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AGGREGATION OF COMPUTING CHANNELS BASED ON THE NVIDIA CUDA PLATFORM FOR CONTROL MODES OF COMPONENTS OF TECHNOLOGICAL SYSTEMS

Today, practice poses problems, the solution of which by well-known standard approaches quite often represents a significant problem, which can be solved only by using multiprocessor computer technologies. In turn, one of the fundamental features of the application of these technologies is reduced to increasing the productivity and speed of calculations. At the same time, the significant performance of calculations allows the solution of multidimensional problems, as well as problems that require a significant amount of processor time. Speed operation allows you to effectively manage not only technological processes, but also provides for the creation of prerequisites for the development of promising and innovative technological processes. Therefore, the application of high-performance computing is an urgent and priority problem today.

The goal of the work is to improve the structure and increase the performance of a multiprocessor computer system by aggregating computing channels based on the NVIDIA CUDA platform for control modes of technological process components. The proposed approach made it possible not only to increase the efficiency of parallelization, but also to significantly reduce the calculation time. In the given development of a multiprocessor system, two NVIDIA GeForce GTX 1080 video cards were "connected". This approach is aimed not only at a significant increase in computing performance, but also at a significant decrease in latency and significant unloading of the system bus.

Compared to the known approach, due to the application of the software-hardware architecture of parallel computing from the NVIDIA corporation based on the CUDA platform, it was possible to increase the volume of video memory by 16 GB on each computing node of the multiprocessor system, as well as to increase the overall performance of the system node by 350 GFL.

The practical value of the conducted research is aimed at solving the problem of intensification of spheroidizing annealing of a long steel product. The direct technological process of heat treatment of metal acquires such advantages as high productivity, a significant reduction in energy consumption, and allows control of technological parameters by the length and cross-sectional area of the metal.

***Key words:** multiprocessor systems, aggregation, speed, memory, computing nodes, technological process, processors, graphic objects, non-graphic computing, annealing, spheroidization.*

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АГРЕГАЦІЯ ОБЧИСЛЮВАЛЬНИХ КАНАЛІВ НА ОСНОВІ ПЛАТФОРМИ *NVIDIA CUDA* ДЛЯ РЕЖИМІВ УПРАВЛІННЯ КОМПОНЕНТАМИ ТЕХНОЛОГІЧНИХ СИСТЕМ

Сьогодні практика висуває задачі, розв'язування яких відомими стандартними підходами досить часто являє собою значну проблему, вирішити яку можна тільки шляхом застосування багатопроцесорних комп'ютерних технологій. В свою чергу одна з принципових особливостей застосування вказаних технологій зводиться до збільшення продуктивності й швидкодії обчислень. При цьому значна продуктивність обчислень допускає розв'язання багатовимірних задач, а також задач, які потребують значного обсягу процесорного часу. Швидкодія дозволяє ефективно керувати не тільки технологічними процесами, а передбачає і створення передумов для розробки перспективних та новітніх технологічних процесів. Отже, застосування високопродуктивних обчислень на сьогодні є проблемою актуальною та першочерговою.

У роботі поставлена мета удосконалення структури і підвищення продуктивності багатопроцесорної обчислювальної системи шляхом агрегації обчислювальних каналів на основі платформи NVIDIA CUDA для режимів управління компонентами технологічних процесів. Запропонований підхід дозволив не лише підвищити ефективність розпаралелювання, але і істотно зменшити час обчислень. У приведеній розробці багатопроцесорної системи «зв'язувалися» дві відеокарти NVIDIA GeForce GTX 1080. Такий підхід спрямовано не лише на істотне збільшення продуктивності обчислень, але і на значне зменшення латентності й істотного розвантаження системної шини.

В порівнянні з відомим підходом за рахунок застосування програмно-апаратної архітектури паралельних обчислень корпорації NVIDIA на основі платформи CUDA вдалося на кожному обчислювальному вузлі багатопроцесорної системи збільшити об'єм відеопам'яті на 16 Гб, а також підвищити загальну продуктивність вузла системи на 350 Гфл.

Практична цінність проведених досліджень спрямована на розв'язування задачі інтенсифікації сфероїдизуючого відпалу довгомірного сталевого виробу. Безпосередньо технологічний процес термічної обробки металу набуває такі переваги, як висока продуктивність, істотне зниження енергоспоживання та дозволяє здійснювати контроль технологічних параметрів за довжиною та площею перетину металу.

Ключові слова: *багатопроцесорні системи, агрегація, швидкодія, пам'ять, обчислювальні вузли, технологічний процес, процесори, графічні об'єкти, неграфічні обчислення, відпал, сфероїдизація.*

Relevance of the research problem

Today, practice raises such problems, the solution of which is more often than not possible only through the use of multiprocessor computing complexes. For example, in the field of metallurgical production, there are many diverse and interconnected processes [1–5]. This can be the process of smelting and pouring iron-carbon alloys, as well as rolling, heating and heat treatment of various metal products, as well as the operation of auxiliary equipment, which includes filling machines, ladles, bowls, etc. At the same time, solving these problems using known standard approaches quite often represents a significant problem that can be solved only by using multiprocessor computer technologies. In turn, one of the fundamental features of the application of these technologies is reduced to increasing the productivity and speed of calculations. At the same time, the significant performance of calculations allows the solution of multidimensional problems, as well as problems that require a significant amount of processor time. Speed operation allows you to effectively manage not only technological processes, but also provides for the creation of prerequisites for the development of promising and innovative technological processes. Therefore, the application of high-performance computing is an urgent and priority problem today.

NVIDIA hardware is used in the design of high-performance computing. In this regard, it becomes possible to use the hardware and software architecture of parallel computing based on the *CUDA* platform (*Compute Unified Device Architecture*). Such a platform allows you to use the resources of video cards for non-graphical calculations. And today this technology is becoming more and more relevant.

Nowadays, modern graphic processors are used not only for processing graphic objects. So, thanks to the programmable unified shader architecture, which allows video chips to work with a large number of data streams, they can also be used to process non-graphical calculations. Such capabilities of video cards appeared after the release of G80 chips from *NVIDEA*, which had a unified shader architecture. Note that the performance of modern graphics processors significantly exceeds the performance of central microprocessors (tens and hundreds of times) thanks to the shader architecture, which allows for a large number of parallel data streams (up to several thousand). At the same time, central processors are focused on executing a single stream of commands.

The technology of non-graphic computing on graphics chips was named *GPGPU* (*General-purpose computing on graphics processing units*). A fundamental feature of this technology is the fact that with appropriate calculations there is practically no load on the processor, and the user can use it for other purposes.

To use video card resources, software developers had to turn to *API* graphics libraries (*Application Programming Interface*): O*penGL* or Direct3D, which significantly complicated the process of creating applications, as it required knowledge of the principles of processing 3D objects, for example, textures, shaders, and so on. With the introduction of the *BrookGPU* compiler, which allowed programmers not to learn the principle of working with 3d models, there was an opportunity to access the computing power of video cards.

Due to the growing interest in non-graphic computing on *GPU*s, video card manufacturers have introduced new developments in the field of *GPGPU* technology. Yes, the *NVIDIA* company offered *CUDA* technology for these purposes. This stage in the development of *CUDA* technology made it possible to use graphic processors in various fields of science, for example, astrophysics, computational biology and chemistry, modeling of fluid dynamics, electromagnetic interactions, computer tomography, seismic analysis, etc. In this work, this technology is used for automated control of the parameters of the technological process of metal processing.

Note that this type of calculation requires that the video card supports the shader architecture. In addition, in these studies, in order to achieve maximum performance, several video cards are used that implement the mode of aggregation of computing channels based on the *NVIDIA SLI (Scalable Link Interface)* technology.

Let's note that today a large number of software products have been created that are focused on the use of *GPGPU* technology. Many of these programs are focused on solving applied problems, video conversion, *HD* video broadcasts, data encryption, etc.

Despite the fact that this technology was developed very recently, it already has practical applications in scientific research. This is explained by the fact that the efficiency of *GPGPU* technology exceeds the efficiency of central processors by many times. So far, only the narrow focus of calculations remains a problem. However, we hope that this barrier will be overcome soon. Thus, today such technology is attracting increasing interest and is becoming more and more relevant.

Analysis of recent research and publications

This research is aimed at the development of new modes of control of the components of technological systems through the use of multiprocessor complexes and is illustrated on the basis of heat treatment (HT) of the workpiece. It is known that billet maintenance is the most promising way of fundamentally improving the consumer qualities of metal products. At the same time, the workpiece for cold landing should have in its initial state the structure of granular pearlite of a certain grade, i.e., one that has a globular form of the carbide phase of a certain size. To obtain the specified structural state, the workpiece is subjected to spheroidizing annealing.

Known technological processes for preparing rolled products for further deformation, which require certain optimization in order to improve them, as well as the construction of new technological lines for metal maintenance require significant costs for conducting numerous full-scale experiments using laboratory and research and industrial equipment, or conducting research in real production conditions . Thus, the development and use of multiprocessor complexes using their mathematical and software is a primary problem. Solving such a problem allows to significantly reduce the number of experimental studies, and also, what is important, the time required for their conduct. This approach makes it possible to obtain the necessary information regarding the development and implementation of various technological innovations.

Many grades of steels – structural, tool, and others for cold tapping – must have a granular pearlite structure in the initial state, that is, pearlite with a globular morphology of the carbide phase of a certain size. Therefore, as is known [6], a special heat treatment is used to prepare a heterophase alloy for cold deformation – spheroidizing annealing. As a result of such an operation, the metal receives a structure with a partially or completely spheroidized carbide phase, which provides the best indicators of manufacturability and economy during its subsequent processing (cold tapping, stamping, clear cutting or cutting).

Today, there are two classical schemes of spheroidizing annealing: annealing at subcritical temperatures and annealing with incomplete phase recrystallization. The disadvantage of heat treatment (HT) according to the first scheme is its long duration. Annealing of metal according to the second scheme allows you to slightly shorten its time intervals. At the same time, as a result of rapid heating and incomplete austenization of steel, partial dissolution of cementite plates occurs. At the same time, during subsequent cooling, the austenite formed disintegrates by an abnormal mechanism into ferrite and cementite, and this, in turn, during further exposure ensures spheroidization of cementite. Under such conditions, the noted scheme differs in lower time costs. However, these schemes are characterized by significant disadvantages of metal heating by external media [6, 7].

During the last several decades, more and more attention is paid to the processes of spheroidization of the carbide phase with the structure of granular pearlite, which are considered as alternatives to the long traditional processes of spheroidizing annealing of steel billets. These include the methods and technologies of combination spheroidizing processing of various types of metal products [8].

A promising direction of intensification of the annealing process of steel products is the use of electric contact or induction heating of the metal being processed [9, 10]. The indisputable advantages of electrothermal treatment are as follows: giving steel products a high complex of properties, which is caused by the specific effect of high intensity of heating on the mechanism and kinetics of structural changes in steel, limited scale formation and decarburization, avoidance of environmental pollution, reduction of the duration of heat treatment by ten times. In addition, and most importantly, the indicated methods of electrothermal treatment of steel allow maintenance in automated flow lines [6]. When implementing the mode of spheroidal annealing of steel in the flow line, a significant contribution to the reduction of the total duration of annealing is provided by both the increase in the heating rate and the increase in the cooling rate at the corresponding stages of the maintenance mode. Therefore, the practical implementation of spherical annealing in flow lines requires, first of all, the solution of new technical problems. However, high-speed maintenance processes will continue to require research, first of all, to control the main technological parameters in order to optimize them.

Therefore, new technological processes of billet maintenance (heating and cooling of metal at the required speed in specific temperature and time conditions), resource-saving technologies for preparing the billet for further processing are the most important prospective directions of the development of the mining and metallurgical complex and mechanical engineering. Control of certain technological parameters and management of the maintenance process can be ensured through the use of multiprocessor complexes.

The purpose of research. The aim of the work is to improve the structure and increase the performance of a multiprocessor computing system by aggregating computing channels based on the *NVIDIA CUDA* platform for control modes of technological system components.

Presentation of the main research material. The system of control modes of technological process components. To highlight the processes that take place in the control system of the components of technological processes, consider the block diagram of its main contours, which is presented in fig. 1.

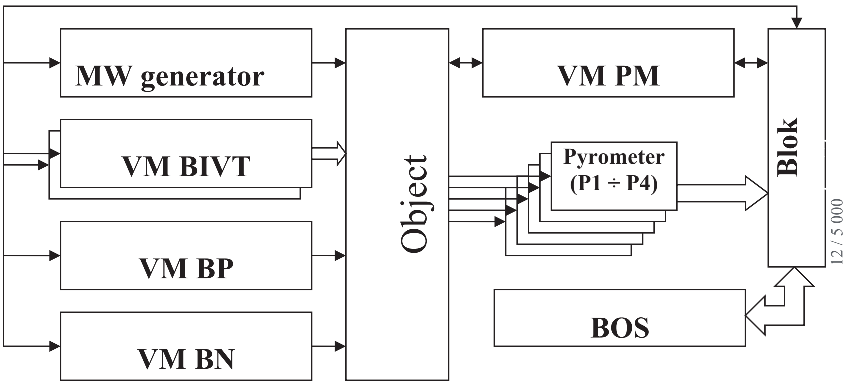

Fig. 1. Block diagram of the contours of the system for controlling the parameters of technological systems.

In fig. 1, the following designations are adopted: *BOS* – multiprocessor system; *VM PM* – executive mechanism of the extension mecha-nism; *VM BIVT* – executive mechanisms of certain blocks of isothermal exposure to metal temperature; *VM BNVT* – executive mechanisms of the non-isothermal metal temperature holding unit; *VM BP* – executive mechanism of the metal cooling unit; *VM BN* is the executive mechanism of the wire heating unit.

The given control system contains blocks that can receive information about the necessary current parameters of the controlled processes themselves. The peculiarity of such a system boils down to the fact that for each of the four processes of technological processing of metal, a two-dimensional problem of thermal conductivity is solved. Under such conditions, *BOS* software is able to control such temperature regimes that occur both over the entire cross-sectional area of the metal and along its length. Control of the specified temperature regimes is performed in the center of the plane of the corresponding cross-section of the wire.

Features of the aggregation of computing channels based on the use of the NVIDIA CUDA platform. *NVIDIA* hardware is used in the design of high-performance computing. In this connection, it becomes possible to use the hardware and software architecture of parallel computing based on the *CUDA* platform. Such a platform allows you to use the resources of video cards for non-graphical calculations. And today this technology is becoming more and more relevant.

Nowadays, modern graphic processors are used not only for processing graphic objects. So, thanks to the programmable unified shader architecture, which allows video chips to work with a large number of data streams, they can also be used to process non-graphical calculations. Such capabilities of video cards appeared after the release of *NVIDIA*'s G80 chips, which had a unified shader architecture. Note that the performance of modern graphics processors significantly exceeds the performance of central microprocessors (tens and hundreds of times) thanks to the shader architecture, which allows for a large number of parallel data streams (up to several thousand). At the same time, central processors are focused on executing a single stream of commands.

The programming procedure used in *CUDA* technology differs from traditional ones in that it completely hides the graphics pipeline from the programmer, allowing him to prepare programs in more familiar "terms". In addition, *CUDA* technology provides the programmer with a more convenient model of working with memory. There is no need to store data in 128-bit textures, since *CUDA* allows you to read data directly from the memory of the video card.

On the other hand, it should be noted that the *NVIDIA GeForce GTX* 1080 video card for this multiprocessor system was selected taking into account the compatibility of the *Scalable Link Interface* (*SLI*). When creating the latest technological processes [3, 4, 7, 10], this approach is extremely relevant. The company's *SLI* technology allows you to distribute the calculation between two video cards. At the same time, *Quad SLI* devices expand this technology – they allow two dual-processor video cards to use four graphics processors at the same time. In the given development of a multiprocessor system, two *NVIDIA GeForce GTX* 1080 video cards were "connected". This approach is aimed not only at a significant increase in computing performance, but also at a significant decrease in latency and significant unloading of the system bus.

Note that an *SLI* bridge is used to "link" two video cards. At the same time, the *NVIDIA* corporation uses a physical connector to connect video cards together, which allows them to interact with each other without using bandwidth in the slots. Therefore, you will need one of two SLI bridges: either a standard bridge (for less powerful cards) or a high-bandwidth bridge (for more powerful cards). For this development, a more powerful card (*NVIDIA GeForce GTX* 1080) was used, which allows the use of a standard bridge, but this will not allow to ensure the full performance of video cards.

When installing an *SLI* system, additional cooling of the multiprocessor system module housing is provided. Such a system uses a case with a 120 mm fan located opposite the video card connectors. Placing a 120 mm fan opposite these two graphics cards allows you to significantly reduce the temperature of the *GPU* graphics cards. Video cards are mounted in such a way that they blow hot air through holes on the back panel of the system case. In this regard, there is no need to apply additional special cooling. In this case, it is only necessary to ensure normal air exchange.

As for power consumption, high-quality power supplies must be used in such systems. A *Corsair HX* 1200 *W* power supply was used in the design of the multiprocessor system, which provides power for the *Quad SLI* system without any problems. The proposed multiprocessor system did not force the power supply unit to work at full capacity. The video cards used in this system also work quite quietly, and even in the *Quad SLI* configuration they have no problems with noise.

In addition, it must be emphasized that the graphics processor, having powerful computing capabilities, still could not completely replace the activity of the central processor, the absolute advantage of which is versatility, but it can significantly relieve the CPU by taking on the loads that are the most time-consuming and complex tasks.

Experimental studies. The developed multiprocessor system with the aggregation of computing channels is used to intensify the spheroidizing annealing of steel products [11, 12]. The installation for intensification of spheroidizing annealing of a long steel product is equipped with a multiprocessor computer system with specially oriented software installed on it. At the same time, the multiprocessor computer system is connected through the information bidirectional communication interface with the technological process control unit. The multiprocessor computer system is made in the form of a separate module and allows, with the help of special software, to set and control the necessary temperature regimes on the entire cross-sectional plane of the sample during heating and holding of the metal, as well as control the mode of non-isothermal annealing of steel, while the multiprocessor computer system aims to control the thermal processing mode is constant in the range of annealing temperatures.

Algorithms for calculating the heat transfer process were implemented using *CUDA* technology. Analysis of the execution time of parallel algorithms showed that the use of *CUDA* technology significantly reduces the time of processing experimental data. Practical testing has shown that the effectiveness of such calculations exceeds by an order of magnitude the statistics of similar calculations on the central processor, even with the use of *OpenMP* technology. Directly, the features of mathematical modeling of metal maintenance processes are fully covered in works [13–15].

Spheroidization of the carbide phase of the metal in the conditions of the appropriate conditions of heat treatment of the workpieces provides the material with a granular pearlite structure. Moreover, rapid spheroidization leads to a more uniform distribution of cementite globules in the ferrite matrix. Steel samples of almost the same hardness after heat treatment acquired a finely dispersed structure that ensures a high level of plasticity of the metal. As a result of rapid heating of the sample and incomplete austenitization of the steel, there are certain changes in the morphology of the carbide phase from lamellar to finely dispersed globular.

Conclusions and prospects for further research.

This work shows ways to increase the efficiency of a multiprocessor cluster system due to the aggregation of computing channels based on the use of the *NVIDIA CUDA* platform. The proposed approach made it possible not only to increase the efficiency of parallelization, but also to significantly reduce the calculation time.

Compared to the known approach, due to the application of the software-hardware architecture of parallel computing from the *NVIDIA* corporation based on the *CUDA* platform, it was possible to increase the volume of video memory by 16 *GB* on each computing node of the multiprocessor system, as well as to increase the overall performance of the system node by 350 *GFL*.

Let's note that today a large number of software products have been created that are focused on the use of *GPGPU* technology. Many of these programs are focused on solving applied problems, video conversion, *HD* video broadcasts, data encryption, etc.

Despite the fact that this technology was developed relatively recently, it already has practical application in scientific research. This is explained by the fact that the efficiency of *GPGPU* technology exceeds the efficiency of central processors by many times. So far, only the narrow focus of calculations remains a problem. However, we hope that this barrier will be overcome soon. Thus, today such technology is attracting increasing interest and is becoming more and more relevant.

The authors see the prospects of further research in this scientific direction in the coverage of issues related to the study of estimations of acceleration of calculations of a multiprocessor system. After all, in order to solve a certain class of applied problems, there is a need to expand the computing power of the system. The established principle of modularity allows you to increase the performance of the computer system by adding new slave nodes. In addition, it would be expedient to derive appropriate analytical ratios for calculating the efficiency of the claimed computing system. This would allow researchers to choose the most efficient configuration of a multiprocessor system and its operating modes. The authors intend to cover this type of research in upcoming publications.

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