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STUDY OF THE APPLICATION HIGH VELOCITY THERMAL SPRAYING TOOLS USED IN TECHNOLOGICAL PROCESSES AND PRODUCTIONS

Abstract. In the article the questions of creation of new designs of thermo-tools for destruction of rocks at processing and extraction of block stone, possessing the raised power characteristics and their application as a working body, the mechanized aggregate of the stone carving machine are considered. Gas-flame processes of applying wear-resistant coatings on the surface of machine parts are also considered. Extension of the field of application of supersonic high-temperature jets is the use of them to remove the insulating coatings of oil and gas pipes, with the introduction of a jet of solid particles (abrasive material or water) to obtain an elastic vapor-gas jet for cleaning the surface of pipes.

Keywords: high velocity sprays, combustion chambers, fuel components (oxygen, propane, kerosene, air), oil and gas pipes, rock.

1. Introduction. Development of facing stone deposits has a number of specific features that allow allocating such type of quarries to a special group of mining enterprises. As noted in [1], these features are as follows:

1. requirement to preserve the key quality indicators of stone in the process of its quarrying (i.e. strength, block size and decorative properties);
2. application of special techniques to separate the stone blocks from the face, their loading, transportation and lifting from the quarry;
3. application of special development system options and deposit opening techniques.

The first feature determines the operating characteristics of dimensional stone quarries. It imposes conditions both on the tools and organization of quarrying operations. Everything is based on the stone integrity preservation. As the quarry operation practice indicates, even when the cracks and micro-orientation of minerals are correctly used, yield of large blocks from the rock mass rarely exceeds 25-30% in principle, and the remaining rock mass is a rubble stone, small blocks, etc.

Knowledge of the massif structure anisotropicity, which should be considered when selecting the development techniques and directions, has a great importance in the process of work organization in the quarry. The massif structure anisotropicity is noted in granites, which simplifies the stone split in the certain directions.

Facing stone is generally quarried by using two techniques:

1. Stone block spalling by using the wedges. Such technique consists in the fact that the holes are drilled along the spalling line, and then the steel wedges are driven into them. A strong mechanical shock is made on these wedges. Such technique is quite laborious and time consuming [2].
2. Thermal stone cutting with fiery jet. Such technique differs with high speed, relatively low cost and high work quality.

Let us consider the second technique in more detail. Thermal technique introduced into production on surface treatment and penetration of slotted workings in the granite massif has significantly increased the work efficiency. There was a possible additional exposure of monolith prepared for breaking. With the application of thermal penetration of slotted workings in the massif, a monolith should be broken when it is exposed on the four planes. A monolith prepared for breaking should be connected with massif by one vertical and horizontal plane. Moreover, the horizontal plane is selected in the place where there is a natural horizontal crack. Such a process layout for breaking has contributed to the stone integrity preservation. Yield of blocks has increased for up to 25–40%. However, the technology basis is an availability of the natural horizontal cracks [1-6].

The main tools for penetration of slotted workings in the granite massifs are hand gasoline-air torches. Such torches enable penetration of slotted workings only in the vertical direction [7, 8].

The depth of workings is generally 1.5-3 meters, although there are examples on penetration of workings to a depth of five meters and more. It is difficult to implement penetration by the hand torches, since they become hard to manage.

In accordance with the terms of reference of the scientific project under the RoK MES grant, a laboratory model of the new machine design - thermal stone cutting unit was designed and manufactured in 2015. The technical requirements include the requirements of design simplicity, maintainability and operating safety, which will ensure a high operating performance of the new machine design.

According to the terms of reference, the thermal stone cutting unit consists of thermal cutter, connection pipes, compressor, fuel and air supply system, as well as transport and supply system. Load bearing characteristics of the unit, including those providing the granite cutting speed of at least 50 mm/min have been justified.

Transport and supply system includes the following requirements for workspace dimensions: horizontal traverse length of at least 4.000 mm and maximum 20.000 mm; vertical traverse length of at least 6.000mm, cutter rotation in the vertical plane of at least 180^0. Electromechanical drive that ensures the specific traverse speeds with step control is required for installation. Cutter weight should not exceed 20 kg.

2. Materials and methods. We have developed the improved and modernized designs of thermodynamic tools as an actuating device (TRV-60, TRV12M). They are equipped with thermodynamic nozzles, which enable increasing the energy parameters of torches. Industrial tests of these tools were conducted.

The following specifications were obtained for thermodynamic tool TRV12M: air flow – 5 m^3/min, fuel flow (gasoline / diesel oil) – 15 L/hour, nozzle diameter – 13 mm, nozzle head diameter – 20(22) mm. The test results have determined the torch flame as equal to 25 cm and three-dimensional machining efficiency as equal to 4000 cm^3/min.

In addition, the alternative designs of BVR80 thermal cutters (Figure 1) and its prototype TR60 have been developed.

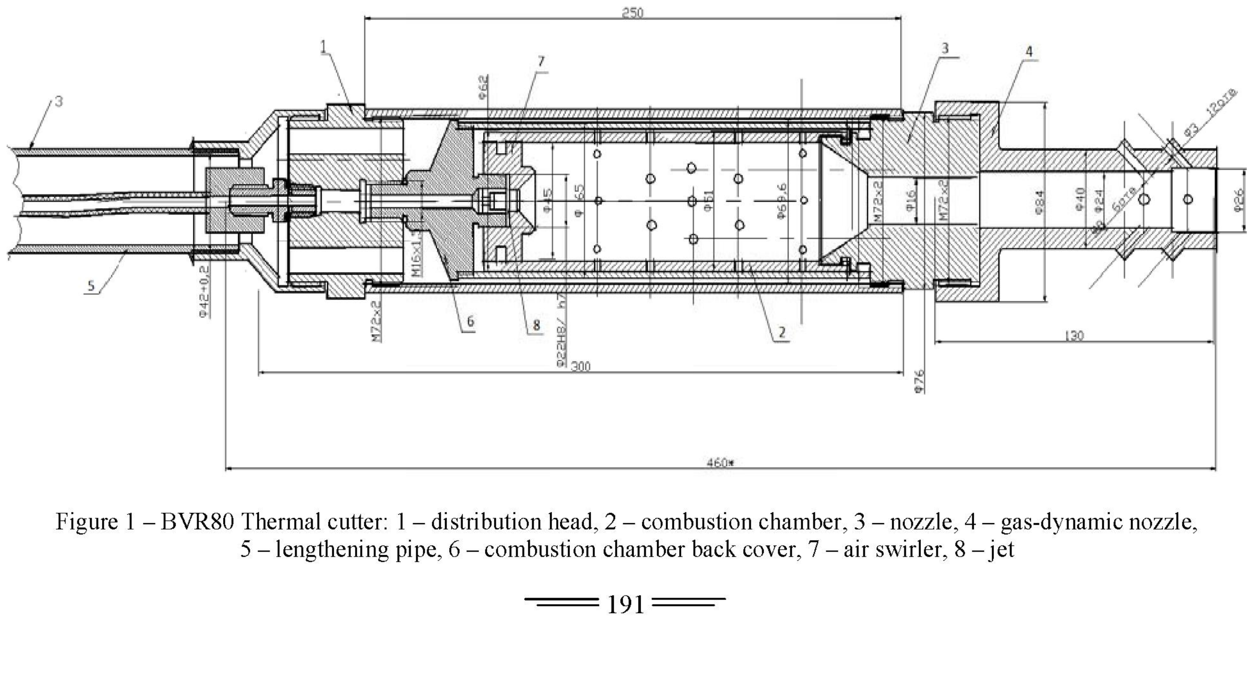

Figure 1 – BVR80 Thermal cutter: 1 – distribution head, 2 – combustion chamber, 3 – nozzle, 4 – gas-dynamic nozzle, 5 – lengthening pipe, 6 – combustion chamber back cover, 7 – air swirler, 8 – jet

Shape and location of nozzles, combustion chamber length, value of slots for air movement in the process of cooling and others have been changed in the schemes proposed.

The most difficult in solving the issue of a mechanized cutting is to obtain a stable working of slots in the areas of granite massif with the inclusion of mafic minerals and other surrounding rocks. Heterogeneity of composition along the cutting line leads to irregular speed of slot workings in depth. When cutting with hand thermal tools, the circumstance does not complicate slot penetration, as in this case, the irregular traverse speed of tool is easily set.

It is quite difficult to set the irregular traverse of actuating device for the stone-cutting machine and provide for an automatic speed control system depending on the thermal breaking of rocks on the face.

Attempts of such solutions were taken in the process of development of the jet-drilling rigs, where the issue was decided regarding a thermodrill feed speed control depending on the rate of face advance, i.e. the issue of maintenance of an optimal distance from the torch nozzle exit to the face. Feed speed control systems that are reliable and easy to use have not been found.

When developing the stone-cutting machines, the feed speed of actuating device should be taken as regular. The value of actuating device traverse speed and gas jet attack angle should be selected so as to reduce the heterogeneity impact in composition of rocks along the cutting line to a depth of slot working, at the same time, by compromising on working efficiency. Such situation when it is necessary to select manual regulation of actuating device (torch) feed speed on more complicated areas should be provided for.

In addition to solution of the task on ensuring a stable working of slots, a number of process tasks should be solved when developing the stone-cutting machines. For the most part, such tasks are common when developing the machines of both vertical and horizontal penetration of slots. Task on a rectangular contour slot working at the gas jet attack angles of less than 90 degrees should be solved here.

The Kharkiv Aviation Institute has determined that cutting is the most effective at the gas jet attack angles of 30-60 degrees.

They use idle stroke in the machine designs developed and perform cutting by traversing the torches only in one direction from the ledge to massif. Such circumstance leads to the fact that the slot working is made as raised. Blinding slot wall looks as inclined; inclination angle is a function of the gas jet attack angle. In such a case, the working stroke length of the torch changes in the process of cutting that makes it difficult to organize an automatic machine operation.

We have developed an experimental stone-cutting unit for penetration of the vertical slotted workings. It consists of a trolley where all the actuating device traverse drives of the machine are mounted. The trolley moves on the rail track along the cutting line. A bracket is mounted on the trolley with the carriage rack, where a rod with thermal cutter is fixed on the hinged bearings. Thermal cutter rotary drive is mounted on the same carriage, refer to Figure 2.

So, the thermal cutter may traverse jointly with trolley along the cutting line, by turning around. The thermal cutter traverse speed along the cutting line is adjusted within 0.25–1.5 cm/sec. The reverse rotation speed is set as constant and equal to 20 rot/min. The rotation angle is adjustable within 90–150 degrees. Thermal cutter drops in depth after each stroke on the value of working.

Driving motion is different in each direction. BVR-80 thermal cutter is installed as an actuating device of the stone-cutting machine.

BVR-80 Thermal Cutter Specifications.

Fuel Component Flows:

Air, m^3/min	- 18-20
Petrol, kg/h	- 35-40
Torch Diameter, mm	- 60

Torch Traverse Motion. Torch motion speed is regulated with variator, which changes the rotation speed of drive roller. Electrical circuit of control over the traverse motion of thermal tool provides for an automatic reverse and a timed shutdown after each stroke, which makes it possible to obtain a vertical wall at the end of slot. Reverse and shutdown at the end of stroke is performed by using the limit switches. Electrical circuit provides for shutdown and activation of the carriage feed with thermal tool by using a push-button control board.

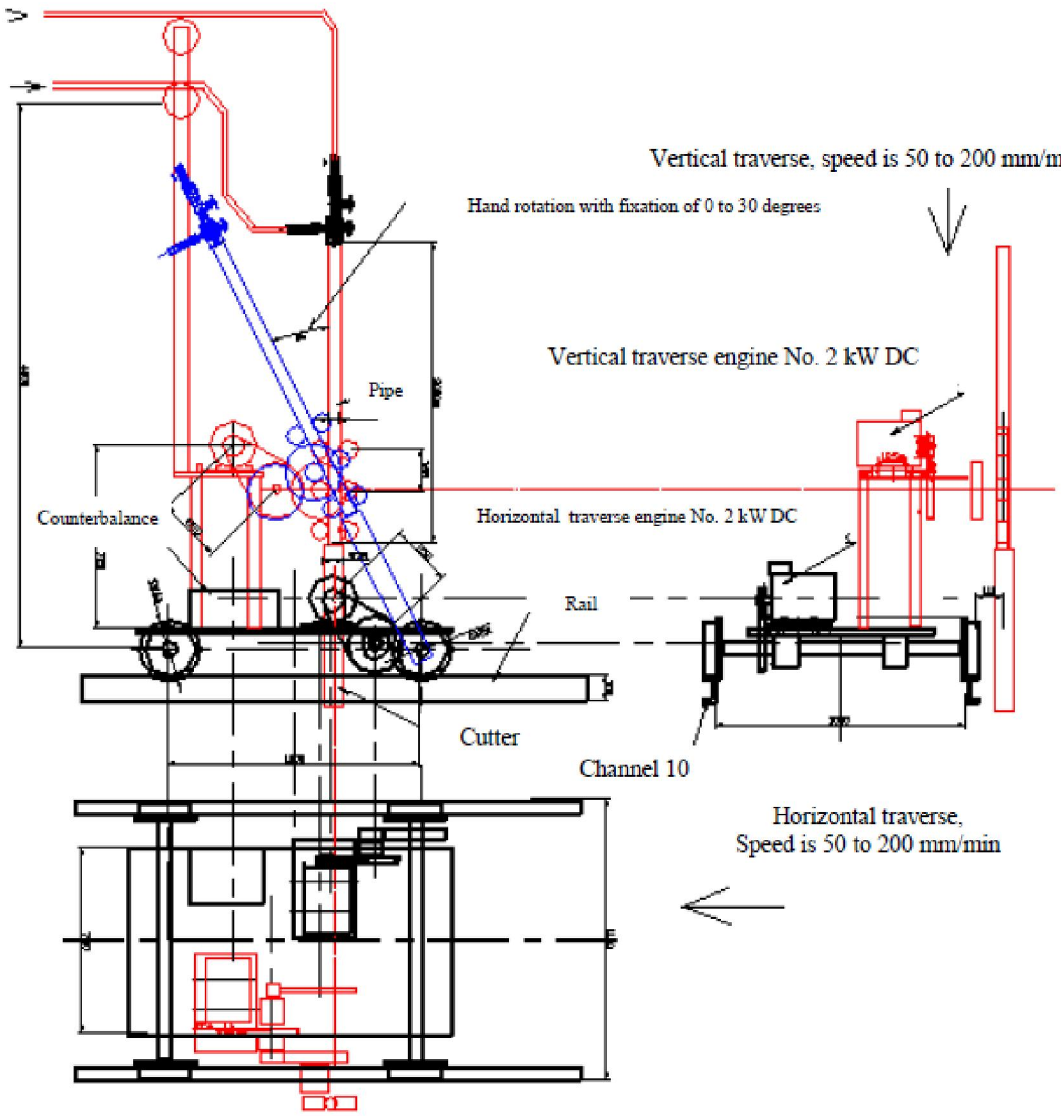

Figure 2 - Structural machine layout with thermodynamic actuating device

The use of gasoline-air torches as actuating devices of the mechanized thermal equipment is restrained by a comparatively low power at the increase of which, their overall dimensions rapidly rises, as well as by the small dimensions of torch flame (0.1–0.15 m) when using the scheme of processing with torch flame throughout its length - "band source". According to this processing scheme, the gas torch jet is directed parallel to the work surface and embedded into the rock by 0.3–0.5 torch nozzle diameter.

However, due to simplicity of gasoline-air torch operation and organization of their supply with fuel components, the use of gasoline-air torches as actuating devices of the mechanized units is relevant. Increase in the power of gasoline-air torches with no significant development of their overall dimensions and increase in the dimensions of torch flame, commensurable with the dimensions of the work surfaces of stone items (border stone, steps, etc.) is possible due to intensification of combustion processes.

One of the techniques for combustion intensification of available jets outside the nozzle exit is a post-combustion of incomplete-combustion products of fuel-rich mixture by atmospheric air ejection. When using heavy fuel mixtures in the torches, the torch ignition technique should be improved.

We have developed a new design of thermodynamic tool as the actuating device. The scheme of such thermodynamic tool is shown in Figure 3. It is proposed to use two nozzle heads in this scheme that allows maintaining the nozzle temperature as not exceeding those permissible. It increases the useful life of the latter [9].

We have developed a design of device for vertical feed of thermal cutter, enabling to enhance the cut quality and efficiency of the stone cutting process, by increasing the rigidity of pipe with thermal cutter at a large cutting depth and reducing the weight load of pipe with thermal cutter on a roller feed [10].

Application of the device proposed will increase the rigidity of pipe with thermal cutter when performing a stone massif cutting, especially at a significant length of the pipe advance downwards. Currently, the pipe advance depth reaches 6 m or more. The high pipe rigidity prevents thermal cutter from oscillation due to the gas jet action that allows making smooth and homogeneous stone cutting profile. It improves the quality of a stone massif cutting process.

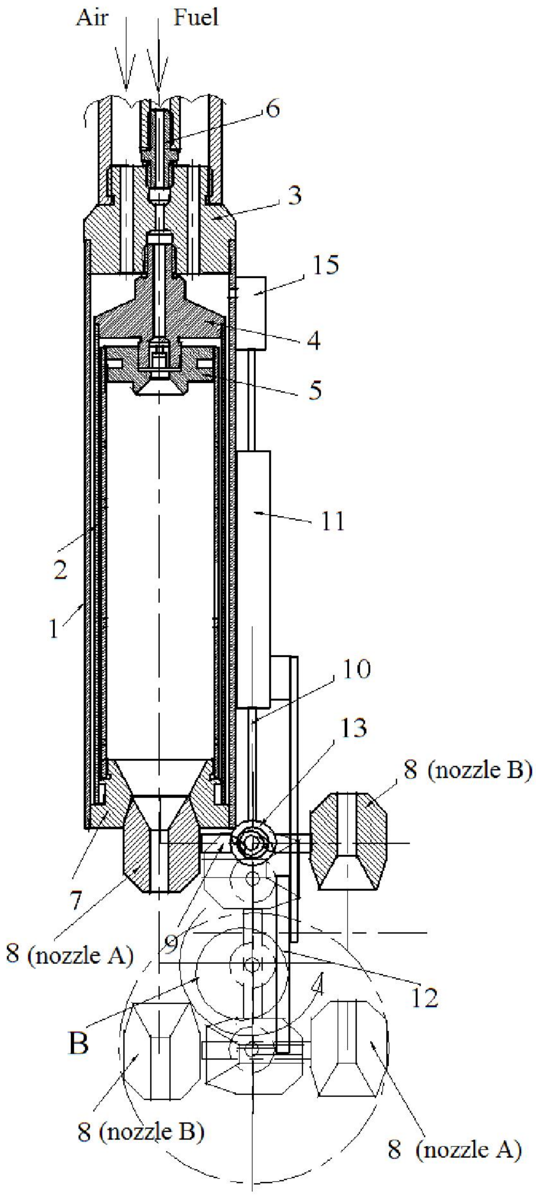

Figure 3 – Thermal cutter for stone cutting with two nozzles:
1 – thermal cutter, 2 – combustion chamber, 3 – distribution head, 4 – jet body, 5 – air swirler,
6 – fuel nozzle, 7 – nozzle body, 8 – changeable nozzle, 9–14 – nozzle rotary and change mechanism

In addition, the cable tension force reduces the impact of pipe/cutter weight force on the feed rolls that allows significantly reducing the pipe slippage in the rolls when lifting the pipe and cutter upwards, especially in case of the rapid lifting.

The specifications obtained are shown in Table 1.

Table 1 – Basic Specifications of the Motorized Machine for Cutting Slotted Workings in the Rock Mass

Name	Value
Cutting Width, at least, mm	80
Cutting Length, at least, mm	20.000
Cutting Depth, at least, mm	6.000
Fuel Type	Diesel
Flow, maximum, L/hour	50
Oxidizer	Air
Thermal Cutter, Length, mm	4.000 - 7.000
Weight, maximum, kg	25
Granite Cutting Speed, at least, mm/min	50

Figure 4 shows the stone cutting process by using BVR60 advanced thermal cutter with a gas-dynamic nozzle.

Figure 4 – Formation of slotted working by using BVR60 Thermal cutter torch with gas-dynamic nozzle

The experiments have shown that the slot width is more than 7 cm that is larger than the outer size of thermal cutter [11].

Other direction of use of the thermotools forming a supersonic high-temperature gas spray (gas-kinetic cleaning) one of the most advanced techniques of the surface treatment in technology of repair of gas of wires.This technique is mostly used in combination with mechanic (mechanical air cleaning) or abrasive (thermal abrasive cleaning) impact.

The scientists from Kazakh National Technical University named after K. I. Satpayev tested the gas-flame destruction of insulation coatings on oil & gas pipes jointly with Intergas Central Asia JSC. They developed a new design of the rocket gun, into which water is injected to form gas/steam mixture, as well as solids (grits or sand), to increase the mechanical part of the spray [12].

Two-phase flow with a high velocity of solid particles will allow increasing the speed at which the coating is destructed and further cleaning of the pipe surface for application of a new coating.

The reached rate of the flame cleaning is 10 m^2/h at the fuel consumption consumption rate, the fuel consumption rate is 17–18 kg/h, the air consumption rate is 3.5 m^3/min. Figure 5 presents the moment when the pipe is cleaned with a thermal hand tool.

Wide opportunities are offered by using high temperature and high velocity gas sprays (gas-dynamic metal-spraying gun) for application of thermal coatings, namely: the strength of adhesion of coating and the surface is increased and the process gets cheaper as compared to the existing plasma and detonation spraying.

Figure 5 – Treatment of the pipe with a thermal hand-tool

There is some experience in creating a pilot installation for cleaning the gas pipelines that was designed by VNIIGaz (Russia) jointly with Van Voskalen company (Netherlands) which proved the viability of using supersonic thermal spray technologies in removing the insulation with simultaneous preparation of the surface for application of new coating during the repair of gas pipelines of a bigger diameter [13].

Metallurgical waste slag, sand, cast-iron breakage with up to 2mm fraction size as abrasive agents; compressed air, liquid fuel, compressed methane or liquefied propane is used as fuel component.

The key task in the modern development of machinery is to improve durability and reliability of assemblies and machine parts in metallurgical, chemical, oil & gas, mining, airspace, etc. industries by reducing the intensity of wear-and-tear and corrosion and by applying the thermal spraying.

The most advanced techniques for application of gas-sprayed coatings include plasma and high velocity gas flame processes [14-16].

Small-sized rocket guns with high energy capacity were first used at the ore-mining and processing enterprises in the USA and the Soviet Union. With high temperature and speed of the gas flow, they proved to be highly efficient in rock breaking, well drilling, surface treatment of granite chunks and mining the slot cuts when mining for the granite chunks.

The flow pattern in the high velocity sprays and their parameters depend on the nozzle shape, the sort of spray medium and ambient variables. According to the listed factors, it is a regular practice to group the sprays into a number of types. Based on the spray medium, distinction is made among one-phase, two-phase and three-phase sprays. Based on the nozzle shape, distinction is made among flat, axially-symmetrical and 3D sprays. Based on the stagnation enthalpy or on the structure of stagnation enthalpy or the structure of internal spray, distinction is made among low-temperature (internal energy of molecules practically consists from the energy of translational and rotational degrees of freedom), high-temperature (vibrational degrees of freedom are excited) and plasma (contribution of ionization energy is significant) sprays.

Based on the off-design (n) which is equal to ratio of the nozzle cross-section pressure to the ambient pressure, there are design ($n=1$), underexpanded ($n>1$) and overexpanded ($n<1$) sprays. Depending on the direction of the ambient motion against the nozzle, distinction is made between sprays injected into the submerged space; concurrent, counter and cross flows. Based on the tenuity, distinction is made between dense sprays and low-density gas sprays. Finally, stationary and non-stationary sprays are distinguished [17].

A high velocity spray is a non-stationary, spatially non-homogenous unstable gas formation. The gaseous environment resists the spray flow and the flow flexes warps and fluctuates. Impact and shock waves observed in the initial gas-dynamic area of high velocity spray interact with each other and the spray boundaries. When the impact waves interact in the spray itself, closed subsonic areas are formed in the flows [18].

The last decade has witnessed a rapid progress of high velocity techniques of application of powered coatings under a common English term HVOF (High Velocity Oxy-Fuel) the Russian counterpart of which is the HVGF (High Velocity Gas Flame). The sprayed materials – polymers, carbides and metals – form high quality thermal-, wear- and corrosion-resistant coatings which can sustain the effects of impact and chemically-active media and high thermal loads.

Alternatives are gas dynamic cold spraying (GDCS), detonation gun (D-gun) and plasma spraying (PS) and supersonic quenching [19].

Table 2 shows that Intelli-Jet is the most advanced installation. It does not require oxygen as the oxidizing agent or water cooling [20-21].

Table 2 – Hourly Consumption of Materials of Some Sonic Gas Flame Installations

		Intelli-Jet	JP -5000	DJ2700	Top Gun
Oxygen, m^3		–	60	18	21
Compressed air, m^3		300	–	23	–
Fuel	Type	Propylene	Kerosene	Propylene	Propylene
	Consumption, kg	30	21	17	16
Nitrogen, m^3		0.96	1.2	1.08	1.02
Cooling water, m^3		–	1	0.72	0.72

According to the review of manufacturers' data [22, 23] (Table 3), Intelli-Jet provides the highest velocity of particles and the maximum temperatures of these particles which are part of alloy matrix is by 100 degrees lower than the cobalt melting point. This features that make them different from other installations lead to reduction in oxidation of particles and allow for improvement in the spraying rate. Feedstock cost-effectiveness for Intelli-Jet means reducing 1.6–2.5 times the relative cost of coatings.

Table 3 – HVGF unit output parameters WG-10Co-Cr Sprayed material, (-45+10) mcm fractions

	Intelli-Jet	JP -5000	DJ2700	Top Gun
Average velocity of particles, m/s	775	665	570	420
Maximum temperatures of particles, K	1543	2078	2253	2573
Spraying rate, kg/h	26	12	9	2.1
Sprayed material utilization ratio, %	68	40	64	60
Spraying relative cost	1	2.5	1.6	1.7

The structure and mechanical properties of the coating depend on the temperature and the velocity of sprayed particles at the moment of their contact with the backing [24].

Supersonic spraying technique is based on continuous combustion of ignitable gas in the oxygen, while forming a supersonic spray on the gun outlet. Powdered material is introduced into the flow; it is heated up and directed at a high speed to the treated part.

The process equipment for high-velocity gas flame spraying includes a high velocity gun, a container for injected powder, control, an ignitable gas bottle and an oxygen bottle.

Coatings formed by high velocity gas flame spraying have strong adhesion, low porosity and significantly increase the service life of equipment operated in the contact with aggressive media or affected by intensive wear. They have the same or even better characteristics as the coatings sprayed with plasma tools but they are 1.5–2 less expensive.

According to GOST 28076-89, thermal spraying is grouped as follows: gas flame spray, plasma spray, plasma arc spray, high-frequency plasma spray, electric arc spray, detonation spray, controlled environment plasma spraying, dynamic vacuum plasma spraying (DVS) and melt spraying. The said GOST does not describe the supersonic spraying which has been dynamically developed for the last 10-15 years in industrially-developed countries by Cabot Corporation, Browning Engineering, Thermodyne Corporation, Perkin-Elmer Corporation (USA), UTP Schweissmaterial GmbH (Germany) and others [25].

The world's best practice of producing gas thermal coatings at supersonic velocities of the particles is called the High Velocity-Oxygen-Fuel or HVOF for short.

The Russian research institute for structural materials and processes (the Moscow State Technical University after N.E. Bauman) has developed the equipment for supersonic gas-flame spraying of wear- and corrosion-resistant coatings, reinforcement, repair and refurbishment of worn parts. A supersonic gas spray generated with special gun is used for spraying the coatings [26].

The working process in gun is similar to that in the microthruster. Due to small dimensions, the equipment can be used in field. The cost of the equipment is around ten times lower than that of foreign stationary installations. The characteristics of the coatings comply with those achieved by the best state-of-the-art plasma equipment at a lesser cost (by 1.5–2 times). The quality of the coatings is 2-3 times higher than that of of standard flame-spraying. Propane/Methane is the fuel agent and oxygen is the oxidizing agent. The velocity of the supersonic spray reaches 2,600 m/s, temperature is around 2,200 to 2,700°C. The porosity of coatings does not exceed 5% and their thickness is 0.1–5 mm. 3.5 kg gun is cooled down with running water; the ignition system is piezoelectric one.

The velocity of heated gas spray on the gun nozzle cross-section reaches 1,700 to 2,700 m/s, which allows obtaining coatings with the adhesion strength of around 100 MPa and coating porosity of 0.5%, which, in their characteristics, is close to coatings produced by detonation spraying. With the thickness of supersonic thermal coating up to 0.3 mm, there is little porosity (according to the data provided by a spraying laboratory of scientific production organisation Tularchermet) [27].

Alloys based on nickel, iron and cobalt, as well as metal carbide and self-fluxing alloys; nitrides of silicone, aluminium, chromium, boron, etc. are used as powdered materials in the supersonic thermal spraying.

The authors have designed a unit for application of thermal coatings applied with supersonic high-temperature gun. The general view of the proposed unit for application of thermal coatings is schematically represented in figure 6 [28].

Also, they have offered a gas-flame spraying of metal powders allowing for increase in strength of adhesion of the spray to the base [29].

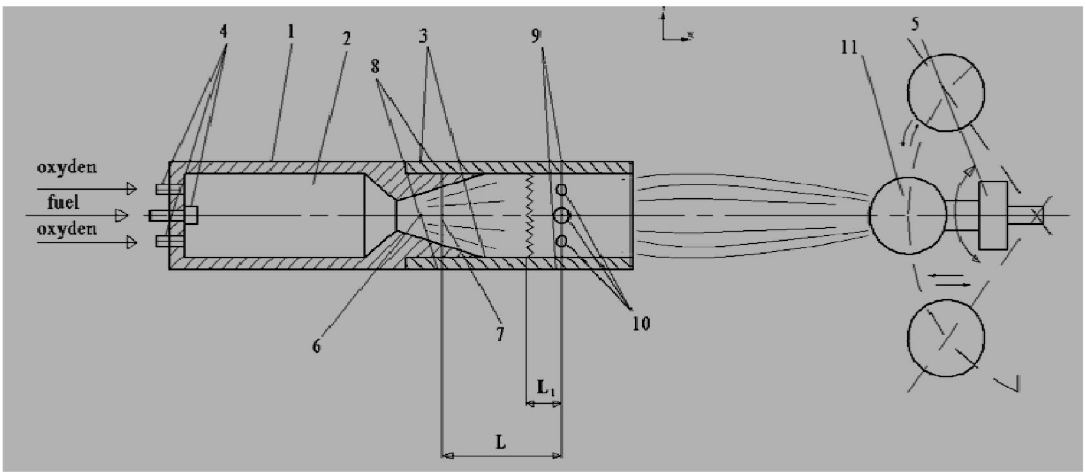

Figure 6 – Unit for application of gas thermal coatings:
1 – combustion chamber, 2 – gas-jet gun, 3 – cylindrical top, 4 – three-channel adjuster, 5 – treated parts handler, 6 – gas-flame gun nozzle, 7 – lengthwise relative cross-section L, 8, 9 – holes, 10 – ring diffuser, 11 – workpiece

Figure 7 shows the described gas-flame spraying of metal powders.

Also, the pipes surface cleaning method and unit were designed to increase efficiency and to expand technological capabilities of cleaning the pipes off the insulation cover [30].

Pipe surface cleaning includes formation of a resilient gas spray and delivering the kinetic energy thereto. This energy is sufficient for destruction of strong materials. Cleaning is carried out consistently, i.e. initially, by using a resilient steam/gas spray that is formed by adding a certain amount of water to a high-speed, high-temperature gas spray. The volume of water determined based on the temperature of the

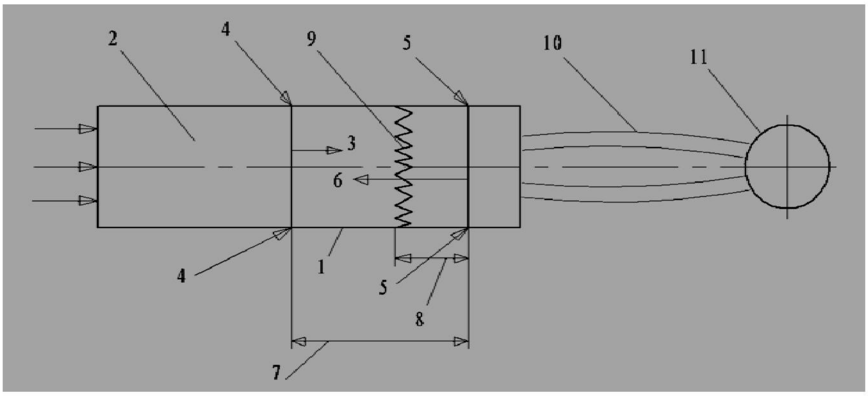

Figure 7 – Schematic diagram of the unit for metal application of flame-sprayed metal powders:
1 – combustion chamber, 2 – heating/burning zone in the combustion chamber, 3 – main spray from the combustion chamber,
4 – feed of sprayed powder, 5 – feed (ejection) of oxidant (the ambient air), 6 – external spray,
7 – the set length of active zone of the main spray, 8 – the set length of the shock-wave formation,
9 – shock wave front (compression wave), 10 – spraying flow, 11 – base for coating formation

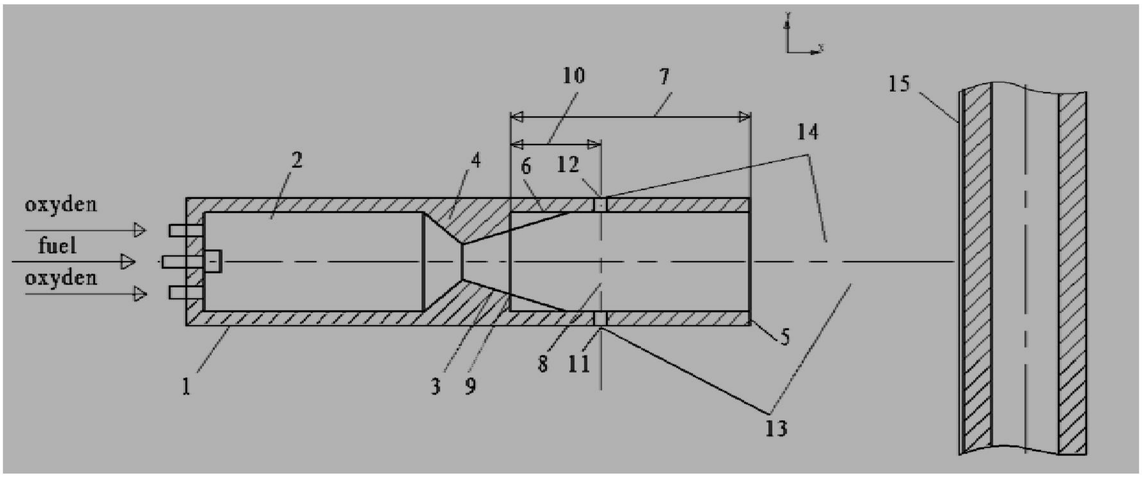

Figure 8 – Sand-blasting unit for cleaning of pipe surfaces:
1 – combustion chamber, 2 – internal contour, 3 – central supersonic nozzle, 4 – external contour,
5 – external nozzle, 6 – extension piece, 7, 10 – the set length, 8 – discharging zone, 9 – section,
11, 12 – channels, 13 – resilient gas/steam spray, 14 – another gas spray, 15 – coating on the treated pipe

Figure 9 - A fragment of introduction into the torch flame to form steam/gas mixture

minimum adhesion of the covering to the pipe surface. Then further cleaning and processing are continued with another gas spray formed by injecting an abrasive mix into the resilient jet.

Figure 8 shows a sand-blasting unit for cleaning the pipe surface.

Figure 9 shows a fragment of creation of torch steam/gas jets used for cleaning of a surface of gas pipes and in processing and cutting the granite rocks.

3. Conclusions.

- the device of the machine equipped with a powerful thermodynamic working organ is developed, which will allow to produce slotted workings, providing an even move of the machine, both in horizontal and vertical directions;
- a review of the application of high-speed and high-temperature gas jets realized in various technological processes (high-speed gas-flame spraying), i.e. a gas-thermal method of applying hardening coatings to the surface;
- further development of gas-flame technologies will allow creating equipment for destruction of insulating coatings of oil and gas pipes during their repair and surface preparation for application of new coatings;
- the conducted experiments showed their expediency and economical efficiency for the destruction of rocks in the course of slit workings.

REFERENCES

[1] Sinelnikov O.B. Natural Facing Stone Quarrying. RAAS Publisher, 2005, p. 244-249.

[2] Levkovskiy G.L. A.S. USSR No. 1789687. Technique for Natural Stone Block Quarrying. Vol. 3, 1993.

[3] Voluyev I.V., Sychev Yu.I., Tkach V.R. Waste-Free Technology for Natural Stone Quarrying and Dressing. Depths, 1994, p. 180-192.

[4] Grigorovich M.B. Deposits of Minerals for Building Materials Industry. Depths, 1987, p. 144-149.

[5] Orlov A.M. Natural Stone Quarrying and Dressing. Stroyizdat, 1977, p. 349-357.

[6] Kosolapov A.I. Facing Stone Quarrying Technology. Krasnoyarsk KrSU Publisher, 1990, p. 192-210.

[7] Dmitriyev A.P., Goncharov S.A. Thermal and Combined Destruction of Rocks. Depths, 1978, p. 304-311.

[8] Goldayev I.P., Fursov A.P. Engineering evaluation technique for air-burning torches of thermal tools. News of Higher Educational Institutions. Mining Journal, Vol. 4, 1972, p. 76-81.

[9] Povetkin V.V., Askarov Ye.S., Povetkin A.V., Shukhanova Zh.K. The RoK Innovation Patent No. 29758. Thermal Cutter for Stone Cutting with Two Nozzles, Vol. 4, 2015, p. 85-95.

[10] Povetkin V.V., Askarov Ye.S., Povetkin A.V., Kerimzhanova M.F. The RoK Innovation Patent No. 30458. Device for Vertical Feed of Pipe with Thermal Cutter for Stone Cutting, Vol. 10, 2015, p. 35-46.

[11] Bukayeva A., Povetkin V., Kerimzhanova M., Tatybayev M. High velocity thermal spraying tools used in technological processes and productions // Journal of Vibroengineering Procedia, Vol. 10, 2016. p. 474-479.

[12] Klimov P.V., Baishuakov A.A., Povetkin V.V. New technical solutions for repair of trunk pipelines // Oil and Gas, scientific and technical journal. Almaty, 2006, p. 89-95.

[13] Veyulin I.I., Gusev V.A., Spirin V.A. Povarov O.V. Supersonic thermal spray technologies for gas pipeline cleaning // Gas industry. Vol. 4. 2003, p. 60-62.

[14] Kalita V.I., Baldayev L.H., Lupanov V.D., Shatov A.P. Modern thermal spraying equipment and coatings // Svar-schik-professional. Vol. 3. 2005, p. 14-15.

[15] Baldayev L.H. Renovation and reinforcement of machine parts by thermal spraying KHT, 2004, p. 134.

[16] Korobov Yu.S. Prolongation of parts service life by supersonic flame spraying // Heavy mechanical engineering. Vol. 7. 2006, p. 34-38.

[17] Dulov V. G. Supersonic gas jets. Novosibirsk, 1983, p. 202.

[18] Isaeva L.A. Application of supersonic currents in technological process of hardening // A compilation of works of 13th workshop on jet, detachable and non-stationary flows devoted to fundamental and applied issues of mechanics of continous environments. Tomsk, 2012, p. 169-172.

[19] Korobov Yu.S. Comparative analysis of supersonic gas-flame techniques for application of coatings // Gas turbine technologies. Vol. 6. 2005, p. 38-40.

[20] Kharlamov Yu.A. Thermal spraying of coatings and environmental friendliness of manufacture, operation and repair of machines//Heavy mechanical engineering. Vol. 2. 2000, p. 10-13.

[21] Nestler M.C., Erning U. Characteristics and advanced industrial applications using the «Diamond Jet Hybrid» – the third generation of HVOF systems// Films and coatings'98. St'Petersburg, Vol.5. 1998, p. 195-202.

[22] Verstak A., Baranovski V. Activated Combustion HVAF Coatings for Protection against Wear and High Temperature Corrosion//Thermal Spray 2003: Advancing the Science and Applying the Technology. Proc. of the ITSC. ASM Publication. Vol. 1. 2003, p. 58-63.

[23] Kreye H. A Comparison of HVOF Systems-Behavior of Materials and Coating Properties // 4th HVOF Colloquium at Erding/Munchen-Bavaria-Nov 13-14. 1997, p. 13-21.

[24] Baldayev L.H., Shesterkin N.G., Lupanov V.A., Shatov A.P. Features of high velocity flame-spraying // Welding production. Vol. 5. 2003, p. 43-46.

[25] Khromov V.N., Vertsov V.G., Korovin A.Ya. etc. From subsonic to a supersonic flame-sprayed coverings in refurbishment and hardening of machine parts // Welding production. Vol. 2. 2001, p. 39-48.

[26] New technologies and equipment at the Intertool-98 exhibition//Tractors and farm machinery. Vol. 2. 1995, p. 48.

[27] Korovin A.Ya., Abashev N.G., Khromov V.N. Experience of the municipal enterprise Orelelektrotrans in parts refurbishment with flame-sprayed coverings: Materials of the scientific and practical conference "State and Prospects of Refurbishment, Hardening and Manufacture of Machine parts". State threads, 1999, p. 74-77.

[28] Baishuakov A.A., Povetkin V.V., Povetkin A.V. Unit for application of thermal-sprayed coatings. Preliminary patent No. 15419-2004 (Request No. 2003/730.1 of 30/05/2003).

[29] Baishuakov A.A., Klimov P.V., Povetkin V.V. Flame spraying of metal powders. Preliminary patent No. 15177-2004. (Request No. 2003/0581.1 of 28/04/2003).

[30] Baishuakov A.A., Povetkin V.V., Klimov P.V. Pipe cleaning technique and unit. Preliminary patent No. 14999-2004 (Request No. 2003/0627.1 of 12/05/2003).

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ТЕХНОЛОГИЯЛЫҚ ПРОЦЕСТЕ ЖӘНЕ ӨНДІРІСТЕ ЖОҒАРЫ ДЫБЫСТЫ ТЕРМОАҒЫНДЫ ИНСРУМЕНТТЕРДІ ҚОЛДАНУЫН ЗЕРТТЕУ

Аннотация. Мақалада тас кескіш механикаландырылған агрегатты жұмыс органы ретінде жақсартылған энергетикалық сипаттамалары бар және оларды қолдануға болатын, тас блоктарды өндіру және өңдеу кезінде тау жыныстарды бұзу үшін жаңа термоинструмент конструкциясын жасау сұрақтары қарастырылған. Сондай-ақ, машина бөлшектер бетіне төзімді қабатты жағуда газ жалынды процестер қарастырылған. Құбырлар бетін тазалауда серпімді газ-бу ағыны алу үшін қатты бөлшектердің (абразивті немесе су) ағынын жүргізуде, мұнай-газ құбырлар қаптамасын оқшаулағыш алуда және оларды пайдалану, жоғары дыбысты жоғары температуралы ағынды қолдану аясы кеңейтілген.

Түйін сөздер: тау жыныстар, термоинструмент, бензин-ауалы жанарғы, тас кескіш машина, отын компоненттері (бензин, керосин, ауа), жоғары дыбыс ағыны, жану камерасы, мұнайгаз құбырлары.

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ИССЛЕДОВАНИЯ ПРИМЕНЕНИЯ СВЕРХЗВУКОВЫХ ТЕРМОСТРУЙНЫХ ИНСТРУМЕНТОВ В ТЕХНОЛОГИЧЕСКИХ ПРОЦЕССАХ И ПРОИЗВОДСТВАХ

Аннотация. В статье рассмотрены вопросы создания новых конструкций термоинструментов для разрушения горных пород при обработке и добычи блочного камня, обладающими повышенными энергетическими характеристиками и их применения в качестве рабочего органа, механизированного агрегата камнерезной машины. Также рассмотрены газопламенные процессы нанесения износостойких покрытий на поверхности деталей машин. Расширением области применения сверхзвуковых высокотемпературных струй является применением их для снятия изоляционных покрытий нефтегазовых труб, с ведением в струю твердых частиц (абразивного материала или воды) для получения упругой парогазовой струи для очистки поверхности труб.

Ключевые слова: горная порода, термоинструмент, бензовоздушная горелка, камнерезная машина, топливные компоненты (бензин, керосин, воздух), сверхзвуковые струи, камера сгорания, нефтегазовые трубы.