S.A. Lebedev and the Birth of Soviet Computing

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In this article, we study the life and work of Sergei Alekseevich Lebedev, one of the world's pioneers in digital computing. Lebedev, working in Kiev, built the MESM, the first Soviet electronic digital stored-program computer (1947-1951). In 1950, Lebedev moved to Moscow, where he soon became the director of the newly established Institute of Precise Mechanics and Computer Technology. There he developed a long line of digital computers based on his work on the MESM. We examine in detail the first three of these machines: the BESM, the BESM-2, and the M-20. Lebedev achieved considerable success not only in the development of indigenous Soviet computers, but in the training of engineers, the founding of computer centers, and the establishment and nurturing of Soviet computing as a scientific discipline.

By the mid-1950s digital computers were being independently researched and developed by a number of Soviet scientists. This article is concerned with the work of the first and one of the most influential pioneers in Soviet computing, S.A. Lebedev. From 1947 to 1951, Lebedev designed and built the Soviet Union's first electronic digital stored-program computer in Kiev. The success of this project led Lebedev to devote the remainder of his career to high-speed electronic digital computers. Despite the fact that Lebedev's influence can be seen in many significant Soviet digital computer projects from World War II to the early 1970s, very little is known about him in the West. With a handful of exceptions,[1-10] few English-language works in the history of computing even mention Soviet developments. This article will attempt to remedy this situation by examining the life and work of Lebedev from roughly 1947 to 1958. During this period the first Soviet electronic digital stored-program computers were built, major computer research and development centers were established, and the first widely disseminated, serially produced Soviet computers were manufactured. Despite very difficult material and financial circumstances, Lebedev successfully designed and built an entire line of digital computers (see Table 1 on page 6) and firmly established electronic computing as a scientific field in the USSR by the late 1950s. It is hoped that through a close examination of Lebedev's life and early work, broader insights into the birth of Soviet computing can be gained.

Sergei Alekseevich Lebedev

Sergei Alekseevich Lebedev (1902-1974) was born on November 2, 1902, in the town of Nizhny Novgorod, Russia. In 1921, he entered the Electrical Engineering Department of the Moscow Higher Technical School (MVTU). While there, Lebedev specialized in high-voltage technologies. His undergraduate thesis, directed by Professor K.A. Krug, examined the relatively new problem of the stability of electrical power stations working in parallel. After graduating in April 1928, Lebedev became both a teacher at the MVTU and a junior scientific researcher at the newly established V.I. Lenin All-Union Electrical Engineering Institute (VEI), where K.A. Krug was the director. At VEI, Lebedev organized a laboratory dedicated to the investigation of electrical networks. A short while later, the Moscow Energy Institute was established, and Lebedev was named one of its first teachers. Throughout the 1930s, he continued to teach and conduct research at both VEI and the Energy Institute into the construction of electric power stations and the reliable transmission of electricity over high-voltage power lines.[11]

Lebedev's research in this area led directly to the need to solve complex mathematical equations, including systems of nonlinear differential equations. Lebedev and a number of other scientists at VEI began to investigate the possibility of solving such equations by mechanical means. One of these scientists was I.S. Bruk, who became interested in analog computing in 1936 after reading about the differential analyzer being built by Vannevar Bush at MIT.[12] Bruk designed his own differential analyzer, which he then constructed over the next several years.[13,14] Another of Lebedev's colleagues at VEI, L.I. Gutenmakher, also became interested in analog computation and built several differential analyzers in the late 1930s and 1940s.[15,16] Most of Lebedev's attention was focused on the construction of electric power stations; nonetheless, he was certainly aware of the work being done on analog machines by Bruk and Gutenmakher, as well as similar Western developments.

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In October 1941, VEI was evacuated to Sverdlovsk as Hitler's armies advanced. Upon his return to Moscow in 1943, Lebedev became the head of a new department at VEI for the automation of electrical systems. One of Lebedev's biographers, academician V.M. Glushkov, goes as far as to suggest that Lebedev himself directed the construction of an analog differential analyzer at this time (1945).[11]* Regardless of whether Lebedev was directly involved in the construction of analog computers at VEI, his work on electric power made him acutely aware of the growing demand in science and engineering for the solution of mathematical problems by mechanical means.

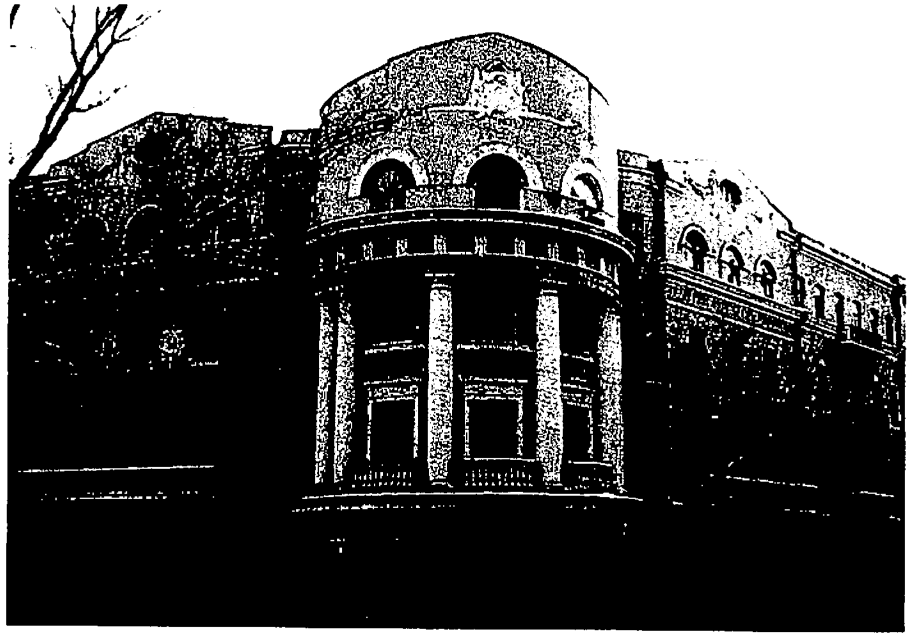

Figure 1. The original site of the Institute of Electrical Engineering (IET), Ukrainian Academy of Sciences, Kiev.

The MESM

In May 1946, Lebedev was appointed the director of the Institute of Energy of the Ukrainian Academy of Sciences in Kiev. Upon his arrival, he initiated a regular seminar aimed at easing the burden of the scientific calculations required for the institute's research. Based on Lebedev's previous experiences at VEI, the group's initial investigations were aimed at producing analog devices. By early 1947, however, Lebedev increasingly turned his attention to digital computing. The seminar he established at the Institute of Energy played a key role in this transformation. Over the next several years, numerous prominent mathematicians, electrical engineers, and physicists participated in this seminar, including B.V. Gnedenko, A.Iu. Ishlinskii, M.A. Lavrent'ev, I.B. Pogrebinskii, and A.A. Kharkevich.[17,18] Many of the concepts and principles that were subsequently incorporated into the USSR's first electronic digital computer, the MESM (*Malaia Elektronnaia Schetnaia Mashina* — Small Electronic Calculating Machine) were discussed and refined at this seminar. S.B. Pogrebinskii, who went on to work on numerous computer projects, presented lectures summarizing Soviet and foreign work on analog and relay computers. A.A. Kharkevich, a physicist, spoke about the development of magnetic recording of electronic impulses.[17] In 1989, mathematician B.V. Gnedenko told us that a number of Soviet mathematicians made presentations on the types of problems that an electronic computer would be useful in analyzing and helped to develop numerical methods by which they could be solved. Other ideas that were soon discussed included the concept behind a stored-program computer, the hierarchical organization of memory, and vacuum-tube circuit design.

By the middle of 1947, more specific design questions were being discussed, such as the advantages and disadvantages of floating-point versus fixed-point and binary versus decimal numerical representation, word length, and different command-address structures. At that time Lebedev and his colleagues were in favor of building a binary machine with a three-address command structure and floating-point numerical representation. Several people argued, however, that a fixed-point design with a small word length (17 bits including the sign) would be sufficient for many problems and far easier to engineer.[17,18] (Floating-point representation was indeed abandoned, although the word length on the MESM was later increased to 21 bits to accommodate many of the ballistic problems the MESM was used to solve.)

About a year after Lebedev was appointed director, in May 1947, the Institute of Energy split into two institutes: the Institute of Thermal Energy and the Institute of Electrical Engineering (IET) (Figure 1). Lebedev became the director of the latter. Shortly thereafter, he began work on the construction of the MESM. With the help of academician M.A. Lavrent'ev, then vice president of the Ukrainian Academy of Sciences, Lebedev convinced the presidium of the academy to set up a special, secret laboratory within his institute for the purpose of investigating electronic computers. The laboratory was called Laboratory Number 1 for Modeling and Control and was formally established on May 16, 1947.**

* This is the only source we are aware of that claims that Lebedev actually directed the construction of an analog computer.

** *Laboratoriia No. 1 dlia modelirovaniia i regulirovaniia.* The name of the laboratory varies slightly from one source to another. Dashevskii and Shkabara[17] call it the "Laboratory of Special-Modeling and Computer Technology." In the Archives of the Institute of Electrical Dynamics of the Ukrainian Academy of Sciences, it is referred to as the "Laboratory of Electronic Calculating Machines," as well as the Laboratory for Modeling and Control. Most often, it is simply referred to as Laboratory No. 1.

Table 1. Main computers developed by S.A. Lebedev.

Machine name	Year of prototype	First year of serial production
MESM	1951-1952	—
BESM-1	1953	—
BESM-2	1958	1959
M-20	1958	1959
BESM-3M/BESM-4	1963-1964	1964
BESM-6	1964-1967	1967

Figure 2. Lev Naumovich Dashevskii.

Once he had received funding, Lebedev set about organizing and staffing his laboratory. By early 1948 there were nine or ten people working in the laboratory. The majority of them had never heard the term "electronic calculating machine" when they joined the laboratory. In an interview with the authors in 1990, S.B. Pogrebinskii and Z.L. Rabinovich, another of Lebedev's young apprentices, recalled the day in August 1948 when Lebedev summoned them to his office and informed them that from that day forward they would be working on the design and construction of an electronic digital computer. At first, both assumed that Lebedev was referring to some sort of arithmometer, and it was some time before they fully understood the implications of their new field of work. Only a couple of the people working in the laboratory had even a superficial familiarity with the work being done in the Soviet Union and abroad on analog machines for solving differential equations. Most were young, and all but one were specialists in radio electronics who had graduated from the Kiev Polytechnic Institute just before the war. Only two possessed graduate degrees, and both of these had only just been defended.[17]

Hence, most of 1948 was spent training these new recruits in the basic principles of electronic computing: the binary system, the properties of vacuum tubes, the stored-program concept, and so on. This was done in a seminar format, led by Lebedev; members of the Institute of Mathematics and the Institute of Physics of the Ukrainian Academy of Sciences also participated. By late 1948, this group had been trained and together with Lebedev completed the basic design of the machine they would build.[19]

In early 1949, the size of the laboratory was increased to approximately 20 people. This allowed Lebedev to divide his team into smaller groups of three or four people, each responsible for working on an individual unit of the machine. By April 1949, Lebedev and L.N. Dashevskii (Figure 2), building on work done over the previous year, perfected the design of the flip-flop circuits that would form the basis of the arithmetic unit. Investigations were also conducted into the generation of steady electronic impulses for the machine's clock. The basic design of the control circuits, a first draft of the arithmetic unit, and many of the features of the main memory were also completed in early 1949.[19]

At the same time, Lebedev was faced with a difficult problem in war-torn Kiev: where to build the machine. Kiev had been particularly hard hit by the war, and nearly everything was in short supply. One of the most severe shortages was in housing and building space. Dashevskii's widow, A.A. Dashevskaia, described in 1990 how her husband was forced to work at the only small table in their one room in a communal apartment, and how he cheerfully chanted "flip-flop, flip-flop" as he labored. Amidst nearly constant interruptions from those who had to walk through the Dashevskiis' room to get to their own, Dashevskii diligently worked on the design of the MESM's arithmetic circuits. Despite the fact that Dashevskii was a decorated war veteran and a Communist party member, the housing shortage was so severe that he was unable to get an apartment of his own.

It is also worth pointing out that very few people within the academy, and even fewer outside of it, were convinced that Lebedev's laboratory should be made a high priority. In the late 1940s, almost no one anywhere in the world recognized the potential of digital computers. Despite the heavy Soviet investment in science and technology in the immediate postwar years, Lebedev had to struggle for financial and material support. In this regard, M.A. Lavrent'ev played a decisive role. He appealed to the Ukrainian Academy of Sciences for space, and in early 1949 a former monastery in the Kiev suburb of Feofaniia was made available.[17]

The Feofaniia Monastery had suffered severe damage during the war, and when Lebedev moved his collective there in the summer of 1949, the working conditions, to say the very least, were extremely primitive. The building contained no furniture of any kind, and there was a complete lack of central heating. Although several of the rooms in the monastery contained wood-burning stoves, the engineers themselves were forced to chop the wood to fuel them.

Another serious obstacle was simply getting to Feofaniia, which is located about 15 kilometers outside Kiev. At that time, there was no public transportation to and from Feofaniia, nor even paved roads. Hence, a small, old Soviet truck called a *gazik* was acquired to transport the engineers back and forth. As often as not, the *gazik* would get stuck in the mud in the spring and fall or in the snow in the winter, and the entire group would be forced to disembark and push.[17]

One final problem that had to be solved before the MESM could be built concerned the size of the machine. It was estimated that the machine would require 50 square meters of space — more than any single room in the monastery. To

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solve this problem, a construction crew had to be brought from Kiev, and one of the walls separating two of the rooms had to be knocked down. The ceiling between the first and second floors had to be removed as well, because the projected height of the machine exceeded that of the two rooms.[17]

By the end of 1949, the main framework for the MESM was in place. Work continued on individual units of the machine in early 1950 and began on the construction of a control panel.[20] In late spring and summer, individual units were installed in the machine and linked together, and testing began. During testing, a number of unexpected problems arose. For example, at one point it became clear that loose wires were charging the machine's housing. If great caution was not exercised, coming into contact with the machine could cause one to receive a 250-volt shock. To alleviate this problem, a special insulating shield between the machine and its metal frame had to be developed.[17]

Another serious problem concerned the roughly 6,000 vacuum tubes used in the machine. The flip-flop circuits, which formed the core of the arithmetic unit, required tubes of a single type operating in parallel. There was little uniformity in the production of the tubes, however, and it was rare for two tubes, even of a single type, to have the same characteristics. Consequently, for each flip-flop circuit, hundreds — and sometimes thousands — of tubes had to be tested. Further, even after a particular tube was deemed acceptable, the characteristics would often change over the life of the tube. A partial solution to this problem was adopted whereby all of the vacuum tubes destined for use in the machine would be placed in special waiting stands where their characteristics would be "trained" for 30 hours. A third problem with the tubes was their tendency to "swing" for about two hours each morning after the machine was turned on. This problem was quickly alleviated by leaving the machine on 24 hours a day. Initially this meant leaving a guard with the machine over night due to the fear that the machine would catch fire while unattended. Soon, however, engineers were working on the machine in round-the-clock shifts, and from that time on the machine was in continuous use except when it was down for maintenance. Finally, because the vacuum tubes generated a large amount of heat, the temperature in the machine room would often hit 30°C in the winter and as high as 40°C during the summer. The building contained no air conditioning, and the machine was cooled only by forced air from fans. In the summer, however, the heat often became so extreme that the tubes began to give off random impulses and the machine had to be turned off and cooled.[17]

By November 1950, although the arithmetic unit still required some further development and the operational memory was not large enough for any problem of practical significance, the MESM was ready for its first test as a fully assembled machine. (Figures 3 and 4 show the MESM.) On November 6, 1950, it solved its first simple problem.[18,19] *

Figure 3. L.N. Dashevskii (seated) and another engineer at the control panel of the MESM.

Figure 4. B.V. Gnedenko (standing) and L.N. Dashevskii at work on the MESM. This photo appeared in the journal *Ogonek* in 1952 with the caption, "In the place of a million calculators."

Two of the engineers working on the MESM at this time describe one of the machine's early successes[17] (p. 46):

> And thus, finally, our MESM began to take its first working steps. Merely to think about the question given to it from the control panel: "How much is 2 × 2?" — to the great joy of all of us, it almost always answered "4."**

During the last two months of 1950, additional memory was added, and the operations of addition, subtraction,

* To the best of our knowledge, there is no record of what this first problem was, but the date of November 6, 1950, is fixed both by Lebedev and his coworkers. In all likelihood it was a simple arithmetic problem, since the machine contained only a temporary, experimental memory of a few words at that time.

** All of the translations in this article were made by Gregory Crowe.

multiplication, and comparison were improved. On January 5, 1951, the MESM was demonstrated to a commission of scholars from the Ukrainian Academy of Sciences that included the chief secretary of the presidium, academician I.T. Shvets; the Communist party secretary of the academy, F.D. Ovcharenko; Lebedev; and others. To commemorate the event, the commission signed an official "Act," which testified that the machine successfully completed the following operations:

1. The addition of two numbers with the output of the result to memory.
2. The subtraction of two numbers with the output of the result to memory.
3. The multiplication of two numbers with the output of the result to memory.
4. The repeat addition of a given number *i* times.
5. The repeat multiplication of a given number *i* times.
6. The calculation of the sum of an uncountable series [*neschetnyi riad*] of *i* members (*i* was given arbitrarily within the limits of the numbers that existed on the model).[21]

Figure 5 shows a plaque at the original site of the IET that commemorates Lebedev's work on the MESM.

At this time, the original goals of the MESM project were fulfilled. Lebedev's initial purpose in creating the MESM was to develop a small, prototype model that would allow him to test his ideas before devoting large amounts of time, energy, and resources to creating a high-speed computer. Before it was successfully demonstrated in January 1951, the MESM was not intended to be a fully functioning, stored-program computer capable of useful applications and practical problem solving. In a report to the president of the Ukrainian Academy of Sciences, Lebedev summarized the work his group had done in the following way[22] (p. 14):

> In '48-'49 I worked out the basic principles of the construction of such a machine. Taking into account the exceptional significance of high-speed electronic calculating machines for our national economy {and especially for military technology} and also the absence here in the [Soviet] Union of any kind of experience in building and operating them, I decided to create as quickly as possible a small electronic calculating machine on which it would be possible to investigate the basic principles of [computer] construction, to verify the methods of solving individual problems, and to accumulate operational experience. In connection with this, it was decided originally to create a functioning model [*deistvuiushchii maket*] of the machine with the goal of transforming it in the future into a small electronic calculating machine.*

This change in goals of the MESM project reflects both the significant initial uncertainty about the endeavor and the rapid pace of achievements in digital computing throughout the world. First-generation digital computers such as the ENIAC or the MESM were the most complex electronic devices ever built at that time. In addition, the vacuum tubes, which were needed by the thousands, were notoriously unreliable. Although it seems hard to imagine today, the possibility that these machines would simply not work well enough to be of practical use was real indeed.

Even before Lebedev had demonstrated that the model MESM worked in practice, however, this had changed, and he began to work on the design of a high-speed computer. This was the start of the BESM project (see below). At the same time he was designing the BESM, Lebedev realized that it would be a number of years before such a project could be completed. In light of this, he simultaneously oversaw the transformation of the MESM from a functioning model to a fully working machine capable of solving real problems.

This work began in earnest in January 1951. The most significant improvements the MESM required involved increasing both the main and auxiliary memory and the addition of input and output units.[22] In particular, Lebedev and his two chief engineers felt that seven essential improvements would have to be made to the MESM[23] (pp. 17-18):

1. Increase the size of the main memory and introduce a permanent system of numerical and command representation
2. Add a number of commands, including an operation for the transfer of control from the main program to a subprogram, and develop and construct new parts of the machine related to their introduction.
3. Add a special unit for rounding off results.
4. Add auxiliary memory devices and a method for the automatic recording of results from the main memory. (In the model, the results had to be read from the machine visually.)
5. Add a teletypewriter for the automated input of data.
6. Introduce an automatic voltage regulator in the power supply of the machine.
7. Replace certain parts of the machine shown to be too unreliable for extended use.

* In the carbon copy of this document in the Archive of the Institute of Electrical Dynamics, Kiev, Lebedev crossed out the phrase in squiggly brackets {} referring to military applications. The same shift in goals is discussed in another archival document.[23] This evolution of purpose for the MESM can also be seen in the naming of the machine[17] (pp. 46-47):

"Sergei Alekseevich [Lebedev] decided to name our machine MESM (Model [*Model'*] of an Electronic Calculating Machine), since its original purpose was to test the correctness of the basic design trends of program-controlled electronic digital calculating machines, to accumulate experience in the assembly of individual units...and to gain experience in programming computers.

"However, subsequently the MESM outgrew this purpose. Once a series of very important problems had been solved on it, it was decided to rename it the Small Electronic Calculating Machine; however, its acronym did not change because of this."

Both model (*model'* and *maket*) and small (*malaia*) in Russian begin with the letter "M."

It was hoped that the improvements would be completed by the end of 1951. The greatest difficulty that Lebedev encountered was in convincing others that his work on digital computing was vitally important and deserved top priority. Two conflicts that arose during 1951 illustrate this clearly: the Ukrainian Academy's desire to transfer Lebedev's laboratory to Moscow, and delays in acquiring a magnetic drum for the MESM.

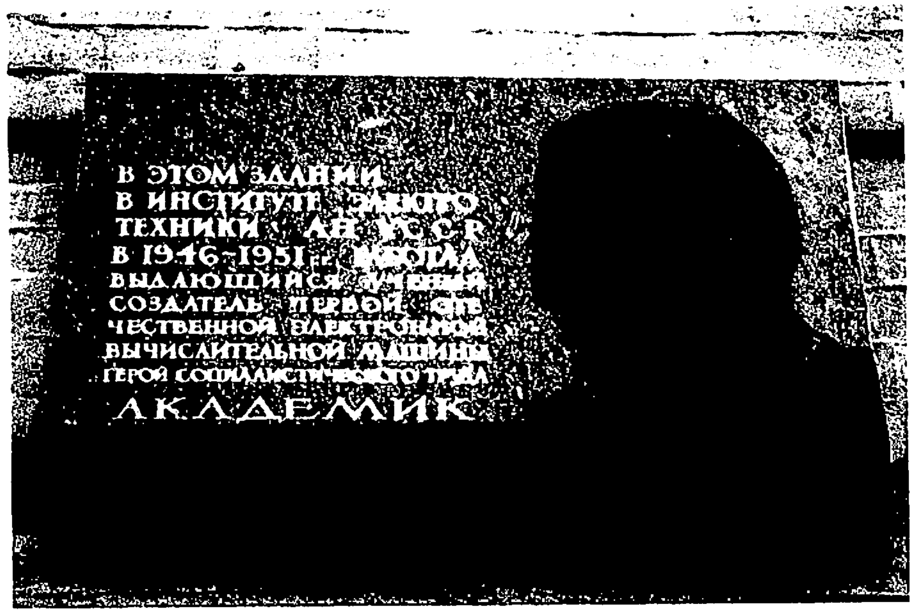

Figure 5. A plaque at the original site of the IET. It reads, "In this building, in the Institute of Electrical Engineering, Academy of Sciences, Ukrainian SSR, from 1946-1951, worked the outstanding scientist and creator of the first indigenous electronic calculating machine, a Hero of Socialist Labor, Academician Sergei Alekseevich Lebedev."

Despite initially providing material and financial support for Lebedev's laboratory, and the success of the MESM test in January 1951, sometime during that month or early February, A.V. Palladin, president of the Ukrainian Academy of Sciences, suggested that Lebedev move his laboratory to Moscow. The formal tone and strong language Lebedev used in his reply seem to indicate that Palladin wanted to get rid of Lebedev and his laboratory. Lebedev responded that the interruption caused by a move would put the project five months behind schedule. In addition, a number of important scientific problems were in the process of being solved on the MESM, and if the machine were moved to Moscow, they would have to be suspended. Finally, Lebedev pointed out that the collective experience of his engineers in Kiev was indispensable to the effective operation of the MESM, and at least in the short term irreplaceable in Moscow. He therefore concluded that transferring the MESM to Moscow was "completely irrational" and would result "not in the acceleration of work on electronic calculating machines, but rather its retardation [*tormozhenie*]." He closed his letter by urging Palladin to provide him with the necessary support to complete his work on the MESM in a timely fashion.[24]

Palladin acquiesced, but support from the Ukrainian Academy was still slow in coming, as is evidenced by the difficulties Lebedev encountered in obtaining auxiliary storage devices for the MESM. In the middle of 1950, Lebedev asked A.A. Kharkevich of the Institute of Physics of the Ukrainian Academy of Sciences to develop a magnetic drum and tape drive that would serve as the MESM's main external storage units. At the time, Kharkevich was the head of the laboratory that was investigating the physics of recording electronic impulses on magnetic materials.[17] He was also familiar with Lebedev and his work through his active participation in Lebedev's early seminars on the principles of electronic computing; hence, he was a logical choice. Kharkevich had promised to deliver the drum to Lebedev by early 1951, but encountered difficulties and repeatedly asked for more time. When by April 1951 the drum was still not completed, Lebedev began to complain openly and bitterly. The primary cause of his anger was his belief that the main reason for the delay was Kharkevich's lack of effort, and not any unforeseen technical problem.[22]

At the beginning of August 1951, Lebedev accepted a resolution of the Council of Ministers of the USSR to complete a fully operational small electronic computer during the fourth quarter of 1951.[25,26] This made the delays in acquiring the drum even more serious. Armed with the Council of Ministers resolution, Lebedev issued another appeal in October 1951, this time to the vice president of the Ukrainian Academy, N.P. Semenenko.[27] In his letter, Lebedev complained not only about Kharkevich's failure to complete the drum, but about a number of broken promises by the academy as well. In particular, Lebedev wrote that the failure of the academy to repair the central heating unit at Feofaniia and to provide military protection for the laboratory could jeopardize the project. The drum eventually was completed in late 1951, while Lebedev's group developed their own magnetic-tape drive for the MESM.*

The lack of enthusiastic support that Lebedev encountered from Kharkevich and the academy illustrates an important point about digital computing in the USSR in the late 1940s and early 1950s. At first glance, Palladin's 1951 desire to have Lebedev's work transferred to Moscow seems quite remarkable. Research and development of digital computers would eventually become a high-priority field with significant applications for science, industry, and espe-

* Two of Lebedev's coworkers claim[17] that he was successful in his demands only after turning to the Communist party for help. They argue that Kharkevich completed the drum only after the Institute of Physics had been criticized for the delay by the party apparatus within the academy.

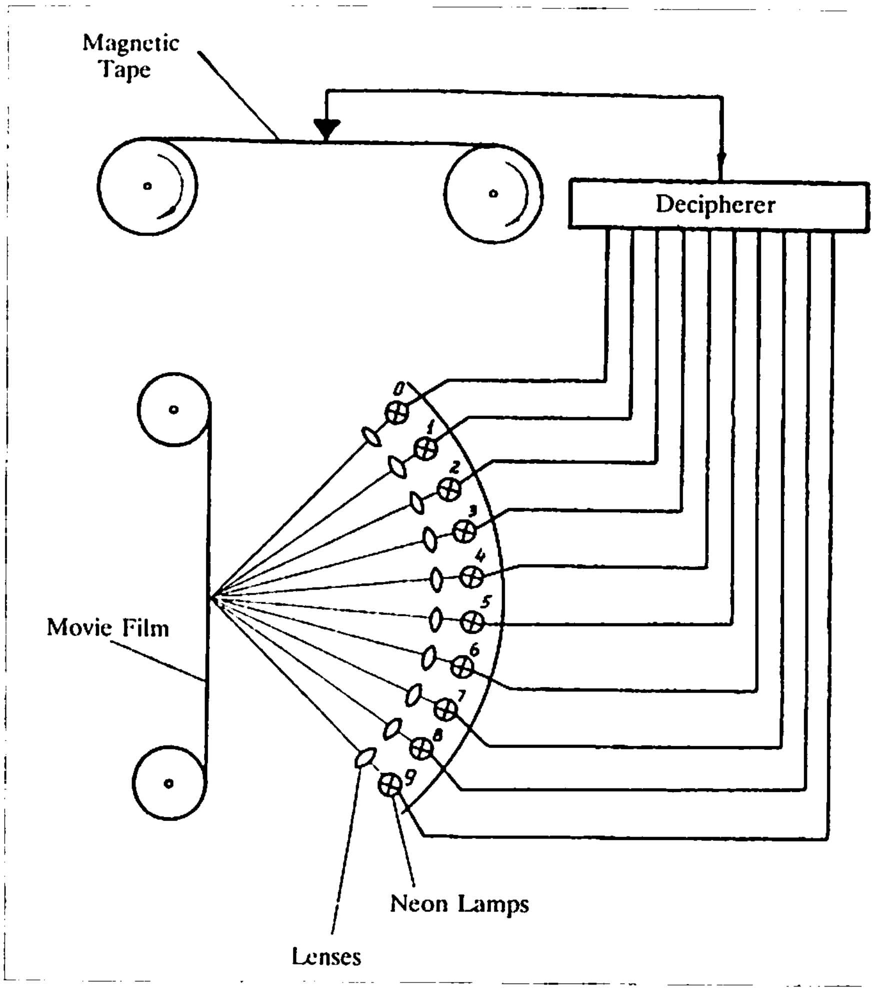

Figure 6. A schematic diagram illustrating the operation of the photoprinter[31] (p. 31).

cially the military. At a time when the Cold War was already raging and Stalin was devoting vast resources to the development of the atomic and hydrogen bombs, the added prestige — not to mention the perks — of overseeing and controlling a project with major military implications would surely have been appealing to Palladin. But one must remember that the value and significance of digital computing in 1951 were far from obvious. As already mentioned, numerous scientists in the Soviet Union and the United States initially believed that such complex devices would never be reliable enough to work, let alone be usefully applied.[28,29] Many others believed that analog computing with its proven success at solving differential equations in the later 1930s and early 1940s held greater potential. And still others argued for some time to come that special-purpose computers designed for a specific set of tasks would be more effective, more reliable, and easier to build.[29,30] Even Lebedev must have harbored some initial reservations, as can be seen in his desire to build a prototype MESM before embarking on the construction of a fully functioning computer.

An interesting consequence, in part a result of the delays in acquiring the magnetic drum and in part of the original lack of input/output devices, was the decision to develop a special printing device called the photoprinter (*fotopechat'* or *fotopechataiushchee ustroistvo*). This device, along with a punched-card reader, was developed in the first quarter of 1951 at the Institute of Precise Mechanics and Computer Technology (ITMVT) in Moscow by a group of scientists under Lebedev's direction.[22]

The photoprinter worked in the following way (see Figure 6): First, a calculation was carried out on the MESM and the results were recorded onto magnetic tape. This tape was then transferred to the photoprinter, where it was read by a special deciphering circuit. Depending on the result, this circuit would activate briefly one of 10 neon lamps, each of which had imprinted on it a single digit from 0 to 9. The light from the lamp was then directed through a system of lenses for magnification and finally used to expose a section of movie film. Once the film was developed, it could be shown in a projector and the results read off the wall or a screen, or it could be used to print the results photographically for more permanent, written storage. The nominal speed of the photoprinter was 200 digits per second, making it far faster than the electromechanical printer that was developed for the MESM at about the same time.[31]

By late 1951 the modifications necessary to make the MESM a fully functioning, operational computer were nearing completion. In December, a commission of the Soviet Academy of Sciences led by academician M.V. Keldysh and including academicians S.L. Sobolev and M.A. Lavrent'ev, came to Feofaniia to test the MESM. The commission stayed for three days, during which the MESM was extensively exercised.[17] On December 25, 1951, the commission formally accepted the MESM for full operation. Following reports by Lebedev to the presidiums of the Soviet and Ukrainian Academies of Science, the MESM was deemed successfully completed on January 12, 1952.[19,20]

At the time it was accepted into formal operation, the MESM had an average speed of 50 operations per second.* It used fixed-point binary numerical representation and a

* This was about half as fast as they had originally hoped. Initial design targets called for a speed of 100 operations per second. Here, as well as in the case of using floating-point numerical representation, a compromise had to be made during the construction of the machine.[22]

Table 2. Characteristics of early Lebedev machines.

Computer	Numerical representation	Circuitry	No. of addresses	Word length	Internal storage	Tape drive*	Magnetic drum*	Input	Output	Size (sq. meters)	Power consumption	Operations per second
MESM	Fixed-point binary	Tubes	3	17 for numbers, 20 for commands	Tubes: 31 numbers, 63 commands	1, up to 250,000 words	1 @ 5,000 words	Punched cards	Mechanical printer, photoprinter	60	25 kW	50
BESM-1	Floating-point binary	Tubes	3	39: 32 mantissa, 5 order, 2 sign	Delay lines/CRTs: 1,024 words	4 @ 30,000 words	1 @ 5,120 words	Punched tape	Mechanical printer, photoprinter		75 kW	1,000 with delay lines, 7-8,000 with CRTs
BESM-2	Floating-point binary	Tubes/semiconductors	3	39: 32 mantissa, 5 order, 2 sign	Ferrite cores: 2,048 words	4 @ 30,000 words	2 @ 5,120 words	Punched tape	Mechanical printer			7-8,000
M-20	Floating-point binary	Semiconductors	3	45 bits	Ferrite cores: 2,048/4,096 words	4+ @ 75,000 words	4+ @ 4,096 words	Punched cards	Mechanical printer, punched cards	150	50 kW	20,000

* The first number is the number of external devices; the second is *each* device's capacity.

three-address command system. Its arithmetic unit was based on flip-flop circuits built from vacuum tubes and was parallel in operation. It had a word length of 17 bits for numeric values (16 plus one for the sign) and 20 bits for commands (4 for the operation, 5 for the first address, 5 for the second address, and 6 for the third). The main operating memory, also based on flip-flop circuits, consisted of two parts. The first part had space for 31 numerical values and 63 commands. The second memory section was of the same size, but read-only. In addition, there was auxiliary memory consisting of a magnetic drum with a capacity of 5,000 words (Figure 7 shows a first-generation magnetic-disk drive) and a magnetic-tape drive used only for the input of initial data or the output of results (the tape drive had a maximum capacity of 250,000 words, depending on the length of the tape, which varied). The possible operations included addition, subtraction, multiplication, division, shift, comparison of two numbers, comparison of the absolute values of two numbers, transfer of the program from central to local control, transfer of a number from the magnetic drum to the main memory and vice versa, the reading of a number or command from the read-only memory, and stop.

Input was normally accomplished by punched cards or by directly punching in codes on the accumulator or via magnetic tape. Output was sent to the tape drive, the photoprinter, or a slower electromechanical printer. The machine occupied approximately 60 square meters, contained 3,500 triode and 2,500 diode vacuum tubes, and consumed 25 kW of power.[32] (Table 2 shows the characteristics of the MESM and the other computers we focus on in this article.)

Lebedev and Western computing

Given that by the early 1950s a number of different computer projects were under way or had been completed in the West, the nature of East-West relations at that time, and the military importance of computer technology, the question may arise: How independent was Lebedev's work on the MESM from Western computer projects? Soviet scholars often raise this question explicitly and are unanimous in their claims that Lebedev worked "absolutely independently"[11] from Western efforts on the construction of the MESM, that his design of the MESM was "new, original, [and] his own,"[33] and that he arrived at the stored-program concept "by an independent path"[18] from John von Neumann. In investigating the origins of computing, Western scholars, unfamiliar with Lebedev's work, grant priority to American and British efforts, and to John von Neumann in particular, for having introduced the stored-program concept.[28,34-36]

The question of the independence of Lebedev's work as well as its significance for the development of Soviet computing is relevant, especially in light of Soviet efforts in the late 1960s and 1970s to copy explicitly the architecture of the IBM 360. To evaluate Western influences on Lebedev's work, it is necessary to discuss what was known about

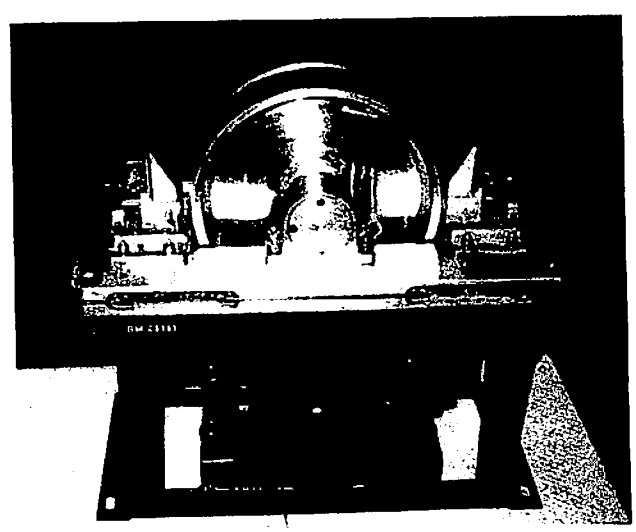

Figure 7. A first-generation Soviet magnetic-disk drive, now in the Polytechnical Museum, Moscow.

Western computing in the USSR at the time Lebedev was designing the MESM (1946-1951).

A.P. Ershov and M.R. Shura-Bura, in an article on the history of Soviet programming, argue that the original Western sources on the stored-program computer concept were unavailable in the Soviet Union at this time (and remain difficult to find even today). For example, John von Neumann's "First Draft of a Report on the EDVAC," written in the spring of 1945 and circulated in manuscript form among the ENIAC scientists that summer, remained unpublished for a number of years.[28,34,36,37] The lectures given in the summer of 1946 at the Moore School[38] where the ENIAC was built also were not widely disseminated. The early works of A.W. Burks, H.H. Goldstine, and John von Neumann[39,40] at the Institute of Advanced Study were difficult to obtain as well. Ershov and Shura-Bura do note, however, that by late 1947 and 1948 a number of indirect descriptions of stored-program computers became available in the USSR through Western journals.* In addition, the proceedings of the widely acclaimed Harvard symposium on digital computing chaired by Howard Aiken, which appeared in 1948, were available in the USSR a short time later.

The first description of Western electronic digital computers to appear in the Russian language was published by M.L. Bykhovskii.[41] This brief article, based on two small announcements that appeared in *Popular Science*, described the Harvard Mark I (ASCC) and the ENIAC. As Ershov and Shura-Bura point out[9] (p. 142), however, Bykhovskii's article

> contained no speculative comments on the material and its title seemingly indicated an analogy with punch[ed]-card equipment (a literal translation of the Russian term used in the title would be "calculating and analytical machines") instead of stressing the birth of a new concept in automatic computation.

In 1948, Bykhovskii also translated a slightly more detailed article on the ENIAC by D.R. Hartree,[42] although it did not discuss the stored-program computer concept either. A year later, in May 1949, on the basis of the Western literature available to him, Bykhovskii published a longer review article on the principles of electronic computing that clearly recognized the significance of the stored-program concept.[43] **

If Lebedev himself and those in the MESM laboratory are to be believed, the Western literature they were able to obtain while they were building the MESM provided little of value. E.A. Shkabara, one of Lebedev's closest assistants and a coauthor of nearly all his early works on computing, recently explained the value of Western literature to us in the following way:

> Yes, we occasionally did receive Western publications, especially engineering and other journals, but often only after significant delays. I would not say that it directed our efforts, but it was often nice to find confirmation of the fact that the lines that we were following were being pursued in the West as well.

Lebedev himself painted a similar picture. On January 8, 1951, he presented a report on the MESM to a closed session of the scientific council of the Institutes of Electrical Engineering and Thermal Energy of the Ukrainian Academy of Sciences. In it he stated that he had information about 18 different computers in the United States, but that this material was of a promotional nature only. After presenting the report, he was questioned further about what he gained from Western literature, to which Lebedev replied[44] (p. 5): "Making use of foreign experience is very difficult since published information is highly inadequate [*ves'ma skupye*]."

In the late 1940s and early 1950s, however, there was intense political pressure on Soviet scientists to belittle the accomplishments of Western scholars. With the arms race and Cold War in full swing, A.A. Zhdanov, a full member of the Politburo, with Stalin's approval, launched a campaign against "idealism" and "cosmopolitanism" in Soviet science. An insistence that Soviet scientists reject all Western contributions in their work was often a leading plank of this campaign. The most notorious example of this ideologization and monopolization in science was the rise of T.D. Lysenko and the defeat of genetics; however, similar efforts were being made in astronomy, physics, chemistry, physiology, economics, and other fields as well.[45] It therefore seems unlikely that even if Lebedev had relied heavily on Western materials that he would have admitted it openly.

In examining the value of Western sources to Lebedev, one must at least consider the possibility that Lebedev may have had access to both published and unpublished information gathered overtly or covertly by Soviet intelligence agencies. This was a period of intense Soviet collection efforts of Western scientific and technical information; their success in obtaining information about the American atomic bomb project, for example, has been well documented.[46-48] Given the obvious potential applications of high-speed computing in atomic energy, space exploration, and the military in general, it seems likely that Stalin's government also would have targeted British and American computer projects. Further, as the leading Soviet scientist in computing in the late 1940s and early 1950s, if such information were available, Lebedev would surely have had access to it.

It is difficult to determine with any certainty what influence this information, if it did exist, and the early published sources had on Lebedev at the formative moments when he was designing the MESM. The MESM was under construction by May 1949, and Lebedev may have completed the design as early as the end of 1947. Thus, of the published literature, only the Western sources mentioned above and Bykhovskii's 1947 and 1948 articles on the ENIAC would

* The journal *Mathematical Tables and Other Aids to Computation*, for example, published a number of brief descriptions of Western computers from 1946 to 1948 and was available in the USSR. The journal also reviewed the volume on the Moore School lectures and the works by Burks, Goldstine, and von Neumann.

** Bykhovskii's article[43] did not mention any Western machines by name, nor did it provide any references; however, it did lay out the basic physical and logical elements of stored-program computers.

have appeared in time to be useful to Lebedev. It is doubtful therefore, at least in designing the MESM, that Lebedev was able to learn much from Western work in computing. It should also be noted that even broad access to detailed Western literature would not mean that it was of immediate practical value. "When the flip-flop circuit of the ENIAC was published in a journal," P.P. Golovistikov, a young engineer working at ITMVT in 1949, explains[29] (p. 31), "I tried it out. In the form in which it appeared in the journal, however, it didn't work. I was forced to change fundamentally its parameters." Golovistikov goes on to state that in testing the published ENIAC design, all of the basic features of vacuum-tube circuits had to be redeveloped in accordance with the tolerances of the Soviet components. The essential point here is that constructing a computer, even given a proven design, is no simple matter, especially when the available components are vastly different from those used in the original machine.

This is not to say that at no time did Western work have any impact on Lebedev, or to imply that he worked in a vacuum, unaware of Western developments. Although the number and availability of Western sources were limited in 1948 and 1949, this was clearly not the case several years later. In addition, as we shall see, many Soviet approaches to particular engineering problems (e.g., the evolution of reliable forms of memory) paralleled and, for the most part, came after those developed in the West. As already mentioned, however, it is one thing to know, for instance, that electric impulses could be "stored" in tubes filed with mercury, and quite another to actually construct a computer memory of mercury delay lines.

Further, it would be a mistake to claim that Lebedev was only, or even largely, interested in copying Western technology. Lebedev sought not only to build computers, but to establish computer engineering and programming as a fundamental area of Soviet scientific research. For this reason, in addition to designing computers, Lebedev also taught courses and trained specialists, sponsored conferences, helped establish, and later directed, the USSR's first institute dedicated to computing, and edited a large number of works on computing. It was his belief that the long-term advantages of indigenous research and development outweighed any short-term benefit that might be gained by mechanistically copying Western designs. Throughout his life, Lebedev remained an advocate of the indigenous development of computers. The clearest example of this commitment came in the late 1960s, when the Eastern Bloc nations, led by the Soviet Union, agreed to develop a unified system of third-generation computers called the ES or Riad computers.[5] After considerable debate, it was decided to base the ES architecture on a direct duplication of the IBM 360. Lebedev was the leading advocate of choosing an indigenous architecture. Despite intense political pressure, he remained adamantly opposed to this decision, and even after it was formally adopted, he and his institute continued to conduct research and development into indigenous Soviet architectures.

The issue of whether Lebedev developed the stored-program concept independently from those who formulated it in the West remains an open one. One thing is clear, however: The MESM was not simply a copy of a Western machine. Whether the initial impetus for the MESM came from knowledge of Western computer projects or completely from Lebedev's mind is of little importance. Its architecture was original, and the successful construction of the MESM allowed Lebedev to develop, test, and refine his ideas about high-speed electronic digital computing. The knowledge he gained served as the basis for the development of indigenous Soviet computer technology over the next two decades.

Lebedev believed the long-term advantages of indigenous research and development outweighed any short-term benefit that might be gained by copying Western designs.

Application and improvement of the MESM

As soon as the MESM was accepted into full operation in January 1952, it began to solve a wide variety of practical problems. Numerous mathematicians and the earliest Soviet programmers traveled to Kiev to work on the MESM, including A.A. Dorodnitsyn, B.V. Gnedenko, M.V. Keldysh, M.A. Lavrent'ev, A.A. Liapunov, M.R. Shura-Bura, and others.[49,50] Two areas in which they actively applied the MESM were ballistics and rocket technology, where it was seen as "manna from heaven."[17] Other areas of application included nuclear energy, the reliable transmission of high-voltage electricity over large distances, problems relating to the strength of mine structures, highway engineering, ballistic problems, and statistical analysis. The most often cited early problem solved by the MESM was one that related to Lebedev's early training in electric power: the solution of a system of nonlinear, second-order differential equations that defined the stability of the high-voltage power lines between the Kuibyshev Hydroelectric Station and Moscow.[32]

From November 1952 until late July 1953, an important group of scientists led by academicians A.A. Liapunov and A.A. Dorodnitsyn worked on the MESM. They used the machine around the clock to solve four problems that required the MESM to execute over 50 million operations.[51] In the course of this work, Liapunov tested and refined what later became known as the "operator method" of programming, which he soon began teaching at the first university course on programming in the USSR at Moscow State University. Liapunov was one of the first Soviet scientists to recognize programming as a distinct and important scientific discipline, and was largely responsible for the rapid development of programming techniques in the USSR.[1,9]

During all of 1952 and early 1953, the MESM remained the only stored-program computer in the Soviet Union.

With the acceptance of the BESM into full operation (see below) in April 1953, however, the work load assigned to the MESM eased slightly. Based on the experience gained during its first year of operation, it was decided to make a number of technological improvements to the MESM. These included replacing all of the vacuum tubes with a more reliable variety, and changing the numerical representation in the machine to a word length of 21 binary bits. During 1953 and 1954, several changes were also made to facilitate the input of data.[52] After these improvements were made, the MESM continued to be used actively until 1956, when it was transferred to the Kiev Polytechnic Institute. There it was used for another three years to train young programmers before being scrapped for parts. Not a single piece of the MESM has survived to this day.

ITMVT and the BESM

While Lebedev organized his laboratory in Kiev and began work on the MESM, academician M.A. Lavrent'ev endeavored to make computing a national priority. In October 1947, he spoke before a general meeting of the Soviet Academy of Sciences. While praising Soviet achievements in most areas of mathematics, he stressed the need for greater efforts in computing or, as he called it, "machine mathematics":

> If in the basic branches of mathematics [in the last 30 years] we caught up, and in many areas even surpassed Western mathematics, then in relation to machine mathematics we need to exert much greater efforts.[53]

Lavrent'ev concluded his speech with a call to establish a new institute dedicated to applied mathematics and computer technology.

The result of these efforts was the establishment of the Institute of Precise Mechanics and Computer Technology (ITMVT) by the presidium of the Soviet Academy of Sciences on July 15, 1948. Academician N.G. Bruevich was named its director, and after organizing the institute during the summer and early fall of 1948, Bruevich formally opened ITMVT on September 16, 1948, with a staff of approximately 60 people.[29]

ITMVT was established on the basis of four different departments from three existing institutes within the Soviet Academy of Sciences: the Institute of Machine Studies [*mashinovedenii*], the Energy Institute, and the Institute of Mathematics. From the Institute of Machine Studies came the Department of Precise Mechanics, which was directed by Bruevich. This department investigated and developed precise instrumentation, and had collaborated with other institutes on several projects to build analog machines. Along with Bruevich came 13 younger scientists including M.L. Bykhovskii, the engineer and translator who at that time had published the most extensive Russian-language article on digital computing.[29]

L.I. Gutenmakher also joined ITMVT with his Laboratory of Electronic Modeling (formerly under the Energy Institute). Gutenmakher was a well-known specialist in analog computation who had worked with Lebedev before World War II at the Energy Institute. Two other departments and their heads were brought to ITMVT from the Institute of Mathematics. The first was the Experimental Calculating Laboratory led by I.Ia. Akushkii. The second was L.A. Liusternik's Department of Approximate Calculation, which was founded in 1942 to meet the computational demands of the Soviet war effort. The chief focus of this department was the development of computational methods for the solution of complex mathematical problems by mechanical means, especially those related to military weaponry. By the end of the war, Liusternik's group had considerable experience in the application of arithmometers, punched-card tabulators, and analog differential analyzers.[54] Liusternik, already an accomplished mathematician, would go on to play a significant role in the development of early programming techniques in the USSR.*

While research and development in digital computing eventually came to dominate ITMVT, initially it concerned only a small part of the institute. In fact, when Bruevich first began to discuss digital computers at a seminar in early 1949, his coworkers immediately raised three basic objections. First, the vacuum tubes were so unreliable and the quantity of tubes required in any potential machine so great that the machine might not be reliable, while analog machines had already proven quite reliable. Second, even if it were shown that universal electronic digital machines could function reliably, given the probable high cost of researching and developing them, it would be more cost effective to develop special-purpose machines. Finally, the experience required to operate such machines seemed overwhelming[29] (p. 29):

> Even if the solution of the problem itself on the machine takes a few minutes, the preparation of the problem can take a few days, or even months.... On an electronic calculating machine, only certain kinds of problems that require a very large number of calculations, but a sufficiently simple program, can be expediently solved. Only a highly qualified specialist, who knows the machine and its structure well, can use it. Therefore, electronic calculating machines will not find wide application; they can only be used in large calculating centers with a large number of mathematicians who prepare problems for them.

Once again, such skepticism was overcome in large part by the influence of Lavrent'ev, who was the key supporter of electronic digital computing in general, and of Lebedev in particular, in the late 1940s and early 1950s. Although Lavrent'ev himself was not a member of Lebedev's laboratory, he was the vice president of the Ukrainian Academy of Sciences from 1945 to 1948, and regularly participated in Lebedev's first seminar series. Later, he became a frequent visitor to Feofaniia and contributed often, if informally, to the MESM's design. It was largely due to Lavrent'ev's sup-

* Among other accomplishments in this field, Liusternik taught a seminar devoted to programming at ITMVT in 1950-1951 and subsequently published one of the world's first systematic treatments of programming on an electronic digital computer.[55]

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Sergei Alekseevich Lebedev

port and influence that Lebedev was successful in establishing his first laboratory. As Lebedev later recalled[30] (p. 41):

> It is not clear how the firstborn of Soviet computer technology would have emerged if it had not been for our kind protector — Mikhail Alekseevich Lavrent'ev....
>
> Above all, it was M.A. Lavrent'ev who endured the storm of protests by those who opposed digital computing machines and who adhered to the differential analyzer and punched-card machines. The thing is that the old classical school of computer technology was not accustomed to and little understood the ideas of electronic technology, in which there was such great speed and complex mechanical devices were nearly absent. Despite all the difficulties, however, Lavrent'ev succeeded in convincing the leadership of the Academy of Sciences and the interested organizations of the necessity of the course of developing electronic computing technology.

A year after ITMVT was founded, in September 1949, Lavrent'ev convinced the director of ITMVT to establish a Department of High-Speed Calculating Machines with the goal of researching and developing electronic digital computers. In March 1950, Lavrent'ev himself assumed the directorship of ITMVT in order to place greater emphasis on digital computing. Within a week, he established a laboratory similar to Lebedev's Laboratory No. 1 for Modeling and Control in Kiev (it even had the same name) and invited Lebedev to Moscow as its head.* Over the next three years, Lavrent'ev nurtured, staffed, and funded this laboratory until it became the largest at ITMVT. Finally, after nearly

* The Kiev laboratory continued to function, and until the final modifications were made to the MESM, Lebedev split his time between Kiev and Moscow.

Sergei Alekseevich Lebedev

Born November 2, 1902, Nizhny Novgorod, Russia.
Died July 3, 1974, Moscow.

Education: Moscow Higher Technical School, 1921-1928.

Career [11, 17, 57, 81-84]

1928-30: Teacher, Moscow Higher Technical School; junior scientific work, V.I. Lenin All Union Electrical Engineering Institute (VEI).
1930: Organized a laboratory for researching electrical power networks, VEI.
1930-35: Teacher, Moscow Energy Institute.
1935: Awarded the title of professor.
1936-46: Named head of the Department of Automation, VEI.
1939: Defended doctoral dissertation on the theory of the stability of energy systems.
1941: Awarded the degree of doctor of technical sciences; evacuated to Sverdlovsk with VEI.
1943: Became a member of the Communist party; returned to Moscow.
1945: Elected an academician, Academy of Sciences of the Ukrainian SSR (AN Ukr. SSR).
1946: Awarded Medal for Meritorious Labor in the Great Fatherland War, 1941-45.
1946-47: Director of the Institute of Energy, Kiev, AN Ukr. SSR.
1947: Awarded the Order of the Red Banner of Labor.
1947-51: Director of the Institute of Electrical Engineering (IET), Kiev, AN Ukr. SSR.
1947-52: Head of Laboratory No. 1 for Modeling and Control, IET, Kiev, AN Ukr. SSR.
1950-53: Head of Laboratory No. 1, Institute of Precise Mechanics and Computer Technology (ITMVT), Moscow, Academy of Sciences of the USSR (AN SSSR).
1953-73: Director, ITMVT, Moscow, AN SSSR.
1953: Elected an academician, AN SSSR.
1954: Awarded the Order of Lenin for the BESM-1.
1956: Conferred the title of Hero of Socialist Labor for design and construction of the BESM-1.
1962: Awarded the Order of Lenin for his work in computing and electrical engineering on his 60th birthday.
1966: Member of a group awarded the Lenin Prize for work in the field of specialized, precise instrument construction.
1969: Awarded the State Prize of the USSR for his design and construction of the BESM-6.
1971: Awarded the Order of the October Revolution for his work in computing.
1972: Awarded the Order of Lenin for his work in computing on his 70th birthday.

everyone was convinced of the value of digital computing, he passed the directorship of the institute to Lebedev in 1953.[9,29]

While the MESM neared completion in Kiev, in Moscow, Lebedev set about teaching the staff of his new laboratory the basic principles of digital computing and the details of his design of a new high-speed electronic computer called the BESM (*Bystrodeistvuiushchaia elektronnaia schetnaia mashina* — High-Speed Electronic Calculating Machine). Throughout the spring and summer of 1950, Lebedev expanded his laboratory at ITMVT by adding a workshop with electricians and technicians to assist in the construction of prototype circuits. Nevertheless, because of the newness of the field, there was an almost constant shortage of personnel, and at every turn Lebedev endeavored to find more people to assist in his work. In the summer of 1950, this shortage led Lebedev to turn to the Moscow Energy Institute (MEI), where he taught in the 1930s. Under an arrangement struck with MEI, Lebedev agreed to provide hands-on instruction at ITMVT for a group of students in the principles of digital computing for a period of two months in exchange for their work in his laboratory. The first group sent to ITMVT, in the summer of 1950, consisted of nine students, including such future leading figures as academicians V.A. Mel'nikov and V.S. Burtsev, who would become the director of ITMVT after Lebedev's death in 1974. These students were immediately put to work and made a part of the regular staff of ITMVT. This arrangement worked so well that it was repeated a number of times over the next few years, and thus with the help of MEI, Lebedev was able to staff his ever-growing project.[56]

After the successful demonstration of the MESM in January 1951, the Council of Ministers of the USSR became convinced that the support of high-speed electronic digital computing should be made a national priority.[22] As a result, two competing computer projects were set up with the goal of creating a world-class high-speed electronic digital computer. Lebedev was to head one of the projects at ITMVT and proceeded with the construction of the BESM. The second project was established under the direction of Iu.Ia. Bazilevskii at the Ministry of Machine and Instrument Construction in Moscow. This group went on to build the "Strela" (Arrow), the first serially produced digital computer in the USSR.[2,9,57] As we shall see, considerable friction arose between the two groups, and owing to bureaucratic squabbles, the completion of a state-of-the-art computer was delayed for several years.

With the added state support, the staff of Lebedev's laboratory swelled to 50 people. During the first quarter of 1951, experimental models of various parts of the BESM were built and tested, including the arithmetic unit, the control unit, and a 1,024-word magnetic drum. Once these experiments were completed, actual construction was halted so that the laboratory could write up the technical documentation of the BESM for formal acceptance by the state.[29]

On April 21, 1951, a high-ranking commission consisting of academician M.V. Keldysh (chair); the Minister of Instrument Construction and Systems of Automation, P.I. Parshin; academician A.A. Blagonravov; and others was established to evaluate the designs of the Strela and the BESM. During May 1951 the commission visited ITMVT and examined the various prototype circuits, units, and devices that had been built and tested for the BESM. The demonstrations were successful; the commission approved the project, and assigned Lebedev and his laboratory the task of completing a fully working version of the BESM by the end of the first quarter of 1953. The Strela was also approved, and Bazilevskii was given the same task.[29]

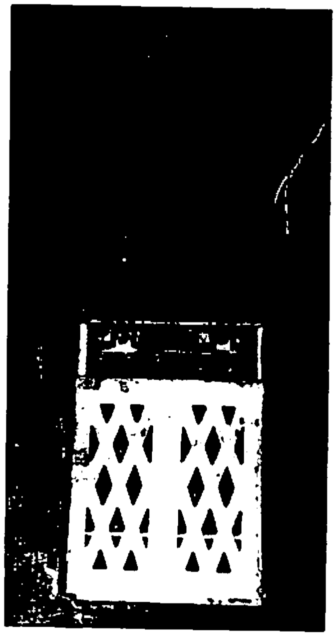

Figure 8. Close-up of a two-tube pluggable block used in the BESM.

Lebedev's design called for the construction of a binary, three-address, floating-point machine with parallel implementation. The word length was to be 39 binary bits (32 for the mantissa, 5 for the order, and 1 for the sign of each). The arithmetic unit was to be based on flip-flop circuits built from vacuum tubes, similar to the design of the MESM. The main memory was to be based on electrostatic cathode-ray tubes with an initial capacity of 1,024 words and the hope of expanding it to 2,048 in the near future. In addition to the electrostatic memory, there was also a read-only memory based on germanium diodes with a capacity of 376 words. External memory was developed in the form of a high-speed magnetic drum with a capacity of 5,120 words and four magnetic-tape drives with a capacity of 30,000 words each. Data would normally be input either from one of the tape drives or via perforated tape. Printing could be accomplished either through a low-speed electromechanical printer or, for larger amounts of data, through a photoprinter similar to the one used with the MESM. The projected optimal speed of the machine was 10,000 three-address floating-point operations per second.[58-60]

It was shortly after this plan was approved that a very important decision was made concerning the basic design for the entire BESM. After some discussion, Lebedev proposed basing all of the units of the BESM on two kinds of pluggable, standardized units. The first type would have two vacuum tubes and the second four (see Figures 8 and 9). Despite the reservations of some engineers that this would unduly restrict the kind of circuitry used in the BESM, Lebedev argued that the standardized units would make replacing and upgrading them much easier. Once the BESM began to operate regularly, this proved to be correct, and a considerable amount of repair time was saved by having readily changeable, standardized blocks of tubes.[29]

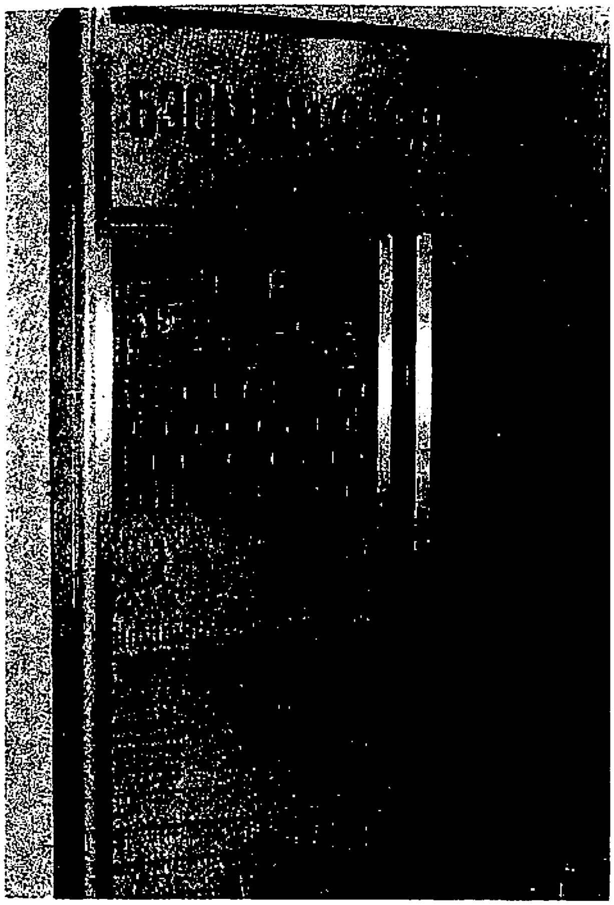

Figure 9. General view of the remaining portion of the BESM at the ITMVT museum, showing the pluggable tube units in place.

In September 1951, the staff of ITMVT moved into a new building on what was then the outskirts of Moscow. Assembly of the BESM and construction of the remaining units began immediately. In the course of 1952, numerous obstacles had to be overcome. The first major problem they encountered was a lack of vacuum tubes. The design specifications of the BESM called for several thousand tubes. Further, a steady supply of many thousands of additional tubes for experimentation and replacement of failed tubes would clearly be needed. Lebedev estimated, for example, that the smaller MESM would require 10,000 replacement tubes in 1952.[61] At this time, however, institutes within the academy were rationed tubes a few at a time. In negotiating with the factory for more tubes, a number of the engineers working on the BESM noticed that the factory had a testbed area where, as part of the quality-control process, the tubes were subjected to high voltages. The engineers convinced the factory managers to allow the BESM to serve as the factory's tube tester. This guaranteed them a temporary supply of tubes until they were able to acquire enough tubes of their own.*

* This story was told by V.S. Burtsev and reported by A.P. Ershov.[9] There were also reports of Lebedev and Lavrent'ev using their own money to buy tubes when supplies were short.

Another obstacle concerned the operational memory of the BESM. Lebedev's design called for an electrostatic memory built on cathode-ray tubes (CRTs) — the fastest type of memory then available. Since the word length on the BESM was to be 39 bits, a minimum of 39 CRTs was needed. (As was done in Western machines, words were stored on the BESM in parallel with a single bit per CRT.) Early in the construction of the BESM, it became clear to Lebedev that it might be very difficult to obtain the necessary number of CRTs because of the relatively small number being produced by Soviet industry. Fortunately, as early as 1949, ITMVT had made an arrangement with the Scientific Research Institute of Automation for the development of a prototype mercury delay-line memory. Although using mercury delay lines for the operational memory of the BESM would greatly reduce the overall speed of the machine, Lebedev decided to develop and test this alternative as a backup to the CRTs.[29,57]

During 1951 the delay-line memory was used to test the individual units of the machine. After the construction of the BESM began in ITMVT's new building and it became clear that the CRTs would not be forthcoming, a team was brought in to build the full-scale delay-line memory. In the end, 70 lines were built: 64 were used in the main memory, one was used as a frequency clock, and five were held as spares. Each line was a meter in length and had a capacity of 16 words with a delay of 640 microseconds, giving the machine a main memory capacity of 1,024 words.[62]

In the fall of 1952, the BESM was ready for testing and debugging.[60] On the whole, the machine worked according to the original design specifications, with the exception of the main memory. Due to the longer access time of the mercury delay lines, the average speed of the BESM was only about 1,000 operations per second. With experimental testing complete in early 1953, the BESM was formally accepted by a state commission in April, despite the fact that its memory fell well short of its design specifications.[2,29]

The completion of the BESM without an electrostatic memory was extremely disappointing to Lebedev and all those who worked on its construction. Most frustrating of all was what appeared to be the reason why they were unable to obtain the necessary CRTs. Although far from plentiful, Soviet industry was producing a steady stream of CRTs at that time. Bazilevskii's design of the Strela also called for CRTs, however, and due to the Ministry of Machine and Instrument Construction's closer ties to industry and its considerable political clout, it gained an effective monopoly on all the CRTs that were produced.[29] This continued to be the case even though it was clear very early that the Strela would be a much less powerful machine, would take longer to complete, and would be several times slower than the BESM with a CRT memory. The Strela was capable of a maximum speed of about 2,000 operations per second, had a simpler command structure, had less external storage, and had weaker input-output devices than the BESM. It did, however, have the advantage of being designed for immediate serial production. Remarkably enough, as late as 1957, in a clear indication of the competitiveness between the two groups, Bazilevskii claimed that the productivity of the

Strela in solving complex mathematical problems was "not surpassed" by the BESM.[57]

Lebedev and Lavrent'ev complained bitterly to both the academy and the government about the fact that they could not obtain the equipment they needed, only to have the Ministry of Machine and Instrument Construction claim that the Strela was superior to the BESM and hence deserved complete priority. Finally, Lavrent'ev managed to convince the presidium of the Soviet Academy of Sciences to set up a commission to compare the two machines. The commission was established in late 1954, and it was quickly determined that the BESM was the better, more productive design. Shortly thereafter, ITMVT received all the CRTs it needed (see Figure 10), and in early 1955 the machine began to operate up to its full design specifications — that is, 7,000 to 8,000 floating-point operations per second.[29]

In the end, the use of electrostatic memory in the BESM was short lived. Even before the CRTs were installed, it was clear that magnetic-core memories would be the way of the future. During 1955 and 1956, several attempts were made to develop such memories at ITMVT.[63-65] By the fall of 1956, an experimental version of a ferrite-core memory, called a Z-type memory, with a capacity of 1,024 40-bit words, had been developed and tested in the BESM.[66] Over the next two years a number of other improvements were made to the BESM. These included adding a second magnetic drum, improving the reliability of the vacuum tubes, upgrading the arithmetic unit, and doubling the size of the ferrite-core memory.[60,67]

During its first few years of operation, the BESM was applied to a number of interesting problems. For the International Astronomical Calendar, the BESM calculated the orbits of nearly 700 asteroids within the solar system, including the gravitational effects of Saturn and Jupiter. The positions of the asteroids were calculated at 40-day intervals for a period of 10 years. In all, some 250 million operations were carried out by the BESM in 20 hours of machine time. The BESM was used around the clock and had a useful operating time of 72 percent. It spent 20 percent of its time on preventative maintenance and 8 percent on unexpected errors, including the time required to repeat lost calculations.[31,59,68]

The BESM was also used to develop an elementary chess program and for the automated translation of scientific and technical texts to and from French, English, and Russian. Despite the modest results of such programs due to the limited sizes of the main and auxiliary memories, many of the engineers believed a new age was dawning in which fully automatic machine translation would soon be a reality — a dream that remains elusive to this day throughout the world.[31,69]

The M-20 and the BESM-2

By 1954 most of the scientists at ITMVT who had been working on the BESM project were available to work on other things. During 1954 and early 1955, experiments were conducted at ITMVT with the goals of

- developing a component base for computers that would be more reliable than vacuum tubes, and
- developing reliable, affordable, high-speed forms of main memory.

At the same time, Soviet industry began to produce sufficient quantities of germanium semiconductor diodes to consider using them in computers.[70] The chief advantages of the germanium diodes were their reliability and the fact that they would greatly reduce the number of vacuum tubes a machine required.

At the end of 1954, Lebedev decided to begin a new computer project based on germanium diodes. The goal was to produce a state-of-the-art machine that would be ready for serial production in the shortest possible time. In the summer of 1955, ITMVT agreed to cooperate on the development and serial production of such a machine with a Special Design Bureau (SKB-245) and the Moscow Calculating Machines Plant, both under the auspices of the Ministry of Instrument Construction and Means of Automation. The machine was given the name M-20, with "20" signifying the goal of having the machine perform 20,000 operations per second.* Lebedev was named the chief designer and took responsibility for developing the architecture, component base, and circuit design of the M-20. At the SKB-245, Mikhail Kirilovich Sulim, the deputy designer, agreed to prepare the technical documentation and to test the prototypes of the different units of the M-20.[70]

The original timetable for the project required Lebedev and the SKB-245 to complete a prototype version of the M-20 by April 15, 1956. The technical documentation to be used by the factory was to be completed by June, and the first three experimental models of the M-20 were to be ready by August 1956.[72] Both groups proudly and optimistically predicted that because of the close cooperation between the design team at ITMVT and the production facilities at the SKB-245, full-scale serial production of the M-20 would begin by early 1957.[73] Indeed, if this had been the case, the total time from design to serial production would have been just over two years — quite an accomplishment even today. During the construction of the experimental model, however, some of the circuits that appeared to work in the prototype failed to function properly when tested at full scale.[70]

Although the cause of the problem was quickly located and the faulty circuits redesigned in a relatively short period of time, the delay had a tremendous impact on both the project and the relations between Lebedev and Sulim. Sulim had promised the ministry that the machine would be in serial production in the first quarter of 1957 and blamed Lebedev and ITMVT for the delay. Sulim reasoned that his team had built the prototypes to ITMVT's design specifications and that therefore the fault must be either in the original circuit design or in the construction of the full-scale model. A number of the SKB-245 engineers went as far as

* The M-20 and its descendants the M-50 and the M-180 should not be confused with the M-1, M-2, and M-3, built in the 1950s by I.S. Bruk at the Institute of Electronic Control Computers of the Soviet Academy of Sciences. Although similar in name, these machines were unrelated to the M-20, M-50, and M-180. Brief discussions of the Bruk machines are available elsewhere.[2,71]

to blame the new germanium diodes that were being used for the first time in the M-20. They argued that the best solution to the problem would be to eliminate the diodes and return to using a greater number of vacuum tubes. Since this would have eliminated the main reason for building the M-20 in the first place and considerably reduced the overall performance of the machine, Lebedev was against it. Lebedev and the chief engineer of the circuit design, P.P. Golovistikov, believed that to overcome the problem they would have to go back to the prototypes for further experimentation.[70]

One consequence of the uncertainty surrounding the completion date of the M-20 and the falling out between Lebedev and Sulim was the desire to produce a serial-production version of the BESM. When the BESM was first put into full operation, serial production was not undertaken because of the lack of CRTs. By early 1955, when the CRTs were finally acquired and the BESM proved to be one of the most powerful machines in continental Europe, the design and production of the M-20 had been given priority. As Golovistikov[70] (p. 76) explained,

> The "guilty one" in all of this was the M-20. Back then it appeared that the M-20 could be created in a very short period, in any case to put it into serial production in 1957. Moreover, industry participated in the [design] work and an industrial group, suitable for serial production, was cultivated. The BESM was made as an experimental machine. In order to put it into serial production, it would have been necessary to rework the construction and make it suitable for serial production. This would have demanded a great amount of effort and a significant amount of time. Therefore, the situation looked like this: Why work on the serial production of the BESM if this work will be finished at about the same time as the appearance of the M-20? Moreover, the M-20 by all of its indicators should considerably outperform the BESM.

Once the timely completion of the M-20 was in doubt, however, this attitude changed. In the middle of 1957, there appeared to be four advantages to developing a serial-production version of the BESM. First, the industrial group being prepared to manufacture the M-20 could also be used for a serial-production version of the BESM. Second, for the serial-production version, the vacuum tubes in the BESM could be upgraded with newer, more reliable tubes and in some cases even replaced with germanium diodes. Third, all of this could be done without changing the basic architecture of the BESM, and as a consequence could be done rather quickly. Finally, an experimental ferrite-core memory being developed for the M-20 had already been tested in the BESM and could be used as the operational memory in the serial-production version. Implementation of these changes began in late 1957 and was completed in the summer or fall of 1958.[29,74] The first of the serially produced BESM-2s, as they were later called, was delivered to the Computing Center of the Soviet Academy of Sciences in the spring of

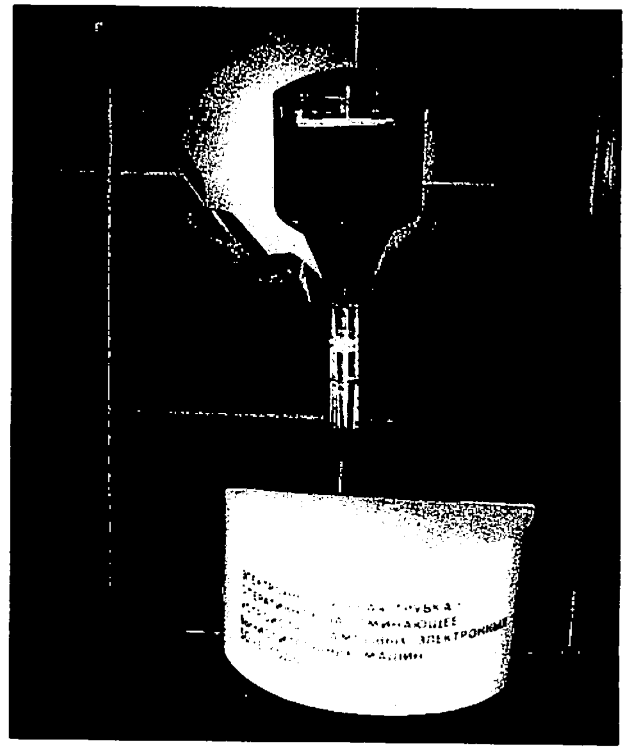

Figure 10. Early 1950s CRT similar to those used in the BESM (Polytechnical Museum, Moscow).

1959. The main reason for the delay of 8 to 10 months was the difficulty in preparing the operational and maintenance documentation. As late as May 1959, the BESM-2 at the Computer Center was still not fully operational, although it was expected that it would be ready in early June.[75] This lack of readily available, thorough documentation was to become a perennial problem for Soviet computing.

In terms of its circuitry, the BESM-2 was very similar to the M-20, while architecturally and in terms of its programming, it was nearly identical to the original BESM (subsequently called the BESM-1). With the switch to a ferrite-core memory, the operational memory was increased to 2,048 words, although the speed of the BESM-2 remained an average 7,000 to 8,000 operations per second. It appears that even as late as 1959 when the BESM-2 went into serial production, the ferrite-core memory was still far from completely reliable. The early production models all had two ferrite cores per bit. This redundancy appears to have been necessary both because of the lack of uniformity in the cores and to provide a backup in case the first core failed. A second magnetic drum was also added to the production model, but otherwise the peripherals were the same as on the BESM-1.[75]

Meanwhile the problems with the M-20 were quickly overcome and it was completed at roughly the same time as the BESM-2 in early 1958. Serial production began in early 1959 at the Moscow Calculating Machines Plant. The M-20 was a three-address binary machine with a 45-bit word length. The nominal speed was 20,000 floating-point operations per second. The main memory was based on ferrite cores and initially had a capacity of 2,048 words with a cycle time of 6 microseconds (a second block of ferrite cores was soon added, increasing the size of the main memory to 4,096 words). Auxiliary memory was available in the form of magnetic drums with a capacity of 4,096 words and magnetic-tape drives with a capacity of 75,000 words each. Most of the M-20s produced came with either three or four magnetic drums and four tape drives. Alphanumeric input was possible via punched cards at a rate of 60 cards per minute. Output could be directed either to a card punch at a rate of 30 cards per minute or to a numeric printer at 20 lines per second.[2,70,76]

Compared with the BESM-2, the M-20 was considerably faster and had both a larger operational memory and more extensive external memory storage. The M-20 also incorporated a number of design features not found in the BESM-1 or BESM-2, including the execution of commands with local parallelism: As one command was being executed, preparation for the following command was being carried out at the same time. The M-20 also had an index register that allowed it to change the address part of a command without changing it in the main memory, as was done on the BESM. In addition, a library of standard subroutines was developed for the M-20.[77]

Direct comparisons of machines with vastly different architectures are difficult; nevertheless, despite its favorable comparison with the BESM-2, the M-20 fell well short of being state of the art when compared with foreign technology. The IBM 709, for example, the first models of which were delivered in early 1958, had a nominal speed of roughly 40,000 operations per second and a larger instruction set and main memory than the M-20.[2,78] The IBM-built NORC computer had a far better operational time versus downtime ratio, despite its generally less reliable electrostatic main memory. By 1958 ferrite-core memories were common in the West and transistorized machines, which were vastly superior in every regard, appeared only a short time later.[35]

Official Soviet policies aimed at creating "proletarian science" and attempts to downplay Western achievements notwithstanding, evaluations of scientific projects were often made based on comparisons with Western developments. Almost the sole yardstick of success was the degree to which the project surpassed the West. This was certainly the case for the M-20. In March 1960, the Soviet Academy of Sciences asked academician A.A. Dorodnitsyn to chair a meeting to evaluate the M-20 and recommend whether its design team should be awarded the prestigious Lenin Prize.[79] Two papers were presented at the meeting: The first by Lebedev was a report describing the machine, its design, and its history; the second by M.R. Shura-Bura, who was involved in developing the software on nearly all the BESM machines as well as the M-20, reported on the instruction set and subroutine library. One hundred fifteen computer specialists from around the USSR attended the meeting to discuss their experiences using the M-20.

After the papers were presented, an often-heated discussion period followed in which the M-20 was repeatedly criticized. For example, one participant pointed out the fact that several Western computers had operational memories of 32,000 words. He then asked[79] (p. 6) whether the fact that the M-20 did not was "a deficiency in the machine or negligence in the design." Shura-Bura weakly replied that the operational memory was sufficient for most tasks, and expressed his preference for expanding the number of magnetic drums rather than the internal memory.[79] N.P. Trifonov of Moscow University complained about the fact that there was still no published technical documentation describing the M-20's system of commands and that this made it very difficult to teach students about the machine. In addition, Shura-Bura had suggested in his report that due to experience gained in the first three years of operating the machine, they were considering making changes in the instruction set. In reply to this comment, Lebedev stated that he was against any changes at this point, precisely because they might delay the publication of the technical documentation of the machine even more. Further, he claimed that it was the responsibility of the factory to produce the documentation, not the design team. Still others complained about insufficient auxiliary memory space and 10 to 11 hours per day of preventative maintenance and downtime due to errors.

Not all of the commentary was negative. Several scientists pointed out that the M-20 was a significant technological advance when compared with earlier Soviet computers. The fact that the M-20 was being successfully serially produced was also seen as a significant achievement in and of itself. Nevertheless, because the M-20 failed to surpass its Western counterparts, it was seen as less than a complete success, and despite a concluding resolution that called for the M-20 engineers to be awarded the Lenin Prize, they failed to receive it.

By 1958 the M-20 and BESM-2 computers were in serial production in the USSR. Despite the fact that the demand for computing technology still far outstripped the available supply of machines, indigenous Soviet design and production of computers were under way. Numerous M-20 and BESM-2 computers were built in the late 1950s and early 1960s. The M-20 soon became the standardized first-generation machine for high-priority (especially military) computing, while the BESM-2 found wide application in scientific computing. At the same time, an important institute for the research and development of indigenous computers had been established. This institute, ITMVT, grew and achieved success largely because of the leadership and work of S.A. Lebedev and the assistance he received from M.A. Lavrent'ev.

Over the next two decades, until his death in 1974, Lebedev directed the design and construction of a number of Soviet computers based on his work on the MESM, BESM, and M-20. These included, among others, the BESM-6, a machine designed in the early 1960s that quickly became the workhorse of Soviet scientific computing. Over 350 of these machines were eventually built. And even though the original design is over 25 years old, many of them are still in operation, or just recently have been retired.

Throughout his career, the machines Lebedev developed were based for the most part on original designs with original architectures. His goal was not only to build high-speed computers, but also to encourage the indigenous development of the nascent field of computer science and technology. On this level, the MESM, BESM, and M-20, as well as much of Lebedev's later work, were significant achievements. In addition, Lebedev transformed a fledgling computer institute into a powerful center of computer research and development, established educational programs in electronic computing at the high school and university levels, sponsored the publication of a wide variety of works on computing,* and chaired the first all-Soviet conference on high-speed computing in 1956.[80] It was largely due to his efforts and those of academician M.A. Lavrent'ev that electronic computing became firmly established as a new scientific discipline in the USSR during the 1950s. ■

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Abbreviations used in references

A AN SSSR: *Arkhiv Akademii nauk SSSR*; Archive of the Academy of Sciences of the USSR, Moscow.

AIED: *Arkhiv Institut Elektrodinamiki*; Archive of the Institute of Electrical Dynamics, Kiev.

AN SSSR: *Akademii nauk SSSR*; Academy of Sciences of the USSR.

AN Ukr. SSR: *Akademii nauk Ukrainskoi SSR*; Academy of Sciences of the Ukrainian SSR.

BESM: *Bystrodeistvuiushchaia Elektronnaia Schetnaia Mashina*; High-Speed Electronic Calculating Machine.

IET: *Institut Elektrotekhniki*; Institute of Electrical Engineering, Kiev.

ITMVT: *Institut Tochnoi Mekhaniki i Vychislitel'noi Tekhniki*; Institute of Precise Mechanics and Computer Technology, Moscow.

MEI: *Moskovskii Energicheskii Institut*; Moscow Energy Institute.

MESM: *Malaia Elektronnaia Schetnaia Mashina*; Small Electronic Calculating Machine.

* In addition to the works listed in the reference list, ITMVT published dozens of works in the 1950s and 1960s under Lebedev's general editorship.

MVTU: *Moskovskoe Vysshee Tekhnicheskoe Uchilishche im. N.E. Baumana*; N.E. Bauman Moscow Higher Technical School.

NZh: *Nauka i zhizn'*; Science and Life.

TsGANKh: *Tsentral'nyi Gosudarstvennyi Arkhiv Narodnogo Khoziaistva*; Central State Archive of the National Economy, Moscow.

UMN: *Uspekhi matematicheskikh nauk*; Achievements of the Mathematical Sciences.

VEI: *Vsesoiuznyi Elektrotekhnicheskii Institut im. V.I. Lenina*; V.I. Lenin All-Union Electrical Engineering Institute, Moscow.

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