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 [III - USSR - 23 S & T]

FIFTH ALL-UNION SCIENTIFIC-TECHNICAL CONFERENCE ON COMPUTER STORAGE DEVICES

Kiev UPRAVLYAYUSHCHIYE SISTEMY I MASHINY in Russian No 2, Mar/Apr 77 pp 133-134

[Article by Ye. A. Brik: "Fifth All-Union Scientific-Technical Conference on Computer Storage Devices"]

[Text] Improvement of digital computers is inseparably linked with the development of computer storage devices (ZU). Increasing demands are being placed on the memory systems of contemporary computers and computer complexes. ZU are being increasingly utilized, with improving performance characteristics, in communications systems, in data transmission systems, in radar, in transportation automated control systems, in automatic control systems for production, industrial processes, and in organizational and administrative activities.

The performance of information storage devices is being improved on the one hand by improving their components and circuitry: by employing new physical principles of information storage, by further development of techniques and by increasing product reliability. On the other hand, a substantial increase in storage system efficiency can be achieved on the basis of improved circuitry: improvement in the hierarchic memory structure, fuller utilization of the capabilities of permanent associative and multiple-function ZU, improved organization of information exchange between storage units, etc.

Broad exchange of experience and know-how in designing new memory systems is of great importance for further development of ZU theory and hardware. Four nationwide conferences on problems of ZU were held in 1963, 1966, 1968 and 1971 toward this end. The fifth conference was held in Tbilisi on 13-15 September 1976.

The conference was attended by 220 delegates and guests from 25 cities throughout the country, and representatives of 118 organizations. The conference was also attended by representatives of CEMA member nations: Bulgaria, Hungary, Poland, Czechoslovakia, and the GDR.

Seven papers on the most vital problems of computer memory theory and technology were presented at two plenary sessions. Specializing sections operating at the conference included ferromagnetic memories, semiconductor core memories, optical ZU, permanent and semipermanent ZU, a section on structure and organization of ZU, ZU reliability, and a section on magnetic recording, magnetic disks and tapes. A total of 16 section meetings were held, at which 110 papers and brief reports were presented and discussed.

The papers presented at the conference indicated that during the Ninth Five-Year Plan theoretical research in the area of mnemology and specific development of devices for storing information in cybernetic systems advanced intensively in this country. Development of a number of new ZU with improved performance constituted an important achievement of Soviet science and technology.

New ferrites were developed, with improved parameters for memory elements. Series production was initiated on elements with an elaborate magnetic circuit, with reluctance modulation, providing improved reliability of ZU and information read-out involving non-volatile recording. Semiconductor integral core memories with user-recorded information have been developed. A new type of cylindrical non-volatile magnetic film has been developed. Research and experimental development of semiconductor integral ZU based on a new metal-nitride-oxide-semiconductor (MNOS) technology has been expanded, as well as ZU based on devices with charge linkage, etc. Vigorous research is in progress on the development of magnetic domain ZU, holographic ZU, opto-electronic ZU, amorphous semiconductor ZU, etc.

The conferees noted that in spite of achieved successes, ZU parameters and availability variety do not yet satisfy the requirements of developing digital equipment; new scientific developments are not being sufficiently vigorously adopted into industrial production. The conference recognized the following areas as being the most critical:

first of all, improvement in the hierarchic structure and organization of computer storage in multiple-computer systems, taking into consideration problems of developing integral information processing systems;

second, further adoption and development of theory and technology of semiconductor ZU with simultaneous improvement of ferrite memories as the main type in building large-capacity storage units;

third, further development of theoretical and experimental work in the area of associative and multiple-function ZU;

fourth, enhancement of the role of core memories for improving the computation process, and in particular more extensive utilization of microprogramming methods.

The conferees are of the view that further research and development should be conducted on the following specific problems:

further miniaturization of ferrite memory elements (utilization of ferrite cores with an outside diameter up to 0.4 mm), improvement in their speed and thermal stability, and development of methods of automated broaching of memory cores in producing large and extremely large capacity memory matrices;

extensive product standardization (registers, assembled memory units, etc) and organization of their manufacture at specialized enterprises;

intensification of development and organization of extensive manufacture of integral semiconductor ZU, density increase to thousands and tens of thousands of elements on a crystal, increase in the percentage of usable items, development and organization of series manufacture of memory units which preserve information when power is switched off;

development of high-reliability ZU for special-purpose equipment, reliability secured by design-engineering and equipment methods;

increase in density of recording on magnetic media, development and manufacture of high-capacity magnetic disk ZU, investigation of the possibilities of building extremely high capacity external storage units with domain ZU and charge linkage devices;

improvement of methods of measuring and testing ZU and development of special bench testing equipment;

further development and series manufacture of cylindrical magnetic film storage units;

investigation and development of optical ZU and amorphous semiconductor ZU;

improvement and standardization of terminology in the area of ZU.

The conference called upon all scientists and specialists in the area of mnemology, ZU theory and technology to intensify and improve the quality of scientific research and design projects and to secure their extensive and rapid adoption in digital computer manufacture and utilization.

3024
CSO: 1870

CYBERNETICS, COMPUTERS AND AUTOMATION TECHNOLOGY

INEFFICIENT USE OF ARMENIAN COMPUTATIONAL CENTERS DISCUSSED

Yerevan KOMMUNIST in Russian 29 May 77 p 2

[Article by B. Melik-Shakhnazarov, director of the Department of Control Problems, VTs [Computing Center], Academy of Sciences of the Armenian SSR: "Paradoxes of the EVM [Computer]: Problems and Judgments"]

[Text] Everything new that occurs before our eyes gains recognition only when it tangibly influences the activity of society. Therefore, despite the fact that there are already 67 computing centers [VTs's] in the republic, 19 of which are independent, they are still far from being generally accepted.

Each of them has only one or two computers, and even those are busy only 8 hours per day compared to the average 14-hour workload throughout the country and the 20-22 hours of possible useful time.

The TsSU [Central Statistical Administration] sets the policy on planned indices for computer operations, and when the plan is not fulfilled, the responsibility for the organization of machine operations is borne by the personnel in the VTs's.

A paradoxical situation is being created. On one hand, more and more organizations are setting up their own VTs's. The number of them has almost doubled during the last five years. But at the same time, the computers in the already existing VTs's are not busy. They can now process almost three times more work than that planned for them and being accomplished by them. The republic's Gosplan has recently spent a great deal of effort on increasing the workload on the VTs's, but the ministries themselves have no need for a greater volume of computations on the computers within their jurisdiction.

The question arises: what is the sense of setting up new centers if these departments can increase the workload on the computers already operating? After all, if the pool of computers on hand in the republic start to operate just two times more intensively, this will allow a reduction of half of the existing VTs's!

Meanwhile, the ministries, departments, research institutes, VUZ´s and KB´s [Design Offices] are irrepressibly striving to set up new VTs´s. It is fashionable! And while the republic´s Gosplan does not permit each "initiator," within the jurisdiction of local organs, to do this, the enterprises of union subordination have no such restrictions.

A situation has now come about in which many ministries and enterprises, having been unable to maintain the planned workload of their own VTs´s, are making the collectives of the VTs´s responsible for the computer standing idle. Even though it is evident that VTs personnel cannot themselves assign work, and that the center was set up just to service the institution which organized it. A low computer load factor has at times been made an indicator of the quality of work of the VTs´s.

The present state of affairs leads to concluding that VTs´s are set up at times not for the purpose of using a computer, but for the sake of placing responsibilities on VTs personnel for development of ASU´s [automated control systems], software and algorithms for the needs of a given institution. In such a situation, the VTs becomes responsible for the low culture of management and scientific organization of labor of the institution to which it is subordinate.

Let us examine a different situation, when the VTs operates well. What are the results of such a symbiosis? The VTs of the Motor Transport Ministry of the Armenian SSR operates so intensively that it can be called one of the republic´s leading organizations in the development and introduction of an industrial ASU. But a first-hand acquaintance with the relations between the VTs and the department directing it shows that a number of ministry employees are not quite satisfied with that situation. They do not even know what a VTs does and do not read its tasking documents, i.e., they do not feel a need for its work and have tried more than once to reduce its financing. It is as if the VTs operates by itself and the apparatus of the ministry by itself. This is the result of a lack of competent interest and management of the operation of a VTs! It is paradoxical, but a fact: the VTs "moves out ahead," cutting itself off from its own department.

Here is another detailed example. The VTs of the republic´s Ministry of Communications, which operates no less intensively than that named earlier and has the full support of its ministry, nevertheless wound up in another extreme situation. The volume of its "planned" workload is so high that the computer in this VTs operates at the limit. The VTs personnel, while having their own computer, lease others.... Such a state of affairs is fraught with serious danger: after all if one of the units of the computer is down for a long time, the useful operational work of the VTs can be disrupted, and this discredits the success achieved by the center´s associates.

These facts show that a small computer workload and shortcomings in the operation of VTs´s are a consequence of the lack of a single manager of their operation, clearly set requirements for them and frequently insufficiently concrete control on the part of the corresponding department. If one approaches this question on a larger account, then the ministries even without their own VTs´s can have algorithms that have already been worked out for execution of its basic tasks, and finished designs for an ASU, and even introduce performance of the most important tasks on leased machines. However, this is not occurring because the majority of the republic´s ministries are economically closed organizations and preoccupied with setting up their own VTs to develop an ASU for its own ministry or to perform individual prestigious tasks. Thus the majority of the established VTs´s are becoming planning-research and not operational organizations.

/Instead of having, in the republic, three or four planning-research organizations of large-capacity for development of ASU´s and packages of programs for all requesters, and several interconnected VTs´s for collective use with a good pool of machines, almost 70 VTs´s have been set up already and cadres of mathematicians, operators-engineers and computing equipment which are insufficient for many other affairs have been "scattered" throughout them. They are doomed thereby to uncoordinated management, costly low-level service, and a lack of flexibility in varying reserves./ [in boldface] Against such a background, the Armenian branch of the All-Union State Planning and Technological Institute of the TsSU of the USSR and a number of other organizations are seeking, in the republic, orders for development of algorithms and programs for control of enterprises and organizations.

But the lack of a computer workload is the fault not only of the organizations which set up their own VTs´s. In the end, they too have their own directing and planning organs. The lack of a workload for the machines illustrates more profound causes, namely a low level of scientific organization of labor of those scientific research institutes, VUZ´s, ministries and departments of the republic where the computer and the services of the VTs are used episodically or not at all.

In an age of scientific and technical progress not one field of science or control can solve its problems without computer assistance. Today even musicologists (YerPI [Yerevan Polytechnical Institute im. K. Marx] is participating in the work) and ethnographers (Institute of Archeology and Ethnography of the AN [Academy of Sciences] of the Armenian SSR) and physiologists (Institute of Physiology of the AN of the republic) are extensively using the services of machines. At the same time, /of 31 institutes in the republic´s AN, only 4 call on the computer services of the VTs of the AN of the Armenian SSR and YerGU [Yerevan State University]/ [in boldface], while the workload on the pool of machines here is only 4 to 5 hours per day. The operating staff consists of 8 people with four large machines. /The institutes of the AN at the same time are continuing to purchase their own computers. The impression is created that the academy´s VTs exists by itself and the institutes of the Academy exist by themselves./ [in boldface]

These facts show a lack of efficient organization of the labor of our researchers.

It is time to recognize that a computational base, large banks of informational data on achieved scientific results and on parameters being researched, software for tasks--these are necessary attributes of a modern researcher, and they are not created all at once. It takes long years of difficult labor.

In conclusion, I want to repudiate the established view that the VTs of the republic's AN should allegedly perform programming of the tasks that are being performed by 30 academic institutes on over 130 scientific problems. This has been ruled out. Today, thousands of specialists in scientific institutions are engaged in the algorithmization of the processes of data processing, and in planning and managing experiments in all fields of science. Finished algorithms and programs requiring specialized knowledge in each specific field are available to them. Each institute must use these pre-prepared scintific aids in its field. The VTs collective can only help in performing calculations, and it is ready to suggest existing standard methods of performing tasks. It should work out all general methodological questions of servicing its users. But it is not entitled to select more specific specializations in today's ocean of problems, for this means non-observance of the principle of ensuring high competence in development, and primarily, this means not offering equal opportunities to all users of the computing capacity.

8545
CSO: 1870

KVANT--A NEW SOVIET SPEEDREADING METHOD DESCRIBED

Sofia OTECHESTVEN FRONT in Bulgarian 29 Jul 77 p 2

[Article by E. Zidarov: "Four Pages Per Minute"]

[Text] Currently scientific and scientific and technical publications total about 60 million pages per year. It has been estimated that in 25 years they will total 250 million and, in 50 years, 3 billion pages per year. Furthermore, there are thousands of articles, reports and, in general, documents which must be read by economic managers or politicians in order to keep up with events.

Could this be accomplished?

Information bureaus, information services, and centers equipped with "intelligent" machines exist in the advanced countries, including ours. They store in their memories information and, whenever necessary, return it to the selecting customer by section or topic. However, regardless of how well these services are organized, man with his personal information remains the most important element in the creative process. For a long time the study of documents by reading them will remain the main action in data gathering. That is why the following question is entirely legitimate: With such an accelerating avalanche of pages could we accelerate the reading process as well?

Statistical data have indicated that most of the literate population in the world reads at the same speed as 1 century ago, when the volume of information was modest: 250-300 words per minute. A probable explanation of this fact is provided by a cybernetic model of the reading process. According to it the process could be conventionally divided into three blocks participating in the processing of the information. The first block is the visual analyzer. The text is absorbed through the motion of the eyes. The information is then processed in the block of the speech analyzer and, finally, in the block of the audial analyzer.

Such multiple-stage processing, however, is not mandatory and does not insure success in reading in the least. It is even a hindrance. A person who focuses on his reading by spelling out the words could not surmount the barrier of 150 to 200 words per minute, being prevented by his audial block. That is precisely why the attack must be focused on speech interruptions and directed against the audial analyzer block. Eliminating it would enable us to accept the text in two stages and, therefore, faster.

This is the basis for modern fast reading methods, already tested and adopted in many countries. A successful method was experimented with in the USSR by the group known as "Kvant." The results uncontroversially prove that after 2 month's training a person may reach a speed of 4 pages per minute and retain it permanently.

Here is what the Kvant method recommends.

In the first training stage we must drop the habit of mentally pronouncing the text. In the second we must master the type of reading technique which would enable us to perceive the text only visually in big information blocks.

In order to supress the mental formulation of the words the method of speech confusion is recommended. To this effect it is sufficient to tap the table with a pencil, using a special rhythm, during the reading. With such a rhythm words cannot be pronounced. If an emphasis is placed the rhythm is violated. However, with recurrent repetitions the pencil technique is mastered and the person drops the emphasis. The scientific interpretation is that under the influence of the special rhythm an effect of induced hindrance develops in the respective area of the cortex which controls the modulation, and the formulation of the words becomes impossible.

The second training stage calls for the development of a habit of reading in big information blocks. This could be achieved by acquiring a new eye-moving technique. In conventional reading the eyes move along the lines from left to right. Even though the movement seems even, it is uneven, with leaps. The text is perceived when the eyes stop at a single point. At the time of the leap the reader sees nothing. The new technique does not call for a faster movement of the eyes but only for the more effective use of the "stops." With a single fixation a person can see not one but several words simultaneously.

How could this be accomplished?

Reading a page the eyes must not crawl along the lines. The sight must move vertically from the top down following an imaginary line somewhere in the middle of the page. Such technique is easily mastered by a person with developed peripheral vision. The others must persistently exercise using so-called (shulte) tables. They represent tables of 25 squares in which the numbers from 1 to 25 are placed at random. With the vertical shifting of the eyesight through the middle of the table the figures should be read in no more than 25 seconds.

Once this technique has been mastered the student begins to read a text. A perpendicular line is drawn with a pencil on the middle of the page. Following it the reader should be able to read the page in 15 seconds.

The experience so-far gained by the Kvant group indicates that with systematic exercises any normal person could increase his reading speed several hundred percent. Many people believe that speedreading has a beneficial influence on the person's overall work capacity and that it energizes the mental processes.

5003
CSO: 2202

ENGINEERING AND EQUIPMENT

EXPERIMENTAL STUDIES OF THE OPERATION OF AN MHD GENERATOR WITH ASH IN THE PLASMA

Moscow EKSPERIMENTAL'NYYE ISSLEDOVANIYA RABOTY MGD GENERATORA PRI NALICHII ZOLY V PLAZME in Russian 1977 signed to press 5 Apr 77 pp 1-32

[Scientific and Technical Report No A 77/3 by D. K. Burenkov, Yu. L. Dolinskiy, V. N. Zhdankin, A. V. Zagorodnikh, V. I. Zalkin, O. B. Zamyslov, V. V. Kirillov, V. F. Korostylyov, I. L. Mostinskiy, R. S. Nekhoroshev, V. N. Sukhov, S. A. Tager and B. Ya. Shumyatskiy, Institute of High Temperatures, Academy of Sciences USSR, 1977, 70 copies, 32 pages]

[Text] Introduction

In the future the most intensively developed electric energy facilities may be magnetohydrodynamic electric power plants [MHDEP] in which high-energy coal will be used as the basic fuel. The main distinguishing feature of coal as a fuel is the mineral content. The latter acts as a source of ash and slag formation as the coal is burned.

The types of Soviet coal that are promising for use in MHDEP facilities are characterized by ash of acid and basic (alkaline) composition. The main components of acid ash are SiO_2 and Al_2O_3, and those in basic ash are mainly CaO and MgO. In addition, the ash of any kind of coal contains Fe_2O_3, TiO_2, K_2O and Na_2O in various amounts. However, the content of alkali metal oxides in ash is always considerably lower than that needed for creating a plasma.

The multicomponent composition of the solid fuel, heterogeneous reaction, interaction of combustion products with the flame surfaces of the combustion units and with the compounds of the ionizing additive, electric and magnetic fields --all these factors complicate high-temperature combustion processes and cause a number of specific problems in using coal as fuel for the MHDEP. Many problems can be solved in experiments in which the combustion of coal as fuel is simulated by the combustion of gaseous fuel doped with the appropriate amount of ash as a mineral component.

By varying the chemical composition and concentration of the ash introduced into the combustion chamber of the experimental MHD facility one can simulate the main wall processes that take place when fuels of various grades are burned, and at the same time appreciably simplify the conditions of the experiment. In this connection, beginning in 1976 a series of experimental jobs was started on the U-02 facility in order to solve problems relating to the use of coal as a fuel on the MHDEP.

The main goals in experimental research on the U-02 facility with simulated combustion of solid fuel are:

1) to study methods of injecting and distributing solid fuel over the cross section of the combustion chamber to form an effective heat-resistant and arc-resistant slag lining on the walls of the combustion chamber and channel of the MHD generator, and to determine the temperature on the flame surface and its effect on the slag composition;

2) to determine the degree of trapping of slag in the combustion chamber and to test possible ways to remove slag and ash from the chamber;

3) to study the behavior of the slag film on the firewalls of the combustion chamber and MHD channel, to investigate the protective, aggressive and electrical properties of the film and its influence on the characteristics of the MHD generator;

4) to study the physicochemical interaction of compounds of ionizable additive with slag and ash, and methods of regenerating the additive when a mineral component is present in the fuel.

1. Technical Specifications and Main Parameters of the U-02 Facility in Experiments on Simulating the Use of Solid Fuel on an MHDEP

The U-02 facility is the only continuous-duty model MHD installation in the world. In accordance with the goals set on each stage of the research, alterations were made in the set-up, and changes were made in the main equipment of the installation, which has gone through several stages of modernization in its development. The original design [Ref. 1], intended for solving fundamental problems in MHD electric power generation, has been considerably improved in application to modeling of the main units of the U-25 facility [Ref. 4], and devices for high-temperature heating of oxidizer and combustion of liquid fuel.

At the present time a program of gradual updating of the U-02 facility is in progress aimed at solving problems in modeling processes and testing basic equipment for an MHD installation on solid fuel. This program is to be realized in two stages. On the first stage the mineral component (ash) typical for the prospective fuels is added to the products of combustion of the gaseous fuel. The next stage calls for conversion to direct combustion of coal.

In 1975-1976 the technological set-up of the U-02 facility was supplemented with a system for injecting ash into the combustion chamber at a rate of 4-12 g/s consisting of a feed hopper, dust injector and dust duct; a scrubber type system for cooling the combustion products and slag granulation; a system for separating and collecting the granulated slag following the diffuser of the MHD generator channel. The main units that ensure operation of the facility in the presence of slag in the combustion products have been developed and tested. Among these are a combustion chamber with temperature at the outlet up to 2700 K, and a spray type scrubber without nozzle for granulating the slag and removing most of it from the combustion products. These systems and units are described below. In addition, supplementary tests were done on the system for wet extraction of ionizable additive to improve the efficiency of trapping both the additive and ash, and systems were updated for cooling the units used in granulating and extracting slag to provide for experimental determination of the effectiveness of trapping additive, slag and ash.

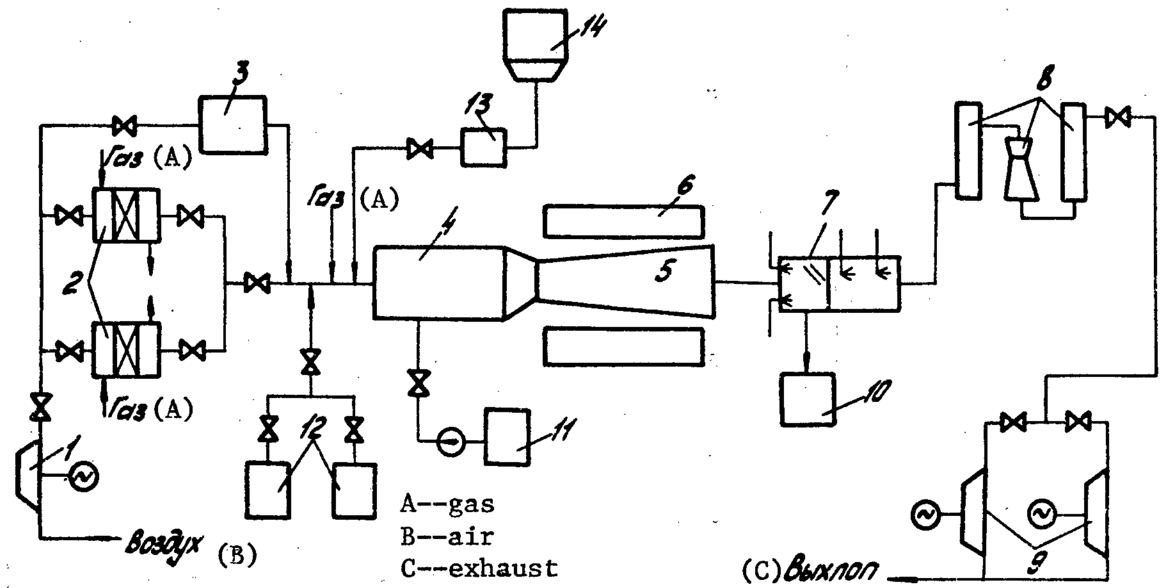

Fig. 1. Schematic diagram of the U-02 installation: 1--blower; 2--high-temperature air heater; 3--electric air heater; 4--combustion chamber; 5--MHD generator channel; 6--superconducting magnet system; 7--spray type scrubber with deflector shields and without nozzle; 8--system for cleaning combustion products; 9--vacuum pumps; 10--receiving hopper for granulated slag; 11--additive injection system; 12--oxygen feed system; 14--ash bin

As a result, the schematic diagram of the U-02 facility took on the form shown in Fig. 1. The circulation system of the U-02 made up of blower (1) at the input and two vacuum pumps (9) at the output gives a working pressure range in the chamber of 0.05-0.14 MN/m^2 and controllable flowrate of combustion products from 0.3 to 1.5 kg/s. The heating system provides air heating to 1800-2200 K when the high-temperature heaters (2) are used, and to 550-600 K when the electric heaters (3) are used. Up to 0.36 kg/s of gaseous oxygen can be injected by oxygen enrichment system (12) consisting of two lox tanks with capacity of up to 6 metric tons each, evaporators, and a system for feeding gaseous oxygen into the air line upstream from the combustion chamber.

In 1976, three series of experiments were done lasting 25, 35 and 33 hours respectively with the following main parameters:

flowrate of combustion products, kg/s	0.6-0.7
pressure in the combustion chamber, MN/m^2	0.088-0.098
air temperature, K	500-550
oxygen content in the oxidizer, %	50
excess oxidant ratio	0.98-1.02
temperature of the combustion products at the inlet to the working section of the channel, K	2500-2550
mass concentration of ionizable additive injected in the form of a 50% aqueous solution of K_2CO_3 with respect to potassium, %	1
average ash flowrate, g/s	5
average consumption of air in transporting ash, g/s	7

2. Main Characteristics of the System for Injecting Ash into the Combustion Chamber

The ash of Kuznetsk lean grade T coal taken from the electrofilters of fossil fuel power plants running on this grade was used to model the physicochemical and electrophysical processes taking place near the wall in the combustion chamber and channel of an MHD generator burning solid fuel, as well as the processes of interaction of the ionizable additive with slags and ash in the gas channel on the first stage of the experimental work. The temperature characteristics of the acid refractory slags formed by this ash are very close to the corresponding characteristics of slags from grades of coal being considered as prospective fuels for the MHDEP. It should be noted that among these fuels are grades of coal that form refractory slags of basic type that are similar in their temperature characteristics, but are distinguished by a much higher content of CaO (up to 60%). Subsequent stages of the research will include experiments with such slags. Table 1 gives the chamical composition of the ash used in our experiments.

TABLE 1
Composition of the initial ash injected into the combustion chamber

(1) Номер серии опытов	(2) Массовое содержание, %								
	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	TiO_2	Na_2O	S_2O_3
1	57,3	22,2	9,5	2,3	3,2	1,6	-	-	-
2	58,6	21,2	7,9	2,7	3,6	1,2	-	-	-
3	59,2	21,6	8,9	2,1	3,7	2,5	0,8	0,7	0,6

KEY: 1--Experiments of series No.
2--Mass content, %

Determination of the size of the initial ash particles showed that these particles are mainly smaller than 100 μm. Calculations show that ash particles of this size will be completely melted in a stream of high-temperature combustion products within 10-12 ms, i. e. directly in the combustion chamber. In using ash with such characteristics, the processes taking place in the region of coal combustion were not modeled, but it would be unreasonable to expect any great differences of processes that take place in the rest of the combustion chamber or the MHD channel, not to speak of the other elements of the gas channel of the MHD installation, regardless of whether coal is burned or ash is fed into the products of combustion of natural gas. The insignificant difference in the chemical makeup of the products of combustion of coal and gas could have no noticeable effect on processes near the wall or the intensity of interaction of the additive with slag and ash.

The system for feeding ash into the combustion chamber consists of a feed hopper with capacity of 0.8 m^3, a dust injector, a dust duct and a unit for distributing the ash over the cross section of the combustion chamber. The main requirement for the ash feed system is a flowrate that is stable in time. To achieve this, it was necessary to test several dust injectors. The difficulties of ensuring a stable flowrate and providing control stem from the small dimensions of the feeders, the tendency of the ash to cake and compaction in the hopper. Stable characteristics at a flowrate of 2-8 g/s were achieved on a mechanical dust injector of vane type. The ash was moved along the dust duct measuring 32 mm in diameter from the dust injector to the unit for distributing the ash over the cross section of the combustion chamber by a stream of air flowing at 6-8 g/s.

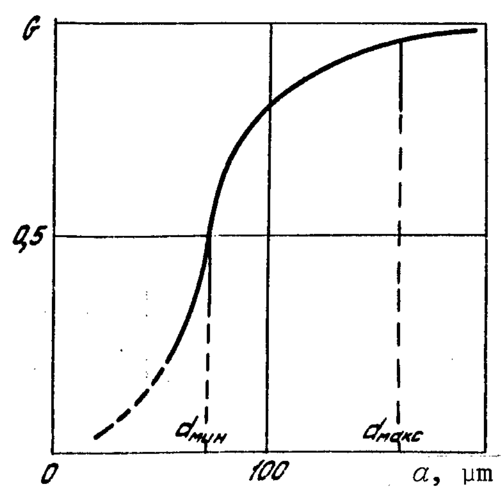

Fig. 2. Size distribution of the initial ash particles: $a_{мин}$ = minimum size; $a_{макс}$ = maximum size

The unit for distributing the ash over the cross section of the combustion chamber was built and tested in two modifications. In the first version, the ash was fed in along the chamber walls corresponding to the anode and cathode walls of the MHD generator channel to form a protective slag coating there. To do this, the ash was injected directly in front of the gas-air nozzles of the burner head that are next to the corresponding walls. Tests showed that with this kind of injection the slag covering on the walls of the combustion chamber and channel is not uniform, and the slag film on the insulation walls of the channel is unstable.

With this in mind, the second version provided for uniform distribution of the ash over the cross section of the combustion chamber, which was achieved by injecting the ash directly into the central zone of recirculation of the combustion products in the chamber. As a result, the ash particles are melted more completely and more uniformly distributed over the cross section, forming a uniform slag coating on the walls of the combustion chamber and channel.

3. The Combustion Chamber in Operation with Ash

The first series of experiments on the U-02 facility used a combustion chamber designed for burning gaseous fuel [Ref. 1]. On the flame side, the housing was covered with a high-temperature lining based on electrosmelted zirconium dioxide stabilized with calcium oxide to a thickness of 100 mm, the inside diameter of the chamber being 300 mm. The flame surface of the slit type burner head was also lined with zirconium dioxide. A water-cooled metal nozzle was used. The temperature of the lining reached 2300-2400 K.

The experiment showed that at such a high temperature of the firewall the slag that is formed when ash is injected into the chamber does not wet the flame surface, nor stick to it, nor form a slag coating. At the same time, the intensive interaction between the slag and zirconium dioxide melts and destroys the lining. Chemical analysis of samples taken from the melted flame surface of the combustion chamber showed up to 45-52% ZrO_2 along with basic ash components.

The main cause of destruction of the ZrO_2-based lining was apparently the presence of aluminum oxide (about 22%) in the slag, interacting with the ZrO_2 and forming a eutectic with fairly low melting point (2000-2030 K). It has been established [Ref. 2] that most kinds of refractories cannot work long in an atmosphere of combustion products containing straight carbon slags at a temperature above the point of onset of the liquid state of the slag because of the intense interaction between the multicomponent slag and the refractories. Experiments done on the U-02 facility using a ZrO_2 lining have once more confirmed this.

For the second series of experiments, a new housing was made for the combustion chamber with ZrO_2-based lining having intensive heat removal. The thickness of the lining was 10-30 mm with internal diameter of 300 mm. The length of the combustion chamber (1200 mm), burner unit and nozzle were left unchanged. A diagram of the chamber is shown in Fig. 3, and the general appearance in Fig. 4.

The second and third series of experiments showed that when the firewall is hotter than 1900 K no stable slag coating is formed, and intensive melting of the lining occurs. In this case the measured wall temperature was 2000-2050 K and the heat flux density was 0.15-0.2 MW/m^2. Inspections during shutdowns showed that the flame surface of the chamber was covered with a molten vitreous yellow-brown film. This film contained up to 52% ZrO_2 [Ref. 5].

A thoroughly molten slag of blue-black color with chemical composition close to that of the initial ash accumulated in the lower part of the chamber. The level of this slag bath rose uniformly from 5-10 mm in the beginning of the chamber and reached the lower tip of the nozzle. Shown in Fig. 5 is the internal appearance of the combustion chamber on the nozzle side after 35 hours of tests with ash.

The intensive destruction of the lining during startups results in a temperature reduction, and a strong blue-black slag coating 2-5 mm thick is formed on the

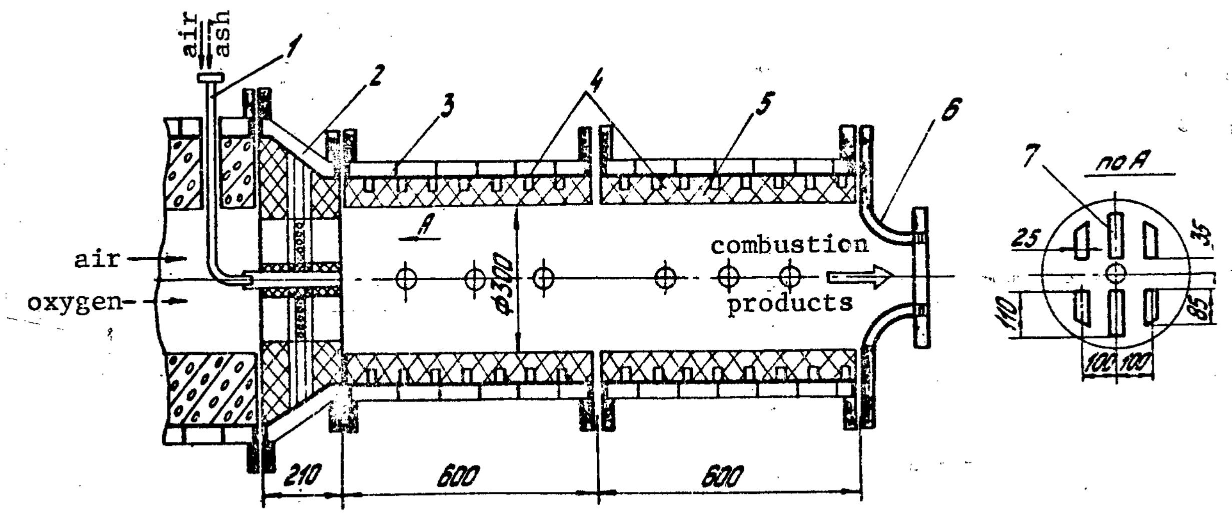

Fig. 3. Diagram of combustion chamber for operation with ash (KS-8U): 1--ash input; 2--burner head; 3--cooled housing; 4--sections; 5--refractory lining; 6--nozzle; 7--slit mixers

[Photo not reproducible]

Fig. 4. General appearance of the KS-8U combustion chamber

[Photo not reproducible]

Fig. 5. Appearance of the flame surface of the combustion chamber on the discharge side after operation with ash injection

[Photo not reproducible]

Fig. 6. Appearance of the firewall of the nozzle after tests with injection of ash and additive

flame surface, the temperature of the flame surface being 1800-1850 K, and the heat flux density rising from 0.2-0.3 MW/m^2. It was noted that the lining is rapidly destroyed and a stable slag coating is formed in the second section of the chamber, which can apparently be attributed to a higher concentration of molten slag particles, and consequently more energetic interaction.

Formation of a slag coating on intensively cooled metal surfaces has its own peculiarities. Experiments showed that without additive injection the formation of a stable slag coating proceeds rather slowly, sometimes over a 2-3 hour period. Formation of the slag coating is much more effective when the chamber operates with an ionizable additive. The metal surface is first covered with a film made up of K_2CO_3 and KOH, apparently resulting from condensation of KOH from the flow on relatively cool surfaces (1200 K). The slag coating forms on this film, as can be readily seen from the photograph of the flame surface of the combustion chamber nozzle in Fig. 6. The thickness of this two-layer film reaches 5-10 mm in corners, and 1-3 mm on surfaces exposed to intensive washing by combustion products.

On the whole, our tests confirmed that the conditions of slag coating formation are identical for ash injection into the products of gas combustion and for coal burning. In subsequent series of tests attention will be focused on the removal of liquid slag from the combustion chamber, determination of the content of compounds of the additive in the liquid slag, and investigation of the conditions of formation and thermal efficiency of the slag coating on walls when the initial ash has other characteristics.

4. Investigation of the Slag Film on the Channel Walls of an MHD Generator, and the Channel Characteristics

On the first stage of studies of the influence that slag films have on the operation of electrodes and the characteristcs of the MHD generator channel in the U-02 facility, emphasis was placed on the operation of the electrodes protruding into the stream, with fairly large thermal flux densities and areas [Ref. 6]. In Ref. 6 the authors note comparatively long times for the formation of a fluid film on the surface of the cold electrode walls. At the current densities typical of industrial MHD generators (0.5-2 A/cm^2) electrodes of various materials operate in a contracted state over a fairly wide range of surface temperatures (from 420 to 1770 K), the parameters of spots and surface temperature of the fluid film being weakly dependent on the material and temperature of the electrodes; at fairly high current densities (3-4 A/cm^2) the films were observed to be eroded under the action of spots. In virtue of this, the effective voltage drops near the various electrodes also showed little difference, and were much lower than in the case of operation without a slag film (particularly for cold metallic electrodes).

This report covers the next stage of the research -- studying the behavior of slag films and phenomena in the vicinity of the electrodes on extended cold electrode walls and their influence on the electric characteristics of the electrodes and of the channel as a whole. An investigation was made of the

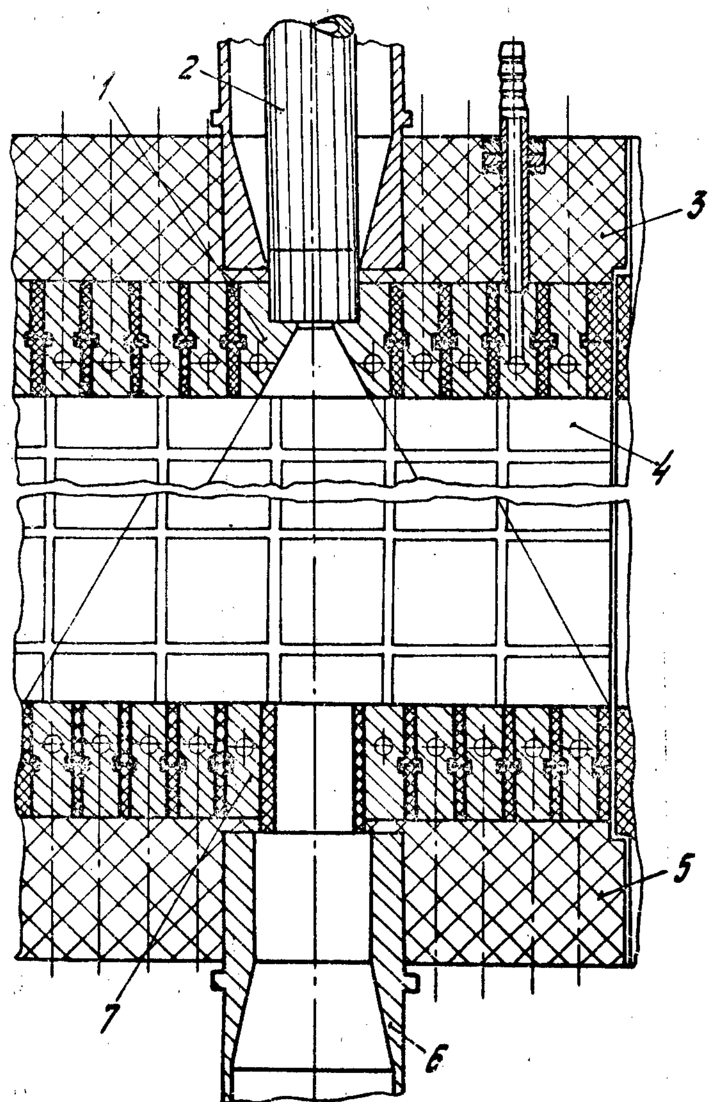

Fig. 7. Working section: 1--module for installation of the optical system; 2--optical system; 3--anode wall; 4--insulation wall; 5--cathode wall; 6 and 7--channel and module respectively for installing the movable electrodes

particulars of electric and thermal characteristics of the channel working with ash injection into the combustion products, and the service life of electrodes made of different materials in the presence of a fluid slag film.

The studies were done on the KE-10U and KE-11U channels of the U-02 facility. The experimental sections of the channels had a cross section of 60 x 260 mm and length of 745 mm (Fig. 7). The electrode walls (Fig. 8) were made of copper water-cooled electrodes with flame surface area of 17 x 60 mm apiece fastened to a glass-textolite carrier base. The electrodes were insulated from one another by T-shaped insulators of dense eluminum oxide 4 mm thick, and the entire lateral surface of the electrodes in the cold zone was coated with K-100

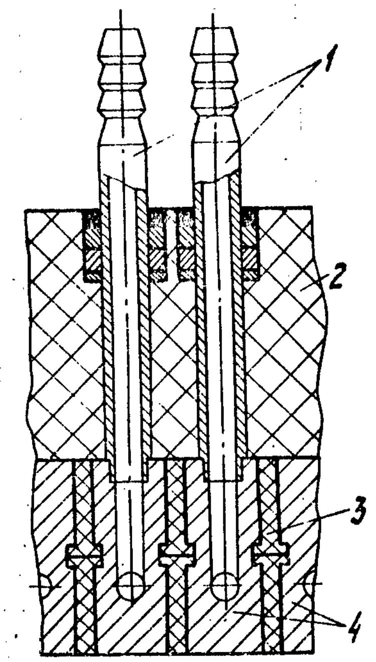

Fig. 8. Electrode wall: 1--coolant feed tubes; 2--base; 3--insulator; 4--electrode

organosilicon insulating varnish. Thirty stationary electrodes were installed on the cathode wall, and another thirty on the anode wall. Between the 15-th and 16-th electrodes on the cathode wall in the KE-11U channel (see Fig. 7) is a water-cooled copper module; during the experiment, movable electrodes made of different materials were installed in this module through a hole in it. A special module for installation of a wide-format optical system was located in the anode wall coaxial with the module for movable electrodes.

The insulation walls (Fig. 9) were made of metal bases to which water-cooled modules with a flame surface of area 40 x 40 mm were fastened. Installed between the modules were aluminum oxide insulators 4 mm thick. The lateral surfaces of the modules in the relatively cool zone were also covered with K-100 insulation varnish. Installed in the upper insulation plate were platinum probes for measuring the plasma potential. The probes were accommodated by insulation tubes of aluminum oxide protruding into the flow of combustion products to a distance of 3 mm so that the platinum of the probe was insulated by the tube of aluminum oxide from the liquid slag film and was in electric contact only with the plasma.

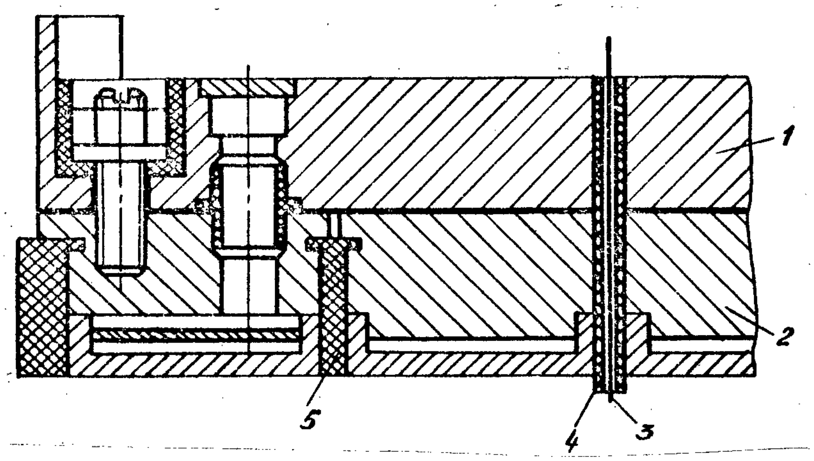

Fig. 9. Insulation walls: 1--base; 2--module; 3--probe; 4--insulation tube; 5--insulator between modules

The channel design includes provision for measurement of the density of heat flux to elements of the electrode and insulation walls by calorimetry of the cooling water. The flowrates of the cooling water were measured by a volumetric method using a semiautomatic system, heating of the water was determined from the readings of twelve-junction Chromel-Copel thermocouples. The temperature of the slag film was measured by an OMP-048 optical micropyrometer and an OPPIR-017 pyrometer precalibrated together through the optical system by using a standard band lamp. At the inlet to the working section of the channel the temperature of the combustion products was measured by the technique of reference to the spectral D-line of sodium.

For purposes of studying the behavior of the slag film on the walls of the MHD channel particular attention was given to the selection and installation in the channel of a special optical system enabling both visual observations of the electrode and insulation walls of the channel and also still and motion picture photography. In the experiments an optical system was used with a large aperture angle giving a field of view of up to 250 mm when the overall diameter was 40 mm, the channel width being 260 mm (see Fig. 7). The optical system was installed in a special module in the anode wall. This system enabled observation of the behavior of slag films and processes in the vicinity of the electrodes simultaneously on 12 electrodes measuring 17 x 60 mm, as well as providing a view of half (with respect to width) of the surface of the upper and lower insulation walls. The spatial resolution of the system and camera was 15-20 lines per mm. Depending on the particulars of the process being observed, motion pictures could be taken over a wide speed range from 8 to $2 \cdot 10^4$ frames per second.

To study the behavior of the slag film on the walls of the MHD channel as well as electric discharge on this film, a technique was used for determination of the temperature fields on the surface of slags from blackening of motion picture film. The phenomenon being studied and a reference emission source (SI-10-300 band lamp) were exposed simultaneously by a mask method on the same frame so that the characteristic curve of the photographic film could be plotted individually for each frame, eliminating errors due to possible lengthwise variations in the sensitivity of the film.

Photometric measurements of the film were done on the G-II automatic microphotometer made by Karl Zeiss. By using the characteristic curve one can determine the emission intensity of the slag surface, and then its brightness temperature. The measurements were compared with the brightness temperature measured at individual surface points by the OMP-048 optical micropyrometer and the OPPIR-017 pyrometer.

It should be noted that conversion from emission intensity to brightness temperature necessitates consideration of the emission of the flow of combustion products. However, according to estimates, for the dimensions of the plasma in channels of the U-02 facility (with the exception of the spectral region of the sodium resonance doublet emission) the spectral intensity of combustion products emitting in a flow at a temperature of 2500-2700 K is weaker than the surface emission intensity when the surface temperature of the channel walls is as low as 1100-1200 K. Therefore when a narrow-band optical filter is used with a passband that does not include the region of emission of sodium D-lines, the error in measuring a surface brightness temperature from the walls of more than 1300-1400 K does not exceed 2-3%. Obviously the error decreases with increasing surface temperature. Since practically the entire surface of the MHD channel is covered with a slag film, and the channel is practically a closed space, the measured brightness temperature of the film surface will obviously be close to its true temperature.

The program of electric experiments included investigation of effective voltage drops across different electrodes with operation on external sources both in the absence of a magnetic field and in a magnetic field with induction of $B = 1.7$ T. The voltage drops in the vicinity of electrodes were studied with respect to the distribution of plasma potential across the channel as determined by probes. The electric characteristics of the channel as a whole were studied both in the purely inductive state ($B = 1.7$ T) when all pairs of electrodes were simultaneously connected to stepwise-controllable resistors (six load steps including open and short-circuit), and in a "braking" state, i. e. with jointly directed induced emf and external electric field. The "braking" mode of operation was realized simultaneously on six pairs of electrodes located in different sections of the channel by connecting them to potentially decoupled simultaneously controlled external sources.

The distribution of potentials of the elements of the channel and probes as well as the currents on the electrodes were fixed on each load step by a "Kompakt" automatic data collection system as well as on laboratory instruments. Continuous curves for the anode-cathode and probe-electrode voltage (the effective voltage drop in the vicinity of the electrode) as a function of the electrode current were recorded by a two-coordinate PDS-021 chart recorder. The parameters of the flow in the channel during the tests were:

Plasma temperature at the channel inlet, K	2500-2550
Pressure in the channel, MN/m^2	0.75-0.85
Velocity of plasma flow, m/s	350-400

The total time of operation of each of the tested channels on the given parameters with injection of ash in the amount of 0.7-0.9% of the mass of the combustion products was from 25 to 35 hours.

Observations of the surface of insulation and electrode walls by the optical system showed that with the first injection of ash a stationary film was formed within thirty minutes on the channel surface with a surface temperature of 1400 K. The slag film was deposited first on the surfaces of the intermodule and interelectrode insulators and close to them, and then the film covered the remaining part of the surface. About 1.5 hours after starting ash injection a fluid slag film appeared (Fig. 10) with characteristic waves on the surface, the average temperature being 1900 K. It should be noted that the fluid slag film first propagated in isolated "rivulets" along the intermodule insulators on the insulation plates, and then (in about 2-3 minutes) became a continuous sheet over all channel surfaces. In general terms, the pattern of development and stabilization of the flow of slag film is similar to that observed in Ref. 7 and 8, and is in agreement with earlier experiments done on the U-02 installation [Ref. 6].

During the tests, the feeding of ash into the combustion products was repeatedly interrupted and restarted, enabling observation of the process of formation of slag films. When a fluid slag film was present on the channel elements after cessation of ash injection, a stationary slag film was retained on the electrode wall in the corners between the electrode and insulation walls and on separate sections of the lower insulation plate.

In repeated tests of the U-02 facility when the combustion chamber already had a slag coating, the time for stabilization of the slag films on the electrode wall decreased to 1 hour. In an even shorter time (about 30 minutes after the beginning of ash injection) a fluid slag film showed up on the lower insulation plate, which is apparently due to the presence of a slag melt in the lower part of the combustion chamber. The rate of displacement of the wave crests over the insulation plates was faster (~5 cm/s) than over the electrode wall (~1 cm/s).

Of considerable importance is the fact that the surface of the crests on the slag film was much hotter than the rest of the film. The temperature on the average over the surface was 1870 according to optical pyrometer measurements, and 1930 K according to photopyrometric analysis of the photographic film (which shows the excellent possibilities of the photometric method). The temperature of the crests from the results of photometry was 2120-2270 K. Considering the sharp dependence of the viscosity of the slag film on temperature, showing a reduction by approximately an order of magnitude with a temperature increase by 200 K (about 1870 K), it can be assumed that mainly it is only the "crests" that move. In such a case the models of laminar motion of the slag film that were considered in Ref. 7 and 8 should be taken as very approximate. The distance between successive crests averages 0.5-1 cm.

The presence of a high-temperature slag film considerably reduces the density of heat flux to structural elements. For instance the heat flux density of 0.7 MW/m^2 to the electrode wall in the absence of a slag film decreased to 0.3-0.4 MW/m^2 when a fluid slag film was present, which is apparently due to a rise in surface temperature during formation of the slag coating.

During the first ash injection (for about the first hour) the density of heat flux to the electrodes of the cathode and anode walls increased from about 0.8 to 0.95 MW/m^2. This is apparently due to the fact that the surface of the metal electrodes was still free of slag film (with the exception of the interelectrode insulators), whereas a stationary slag film with surface temperature of 1570 K was formed on the surface of the lower insulation plate, emitting heat toward the electrode wall. Then, as soon as a fluid slag film was visually observed on the cathode wall, the heat flux to the wall decreased to 0.3 MW/m^2.

An investigation of the electric characteristics of KE-10U and KE-11U films in the presence of slag on their surfaces showed two new peculiarities distinguishing them from analogous characteristics described in Ref. 6 or found in the absence of a film.

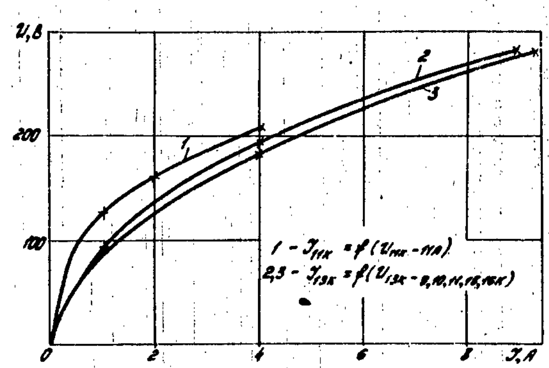

Fig. 11. Current-voltage characteristics of electrodes in operation from an external source (in the subscripts the letter K stands for cathode and A stands for anode, while the numbers stand for the electrode number)

In the first place, as can be seen from Fig. 11, showing the current-voltage characteristics of individual cathodes with different numbers of response anodes connected, the electrical characteristics are little dependent on the total area of the connected electrodes. This is also confirmed by comparing Fig. 11 and Fig. 12, showing the electrical characteristics of three pairs of electrodes with combined operation from a single source. Actually the total current through three cathodes connected in parallel (9, 11 and 13, see Fig. 12) differs little from the current flowing through one of the cathodes (11 or 13 in Fig. 11) for the same voltage between electrodes. Approximately the same values of total current were observed with joint operation of electrode pairs No 8, 9, 10, 11, 13, 14, 15 and 16, each pair operating from an individual source (Fig. 13).

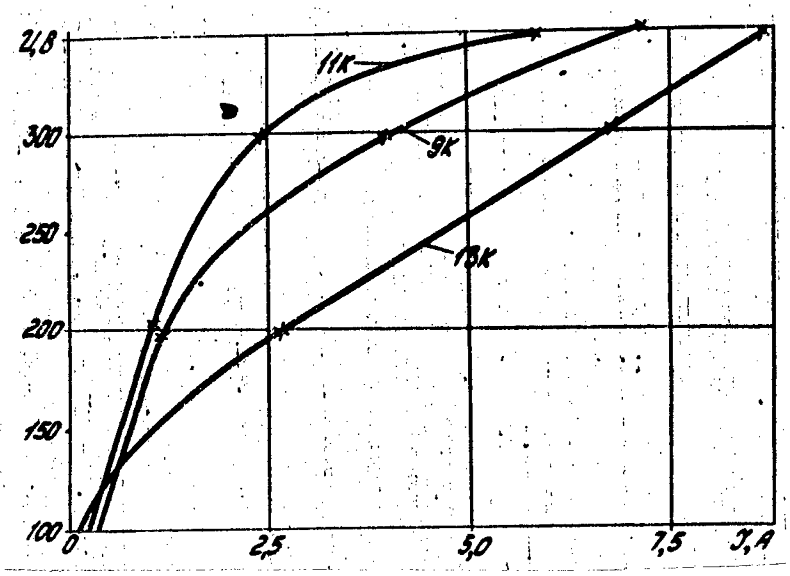

Fig. 12. Current-voltage characteristics of electrodes with combined operation from a single source (the cathode number is shown on the curves)

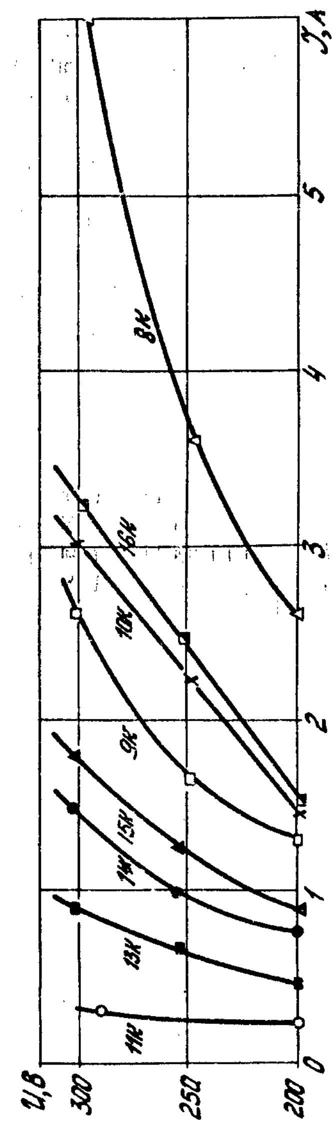

Fig. 13. Current-voltage characteristics of electrode pairs with combined operation from a single source

Thus under the conditions of the experiments the total current is weakly dependendent on the number of simultaneously working electrodes.

A secondary peculiarity is that the currents obtained from flat electrodes set flush with the extended electrode wall are much lower than those previously obtained [Ref. 6] under similar conditions on electrodes protruding into the flow.

The electrical characteristics of the electrodes are also poorer than those studied in Ref. 6 on flat cylindrical electrodes surrounded by ceramic insulators. Apparently this is due to the comparatively high effective electrode differentials ΔU_K, and in particular to the threshold values of ΔU_K at which current appears. As experiments in the induced mode (close to short circuit) have shown, these values of ΔU_K come to more than 100 V. At current densities to the electrodes of the order of 1 A/cm^2 the electrode drops amount to 120-140 V (Fig. 14), where previously they were 50-70 V on electrodes protruding into the flow, and 80-100 V on flat electrodes surrounded by ceramic insulators.

In the induced mode in the presence of a slag film the open-circuit voltage found in the experiment decreased by an average of 20-30% lengthwise of the channel as compared with the theoretical value ($U \times B \times Y$). The average short-circuit current density was 0.1 A/cm^2, which is also much lower than in the case of electrodes protruding into the flow. The short-circuit current lengthwise

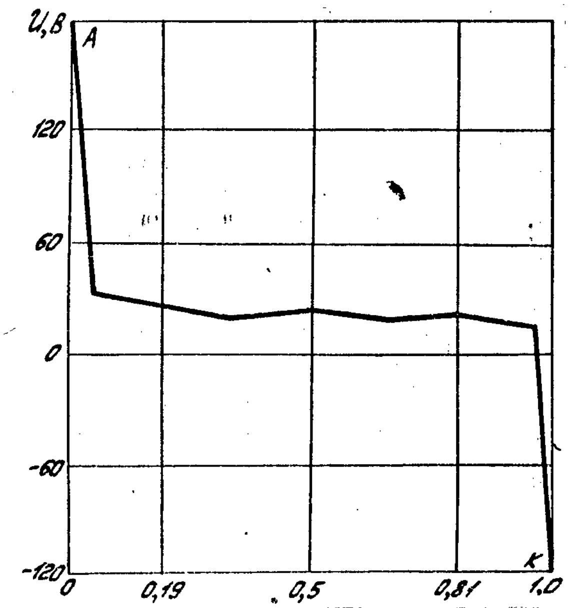

Fig. 14. Transverse distribution of potentials

of the channel was irregular, reaching 0.3 A/cm^2 on individual electrode pairs. The short circuit currents were unstable both with respect to the length of the channel and in time, and the nonuniformity of short-circuit currents increased after long operation with ash injection.

Investigation of the behavior of cathode spots on flat metal electrodes in the presence of slag films showed that in the case of electrodes protruding into the flow [Ref. 6] there is a relatively large number of spots (see Fig. 10) with approximately the same average current per spot (1-2 A).

Cathode spots were observed burning on the surface of slag films most frequently on their border with the part of the surface free from films. The elimination of films from part of the surface in the presence of cathode spots showed up with particular clarity at average current densities of more than 0.5 A/cm^2, the dimensions of the regions free from slags reaching 1 cm and more, and decreasing to a few millimeters with a drop in current. Apparently, just as in the case of electrodes protruding into the flow that were studied previously, this disruption of integrity of the fluid film is a consequence of destruction under the action of cathode spots (in particular due to evaporation). As a rule, within a certain time these regions were once again covered with a flowing film of slag; however, a region free from slag showed up in another place. The same kind of film destruction under the action of spots has been observed subsequently in Ref. 8.

The observed destruction of the slag film is obviously a very important fact that is evidence of certain difficulties in the creation of a continuous protective film. Apparently it will be especially difficult to create a continuous film in long channels at high current densities (more than 1 A/cm^2), although the idea of a protective slag film on electrodes has been put forth in many papers, e. g. in Ref. 9. In this connection it is advisable to study these problems in particular detail.

Computational estimates have shown that the main components in the material balance on the electrode walls of the MHD channel may be the arrival (or the departure) of ash particles at the electrode wall as a consequence of electrophoresis (especially in view of the existence of a particle charge due to thermionic emission from the particle surface) and vaporization of slag films under the action of spots. The destruction of films under the effect of spots observed in the experiments can be evaluated by a coefficient of electric transfer of the order of 10^{-3} g/C. With this kind of erosion and the intensity of film flow observed in the experiments at the inlet to the channel, the length of the section where the film will remain intact may vary from 0.2 to 10 m, depending on current density and other conditions. To overcome these difficulties it is advisable to consider the question of more optimum distribution of ash over the cross section of the flow.

In addition to the appearance of cathode spots on the boundary with the clean surface it is typical to observe motion of spots in "chains" in the direction of flow, and also a certain immobilization of spots at the hotter "crests" of waves on the slag film (see Fig. 10) which is apparently due to the above-mentioned relatively high surface temperature (2200 K) and the comparatively low thickness of the cold boundary layer at this point.

Another distinguishing feature is that the location of burning spots does not coincide with the location of electric contact between the electrode metal proper and the molten slag film. For instance in operation of an isolated electrode (size 17 x 60 mm) the region of the film surface where cathode spots are found burning is 3-4 times the area of the electrode proper covered by the current (see Fig. 10). Just as in the case of electrodes protruding into the flow [Ref. 6], slag film regions with a high temperature are observed that are apparently heated by currents flowing from the areas of spot burning to areas of electric contact between the slag film and the metal. As evidence of the fact that the fluid electrically conductive slag film is in contact with the metals only at isolated points, witness the appearance of small "holes" in the continuous slag film as current is flowing (see Fig. 10) with no arc spots near them. These "holes" are apparently caused by destruction of the film "from the inside" as a consequence of gas release beneath the film at points of breakdown of the comparatively cool sublayer of slag in contact with the metal surface.

Our studies of the behavior of the slag film and cathode spots on the surface of electrode walls suggest a hypothesis that explains the peculiarities of electric characteristics of the electrodes mentioned above. Apparently the main cause of these peculiarities is the presence of a solid slag sublayer of low transparency on the surface of the electrodes. Electric contact between the fluid slag film and the metal occurs at isolated points of the surface with breakdown of the nonconductive sublayer, which requires maintaining the corresponding high voltage drop. Obviously the number of contact points (which are visible as small dark regions that are free of the film) depends mainly on the overall current through the electrode. It can be assumed that the behavior of the slag film depends on the thickness of the boundary layer on the surface and the density of the heat flux to the wall.

The structure and electrical resistance of the cool slag sublayer are apparently different for an extended cool wall and for electrodes protruding into the flow. In virtue of this, in the latter case the above-mentioned contacts are made much more readily and do not strongly influence the electrical characteristics of the electrodes. It should also be borne in mind that the comparatively thicker boundary layer on flat electrodes also has a detrimental effect on their electrical characteristics. A comparison of their characteristics with those of hot ceramic flat electrodes working in the absence of slags and having approximately the same temperature shows an appreciable additional resistance in the case of slags, which is apparently the resistance of the cool slag sublayer.

Actually, estimates made with electrode operation at a current density of 1 A/cm^2 have shown that of the approximately 120 V drop in the electrode vicinity, 70% goes to the slag layer in the electrode region, whereas the electrode voltage drop was much lower in the case of electrodes protruding into the flow.

A probable cause of the appreciable reduction in open-circuit voltage (with respect to the theoretical induced emf) is the high resistance of slag films at low currents and the flow of currents over the slag film on the insulation walls. Leakage currents necessarily flow through the slag-metal contact, and therefore may be considerably higher than the short-circuit currents determined in the electrode circuits. As evidence of the comparatively high leakage currents shorted through the slag film witness the fact that the intensities of the hall field lengthwise of the channel show little difference for short-circuit and open-circuit experiments (Fig. 15). The effective resistances $R_{\alpha-\kappa}$ of the channel insulation and the internal resistance r_0 were determined from open-

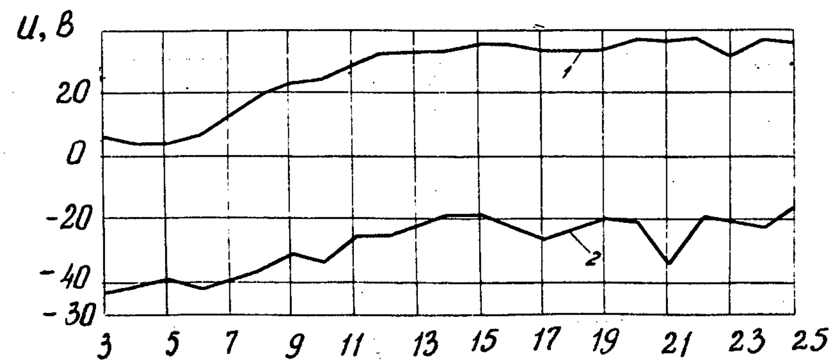

Fig. 15. Longitudinal distribution of potentials under open-circuit (1) and closed-circuit (2) conditions

circuit and short-circuit experiments. For instance the internal resistance during startup of the KE-10U channel varied over a range from 0.15 to 1 kΩ, and for the KE-11U channel it was 0.06-0.12 kΩ. From a comparison with the data given above from experiments with high current densities it can be seen that when the current increases the internal effective resistance of the slag film drops noticeably (by an order of magnitude) which also may be caused by the peculiarities of the contact between slag films and electrodes.

Thus these experiments suggest that the presence of a cool hard slag sublayer (with temperature from 600 to 1500 K) adjacent to the electrode is very detrimental to the electrical characteristics of the channel. The electrodes are in contact with the fluid slag film at isolated points of the surface when this nonconductive cool sublayer breaks down. Considering our results, it would seem advisable to provide for a certain warming of the electrode walls, for instance by covering part of their surface with ceramic materials or rammed linings. Such warming of electrode walls has now been effected on the KE-12U channel, which is ready for testing.

5. Systems for Cooling Combustion Products and Trapping Additive, Slag and Ash

Located behind the diffuser of the MHD channel (see Fig. 1) is a spray type scrubber without nozzle in which the combustion products are cooled from 2300-2400 to 400-500 K by water dispersed through atomizers. Atomizers of two types were used in the experiments: direct-spray and centrifugal. They were installed in several cross sections along the gas stream and gave drops with median size of 300-500 μm. The drops were entrained by the gas flow, heated and partially vaporized, cooling the combustion products. Some of the vaporized drops fell on the walls of the gas duct, and the others were separated from the flow at the turn of the gas line toward the foam unit. The separated moisture ran into collection tanks, and the combustion products enriched with water were sent to the foam unit where they were washed with water cooled to 290-300 K. This caused intense condensation of vapor, and almost all the water sent to the scrubber for cooling the gases was returned to the cycle.

In addition to the heat exchange in the scrubber, the solid particles of slag and additive were removed from the gases. The slag was removed first. To separate the largest slag particles, two water-cooled shields were placed in the initial section of the scrubber, forming a labyrinth in the gas flow and throwing the slag particles downward into a special bin. Experience has shown that in this way up to 80% of the slag is removed from the stream. The remainder is carried downstream in the form of highly dispersed fly ash (with particle size mainly 10-20 μm). This ash partly settles out along with surplus moisture on the walls of the scrubber and is washed into the hopper, and part of it enters the system of additive extraction and is trapped in the foam unit and the Venturi scrubber.

The presence of fly ash and drops of water in the gas flow is conducive to heterogeneous condensation of the additive in the process of cooling of the combustion products. Condensation of the additive on cool drops may even begin in the high-temperature zone, where most of the additive is in the form of KOH vapor. With a reduction of gas temperature to 1470 K there is a reaction between KOH and CO_2 in the flow producing K_2CO_3 that begins to condense in virtue of the low vapor pressure. In this case the centers of condensation are both particles of fly ash and drops of water. And although the steam formed as water drops evaporate does interfere with the condensation of sodium additive on drops, experiments have shown that up to 40% of the injected additive is trapped in the scrubber and carried away with the spray liquid.

The additive condensed on the fly ash forms agglomerates with dimensions of several micrometers. Particles of this size are more readily trapped than the particles with measurements of a fraction of a micrometer that are typical of MHD installations working on clean fuel. This was confirmed by studies of efficiency of additive trapping by a foam unit with Venturi scrubber. The system is described in detail in Ref. 10.

A foam unit 1.4 m in diameter with three distillation grid plates 5 mm thick having openings 6 mm in diameter (free cross section 0.25 m^2/m^2) caught from 50 to 78% of the incoming additive. This relatively high efficiency was the result of intense condensation of water vapor, since from 0.3 to 0.5 kg of vapor was condensed in the foam unit per kg of dry gases. As a result the dust content of the gases (chiefly due to additive) at the inlet to the Venturi scrubber was equal to 3 g/mm^3. The Venturi scrubber operated at a gas velocity of about 200 m/s in the throat and specific reflux of 3.g $l \cdot g$/kg of gases (pressure drop about 2 kN/m^2)*, and the dust content of the gases from the outlet was less than 0.01 g/nm^2, i. e. the the efficiency of additive trapping by this apparatus was greater than 99%. On the whole, less than 0.05% of the additive injected into the combustion chamber was entrained with the departing gases.

Thus the studies done on the U-02 facility on additive trapping in the presence of ash proved the high efficiency of operation of the units of the extraction system as compared with trapping of pure additive (when the U-02 facility was operated on clean fuel).

6. Investigation of Interaction Between the Ionizable Additive and Slag

This research may be of great practical interest; the type of combustion chamber of the MHDEP depends to a great extent on the interaction between additive and slag. According to thermodynamic calculations [Ref. 11] the slag may absorb up to 50% of the additive. In this case steps must be taken to extract nearly all the slag before injecting the additive. This is a complicated problem, requiring two-stage or three-stage combustion of the coal with partial or total gasification, which complicates the design of the chamber and increases heat losses. However, experiments done at the Space Institute of Tennessee University [Ref. 12] have given very encouraging results: much less additive gets into the slag than is predicted by thermodynamics. This is explained by the limiting role of gas-slag mass exchange, and apparently by the low rate of diffusion of the additive into the liquid slag (into droplets or into the film on the wall of elements of the MHD generator).

As was pointed out in section 5, the main quantity of slag was extracted in the zone of the labyrinth just behind the diffuser of the MHD channel, finer fractions were trapped in the scrubber without nozzle, which provided cooling of the gases, and the rest was trapped in the foam unit with Venturi scrubber. In all cases the slag was removed by water, the water-soluble compounds being washed out of the slag particles as they came into contact with water (if the particles were sufficiently fine or porous). This must be taken into consideration when analyzing specimens taken during the experiment.

Samples that had not been washed in this way were taken from various elements of the loop (combustion chamber, MHD channel, diffuser) after completion of the experiment and cooling of the U-02 facility. Analysis of these samples gave

*The reason for maintaining such a high drag was to maximize the protection of vacuum pumps against the possibility of ash contamination.

some information on the proportion of water-soluble and water-insoluble potassium compounds in the slag. Let us examine some data obtained in experiments with ash and additive.

In the high-temperature region the vaporous additive (in the form of KOH and even potassium vapor) is in contact with the molten slag, while in the scrubber zone and beyond the additive settles out on solid ash particles. In this case the additive is mainly in solid form (K_2CO_3), and chemical reaction with the slag is practically eliminated. Chemical analysis of the initial slag (see section 2) showed that it contains considerable amounts of SiO_2 and Al_2O_3. In this case the chemical reaction of potassium additive with slag should lead to the formation of kalsilite $KAlSiO_4$, a compound that is practically insoluble in water, which was confirmed by analyses of slag specimens.

Analysis of slag samples taken from the combustion chamber after shutting down the U-02 loop showed that they contained about 3% potassium. Results were completely different for analysis of slag specimens taken from the cathode and anode walls of the MHD generator channel (16.2 and 21.1% respectively). Attempts to extract this potassium with hot water (by grinding the specimens into fine powder and boiling in water) were nearly useless -- only about 1/20 of the absorbed potassium could be removed, i. e. as we expected the main quantity of potassium is in the slag in the insoluble form of $KAlSiO_4$, which was confirmed by x-ray structural analysis.

Given in Table 2 are data of chemical analysis of slag samples taken during the experiment from four zones: 1--from under the the deflector labyrinth just behind the diffuser of the MHD channel; П and Ш--from the waste following the scrubber-cooler; 1У--from the system of additive extraction. All these samples had been in contact with water, and soluble potassium compounds had been washed out of the slag to a great degree.

TABLE 2

Место отбора (1)	(2) Массовое содержание, %						
	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	ZrO_2	K*
1	24,1	18,0	6,0	4,1	4,2	39,6	4,0
П	47,2	19,5	10,8	3,2	2,8	5,4	11,1
Ш	40,7	21,2	13,3	5,0	3,3	7,5	9,0
1У	34,3	17,4	13,0	7,4	3,6	11,5	12,8

*The potassium content in the specimens was determined by plasma photometry

KEY: 1--Sample point; 2--Mass content, %

These data suggest certain preliminary conclusions. First of all the interaction between the potassium additive and slag films running over the walls is comparatively low (3% in the combustion chamber and 4% at the inlet to the scrubber), and since it is from just these areas that most (up to 80%) of the slag is extracted, the additive lost with the slag (assuming injection of 5 g/s of ash and 7 g/s of potassium) amounts to 1.5-2.0% of the injected additive. The high concentration of potassium in samples taken from the channel is apparently due to the long time of contact between this slag and KOH vapor, as well as the possibility of additive condensation on the cool surface under the slag. It is still not clear why there is a high concentration (up to 12.8%) of potassium in the ash trapped by the additive extraction system.

Our experiments are the first stage (to some extent a preliminary stage) in the research, and the results must be carefully verified in the next step planned for 1977-1978.

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