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Paper

THE TECHNOLOGY AND THE MACHINE FOR CUTTING WALL STONE OF THE CORRECT FORM BY ULTRA-HIGH PRESSURE WATERJETS

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ABSTRACT

The objective of this study was mastering the essence of a new technological approach - technology UHPWJ for cutting a wall stone of the correct form from rock with strength up to 40 MPa and development a special machine for its realization. The research into cutting tuff by UHPWJ technology allows to determine the optimum technical parameters, different variants of technological schemes of the new machine and its main nodes. Proposed technology consists of two sequentially executed operations. The first operation is made by transversal UHPWJ cutting with multi heads. During the second operation the carriage of the machine is turned by 180^0 and the longitudinal cutting is done simultaneously with two heads. The first UHPWJ cutting head executes back cutting, and the second head with a diamond disk saw completes the cutting of a sole. The UHPWJ technology allows improving the ecological conditions of the environment and increasing the utilization of quarries more than two times.

1. INTRODUCTION

The objective of this study is to master the essence of a new technological approach – that of using an ultra-high pressure water jet (UHPWJ) for cutting a wall stone of the correct form and the development of a special machine for its realization. A "wall stone" is defined as a block of a natural stone of rectangular form with sizes up to 200*300*400 (500) mm. Such stones of soft rock have a strength up to 40 MPa and are major building materials used in Armenia and in other countries of the CIS, particularly, Kazakhstan and Turkmenia and in the Middle East.

The technology for the production of wall stone of correct form has not changed for more than 50 years. Production of a stone is accomplished by an open method using low-bench stone cutting machines of CMP-026/1 type. Weight of such a machine is about 17 tons, overall dimensions are 5,300 * 6,000 * 4,000 mm, and usual power of electric motors of more than 75 kw. The width of the kerf of the disk saws is usually 15-20 mm. The overall performance of these machines is limited by the cutting capabilities of the disk saws. The hard-alloy cutters of the disk saws frequently fail from rigid additions in the rock, facial and radial beating of teeth, inevitable vibrations etc… The downtime resulting from permutation of the rails, replacement of disk saws and alignment are significant. The vibration of multi-ton machine leads to natural cracks in the mountain, which results in accumulation of large amount of scrap. The effectiveness of stone production of the quarry can be judged by the yield: useful stone volume does not exceed 35-40% of the total production volume. Because disk saws are unable to cut the more rigid underlying strata of a mountain array, they leave a mountain of scrap, irreparable damage to the environment, and hundreds of abandoned quarries.

2. PROBLEM STATEMENT

The urgency of this work is dictated by the need of a solution for the above-stated problems. Large preliminary research was conducted on the problem in order to find out:

- if research on cutting mountain rock by small strength UHPWJ technology has been conducted;
- if there are other companies that manufacture machines for production of wall stone of correct form;

The conducted survey has led us to the following conclusions.

- We studied others' research into cutting of stones from rigid rock such as granite, basalt, marble, etc. by UHPWJ [1, 2]. In particular, there are many reports about producing individual pieces of architectural elements using this technology, e.g. "Florentine floors", etc. However there are no results on mass production of wall stones of correct form from soft rock of small strength (up to 40 MPa);
- Companies do not manufacture a machine for production of wall stone of correct form from mountain rock using UHPWJ technology;
- The hydrodemolition equipment of the companies CHEMAC Inc, Conjet AB and others for destroying concrete and asphalt covers using water jet technology operates by self-propelled frame [3, 4]. These machines could become a good basis for the

creation of a special stone cutting machine for production of wall stone of correct form;

- There are a number of machine tools, where several water jet heads work simultaneously. For example, the machine WARDJet Z - 513 of the company WARD*Jet*. Inc has 6 such heads [5]. This principle can be used in the new machine for carrying out some technological operations.

3. RESEARCH INTO THE UHPWJ CUTTING PROCESS OF TUFF

The success of the realization of the project will largely depend on scientifically substantiated and thorough research into the UHPWJ cutting process of tuff mountain rock of strength up to 40 MPa. Based on the results, the technical and operating characteristics of the future machine will be determined and the technical specification will be composed.

The research into cutting tuff by UHPWJ was made using the M - 329/IFB machine produced by Flow International. The cutting parameters and conditions were defined by the following magnitudes:

- Pressure ***P*** of water jet: 2,830-3,655 bar;
- Cutting speed ***V*** : 127-3,000 mm/min:
- Abrasives: garnet 0.15-0.30 mm, concentration ***A*** is 0.334; 0.554 kg/min;
- Nozzle sizes: 0.762 and 1.016 mm, the water flow ***Q*** is correspondingly 3 and 3.7l l/min.

The experimental samples are from tuff quarries in Artik city in Armenia. The samples had the following structure and physical-mechanical properties: SiO_2- 65.7%, TiO_2- 1.2%, Al_2O_3- 15.4%, Fe_2O_3-5.8%, MgO-1.1%, CaO-3.5%, volumetric weight 1,120 kg/m^3; porosity 56.2 %, strength of dry and water-absorb conditions, correspondingly, 111 kg/sm^2; 89 kg/sm^2.

Several bars of 50mm size were used as thick experimental samples, which has facilitated measurement of cutting depth and of the kerf profile.

Research in UHPWJ cutting area indicates that the depth ***H*** of cutting is the most essential parameter of the process. Therefore, the research was carried out for two ranges of depth. For cutting depths in the ranges up to 80 mm and 81-200 mm the following equations are obtained:

$$H = 1.36\ A^{0,16}\ P^{0,69}\ Q^{0,05}\ V^{-0,23} \qquad (1)$$

$$H = 0.07\ A^{0,36}\ P^{1,25}\ Q^{0,28}\ V^{-0,36} \qquad (2)$$

The equations allow to make important conclusions about the choice of optimum parameters for UHPWJ cutting of tuff rock of strength up to 40 MPa and for development of the technical project of the special machine for production wall stone of correct form.

The experimental studies for small depth of cutting (below 40-50 mm) shows much smaller influence of the variable factors, than that observed for large depths, and the cutting speed can reach up to 2,500-3,000 mm/min. This justifies the expediency of creating an edge trimming machine for edging of slab workpieces of tuff, marble and similar rocks.

For cutting depths of 150-200 mm quite small speed of cutting 127-300 mm/min leads us to conclude that to maintain the required productivity it is necessary to use an assembly with many cutting heads.

For a given machine for UHPWJ cutting, equations (1) and (2) allow to determine the optimum cutting speed on the basis of pressure of a water jet, water flow and abrasive concentration for the given thickness of tuff.

4. TECHNOLOGY AND SPECIAL MACHINE

The comparatively small force of UHPWJ cutting allows to introduce radical modifications in the design of machines for production wall stone of correct form. These modifications consist of replacing of rail multiton machine with the incomparably lightweight wheel machine, which has better mobility in the quarry.

On Fig. 1 the transversal (a) and the longitudinal (b) sections of horizontal and back technological operations of cutting wall stone of correct form are shown. In this case the horizontal cut of a stone is carried out by a diamond saw in order to maintain the flatness of the quarry after periodic shift of the machine by the breadth ***B*** of the stone.

During the execution of the first operation the distance ***L*** between cutting heads is adjusted to equal the length of a stone. The simultaneous cutting of several grooves is carried out to ensure the depth of cutting is equal to stone height ***H***. To perform the next cycle the machine moves to a new position from final groove on size of stone length ***L***. The transversal grooves are repeated along the length of the open trench.

During the second technological operation the carriage of the machine is turned by 180^0. The head for back cutting is aimed in the direction of movement at distance 0,5***D*** + 5/10 mm from the diamond saw and at stone breadth ***B*** from the ledge of a trench, where ***D*** is the diameter of the diamond saw. After completing one longitudinal cut, with lifted head, the machine is reset to ensure displacement of the head by the breadth ***B*** of a stone. For the breadth of a stone 188/240 mm, the diameter of a diamond saw is 630/800 mm, the breadth of a saw is 4.5/5.5 mm and for strength of a stone of up to 40 MPa, the power of cutting does not exceed 3/4 kw.

For production of a brick size stone, which has large demand in construction, an additional cutting head (14) is installed perpendicularly or in parallel to the plane of the diamond saw ensuring enhancement of the machine's productivity.

The design features of the new machine for production of wall stone of correct form are indicated in the patent specification [6] (Fig. 2). The machine has a four-wheel automotive frame (1), the chassis (2) with high pressure pump (3) and the supplying hydroinstallations. At the top of the chassis there is a round rotary directing (4) and the support mobile carriage (6). At the edge of the carriage longitudinal directing (8), there is UHPWJ cutting head with six nozzles (9) at distance ***L*** from each other (7). On the other edge/side of the carriage on longitudinal directing (10) diamond heads (11) with a diamond disk saw (12) are installed. A diamond saw in a certain position for the back cutting head (13) is installed.

The machine is equipped with electronic control system, servo-mechanism for rectilinear movement of the machine, the high pressure hydrocommunications, the standard nodes from the hydrodemolition machines.

When the cut breadth does not exceed 1-3 mm and the forces of cutting are rather small, the production of stone of correct form by UHPWJ technology uses a machine of weight of only 3-4 tons, excludes formation of vibration, scraps and stone chopping and the degree of quarry utilization increases twofold on average and the volume of useful stone increases up to 80-90%.

In the table 1, the productivity $\boldsymbol{Pr}$ of cutting stone of correct form is given for various cross-sections and amounts $\boldsymbol{I}$ of stone. We consider, sequentially, the case when one brick is cut at horizontal disposition, two bricks – at vertical and horizontal dispositions and three bricks at vertical disposition, and the stones with transversal sizes of 150*150 mm and 190*190 mm are produced.

In the table 1, V_w is the waterjet cutting speed, V_d is the velocity of submission in the time of diamond cutting, $Pr_{,w.t}$ is the productivity of transversal waterjet cutting with number of cutting heads equal to 6; $Pr_{,d}$ is the productivity of diamond cutting, $Pr_{,w.l}$ is the productivity of longitudinal waterjet cutting. The total productivity $\boldsymbol{Pr}$ is taken as the least signficant of $Pr_{,d}$ and $Pr_{,w.l}$.

Comparison of the productivity of the new machine versus the productivity of the old machine CMP-026/1 yields the following: for production of wall stone of correct form by small sizes, as a brick, productivity of the machines are almost the same. For production of wall stone with transversal sizes of 150*150 mm and higher, productivity of CMP-026/1 is almost twice higher. However, if we consider the additional costs of the CMP-026/1 machine, related to permutation of the rails, repair of the machine during transition from transversal cutting to longitudinal, clearing of the working zone of the machine from sub-standard stones and waste, and the negative influence of the old technology on the environment, introducing UHPWJ technology and special machine will be economically expedient for production of wall stone of correct form.

There are also developments of machines, in which the transversal and longitudinal technological operations are carried out separately. In this case the summary productivity is higher and the organization of production is much easier.

5. CONCLUSIONS

About 6,000 CMP-026/1 machines are currently maintained in CIS countries. The majority of them are physically and morally outdated. At the same time, there is a great demand for machines for production of wall stone of correct form. Utilization by the new machine of nodes and details of machines and tools working by UHPWJ technology gives the basis to assume that the creation of the new machine will be expedient and adequate from the engineering standpoint.We believe that department "Stone Cutting Systems" of State Engineering University of Armenia in cooperation with "Stone Cutting Machines" company and in creative connection with the leading producer of UHPWJ technology will solve this problem in the very near future.

6. REFERENCES

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2. www.marblecutting.com.
3. www.jetedge.com.
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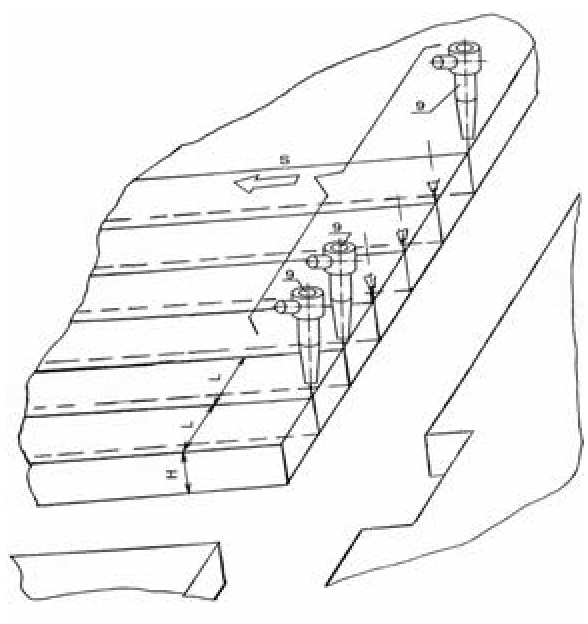
6. Asatryan J., Suvaryan Kh. "The machine for production a stone." *Patent of Republic of Armenia # A2 1839, 2006*.

7. TABLES

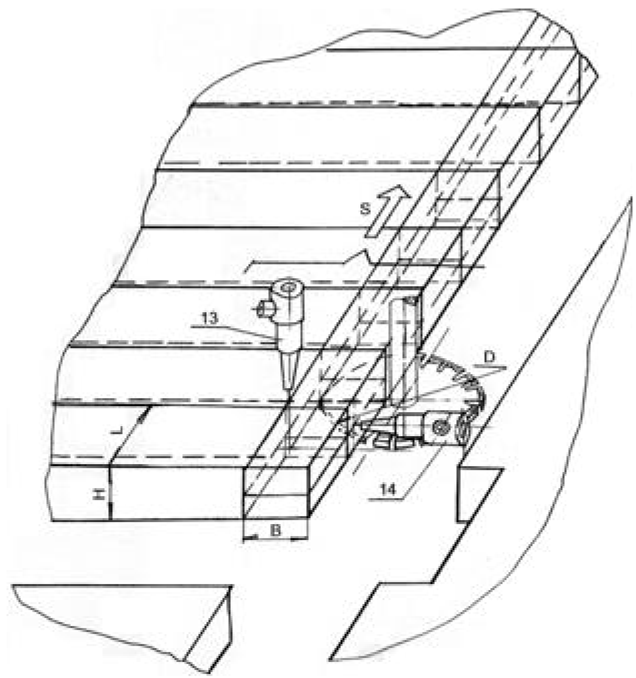
Table 1. The table of productivity UHPWJ cutting wall stone of correct form (tuff by strength up to 40 MPa)

#	***H***, m	***B***, m	***I***, item	V_w, m/min	V_d, m/min	$Pr_{w.t}$, m^2/hour	Pr_d, m^2/hour	$Pr_{w.l}$, m^2/hour	***Pr***, m^2/hour
1	0.065	0.13	1	1.50	1.54	35.1	12.0	5.9	41.0
2	0.130	0.13	2	0.30	1.54	14.1	12.0	4.7	18.8
3	0.130	0.20	3	0.30	0.75	14.1	9.0	7.0	21.1
4	0.150	0.15	1	0.25	1.20	13.5	10.8	2.3	15.8
5	0.190	0.19	1	0.13	0.75	8.9	8.6	1.5	10.4

8. GRAPHICS

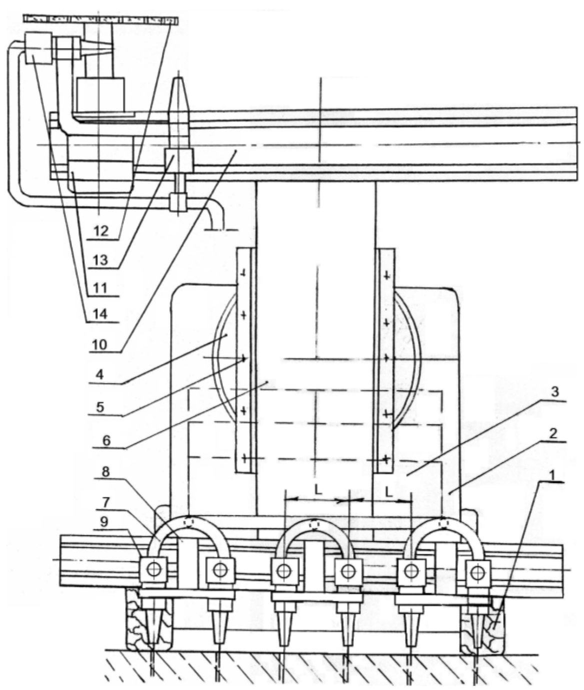


a.



b.

Figure 1. The transversal (a) and longitudinal (b) projec tion – of a horizontal and back technological cutting operations.



a.

b.

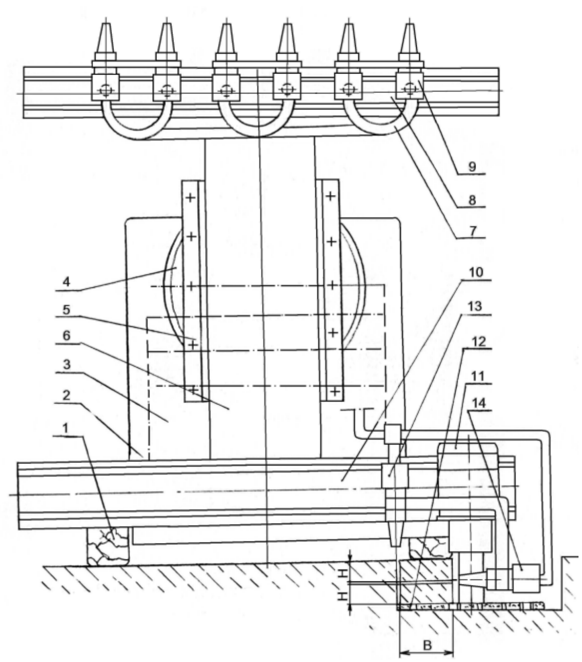


Figure 2. The front views of the machine for production of wall stone of correct form: during transversal (a) and longitudinal (b) cutting.