ISSN 1995-2732 (Print), 2412-9003 (Online)
УДК 622.1
DOI: 10.18503/1995-2732-2022-20-2-13-22

IMPLEMENTING A DISCHARGE SLOT WIDTH CONTROL SYSTEM IN CONE CRUSHERS

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Abstract. It is well known that a crushing process is one of the most energy intensive technological processes in mineral processing. The aim of this process is to achieve the required size of the processed raw material. The course of the crushing process is characterized by the influence of a number of basic factors: multidimensionality, multiple connections, nonlinearity, physical and mechanical properties of the mineral, shape and size of rock lumps, position of the crushing material inside the crushing chamber, lumps movement speed, wear of a liner and elements of the crusher, as well as design parameters of the crusher. Efficiency of the crushing process in the process flow of solid mineral processing is achieved by applying reasonable operation parameters of crushing equipment, ensuring the set performance and particle size distribution of the crushed ore at minimum electricity consumption. When processing minerals, the size is often monitored between individual operations. **Objective.** The objective is to provide an innovative solution in developing intelligent systems for automatic control, resulting in adaptive control, depending on changes of the material size distribution by making measurements "inside" the technological equipment. **Methods Applied.** Methodology of fuzzy logic theory and fuzzy sets was used. **Originality.** We made it possible to distinguish frame differences in a video stream to detect defects and wear of a crusher liner. **Result.** The paper identifies an approach to monitoring the discharge slot width for crushing and milling complexes using intelligent control methods.

Keywords: minerals, crusher, control, sensor, fuzzy logic, controller.

For citation

Grishin I.A., Bochkov V.S., Velikanov V.S., Dyorina N.V., Surovtsov M.M., Moreva Yu.A. Implementing a Discharge Slot Width Control System in Cone Crushers. *Vestnik Magnitogorskogo Gosudarstvennogo Tekhnicheskogo Universiteta im. G.I. Nosova* [Vestnik of Nosov Magnitogorsk State Technical University]. 2022, vol. 20, no. 2, pp. 13–22. https://doi.org/10.18503/1995-2732-2022-20-2-13-22

О ВОЗМОЖНОСТИ РЕАЛИЗАЦИИ СИСТЕМЫ КОНТРОЛЯ ШИРИНЫ РАЗГРУЗОЧНОЙ ЩЕЛИ В КОНУСНЫХ ДРОБИЛКАХ

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Аннотация. Общеизвестно, что процесс дробления является одним из самых энергоемких технологических процессов в переработке полезных ископаемых. Цель данного процесса заключается в достижении требуемой крупности перерабатываемого сырья. Ход протекания процесса дробления характеризуется влиянием ряда основных факторов: многомерность, многосвязность, нелинейность, физико-механические свойства полезного ископаемого, форма и размер кусков горной породы, положение дробимого материала внутри камеры дробления, скорость движения кусков, износ футеровочной брони и элементов агрегата, а также конструктивные параметры дробилки. В технологической цепочке переработки твердых полезных ископаемых эффективность процесса дробления достигается реализацией рациональных режимных параметров работы дробильного оборудования, обеспечивающих заданную производительность и гранулометрический состав дробленой руды при минимальных затратах электроэнергии. В процессе переработки полезных ископаемых крупность чаще всего контролируется между отдельными операциями. **Цель исследования.** Инновационное решение в области создания интеллектуальных систем автоматического управления, следствием чего является возможность адаптивного управления в зависимости от изменения гранулометрического состава материала за счет измерений «внутри» технологического оборудования. **Используемые методы.** Использована методология теории нечеткой логики и нечетких множеств. **Новизна.** Реализована возможность распознания различий кадров видеопотока для обнаружения дефектов и износа футеровочной брони дробилок. **Результат.** В работе определен подход в контроле ширины разгрузочной щели для дробильно-измельчительных комплексов с использованием методов интеллектуального управления.

Keywords: полезное ископаемое, дробилка, управление, датчик, нечеткая логика, регулятор.

Для цитирования

Implementing a Discharge Slot Width Control System in Cone Crushers / Гришин И.А., Бочков В.С., Великанов В.С., Дёрина Н.В., Суровцов М.М., Морева Ю.А. // Вестник Магнитогорского государственного технического университета им. Г.И. Носова. 2022. Т. 20. №2. С. 13–22. https://doi.org/10.18503/1995-2732-2022-20-2-13-22

Introduction

The technological steps in the processing of solid minerals have remained unchanged for several decades. Crushing and grinding are energy intensive processes. According to UNESCO, humanity spends up to 5–7% of all energy generated on crushing and grinding [1]. For example, the cost of crushing and grinding in the ore concentrate cost reaches 40%. A large amount of crushing equipment is in operation in modern industrial production. Cone crushers are the most commonly used type of crushers for the medium (MCC) and fine (FCC) crushing stages in the mining industry. In scientific and technical literature the process of crushing rock in cone crushers, which takes place between stationary and rotating inner cone, is described in detail and the main parts of these crushers are: cylindrical body, mounted on a base, stationary cone, movable crushing cone, mounted on a shaft and supported by a spherical thrust bearing, drive mechanism. This type of crushers is used for materials with different physical and mechanical properties. Cone crushers do not need feeders and can work "under the hopper", i.e. with the working space completely filled with ore coming from the hopper (**Fig. 1**) [2, 3].

When creating modern automatic control systems of cone crushers, one of the important factors in their development is the adoption of a reasonable efficiency criterion that reflects the objective laws of the crushing process. The application of reasonable criterion in realization of crushing process control method based on material particle size distribution control will provide increase in productivity and reduction of energy consumption for crushing [4–6].

When considering this issue, the following circumstance should be taken into account. Crushing equipment is operated in different branches, therefore, in our opinion; there cannot be one generalized criterion of material crushing efficiency. So, for example, the specific income E considering relative output of various commodity fractions of crushed rock of various costs and most fully conforming to the enterprise purpose function as a whole is accepted for building branch as criterion of efficiency of process of crushing [7].

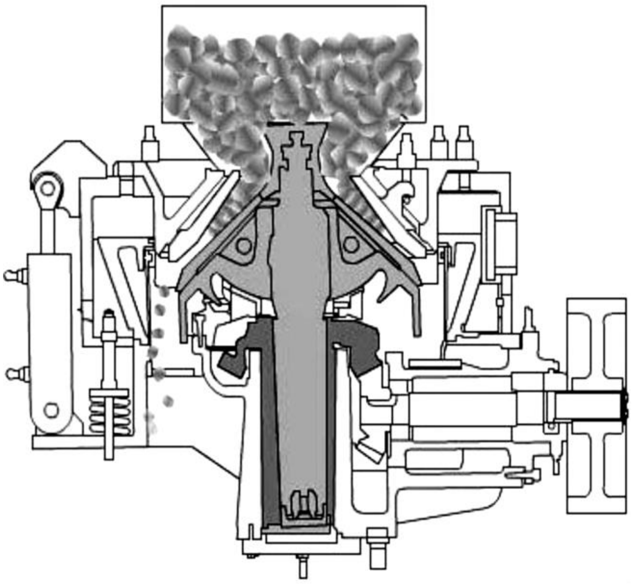


Fig. 1. Medium cone crusher
Рис. 1. Конусная дробилка среднего дробления

In [8–10], in continuation of Z. Ganbaatar's research, the author, after adjusting and adapting to new conditions, especially the fine crushing process in a closed cycle and reducing the size of the crushed ore, adopted the "Productive grade yield" as an efficiency criterion.

The crushers are currently equipped with local automated control systems (ACS) for the main and auxiliary drives. All of the automated control systems currently implemented in cone crushers can be divided into two groups: throughput control systems and gradient control systems. Grain size distribution control systems are based on the Hydrocone crushers from Sandvik Rock Processing. As an object of automation a cone crusher can be represented as follows (**Fig. 2**) [7].

The size of the crusher's discharge slot and the rotation speed of the crushing cone are the most common controlling influences in the ACS of the granulometric composition.

In researches [7] the analysis of influence of speed of rotation of a cone on granulometric of crushed product (crushed rock) is carried out. It is established, that decrease in speed of rotation of a cone leads to decrease in productivity, and increase – slightly increases a output of fraction 5–20 mm with simultaneous increase in a output of waste (fraction 0–5 mm).

However, it should be noted that there is no consensus about essential influence of the size of unloading slot on granulometric composition.

Thus, the authors in [11] note that in cone crushers of coarse crushing the possible deviations of the width of the discharge gap from the specified value, as a rule, are timely eliminated by the maintenance personnel during preventive inspections. In addition, the change in the width of the discharge gap on the grain size distribution during operation is so small that its effect is negligible. This can be interpreted in different ways, since the maintenance and repair system (M&RS) has undergone significant changes in the plants.

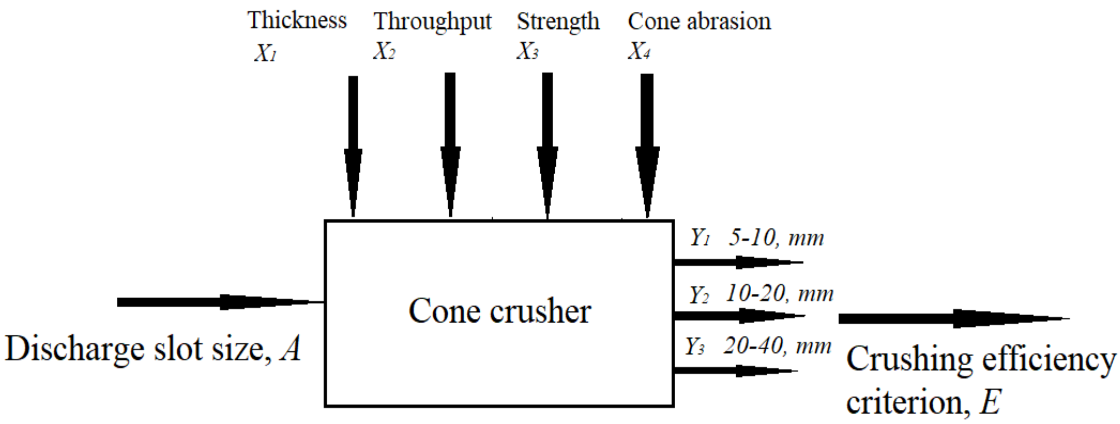


Fig. 2. Cone crusher as an object of automatic control [7]
Рис. 2. Конусная дробилка как объект автоматического управления [7]

The proportion of the crushed product fraction changes due to a widening of the discharge gap caused by abrasion of the liner mantle plates and the inside of the cones. Wear of the liners has a significant effect on the crusher's throughput capacity. This ultimately determines the qualitative deterioration of the granulometric composition of the crushed rock. It should be noted that the labour and maintenance costs of replacing the liners is costly. The analytical dependence which allows calculating the width of the discharge slot $A_\Delta(t)$ at a certain time t of the equipment operation is as follows [12]:

$$A_\Delta(t) = A_\Delta + \int_0^t v(A_1)dt + \int_0^t v(A_7)dt.$$

The laws studies of particle size distribution formation in a closed cycle "crushing - screening" have shown that an important factor in the process is the width of the crusher's discharge slot [13]. Increasing the discharge slot width naturally increases the plus class output of the screening operation (**Fig. 3**).

This conclusion is supported by other studies [14, 15], which point out that the granulometric composition non-compliance of the crushed rock with the required values is a determining indirect indicator of the need to stop the crusher for inspection and repair.

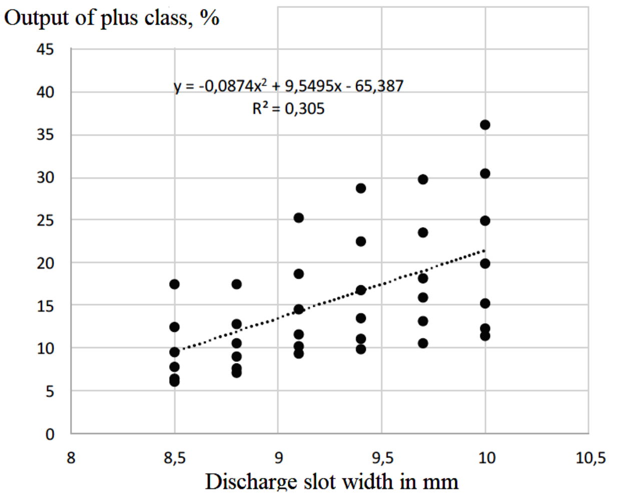


Fig. 3. Dependence between the yield of the oversize products and the discharge slot width of the KMD-3000T2-DP crusher according to the common data array [13]

Рис. 3. Зависимость выхода надрешетного класса от ширины разгрузочной щели дробилки КМД-3000Т2-ДП по общему массиву данных [13]

Materials and methods

To date, the particle size distribution control of the crushed product (hence the width of the crusher's discharge slot) is usually carried out more between individual operations on conveyors. A method of optical control using optical analysers has been known since the mid-1960s.

In a number of publications the visiometric analysis method for size distribution of crushing products is mentioned as a promising direction for the control of particle size distribution. In terms of technical implementation, visiometric monitoring system includes illuminating device, video camera and processor, etc. (**Fig. 4**) [16].

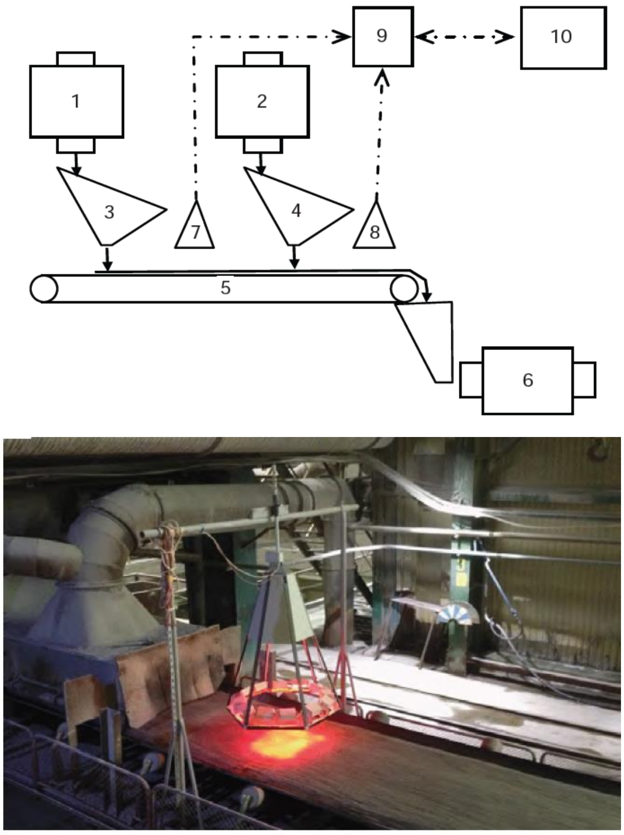


Fig. 4. Schematic diagram and general view of the Granix visiometric analysis unit [16]:
1, 2 are crushers; 3, 4 are screens;
5 is a conveyor; 6 is a drum mill; 7, 8 are video imagers; 9 is a processor; 10 is a server

Рис. 4. Схема и общий вид установки визиометрического анализа «Граникс» [16]: 1, 2 – дробилки; 3, 4 – грохоты; 5 – конвейер; 6 – барабанная мельница; 7, 8 – устройства съема видеоизображений; 9 – процессор; 10 – сервер

In the development of further research, the research team under the leadership of Professor

V.V. Morozov (MISIS) created an improved system and methodology for assessing the grade of copper-molybdenum ore based on the results of its optical characteristics measurements using modern algorithms of colour image recognition.

From our point of view, promising solutions in the area of unloading slot width monitoring are:

- the possibility of using video endoscopic equipment. The idea of using the endoscopic survey method is not new in principle. The endoscopic research method of disintegration of intracircuit massif of mine workings was offered by VNIMI at the beginning in 1970s of the XX century. Currently, Kuzbass-COT Elektro Ltd manufactures the "Smart Partner" explosion-protected video endoscope. The video endoscope together with other means of mining control allows optimisation of production processes and saves time for surveyors and geologists.

Industrial video endoscopes are successfully used to identify surface defects in lining mantle. Visual monitoring of any point in the working area of a cone crusher is carried out through the process openings (**Fig. 5**);

- ultrasonic method. In order to establish the actual values of the lining mantle, an ultrasonic thickness gauge can be used, which has an alphanumeric data logger and a colour transflective display, allowing the inspection results to be displayed as a cross-sectional view. The ultrasonic method also makes it possible to detect latent defects - the presence of defective cracks that run along the entire depth of the lining mantle [14, 17, 18].

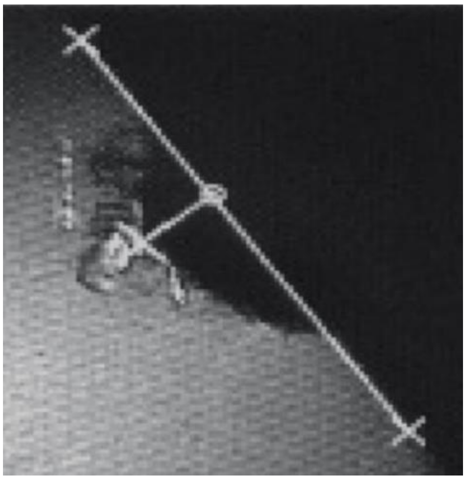


Fig. 5. Liner surface damage assessment using a video endoscope [12]
Рис. 5. Оценка размера поверхностного разрушения футеровочной брони с использованием видеоэндоскопа [12]

Findings and discussion

The idea of assessing the condition of the crusher liner mantle is based on research to establish quality indicators of materials, products and structures in industrial safety [19], namely the quality assessment of concrete samples.

Thus, we propose the following: continuous monitoring the condition of the lining mantle using a video endoscope; data consolidation about the strength characteristics of the mantle material and dynamic characteristics (change in continuity over time) accompanying the mantle destruction; visual analysis of mantle destruction, using the results of video stream processing frames and expert evaluation (**Fig. 6**).

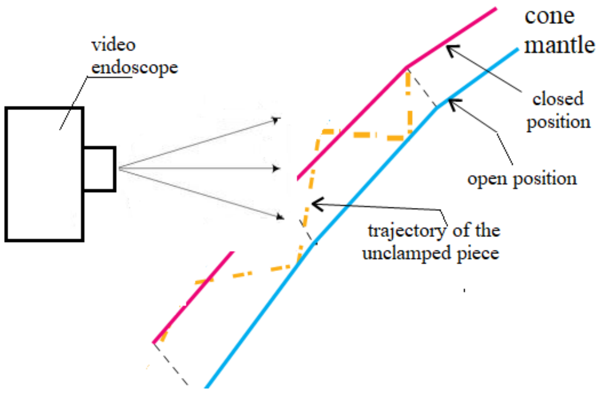


Fig. 6. CCTV monitoring of the crusher liner condition
Рис. 6. Схема видеонаблюдения за состоянием футеровочной брони дробилки

The camera is statically installed in the process opening.

First step: the camera takes a picture of the lining mantle when it is in perfect condition, i.e. without any damage. This picture will hereinafter be referred to as Photo_0.

Second step: at certain time intervals, e.g. every 3 days, the camera takes pictures of the lining mantle (Photo_1, Photo_2, etc.).

The third step: a program is created which:

1) converts the photos to black and white format. This is necessary to highlight defects in the photos;

2) compares the photos obtained later with Photo_0 and determines the differences between the photos;

3) determines degree of differences between photos by a percentage, i.e. 30% – degree of differences is small; 50% – differences are present; 75% – degree of differences is high;

4) the percentage is stored in a file for further processing.

Step four: a second programme is created which reads the data from the file and, using a plug-in card and LEDs, sends a signal according to the percentage.

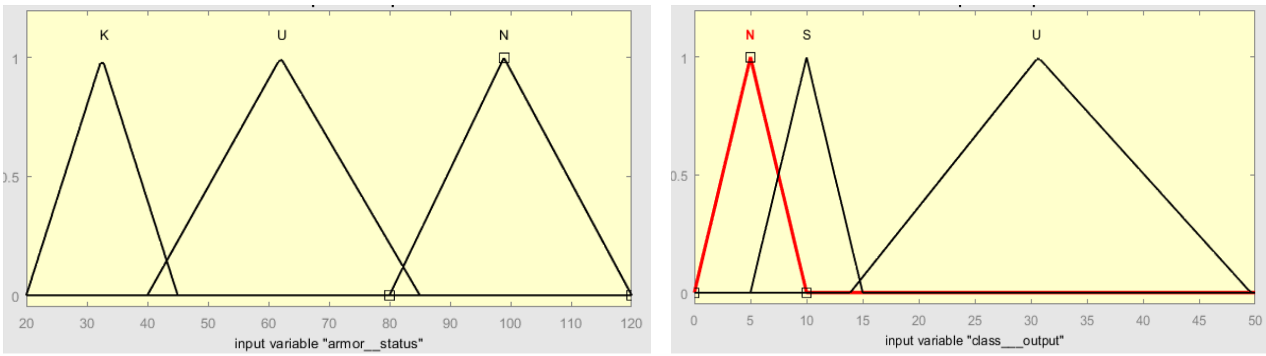
In order to be able to realise an ACS for output slot control, information on the material flow both into and out of the crusher is required. This information is usually contradictory and uncertain. Therefore from our point of view it is reasonable to apply fuzzy control methods. Since the basic provisions of fuzzy sets and fuzzy logic theory are set out in detail enough in the scientific and technical literature, then let's turn directly to the practical use side of fuzzy control methods for the developed ACS for crusher type FCC-1750Gr-C [20-22]. In our case as a regulator of width of a discharge gap it is justified to apply the fuzzy regulator (FR). Adjustment of FR is carried out in several stages. To synthesize FR let's define the main fuzzy variables, define their term-menu and set the membership functions for each term-menu of fuzzy variables. There are two control signals on FR input - state of lining mantle and output of class larger than required maximum piece, and width of unloading slot on output accordingly.

Experts were involved for phase identification. By expert methods, the term-numbers and membership functions of all linguistic variables are determined (**Table**).

Fig. 7 shows a graphical representation of the membership functions (MFs) of the input fuzzy variables using the MatLab environment of the Fuzzy Logic package.

T a b l e . Formalisation of fuzzy linguistic variables
Таблица. Формализация нечетких лингвистических переменных

Name of the fuzzy variable	Definition area	Term sets	The area of the term set definition
Input linguistic variables			
<status of lining mantle>, mm	[120;20]	<Normal>=N	[120;80]
		<Satisfactory>=S	[85;40]
		<Critical>=C	[45;20]
< class output larger than the required maximum piece>, (%)	[0;50]	<Normal> (plus class output)=NPCO	[0;10]
		<Satisfactory>=SPCO	[5;15]
		<Unsatisfactory>=Non-PCO	[14;50]
Output linguistic variable			
<discharge slot width>, mm	[9;20]	<Normal>=N (Discharge gap according to crusher manufacturer's product catalogue)	[10;12]
		<Enhanced>=U	[15;20]
		<Critically increased>=CU	[20;25]



a b

Fig. 7. Term set of input parameters: a is a liner condition; b is yield of the size coarser than a required maximum piece
Рис. 7. Терм-множество входных параметров: а – состояние футеровочной брони; б – выход класса крупнее требуемого максимального куска

Fuzzy logic inference rules are also drawn from experts, in our case they are of the following form:

*R_1: if the condition of the lining mantle is "**N**" and the class yield is larger than the required maximum piece "**N**" then the width of the discharge slot "**N**".*

……….

*R_n: if the state of the lining mantle is "**S**" and the class yield is larger than the required maximum piece "**N**", and then the discharge slot width is "**enlarged**".*

A set of fuzzy logic inference rules is also implemented using this software package.

Directions for further research

Implementation of ACS for controlling the discharge slot width in cone crushers in MatLab using the Simulink application.

Conclusions

To date, the absence of automated grit size control systems on cone crushers of fine crushing in domestic production, in particular, crushers of PJSC "Uralmashzavod", has a negative impact on their competitiveness in comparison with their foreign analogues. Therefore, the implementation of the proposed approach will significantly increase the consistency of particle size distribution at the outlet of the crusher and reduce energy consumption for crushing, which increases significantly when the average particle size increases after crushing.

Among the supposed difficulties which can appear at realization of the offered approach is a working zone dustiness of a cone crusher and, accordingly, application necessity of either special video systems, or techniques of dust suppression, for example irrigation of crushed ore on an exit from the crusher. It should also be noted that the use of hydraulic actuators for adjustment of the outlet slot, with all its advantages, namely the accuracy of regulation and high developed forces, may cause contamination of hydraulic cylinders due to, again, the dustiness of the crusher's working space. However, this problem can be solved by the use of various protective gaskets and by removing the hydraulic cylinders from the working area.

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Поступила 25.03.2022; принята к публикации 08.04.2022; опубликована 28.06.2022
Submitted 25/03/2022; revised 08/04/2022; published 28/06/2022

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