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Genesis of the Explosive Stamping Goals and Objectives (to the 70th Anniversary of One Scientific School of the KhAI)

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The paper is devoted to development of one of the scientific schools Kharkiv Aviation Institute (Now National Aerospace University named after M. E. Zhukovsky “KhAI”). This school was born after World War II quite hard after period of National economy restoration and now it continues to develop during last 70 years. The article deals with the origins and genesis of objectives and tasks formulated for think tank and followers during dozens of years. Influence of the world geopolitics on development of mentioned scientific school and reached results is shown. From relatively primitive goals and tasks formulated by R. V. Pikhtovnikov in 1949 up to complicated problems of controlling of impulse energy flows to get high-precision large-dimensional sheet articles. From development of simple manufacturing process conducted in field conditions up to creation of up-to-date manufacturing complexes with correspondent buildings, equipment and technological jigs.

Paper draws attention that successful development of scientific school and international expansion of labor market were stipulated by governmental support, both financial and organization ones. Paper shows results of technological systems development. Defefinite analogy with development of biological systems can be observed, i.e. evolution from the simplest to more complicated under influence of external factors.

One has to note that paper deals with development of only one direction of scientific school, i.e. sheet articles forming. Research and development of such two other directions as impulse forming by impact of solid and impulse volumetric forming are waiting for their researchers. Authors of the paper tried to escape of conventional approaches of scientific schools description and concentrated on studying of objectives and tasks occurred in frames of considered scientific school. Therefore, the paper doesn’t mention many names of scientific advisors of different directions, titles of exact studies and topics, which involve crucial contribution in achievements of mentioned scientific school.

Keywords**:** explosion, high explosives, electric discharge, stamping, sheet parts, high technologies.

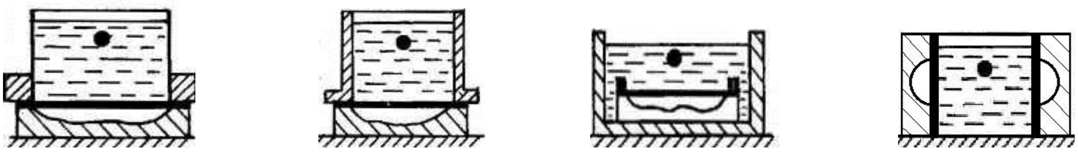
The Problem

In the spring of 1949the Head of the Aircraft Engineering Department of the Kharkiv Aviation Institute R. V. Pikhtovnikov filed applications for inventions of a method and device for processing metals with explosive energy and, on his own initiative, the first studies of the technological possibilities of this proposal began. The following aspects were evaluated: types of explosives–brisance, propelling (gunpowder), combustible gases; schemes for transferring energy from the explosives volumes to the subject of processing; the choice of the processing subject and similar questions. In their work, the team faced great difficulties – lack of materials, experience and other conditions, but was full of enthusiasm. R. V. Pikhtovnikov and his associates were attracted by the possibility of using the large energy stored in a small volume of explosives, and, accordingly, high pressures for shaping large and heavy parts.

It should be noticed that this was a period of active revival of the country's industrial potential destroyed by the war and, in particular, aircraft construction. Large aircraft were in demand for the transport of heavy cargo over long distances. In addition, this required the appropriate technology and equipment. The factor of the "cold" war and the possible dispersal of production also should be taken into account. This gave rise to the idea of the priority development of the "field" stamping technology. It provided for the creation of open landfills for blasting operations outside the city. The landfills could be equipped with the simplest technological equipment and stamping equipment, including concrete. They had to consume a minimum amount of electricity and be very mobile.

Main Part

To carry out such work, the simplest standard schemes (Fig. 1) with disposable pools (Fig. 1, *a*) made of thick paper or cardboard (plywood) were developed. They were installed directly on a flat workpiece. The cavity of the pool was filled with water, and a charge of high explosive was suspended on the guy wires. After the production of such an explosion, the workpiece beard against the matrix, the pool collapsed and the transmission medium (water) was scattered on the sides. This option was quite acceptable when working out the technical process, but little acceptable even for the manufacture of small batches of parts. The increased consumption of disposable pools and water as a transmission medium has greatly increased the cost of the manufacturing process.



a *b* *c* *d*

Figure 1 – Typical schemes of explosive stamping from sheet blanks:
a – with a one-time destructible pool, *b* – with a removable pool, *c* – with stationary pool; *d*–stamping-distribution

For larger parts (more than 500 mm in diameter), it is rational to use removable pools (Fig. 1, *b*). However, even in this case, an increased water consumption, a significant time for filling the cavity of the pool with it lengthen the process.

A more rational scheme is using a stationary pool (Fig. 1, *c*). In this case, the installation of the work piece on the matrix, pressing its flanges to the matrix and installation of the charge (charge system installation) are carried out in an open space. The prepared equipment is lowered onto the sabot plate into the pool filled with water with the help of lifting mechanisms. An explosion is made; the rig is reinstalled on an open area and disassembled.

In the simplest case, the sealing of the matrix cavity and the junction of the disposable or removable pool with the equipment was carried out using plasticine. Before the explosion, the cavity of the matrix was evacuated to values of 0.4 ... 0.6 atm. For this, a vacuum pump with a large-volume receiver was located on the working platform.

The use of such schemes did not limit the dimensions of the stamped parts. Stationary pools were made with a diameter of 2.0 ... 8.0 m (at different enterprises).

Initially, for pilot and individual production, the simplest equipment was used, made of concrete, sometimes it was faced with glass cloth impregnated with cold curing epoxy resin.

For the conditions of pilot and individual production, these schemes have shown their efficiency and effectiveness.

By the way, at the end of the 80s of the last century, the president of one of the three American "explosion factories" visited KhAI and demonstrated the production conditions they used - the same open areas, threaded or wedge mechanisms for flange clamps and similar manufactured parts.

In 1953, in his doctoral dissertation, R. V. Pikhtovnikov substantiated and outlined the ways of development of stamping-drawing and covering by explosions. In the conclusions of the work, it was emphasized that the use of explosive energy carriers is very effective and all pulse technologies are promising for the manufacture of large-sized parts. The defense of the thesis was postponed for a long time due to the lack of opponents on the topic. This testified to the novelty of the work topic.

As a result of the analysis of the explosion processes flow and the energy transfer to the object of processing and numerous experiments, it became clear that it is rational to use high explosives for sheet metal stamping with the transfer of released energy to a large area of the workpiece through the transmission medium (water, sand, elastic materials); propelling explosives (gunpowder, combustible gases) - for throwing a solid tool and its impact on the object being processed. However, in this process, two options are possible:

– direct action of the tool on the workpiece, for example, for cutting metal;

– throwing a projectile that, striking the water, creates increased pressure in it (hydraulic shock), which is used to deform the sheet blank.

The development and research of the processes of knife throwing by a gas explosion led to the creation of well-known machines for impulse cutting of hot and cold alloys, large section rolled products, and chip pressing.

Research into the processes of projectile throwing and the occurrence of hydraulic shock made it possible to create widely used powder press guns. Their first model began to be applied at the KhAI in 1960, and the further development of this direction made it possible to create a large series of press guns used for stamping pipe billets up to 300 mm in diameter.

Impulse stamping of sheet blanks has shown its effectiveness and no alternative in several directions. One of the major users of such technologies has become engine factories that manufacture air-jet engines, gas turbines and liquid-jet engines. Serially and large-scale manufactured casings have overall dimensions of 300 ... 2000 mm with various types of pockets, rifts and other local elements. Such production cannot be carried out in open landfills and depend on the weather. Building special workshops task arose.

In the other direction - stamping by explosion of large-sized flat sheet blanks, the "field" technology has justified itself.

The most striking and indicative is the technological process of manufacturing a batch of parabolic reflectors with a diameter of 5000 mm from steel 1X18H10T (Fe; C 0,07-1; Si ≤ 0.8; Mn 1-2; S ≤ 0.02; P ≤ 0.035; Cr 17-19; Ni 10-11; Ti (5C-0.7)) with a thickness of 5 mm for the Central Research Institute "Morfizpribor" (Fig. 2). The reflector was made at an experimental site organized in a forest near Leningrad. A concrete matrix lined with fiberglass composite material was used as a tooling. In the act of work performed, it is written that the technical and economic effect of using explosive technology is 65 thousand rubles (compared to the manual method) with a very high quality (accuracy) of parts. To manufacture them in the traditional way, a press with a force of 70,000 tons would be required.

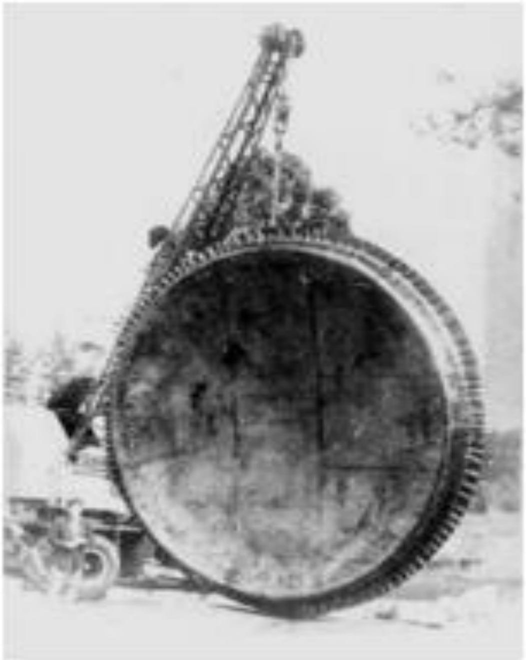


Figure 2– Explosion-stamped parabolic reflector, diameter 5000 mm

At the Zhdanov (now Mariupol, Ukraine) plant of transport engineering, the production of bottoms and partitions for railway cisterns was organized. These parts with a diameter of 3.6 m and a thickness of 16 mm were stamped by explosion on an experimental open ground.

For one of the enterprises in Krasnodar (Russia), batches of tubular elastic deformation compensators (bellows) with a diameter of 500 mm and 800 mm were stamped from multilayer aluminum shells.
Minimum capital costs, simple composition of the technological process, practically unlimited energy capabilities and the great interest of industrial enterprises, especially the military-industrial complex, in the manufacture of large-sized sheet parts from high-strength difficult-to-work materials contributed to the beginning of the widespread introduction of explosive stamping. Explosive stamping technologies were introduced at the enterprises of Minaviaprom, Minsredremash, Minobschemash, the Ministry of Defense Industry, the Ministry of Transport Engineering, in the cities of Moscow, Leningrad (St. Petersburg), Voronezh, Zhdanov (Mariupol), Kyiv, Kharkov, Krasnodar, Mykolaiv, Pavlograd, etc. In 1965, the real economic effect amounted to more than 840 thousand rubles, and the expected economic effect from the expansion of the use of this technology approached 12 million rubles

There remained a large nomenclature of parts of relatively small curvature made of aluminum and titanium alloys up to 2.5 mm thick, the prospects for mass production by explosion of which were unclear. At the enterprises of Minaviaprom, such parts began to be produced on electrohydraulic presses of the PEG type produced by the Savelovsky Machine-Building Plant. In the production of medium-sized parts, they showed their effectiveness, but when manufacturing parts with overall dimensions of 1 m or more, difficulties arose associated with insufficient power-to-weight ratio and, consequently, low resistance of working electrodes.

In 1963, by the Resolution of the Council of Ministers of the Ukrainian SSR, a problem scientific and technical laboratory for the use of pulsed energy sources in industry (PNIL) was organized at the KhAI. It consisted of three departments under the scientific leadership of professors R. V. Pikhtovnikov, V. G. Kononenko, and Yu. N. Alekseev.

During this period, it became clear that explosive technologies should not be carried out in the field, but under conditions of mass production in special rooms and regardless of the weather.

In the mid-60s, KhAI was subordinated to the USSR Ministry of Higher and

Secondary Education. PNIL fell under the control of the USSR State Committee for Science and Technology. At the same time, a Resolution of the Party and the Council of Ministers of the USSR was issued on the intensification of research and the introduction of impulse technologies into production in the main industries. State support for these works began. Financing was opened for the construction of workshops and stamping areas by explosion at a number of industrial enterprises (Zaporizhzhia, Mykolaiv, Rybinsk, etc.), at a heavy tractor machine building plant (Zhdanov, now Mariupol).

By the beginning of the 70s, plans for the construction of workshops were largely implemented. However, a new task has emerged - protecting the structures of workshops from the harmful effects of an explosion (emissions of large amounts of water on the floors of workshops (sultan), seismic impact on the environment), and acoustic impact on workshop personnel. The problems that arose were gradually solved and the shops worked successfully, producing up to hundreds of thousands of parts per year (Motor Sich, Zaporizhzhia).

The shells of complex shape with all sorts of stampings, rifts and pockets turned out to be of excellent quality and practically did not require manual revision. The ends were trimmed to size using mechanical equipment. The shell materials were varied: aviation aluminum and titanium alloys, high-strength steels and heat-resistant alloys (Fig. 3).

Figure 3 – Exploded shell-type parts

Manufactured by stamping explosion shells are characterized by low cost price, high reliability under the influence of vibration loads, dimensional accuracy and surface quality. Their production expanded and the task of automating the design of technological processes and their optimization for various target functions and, first of all, expanding the technological capabilities of the process and increasing the durability of the tooling began to appear.

After the death of R. V. Pikhtovnikov, V. K. Borisevich defended his doctoral dissertation in 1979, substantiating the need to control impulse loading in terms of intensity and its optimization and became the scientific supervisor of NIL-1 (divisions of PNIL).

Figure 4 – Box-type cab parts for industrial tractors

Since the end of the 60s of the last century, PNIL has been conducting research in the direction of expanding the possibilities of using explosive stamping for the production of different types of sheet parts - bottoms, box-shaped parts (Fig. 4), one and a half, small and bent profiles, batch deformation of complex parts (Fig. 5). Most of the developed processes were introduced into production

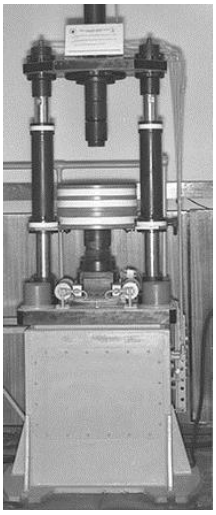
Figure 5 – Sheet parts with overall dimensions of more than 1.5 m, obtained by explosion

The limitation of the mass of propellant charges placed in a special cartridge and the sufficient strength of the barrel made it possible to simplify safety requirements (in comparison with the explosions of high explosives) and to operate the press cannons in the workshop, but in a separate room. This has created the conditions for their widespread use at numerous factories in the country for stamping parts from tubular blanks, glasses (Fig. 6), as well as for the implementation of original deformation processes (expansion, bending of pipes and small radii, assembly of tubular hinges, etc.).

The peculiarities of the explosion of gunpowder made it possible to mechanize and further automate the stamping processes on press guns.

A group of researchers designed explosive devices for operation in a workshop (vacuum chambers, blasting presses). These works were aimed at changing the conditions for carrying out blasting operations for stamping from "field" conditions to workshop and serial. The creation of blasting presses was hampered by the low durability of blasting chambers and the rules of safe work.

The problem of a rather low efficiency of stamping of thin sheet large-sized parts on electro-hydraulic presses, widely used in the aviation industry, was partially solved as follows.

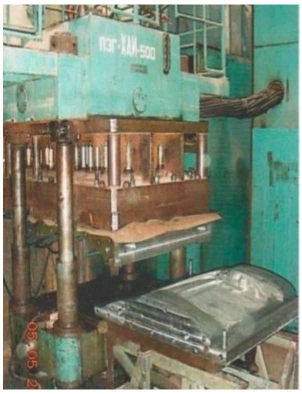


a

b

Figure 6 – Powder press cannon without breech (*a*) and samples of parts, stampedonit (*b*)

In 1979, Yu. I. Chebanov and M. E.Taranenko and co-authors applied for an inventor's certificate "Device for EGS", in which the EG discharge was carried out on several electrodes. Was received a patent of Ukraine for invention No. 4702, publ. 28.12.94, bull. 7-1. Later, on the basis of it, a unique EG-press with a stored energy of up to 500 kJ PEG-KhAI-500 was created, which implemented the space-time control of loading the workpieces (Fig. 7). This press was used to test the technologies of sequential stamping of large-sized parts of various types: car body panels, high-precision parabolic antennas for space communications, stiffening panels for aircraft structures and heat exchanger panels, parts for transport systems of bulk products and other parts.

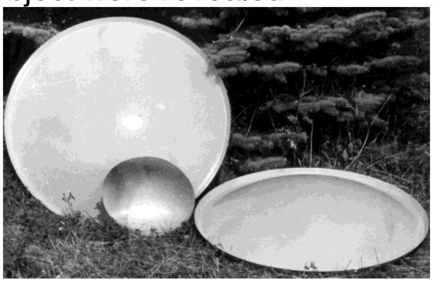


Technica lspecifications	
storedenergy, kJ	up to 500
number of discharged circuits, pcs.	28
operating voltage, kV	up to 40
workin gareasize, mm	1130×1580
height of stamping space, mm	650
average cycletime, s	280
rational thickness of stamped blanks, mm: - steel - aluminumalloys	 up to 1,5 up to 2,5

Figure 7 – PEG-KhAI-500 press

The fundamental difference of such a press, in addition to the large stored energy (500 kJ is equivalent to ~ 100 g of ammonite 6 GV), is the ability to control the place of sequential loading of the workpiece in sections and the spectrum of the generated pressure of the loading pulse. Quite broad possibilities of loading control make it possible to stamp complex parts in shape, accuracy, geometry and with a high degree of relaxation of residual stresses (much less warpage) Fig. 8.

With further studies of the possibilities of time-based control of loading, new potentially attractive features of a powerful vibration-impulse effect on the processing object were revealed.


a


b


c

Figure 8 – Appearance of parts made on the PEG-KhAI-500 press:
a – high-precision parabolic mirrors of space communication antennas with a diameter of 900 mm; *b* – an element of the pneumatic transport system of bulk products; *c* – fender of the car VAZ 2106

This effect leads to relaxation of residual stresses or a sharp increase in the accuracy of the shape of the part and a decrease in its warpage.

The high accuracy of the working surface of the space communication antenna mirrors was obtained by shaping them by an explosion. So the amplification coefficients for the corresponding diameters were: Ø 900 mm - 40.7 ± 1.25 dB, Ø1200 mm - 43.3 dB and Ø1500 mm - 44.8 dB. Mirror material - aluminum alloy D16 AM of 2.0 mm thick. Such high quality indicators specify the minimum degree of warping (spring back) of the mirror. The resulting effect is largely due to the chosen sequence of shaping - stamping was carried out in two transitions. At the second transition, the loading mode was chosen so that the workpiece hit the matrix at a certain speed. This creates some disturbance in the structure of the metal of the workpiece. Research in this direction should be continued, but now we can talk about the beginning of the formation (construction) of functionally oriented technologies.

It is becoming clear that technological genesis of a deeper level require high pressures and short duration of their action. To this must be added the studied possibility of controlling the parameters of the explosion in space and time.

It should be emphasized that the time scale of the loading factors corresponds (is close) to the periods of wave (oscillatory) processes of plastic deformation propagation. The amplitude parameters are commensurate with the forces of interaction between the elements of the crystal lattice.

Based on these prerequisites, the idea arises of the need to use these correspondences for the implementation of better transformations at the micro- and nonstructural levels.

The development of the scientific school of impulse pressure treatment was dealt two tangible blows: the breaking of ties with our colleagues and customers, as well as the Resolution of the Government of Ukraine on toughening the rules for conducting blasting operations. Today an electrohydraulic laboratory equipped with two EG-presses continues to work at NAKU "KhAI" and the explosive technologies are being researched in two areas - at the Motor Sich enterprise (Zaporizhzhia) and at the Kremenchuk Mykhailo Ostrohradskyi National University (Kremenchuk) under the scientific guidance of prof. V. V. Drahobetskyi.

The development of pulse processing methods is moving towards the creation of combined processes. In such processes, cladding, forming, hardening, sintering, pressing, etc. occurs as a result of the simultaneous interaction of two or more stages of loading, which are carried out according to their own mechanisms. Separation in time is extremely small (within hundreds of microseconds). Separation in space and technological equipment, rigidly connecting the processing processes, correspond to traditional combined technologies. Combined processes of stamping and explosion welding, welding and hardening by explosion, hardening and welding by explosion, hardening by traveling and converging shock waves, additional pulsed loading with sintering of powder materials and casting have been implemented.

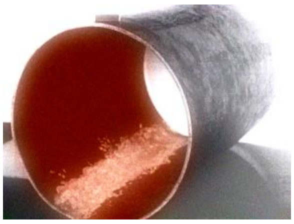


Figure 9 – Multilayer part made by explosive cladding

The possibility and technical and economic efficiency of combining the processes of stamping and explosion welding to obtain spatial parts from sheet layered workpieces has been scientifically substantiated (Fig. 9). Models have been developed for the dynamics of elastoplastic deformation of laminated workpieces pre-welded by explosion, a package of monolithic workpieces when combining the operations of welding and punching by explosion, calibration of a multilayer wall of layered spatial products. The models take into account the inhomogeneity of the mechanical characteristics over the thickness of each component of the layered workpiece, welded by the explosion, and the thermal effects when combining the processes of welding and stamping by explosion.

The influence of the impact interaction of the workpiece with the wall of the matrix on the geometric parameters of the resulting polyhedral pipe is established and an explanation is given to the fact of the absence of local thinning in radius transitions.

A model for the dynamics of elastic-plastic deformation of thick-sheet workpieces was further developed, taking into account the impact interaction of the workpiece element with the matrix, intensive hardening of the copper alloy and optimization of loading parameters.

Figure 10 – Mouldtube

Technological parameters of forming multifaceted pipes (Fig. 10) by methods of metal forming by pressure have been compiled and it has been established that the process of hydroexplosive stamping is superior to traditional methods of forming in terms of quality indicators at significantly lower costs for technological equipment.

An industrial highly efficient technology for the production of cutting, destructive and shaping tools from tungsten-cobalt and tungsten-nickel alloys by direct regeneration of secondary raw materials has been developed. The technology fundamentally differs from the existing ones in high technical and economic indicators, productivity, low energy consumption and environmental friendliness.

The fundamental possibility of using shock-wave treatment as a factor stimulating the processes of destruction of powder products of any configuration in order to obtain high-quality powder for further molding, sintering and production of tools for various purposes has been established. An ecologically clean technology for processing super hard materials, cermet components of outdated military equipment and various types of ammunition has been proposed.

The reserves for increasing the wear resistance of explosion-hardened parts consist in optimizing the parameters of the hardening process and developing combined processing technologies. Thus, the processes developed schemes of the method of combined hardening of excavator bucket teeth (hardening by an overhead charge for hardening by shock waves from collision with a thrown plate) provide high productivity.

The given results indicate the possibilities of transition to a deeper level of technological transformations under explosive loading.

A schematic representation of goals, objectives and directions of development is shown in the diagram (Fig. 11). It can be seen that the emerging needs were satisfied.

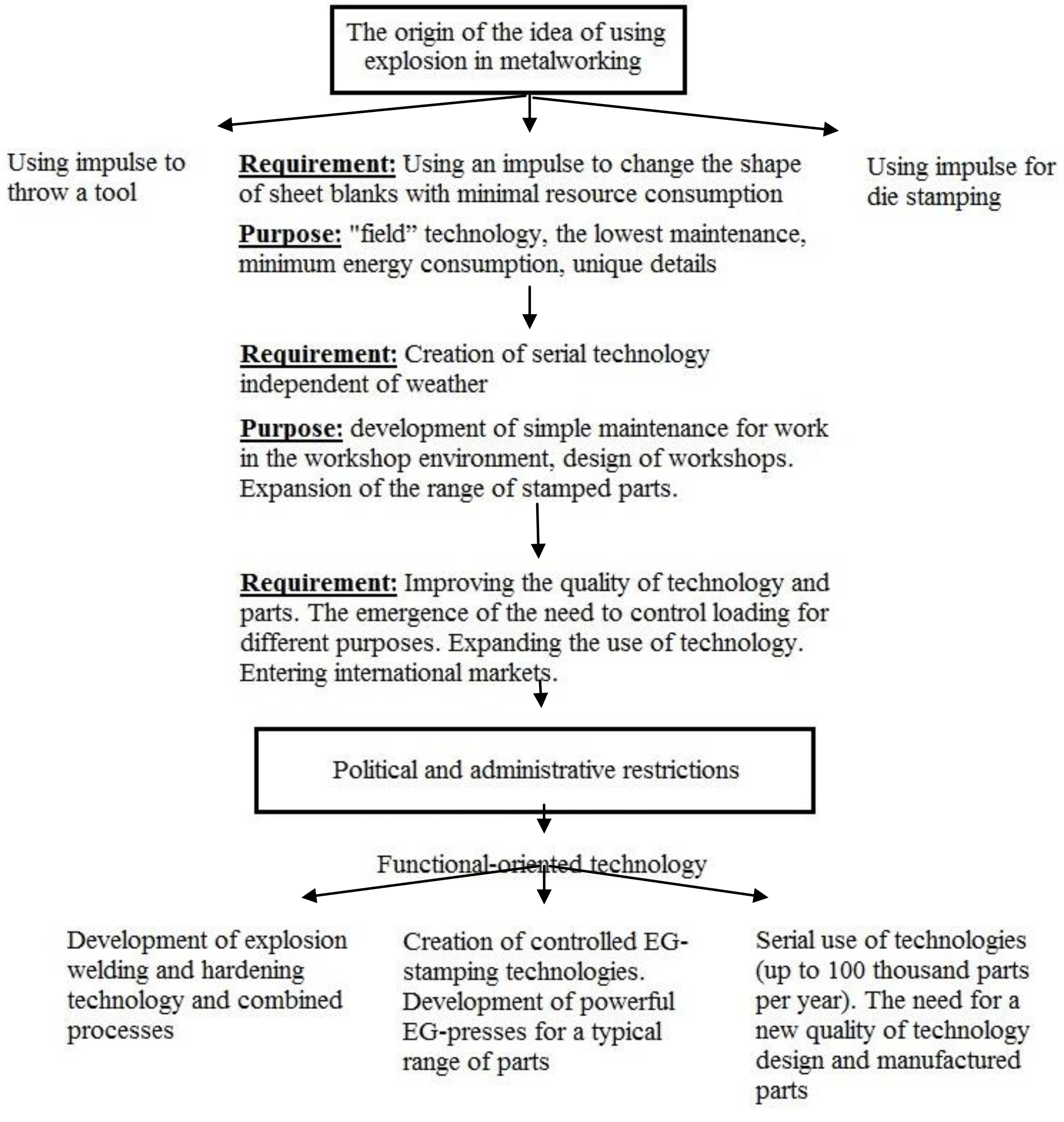


Figure 11 – Scheme of genesis of goals and objectives of explosive processing research

Conclusion

Based on the foregoing, it is clearly seen that impulse technologies have a great potential for development and improvement, can be used on Earth and in space (as R. V. Pikhtovnikov dreamed of), to adapt to different production conditions and increasing requirements for its quality. In general, it is absolutely clear that the scientific school, despite the difficulties, continues to develop: it covers the quality of manufactured parts, it adapts plastically to the requirements of production.

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Генезис цілей і завдань вибухового штампування (до 70-річчя однієї з наукових шкіл ХАІ)

Стаття присвячена розвитку однієї з наукових шкіл Харківського авіаційного інституту (нині Національний аерокосмічний університет імені М. Е. Жуковського «ХАІ»). Ця школа народилася після другої світової війни, досить важко після періоду відновлення національної економіки, і зараз вона продовжує розвиватися протягом останніх 70 років. У статті йдеться про походження та генезис цілей та завдань, сформульованих для аналітичного центру та послідовників протягом десятків років. Показано вплив світової геополітики на розвиток зазначеної наукової школи та досягнуті результати. Від відносно примітивних цілей і завдань, сформульованих Р. В. Піхтовніковим у 1949 р., до складних задач управління потоками імпульсної енергії для отримання високоточних великорозмірних листових деталей. Від розробки простого виробничого процесу, що ведеться в польових умовах, до створення сучасних виробничих комплексів з відповідними будівлями, обладнанням та технологічними елементами.

Документ звертає увагу, що успішний розвиток наукової школи та міжнародне розширення ринку праці зумовлені державною підтримкою, як фінансовою, так і організаційною. У роботі наведені результати розвитку технологічних систем. Можна спостерігати певну аналогію з розвитком біологічних систем, тобто еволюція від простої до складнішої під впливом зовнішніх факторів.

Слід зазначити, що у статті йдеться про розвиток лише одного напрямку наукової школи, тобто формування листових виробів. Дослідження та розвиток ще двох таких напрямків, як імпульсне формування під впливом твердого тіла та імпульсне об'ємне формування, чекають на своїх дослідників. Автори статті намагалися відійти від загальноприйнятих підходів опису наукових шкіл і зосередилися на вивченні цілей та завдань, що відбуваються в рамках розглянутої наукової школи. Тому у статті не згадується багато прізвищ наукових керівників різних напрямків, назв точних досліджень та тем, які мають важливий внесок у досягнення зазначеної наукової школи.

Ключові слова: вибух, бризантні вибухові речовини, електричний розряд, штампування листових деталей, високі технології

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