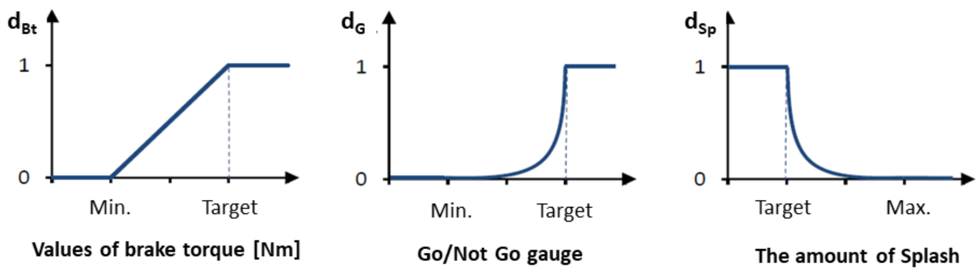

Fig. 3. – Desirability functions

The objective function for the optimization is as follows (based on the individual d-functions):

$$D = \sqrt[3]{d_{Bt} \cdot d_G \cdot d_{Sp}} \quad (2)$$

The closer its value is to one, the more complex expectations are met.

2. Measurement results

The parameter settings of the experiments and the obtained results are summarized in Table 4. It is seen that the experiments were performed in a random order and each setting was repeated three times.

Table 4 - Objective functions chosen for multivariate optimization of parameters

Standard order	*Run order*	*F [kN]*	*t [period]*	*I [kA]*	*Brake torque [Nm]*	*Go/Not Go*	*Splash*
1	9	3	4	11	53	0	1
2	11	3	4	11	48	0	1
3	29	3	4	11	63	0	1
4	15	3	6	9	53	1	0.5
5	18	3	6	9	54	1	1
6	31	3	6	9	52	1	0
7	37	3	6	13	74	0	1
8	40	3	6	13	58	0	1
9	45	3	6	13	59	0	1
10	1	3	8	11	77	0	1
11	30	3	8	11	75	1	0.5
12	42	3	8	11	74	1	0
13	8	4.5	4	9	43	1	0.5
14	14	4.5	4	9	47	1	0
15	32	4.5	4	9	47	1	0
16	7	4.5	4	13	81	1	0.5
17	26	4.5	4	13	82	0	1
18	38	4.5	4	13	84	1	1
19	5	4.5	6	11	70	1	0
20	6	4.5	6	11	70	1	0
21	10	4.5	6	11	68	1	0.5
22	12	4.5	6	11	71	1	0
23	22	4.5	6	11	62	1	0.5
24	33	4.5	6	11	64	1	0.5
25	34	4.5	6	11	63	1	0
26	39	4.5	6	11	70	1	0.5
27	41	4.5	6	11	64	1	0
28	27	4.5	8	9	48	1	0
29	35	4.5	8	9	48	1	0
30	36	4.5	8	9	48	1	0
31	4	4.5	8	13	80	1	1
32	16	4.5	8	13	79	1	1
33	24	4.5	8	13	74	0	1
34	2	6	4	11	58	1	0
35	13	6	4	11	61	1	0
36	20	6	4	11	59	1	0
37	3	6	6	9	36	1	0
38	28	6	6	9	38	1	0
39	44	6	6	9	37	1	0
40	23	6	6	13	78	1	0.5
41	25	6	6	13	78	0	0.5
42	43	6	6	13	72	1	0.5
43	17	6	8	11	53	1	0
44	19	6	8	11	52	1	0
45	21	6	8	11	49	1	0

The effect of one factor is the average difference between the upper and the lower levels. The main effect plot shown in Fig. 4 are suitable for representing the effects of individual factors. The main effect plots give the average value of all the experiments measured at each level of the given variables (*F*, *t*, *I*) (in the case of *F*, for example: 3-4.5-6 kN). Based on the Fig. 4, it can be concluded that the largest effect was the change in the current magnitude, as the latter increases, the average of the break torque also increases monotonically. At the same time, it is also clearly visible that the second largest effect was the electrode force. As a result of changing the current flow duration, the average of the break torque changes only slightly.

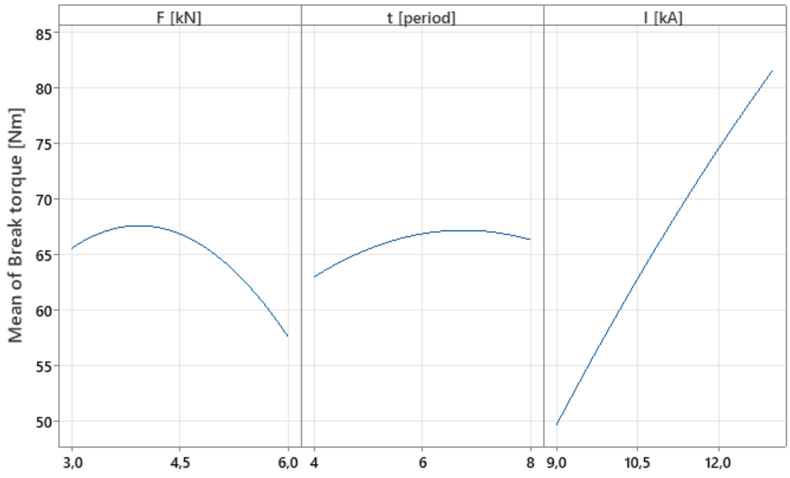

Fig. 4. – Main effect plots for break torque

The interaction plot shown in Fig. 5 are suitable for examining (graphically illustrating) the interactions of the factors. The interaction between individual factors is that if the effect of one factor on the break torque depends on the set value of the other factor. To get to know the interactions, it is advisable to search for the optimum by changing not one but all factors together.

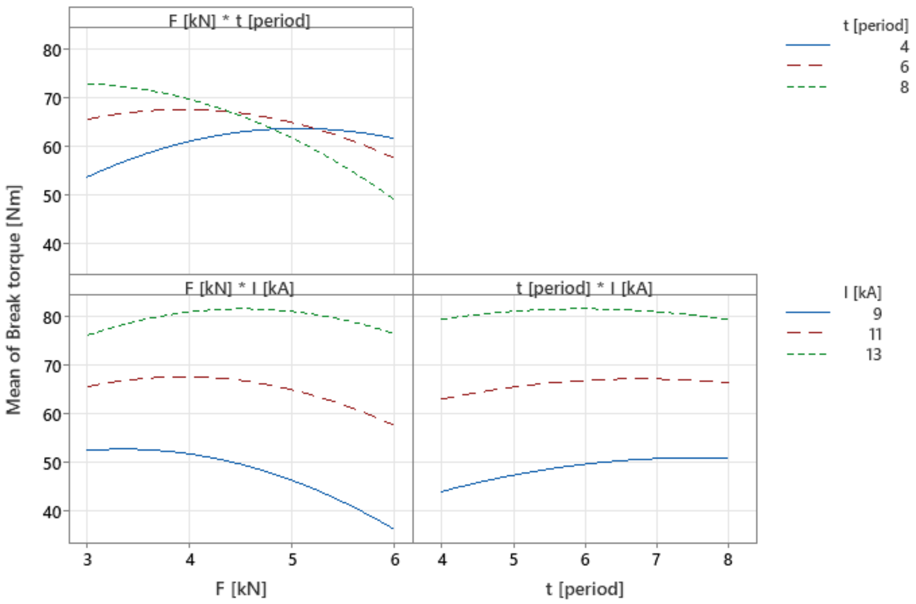

Fig. 5. - Interaction plots for the break torque

It can be seen in Fig. 5 that the effect of the electrode force on the average break torque depends somewhat on the set value of the current (lower left graph). This can be determined from the fact that the curves representing the effects are not perfectly parallel to each other, so we can say that there is a weak interaction between the two factors. The effect of welding time on the average break torque is the same at all three levels of current strength, the curves representing the effects can be considered practically parallel to each other, so there is no interaction between the two factors (lower right graph).

If the effect of the electrode force on the average break torque is examined (upper part of Fig. 5) as a function of the welding duration, it is clearly seen that the latter's effect on the average break torque depends significantly on the level of welding time. The curves representing the effects cross each other, so it can be concluded that there is a strong interaction between the two factors.

Since there is a significant interaction between the individual factors, the main effect plots shown in Fig. 4 are not suitable for drawing extended conclusions.

The series of experiments shows the importance of the settings required to achieve the average break torque of 60 Nm marked in orange in Fig. 5. Because the former can be realized by setting a parameter combination with a period of t = 4 and F = 3.8 kN or a parameter combination with a period of t = 8 and F = 5.1 kN, with identical current (I = 11 kA). There is a significant difference between the two settings in terms of both the welding time and the electrode force, but at the same time, the achieved result in terms of the break torque is approximately the same, the difference between the two settings is only 0.8 kN.

3. Statistical evaluation and optimization

3.1. Estimated model

The mathematical equation of the break torque (T_b) determined by regression is as follows:

$$T_b = -151.5 + 19.15 \cdot F + 24.21 \cdot t + 11.30 \cdot I - 2.345 \cdot F^2 - 0.554 \cdot t^2 - 0.314 \cdot I^2 - -2.646 \cdot F \cdot t + 1.381 \cdot F \cdot I - 0.437 \cdot t \cdot I + \varepsilon \qquad (R^2 = 95.64\%) \quad (3)$$

Eq. 3 is the estimated regression function, and by substituting the parameters F [kN] (electrode force), t [period] (duration of current flow) and I [kA] (welding current) into it, the expected magnitude of the break torque is obtained. The previous assumption that there would be a quadratic effect in the system proved to be true based on the quadratic terms in the model and their non-zero coefficients. A graphical representation of the equation can be seen in Fig. 6.

The coefficient of determination is a measure between 0 and 1, which indicates the goodness of the regression estimate, in this case it is 95.64%. A value close to one indicates that 95.64% of the variance of the break torque can be explained by the regression model (Eq. 3).

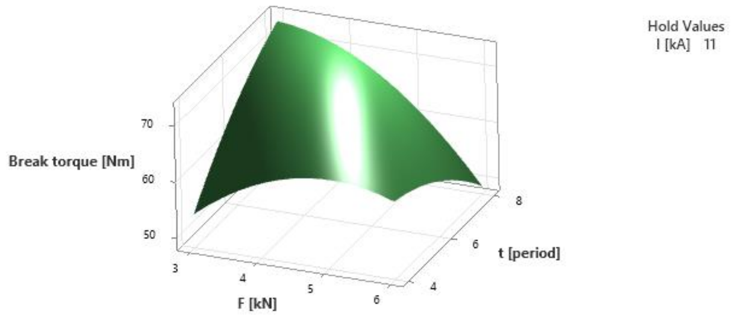

Fig. 6. - Surface plot of break torque as a function of electrode force and time period at constant current

The repeated standard deviation of the obtained mathematical model was 3.26 Nm, which means that the results estimated by the model approximate the real (measured) values with a 95% probability in the range of ±6.51 Nm, i.e., the repeated weldings and the break torque tests gave fluctuating uncertainty in such a large range.

3.2. Examination of residuals

The goodness of the obtained regression model was checked by examining the difference between the values estimated by the model and the measured (real) values, i.e. the residuals. The fit is good if the residuals are normally distributed, fluctuate randomly with zero expected value and within the group the standard deviations are the same, i.e. $\varepsilon \sim N(0,\sigma^2)$.

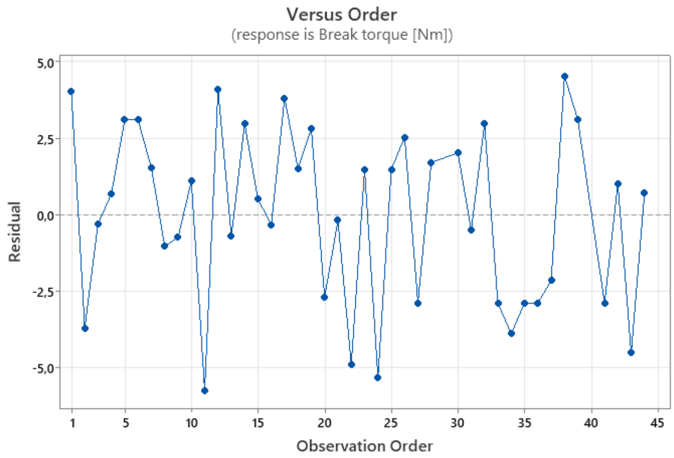

Fig. 7. - Residuals in the sequence of the experiments

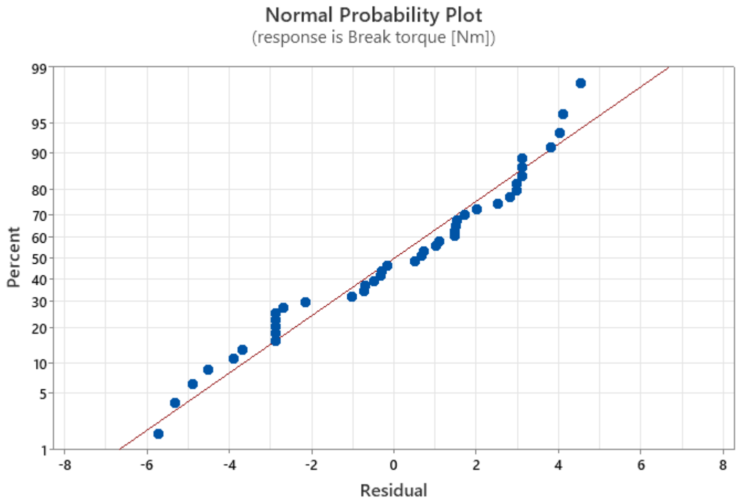

Fig. 8. – Normal probability plot (response is break torque [Nm])

The residuals can be illustrated in two ways: on the one hand, they can be represented in the order in which the experiments were carried out (Fig. 7), and on the other hand, on a so-called normal probability plot suitable for examining the normal distribution (Fig. 8). Based on the Fig. 8 the residuals are normally distributed resulting the straight line in the probability plot. The residuals of the break torque values are located along the drawn line and fluctuate randomly around it. There are practically no outliers between the points on the plot. The distribution of the residuals also meet the criteria. Based on the above, it can be stated that the regression equation well represents the relationship between the dependent (break torque) and independent (*F*, *t*, *I*) variables.

3.3. Optimization

The multivariate optimization was performed using the desirability functions according to Fig. 3. The individual desirability function values (d_{Bt}, d_G, d_{Sp}) can be found in Table 5. The value of the optimization objective function (Eq. 2) was D = 0.8314, which means that the complex expectations are met at a high level.

Table 5. – Desirability objective function values

Variable	*Value of desirability function (d_i)*	*Value of the output parameter (y_i)*
Break torque [Nm]	0.57469	63.6
Go/Not go	1	1
Spatter	1	0

With the expectations in Table 5, the parameter values shown in Table 6 were calculated as the result of the multivariate optimization.

Table 6. - Optimized welding parameters for multiple response

Parameters	*Optimized values*	*Recommended starting values*
F [kN]	6	4.5
t [period]	4	6
I [kA]	11.2	11

Calculating with the optimal parameter settings, the value of the break torque will be 63.6 Nm, which is much higher than the expected minimum of 20 Nm.

It can be seen in Table 6 that the optimal welding parameters differ considerably from those recommended (by the manufacturer) in the same table. Using the former, the electrode force is 1.5 kN higher, but the joint can be done with almost 34% less welding time and a small amount of spatter. And it can be considered practically that the nut will perform its function in any case, and the bond strength achieved will exceed the minimum prescribed value.

3.4. Confirmation

Confirmation is certainly one of the most exciting points of the experimental design, during it is checked whether the results calculated during the optimization are also suitable in the real environment. The test welding was repeated, setting the input parameters to optimal values. This was repeated three times in the same way as all previous measurements.

Table 7 shows the measurement results calculated from the model and measured during the control experiments. In the table, the deviation of the former two is marked with a red. The repeated measurements showed that the model (Eq. 3) describes the break torque accurately, and the categorical dependent variables (Go/Not go, splatter) were also adequate. In this parameter space (Fig. 1), the break torque was almost perfectly described by the obtained mathematical model since there was a maximum of 2.6% difference between the calculated and measured values.

Table 7. - The measurement results during the confirmation experiments

No. of meas.	*Splash*	*Go/ Not Go*	*Brake torque [Nm]*
1.	0.5 (+0.5)	1	62 (-1.6)
2.	0	1	63 (-0.6)
3.	0	1	62 (-1.6)

Conclusions

During the investigation of the bump welding process, the values of three welding parameters were systematically changed: the electrode force, the welding cycle time and the welding current, using the method of design of experiments. The amount of welding current had a significant effect on the value of the break torque of the finished butt-welded joint. An interaction was demonstrated between the electrode force and the cycle time parameters, according to which the value of the break torque was influenced by the value of the period time at a given electrode force.

During the examination of the welding quality, the degree of spatter occurred was determined with the given settings in a subjective way, as well as checking the welded nuts with a thread gauge. The optimal setting of the parameters of the bump welding process was determined by multivariable optimization for a total of three output characteristics (brake torque, spatter rate and thread caliber control), which was verified during the confirmation experiments.

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Development of Mobile Communal Overpasses Applied During Repairing of Urban Communal Networks

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Abstract. The issues of design and research of the operation of communal overpass structures that are mobile and modular are outlined. The proposed overpasses are mobile bridge structures equipped with their own chassis for their movement. They are designed for vehicles to pass through them and are used to eliminate traffic jams on city roads and during the repair of underground communal networks. The idea of using overpasses is to eliminate traffic congestion, improve the ecological state of cities by developing structures, creating a methodology for calculating and designing mobile and modular overpasses. The term communal overpass includes mobile and modular overpass in its meaning.

Keywords: mobile overpasses, modular overpasses, temporary bridges, traffic jams, congestion elimination, strength and stability calculation.

Introduction

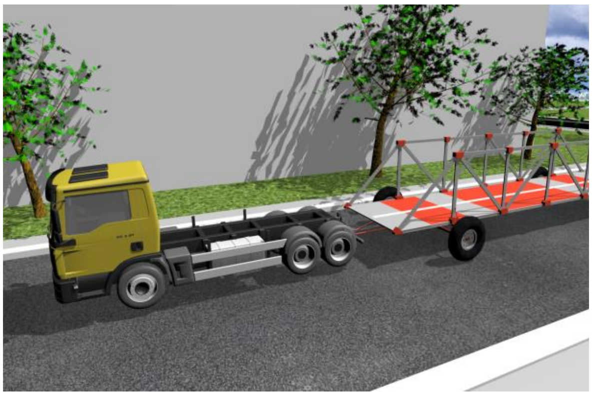
Every year in large cities and metropolitan areas the number of different vehicles is growing. In such conditions of heavy urban traffic, traffic jams and congestion occur due to various reasons: car accidents, rush hour, repair works on highways, repair of urban communal networks. In many large cities, there is a problem of solving traffic jams during the natural traffic and during the repair of urban infrastructure. For large cities, this is an acute transport problem. As you know, traffic jams and congestion on city highways worsen the transport logistics of the city, cause economic damage to entrepreneurs, the city budget, etc.

One of the causes of traffic jams on city roads is the repair of communal network pipes (heating, water, etc.) located under the carriageways of city roads. This is especially true for the cities of the Republic of Kazakhstan, Russia and the CIS countries. During the repair of urban utility networks, vehicles are forced to bypass repair trenches along other streets, which creates traffic jams and worsens the transport picture of the city. There is a need for direct crossing of repair trenches by traffic flows to eliminate traffic jams and continuous traffic [1].

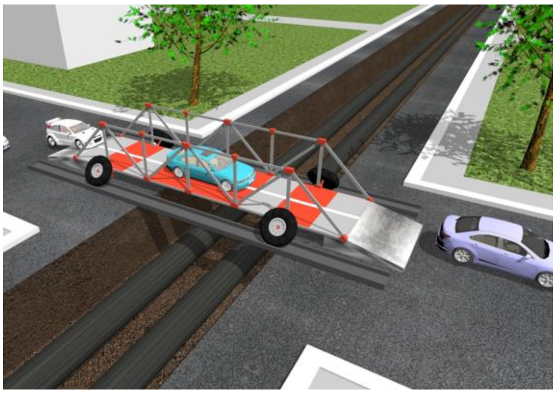
To solve this problem, we propose the design of mobile communal overpasses (Figure 1, Figure 2). They are temporary mobile bridge crossings equipped with their own running gear. Such mobile overpasses are installed on top of the road lanes in those areas where underground repairs of utility networks under the roads are taking place. This contributes to the movement of vehicles on an emergency or repair site and, accordingly, eliminates traffic jams and the need to bypass repair sections of roads.

The use of the overpasses suggested by us significantly improves transport logistics in the city during traffic jams or repair work on communal networks: it reduces the formation of traffic jams, there are no forced detours of repair sites, and the inconvenience for car drivers and residents of city districts, where forced detours would occur, is reduced. Also, the use of overpasses can improve the ecology of cities, because traffic jams cause great harm, due to the simultaneous constant emission of pollutants from car exhaust gases [2].

Such mobile overpasses can be used not only to eliminate traffic jams and underground repair work in urban areas, but also in emergency situations caused by floods, earthquakes, resulting in the destruction of various infrastructure – roads, bridges, crossings, that is wherever it is necessary to establish temporary bridge crossings.



Transport position



Operation position

Fig. 1. - Mobile communal overpass

A distinctive feature of overpasses is their mobility that is moving on their own chassis using a car trailer or by trucks. Quick assembly and disassembly at the place of its installation due to the use of unified collapsible modules and methods of their attachment to each other and to the ground base. This ensures fast delivery to the necessary areas with traffic jams, repair areas of utility underground networks or to areas with damaged infrastructure caused by various emergencies.

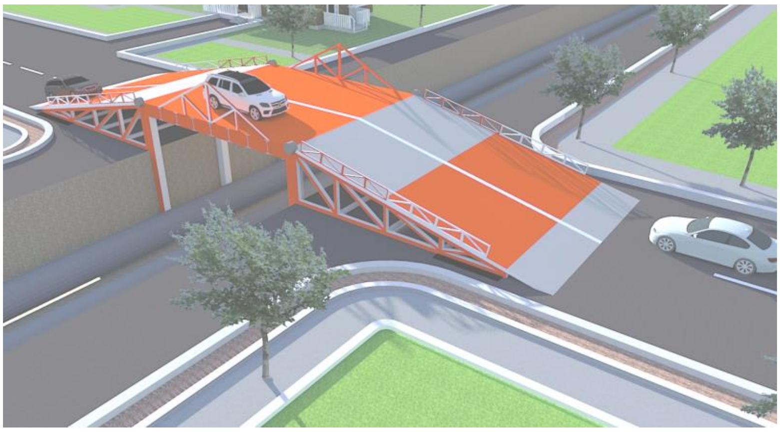


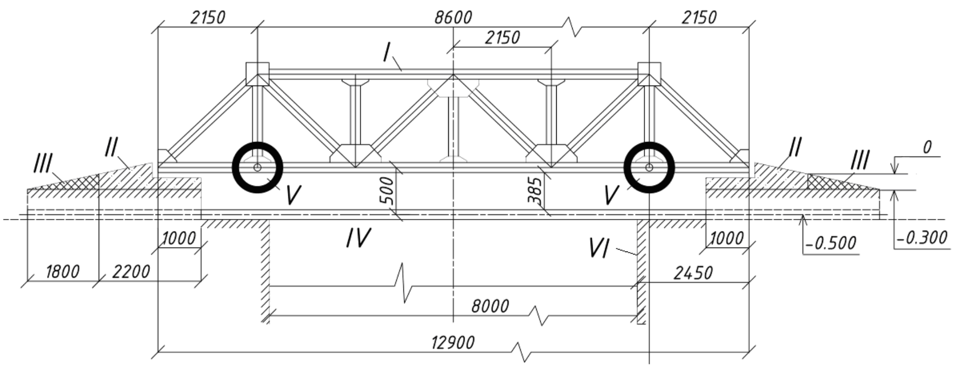
Fig. 2. - Modular communal overpass

An analysis of the state of this topic in Kazakhstan, the CIS and abroad showed the almost complete absence of the existence of such mobile bridge structures to eliminate traffic jams while urban repair needs and emergency conditions. Separate elements of a similar theme are partially developed in military bridge building by the development of tank bridge layers, etc. The issue of creating mobile overpasses has not been developed in civil transport construction and requires a comprehensive study and creation of scientific foundations for the design of mobile overpasses for various conditions of their operation. Thus, mobile overpasses have no analogues in the world, and represent a new type of transport which in a stationary position is a bridge (overpass), and when moving it is a vehicle.

1. Materials and methods

We have developed several options of communal overpasses: mobile (Figure 1) and modular overpass (Figure 2). Such overpasses are installed through the repair ditches of communal networks and allow not to stop traffic in the area of repair sections of roads for the entire period of underground repair.

The communal mobile overpass is a single platform, equipped with its own running gear and delivered to the installation site using a tractor on a trailer (Figure 3). After delivery, it is installed by sliding through the trenches with the help of guide skids thrown over the trench. After sliding, the overpass structure is lowered onto reinforced concrete supports. The overpass is intended for passing cars and lightly loaded trucks through trenches up to 8 m wide and up to 3 m deep. The width of the carriageway is 2.5 m, with the calculated load on the carriageway of up to 3 t/m^2. The overpass with a span of 12.9 m and a width along the framework axes of 3m is designed from a single-span supporting structure under which the running gear is designed.



Explication of structural elements:

I – bearing structure of the roadway of the overpass
II – supporting reinforced concrete supports
III – rammed ground ramps
IV – metal guide skids
V – undercarriage of the overpass with wheels in the upper position
VI – trench board

Fig. 3. - Scheme of a mobile communal overpass

Unlike a mobile overpass with a single platform, a modular overpass is assembled from unified collapsible modules of two types: one horizontal module and two inclined modules (Figure 4). The horizontal (orthogonally oriented) module is a spatial steel frame, the base of which is attached to the bottom of the repair trench by special methods. The upper part of the frame is a roadway in the form of an orthotropic plate with reinforcing ribs. The inclined module is a steel framework bearing the roadway also in the form of an orthotropic plate. The base of the framework rests on the soil base, the other part of the trusses rests on the bearing frame (Figure 4).

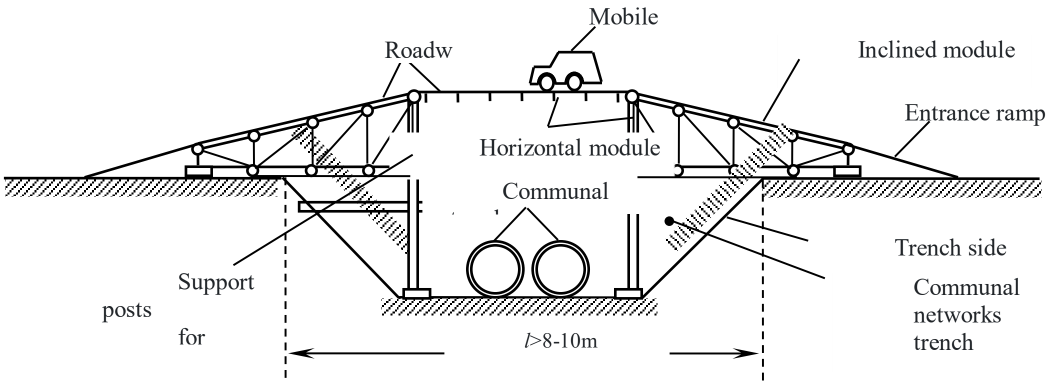


Fig. 4. - Scheme of a modular communal overpass

Adhesion of inclined modules to the supporting frame allows avoiding the load on the edges of the sides of the repair trenches and reduces the likelihood of their collapse during the operation of the overpass. However, the second support devices of the inclined modules are in force interaction with the natural soil base, and therefore, the task is to further study the stress-strain state of the soil mass and prevent the collapse of the trench sides.

The overall dimensions of "single-lane" modules are as follows: the length of an orthogonally oriented module is from 8 m; width – 3.5m; height (taking into account their installation at the bottom of the trenches) – 5m. The length of the inclined module is 4m; width – 3.5m; greater height – 0.85m; smaller height – 0.1m. The main difference between a modular overpass and a mobile overpass is the ability to overcome trenches with a width of more than 8m (Figure 4). To overcome trenches of this width, composite modules have been developed for the strength and stability of the entire structure as a whole.

The bridge crossing is delivered to the installation site in separate modules and assembled in a “single-lane” or by a coupling method in a “two-lane” form. After using the communal overpass, it is dismantled into individual modules at the “coupling” points, and then they are delivered to their storage sites.

2. Main results

2.1 Solutions obtained

Our research group has developed scientific theoretical foundations for the calculation and design of mobile and modular overpasses of various types, including design solutions for the development of all its parts and assemblies.

Space-planning and design solutions have been developed for the design of unified modules of mobile bridge crossings, providing the required bearing capacity of its carriageway for the passage of the type and number of rolling stock determined by the standards of automobile bridge building. In this case, a preliminary selection of the shapes and dimensions of the cross sections of the supporting structures is also carried out for the performance of their further calculations.

Calculations of orthotropic plates of the carriageway of bridge crossings were carried out by various numerical methods, such as the method of finite elements, finite differences, etc.

The stress-strain state of spatial frames of orthogonally oriented overpass modules was studied on the basis of calculations of the force state by the analytical displacement method with the formation of common matrices that take into account the parametric variability of the geometric and stiffness characteristics of the bearing elements of spatial frames. This allows automatic calculation of similar frames for bridge crossings of various design solutions and purposes. Here, the final selection of the cross sections of the load-bearing structures of the space frame is made on the basis of the normative conditions for strength, rigidity and stability, taking into account the specific requirements for automotive bridge construction.

The work of load-bearing flat statically indeterminate frameworks of inclined modules of overpasses has been studied by the analytical method of forces. Here we study the influence of the stiffness characteristics of the framework rods, changes which can have a significant result on the force and stress state of the framework as a whole.

The interaction of the overpass support devices with the natural ground base was studied and an analysis of the stress state of the ground mass in the area of the trench sides was developed [3].

On this basis, practical foundations have been developed for calculating the strength and stability of the corresponding volume of a ground mass under load from the pressure of the overpass support devices and recommendations for preventing their collapse during the operation of the overpass [4].

The design of the running gear, steering mechanisms, lifting-turning wheels and other parts have been developed. Various types of overpass supports have also been developed, the mechanisms for fastening modules for which the relevant patents and intellectual property certificates have been obtained.

To create an effective design solution for mobile overpasses, based on the mathematical theory of optimization, methods of optimization calculations have been developed in order to minimize the metal consumption of structures to reduce their cost.

2.2 Design solutions

The supporting structures of all types of overpasses are made of hardened steel grades. The roadway is made of thin corrugated steel or rubberized fabric to ensure the required adhesion of vehicle tires.

Preliminary selection of cross-sections of load-bearing elements of modules of bridge crossings of all types is based on the conditions of strength, rigidity, stability with a sufficient margin, taking into account possible overloads and the dynamic effect of traffic on the carriageway of the rolling stock. The value of bridge loads is accepted according to the conditions of euronorms.

Geometrical and stiffness characteristics of load-bearing structures are generalized and reduced to leading parameters for the possibility of calculating elements of collapsible modules for various purposes. and target functions.

Supporting racks orthogonally oriented communal module on the bottom of open ditches and trenches is made through non-removable concrete piles-racks.

Conclusion

The theoretical foundations of calculations developed and described above make it possible, on a practical basis, to design overpasses of various types, starting with the development of their constructive solution, selection of cross-sections of load-bearing structures according to the conditions of their strength, rigidity and stability, taking into account various loads: both static and dynamic, arising from the movement of rolling stock along the roadway. Using optimal design methods, it allows to create economical and reliable designs of overpasses.

The theoretical and applied developments described in the paper make it possible to obtain reliable and economical solutions for the design and construction of practical mobile and modular overpasses.

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The Impact of the Modernization of the Ignition and Injection System in the Dniepr MT 11 Motorcycle on the Frequency of Service Operations

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Abstract. Circular economy principles works with nature built environment with water, air, carbon cycles with no waste. Industrial revolution enable society led to development of engine and became more powerful machines. This include motorcycle which is has a life span based on the revolution of engine technologies. Modern ignition and injection systems significantly reduce servicing. In the Dniepr MT 11 motorcycle from 1989, in accordance with the manufacturer's guidelines, the following should be checked every 5,000 km: cleanliness and fastening of the interrupter contacts, oiling the felt and friction elements of the ignition advance mechanism, and adjusting the spark plug gap. As regards the fuel supply system, the carburetor should be washed and blown out and the tap strainer should be cleaned every 500 km. Additionally, due to climatic conditions, the position of the carburetor needle should be adjusted. In addition, before working on the fuel system, check the gap between: spark plug electrodes, breaker contacts, valve stems and levers. After modernization and the use of an electronically controlled injection and ignition system, service activities were limited to adjusting the gaps on the spark plugs (every 5,000 km) and replacing the fuel filter and cleaning the filter element in the pre-filter every 30,000 km. The developed solutions confirm the possibility of improving the operation of older structures in the field of injection and ignition systems at the level of modern structures.

Key words: motorcycle operation, modernization, improvement of operational properties, new technologies in old structures, motorcycle use, circular economy

Introduction

Historically, in 1963, motorcycles have played a crucial part in the motor vehicle fleets of some currently developed countries such as Poland (70%), Sweden (70%), Portugal (64%), Japan (60%), Netherlands (58%), Italy (55%), Austria (44%), and France (41%). By the year 2010, these percentages have dropped to below 14% [1]. End-of-life vehicles (ELVs) include motorcycles are fast-growing waste streams in the EU. In industrialised countries with saturated markets the new technologies faster with new trend which the number of new goods coming to market is comparable to the number of similar goods going to waste [2]. Thus, the disposal require specific collection and treatment activities to avoid environmental pollution and resource depletion fed by the linear economy model [3]. It is important to understand this issue of discontinuity. Circular Economy is a conscious choice to cope with abundance and to reduce waste and shift a consumer society based on fashion [2]; example restoration of engine of antique motorcycles.

Modernizing the design of the fuel supply and ignition systems in motorcycles can bring many benefits. The first is greater fuel savings. Modern systems utilize advanced fuel injection technology, which allows for precise control over the fuel-air mixture [4,5]. This results in better combustion and improved fuel efficiency, leading to reduced fuel consumption and longer riding range. The second is enhanced performance. Upgrading the fuel supply and ignition system can significantly enhance the overall performance of motorcycles. Modern systems provide better throttle response, smoother acceleration, and increased power output [6]. This can greatly improve the riding experience and make the motorcycle more enjoyable to ride. Thirdly, easier starting. Traditional carbureted systems often require manual choke adjustments and multiple attempts to start the engine, especially in cold weather. Modern fuel injection systems eliminate these issues by automatically adjusting the air-fuel mixture based on various parameters, ensuring easier and more reliable starting [7]. Fourthly, reduced emissions. Modern fuel injection systems are designed to meet stringent emission standards. By precisely controlling the fuel delivery, these systems can optimize combustion and minimize harmful exhaust emissions, contributing to a cleaner environment [8]. Fifth, diagnostic capabilities. Modern systems often come equipped with onboard diagnostics, allowing for easier troubleshooting and maintenance. These diagnostics can provide valuable information about the performance of the fuel supply and ignition system, making it easier to identify and address any issues [9]. Overall, modernizing the design of the fuel supply and ignition system in motorcycles offers improved fuel efficiency, enhanced performance, easier starting, reduced emissions, and advanced diagnostic capabilities. These advantages make it a worthwhile investment for motorcycle owners seeking a more efficient and enjoyable riding experience.

The aim of the article is to determine the impact of modernization of the injection and ignition system in the Dniepr MT 11 motorcycle (Fig. 1) on service operations during everyday operation.

Fig. 1. – Dniepr MT 11 motorcycle

1. Materials and method

In the Dniepr MT11 motorcycle, the ignition and injection systems work with a counter-rotating boxer engine. The cylinders lie in one plane opposite each other [10]. Arranging the cylinders in this way makes it difficult to use a single source of power for the fuel-air mixture. The use of two carburetors in the system, one for each cylinder, increases its power and facilitates starting the engine. Figure 2 shows the engine with the installed systems. The valve timing mechanism is responsible for closing and opening the intake and exhaust valves at a time that corresponds to a specific angle and rotation of the crankshaft. Therefore, the timing shaft makes one revolution and the crankshaft makes two revolutions. This information is important when the ignition system's impulse wheel is mounted on the camshaft. Then it must have twice as many teeth as if it were mounted on the crankshaft. Maintenance of the ignition system mainly concerns the ignition advance breaker, which should be kept clean. At the same time, check the fastening of the interrupter, oil the felt and the friction surfaces of the ignition advance mechanism. Contacts and any adjustments should be made every 5,000 km during normal operation, and every 500 km at the beginning of use. After removing the current ignition system, a contactless ignition system can be installed. In place of the interrupter, a toothed disc will be placed on the camshaft, and dismantling the ignition coil will enable the installation of inductive sensors. The coil will be changed to a bipolar coil, mounted externally to the crankcase housing. The power supply system consists of: a fuel tank, a three-position tap with a fuel filter and a separator, two carburetors, an air filter, fuel lines and air lines. The petrol tap is directly screwed into the fuel tank. Gasoline flows by gravity to the fuel tap, which has two fuel lines in the tank at different heights. Additionally, it has a mesh settler, which is the only fuel filter. It is then connected to carburetors with rubber hoses. Two K63T carburetors are interchangeable, power the engine, are mounted on the cylinder heads. This is where the intake manifolds will be attached after dismantling the carburetors. When the motorcycle is operated in specific conditions, e.g. hot climate, temperature 35-40C° or higher or at an altitude of 2000m or higher above sea level, it is recommended to lower the dosing needle. When operating the engine in cold climate conditions, air temperature – 15C° and lower, it is recommended to raise the dosing needle. Two exhaust system solutions were used in the Dniepr MT 11 motorcycle. The modernized vehicle has a solution with two separate exhaust systems, one for each cylinder. Modernization requires connecting these systems in order to correctly read the exhaust gas composition using a lambda probe.

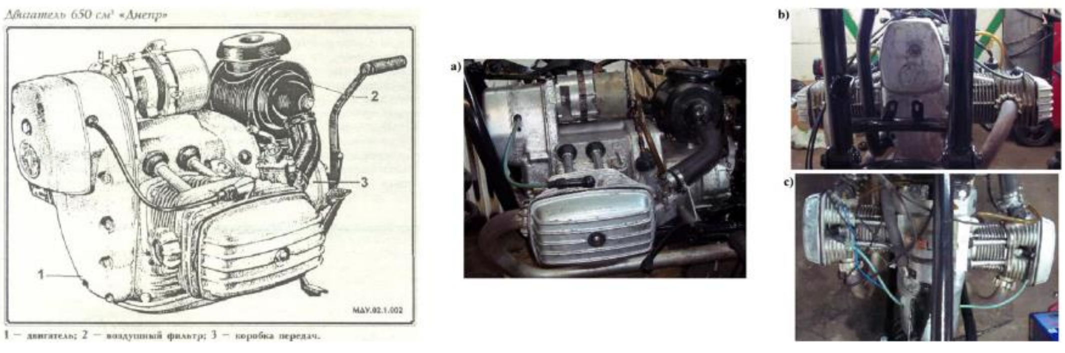
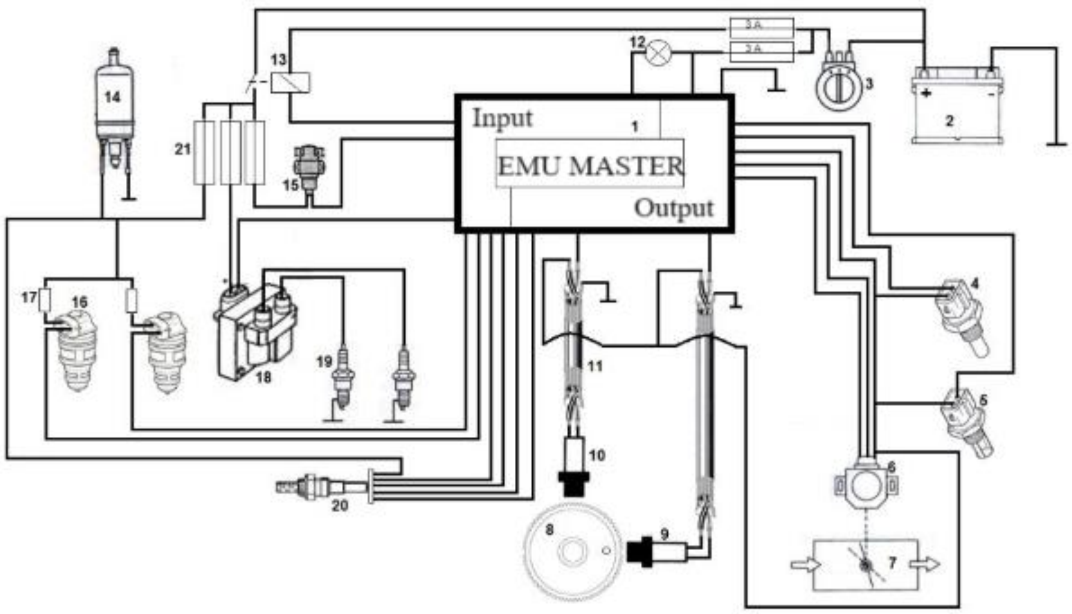


Fig. 2. – Internal combustion engine with a displacement of 650 cm^3 Dnepr where: 1 – engine, 2 – air filter, 3 – gearbox, engine photos 650 cm^3 Dniepr engine, where a) view from the right side, b) main view, c) view from above

After the modernization, the motorcycle has an integrated ignition and injection system, presented in the electrical diagram (Fig. 3). The heart of the system is the ECUMASTER EMU controller. It is a universal controller that allows you to manage the operation of an engine with an integrated ignition and injection system. It allows you to monitor and control all components responsible for the operation of the engine and can operate in an emergency mode resulting from incorrect operation of sensors or damage. The modernized ignition system used is an electronic system where the spark is released turns on electrically and the ignition timing adjustment is electrical. The system uses the induction phenomenon to generate high voltage. The modernization of the fuel supply system is based on the 32 MM4 injector assembly from Weber, used, among others, in the Opel Astra F 1.4i car. The purpose of the injector assembly is to supply fuel to all four cylinders through one injector. The modernized motorcycle uses two such injector assemblies, one for each cylinder.

The SPI (Single Point Injection) injection system has one electronically controlled injector, mounted centrally in relation to the cylinders, directly over the throttle in a common housing. It dispenses fuel in portions to the intake manifold. In the original applications of the 32 MM4 injector assembly from Weber, the intake manifold assumes the role of a distributor of the combustible mixture to individual cylinders. The Weber 32MM4 injection unit consists of two basic parts: upper and lower. The upper part consists of the injector, fuel pressure regulator, air temperature sensor, fuel supply and return connections to the tank. The lower part consists of the throttle, throttle position sensor, idle speed control stepper motor and fuel vapor inlet connector.

In the modernization used, the injector assembly of the first cylinder is powered by an electric fuel pump. The fuel pressure regulator of the first cylinder is always open, so fuel flows freely to the injection unit of the second cylinder. The constant opening of the fuel pressure regulator allows the pressure spring to be removed from it. The second cylinder fuel pressure regulator regulates the fuel pressure in both injector assemblies. Two filters are used in the system. The first one is necessary due to the possibility of contamination in the system. The second BOSCH fuel filter, 0 450 905 280, stops impurities in the gasoline, protecting the precise elements of the fuel system against wear.



1 – EMU MASTER controller, 2 – 12V battery, 3 – ignition switch, 4 – engine temperature sensor, 5 – air temperature sensor in the intake manifold, 6 – throttle position sensor, 7 – throttle, 8 – impulse dial, 9 – inductive sensor (determines the compression point of the first cylinder), 10 – inductive sensor (informs about the rotational speed and determines the position of the shaft), 11 – two-wire shielded cable, 12 – check engine light, 13 – system relay, 14 – fuel pump, 15 – idle speed control valve, 16 – injector, 17 – resistor, 18 – high voltage coil, 19 – spark plug, 20 – oxygen sensor in exhaust gases; 21 – fuse

Fig. 3. – System diagram after modification

The electric fuel pump is connected through a relay connected to the ignition switch. The pump selection depends on the injectors used, which require a supply pressure of 0.08 MPa. The capacity of the installed pump is 120 L/H.

The CLT engine temperature sensor is an NTC thermistor characterized by non-linear resistance, strongly dependent on temperature. The resistance of this sensor decreases as the temperature increases. The sensor is located in the head cover of the first cylinder. Supports engine operation control. Due to the engine temperature, the composition of the fuel-air mixture and the ignition advance angle change.

The inlet air temperature sensor, often called IAT (Inlet Air Temperature), as an NTC thermistor, is characterized by non-linear resistance strongly dependent on temperature. It is mounted in the injector assembly in front of the throttle (Fig. 4). It is used to plot the mass of sucked air. This sensor is installed in both injector assemblies, but the controller can only read the signal from one sensor. The characteristics of the CLT engine temperature sensor and the IAT intake air temperature sensor are similar, but they are created for different temperature ranges. The intake air temperature sensor is more sensitive to temperature changes. In case of sensor damage, the controller adopts the programmed constant temperature value.

The socalled absolute pressure sensor the MAP sensor is built into the controller and connected to the two intake manifolds through wires built into each manifold. The sensor measures pressure in the intake manifold and atmospheric pressure. The following function of the sensor is to determine the engine load. It is a basic parameter when calculating the fuel dose and ignition advance angle. The connection of the manifolds and the location of the measurement holes as close to the throttle as possible allows for obtaining a result that most accurately reflects the average pressure value in the intake manifold. The connecting hoses are made of material with durable walls, which prevents the cable from getting stuck and making the measurement impossible. The measurement range of the intake manifold pressure sensor installed in the controller is 400 kPa.

The TPS throttle position sensor, together with the absolute pressure sensor, allows you to define the engine load. Supports the calculation of the mixture enrichment factor when accelerating. This is one of the key signals needed to control the operation of the idle speed valve. The sensor is located in the injector assembly and responds to the movement of the accelerator lever by moving the cable. The controller allows reading the throttle position only from one sensor.

The Bosch LSU 4.2 lambda probe used in the modernized system is a broadband probe. It allows you to determine the composition of the fuel-air mixture based on the composition of exhaust gases. The lambda probe is installed in the exhaust system in front of the muffler and behind the connection point of the exhaust pipes of both cylinders. As already mentioned, due to the fact that the controller can only support one lambda probe, the exhaust system had to be modified in such a way as to connect the exhaust systems of both cylinders. This allows for measurement of the average exhaust gas composition of all cylinders. The installation conditions of the lambda sensor require that the exhaust gas temperature does not exceed 750°C, the installation position should be as close to the vertical as possible.

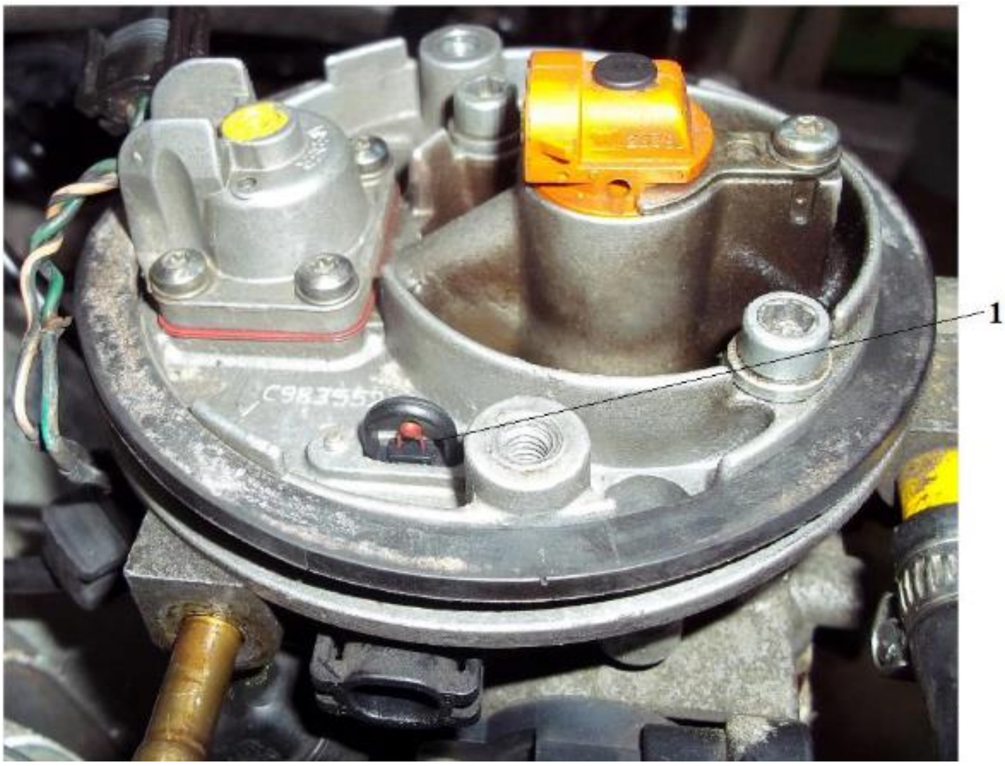


Fig. 4. – Installation location of the intake air temperature sensor, where: 1 – IAT

2. Results and discussion

Contact-controlled ignition systems had reached the limit in the development of maximum ignition energy, which was crucial in engine design. Wearing contacts did not allow for constant maintenance of the ignition timing, which resulted in misfires, which led to higher fuel consumption and, consequently, the exhaust gas composition was more harmful. Contactless electronic systems are a solution to precisely setting the ignition moment. These solutions are based on the operation of inductive or hall effect sensors. Advantages of the contactless ignition system: greater maintenance-free and durability, ability to operate at higher rotational speed, higher ignition voltage, maintaining the set ignition moment, short-circuit angle control and primary current limitation, elimination of quiescent current. The division of ignition systems is presented in table 1. The area in table 1 marked in pink is the current solution, the blue area is the ignition system after modification. This system may be the best available because it eliminates mechanical control elements, which prevents any disruptions due to wear or contamination of the elements .

Table 1. Division of battery ignition systems

Battery system:	with ignition coil	transistor	electronic
Spark release:	mechanical	electronic	electronic
Ignition timing adjustment:	mechanical	mechanical	electronic
A phenomenon used to produce high voltage:	induction	induction	induction
High voltage distribution to cylinders:	mechanical	mechanical	electronic

Injection systems can be divided according to: fuel and air dose regulation strategy, injector placement, and dose regulation implementing mechanism. The first one, due to the fuel and air dose regulation strategies, can be divided into systems controlled by: throttle position, cargo pressure behind the throttle, and air flow rate. The second division can be made in terms of the location of the injector and can be divided into: central injection with one injector in the intake manifold, direct injection into the combustion chamber with an injector in the cylinder and injection with individual injectors placed in the intake ports. System with individual injection into the intake channel is divided into two solutions: direct injection into the intake stub and direct injection into the intake stub with the stream directed towards the intake valve. The third division, taking into account the implementation mechanism of dose regulation, is divided into electronic and mechanical. Injection systems: allow you to increase the average effective pressure by uniformly feeding the cylinders. Lower flow resistance through the intake system allows for a higher filling factor. A more precise composition of the fuel-air mixture reduces harmful components in exhaust emissions. A faster response of the system to new operating conditions results in an improved ability to accelerate. Vehicle tilts do not affect the operation of the system. It allows for self-diagnosis of the system and can operate in emergency mode. Reducing system maintenance to a minimum, consisting of replacing filters. Power system components are more durable and reliable. They increase engine power and dynamics and reduce fuel consumption. A comparison of ignition and injection systems is presented in table 2. The comparison of selected systems shows that the Motronic system is the closest to the designed solution.

Table 2. Comparison of ignition and injection systems

Bosch system:	Control:	Injection system:	Type of injection:	Integration with the ignition system:	Feedback signal:
Mono-Jetronic	electronic	central	periodic	no	Yes
K-Jetronic	mechanical-hydraulic	individual	continuous	no	no
KE-Jetronic	electronic, mechanical, hydraulic	individual	continuous	no	yes
L-Jetronic	electronic	individual	periodic	no	yes
LH-Jetronic	electronic	individual	periodic	no	yes
Mono-Motronic	electronic	central	periodic	yes	yes
KE-Motronic	electronic	individual	continuous	yes	yes
Motronic	electronic	individual	periodic	yes	yes
After Modernization	electronic	individual	periodic	yes	yes

For proper operation of the ignition and plug-in systems, it is necessary to determine the engine operating conditions. Both systems can use the same sensors, and the systems also influence each other. To solve this problem and simplify the system, a common controller is used, responsible for the operation of both sensors, so that the same values are not measured twice. These systems are known as "Motronic", "Digital engine control system", "Electronic engine control system". The systems discussed have a common feature - they are based on the principle of operation of electronic ignition and injection systems, creating their combinations. These systems can be enriched with a number of additional functions that support even more precise control and regulation. Depending on their advancement, ignition and injection systems use signals from sensors: engine speed, crankshaft position, camshaft position, throttle angle, engine temperature, intake air temperature, knock sensor, code connector, battery voltage, automatic transmission activation signal, signal from the flow meter, signal from the lambda probe, signal from the brake pedal position sensor and vehicle speed.

The serviceability of the systems has been limited to current operating standards. The ignition system only requires adjustment of the spark plug gap. However, the fuel supply system requires periodic replacement of the fuel filter and cleaning of the filter element in the oblique filter. A comparison of the serviceability of the ignition and fuel supply systems before and after modernization is presented in Table 3.

Table 3. Comparison of the serviceability of the ignition and fuel supply systems, before and after modernization

Before modernization		After modernization	
Action	Repetition frequency	Action	Repetition frequency
Ignition system			
Maintaining cleanliness	5,000 km	Adjusting the gaps on the spark plug	5,000 km
Checking the fastening	5,000 km		
Oiling the felt	5,000 km		
Oils for the friction surfaces of the ignition advance mechanism	5,000 km		
Adjusting the gaps on the spark plug	5,000 km		
Fuel supply system			
Flushing and blowing carburetors	500 km	Replacing the fuel filter	30,000 km
Cleaning the faucet strainer	500 km	Cleaning the fuel pre-filter element	30,000 km
Needle adjustment depending on climatic conditions	Not specified		
Additionally, before working on the fuel system, you should: • Check the gap between the spark plug electrodes. • Check the gap between the breaker contacts. • Check the gap between the lever valve stems.			

The view from the left side of the motorcycle (Fig. 5) and the view from the top of the motorcycle (Fig. 6) show that the modernization did not reduce the driver's space. Presentation of the stages of changes made under the front cover of the crankcase (Fig. 7). The spaces occupied by the modernized systems meet the conditions for safe operation.

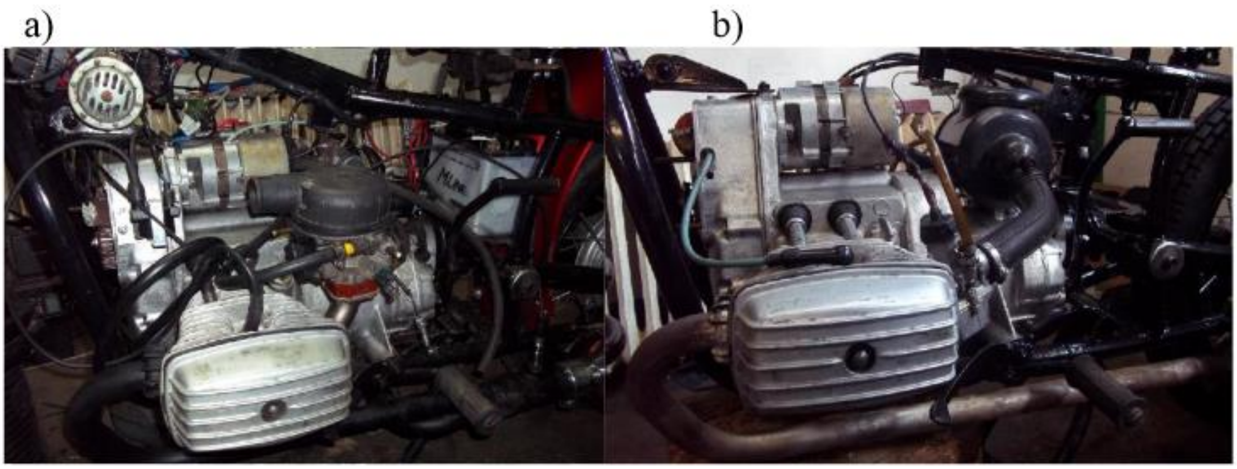


Fig. 5. – View of the model from the left side of the motorcycle, where: a) after modification; b) before modification

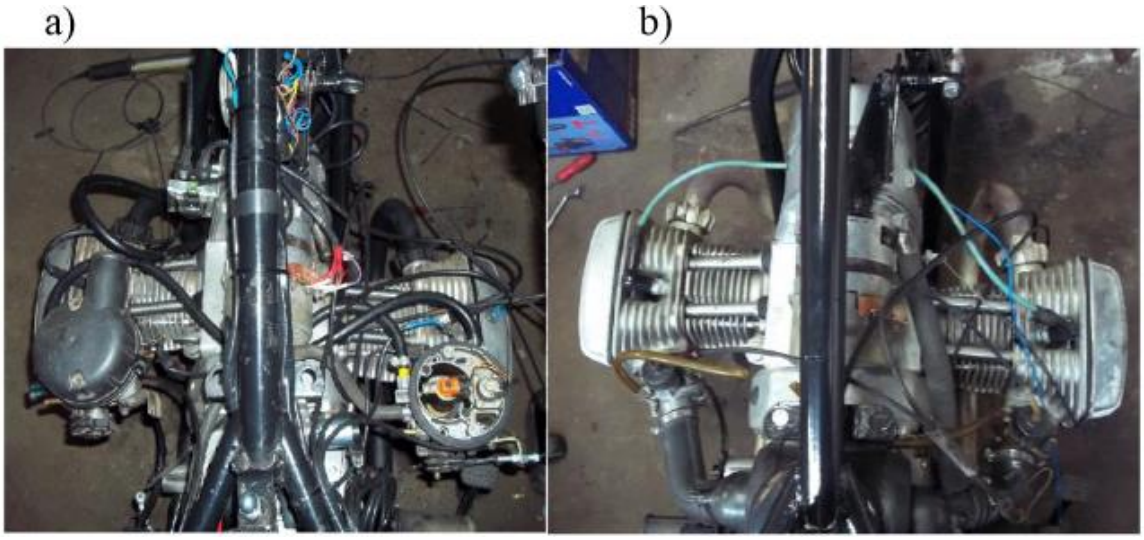
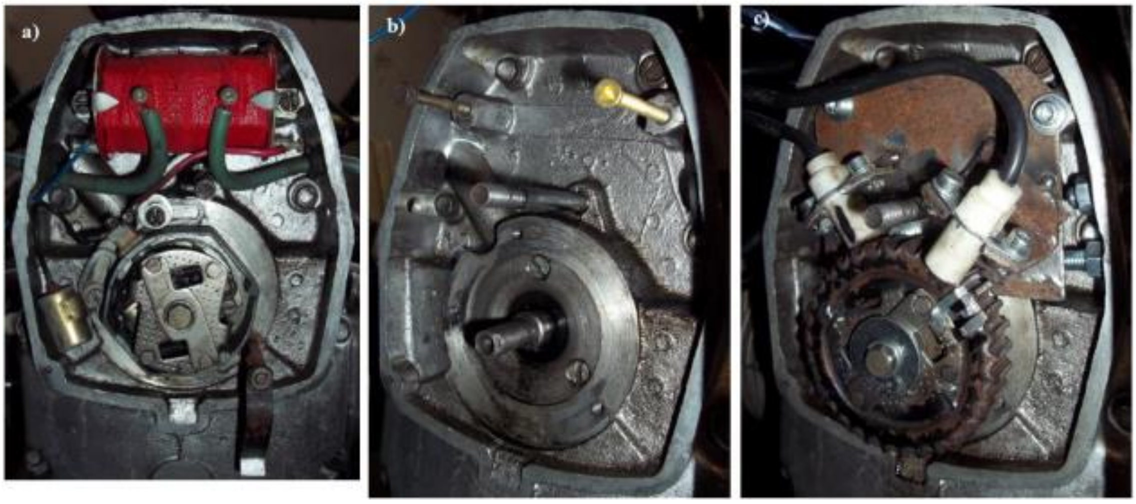


Fig. 6. – Top view of the motorcycle, where: a) after modernization, b) before modernization



a) before modernization, b) after dismantling the ignition system, c) after modernization

Fig. 7. – View of the space under the front cover of the crankcase

Conclusion

Modernization of the ignition and fuel supply system in the Dniepr MT 11 motorcycle made it possible to reduce the emission of harmful exhaust gases, fuel consumption, and improved the dynamics of drying, which was confirmed by previous tests. The article also shows improvement in the aspect of service work. The number of activities has been significantly reduced and the period of their performance extended. The advantage of the revised modernization is that in most cases the existing installation holes were used to carry out the modernization. For this reason, the motorcycle can be restored to its pre-modernization condition without any major difficulties. The spaces occupied by the modernized systems meet the conditions for safe operation and do not pose a threat to life or health. Additionally, they do not limit the driver's space and do not extend beyond the outline of the vehicle. After connecting to a PC, you can also preview parameters and activate or deactivate selected functions. Additionally, the injection system makes it easier to start the engine by performing pre-injection. The research carried out is described in the contemporary European trend, which aims to extend the life of products. From the point of view of environmental protection, it is equally important to reduce fuel consumption and exhaust emissions as well as maintain the functionality and attractiveness of the product in the long term. This study also have direct significant contribution to the sustainability 3R (Recycle, Reduce and Reuse) which is providing continuity of the product (motorcycles) lifespan. At the hand, it is concluded to the perspective circular economy, old product is possible to reform into more fashionable way of use in the form of antique restoration and preservation.

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Developing the Technology and Bench Testing Methods of Supporting the Rock Massif

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Abstract. There have been developed nomograms to determine the speed of driving development workings and the number of tunneling team, taking into account the control of geomechanical processes in side rocks. The feasibility study of the developed technological solutions has been substantiated and the scope of their application has been determined. The practical approbation of the results for the conditions of the Karaganda coal basin mines has been presented. Based on the obtained results, comparative mine tests of imported (the JV Minova-Kazakhstan LLP) and experimental (domestic) samples of roof bolting were carried out. Testing the anchors at the Saranskaya and Kostenko mines of the CD ArcelorMittal Temirtau JSC showed their efficiency and effectiveness. Implementation of the proposed developments made it possible, together with the specialists of the CD ArcelorMittal Temirtau JSC and the BASF Central Asia LLP, to introduce innovative industrial developments into production.

Keywords: development, technology, nomogram, development working, roof bolting, steel anchor, mine working support, rope anchor.

Introduction

There have been developed nomograms to determine the speed of driving development workings and the number of tunneling team, taking into account the control of geomechanical processes in side rocks (Figures 1 and 2).

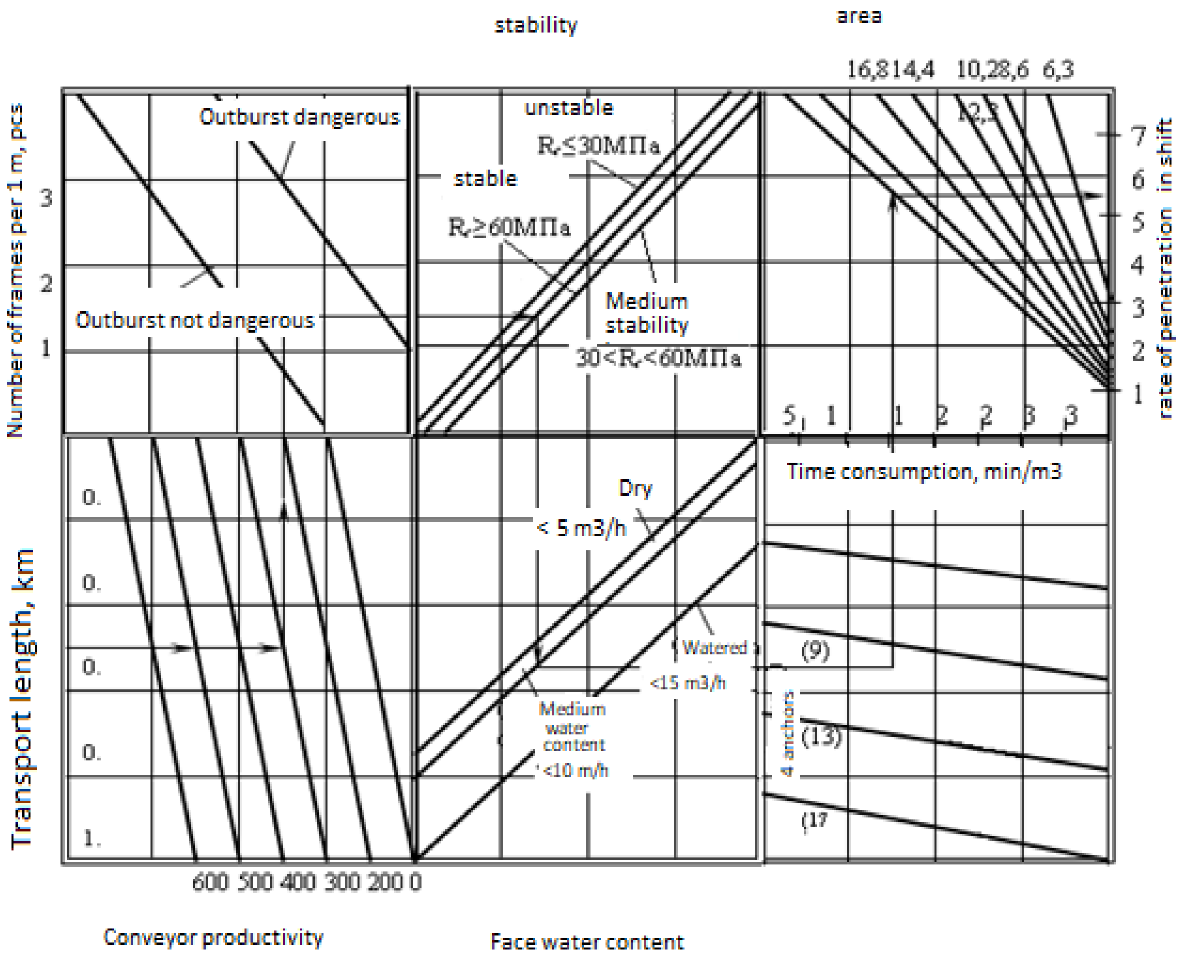


Fig. 1. – A nomogram for determining the speed of driving development workings

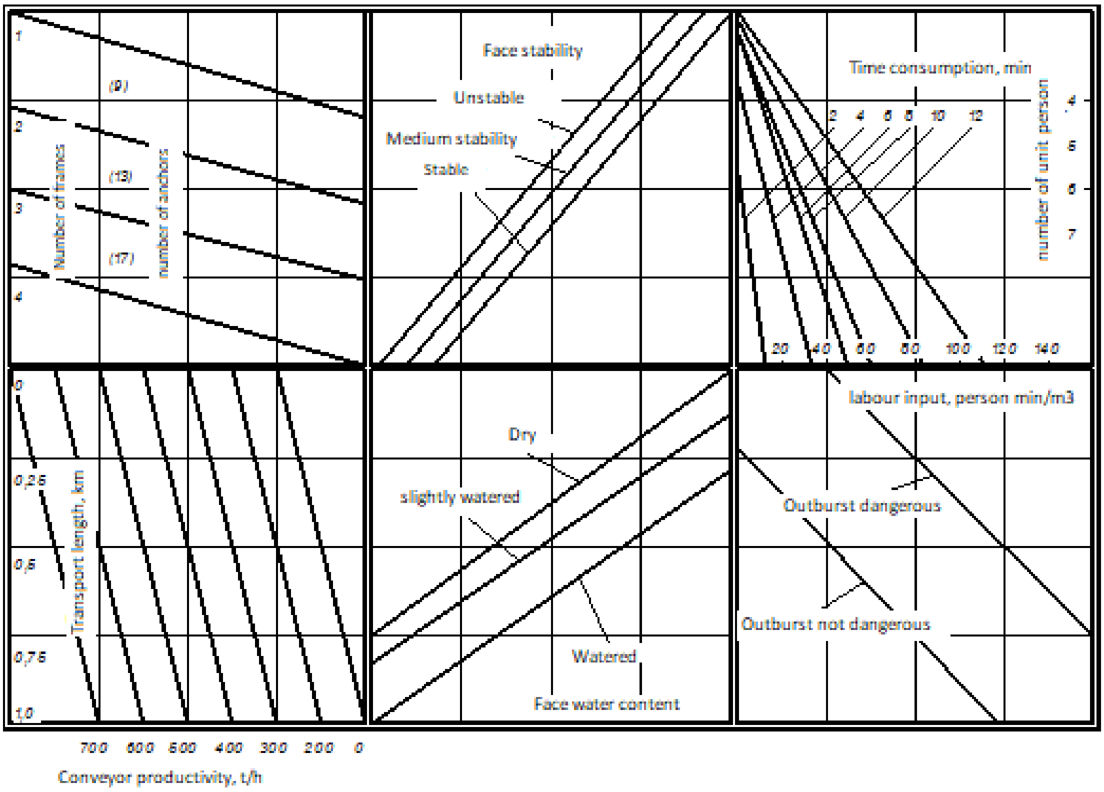


Fig. 2. – Determining the number of the tunneling team

There has been established the labor intensity and the cost dependence on the speed of driving workings (Figure 3).

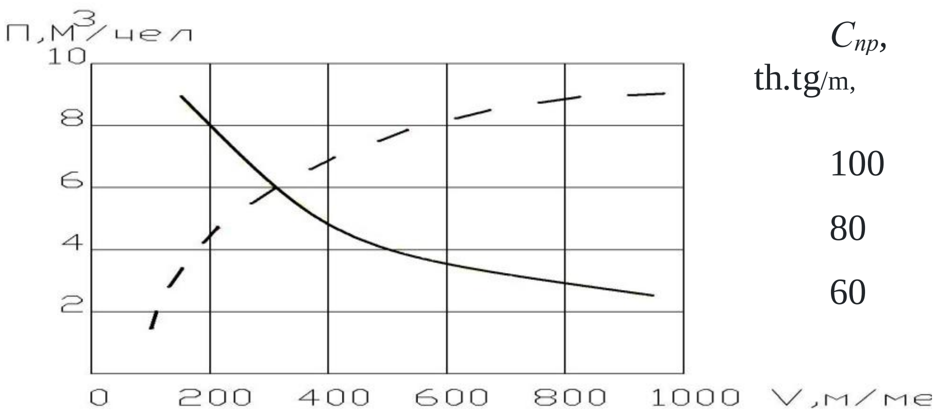


Fig. 3. – Labor intensity (*П*) and cost (*Cnp*) dependence on the speed of driving mine workings

1. Methodology

1.1. Feasibility study of the developed technological solutions and determining the scope of their application

The economic effect conditioned by introducing roof bolting of mine workings at a mining enterprise is determined as the sum of the economic effects obtained when driving individual workings in specific mining and geological conditions:

$$E_{à.ê} = \sum E_i \cdot g_i \text{ , tenge/year,} \quad (1)$$

where E_i is the economic effect per running meter of the *i*-th working when introducing roof bolting, tenge;

g_i is the annual volume of driving the *i*-th working with developed for these mining-geological conditions support passport, m.

When using various types of supporting mine workings at the Saranskaya mine, the cost of a running meter of m of driving with metal frame support (MFS) with a clear cross section of 14.4 m² in increments of 1.0 m is 97,932 tenge.

The cost of a running meter of driving the same section with a fixed roof bolting with 13 anchors per 1 m is 69446 tenge, with cost savings of 28 thousand tenge per a running meter.

With the use of roof bolting, the distance between frames increases and metal consumption decreases, bringing the behavior of the near-contour massif to the elastic-plastic model of a solid body.

The tests carried out at the Saranskaya mine made it possible to establish that a satisfactory condition with a stable roof (rock strength for uniaxial compression R_c is higher than 60-80 MPa) is achieved with the mounting density of one anchor per m^2; with rocks of medium stability ($30< R_c<60$MPa) 1.5 anchor/m^2; with unstable rocks (R_c <30MPa) 2 anchors per m^2.

Comparing with the actual density of the anchors, it can be seen that the density can be reduced by 10 -15% with the developed solutions. This will allow obtaining the economic effect of 5-7 thousand tenge per meter of the working.

1.2 Determining the mine working roof bolting effective field of application depending on the influencing factors

It is important to combine the operating modes of flexible anchor and metal frame support (MFS) in order to provide high bearing capacity with the transition from the limitedly pliable mode of fixed anchors to the joint rigid mode of operation using the surrounding rock massif self-supporting.

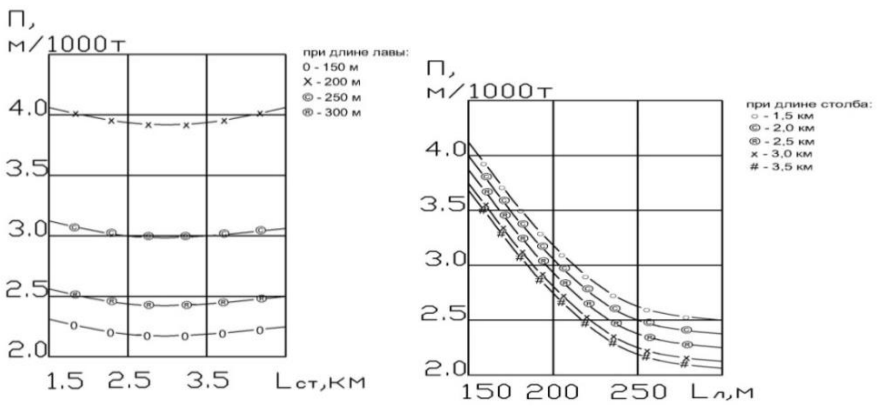
The use of a limitedly pliable roof bolting that acts as a stress compensator, will make it possible to remove critical loads and to unload the support through the vault of the enclosing rocks onto its supporting heels.

The first stratification of side rocks occurs at the distance of 1.6 - 2.0 m from the contour of the working (20 minutes after exposure), which predetermines the conditions for triggering the pliability nodes of the roof bolting by up to 0.07 - 0.1 m with mounting anchors at an angle to layering.

To automate the calculations, a technological and mathematical model of the subsystem "driving development workings" has been developed.

The criterion of its effectiveness is the cost of mining and preparatory work. The calculations were made using a program module in the Borland Delphi 7.0 object-oriented programming language.

The results of calculations to determine the optimal parameters of technological schemes of the "stoping and mining operations" subsystems are shown in Figure 4.



a) b)

Fig. 4. – The amount of mining operations dependence on the extraction column parameters

At this, with increasing the length of the longwall ($L_л$) the amount of mining preparation work (*П*) decreases according to a hyperbolic dependence (Figure 4, a), and with increasing the length of the extraction column, the range of values within L_{cm} from 2.7 to 3.2 km is more preferable (Figure 4, b).

With increasing the length of the longwall, the amount of mining operations *П*) decreases proportionally to the range of $L_л$ = 260 - 270 m, then the curve flattens out and the dependence becomes less pronounced.

With increasing the length of the extraction column, the volume of penetration decreases slightly (R^2= 0.87):

$$П = –83.5L_{л} +479.7; \quad П=0.71L_{ст} + 1.23, \quad m/1000\ t. \qquad (2)$$

With increasing the length of the extraction column by 0.5 km (or 1.25 - 1.3 times), the reduction in the amount of mining operations is achieved by 0.3 - 0.35 m/1000 tons (or 1.1 - 1.15 times).

The effective scope of roof bolting of mine workings has been determined depending on the influencing factors.

A technological-mathematical model of the subsystem "stoping and mining preparation operations" has been developed, based on which the optimal parameters of technological schemes have been established.

With increasing the length of the longwall, the amount of mining and preparatory work decreases according to a hyperbolic dependence. The optimal length of the extraction column is in the range of values from 2.7 to 3.2 km, and for the longwall 260 - 270 m.

2. Results and discussion

2.1 Innovative work for implementing the developments in industrial conditions

Innovative work to implement the developments in industrial conditions includes a set of works at the technology, methods, means, methods of calculating parameters and evaluating the efficiency of their use in the Karaganda coal basin mines.

In accordance with the instructions for calculating and using roof bolting in the Karaganda coal basin mines, the mines must take prompt measures to correct the passport of the working roof bolting. This primarily concerns the use of longer anchors, which mismatch in mines leads to decreasing the quality of supporting and increasing labor costs [1-5].

In this regard, in order to design innovative industrial developments for roof bolting systems and geomechanical prediction of rock pressure manifestations around development workings, an addendum to the "Instructions for calculating the parameters of roof bolting" is being developed using the analytical finite element method and the theory of kinetic strength of rocks, with automation of the development process passports for supporting workings.

These works are carried out in accordance with the agreement reached with the General Director of the ArcelorMittal Temirtau JSC. Specific approaches to the development of the "Methodology of calculating the parameters of roof bolting" are agreed with the General Manager for the Coal Mining ArcelorMittal Temirtau JSC.

Based on this, the “Work Plan of developing the “Methodology of automated calculation of roof bolting parameters for the conditions of the Karaganda basin” was developed and approved by the Technical Director of the CD ArcelorMittal Temirtau JSC to design an automated software package using the existing “Methodology ..., 2008” with implementing geomechanical models of rock massif behavior using the finite element method according to the ANSYS program and the method of boundary integral equations according to the theory of kinetic strength of rocks, taking into account the effect of principal stresses.

An experimental version of the automated technique has already been developed and is being calibrated and tested to check the convergence with experimental data [6–10].

Based on the obtained results, comparative mine tests of imported (the JV Minova-Kazakhstan LLP) and experimental (domestic) samples of roof bolting were carried out.

To test the best foreign samples of anchor fastening systems, the JV Minova-Kazakhstan LLP purchased:

- rope anchors (30 pieces);
- anchor cement (135 kg);
- rented pump UNI-40.2 (for 5 days) for mounting.

To control measurements:

- anchor load indicators (step-5 pieces);
- rock pressure indicators Tell-Tales (2-stage-2 pieces) (see Figures 5 – 8).

Fig. 5. – Mine pressure regulators and benchmark stations for measuring rock deformations

The authors developed progressive technological solutions according to which working drawings were made, according to which at the Machine-Building Plant No. 1, two experimental samples of domestic anchor designs were made. After verification tests for performance, strength and bearing capacity, there will be made in the a batch of approximately 50 pieces of each design.

Two modifications were made as follows: a rope and a stackable steel-polymer anchor, as well as support washers of anchor bolts adjustable at the mounting site (Figures 7 - 14).

Fig. 6. – Roof bolting of the JV Minova-Kazakhstan LLP (rope anchors)

Working drawings for manufacturing domestic designs of roof bolting systems are shown in Figures 7 - 14.

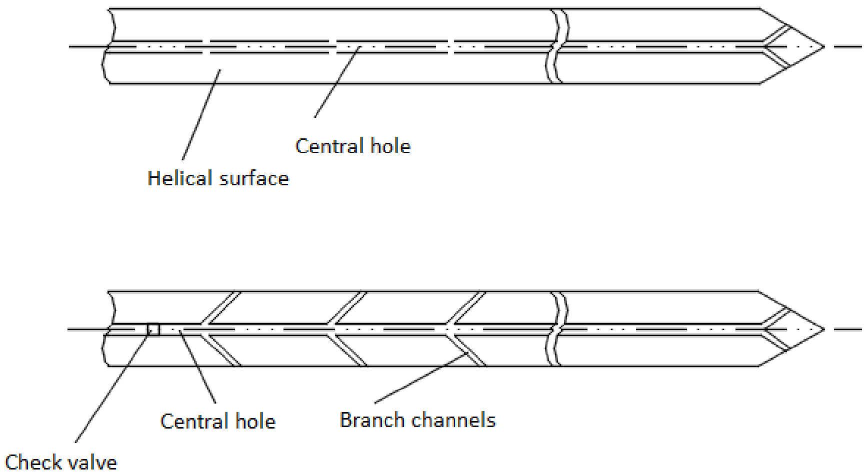
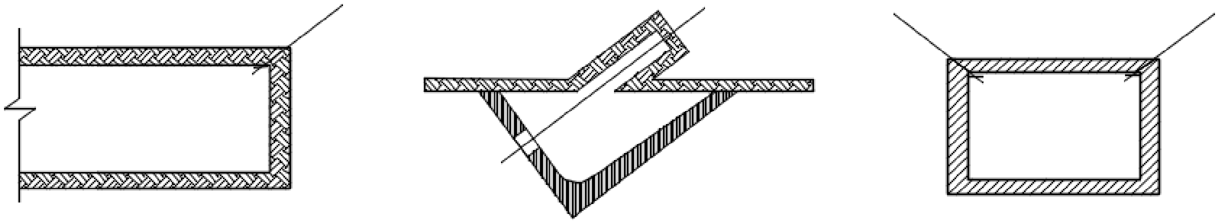


Fig. 7. – An anchor with an internal (or external) notch hole

Internal (or external) notch holes were designed to feed the fixing compound into the hole through the holes (or through plastic tubes in the notches) after its mounting. This will allow concentrated distributing the fixing compound over the surface of the hole, which will make it possible to fix more effectively fix the anchor to the adjacent rocks and to improve its strength characteristics.



a) b) c)

a – supporting the stope face; b – *a* type; c – supporting the working sides

Fig. 8. – An angle pickup with a hole

This type of support is applicable in development workings directly at the bottom of the face, which will protect against oversized lunges (braces) and due to design features (a corner with holes) will allow distributing evenly the load on the anchor in the future and using this support more efficiently.

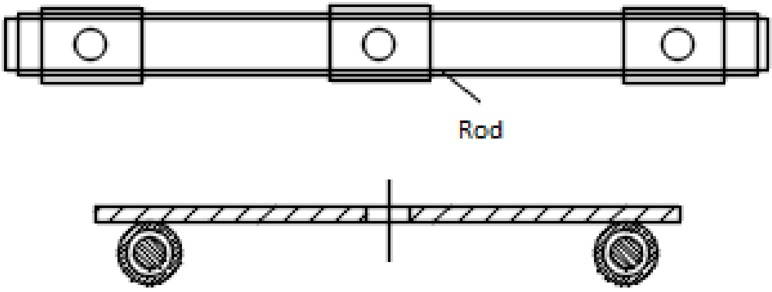
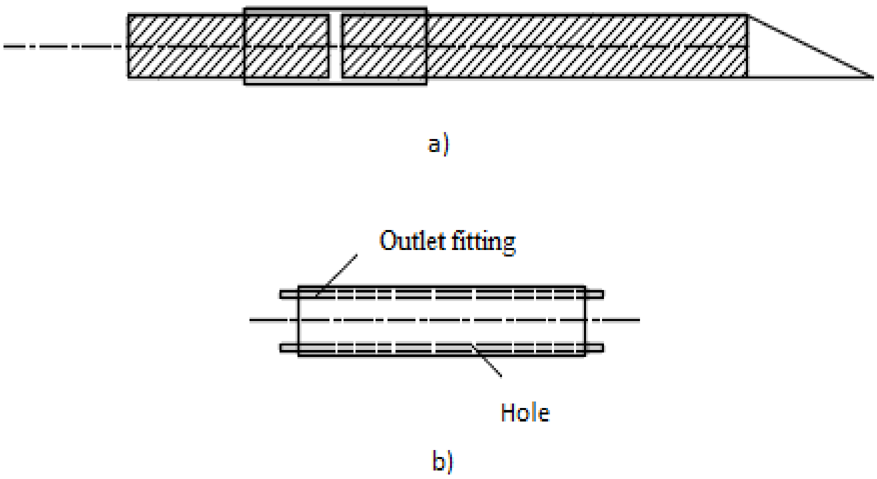


Fig. 9. - An adjustable metal pickup

The metal pickup has been designed for supporting the roof, with the help of tubes the plates it can move along the metal rod, which allows changing the place of the anchor mounting, in particular if there are geological disturbances, and the load on the support is evenly distributed due to the metal rod.



a – general view of the extendable anchor; b - coupling with fittings

Fig. 10. – A coupling for roof bolting

The coupling for roof bolting has been designed to increase the length of the anchor, which allows using this bolt in various conditions, and through the holes in the coupling, a fixing compound it can be fed into the hole.

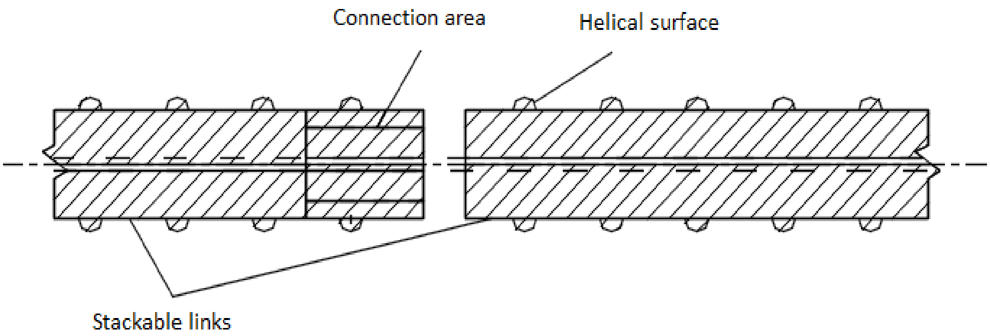


Fig. 11. – An extensible steel anchor

This design allows increasing the length of the steel anchor, due to which it becomes possible to use it in various mining and geological conditions in terms of the composition and thickness of the near-contour rocks. The helical surface of the anchor will secure the anchor in the hole, and a fixing compound is fed through the hole in the center of the anchor.

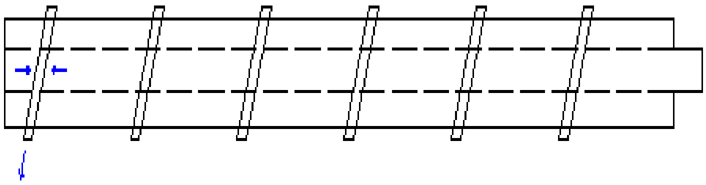


Fig. 12. – A drill rod for drilling the inner surface of the hole

The drill rod for drilling the inner surface of the hole allows forming during the reverse stroke of the drill rod, helical spiral groove on the inner surface of the cavity of the hole, which makes it possible to improve the quality of fixing the steel-polymer anchor in the drilled hole.

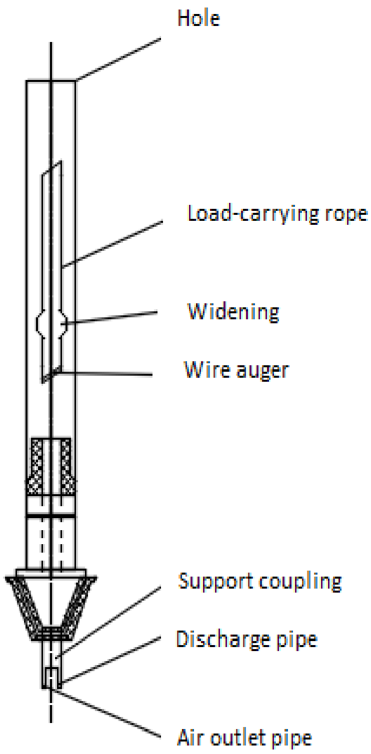


Fig. 13. – A rope anchor

The rope anchor has been designed for supporting mine workings by deep anchoring of surrounding rocks. The rope anchor is fixed using a polymer composition or cement mortar along the entire length of the hole.

To control the completeness of filling the hole with a fixing composition, a central air outlet tube is introduced into the anchor design.

The injection of the bonding composition into the borehole is stopped when resin appears from the air outlet tube.

The rope anchor consists of 5 - 6 braided wires with the diameter of 6 mm (or in a cable version) and a tube installed in the middle (or along the contour) with the diameter of 6 mm and the wall thickness of 1.5 mm.

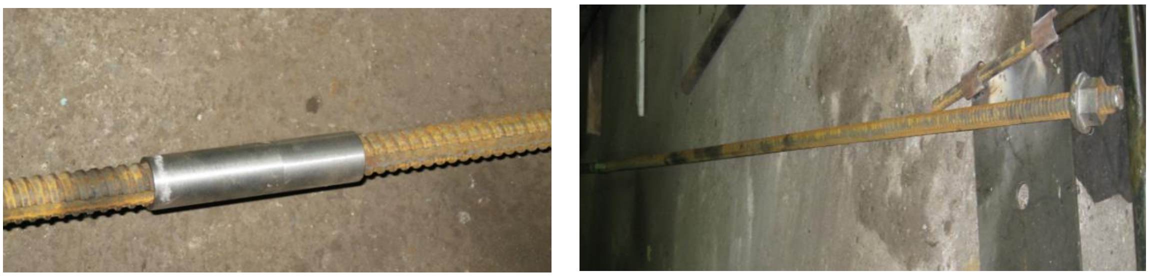
The total diameter of the anchor is 15 - 25 mm, the total length varies according to need.

At the head of the anchor, a sleeve about 120 mm long with the external thread M 30 is used.

Pilot samples of anchor fastening, made according to working drawings in the conditions of Machine-building plant No. 1 are presented in Figures 14 - 17.

a) b)

Fig. 14. – An extensible steel-polymer anchor in assembled (a) and dismantled (b) state



a) b)

a – coupling; b – assembled anchor

Fig. 15. – Extensible (using a coupling) steel anchor

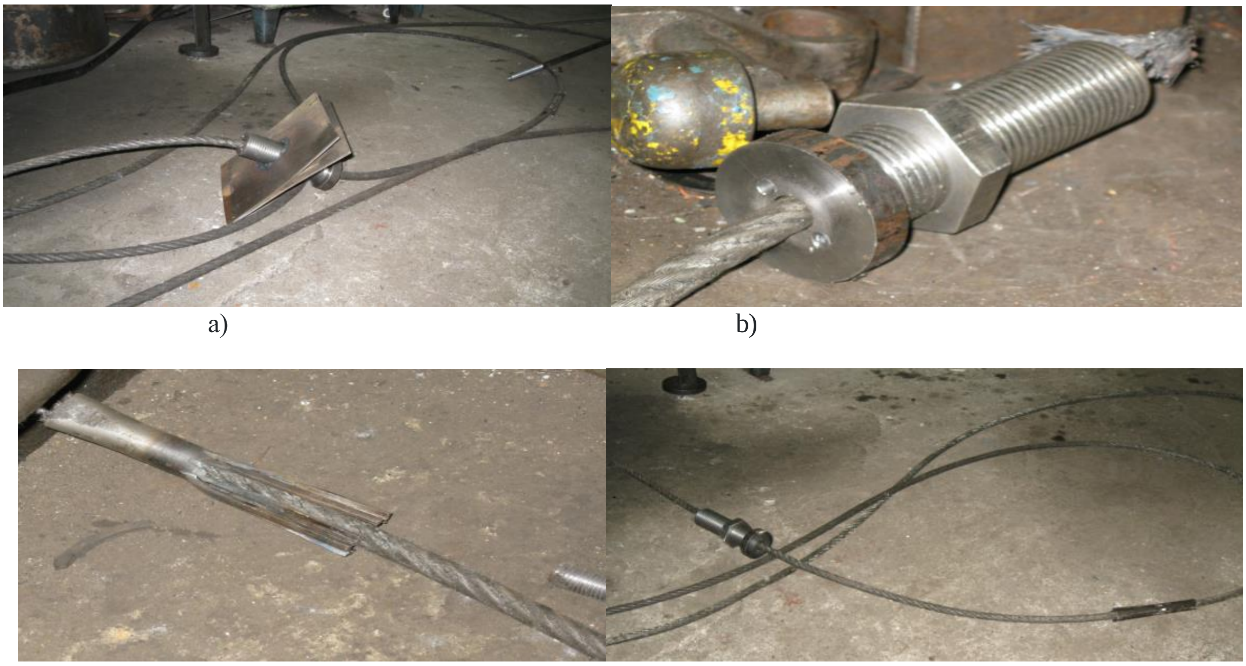
A rope 500 m long, 20 mm in diameter, purchased from the GZP Atlant LLP, was delivered to the plant (see Figure 18, c). 100 units of rope anchors were made of it, including those with plastic tubes for injection chemical or cement base (a); for the ampoule mounting (b), which were tested at the Saranskaya mine.

The plant manufactured five couplings with the diameter of 28 mm for splicing steel-polymer anchors; drill bits with the diameter of 30 and 32 mm for drilling holes for spliced anchors; adapters for mounting rope anchors on chemical ampoules (see Figure 18, d, e (dismantled and assembled).

In the production conditions of the Saranskaya and Kostenko mines there were carried out industrial tests of foreign anchoring systems manufactured by the JV Minova LLP and domestic products manufactured according to the developed drawings at Mashzavod No. 1 LLP (see Figure 18).

The carried out tests of roff bolting at the Saranskaya and Kostenko mines os the CD ArcelorMittal Temirtau JSC showed their performance and efficiency recorded in the "Industrial Test Reports".

Implementation of the proposed developments made it possible to introduce, together with the specialists of the CD ArcelorMittal Temirtau JSC and the BASF Central Asia LLP, innovative industrial developments into production.



a) b)

c) d)

a – washer; b – wellhead sleeve with holes for supplying a fixing chemical or cement composition and air discharge; c - spacer retaining end stop of the anchor; g – assembled

Fig. 16. – A rope anchor

Fig. 17. – An adjustable pickup of the roof bolting

There has been completed production, implementation and design work for implementing the technological developments for mine working roof bolting in industrial conditions; an automated method of calculating parameters and evaluating the efficiency of their use in the mines of the Karaganda coal basin.

a) b) c)

d) e)

Fig. 18. – Manufacturing rope anchors at Mashzavod No. 1 (a); a rope (b)

Conclusions

At the development depths reached in the basin (600-850 m), it is impossible to achieve non-repair maintenance of workings with modern supports. This would require support resistance of more than 1.7 MN/m^2, while modern supports have resistance that does not exceed 0.2 MN/m^2. It is necessary to look for the other ways to improve the condition of workings and to save material resources.

The exploited types of metal-arch supports are quite expensive and not technologically advanced, which affects the speed and conditions of driving mine workings.

Increasing the level of underground coal mining is possible only if there is a rational technology of driving and reliable supporting of development workings that ensure increasing the amount of mining and tunneling. Therefore, the development of a progressive technology of driving workings based on determining the stress-strain state (SSS) of the massif and its effect on the parameters of supporting is an important scientific and technical task of mining.

25 - 45% of the total length of the development workings are constantly affected by the stoping operations. In the mines of the Karaganda basin, the multiplicity of re-supporting the excavation workings reaches 2, 3 and even 4, while 15-25% of them are repaired annually.

The volume of implementing roof bolting for workings in the mines of the Coal Department of the ArcelorMittal Temirtau JSC is 12% in pure form, and 36% in mixed form. For a wider use of roof bolting, it is necessary to substantiate its parameters depending on the development conditions, to determine the area of possible and effective operation and to develop progressive technological schemes for its construction. The weakest link in solving the issues of increasing the roof bolting efficiency is insufficient knowledge of geomechanical processes near mine workings.

In order to make sound technological decisions on determining the roof bolting parameters for its effective operation, there is needed a geomechanical prediction of the near-contour rock massif stress-strain state of the working.

Using the existing methods of calculating the roof bolting parameters shows that they do not always provide reliable supporting of production workings, especially in the zone the mining operations impact. Currently, about 46% of the excavation workings do not correspond in size to the operating conditions. Therefore, the development of ways to support effectively development workings is an important task in the field of mining and preparation works.

To increase the efficiency of using roof bolting, there are intentions to leave coal pillars by analogy with the coal industry in Great Britain, Australia and the USA. However, at this, the loss of coal in the subsoil will increase, its spontaneous combustion and occurrence of the reference pressure zones (RPZ) are possible during the development of the remaining layers of the formation. Further expansion of using roof bolting is planned through the use of cable, beam and self-drilling anchors, for which it necessary to develop an addendum to the current methodology of calculating the parameters of their operation.

Improving the technology of driving excavation workings with justification of the parameters and scope of anchor bolting based on the identified patterns of behavior of adjacent rock massifs is an important problem for the mining industry.

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Cooling Boiler Thermal Insulation

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Abstract. A group of engineers developed a project and technology for mounting heat-insulating blocks for the cooling boiler insulation. All the decisions were made on the basis of many years of experience with the boiler equipment of the converter shop. The technical solutions in this proposal are aimed at reducing consumables and time spent for work on the cooling boiler insulation, compared with the other analogues. This article presents a quick-detachable and maintainable design of the cooling boiler thermal insulation.

Key words: cooling boiler, heat-insulating, mounting plates

Introduction

A team of employees has been successfully cooperating and providing work for its partners since 2002. Relying on effective management, experience and professionalism of employees, production workshop and quality management system, employees provide a wide range of services for the energy and metallurgical industries, the construction industry and mechanical engineering. In the period from 2014 to 2020, a team of employees performed mounting and repair work at the converter shop of the metallurgical plant of the ArcelorMittal Temirtau JSC. The company performed such works as repair of sliding parts of cooling boilers of converter gas, replacement of skirts, and heating surfaces of the stationary part of cooling boilers.

Such sophisticated equipment as cooling boilers of converter gases is designed for cooling and heat recovery of waste gases from steel-smelting converters. They also serve to generate steam for the technological needs of the plant. The design of the cooling boilers takes into account high thermal loads, their cyclicity, high dust content of gases leaving the converter neck.

1. Methodology

Rational use of fuel and energy resources, environmental protection are among the most important problems facing humanity [1]. High-temperature processes are carried out in technological furnaces (the metallurgical, the chemical, the petrochemical and the other industries) with an extremely low fossil fuel utilization rate (20–40 %). As a result, these industries emit gases whose temperatures sometimes exceed 1000 °C, toxic substances, fine dust of the raw materials used and other technological waste that pollute the environment [2]. Therefore, the processing and operation of waste from these technological processes is an important task [3]. Its implementation is possible on the basis of the use of their heat in waste heat boilers or with the joint organization of technological and energy processes in energy technological units.

Improving the efficiency of using fuel and energy resources (FER) at ferrous metallurgy enterprises in modern conditions is one of the main aspects [4]. Ferrous metallurgy is one of the most energy-intensive industries. The share of fuel and energy costs in the total factory production costs is more than 30 %. The largest consumers of fuel in production are blast-furnace and rolling production. Electric steel-smelting production, oxygen stations, and the main consumers of heat are coke-chemical production [5]. The high energy intensity of metallurgical industries with constant increasing the prices for fuel and energy resources puts the problem of energy and resource saving in one of the first places [6]. In this industry the energy saving potential reaches 30 %.

In steelmaking, when steel is smelted, a significant amount of heat leaves the furnace in the form of physical heat of flue gases, as well as heat released during cooling of the furnace elements [7]. Converter gas is used as a fuel secondary energy resource when gas is removed without afterburning. In this case, it is a very valuable technological and energy fuel. In most cases, it turns out to be expedient to use not only physical heat of the exhaust gas but also to dispose it as a chemical raw material or fuel. In order to utilize converter gas as a process gas, it is withdrawn, cooled and purified, mainly in electrostatic precipitators. The use of converter gas as a fuel is one of the reserves for saving fuel and energy resources. The use of waste heat in the cooling boiler of converter gases provides additional products in the form of power or process steam, hot water, steam-water coolant, etc., which leads to fuel savings at the enterprise. The use of converter gas after cooling and purification as a fuel, for heating charge materials of converter production, as a reducing agent for iron ore raw materials for blast furnaces, for generating electricity and steam will save fuel and energy resources and primary natural resources. Efficient use of secondary energy resources makes it possible to replace purchased fuel and energy resources, which significantly reduces energy intensity and production costs. The maximum use of secondary energy resources and the introduction of energy-saving measures simultaneously solve environmental problems at enterprises and reduce the amount of harmful emissions into the atmosphere.

The temperature of gases before gas cleaning should not exceed 200 - 300 °C [8]. Since the temperature of the gases at the outlet of the converter is on average 1600 °C, they must be cooled before gas treatment. To cool converter gases, waste heat boilers of various designs and principles of operation are used. They are called converter gas coolers (CGCs). Given that converter gases contain high concentrations of carbon monoxide, the coolers used and the entire system for removing smoke along the gas path must be explosion-proof. To ensure explosion safety, two principles can be used as the basis for the hood systems:

1. reducing the concentration of carbon monoxide due to its multiple dilution;
2. removing gases with a high concentration of carbon monoxide (≥ 74.5 %).

This is achieved in various ways that differ mainly in the excess air ratio at the outlet of the cooler. With any method of removal and cooling of gases, gas cleaning must provide such purification that when gases are released into the atmosphere in the surface layer, the dust concentration should not exceed sanitary standards (maximum permissible concentrations). When the converter gas is cooled, it is possible to saturate the gas with water vapor, which is undesirable from the point of view of using this gas as a process gas.

The oxygen-converter steelmaking method has many advantages. The disadvantage of the process is the intensive formation of dusty gas. Purification and subsequent cooling of gases leaving oxygen converters continues to be the main one of the most difficult problems. The amount of dust carried out of the converter reaches 1.5 % of the metal charge. The dust content of converter gases reaches 200 g/m³. Therefore, gas purification is mandatory. The permissible content of dust in gases emitted into the atmosphere is 100 mg/m³. Gas cooling and purification are components of the oxygen-converter method of steel production with iron purging with commercially pure oxygen. The costs for the construction of installations for cooling and cleaning gases to sanitary standards, as well as for their maintenance, are very significant. All oxygen converters must be equipped with the systems that provide cooling and purification of converter gases or their combustion products. The main devices of wet gas cleaning schemes are scrubber-coolers, Venturi scrubbers with various kinds of droplet separators. The principle of wet gas cleaning is based on the contact of a dusty stream with a liquid. In most cases, when the temperature of the gas and liquid is different, dust collection is accompanied by heat and mass transfer processes. The contact of a gas with a liquid also promotes absorption of gaseous components. Thus, with the help of wet-type apparatuses, a complex problem is solved: cooling, dust collection and to some extent purification from harmful gaseous impurities.

2. Results and discussion

A cooling boiler or converter gas cooler (CGC) is designed for post-combustion of carbon monoxide (CO), which is up to 90 % of the gases released from the converter during the melting period, and cooling hot (up to 1700 °C) gases to temperatures that ensure safe operation of gas cleaning equipment.

The cooling boiler of converter gases is a radiation-convective, U-shaped layout, water-tube, drum boiler, made of gas-tight membrane panels, with combined circulation of boiler water:

- screens of the gas duct, transition gas duct, lowering gas duct, convective screens, the protective screen of the lower collectors of the gas duct, the protective screen of the lifting gas duct work with forced circulation,
- lifting flue screens operate with natural circulation.

The cover, the sealing screens of bulk materials windows, the oxygen lance windows, the measuring lance window sealing unit, the protective screens of the junction of the sliding gas duct with the lifting gas duct, the protective screen of the boiler downstream gas duct sealing unit with a dry hopper are not included in the boiler circulation circuits and are cooled by running process water.

The boiler consists of the following parts:

• shielded flue,
• drum,
• cooling circuits for heat-receiving surfaces,
• heating systems,
• systems for feeding the boiler with water,
• steam separation systems,
• steam removal systems from the boiler,
• make-up systems,
• systems for maintaining the water-chemical regime,
• systems for heating the boiler during the inter-purge period,
• monitoring and control systems.

The gas duct consists of a retractable gas duct and a stationary gas duct. A retractable gas duct is the lower part of the gas duct located above the neck of the converter. Structurally, the retractable gas duct is a 4-faced gas-tight gas duct, the longitudinal axis of the lower vertical part of which is coaxial with the vertical axis of the converter, and the longitudinal axis of the upper inclined part is 36 °52’ to the vertical axis. The walls of the retractable gas duct are made of membrane screens. Each wall screen of the retractable gas duct is assembled from pipes. To ensure even distribution of water between the screen pipes, removable throttle washers are installed in their inlet sections, protected by lattice filters. The inlet collectors of the screens are made of pipes. The inlet manifolds are equipped with necks closed with removable hatches, the outlet manifolds are equipped with fittings with welded hatches. On the inclined section of the left screen, windows for the passage of oxygen and measuring lances are made by pipe routing. On the lower sections of the front and rear screens, pipes are laid out for introducing bulk materials into the converter. The left screen of the retractable gas flue is equipped with three transverse stiffening beams, the right one with two beams. The retractable gas duct is mounted on a retractable trolley through a support belt made of pipes. The support belt of the retractable gas duct is attached to the inclined sections of the front and rear screens with the help of vertical ribs.

In order to reduce the coefficient of friction, graphite is poured under the sliding supports of the belt in the course of mounting. To ensure close values of thermal expansions of the screens of the retractable gas duct and the support belt, the latter is included in the boiler circulation circuit. The lower collectors of the screens of the retractable gas flue are protected from radiation from the converter and from mechanical impact from the buildup on the neck by a protective screen of the retractable gas flue. The screen is a flat single-pass gas-tight panel made of pipes. The screen is attached from below to the lower collectors of the wall screens of the retractable gas flue. The inlet and outlet collectors of the screen are made of a pipe. The upper part of the retractable gas flue adjoins the lower part of the lifting gas flue. The gap between the retractable gas duct and the lift gas duct is sealed and is blocked along the perimeter from the outside by two protective screens at the junction of the retractable gas duct with the lift gas duct that is U-shaped and flat. The U-shaped screen is attached to the lower collectors of the lifting gas duct (left, rear and right), and the flat one is attached to the upper collector of the front screen of the sliding gas duct. Screens are made of parallel tubes. Stationary gas duct of U-shaped layout, consists of lifting and lowering gas ducts and a transitional gas duct connecting them.

The stationary gas duct is mounted on the metal structures of the workshop using a tubular support belt attached by vertical scarves to each screen of the lifting and lowering gas ducts. To ensure close values of thermal expansion of the flue screens and the support belt, the latter is included in the boiler circulation. Graphite is poured under the sliding supports of the support belt to reduce the coefficient of friction in the course of mounting. The lifting gas duct is structurally a 4-sided gas-tight gas duct whose lower inclined part is pine with the axis of the upper inclined part of the retractable gas duct, and the longitudinal axis of the upper part is vertical. Lifting flue screens are made of pipes, all-welded panels. Along the height of the flue there are stiffening belts made of I-beam. In the front screen, the piping made a window for installing an auxiliary burner. The opening above the lifting gas duct, formed by the side and front screens of the lifting gas duct and the rear screen of the lowering gas duct, is covered by a removable flat gas-tight ceiling screen (cover). The cover is made of pipes placed in the form of a coil. Sealing the gap between the opening and the lid is ensured by immersing the "knife" of the lid into a bath filled with sand. The bath is formed along the perimeter of the opening by the inclined upper sections of the screens forming the opening, and the protective screen of the lifting gas duct adjacent to them.

The gas-tight, box-shaped, single-pass protective screen is made of parallel, horizontally located one above the other pipes. The input and output collectors of the screen are installed vertically and adjacent to each other. The lower gas duct is structurally a vertical 4-faced gas-tight gas duct, the walls of which are made of pipes. The front screen of the downcomer gas duct is L-shaped. The upper section of the screen forms the lower part of the transition flue, and the short outlet section descends down to the junction with the upper part of the rear screen of the lifting gas duct. The rear screen of the downcomer is also L-shaped. The upper horizontal section of the screen forms the ceiling part of the downcomer and transitional flue. The side screens of the downcomer are flat and straight. In them, windows for repair manholes are made by piping. In the downcomer flue, parallel to the side screens of the gas flue, there are vertical convective screens made of pipes. The end sections of the inlet manifolds through the windows are made by piping the front and rear screens, going outside the downcomer duct. The screens are suspended from the steel structures of the workshop by rods attached to their upper collectors. The sealing of the gap between the lower headers of the downcomer and the dry gas cleaning hopper is ensured by means of a "knife" immersed in a "bath" filled with sand. The tub is welded along the perimeter of the dry bunker. The knife is protected from high temperatures by a protective screen of the downcomer, which is a 2-way gas-tight panel made of pipes, welded around the perimeter to the lower collectors of the downcomer gas flue screens. The transition gas duct is formed by the upper sections of the front and rear screens of the downcomer gas duct and the side screens of the transition gas duct. Each side screen of the transition gas duct is a flat vertical screen made of pipes. The inlet collectors of the screens are made of pipes.

Based on the laws of thermodynamics on the conservation of energy for a closed system, where the consumption of supplied thermal energy can be spent on increasing its internal energy and on the work done against external forces, and on the impossibility of heat transfer from a body with a lower temperature to a body with a higher temperature, due to the insulation, a significant reduction in heat transfer from the heating surfaces of the cooling boiler to the space of the converter shop and increasing the efficiency of the cooling boiler is ensured. The first law of thermodynamics is the law of conservation of energy as applied to thermodynamic processes: energy does not disappear into nowhere and does not arise from nothing but only passes from one form to another in equivalent quantities. Heat transfer is the physical process of transferring thermal energy from a hotter body to a less hot one, either directly (on contact), or through an intermediary (conductor) or a separating partition (body or medium) from any material. When the physical bodies of one system are at different temperatures, then there is a transfer of thermal energy, or heat transfer from one body to another until thermodynamic equilibrium is reached.

Spontaneous heat transfer always occurs from a hotter body to a less hot one, which is a consequence of the second law of thermodynamics, and this process is irreversible. To prevent this process, a group of engineers headed by Yu.A. Ivashin developed thermal insulation with an air cushion. This air cushion is located between the outer part of the cooling boiler and the inner part of the hinged heat-insulating blocks. Such an air cushion, together with heat-insulating blocks, prevents the passage of hot gases into the space of the converter shop, providing the effect of a thermos.

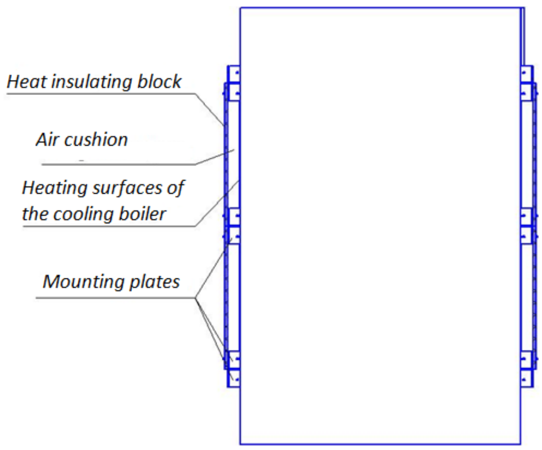

Fig. 1 - Thermal insulation design in section

The design of fasteners of heat-insulating blocks includes:

1) mounting plates;
2) heat-insulating block;
3) mounting handle.

Description of the insulation design

1. Mounting plates are a curved sheet of metal, which has oval-shaped through holes for mounting heat-insulating blocks. The angle between the end surfaces of the plate is 90°.

2. The thermal insulation block is curved and divided into three layers: an inner heat-resistant layer, an intermediate thermal insulation layer, and an outer protective layer.

The material of the inner layer is able to withstand temperatures up to 500°C.

The material of the intermediate heat-insulating layer is a mineral plate.

Advantages of the mineral plate are as follows:

- fire resistance;
- insignificant degree of thermal, and also natural shrinkage;
- the dimensions and shapes of materials from the mineral plate do not change during the entire period of operation;
- stability of volume and shape in all conditions;
- low thermal conductivity. The material has a high thermal resistance;
- high strength and corrosion resistance;
- environmental friendliness. The material is absolutely safe and harmless to humans;
- the material of the outer protective layer is a heat-resistant fabric (PTFE) coated with PTFE, 0.5 mm thick and 260°C temperature resistant.

3. The mounting handle is a "L-shaped" bent round rod.

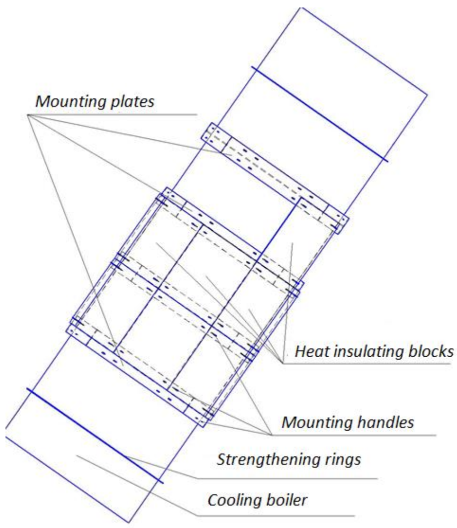

Fig. 2 - Heat insulating blocks mounting design

The technology of mounting heat-insulating blocks

The mounting plates, in the amount of four pieces per tier, are alternately attached to the reinforcing rings of the cooler boiler forming a rim. This operation is carried out along the entire length of the cooling boiler. Next, heat-insulating blocks are fixed. Holes are made in heat-insulating blocks for fastening. Before fixing the heat-insulating block, it is necessary to insert the fixing handles into it. To connect the heat-insulating blocks to the mounting plates, it is necessary to ensure the alignment of their holes, then turn the previously inserted fastening handles by 90o and thereby fix the heat-insulating block. To connect the heat-insulating blocks to each other and to the mounting plates, there is used the stepped overlap type of connection. Thus, eight heat-insulating blocks are fixed on one tier. This method of insulation is applied along the entire length of the cooling boiler.

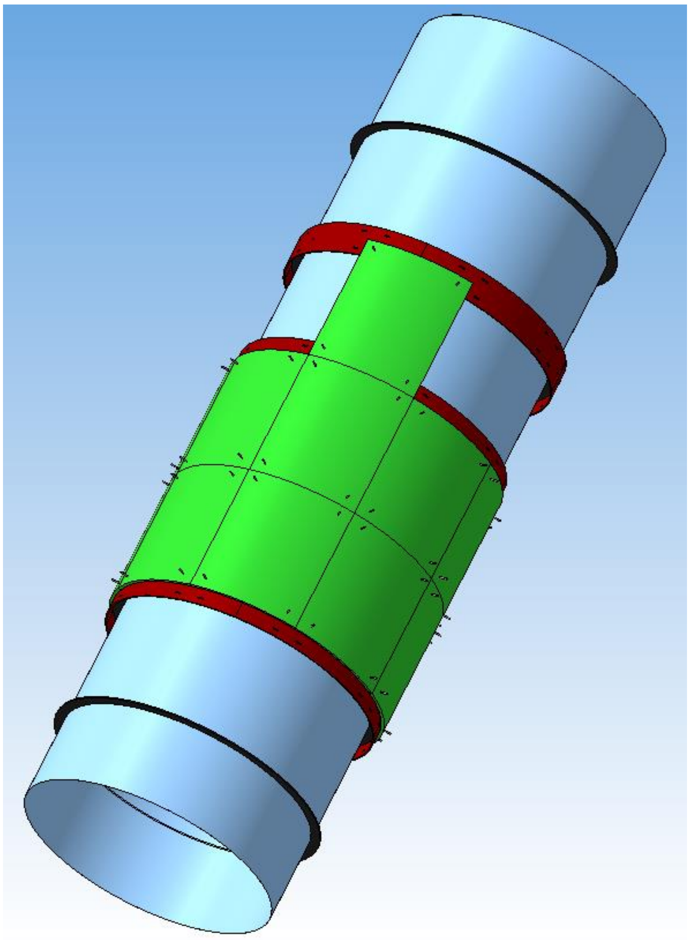

Fig. 3 - Cooling boiler thermal insulation (3D-model)

Conclusions

The technical decisions in this proposal are aimed at reducing the time spent for insulating the cooling boiler, in comparison with the other analogues. This design of thermal insulation of the cooling boiler is maintainable. Thermal insulation blocks are numbered and listed in the technical documentation. Each of the thermal insulation blocks is attached independently of the other blocks with four mounting handles, which makes it easier to mount and to reduce the time spent for replacing the thermal insulation. The insulation provides a significant reducing of heat transfer from the heating surfaces of the cooling boiler to the space of the converter shop and increases the efficiency of the cooling boiler.

The advantages of the presented technology are as follows:

- reducing the boiler-cooler and converter downtime during repairs;
- reducing the risk of water ingress into the liquid metal of the converter and accordingly, reducing metal pops, which provides for safer working conditions in the converter shop.

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The Evaluation of the Technical Condition of Parts and Assemblies of Mining Equipment Based on the Analysis of a Sample of Working Fluids

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Abstract. The article is informative and is devoted to the description of methods for research samples of hydraulic and lubricating fluids of technological equipment at the gold mining enterprise JSC "AK Altynalmas". The advantages of methods for monitoring the working state of the mining machine are given. The analysis of the results of laboratory studies of the working fluids of the CAT 992K loader was carried out.

Key words: hydraulic fluid, lubricating fluid, loader, maintenance

Introduction

The productivity of the enterprise directly depends on the state of technology. Thus, the most important criterion for the profitability of a mining company is the material costs of extracting 1 ton of minerals. Any measures to improve operation and reduce costs per ton carried out in a mining area are directly reflected in its economic performance.

This important criterion is influenced by many factors, so among them there is no more significant than the reliability and availability of mining equipment. To ensure that the equipment operates at the required performance, regular maintenance is need. But every minute that the equipment is being serviced or repaired becomes a minute that the machine is not drilling, digging, dozing, or transporting ore.

Preventive maintenance is a process that uses machine downtime to a high degree and returns the machine to work as quickly and efficiently as possible.

Maintenance keeps mining machines and equipment in top condition, avoiding costly failures and unexpected shutdowns, and optimizing equipment operating costs. This process is very important for the successful implementation of the maintenance and repair system in a mining enterprise. Maintenance is considered as one of the main tasks in the overall management strategy of equipment maintenance. The process allows you to identify defects at an early stage, plan and carry out equipment repairs before failure occurs.

The evaluation of the technical state of mining equipment during operation became possible due to the introduction of technologies for monitoring the working condition of the machine. Machine's monitoring systems provide critical, event-driven data on machine technical condition and operation across the entire fleet. Information can be downloaded directly from machines and analyzed using a wide range of diagnostic and analytical reporting tools. Monitoring systems of working capacity identify potential problems before failure occurs, therefore minimizing unplanned downtime and loss of productivity. These tools also help control operating costs and improve efficiency by streamlining management and planning for maintenance and service.

Thanks to timely maintenance and instant availability of current status information at any point in the operation, mining enterprises are able to better plan maintenance schedules.

To maintain the working capacity of mining equipment, service life, and reduce downtime, one of the effective methods is the diagnostic control of mechanisms based on the actual state of lubricating and hydraulic oils.

The analysis of the performed works of maintenance and evaluation of the technical condition based on the results of samples of working fluids will be considered using the example of the front-end loader CAT 992K of the JSC "AK Altynalmas" enterprise.

1. Object of study

The CAT 992 front loader model appeared in 1968 and has been constantly improved since that time. The loader is safe in operation, high performance and reliability [1].

Fig. 1 - Front-end loader 992K

Loader CAT 992K is designed for lifting, transporting and stacking various loads. It can be bulk materials, soil, rocks, grain, snow and small objects. The technique is widely used in warehouse organization, agriculture, public utilities, construction sites, mining (Figure 1).

The CAT 992 front loader features grouped service points (Table 1). Combined with diagnostic tools such as VIMS, Product Link, and Electronic Technician, servicing the 992K is simple and efficient [1].

Table 1. Types of work during maintenance of the CAT 922K front loader

No.	Maintenance points
1	Service center for diagnostics and analysis of working fluids
2	Centralized hydraulic system service unit
3	Electrical lockout point
4	Pressure measuring points for remote diagnostics on the front frame
5	Pressure measuring points for remote diagnostics on the rear frame
6	Electrical service point
7	Engine filter service point

2. Analysis of the results of samples of working fluids

The regular evaluation of the state of technical fluids of mining equipment helps the enterprise to monitor the current state of the system, assembly or unit, to identify the level of their wear by the degree of contamination and the content of impurities in technical fluids and other hidden problems before failure, as well as to prevent unforeseen breakdowns and unplanned downtime. Fluid analysis provides an evaluation of the condition of parts of engines, transmissions, hydraulics, onboard gearboxes, differentials and compressors by the removal of wear particles into oil (iron, copper, lead, aluminum and more than 30 other elements). Based on the results of the analyzes, diagnostic work is carried out and repairs are performed.

Figure 2 shows a fragment of a laboratory analysis of sampling of lubricants and hydraulic fluids of a CAT 992K front loader. Oil sampling is carried out two days before the scheduled maintenance of the machine. Laboratory analysis is carried out for oils used in the internal combustion engine (ICE), transmission, chassis, steering system, hydraulic drive.

At JSC "AK Altynalmas" the following methods to study samples of working fluids are used:

1. Membrane Patch Colorimetry (MPC), varnish potential testing (ASTM D7843) is an analytical test to determine the propensity for a lubricant to form varnish deposits [2,3].

2. Analytical ferrography - a method of magnetic deposition of metal wear particles from samples of working fluids [4].

The first method is two-step process: filtration and color measurement. During the first part, 50 mL of the working fluid to be tested is diluted with an equal volume of petroleum ether. This mixture is filtered through a 0.45 μm nitrocellulose patch which is then rinsed with petroleum ether and dried (Figure 3,a). The intensity and color of the patch are then measured against a control patch using a spectrophotometer that calculates the color difference, or «ΔE» value [3]. The ΔE value are presented in Table 2.

Table 2. Varnish potential scale

№	ΔE value	Result	Description
1	< 15	Good/Normal	Oil is usable
2	15 - 25	Monitor	The oil is usable. But you should monitor the condition of the equipment, wear of some elements is possible
3	25 – 35	Abnormal	The oil is usable. But you should monitor the condition of the equipment, wear of some elements is possible
4	> 35	Critical	Oil is not suitable for use

The following apparatus and consumables are required to complete the MPC test: Patch test kit apparatus (glass or heavy duty stainless steel), hand or electric vacuum pump and spectrophotometer (Figure 3,b).

The second method is to study oil samples using a microscope in transmitted, reflected and dichromatic light. There are two ways:

- high-quality, allowing to determine and prevent malfunctions of units and mechanisms of machines by the composition of particles of aluminum, iron, silicon, molybdenum, tin, lead, chromium, copper, zinc, etc., resulting from wear. Thus, knowing the chemical composition of metals from which parts of units and mechanisms are made, it is possible to determine the source of wear products. Thus, the results of sampling of hydraulic oil and the front left onboard gearboxe of the loader made it possible to identify the wear of pump parts and thrust washers, respectively (Figures 2, 4);

- quantitative, which determines the degree of wear of parts by the number of particles contained in the liquid. For example, as a result of the analysis of lubricating oil in the transmission, the number of particles with a size of 4 microns is 23; 6 µm - 22; 14 microns - 20, which does not go beyond the allowable values (Figure 5).

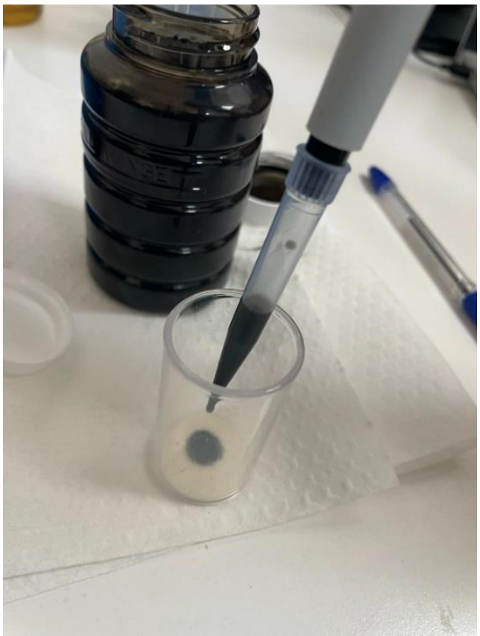
ALTYNALMAS АО АК АЛТЫНАЛМАС Friday, February 24, 2023 5:15:09 PM

PMS Oil Laboratory Analysis Information Sheet Информация по маслу, подлежащее лабораторному анализу

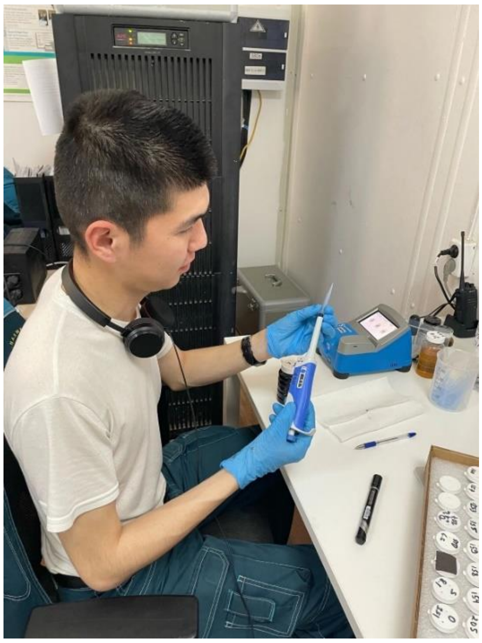
Оборудования:	**207**	Unit Make	CATERPILLAR	Дата отбора образца масла Sample Date:	22-Feb-2023
		Model	992K	Фактическая дата PMS Actual PMS:	
Location	AA PROJECT 2 PUSTYNNOE HD EQPT	Year	2018	Hour Meter моточасы:	
				Запланированный PMS Scheduled PMS:	Friday, February 24, 2023

Oil sampling point	oil condition	Volume	OEM	Oil life	Operating time of a mechanical unit	Oil change	Kidney loop	Oil Top-up	Oil condition	Recommendation	Remarks
1 Combustion engine	DELVA C MX 15W40	120	250	169	13129	☑	☐		В норме Normal	Пригодно к использованию Still FIT for further use	OEM 250 Hours Следуйте регламенту по замене масла.
2 Transmission	MOBIL TRANS HD 30	170	1000	447	13129	☐	☐		В норме Normal	Пригодно к использованию Still FIT for further use	
3 Hydraulics	HYDRAULIC 10W	300	2000	447	13129	☐	☐		Выше нормы Abnormal	Пригодно к использованию Still FIT for further use	Мониторинг/Monitoring: Высокое содержание железа. Возможно идет износ насоса, клапанов или цилиндра.
3A Steering system	HYDRAULIC 10W	185	2000	447	37452	☐	☐		В норме Normal	Пригодно к использованию Still FIT for further use	
4A Front axle	SPIRAX S4 CX	360	2000	4263	13129	☐	☐		Нет пробы		Проба не была отобрана, рекомендация основана на результатах предыдущих анализов.
4B Rear axle	SPIRAX S4 CX	345	2000	1198	13129	☐	☐		Нет пробы		Проба не была отобрана, рекомендация основана на результатах предыдущих анализов.
4E Rear left onboard gearboxe	SPIRAX S4 CX	172	2000	1198	13129	☐	☐		В норме Normal	Пригодно к использованию Still FIT for further use	
4F Rear right onboard gearboxe	SPIRAX S4 CX	172	2000	1198	13129	☐	☐		В норме Normal	Пригодно к использованию Still FIT for further use	
4G Front left onboard gearboxe	SPIRAX S4 CX	180	2000	4263	13129	☐	☐		Выше нормы Abnormal	Пригодно к использованию Still FIT for further use	Мониторинг/Monitoring: Содержание меди увеличивается. Возможно идет износ упорных шайб.
4H Front right onboard gearboxe	SPIRAX S4 CX	180	2000	4263	13129	☐	☐		Выше нормы Abnormal	Пригодно к использованию Still FIT for further use	Мониторинг/Monitoring: Высокое содержание меди.

Fig. 2. - Fragment of the analysis of sampling of the working fluids of the loader

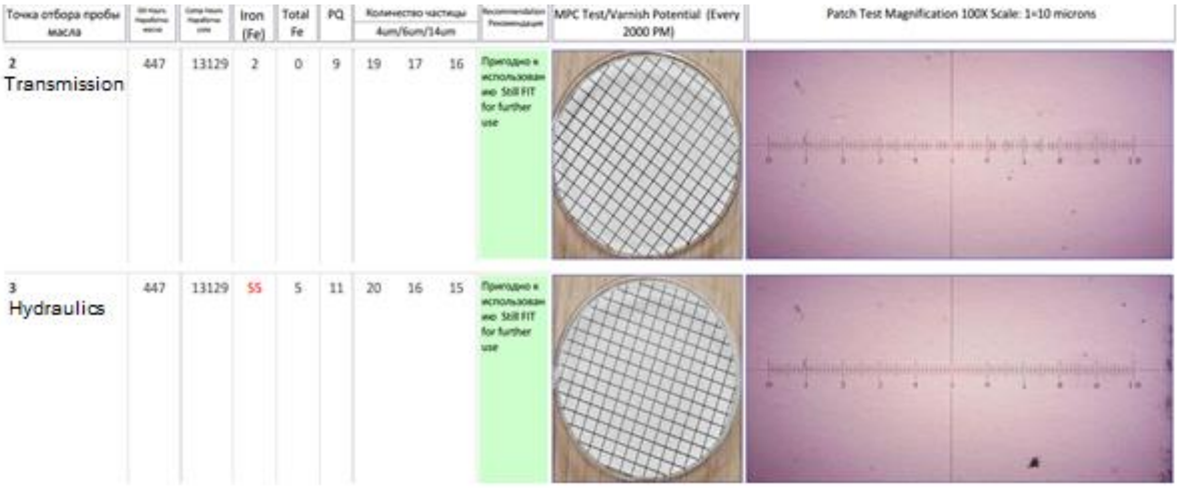


a)



b)

Fig. 3 – Working fluid analysis by Membrane Patch Colorimetry



Точка отбора пробы масла	Oil Hours Наработка масла	Comp Hours Наработка узла	Iron (Fe)	Total Fe	PQ	Количество частицы 4um/6um/14um			Recommendation Рекомендация	MPC Test/Varnish Potential (Every 2000 PM)	Patch Test Magnification 100X Scale: 1=10 microns
2 Transmission	447	13129	2	0	9	19	17	16	Пригодно к использованию Still FIT for further use		
3 Hydraulics	447	13129	55	5	11	20	16	15	Пригодно к использованию Still FIT for further use		

Fig. 4 - Qualitative method of Analytical Ferrography

Точка отбора пробы масла	Oil Hours Наработка масла	Comp Hours Наработка узла	Iron (Fe)	Total Fe	PQ	Количество частицы 4um/6um/14um			Recommendation Рекомендация	Magnetic Plug Магнитная пробка
4G Front left onboard gearboxe	4263	13129	12	0	6	23	22	20	Пригодно к использованию Still FIT for further use	

Fig. 5. - Quantitative method of Analytical Ferrography

For measuring the mass fraction of diesel, gasoline or other light hydrocarbon fuels in motor, turbine and other machine oils on synthetic and mineral bases, JSC "AK Altynalmas" uses Spectro FDM analyzers of fuel content in oils (Figure 6). The principle of operation of the analyzers is based on Henry's law, according to which the concentration of fuel vapors over an oil sample will be proportional to the percentage of dissolved fuel in the oil sample [5].

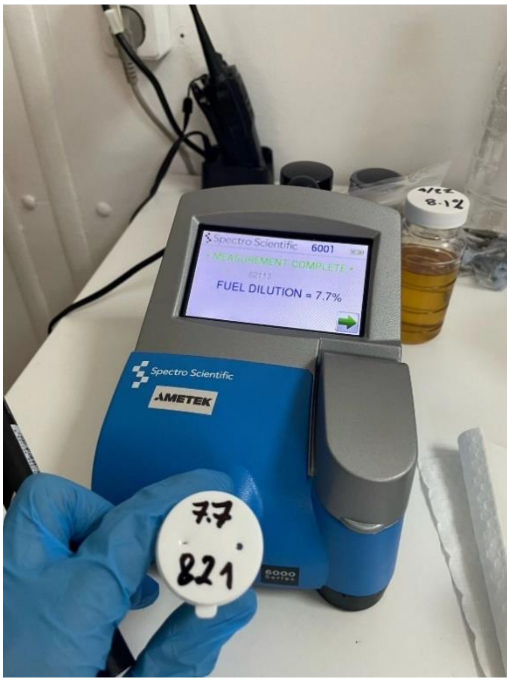


Fig. 6. - Spectro FDM Analyzer

Fig. 7. - Oil sampling

The finished laboratory analysis should contain the following information (Figure 3):

- name and information about the equipment; type of maintenance; oil sampling date.
- brand of oil, its volume in the system and the number of hours worked;
- the condition of the oil and recommendations for its further use.

In order for information on fluids to be reliable, it is necessary to take oil samples regularly at certain intervals. Sampling is recommended to be carried out from the same place where the working fluid does not stagnate, in the same way keeping clean (Figure 7).

Conclusion

Sampling analysis of hydraulic and lubricating oils helps prevent serious breakdowns and equipment malfunctions. This method is one of the promising directions in the field of mining equipment diagnostics, which allows not only to control the quality of working fluids, but also to significantly increase the productivity and service life of equipment, and reduce the time and cost of maintenance.

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