Ergonomic component when designing mining machines: new scientific and practical works

V S Velikanov¹, N V Dyorina, E A Pikalova and Yu V Yuzhakova
Nosov Magnitogorsk State Technical University, Magnitogorsk, Russia,

¹ E-mail: rizhik_00@mail.ru

Abstract. This article is devoted to a review of publications in the field of ergonomic reengineering of mining machine workplaces. It has been established that the efficiency and quality of labour operations directly depends on the level of ergonomic support of the operator’s workplace. The authors of the paper present the publications of foreign scientists dealing with ergonomic support of mining machines, as well as machinery and equipment of related industries.

1. Introduction
Designing ergonomic workplaces starting from over is already a fairly well-studied area, so experts in the field of human factors and ergonomics have a more difficult task - to formalize, simulate and mathematically describe the process of ergonomic reengineering, that is, redesigning existing jobs with established resources and certain conditions.

Generally speaking, the ergonomic support for redesign consists in the establishment and implementation of ergonomic requirements and the formation of the ergonomic properties of the man-machine-environment system. It is implemented in the form of a set of interrelated organizational activities, research and design work, which increases the efficiency of the system and the quality of work, convenience and safety of operation and maintenance. [1-3].

The objects of ergonomic redesign are the process (organization, algorithm) and means of activity - external, technical (product, machine, equipment) and internal, inherent in man (knowledge, skills), as well as the conditions of activity (workplace, environment, psychological climate). As a result of ergonomic redesign, rational functions that a person will perform should be defined: methods for implementing these functions (cyclograms, activity algorithms, work-rest mode); characteristics of information [1-4].

In the initial development period of technical systems, an important role was played by the “machine-centric approach”, according to which the technical components of the system were considered primary, and the role of a secondary link was assigned to a man, forced to adapt to the technology capabilities. As the practice of such a machine-centric approach to the creation of a new technology has shown, in some cases the level of its efficiency is no more than 30-50% of the inherent technical capabilities. Such an approach is unproductive when analysing complex systems, since human behaviour is carried out in a complex, poorly formalized way [5, 6].

Understanding the ineffectiveness of this approach led to the emergence of an equal-component, and then anthropocentric approach, formulated by B.F. Lomov. Its essence is that the machine is an instrument of labour, with the help of which human activity can be carried out. Despite the promising
approach, a long period of its development questioned its effectiveness. The fact is that psychological knowledge alone was clearly not enough to design complex technical systems at all levels of their creation and operation.

Within the framework of the anthropocentric approach, a number of more specific concepts have been developed:

- V.F. Venda’s multi-level adaptation of a man and machine;
- V.M. Akhutina’s synthesis of adaptive biotechnical systems of ergatic type;
- V.Ya. Dubrovsky and L.P. Schedrovitsky’s anthropomorphic concept;
- A.I. Prokhorov and B.A. Smirnova’s procedural concept;
- system-anthropocentric concept of engineering and psychological design of A.I. Naftul’eva.

The modern scientific position in most engineering-psychological and ergonomic research is an anthropocentric approach. At the same time, in practice, the position of many developers of technology, who face the negative consequences of the human factor in modern production, boils down to maximum automation of control systems, i.e., reflects the machine-centric approach [5, 6].

Simultaneously with the anthropotech approach, a “system-technical” approach emerged, in which the roles of a man and technology are equalized. However, it lacks proper development, but in this case due to the low psychological literacy of engineers, which was manifested in their ignoring psychological knowledge [5, 6].

The light form of the anthropocentric methodology was the “person-oriented” approach (P.Ya. Shlaen, V.M. Lvov), which determines the need to take into account human capabilities in the system, but mainly in the first stages of its design. Next is the ergonomic control of the system development process, the evaluation of its ergonomics. This approach is widespread in the engineering environment of ergonomic design. However, the given approach, allowing the design of well-known systems and products, nevertheless, it is ineffective in creating new models of technology and systems "man-machine" [5, 6].

In Russia, active work in the field of ergonomic support of mining machines was carried out at the beginning of the 90s in the last century.

The ergonomic studies of mechanized supports were carried out by V.I. Danilyak, V.M. Rachek, N.I. Menaylo, V.E. Grishchenko, L.I. Habaznya, A.E. Krivenko and other scientists. In order to solve the problems of modeling the “operator-mining machine” system at Moscow Mining Institute at the Department of Mining Machines, a three-dimensional model of the excavation machine operator was developed by means of the AutoCAD automated design system. The model is a three-dimensional anthropo-man-simulator (figure 1), which, unlike the flat one, can be used not only in the side view, but also in any projection [7, 8].

Figure 1. Using the graphical phantom operator for assessing the control location of the powered support unit SP-138.
As an example, the authors of the development provide an analysis of the motor field of the operator of the powered support SP-138 cleansing complex using a mathematical model of a computer phantom. The working space is horizontally limited by support props. In the mathematical model, they are considered as a set of cylindrical surfaces. The width of the working space in which the operator can be placed without taking into account the mobility of the hands is equal to the distance between the rows of props. The position of the operator in the workspace is determined by its anthropometric parameters [7, 8]. The length of a man’s arm ranges from 0.71 to 0.84 m. When the control is seized, it is reduced to 0.583 \( \div \) 0.713 m, respectively. In order to control the support, the operator must be no more than 0.55 \( \div \) 0.7 m from the control panel, depending on the size of the body. The height of the operator's support space (figure 2) is determined by the thickness of the formation minus the thickness of the overlap and the base and the gumming size.

\[]\text{Figure 2. Operator's range of support when working in a sitting position on the heels: 1 — optimal reach zone; 2 - maximum reach zone.}\[

In further studies, the authors’ team used the Bentley technology, which is the basis of the graphic package MicroStation / J, which combined the advantages of graphical, mathematical and model methods of ergonomic design into a single system (figure 3).

\[]\text{Figure 3. Result of the simulation of the “operator-powered support unit” system using Bentley technologies}\[

V.S. Golovin’s work “Ergonomics of Mining Equipment” (1990) is devoted to the issues of ergonomics in relation to excavator equipment, according to the developed methods, measurements of vibrations, noise, light, microclimate, dust and visibility were carried out. It is established that the
ergonomics of the mining machine is a holistic characteristic that grows out of the following ergonomic properties: controllability, maintainability, uptake, habitability and adaptability. Each ergonomic property, in turn, is determined from a series of complex indicators that represent different but interrelated aspects of these properties. The work also assesses the driver’s work in order to increase the efficiency of the equipment by taking into account human capabilities at all stages of its interaction with the machine [9].

In 2006, Khusainov V.G. defended a thesis on the topic “Justification and calculation of ergonomic indicators of career crawler excavators manufactured by OJSC Uralmash [10]. Based on the generalization, development and deepening of the calculation theory, ergonomic indicators of career excavators, it was confirmed that the low competitiveness of domestic excavators is due to the influence of a number of factors, among which the low level of controllability and maintainability is of decisive importance. In the work, the modeling of the controllability and maintainability elements of mining excavators produced by OJSC Uralmash with the implementation of structural and technological solutions according to the ergonomic criterion (figure 4) was made [10].

![Figure 4. Visibility analysis model from the excavator operator’s workplace developed in AutoCAD2004.](image)

It is very important to note foreign research works in the field of ergonomic support of mining machines, placed in international reference databases.

A detailed review of works in the field of the theory and practice of ergonomic research is presented in [11]. It is determined that the researchers have quite diverse methodological tools - about 150 methods. It is necessary to mention that due to the complexity and variety of technical systems, new methodological requirements appear in the development of human-machine systems.

In [12-15], the use of the method of virtual prototypes for the creation of mining machines, which are produced in small batches or in the form of individual copies, is justified. Many technical tools used in the mining industry require the presence of a person (operator), so designers must constantly improve their designs to ensure maximum safety of working conditions. For that purpose, at the design stage, methods and tools are used to evaluate future technical developments.

The criteria for evaluating a virtual prototype are two main groups: technical and anthropotechnical (figure 5) [15].

![Figure 5. The main criteria groups for evaluating the virtual prototype mining machine (Tokarczyk, 2012).](image)
Technical criteria relate only to the evaluation of technical characteristics and allow to evaluate its features, such as functionality, durability, reliability, etc.

Anthropotechnical criteria depend on the presence of a man inside the machine or equipment. In this group, we can distinguish ergonomic criteria: limb ranges - identification of range zones and comfort zones, including the need to work in uncomfortable body postures; line of sight; loads in the musculoskeletal system - the ability to influence forces and torques on the limbs; safety criteria - protection against mechanical hazards; head injury criterion; noise; vibration; risk of slipping, stumbling, falling; proper lighting - the absence of shaded areas, glare and strobe effect (figure 6) [15].

![Figure 6. Underground Locomotive Cab Model.](image)

Using the virtual prototyping method, on the one hand, reduces the likelihood of design errors, and on the other, it allows the evaluation of prototype machines based on anthropometric criteria using hardware and software capabilities, as well as automating the design process and provides a comparative assessment of similar design cabins.

It is also very important to dwell on a number of publications concerning the ergonomics of mechanized mining [16], improving the safety of mining equipment through human-oriented design [17], protective structures for mining machines [18], computer analysis of the vehicle operator's cabin [19], as well as ergonomic assessment of the crane cabin in the metallurgical industry [20], methods for calculating the seat height with an emphasis on the optimal position of a person based on trigonometric ratios [21], estimates of the survey qualities of cabs of various types (figure 7) [22], vibration analysis on the operator's seat [23].

![Figure 7. 3D cabin model for the visibility quality assessment.](image)

Conclusions
In modern conditions, there is a growing demand not only for the technical level of mining machinery, but also for a qualitative change in its consumer properties, the most important of which are ergonomic properties that determine the safety and ease of a mining machine operation.
Conducting further ergonomic research will ensure competitiveness and compliance with the requirements of ergonomic standards of modern mining machines and ultimately improve the reliability of human activities – of the operator.

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