Ljubinko Janjušević

MIHAILO PETROVIĆ'S WORK ON DEVELOPMENT OF MILITARY STRUCTURES AND EQUIPMENT

RAD MIHAILA PETROVIĆA NA RAZVOJU VOJNIH KONSTRUKCIJA I OPREME

Originalni naučni rad / Original scientific paper
UDK /UDC: 623(497.11)
51:929
Rad primljen / Paper received: 10.08.2018

Adresa autora / Author's address:
University of Belgrade, Innovation Centre of the Faculty of Mechanical Engineering, Belgrade, Serbia

Keywords
- range finder
- automatic transmission
- ballistics
- gun barrel

Ključne reči
- daljinometar
- automatski menjač
- balistika
- puščana cev

Abstract

Analysed are the developments of military equipment and the impact of Mihailo Petrović's inventions on them. Great contribution from the works of our scientists and inventors to the development of world science in the late nineteenth and early twentieth century is noted. The great mathematician, physicist and theorist believed that only the specific mechanisms and technical solutions, or how he used to say – materialized differential equations basically serve people. A presentation of his solutions and comparing them to the present state of knowledge has clarified him as an important pioneer in solving many technological problems. The aim of his inventions was primarily an attempt to solve the major problems of science and technology of his time. Always keeping in mind the ability to manufacture, he installed conventional industrial machine members into 'his mechanisms'. A review of his work from this perspective proves the significance of his solutions to future technical development, but at the same time the unreadiness of the industry to invest 'unsafe' regardless of their far-reaching benefits. Taking into account primarily the needs of the industry and its capabilities, Mihailo Petrović solves vital problems and opens the way for new ideas and improves existing solutions. When talking about his ideas, we need to take into account the current needs of the industry, and also to prepare future developments and uncertainties.

Izvod

U radu su analizirani pravci razvoja vojne opreme i uticaj pronalazaka Mihaila Petrovića. Ukazano je na veliki značaj rada našeg naučnika i pronalazača na razvoj svetske nauke sa kraja XIX i početkom XX veka. Veliki matematičar, fizičar i teoretičar smatrao je da samo konkretni mehanizmi i tehnička rešenja, kako on to bolje kaže materijalizovane diferencijalne jednačine, konkretno služe ljudima. Prikazom njegovih rešenja i njihovim upoređivanjem sa današnjim saznanjima rasvetljen je njegov značaj kao začetnika rešavanja mnogih tehnoloških problema. Cilj njegovih pronalazaka bio je u prvom redu pokušaj rešavanja trenutno najaktuelnijih problema tehnike i tehnologije svoga vremena. Uvek imajući u vidu mogućnosti proizvodnje, u „svoje mehanizme“ ugrađivao je mašinske elemente poznate industriji. Posmatranjem njegovog dela iz ove perspektive definisan je značaj njegovih rešenja na dalji razvoj tehnike, ali i nespremnost industrije na „nesigurna“ ulaganja bez obzira na uviđanje njihovog dalekosežnog značaja. Vodeći računa u prvom redu o potrebama industrije i njenim mogućnostima Mihailo Petrović rešavajući vitalne probleme otvara put novim idejama i unapređivanju postojećih rešenja. Kada govorimo o njegovim rešenjima, treba voditi računa o trenutnim potrebama industrije, ali i o njenom budućem razvoju i njegovoj neizvesnosti.

INTRODUCTION

During the first half of the nineteenth century, the first significant solutions based on scientific inventions emerge, and thus begins the period of fast scientific development which upgrades the experience as a principal source of technological innovations. More than anything this refers to the demands of industrial manufacture. Namely, innovations based on experience with existing technology could not result in major changes to manufacture, more productive means of work, or new products and processes.

Significant technical – technological discoveries started with Watt inventing the steam engine (near the end of the eighteenth century), marking the beginning of an industrial revolution era which has during the nineteenth century, lead to a revolutionary transformation of the development of social production capacities. This century-long development contributed to the creation of material wealth, the likes of which was impossible to generate in the previous centuries of human existence.

In addition to changes in the technology, technics, structures and science as a whole, the success has depended on the general level of a country's development, capital availability and the workforce, as well as the entrepreneurial initiative and other political and social aspects.

At the end of the nineteenth and at the beginning of the twentieth century, drastic changes in modern-day society and the global relations system occurred, due to the period of sudden industrial production growth. Industrial society in highly developed market-oriented industries enters a stage of mass discovery and application of (up to that point) inconceivable theoretical and fundamental scientific possibilities. It uses the results of theoretical scientific thought in order to accelerate industrial growth, conquer new technologies and introduce technological-technical solutions into the manufacturing process. Considerable development and increased application of production technologies had occurred which in turn encouraged a new wave of industrial growth.

PATENT FR.413.730 (RANGE FINDER WITH A SEXTANT)

This invention is declared a patent by the French Patent Office in August 1910. The application was submitted by both Mihailo Petrović and Milorad Terzić. The solution is related to a range finder whose function is based on the sextant principle (an instrument used for angular distance measurement), wherein the necessary distance to an observed object is obtained from the observation deck, based on the observation angle value, the corresponding convergence angle and the distance between two points of observation. Such a range finder construction represented a first-time application of sextant function and properties for such a purpose.

The sextant (*sextans* in Latin, a genitive of the word *sextantis* which means one sixth) is a manual instrument used to measure the angular altitude of celestial bodies. It was most commonly used for ship and airplane navigation. Even Isaac Newton (1642-1727) was involved in figuring out how a navigation instrument with a double light reflection works, developing the sketches of an octant in the process. Unfortunately, his results were not published until 1742. Two more scientists worked on the octant problem, simultaneously and independently, around the year 1730. These were the English mathematician, John Hadley, and American Thomas Godfrey. However, it turned out that the maximal angle that can be measured by the octant (90°) is insufficient, hence in 1757, John Bird created the first instrument with a larger scale (of 120°) – the sextant.

The instrument's function and its application were an innovation and a revolutionary idea aimed to emphasize the use and potential of artillery fire. The way in which the distance from the target is measured was a significant problem for the artillery, since measuring of observation angles and knowing of distances between two observed points made this task complex, due to trigonometry calculations involved. The solution to this problem seemed simple, to observe only a single point instead of two, without the need for additional calculations. With current instruments, these types of distances could not be determined directly, but required observing two different locations and measuring angles, wherein the distance is calculated using trigonometry.

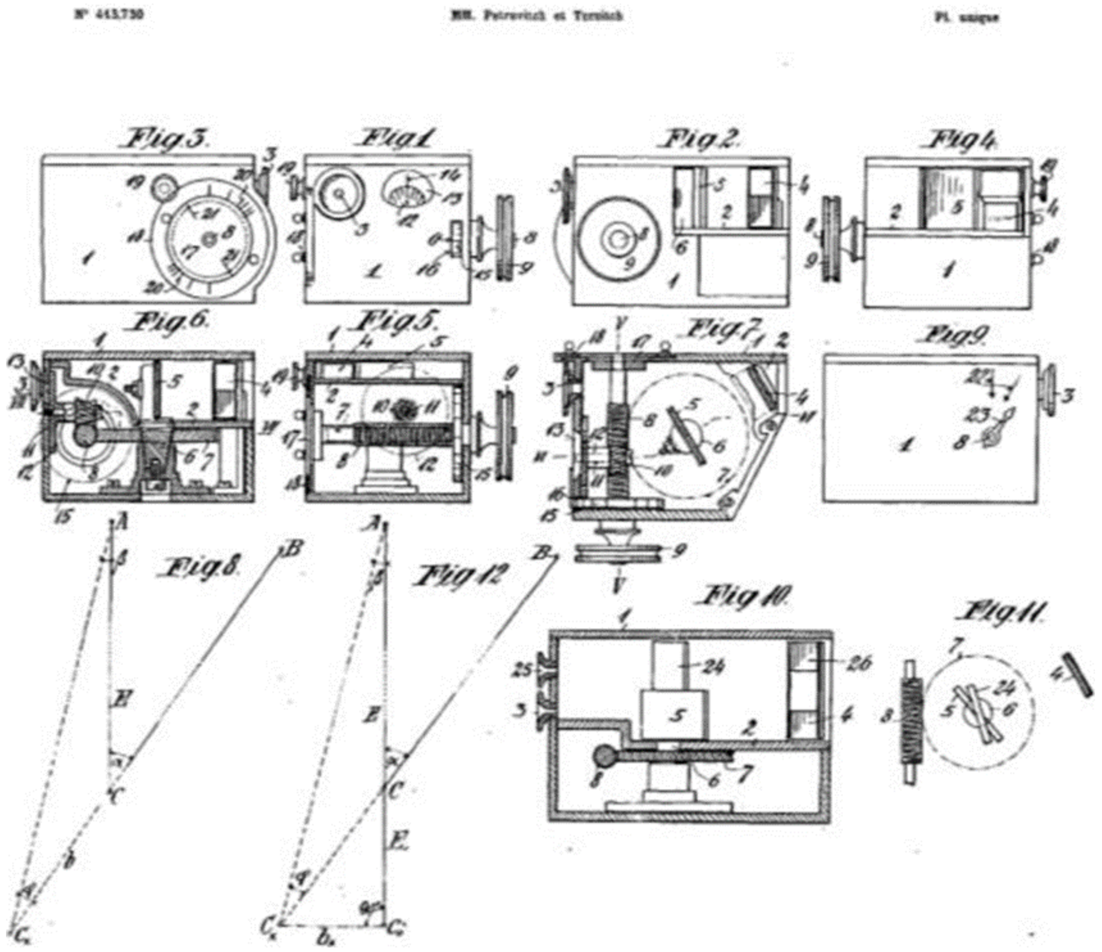

Figure 1. Design solution of the instrument.

The new solution was to measure the distance to the observed object using two points, but from a single position. The instrument worked based on the relations for angles which represent the instrument's property. This work principle can be achieved in various ways. The patent presented three ways (possibilities) of the design solution of the instrument (Fig. 1).

Unpublished manuscripts (found in Mihailo Petrović's legacy) contain the range finder diagrams. It is assumed that these diagrams belong to the Petrović-Terzić patent. As a man familiar with mathematics and laws of physics on one hand, and a man fully aware about the state of our industry and its possibilities, along with the condition of developed factories all over the world, Petrović was tasked with designing of new equipment. He was considered an expert in global scientific flow and achievements, as well as in scientific development.

The invention, meant to be used by the Military – Technical Institute in Kragujevac, in order to conquer new technologies, was realised in Serbia in 1910 and in Russia in 1912. Manufacturing of one such device meant the process of including its manufacturers into the group of important exporters of precision military equipment and keeping up with the largest global manufacturers of these devices.

Petrović's solution for the instrument provided higher precision than in the state-of-the-art ones by a margin of 30% (0.5 m at 900 m). However, it also required specific machinery in order to achieve this increased accuracy. These issues were mostly solved relying on the skills and abilities of workers involved in the production.

By today, a large number of manufacturers of similar devices developed an entire palette of such instrument models.

TOLERANCE EFFECT ON INSTRUMENT ACCURACY

The accuracy of all, including measuring instruments, depends primarily on manufacturing tolerances. The quality and precision of each machine member depends on the applied technology and the possibilities of each individual machine used in the manufacturing process. However, it should be noted that up to then an international tolerance system has not been established, also there were no obligations or recommendations in this sense. Each factory had its own equipment and was familiar with its possibilities. The manufacturing technology for each machine member and its properties were each factory's own little secret.

Thus, a device or an instrument needed to be manufactured entirely by one factory. Any connections between factories or use of standard parts were practically disabled. Cooperation was unimaginable since each factory had its own set of standards and regulations differing from the rest.

For individual groups of machine members, the price dependence (coefficient) from machine member tolerance value is given in Table 1. This research was performed in the 'nineties' by the Swedish shipbuilding association.

Properties of a more complex assembly or instrument were obtained once manufacturing has completed (previous calculations were hard to perform), since manufacturing of each individual member did not take into account the shape and position tolerances, or free dimension tolerances, achieved through individual machining processes. During instrument development, the accuracy actually represented properties and capabilities of machines used to manufacture individual parts.

Table 1. Cost coefficients vs. manufacturing tolerances.

Group No.	TOLERANCE [mm]						
	0,300	0,150	0,075	0,040	0,020	0,010	0,005
5	0,56	0,70	1,02	2,00	4,43	5,55	7,06
6	0,18	0,26	0,37	1,98	2,88	3,46	5,48
4	0,57	0,76	1,07	1,51	2,31	3,32	5,05
7	0,15	0,31	0,38	0,86	1,16	2,56	3,84
3	0,33	0,38	0,44	0,55	0,68	1,90	4,32
2	0,19	0,24	0,29	0,38	0,50	1,07	2,37
1	0.06	0.06	0,07	0,20	0,21	0,24	0,47

Calculating of the instrument error and the way in which they are manufactured were not considered by Mihailo Petrović, and this is the very reason why his revolutionary idea was not widely used. During the development of one such measuring instrument, the use of very precise manufacturing equipment was necessary. The tolerance of each individual element affects the accuracy of the instrument as a whole.

Shown in Figs. 2, 3 and 4 are the effects of the error of individual working quantities on its total accuracy. Scheme were made taking into account original drawings of Mihailo Petrović - Alas. The instrument measuring accuracy and error were calculated assuming an ideal instrument working under ideal conditions. Figure 2 shows the effect of angle α error on measuring results. It presents the accuracy deviation of the measured distance from the accuracy of angle α. Angle α tolerance consists of the sum of tolerances of all elements of the instrument which take part in its defining.

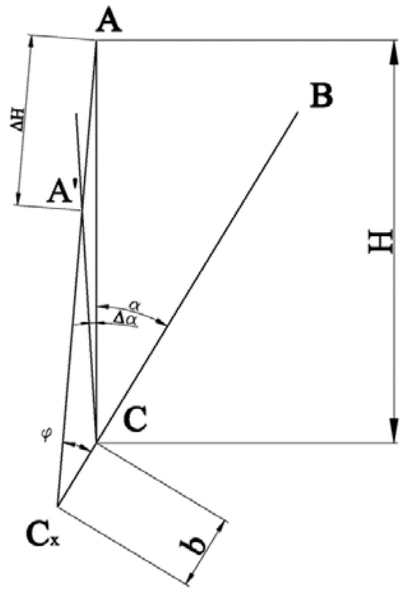

Figure 2. Effect of angle α on instrument accuracy.

Figure 3 shows the effect of angle φ tolerance on instrument accuracy. Precise instrument work requires accurate functioning of every member, i.e. their properties.

The properties of individual members are mainly the result of manufacturing technology. In this case, it is assumed that all members not involved in defining the angle φ, work ideally. A similar rule applies to all other cases. Finally, the effect of distance error between the mirrors on the measured distance to the observed object is shown.

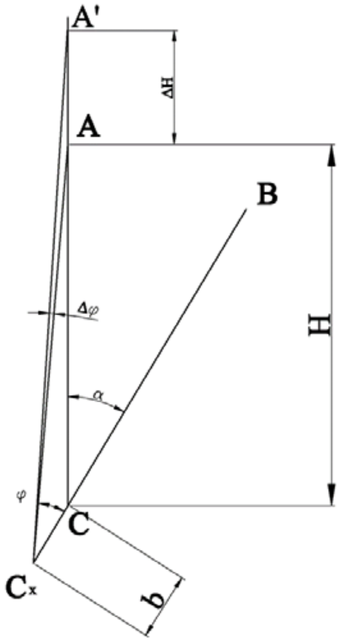

Figure 3. The effect of angle φ on instrument accuracy.

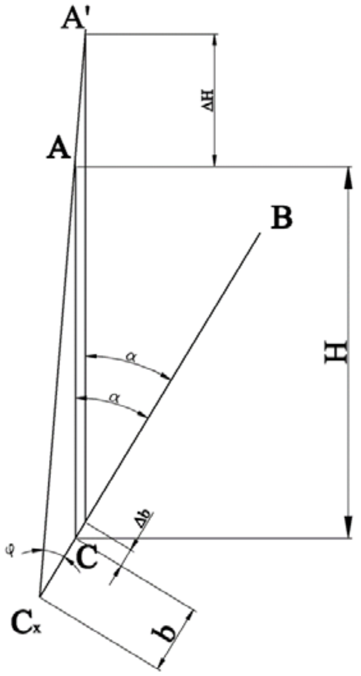

Figure 4. Effect of tolerance value b on instrument accuracy.

Instrument work tolerance, i.e. measured distances, is a complex function of all individual member properties. It can be considered that the instrument is being operated in an ideal manner. Instrument accuracy can be represented as a function of effects of error caused by parameters influencing its work:

$$\Delta H = f(\Delta\alpha, \Delta\varphi, \Delta b).$$

In this case, the ways in which the instrument is used and the necessary operator skills will not be taken into account.

PATENT FR.503.321

This device, which records fast motion of bombs, mines and air torpedoes launched from smooth tubes, is also meant for military use. Development and improvement of military equipment means an increase in army efficiency and reduction in its costs for the country.

The aim of this device is to add fast rotation to the launched missile, therefore increasing its efficiency. In other words, the contribution of Petrović's inventions consisted of modernizing the existing equipment in order to improve its efficiency with minimal costs. These devices enable the launching of long-range missiles from trenches, at distances which significantly exceed those achieved by smooth gun barrels currently used and whose missiles typically only reach second lines of enemy trenches. Barrels of medieval firearms were made without grooves, i.e. smooth, due to a lack of an adequately developed barrel grooving technique, and were bored using a rotating drill, often water-powered. Due to an outdated way of manufacturing gun barrels, the weapons had very poor ballistic performance. By the middle of the XIX century, there were no scientific studies on weapon ballistics even though research has been carried out in that direction.

The practice of etching a spiral groove inside the gun barrel began in the middle of the XIX century (Fig. 5) which allowed more accurate shots.

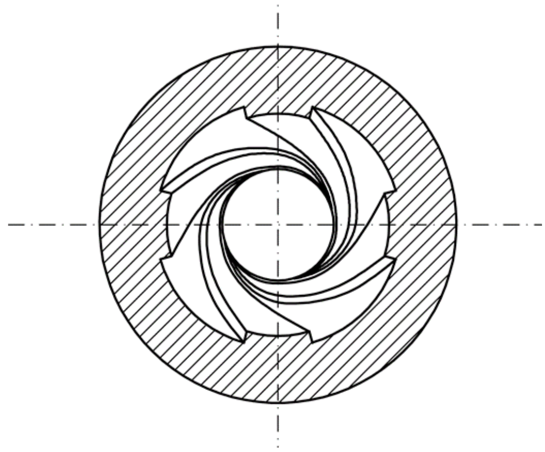

Figure 5. A cross-section of a gunshot tube with a groove

At this point, everyone whose metallurgy was up to the task started doing this. Gun barrels had what was most important for shooting – a groove that will provide gyroscopic rotation to the missile.

During the second half of the XIX century, the military industry in developed countries of western and central Europe achieved significant technical advancements. Machine equipment is modernised using new inventions, the production of cannon and gun ammunition is improved, along with the grooving technique of gun barrels for the purpose of faster projectile rotation and more accurate shooting. In addition, adjusting of the calibre in order to increase the range of firearms was performed, while more and more attention was devoted to the ballistic problems.

Experiments performed during the first half of the XIX century had shown that grooves with screwed stripes provided the missile with faster rotation, increasing its velocity and accuracy. Instead of using round projectiles, elongated projectiles are introduced (Fig. 6), which were heavier and more devastating.

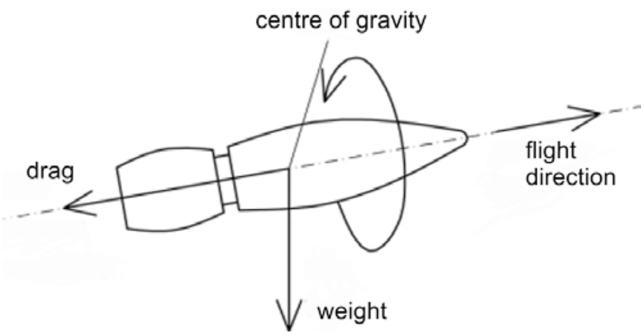

Figure 6. A projectile.

GUN BARREL GROOVING

A large step is made in the second half of the XIX century. In order to increase the range and penetration of projectiles, weapons with a grooved gun barrel are introduced from 1855-1880. First models were actually the currently available ones with adjusted smooth barrels and they used elongated projectiles instead of round ones. Grooved gun barrel weapons were already manufactured back in the XVII century, but maintenance and loading were extremely complicated and thus they started dominating over smooth gun barrel weapons only when the metallurgy and the new firing systems had developed in the XIX century. Grooves and slots enable the fired projectile casing to fit into them, thus gaining rotational motion while being fired from the gun barrel which results in improved stability and trajectory to its target. Thanks to this rotation, the maximum range accuracy is achieved. Deep boring refers to boring of holes deeper than $10 \times D$. Depths that can be achieved using different deep drilling tools can go all the way up to $150 \times D$. In most cases involving deep boring, the principal rotation motion is performed by the workpiece, and the linear motion is performed by the tool. In this case, the greatest issue is related to cooling of the tool and its stiffness, due to which several procedures were developed for this kind of machining, wherein the tools are made of high-speed steel for all cases. Grooves are shaped like spiral polygons with a cross-section resembling a square with filleted angles and slightly rounded sides, hence this machining process is referred to as polygonal rifling.

Improving of cutting properties of industrial tools in the second half of the XIX century makes a huge step in machining processes of all types, especially for metallic materials. This resulted in increased productivity, reduced machining costs and most importantly, higher quality of machined parts. As expected, lower product costs are achieved, whereas manufacturing becomes easier.

During the development of tool materials, one of the most significant moments was the development of high-speed steels whose properties represent a turning point in machining processes. As for the manufacturing process itself, tools represent one the most important prerequisites to begin with.

High-speed steel is aimed to work in elevated temperature conditions. More often than not, high-speed steels are subjected to local heating, significant wear and impact loads on the tools during exploitation. The chemical composition of this group of steels is characterised by increased carbon content and alloying using hard carbides. Increased carbon content results in the forming of carbides which are stable at increased temperatures, as well.

The aforementioned composition and the achieved microstructure of high-speed steels leads to high wear resistance at elevated operating temperatures. However, all this results in low toughness. Taking into account that high-speed steel involves a high level of alloying, this group of tool steels is one the most expensive. This represents one of its greatest disadvantages.

MIHAILO PETROVIĆ’S WORK

As an all-round person, Mihailo Petrović Alas studied various fields of human activity, however it should be emphasised that he devoted most of his life to mathematics and engineering. While most of his published papers are in the mathematic field, his contribution to physics, chemistry and astronomy must not be neglected. All of his patents represent, as he says himself, a materialisation of his theoretical knowledge. These are the mechanisms required for extensive knowledge of mathematics and mechanics in order to construct and understand these patents. Mihailo Petrović knew mathematics and mechanics very well and used his theoretical knowledge successfully, applying it to his analyses or when synthesizing different mechanisms. He used his mathematical knowledge mainly for explaining the principles by which the operation of his mechanisms are based on.

Mihailo Petrović Alas’ patents represent the solutions of problems that the mechanics and industry of the time was facing. It involved solving problems related to the current production with currently available means. In a given time, technology could not keep up with certain improvements, or new solutions. The reason why the necessary technology, materials and often the ideas themselves could not be realised was simply because the market was not ready to accept such a device.

In order to realise the idea and to manufacture a new mechanism which it represents, the first assumptions to be taken into account are the market needs and its willingness to accept something new and different. Next, taking into account its response, it was important to have access to machines and equipment used for the manufacturing process, and most importantly, the investments need to be economically justifiable.

CONCLUSION

One must always take into account that the very existence of technological innovations, regardless of the obvious advantages, is not and cannot be a sufficient condition for application. An identical technology innovation can result in completely different effects in various political and economic systems. Each specific society is characterised by a set of objective and subjective constraints which are above all a consequence of the achieved level of industrial and social development.

Major objective constraints in applying new technical-technological solutions are related to the structure of available production factors, followed by the magnitude of available accumulation, the degree of regional differences and the proclaimed goals of social-economic development.

Scientific research in applied sciences involves determining inter-relationships which confirm the basic truth about the researched subject, along with the possibility of its application. This is of great significance since it allows applied theoretical knowledge in practice.

Solutions by Mihailo Petrović Alas represented the ways in which available theoretical knowledge could be applied to practical problems. Further industrial development was only possible by using new ideas in production rationalisation and the most effective use of all available potentials. In order to make the product as acceptable as possible, it was necessary to take advantage of everything necessary for its production and application. The functioning of a system as a whole begins with an idea which needs to be realised as efficiently as possible.

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