HISTORY OF TECHNOLOGY

DOI: 10.32703/2415-7422-2024-14-2-465-486

UDC 94:621.313:001(9):330.34 (477)

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Work at the Kharkiv Electromechanical and Turbo-Generator Plant on the project of electromagnetic torpedo tubes (1936–1938)

Abstract. *The article, based on archival documents of the Kharkiv Electromechanical Plant, highlights the activities of scientists of this enterprise during 1936–1938 on the project to create electromagnetic systems for bubble-free torpedo firing, which in today is completely new information for historians of science and technology, and for specialists in the field of electrical machine engineering too. This project arose as a result of a confluence of several circumstances, one of which was the need of the Soviet naval submarine fleet on the eve of World War II to improve itself torpedo armament with systems that would not reveal submarines when firing torpedoes from a submerged. Another circumstance was that since 1934 the Kharkiv Electromechanical Plant was the main enterprise in the Union of the Soviet Socialist Republic for the production of electromechanics for ships of all classes and for all coastal defense facilities, and therefore its administration and the scientific and technical personnel who were involved in defense issues at the plant, were aware of this problem. At the same time, some of the latter, working part-time at the Kharkiv Electrotechnical Institute, from the first half of the 1930s, along with the studies problems of rotary electric machines, actively developed the direction of electric machines with the axial [linear] direction of rotor movement, and achieved significant results in this. Thus, by 1936, conditions had been formed when meeting the need to provide Soviet submarines with bubble-free torpedo firing systems became theoretically possible through the use of electromagnetic torpedo launching according to the methods developed by Kharkiv scientists for linear electric machines, and by torpedo tubes whose corresponding equipment for which's could be manufacturing at Kharkiv Electromechanical Plant. However, this theoretical possibility required practical confirmation, for which the "Magnetic Torpedo Pusher" project was organized, carried out by the same specialists who were engaged in the study of linear*

electric machines both at the Kharkiv Electromechanical Plant and at the Kharkiv Electrotechnical Institute. The purpose of the project was to select a possible version of the fundamental design of an electromagnetic torpedo tube and test the functionality created according to the chosen design option using model experiments. Studies have shown that pushing a torpedo out of a torpedo tube within the framework of the modes established by the customers of the project is possible with the help of a running magnetic field, however, the electromagnetic method of launching a torpedo does not make it completely bubble-free, but only leads to a decrease in the volume of the air bubble formed during the firing. Wherein, the use of electromagnetic launch of torpedoes on existing and designed projects of Soviet submarines turned out to be impossible due to significant changes in the weight and size characteristics of the electrical power equipment, that need to be installed in this case. Meanwhile, the same degree of reduction of the air bubble without any significant additional costs has already been achieved in the designs of pneumatic torpedo tubes of Stalinets-type submarines, projected by order of the Soviet Union by German and Holland designers, which completely deprived the project of torpedo tubes with electromagnetic action of its attractiveness, and led to its closure. At the same time, despite the unsuccessful result of this project in the context of creating a bubble-free torpedo firing system, its implementation allowed Kharkiv scientists to validate and verify the methods they created for calculating and designing linear electric machines, as well as to determine the optimal designs of magnetofugal stators, which was subsequently used in the creation special electromechanical equipment for the mining and construction industries.
Keywords: *bubble-free torpedo firing; electromagnetic launch; linear electric machines; submarine*

Introduction.

During World War I, the problem of submarines discovering themselves at the moment of launching a torpedo by them from submerged condition at an attacked ship was revealed. It occurred as a result of a bubbles of air rising from under the water at the location of the submarine, which formatted after pneumatic push out of torpedoes from the torpedo tubes. This phenomenon led both to decrease in the effectiveness of attacks by submarines [since the enemy could timely detect the launch of a torpedo and take appropriate measures to evade a meeting with a torpedo], and to an increased risk of damage or even loss of submarines [since a submarine that had unmasked itself might not have time to take actions that would allow her to hide from enemy anti-submarine weapons]. Therefore, in the interwar period, virtually all countries that had underwater shipbuilding were looking for ways to organize bubble-free firing of submarine torpedo tubes, and the Soviet Union was no exception, although Soviet specialists didn't manage to achieve any most results in this area before beginning World War II (Beloshitskiy & Baginskiy, 1960). The only series of Soviet submarines equipped with means that partially reduce the volume of the air bubble released during the pneumatic launch of torpedoes from a submerged position [*Stalinets*] was designed in 1933–1935 by the German company *DeSchiMAG*. However, these devices, the operating principle of which was based on the piston-less removal of air from the torpedo's ejection into the interior of the submarine, were still quite primitive at that time – they did not remove the entire volume of air and had significant limitations on the maximum depth from which torpedoes could be launched, and until the early 1940s [when these shortcomings were eliminated] were used by German shipbuilders only for export versions of submarine projects. For their own needs, they, like other leading global submarine manufacturers, created more advanced bubble-free firing systems in the 1930s that did not allow the air bubble to escape at all when launching a torpedo – both pneumatic [piston] and pneumohydraulic, as well as all kinds of mechanical ones. But the former were expensive to manufacture and still had limitations on the depth at which torpedoes could be launched, while the latter, without such limitations and being cheaper, were quite bulky [which did not allow their use in small-displacement submarines and significantly worsened the performance characteristics of large submarines] and, in addition, did not guarantee the desired [more than 10 m/s] speed of the torpedo exit from the pipe of the torpedo tube (Gabler, 1972).

Meanwhile, the designs of the systems that ensured completely bubble-free firing were kept in the strictest confidence, and Soviet intelligence was unable to gain access to them, at least to the extent that they could obtain the relevant technical documentation in sufficient quantities for Soviet industry to create its own similar serial devices based on them. At the same time, taking into account the aforementioned shortcomings of the bubble-free firing systems used abroad, it was desirable for the command of the Soviet submarine fleet to obtain at its disposal such torpedo launchers, the design of which, on the one hand, would exclude their occurrence in principle, and on the other hand, would be universal for all types and kinds of torpedoes, the improvement of which in the interwar years occurred at a rapid pace (Kirby, 1972). And since the international situation in the second half of the 1930s tended to annually approach a global military conflict, an urgent solution to this problem for the Workers-Peasants Red Fleet [*WPRF*] of the USSR was quite important.

Based on this situation, the Soviet government decided to look for alternative ways to foreign borrowings to create its own bubble-free torpedo firing systems, one of which involved an electromagnetic launch of a torpedo from a torpedo tube. In 1936, this device option for a bubble-free launch system was proposed to be studied to a team of researchers at the Kharkiv Electromechanical Plant [*KhEMP*], since 1934, by decision of the Soviet government, *KhEMP* was designated the head enterprise in the USSR for the production of electromechanics for ships of all classes and for all coastal defense facilities (Annienkov, 2019). The very emergence of the idea of electromagnetic launching of torpedoes is due to the fact that in the early 1930s in the Soviet Union the advantages of using an electromechanical drive, which were achieved thanks to its widespread distribution due to the intensive electrification of all spheres of public life during the 1920s, became obvious. And at the same time, the range of areas of use of electric machines, as their designs were improved, continued to expand, which allowed both the country's leadership and electrical machinery scientists to imagine more and more new possible forms of application of electromechanics, including those which operating principles were based on non-traditional ways to use the energy of the electromagnetic field. In the era discussed in this article, these methods also included those, due to the use of which the rotor of the electric motor performed not rotational, but rectilinear or curvilinear movement. In the Ukrainian SSR at that time, the problems of linear electric machines were actively studied at the Kharkiv Electrotechnical Institute [*KhETI*] and at *KhEMP*, which we can also assume, along with the previously indicated role of the latter in the production of naval electromechanics in the USSR, favored the placement by the Soviet government of an order for research into the possibility of creating electromagnetic systems for bubble-free torpedo firing exactly in Kharkiv.

In parts, the issue of research work of Kharkiv scientists in the field of linear electric machines is clarified: in the monograph Essays on the history of the development of applied technical sciences in Ukraine: From the experience of the Kharkiv Polytechnic Institute (Tverytnykova, Posviatenko, Melnyk, 2015), in the dissertation *Contribution of scientists of Kharkiv Technological and Electrotechnical institutes to development of electrotechnical branch of Ukraine (1885–1950)* (Tverytnykova, 2009) and in the publication *Research work in the field of electric drives at the Kharkiv Electrotechnical Institute (30–40 years of the twentieth century)* (Tverytnykova, 2008). However, in these scientific works only the relevant activities of *KhETI* scientists are considered and no attention is paid at all to the study of the problem of linear electric motors on *KhEMP*, despite the fact that in the presented publications the main place of work of most of the researchers mentioned in connection with the topic of linear electric machines was *KhEMP*, and in *KhETI* they worked part-time. Also, in the cited publications, the research work of Kharkiv scientists in the field of linear electric motors is considered superficially, in contrast to the work in the field of traditional electric machines, which can be explained by the fact that the real consumer properties of the linear electric drive achieved in the interwar period throughout the world [including *KhEMP* and *KhETI*] in many cases were much inferior to the expected ones, and were often even worse than the properties of the non-electric drive of units, for the replacement of which, in fact, the corresponding linear electric machines were developed (Shturman, 1948a). That is, the achievements of both *KhEMP* and *KhETI* scientists in the development of linear electric motors were significantly inferior to their achievements in the development of rotary motors, so much significantly so that a more in-depth mention of this issue by historians has unfairly would level the overall indicator of research results conducted at these institutions in the 1930s, which the above authors would apparently like to avoid.

Moreover, since the end of the 1940s, judging by the avalanche-like decline in the publication activity of Kharkiv scientists in the subject of linear electric machines, the corresponding issues began to be studied by them episodically, while the activity in studying the problems of rotary electric machines remained consistently high until the beginning of the 1990s. Hence, taking into account the fact that the studies of rotary machines in Kharkiv at the time of preparation of the analyzed historiographic material had almost a century-long history of highly dynamic development, and the study of linear electric machines began in parallel with the previous process only in the mid-1930s and by the end of the 1940s had left the dynamic phase, we can talk about its acquisition of a certain secondary importance [or fragmentariness] in the history of scientific support for the development of Ukrainian electric machine building, and, as a consequence, less interest of historians in this event. In any case, the previously mentioned superficiality of historians' coverage of the issue of research by Kharkiv scientists into linear electric machines has influenced the fact that even in those minor references to the facts of achievements of domestic scientists in the field of linear electric motors that are found in the historiography of Ukrainian electrical machinery, information about work on military topics is completely absent, and there is only information about the civilian use of the corresponding developments of Ukrainian specialists.

However, it should be noted that the issue raised in this article had the status of extreme confidentiality for a long time, as a result of which the relevant archival documents were declassified only in the 1990s and 2000s, and it was never mentioned in any forms in widely available publications. Even the initiator of the systemic research organization in the field of linear electric machines in Ukraine, who was directly related to the emergence of the project for the creation of electromagnetic systems for bubble-free torpedo firing – G. I. Shturman, mentioning in the second half of the 1940s the work carried out in Kharkiv since the mid-1930s on the creation of electric machines of magnetofugal action, does not indicate the original purpose of this work and avoids any technical and technological specifics that could give at least a hint of the military application of the results of the corresponding developments. He limits himself to more general formulations, such as: "magnetofugal induction motors" or "cylindrical magnetofugal engines", by the way, directly indicating that the leading organization in carrying out this work was *KhEMP*, and not *KhETI* (Shturman, 1948a, 1948b). Later researchers of the theory of linear electric motors, who did not participate in the project to create electromagnetic systems for bubble-free torpedo firing, especially do not indicate this aspect of research activities at *KhEMP* and *KhETI* in their scientific papers, concentrating on the general economic application of the corresponding technology, in accordance with the trends in its use that formed in the 1940s (Rogachev, 1948a, 1948b; Taraschanskiy, 1948a, 1948b, 1948c). Thus, information about the study by *KhEMP* scientists during the second half of the 1930s of the possibility of creating electromagnetic systems for bubble-free torpedo firing was unavailable not only to historians, but also to the vast majority of specialists in the field of linear electric motors, which is why the problem raised in this article remains today not only unexplored, but generally unknown, which makes this article actuality.

Research Methods.

This study is based on the principles of historicism and objectivity, which made it possible to recreate the real historical picture of the implementation of the project of electromagnetic torpedo tubes at *KhEMP* with maximum reliability. The use of the problem-chronological method made it possible to find out the reasons for the formation of established ways of carrying out experimental work within the framework of this project, and the retrospective one – to show the patterns of this process. Using the chronological method, the appropriate sequence of presentation of the obtained historical information was achieved, and using the methods of logic, analysis and synthesis, the conclusions and statements presented in the article were obtained.

Results.

Based on the top secret orders of the People's Commissariat of Heavy Industry USSR: No. 5s.s. and No. 102s.s. of 1935, as well as No. 6s.s. of 1936, a group of scientific-technical employees of the Bureau of Special Electrical Engineering *KhEMP* under the leadership of G. I. Shturman, in March 1936, began studying the possibility of creating a bubble-free torpedo firing system for submarines, the operation of which would be based on the use of electromagnetic energy (The State Archive of Kharkiv Region [SAKhR], 1936a). This project received the official name “Magnetic Torpedo Pusher” [*MTP*], and at the first stage it involved an analysis of the feasibility of three design principles for its implementation: solenoid, electrodynamic and magnetofugal (SAKhR, 1937a). The solenoid principle provided for an initial asymmetry in the relative position of the solenoids and the torpedo [as a core], which required the presence of a special device that turned off the solenoids at the moment when the torpedo approached the equilibrium magnetic position, since otherwise effect of a braking the torpedo would occur. Thus, the electromagnetic force would not act during the entire movement of the torpedo, but only at the initial moment, during which it would have to be given kinetic energy sufficient to push out, by inertia, a projectile weighing 1,600 kg, with a diameter of 0.533 m and a length of 4.8 m into an environment of increased hydrodynamic resistance at a speed of at least 12 m/s (SAKhR, 1938a). That is, the use of the solenoid principle initially presupposed the installation on submarines of either heavy-duty pulse generators or sections of the same heavy-duty starter-type batteries, which by definition required an increase in the weight and size parameters of submarines: both those already built, those under construction, and those at the design stage.

The electrodynamic principle of launching a torpedo was based on the Biot-Savart-Laplace law, according to which the torpedo would receive the necessary ejection force continuously – from the interaction of the magnetic field of the torpedo tube frame and the electric current passing through the elements of the torpedo, that located in the magnetic field, which, however, provided for the presence in the torpedo tube open current-carrying parts, as well as sliding conductive contacts along the body of the torpedo itself. This point led both to intense corrosion of torpedo tubes and to the risk of frequent uncontrolled short circuits, as well as to the occurrence of the phenomenon of electrolysis and, as a consequence, intense gas formation, which partially neutralized the original goal of achieving bubble-free torpedo firing (SAKhR, 1937a). At the same time, both the first and second design principles were united by the use of direct current, with the inherent phenomenon of sparking the switching parts of electric machines, which is extremely undesirable for submarines, and in the second option was aggravated by use of low-voltage currents, but of high strength, although such significant generating capacities as in the first option was not required here. In any case, based on the above arguments, the team of authors rejected the solenoid and electrodynamic principles of the design of the proposed torpedo tube, and even at the initial stage in 1936, they finally settled on the principle of magnetofugal action, which probably facilitated by the fact that the immediate supervisor of developers – G. I. Shturman by that time already had his own theoretical developments in the field of designing linear electric machines with magnetofugal action. Thus, the method of electromagnetic launching of torpedoes accepted for study was based on the fact that the torpedo [like a solid squirrel-cage rotor of an asynchronous AC motor] was ejected by a running magnetic field from the active part of the torpedo tube, which was a deployed multiphase stator. Despite the structural complexity of the magnetofugal torpedo tube, its undeniable advantage was that, according to preliminary theoretical calculations, confirmed by static mock-up tests (Fig. 1), this principle could be implemented on existing torpedo tubes and torpedoes without any significant alterations, and therefore did not require replacement of the torpedo arsenal of the *WPRF* of the USSR (SAKhR, 1937a).

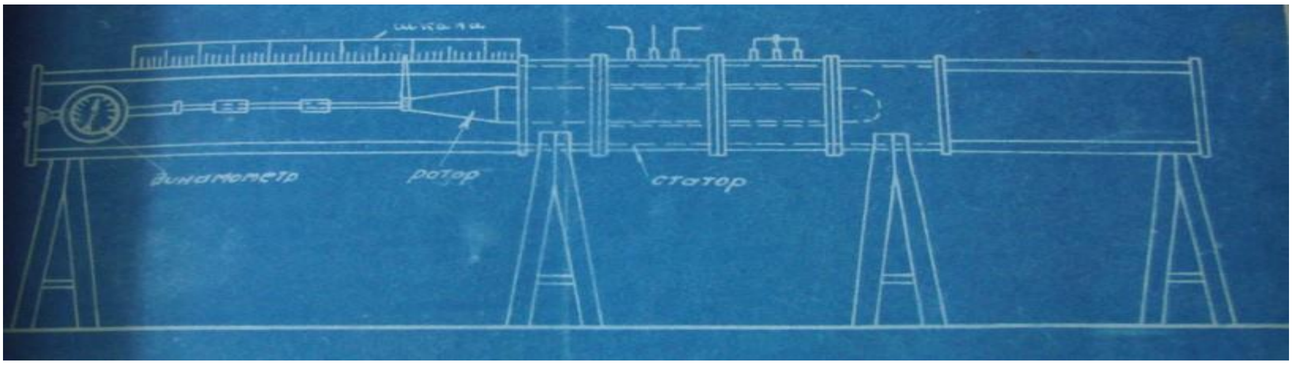

Figure 1. Scheme of an experiment installation for static testing of the possibility of magnetofugal launch of torpedo (SAKhR, 1937a).

Meanwhile, during 1936, political repression began to unfold at *KhEMP* against representatives of the opposition to the Stalinist course of building socialism in the Soviet Union, as a result of which G. I. Shturman (Fig. 2) [as Trotskyist] was accused of "counterrevolutionary sabotage" by the factory Bolsheviks at the beginning of 1936 and was dismissed from the enterprise by the end of that year, and the *MTP* project was headed by his brother L. I. Shturman (SAKhR, 1936b; SAKhR, 1937b). In this situation, attention is drawn the fact itself that, unlike most similar cases in the USSR in the second half of the 1930s, public accusations of party activists G. I. Shturman were not further developed than as dismissal, when usually those subjected to a similar public accusation were then brought to a criminal court, by decision of which they were either imprisoned or executed, after which their closest relatives were brought to trial [with various consequences]. However, G. I. Shturman [who, of course, like the majority of those repressed by the Soviet totalitarian machine, did not commit any sabotage], unlike many accused of Trotskyism, never denied his commitment to L. D. Trotsky, and moreover, he never abandoned this commitment. However, if usually even those suspected of simply sympathizing with L. D. Trotsky, as well as their relatives, since 1936, criminal repressions fell like an avalanche, G. I. Shturman, having been fired from *KhEMP*, found a permanent job at *KhETI*, where he had previously worked part-time, and from where in 1937 he was transferred to the Ural Industrial Institute.

Figure 2. G.I. Shturman [1903 – 1964] (The Scientific and Technical Library of NTU «KhPI», 2024).

Also, repressions did not affect L. I. Shturman [if not considering as such his exclusion from candidate to Bolshevik Party members], who, after the dismissal of his brother, as already mentioned, headed the work on the *MTP* project, but in a new factory research unit created after January 1937, when *KhEMP* and the Kharkiv Turbogenerator Plant were merged into a single Kharkiv Electromechanical and Turbogenerator Plant *KhETP* (SAKhR, 1936c; Voznesenskiy, 1965). This division, created on the basis of the Machine Laboratory, was called the Special Drives Laboratory [*SDL*], and in it, in addition to L. I. Shturman in group studying the electromagnetic launch of torpedoes included engineers M. G. Sorokin and B. A. Zilbershtein, as well as installation technician L. A. Amolin (SAKhR, 1937a). *SDL* itself instead of G. I. Shturman was headed by E. M. Bogdanov, and structurally the laboratory became part of the Special Design and Installation Bureau [*SDMB*] of the Technical Department for Design and Installation [*DIT*] *KhETP*, headed by M. G. Waisman. Thus, we have every reason to assume that both for the *MTP* project and for the study of the problems of linear electric machines in general, a qualificative personnel for replacement to the Shturman brothers and announced in 1937 the Trotskyist B. A. Zilbershtein the Soviet government did not have, and it abandoned the criminal repressions practiced in such cases, although apparently a certain unspoken forceful pressure was exerted on these scientists by the authorities, since in subsequent years none of them showed any political activity (SAKhR, 1937c).

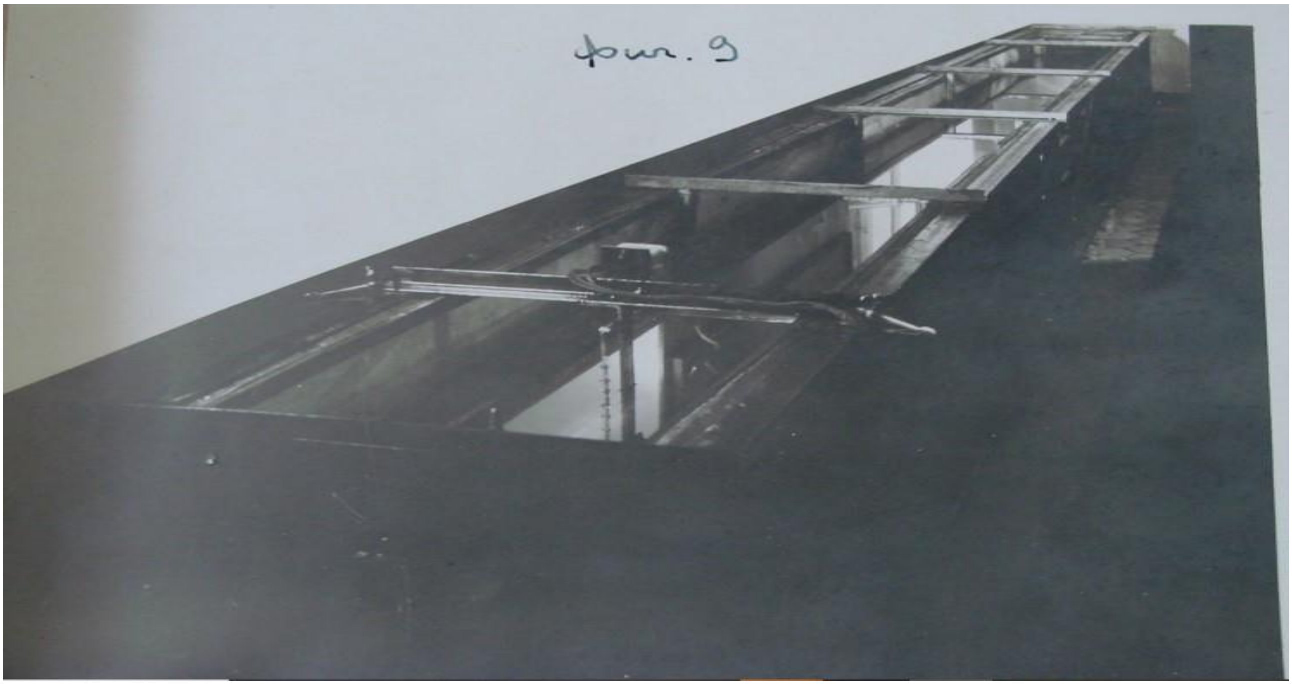

Figure 3. A pool for dynamic testing of a magnetofugal launch of the torpedo from the 1:5 scaled copy 21" torpedo tube in armament with the submarine forces of the *WPRF* USSR (SAKhR, 1937a).

In any case, work on the *MTP* project required its continuation, since the static tests carried out confirmed only the very possibility of using a running magnetic field to push a torpedo out of the torpedo tube, but did not reveal how effective this possibility would be in real conditions, and how it should torpedo launchers should be prepared so that this capability can be implemented on submarines in principle. For this purpose, dynamic testing of a magnetofugal torpedo tube became necessary, however, due to the high cost of the corresponding work on full-real objects with complete uncertainty of the results of these tests, by a meeting of the management: of *KhETP*, the Mine-Torpedo Research Institute [*MTRI*], Leningrad Mechanical Plant No. 103 [manufacturer of torpedo and torpedo tubes], as well as the Armament Directorate of the *WPRF* USSR, it was decided for these dynamic tests to build special stands at *KhETP* for simulating real torpedo firing conditions (SAKhR, 1938a). In accordance with this decision, in the *SDL* room, to simulate torpedo firing conditions, a special steel pool 8 m long, 0.6 m wide and 0.7 m high was built (Fig. 3), which housed a five-fold reduced working copy of a standard torpedo submarine apparatus with a caliber of 21 inches (Fig. 4), equipped with measuring instruments and special devices that recreate, on an appropriate scale, the loads on the elements of torpedo tubes and torpedoes that occur in real conditions. The number of models to be tested was not initially established, but it was intended to carry out tests until such a result was obtained that would give an unambiguous answer to the advisability of using magnetofugal torpedo tubes, and the first model to be tested was called *MTP-1*. Thus, all tested copies of the torpedo tube and torpedoes had to be equipped with electromechanics that would create the necessary magnetofugal action, and the design of which would be modified based on the results of previous experiments. Changes could also be made to the design and equipment of the test benches themselves if the results of the experiments would be revealed that the simulated conditions turned out to be different from the specified ones or if the installed measuring instruments could not clamp the researched loads parameters.

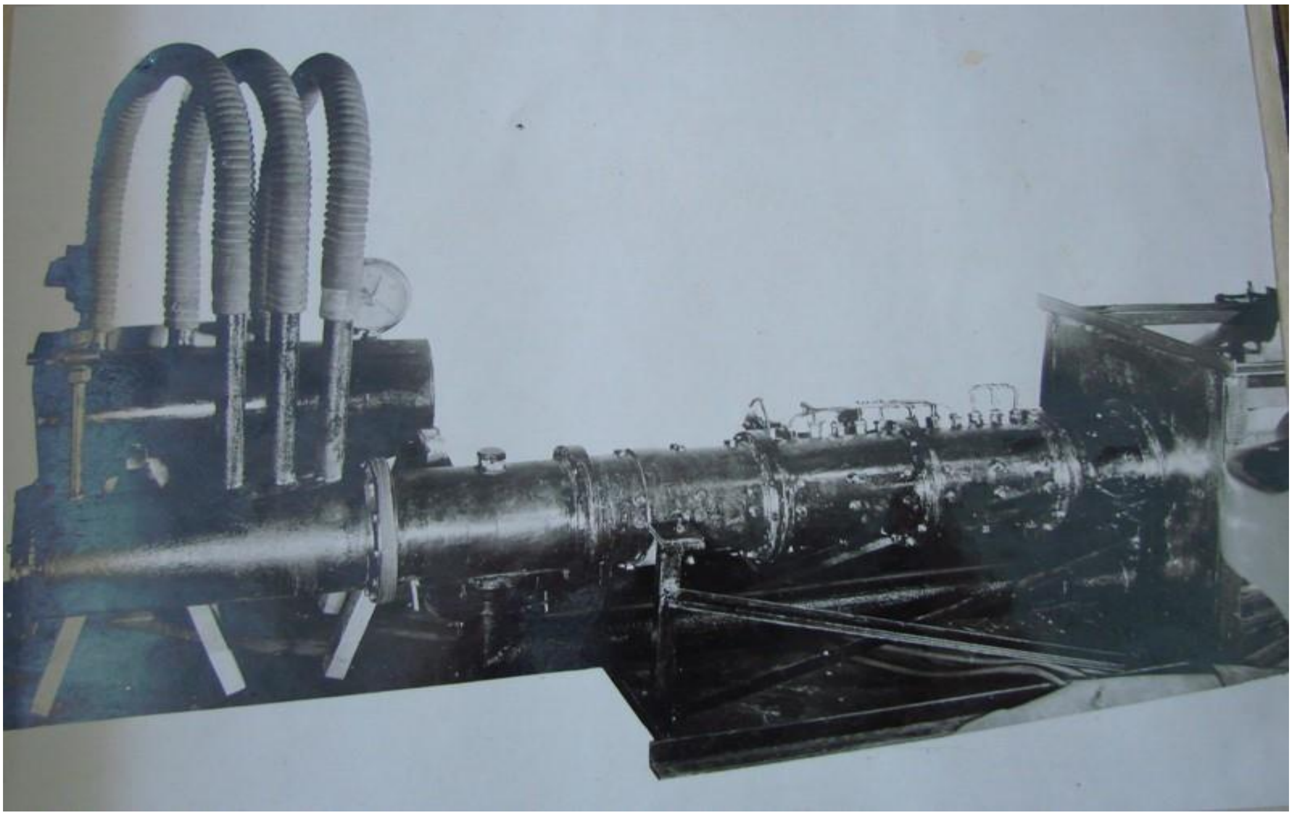

Figure 4. A working copy of a 21" torpedo tube of Soviet submarines on a scale of 1/5 of the original, intended for dynamic testing of magnetofugal launches of torpedoes (SAKhR, 1937a).

The results obtained in 1937 during dynamic tests at the *MTP-1* installation showed that the tactical and technical requirements set by the customer directly for the launch of torpedoes, in laboratory conditions were achieved (Fig. 5). This was the impetus for the *SDMB DIT KhETP* team to begin designing a six-tube magnetofugal torpedo system, based on the six-tube pneumatic torpedo system used on Soviet submarines. However, the lack of experience in creating torpedo tubes forced Kharkiv designers to turn to specialists from Plant No. 103 and *MTRI* for help in this matter, while insisting to the government on the need to build a full-size prototype, since the installation *MTP-1* did not allow research in the first place , issues of full hydraulic compensation for torpedo launch and optimal design and location of the magnetofugal stator for maintaining stable electrical power and weight balances of submarines (SAKhR, 1937d). Based on the importance of this issue for determining the impact of the use of magnetofugal torpedo tubes on the design of submarines as a whole, both Plant No. 103 and *MTRI* did not refuse *KhETP* the necessary consultations, at the same time not supporting the *SDMB DIT* proposition to build a full-size prototype, and insisting on maintaining the originally adopted tactics of testing. As a result of a short debate, the government made a decision in favor of Plant No. 103 and *MTRI*, as a result of which the work plan of *SDMB DIT KhETP* for 1938 included the continuation of research on the *MTP* project with the construction of new test models on the mechanical basis of the *MTP-1* installation in that quantity , which was necessary to study all those nuances of using a running magnetic field to push out torpedoes, which were of decisive importance for deciding on the feasibility of creating magnetofugal torpedo tubes (SAKhR, 1938b).

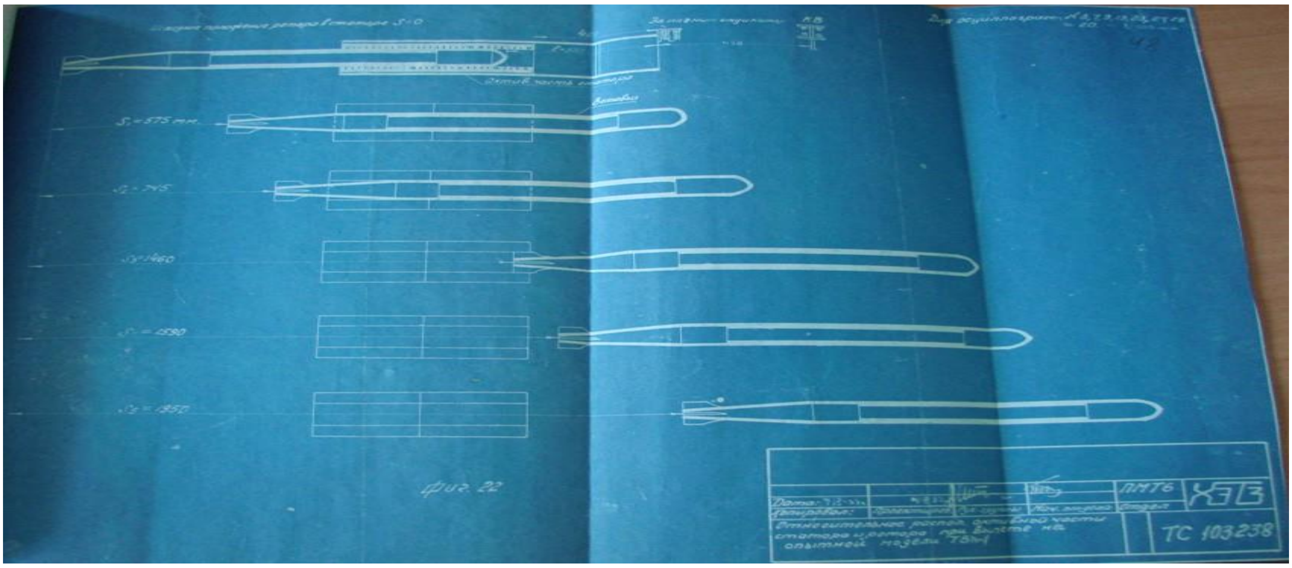

Figure 5. The stroke of a torpedo model on a scale of 1:5, achieved on the *MTP-1* installation (SAKhR, 1937a).

In accordance with the work plan, during 1938 *SDMB DIT KhETP* on the basis of *MTP-1*, 3 more experimental installations for dynamic tests and a separate installation for static tests of the magnetofugal stator were built (Fig. 6), which were all carried out on scale 1:5 to the original. At the same time, before 1938, certain changes occurred in the research team, which, however, affected not so much the quality as the pace of research on the *MTP* project. So, *SDL*, instead E. M. Bogdanov of defending the need to conduct tests on the *MTP* project on life-size models, was headed employee by *SDMB DIT KhETP* M. L. Sosnov, who was more loyal to the original scheme of conducting experimental work, and B. A. Zilberstein, who also considered the transition to full-scale testing of magnetofugal torpedo tubes premature, was removed from the *SDL* team and promoted to the position of head of the Combat Mechanisms Group, of which *SDL* became a structural unit. That is, in 1938 L. I. Shturman was practically deprived of influence on the organization of work on the *MTP* project as a whole, and remained only the head of mock tests of the possibility of using the magnetofugal method of pushing torpedoes out of submarine torpedo tubes. Thus, all attempts made by L. I. Shturman's to scale up the *MTP* project by involving Plant No. 103 and *MTRI* in it as subcontractors, those manufacturing and testing not mock-ups, but prototypes of magnetofugal torpedo tubes and, thereby, to gain the opportunity for a longer-term existence of the project, were stopped. The latter was necessary for L. I. Shturman for the reason that in the course of research within the framework of the *MTP* project at *KhETP*, he should obtain results that, the benefits of which for implementation this project were not yet entirely clear, however they were very relevant for the theory of linear electric machines, that being developed at *KhETI*, where he also worked at part-time after his brother left for the Urals, but yet with less funding for corresponding research. Now, with the final foothold of only mock-up tests by the *MTP* project, the time frame for research work was significantly compressed, since the rather long stages required to create and refine full-size prototypes was eliminated.

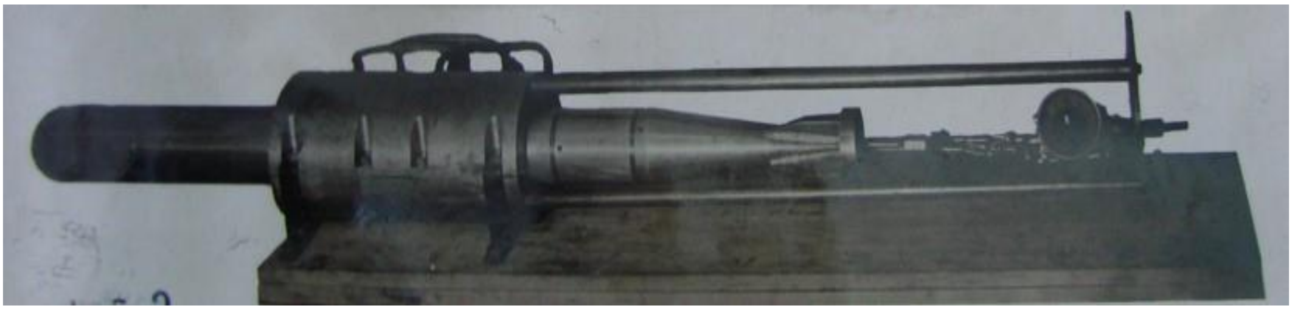

Figure 6. Installation for mock-up static tests of magnetofugal stator designs (SAKhR, 1938c).

Concentrating on mock-up tests, L. I. Shturman and M. G. Sorokin first of all tried to operate the optimal design of a magnetofugal starter on mock-ups, since it was this point that was decisive for solving all the other problems [with hydraulic compensation of torpedo launch, etc.], which were discussed above. It should be noted that scientists, using a new installation for static tests (Fig. 6), as well as on the *MTP-2* dynamic test model, were able to determine the most technologically advanced design of a magnetofugal stator – from a detachable thick-walled pipe with screw threads on its inner surface, which made a range of options placement of such a stator in the axial direction of the pipe of torpedo tube is wider. That is, from the point of view of meeting the weight and size requirements for submarine torpedo launchers and ease of manufacture, this design was optimal, but its traction characteristics turned out to be worse (Fig. 7) than the laminated design used on the *MTP-1* model. Therefore, to reduce losses of electromagnetic energy in the stator, in the next model *MTP-3* it was milled from the inside by 32 radial grooves 2 mm wide and 20 mm deep, which, however, only slightly increased the efficiency of the design, at least not so much that the total capacity power-plants used to ensure the normal mode of torpedo launch when using a solid stator was both economically and technically justified by the simplicity of its design (SAKhR, 1938c). Thus, in the *MTP-4* model, scientists returned to the laminated types of magnetofugal stator designs as the most rational from the standpoint of minimizing energy consumption for each torpedo launch.

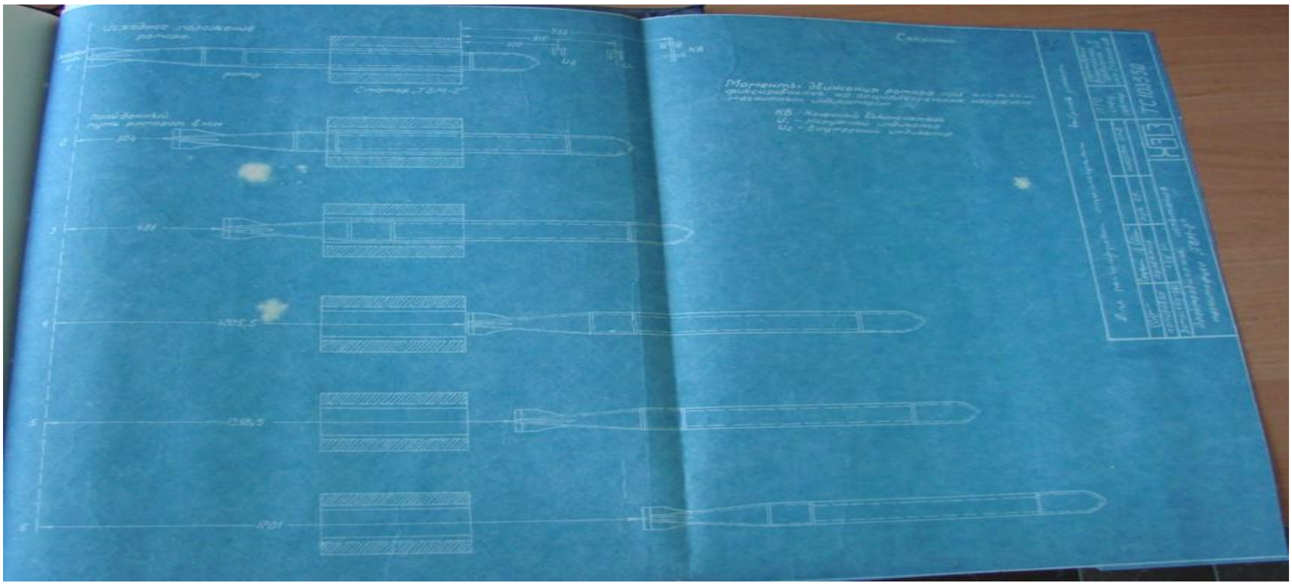

Рисунок 7. The stroke of a torpedo mock-up on a scale of 1:5, achieved on the *MTP-2* installation (SAKhR, 1938c).

By the end of 1938, having testing various versions of laminated stators on the *MTP-4* model, the final design diagram of a magnetofugal torpedo tube with an efficiency equal to that of a pneumatic device had been obtained at *SDL SDMB DIT KhETP*, although the efficiency of the entire electromagnetic torpedo launch system at whole continued to be inferior to the efficiency air system. At the same time, in addition to previously established problems of a non-electrical nature that arise during the process of pushing a torpedo out of a standard torpedo tube using a running magnetic field, already during tests on the *MTP-3* model, the problem of rapid wear of the insulation of current-conductive elements inside the torpedo tube under the influence of variable [water/air] environment they located, as well as at hydraulic pressure greater than 10 atm (SAKhR, 1938a). The types of insulating materials known at that time in the Soviet Union did not guarantee the minimum required by the customer [5-

year] service life of torpedo tubes before their overhaul, even in peacetime conditions, with rare use of torpedo systems for their intended purpose [and therefore without a significant load on current-conductive elements], which was absolutely unacceptable for the *WPRF* when preparing the USSR for a global and long-term armed conflict. And although in the *SDMB DIT KhETP* during the period under review [*regardless of the* MTP *project, according to the relevant resolution of the 2nd conference on ship electrical equipment, held in Kharkiv on February 07–13, 1937 (SAKhR, 1937e)*], intensive work was carried out on the creation of insulating materials with qualities that meet the requirements for the insulation of conductive parts of torpedo tube magnetofuges, their completion had a rather vague prospect both in terms of time and result (SAKhR, 1939). Therefore, as a temporary measure, *SDL* specialists proposed a fairly simple method of mechanically solving this problem – by placing the conductive parts of the magnetofugal stator in a sealed casing made of stainless non-magnetic material [stainless steel, brass, zinc, etc.] (Fig. 8).

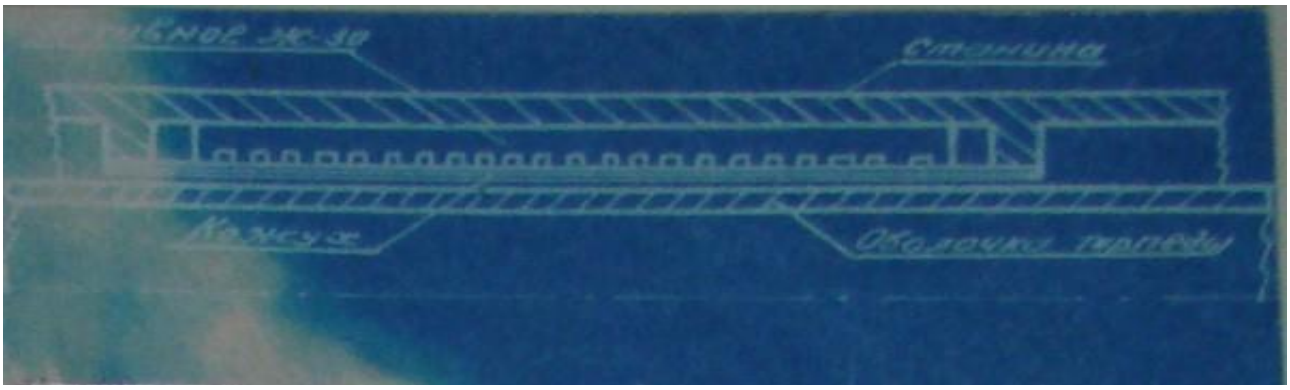

Figure 8. Insulation scheme of the conductive parts of the magnetofugal stator in the torpedo tube pipe, proposed by *SDL SDMB DIT KhETP* (SAKhR, 1938c).

The simplicity of solving the problem of insulating the current-conductive parts of the magnetofugal stator led, however, to an increase in power losses in the magnetofuge and, as a consequence, to the need to increase the power of the installations that provide it with electricity, and therefore their weight and size parameters. Thus, all three options for powering magnetofuges with energy, developed during the re-design of a 6-tube magnetofugal torpedo tube [from two shock generators; from one shock generator with a mechanical energy accumulator [flywheel]; from an accelerating action generator], assumed installation on the submarine of appropriate equipment weighing about 30 tons [and this is not counting the increase in the weight of torpedo tubes], which made the use of this method of launching torpedoes only theoretically possible on operational submarines, and only on squadron and cruising types of them (SAKhR, 1938a). At the same time, dynamic model tests have shown that the electromagnetic launch of a torpedo by itself does not ensure its completely bubble-free exit from the torpedo tube [which determined by the physics of the movement of bodies in an aquatic environment] and for this, the presence of an air compensation device is still necessary (Owis & Nayfen, 2003; Phan, Nguyen, & Park, 2020). In addition, the use of an electromagnetic launch system required a fairly large number of auxiliary electromechanical devices and controls, and this made such a system not only more cumbersome, but also less reliable than a pneumatic one, which implied simultaneous mandatory use on submarines and the latter as a backup one. That is, arming even large submarines with magnetofugal torpedo tubes presupposed either the creation of new projects for such submarines, or a radical redesign of existing ones, wherein with the very dubious combat effectiveness of electromagnetic torpedo firing. This circumstance served as an argument for the curtailment of the *MTP* project at the end of 1938 and news's about all the work of Kharkiv scientists in the field of linear electric machines before the outbreak of the Soviet-German war in 1941 in historical documents is associated exclusively with their civilian use - in the construction and mining industries.

Discussion.

The short life of the *MTP* project was one of the reasons that the total number of documents accompanying it did not form such a large amount of information about it that would allow obtaining complete information about the work on the project even after a significant period of time and, as a consequence of it, the loss of part of the documentary base. On the other hand, the analysis of other short -term research projects, performed in this time on *KhETP*, shows that the volume of documents accompanying such draft documents also depended on that degree of importance of research results for the Soviet government that it expected from them. Hence, in our case, the insignificant documentary support of the *MTP* project may also indicate an initially skeptical assessment by the military and party-economic leadership of the USSR of the possibility of creating effective electromagnetic systems for bubble-free torpedo firing. Thus, due to the weakness of the historical source base, the motivations given in this article for the scientists who carried out the *MTP* project and the customers regulating their actions are justified not so much by direct relevant documentary evidence, but by the results of an analysis of the historiography of the development of the theory and practice of constructing linear electric machines in Ukraine during 1930s, as well as the empirical knowledge of the author of this article about the traditions of office work relative to research projects established at *KhETP* during this period in a whole. Therefore, in a case if the base of relevant historical sources to be expanded, it may be possible to discover additional motivational factors was established as a result of interactions between customers and performers and that influenced the way of *MTP* project implementation.

Conclusions.

The project of electromagnetic torpedo tubes appeared as a result of a confluence of circumstances when, on the one hand, the Soviet naval forces had a need to arm submarines with bubble-free torpedo firing systems, and on the other hand, the development of the Ukrainian segment of Soviet electrical machinery reached a level that allowed it to resolve this problem in the specified method. The last point does not allow us to consider the mentioned coincidence of circumstances as accidental, but rather, on the contrary, as a natural result of the measures taken during the 1920s–1930s by the Soviet government to develop scientific support for Ukrainian electrical machinery, as a result of which the achievements of domestic scientists in the field of linear electrical machines made creating electromagnetic torpedo tubes are possible in principle. At the same time, the theoretical possibility of creating electromagnetic systems for bubble-free torpedo firing did not yet mean that it could be implemented in practice, since the physics of launching a torpedo by a submarine in an underwater position has a number of nuances that cannot be resolved using electromagnetism by definition. This was the factor that influenced the Soviet government to limit work on the creation of electromagnetic torpedo tubes to only mock-up studies, the feasibility of what for the fleet was subsequently confirmed by the results of these studies. However, for Ukrainian scientists who were entrusted with carrying out the corresponding scientific project, more important than the practical confirmation of the possibility of electromagnetic launch of a torpedo were the validation and verification of the calculation and design methods they developed for linear electric machines, the improvement of which, based on the results of this particular project, made it possible to make a qualitative leap in the production of linear electric motors. Therefore, the creative team of researchers was interested not only in mock tests, but also in testing full-size prototypes of electromagnetic torpedo tubes, which would make it possible to test methods for calculating and designing linear electric machines with more accurate results, and also would give a greater margin of time for adjusting these methods due to the duration manufacturing cycle of these prototypes. The antagonism of the interests of customers and researchers on the issue of ways to implement the experimental part of the project indicates the skeptical attitude of the government in the second half of the 1930s to the relevance of the issue of developing the theory of linear electric machines. This allows us to consider the creation of linear electric motors for certain categories of equipment for the mining and construction industries mentioned in the historiography of Ukrainian electrical engineering of the studied chronological period as the fruit of the enthusiasm of Ukrainian electrical mechanical engineers rather than the result of a targeted sectoral scientific and technical policy of the Soviet government. Nevertheless, this achievement of domestic specialists in the field of linear electric machines undoubtedly became possible thanks to the use of the results of the work that they carried out as part of the implementation of project of electromagnetic torpedo tubes. And since these results were of fundamental importance for the development of the theory of linear electric machines, despite the revealed impossibility of their use to ensure bubble-free torpedo firing, the corresponding research project can be considered unsuccessful only in this context.

Funding.
This research received no external funding.

Conflict of interest.
The author declare no conflict of interest.

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Робота на Харківському електромеханічному і турбогенераторному заводі над проєктом електромагнітних торпедних апаратів (1936–1938 рр.)

Анотація. *Діяльність учених Харківського електромеханічного і турбогенераторного заводу над проєктом електромагнітних систем безбульбашкової торпедної стрільби впродовж 1936–1938 рр. на сьогодні є новою інформацією як для істориків науки і техніки, так і для спеціалістів у галузі електромашинобудування. Цей проєкт виник внаслідок збігу кількох обставин, одним з яких стала потреба радянського військово-морського підводного флоту напередодні II Світової війни в удосконаленні свого торпедного озброєння системами, що не демаскували б субмарини під час пуску*

торпед з підводної позиції. Іншою обставиною стало те, що Харківський електромеханічний завод з 1934 р. був головним підприємством у СРСР з виготовлення електромеханіки для кораблів усіх класів та для всіх об'єктів берегової оборони, а відповідно його адміністрація і той науково-технічний персонал, котрий на заводі займався оборонною тематикою, були обізнані за вказану проблему. Одночасно, частка співробітників з числа останніх, працюючи за сумісництвом у Харківському електротехнічному інституті, з першої половини 1930-х років поряд з проблематикою ротаційних електромашин активно розробляла напрям електромашин із лінійним рухом ротору, і досягла в цьому суттєвих результатів. Таким чином, до 1936 р. сформувалися умови, коли задовольняння потреби в забезпеченні радянських субмарин системами безбульбашкової стрільби стало теоретично можливим завдяки застосуванню електромагнітного пуску торпед, відповідно до методик, розроблених харківськими науковцями для лінійних електромашин, і з апаратів, оснащення яких виготовлювалося б на Харківському електромеханічному заводі. Проте ця теоретична можливість вимагала практичного підтвердження, для чого й було організовано проєкт «Торпедний виштовхувач магнітний», виконавцями якого стали ті самі спеціалісти, котрі займалися дослідженням лінійних електромашин як на Харківському електромеханічному заводі, так і в Харківському електротехнічному інституті. Метою проєкту стало: вибір можливого варіанту принципового устрою торпедної установки електромагнітної дії і перевірка працездатності побудованої згідно обраного варіанту конструкції за допомогою макетних випробувань. Проведені дослідження показали, що само по собі виштовхування торпеди з торпедного апарату в межах встановлених замовниками проєкту режимів можливо за допомогою біжного магнітного поля, однак електромагнітний пуск торпеди не робить його повністю безбульбашковим, а лише веде до зменшення об'єму утворюваної при пострілі повітряної бульби. При цьому, застосування електромагнітного пуску торпед на існуючих та проєктованих конструкціях радянських субмарин виявилося неможливим через значні зміни в такому випадку масогабаритних характеристик встановлюваного на них електроенергетичного устаткування. Між тим, такий же ступінь зменшення повітряної бульби вже був досягнутий у конструкціях пневматичних торпедних апаратів субмарин типу «Сталинец», спроєктованих за замовленням Радянського Союзу німецькими та голландськими конструкторами, що повністю позбавило проєкт торпедних апаратів електромагнітної дії своєї привабливості, і привело до його закриття. Проте, незважаючи на невдалу результативність цього проєкту в контексті створення системи безбульбашкової торпедної стрільби, його здійснення дозволило харківським ученим валідувати та верифікувати створювані ними методики розрахунків і проєктування лінійних електромашин, а також визначити оптимальні конструкції магнітофугальних статорів, що в наступному було використано *при створенні спеціального електромеханічного обладнання для гірничодобувної та будівельної індустрій.*

Ключові слова: *безбульбашкова стрільба; електромагнітний пуск; лінійні електромашини; субмарина*

Received 17.05.2024
Received in revised form 29.07.2024
Accepted 15.08.2024