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Ye. Shayakhmetov[1], R. Sovetbayev[1], K. Ozhmegov[2], A. Bilyalov[1]*, A. Nurbekov[1]
[1]Shakarim University,
071412, Қазақстан Республикасы, Семей қ., Глинки к-сі, 20 А
[2]Technical University Czestochowa,
J.H. Dąbrowskiego Street 69, 42-201 Częstochowa, Poland
*e-mail: Altshok@bk.ru

EFFICIENCY OF USING POLYMER CONVEYOR ROLLERS AND COMPARATIVE ANALYSIS OF THEIR MANUFACTURING TECHNOLOGIES

Abstract: *This paper presents an extended comparative analysis of the traditional injection molding technology and additive 3D printing technology in the production of polymer rollers for belt conveyors of various applications. The technological features of the processes, their production limitations, economic feasibility, and areas of rational application in mass and small-batch manufacturing are considered.*

The mass and dimensional characteristics of the rollers were calculated, and the reduction in metal consumption compared with conventional steel analogues was evaluated. The influence of reducing the mass of rotating components on the dynamic parameters of the system, including starting loads, operating modes, and overall energy consumption of the conveyor line, was analyzed.

It is shown that the use of modern polymer materials allows reducing the roller mass by more than two times without deterioration of operational characteristics. This contributes to improved energy efficiency, reduced wear of drive units, and increased service life of the equipment.

Criteria for selecting the manufacturing technology depending on production volume, strength requirements, and operating conditions are determined.

Key words: *conveyor roller, 3D printing, polymer materials, idler rollers, additive manufacturing, energy efficiency, material consumption*

Introduction. Belt conveyors are the main transport equipment used in mining, construction, and cement industries. A significant portion of the conveyor mass and energy consumption is associated with idler supports. The mass of rotating elements directly affects starting loads, dynamic operating modes, and drive power consumption.

Traditionally, rollers are manufactured from steel. However, the development of high-strength polymer materials (HDPE, UHMW-PE) enables replacement of metal components while maintaining operational performance. An additional interest lies in selecting a rational manufacturing technology – injection molding or additive manufacturing.

Additive technologies are actively being implemented in almost all industrial sectors and in everyday life. For example, in medicine, 3D-printed elements of the human skeleton – bones, joints, teeth, etc. – are successfully implanted worldwide.

In mechanical engineering, 3D technologies are also used in the development of new products where they are most effective, since they simplify the technological process and optimize costs. The application area of 3D technologies in mechanical engineering is quite wide and includes the following tasks [1-3]: manufacturing prototypes for design validation, conducting technological and other experiments, creating master patterns for casting, rapid production of tooling, and manufacturing mold-forming elements of dies.

For example, if manufacturing a part or its prototype using traditional production methods may take months (development of working drawings, process planning, cutting parameter calculations, blank preparation, machining, and final production), then using 3D technology the time from drawing to a plastic (or metal, depending on printer type) manufacturing time is reduced to several hours. This saves time for design refinement and testing, reduces part weight, and lowers project cost.

The objective of the study is:

– comparative analysis of manufacturing technologies for polymer roller components;

– evaluation of mass and metal consumption reduction;
– determination of the potential impact on conveyor energy efficiency.

Materials and Methods This study compares the efficiency of traditional technology and 3D technology for manufacturing a conveyor roller from polymer materials. The development of modern polymer materials makes it possible, without loss of strength, to replace traditional metal parts with their analogues made of polymer materials.

The proposed roller is shown in Figure 1, where the shaft (pos.2), bearing (pos.11) and seal cover (pos.7) are made of metal. The roller was designed for application at JSC "Semey Cement"; purpose – transportation of limestone; main parameters: three-roller belt conveyor; rollers diameter 127 mm, length 315 mm; idler support width 1000 mm; distance between idlers of the upper strand 1.2 m (84 rollers per 100 m).

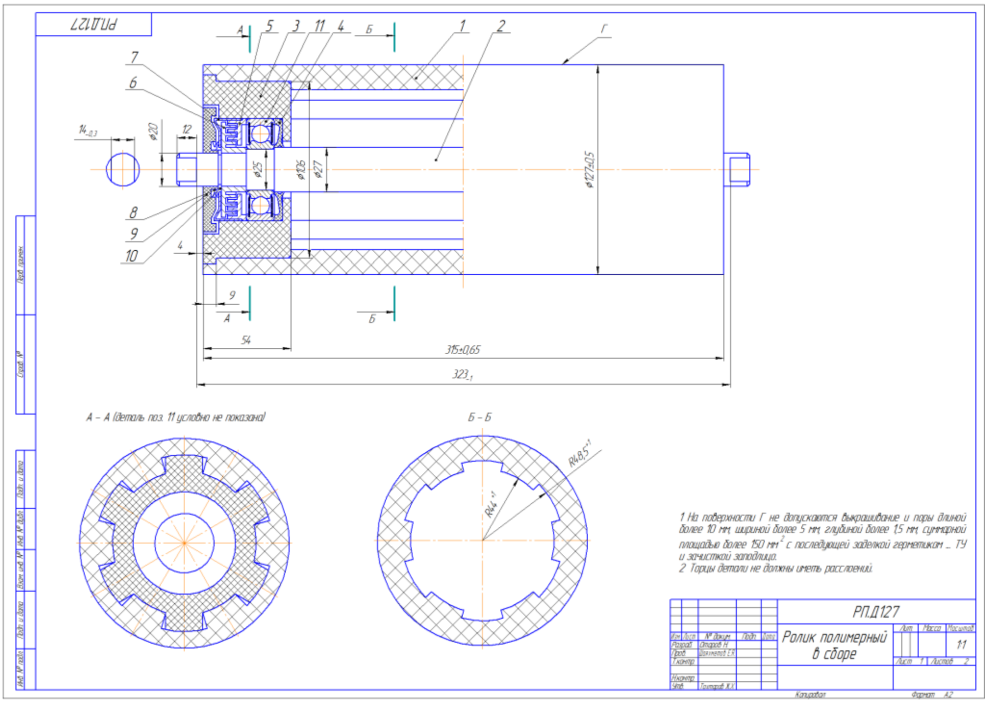

Figure 1 – Roller made of polymer materials in assembly
(1 – roller tube, 2 – shaft, 3 – bearing seat, 4 – protective washer, 5 – inner labyrinth seal, 6 – outer labyrinth seal, 7 – seal cover, 9 – cover, 10 – retaining ring, 11 – bearing 180305)

The feasibility of using polymers in the production of conveyor rollers primarily determined by the load-bearing capacity of the assembly. At the same time the technical-economic parameters of the rollers and of the conveyor itself improve: mass decreases, conveyor energy efficiency increases, durability and reliability of modern polymer materials are comparable with the service life of metal rollers, increased corrosion resistance, resistance to aggressive media, non-sparking behavior. As a result of implementation of modern plastics reduces steel consumption, and due to the production technology of polymer parts the material utilization factor significantly increases [4, 5].

One of the main materials for manufacturing roller parts from polymers in our case is HDPE – High-density polyethylene (HDPE) (Table 1) (substitute material: UHMW-PE (Table 1.1) – ultra-high molecular weight polyethylene).

Strength evaluation of HDPE applicability

Table 1 – Comparative characteristics of materials HDPE (PE-HD) and Steel 3 (St3)

Parameter	HDPE (PE-HD)	Steel 3 (St3)
Material	Thermoplastic (high-density polyethylene)	Carbon structural steel
Density	940-970 kg/m³	~7850 kg/m³
Tensile strength	20-35 MPa	370-510 MPa
Thermal conductivity	~0.4 W/m·K	~45-60 W/m·K
Corrosion resistance	Very high	Low (requires protection)
Chemical resistance	Excellent	Medium / low
Service life	25-50 years	20-50 years (with corrosion protection)

Table 1.1 – Comparative characteristics of materials UHMW-PE and Steel 3 (St3)

Parameter	UHMW-PE	Steel 3 (St3)
Material	Thermoplastic (ultra-high molecular weight polyethylene)	Carbon structural steel
Density	~930-940 kg/m³	~7850 kg/m³
Tensile strength	20-40 MPa	370-510 MPa
Thermal conductivity	~0.4 W/m·K	~45-60 W/m·K
Corrosion resistance	Very high (does not corrode)	Low (requires protection)
Chemical resistance	Excellent	Medium / low
Service life	20-50 years (depends on load and UV exposure)	20-50 years (with corrosion protection)

The choice of material depends on: load (light / medium / heavy), type of transported material (limestone, ore, cement, etc.), operating temperature, belt speed, and environmental conditions (moisture, abrasive, chemicals).

The optimal material in our case for unloaded and medium-loaded rollers (cement, medium-size crushed stone) is UHMW-PE, however, to reduce cost the use of HDPE is possible.

The reduction in strength compared with metal is partially compensated by increasing the thickness of the polymer roller tube and introducing stiffening ribs (Figure 1).

These materials belong to thermoplastic plastics, which occupy a special place among polymer materials. Thermosetting and thermoplastic plastics are materials obtained on the basis of natural and synthetic high-molecular compounds (polymers), which due to their plasticity can change shape under the action of heat and pressure [6].

The most suitable traditional method in our case for producing the parts «roller tube» and «bearing seat» (the largest parts, on the example of which the technology was developed) from thermoplastic plastics is injection molding. Special injection molding machines have been created for this process.

Principle of operation of an injection molding machine: powder or granules of the initial polymer are fed into a hopper and then into a heated working cylinder; in the cylinder melting occurs and the molten polymer is fed under pressure into the mold. Upon cooling, the thermoplastic polymer acquires the shape of the required part [7].

The technological process [7] of injection molding for the parts «roller tube» and «bearing seat». Material of the parts – thermoplastic plastic, high-density polyethylene. Production type: batch production

1. Preparatory stage. At the preparation stage the formulation of the used composition is developed, proportions of materials for the raw mixture are calculated. Properties of the future part strongly depend on the components of the plastic; for each part the composition and mass fractions differ. At this stage dyes are added, and all ingredients of the future raw material are dried and mixed.

2. Equipment setup stage. Injection molding machines are adjusted by the operator; the molding program is entered and molds are installed.

3. Loading stage. The prepared raw material is loaded into the hoppers for the further process.

4. Molding stage. First, the raw material enters the mold through the runner channels and is heated to the temperature required for the process. Then, by direct injection (or under screw action) the heated material under pressure enters the mold and fills it.

5. Completion stage. The plastic that filled the mold cools. The temperature of the material decreases near the mold walls and then throughout the volume. The crystallization process occurs according to the known mechanism. The finished product is removed from the mold and mechanically freed from the elements of the runner system.

6. Final finishing stage. Some parts at this stage require machining for final finishing. In our case machining is required for the «bearing seat» part, where the internal bearing mounting surfaces are machined.

The described stages represent the traditional technological process of injection molding for the parts «roller tube» and «bearing seat»; the process can be easily automated depending on the need and the type of production.

Note: Strict adherence to the technological regime is required, since the shrinkage of the part depends on pressure and temperature.

In the chemical industry, in the production of plastic parts, manufacturing costs are distributed as follows: raw materials on average 60-70% of production cost, fuel and electricity about 10%, depreciation deductions 3-4%, workers' wages from 3 to 20% of product cost depending on the type of production [1].

The main technological parameters of injection molding for high-density polyethylene are presented in Table 2 [8].

Table 2 – Technological parameters of injection molding for high-density polyethylene (High-density polyethylene (HDPE)) HDPE (PE-LD) [8]

<table>
<tr><td colspan="7">Injection pressure and injection speed during molding</td></tr>
<tr><td>Material name</td><td colspan="3">Injection pressure, kg/cm²</td><td colspan="3">Mold filling conditions. Injection speed.</td></tr>
<tr><td>HDPE (PE-LD)</td><td colspan="3">500-1200</td><td colspan="3">The melt has good fluidity. The mold must be filled quickly.</td></tr>
<tr><td colspan="7">Features of thermoplastic molding</td></tr>
<tr><td>HDPE (PE-LD)</td><td colspan="6">Due to relatively high shrinkage of molded products requiring dimensional accuracy, prolonged holding under pressure is applied. Heating occurs mainly due to friction heat. Back pressure: 50-190 bar. Residual material cushion: 2–8 mm depending on dosing stroke and screw diameter.</td></tr>
<tr><td colspan="7">Injection molding temperature regime (Note: The temperature regime should be adjusted according to the specific grade and batch of material.)</td></tr>
<tr><td rowspan="2">Name</td><td rowspan="2">t^0C</td><td colspan="2">t^0C</td><td rowspan="2">Residence time in the cylinder, min</td><td colspan="2">t^0C, Cylinder temperature limit</td></tr>
<tr><td>Nozzle</td><td>Mold</td><td>tмин</td><td>tмах</td></tr>
<tr><td>HDPE (PE-LD)</td><td>200-280</td><td>240-250</td><td>30-80</td><td>-</td><td>-</td><td>400</td></tr>
<tr><td colspan="7">Density and shrinkage of thermoplastics</td></tr>
<tr><td>Name</td><td colspan="3">Density, g/cm³</td><td colspan="3">Shrinkage%</td></tr>
<tr><td>HDPE (ПЭНД)</td><td colspan="3">0,91-0,93</td><td colspan="3">1-4</td></tr>
<tr><td colspan="7">Tooling design features</td></tr>
<tr><td>Name</td><td colspan="6">Design features of the nozzle, runners, and molds</td></tr>
<tr><td>HDPE (PE-LD)</td><td colspan="6">For rapid mold filling, short runners and large cross-section distribution channels should be used. The runner cross-section shape is round trapezoidal. Pin gates with a diameter of 1-1.5 mm and a length not exceeding 2 mm. Good air venting conditions must be provided from the mold cavity. When molding large and flat products, it is advisable to have multiple distribution channels or several pin gates in the mold. The gate location is important. Open nozzle. Vent channel depth not more than 0.02 mm.</td></tr>
</table>

Compared with other plastics, polyethylene is characterized by a higher shrinkage during cooling of parts, which is associated with a higher degree of crystallinity and density. The data presented above characterize the influence on shrinkage difference in both directions of injection temperature, part thickness, pressure value, type and size of gates, uniformity of cooling and other factors. According to Table 1, the shrinkage under these conditions for HDPE (PE-LD) material is 1-4%. Considering the adopted material density of 0.93 g/cm³, for this density we accept shrinkage of 4%, and taking this shrinkage into account we can calculate the mold cavity dimensions of the «roller tube» part (Table 3) and the «bearing seat» part (Table 4).

Table 3 – Dimensions of the «roller tube» part for the mold considering shrinkage

Dimension name	Part dimensions	Dimensions with shrinkage allowance (for mold)
Outer diameter	127	132
Length	315	340
Inner diameter	106	101.8
Inner diameter	88	84.48

Selection of the main technological equipment [9]. The calculation is performed for the «roller tube» part, as having larger dimensions compared to the other roller parts (including the «bearing seat» part).

Table 4 – Dimensions of the “bearing seat” part for the mold considering shrinkage

Name	Part dimensions	Dimensions with shrinkage allowance (for mold)
Outer diameter	106	110
Outer diameter	114	118.5
Outer diameter	87	90.5
Outer diameter*	78	82
Outer length	54	56
Outer length	9	9.4
Inner diameter*	78	74.8
Inner diameter*	62	59.5
Inner diameter	36	34.5

*Note: * – possibility of adjusting the size by machining.*

The calculated value of the injection volume of the injection molding machine is determined by the formula:

$$V = \frac{Gn+G_л}{\rho} \cdot \frac{1}{k} = \frac{1640 \cdot 1+10}{0{,}93} \cdot \frac{1}{0{,}6} = 2946 см^3,$$

where V – calculated injection volume, cm³; G – mass of the product, g; n – number of mold cavities; Gл – mass of the runner system, g; ρ – density, g/cm³; k – coefficient of machine injection power utilization (according to [9] k = 0.5).

Mass of the «roller tube» part: G=Vρ=1764.1× 0.93=1640 g; Mass of the runner system (maximum) G = 10 g.

We select the type of injection molding machine based on the dimensions and design features of the «roller tube» part. From [6], Table V.3 we select machine D 3140-4000, according to Table V.4 suitable for working with high-density polyethylene.

Main technical characteristics of the injection molding machine: nominal injection volume per cycle, cm³ – 4000; nominal hydraulic pressure, MPa – 20; maximum distance between movable and fixed plates, mm – 2120; nominal injection pressure, MPa – 132.

Prototypes of the roller parts (Fig. 1) were created using 3D technologies in the Digital Engineering laboratory of NJSC “Shakarim University” on Creality K1max 3D printers.

The mass was calculated (Table 4). The mass of parts is determined by the known formula through volume and material density m = Vρ, where density of HDPE (high-density polyethylene) ρ = 0.93 g/cm³, density of steel 7.85 g/cm³.

Based on the data in Table 5, a comparative analysis of polymer rollers and traditional rollers can be carried out; all data are summarized in Table 6.

Table 5 – Mass calculation of roller parts with polymer materials

№	Part name	Material	Mass	Total mass	Note
1	Roller tube	HDPE	m=Vρ=1764.19×0.93=1640 g	1640 g	qty – 1 pc
2	Bearing seat	HDPE	m=Vρ=263.1×0.93=244.6 g	489.2 g	qty – 2 pcs
3	Protective washer	HDPE	m=Vρ=6.1×0.93=5.7 g	45.4 g	qty – 2 pcs
4	Inner labyrinth seal	HDPE	m=Vρ=8.7×0.93=8.1 g	16.2 g	qty – 2 pcs
5	Outer labyrinth seal	HDPE	m=Vρ=14.8×0.93=13.8 g	27.6 g	qty – 2 pcs
6	Cover	HDPE	m=Vρ=34.7×0.93=32.3 g	64.6 g	qty – 2 pcs
7	Shaft	Steel 5	m=Vρ=174.1×7.85=1370 g	1370 g	qty – 1 pc
8	Seal cover	Steel 3	m=Vρ=10.9×7.85=85.6 g	171.2 g	qty – 2 pcs
9	Retaining ring	Steel 3	6.2 (GOST)	12.4 g	qty – 2 pcs
10	Bearing 180305	-	144 g (GOST)	288 g	qty – 2 pcs
	Total mass			4124.6 g	

Table 6 shows that the weight of the rotating parts of the metal idler support exceeds the weight of the idler support with polymer rollers by more than 2 times (24.9/11.7 = 2.12). Also, under the accepted conditions, for 100 meters of conveyor we obtain a difference of (2091.6 − 982.8 = 1108.2 kg) 1108.2 kg. Thus, for every 100 meters of conveyor its mass decreases by almost one ton, which in the case of multi-kilometer conveyors provides significant material savings and, of course, increases the energy efficiency of the conveyor itself, results in significant energy savings.

Table 6 – Comparative table of efficiency and main parameters of a metal roller and a conveyor roller with polymer parts

№	Parameter	Traditional roller with metal roller tube	Roller with polymer parts	Note
1	Roller service life, year	0.4 [10]	1.0 [10]	
2	Roller weight, kg	8.3 [11]	4.2 (Table 4)	
3	Mass of rotating parts of idler support, kg	24.9 [11]	11.7	Size 1, GOST 22646-77
4.1	Required material amount per idler support – plastics, kg	0.1	6.18	
4.2	Required material amount per idler support – metal, kg	24.8	5.52	
5	Weight of idler supports per 100 m of conveyor (≈ 84 idlers per 100 m)	2091.6 kg	982.8 kg	

Conclusion

1. The use of polymer materials makes it possible to reduce the roller mass by 53%.

2. When the mass is reduced by 2 times, the moment of inertia also decreases proportionally, which leads to: reduction of starting currents, decrease of dynamic loads, reduction of energy consumption during acceleration.

3. For every 100 m of conveyor, a reduction in metal consumption of 1108 kg is achieved.

4. Polymer rollers are advisable to use in unloaded and medium-loaded sections.

5. Comparative analysis of traditional technologies for manufacturing polymer roller parts and 3D printing technologies showed that the efficiency of a particular method strongly depends on the type of production. Thus, for mass large-scale and serial production the most advantageous method is manufacturing polymer parts by injection molding. The application of 3D printing is significantly limited by the printing speed; therefore, its use for producing such parts is currently limited to single-piece and small-batch production.

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Е.Я. Шаяхметов[1], Р.А. Советбаев[1], К. Ожмегов[2], А.К. Билялов[1]*, А.Н. Нурбеков[1]
[1]Шәкәрім Университет,
071412, Республика Казахстан, г. Семей, ул Глинки, 20 А
[2]Ченстоховский политехнический университет ,
J.H. Dąbrowskiego Street 69, 42-201 Częstochowa, Польша
*e-mail: Altshok@bk.ru

ЭФФЕКТИВНОСТЬ ИСПОЛЬЗОВАНИЯ ПОЛИМЕРНЫХ КОНВЕЙЕРНЫХ РОЛИКОВ И СРАВНИТЕЛЬНЫЙ АНАЛИЗ ТЕХНОЛОГИЙ ИХ ИЗГОТОВЛЕНИЯ

В статье представлен расширенный сравнительный анализ традиционной технологии литья под давлением и аддитивной технологии 3D-печати при производстве полимерных роликов для ленточных конвейеров различного назначения. Рассмотрены технологические особенности процессов, их производственные ограничения, экономическая целесообразность и области рационального применения в массовом и мелкосерийном производстве.

Рассчитаны массогабаритные характеристики роликов и проведена оценка снижения металлоёмкости по сравнению с традиционными стальными аналогами. Проанализировано влияние уменьшения массы вращающихся элементов на динамические параметры системы, включая пусковые нагрузки, режимы работы и общее энергопотребление конвейерной линии.

Показано, что использование современных полимерных материалов позволяет снизить массу ролика более чем в два раза без ухудшения эксплуатационных характеристик. Это способствует повышению энергоэффективности, снижению износа приводных узлов и увеличению срока службы оборудования.

Определены критерии выбора технологии изготовления в зависимости от объёма производства, требований к прочности и условий эксплуатации.

Ключевые слова: *ролик конвейера, 3D печать, полимерные материалы, роликоопоры, аддитивные технологии, энергоэффективность, металлоемкость.*

Е.Я. Шаяхметов[1], Р.А. Советбаев[1], К. Ожмегов[2], А.К. Билялов[1]*, А.Н. Нурбеков[1]
Шәкәрім университеті,
071412, Қазақстан Республикасы, Семей қ., Глинки к-сі, 20 А
[2]Ченстохов политехникалық университеті,
J.H. Dąbrowskiego Street 69, 42-201 Częstochowa, Poland
*e-mail: Altshok@bk.ru

ПОЛИМЕРЛІК КОНВЕЙЕР РОЛИКТЕРІН ҚОЛДАНУ ТИІМДІЛІГІ ЖӘНЕ ОЛАРДЫ ДАЙЫНДАУ ТЕХНОЛОГИЯЛАРЫН САЛЫСТЫРМАЛЫ ТАЛДАУ

Мақалада әртүрлі мақсаттағы таспалы конвейерлерге арналған полимерлік роликтерді өндіруде дәстүрлі қысыммен құю технологиясы мен аддитивті 3D-басып шығару технологиясының кеңейтілген салыстырмалы талдауы ұсынылған. Процестердің технологиялық ерекшеліктері, олардың өндірістік шектеулері, экономикалық тиімділігі және жаппай және шағын сериялы өндірісте ұтымды қолдану салалары қарастырылған.

Роликтердің массалық-габариттік сипаттамалары есептеліп, дәстүрлі болат аналогтарымен салыстырғанда металсыйымдылықтың төмендеуі бағаланды. Айналмалы элементтердің массасын азайтудың жүйенің динамикалық параметрлеріне, соның ішінде іске қосу жүктемелеріне, жұмыс режимдеріне және конвейер желісінің жалпы энергия тұтынуына әсері талданды.

Заманауи полимерлік материалдарды қолдану ролик массасын пайдалану сипаттамаларын төмендетпей екі еседен астам азайтуға мүмкіндік беретіні көрсетілді. Бұл энергия тиімділігін арттыруға, жетек тораптарының тозуын азайтуға және жабдықтың қызмет ету мерзімін ұлғайтуға ықпал етеді.

Өндіріс көлеміне, беріктік талаптарына және пайдалану жағдайларына байланысты дайындау технологиясын таңдау критерийлері айқындалды.

Түйін сөздер: *конвейер ролигі, 3D-басып шығару, полимерлік материалдар, роликті тіректер, аддитивті технологиялар, энергия тиімділігі, металсыйымдылық.*

Авторлар туралы мәліметтер

Ержан Ярнарович Шаяхметов – PhD, «Автоматтандыру және ақпараттық технологиялар», Шәкәрім университеті, Қазақстан Республикасы; e-mail: shaiakhmeterzh@mail.ru. ORCID: https://orcid.org/0000-0002-7986-0083.

Раил Аянович Советбаев – PhD, «Автоматтандыру және ақпараттық технологиялар», Шәкәрім университеті, Қазақстан Республикасы; e-mail: rsovetbayev@mail.ru. ORCID: https://orcid.org/0009-0007-3605-515X.

Кирилл Ожмегов – PhD, Өндірісті басқару кафедрасы, Ченстохов политехникалық университеті, Польша; e-mail: kvozhmegov@wp.pl. ORCID: https://orcid.org/0000-0002-7103-2945.

Альтаир Канатович Билялов* – магистрант БББ 7M07104 – Машина жасау, Шәкәрім университеті, Қазақстан Республикасы; e-mail: Altshok@bk.ru.

Аслан Нурбекович Нурбеков – бакалавр БББ 6B07108 – Машина жасаудағы цифрлік технологиялар, Шәкәрім университеті, Қазақстан Республикасы; e-mail: aslannurbekov2@gmail.com.

Сведения об авторах

Ержан Ярнарович Шаяхметов – PhD, старший преподаватель кафедры «Автоматизация и информационные технологии», Шәкәрім университет, Республика Казахстан; e-mail: shaiakhmeterzh@mail.ru. ORCID: https://orcid.org/0000-0002-7986-0083.

Раил Аянович Советбаев – PhD, преподаватель кафедры «Автоматизация и информационные технологии», Шәкәрім университет, Республики Казахстан; e-mail: rsovetbayev@mail.ru. ORCID: https://orcid.org/0009-0007-3605-515X.

Кирилл Ожмегов – PhD, кафедра производственного менеджмента, Ченстоховский политехнический университет, Польша; e-mail: kvozhmegov@wp.pl. ORCID: https://orcid.org/0000-0002-7103-2945.

Альтаир Канатович Билялов* – магистрант ОП 7M07104 – «Машиностроение», Шәкәрім университет, Республика Казахстан; e-mail: Altshok@bk.ru.

Аслан Нурбекович Нурбеков – бакалавр ОП 6B07108 – Цифровые технологии в машиностроении, Шәкәрім университет, Республика Казахстан; e-mail: aslannurbekov2@gmail.com.

Information about the authors

Yerzhan Shayakhmetov – PhD, «Automation and Information Technologies», Shakarim University, Republic of Kazakhstan; e-mail: shaiakhmeterzh@mail.ru. ORCID: https://orcid.org/0000-0002-7986-0083.

Rail Ayanovich Sovetbayev – PhD, «Automation and Information Technologies», Shakarim University, Republic of Kazakhstan; e-mail: rsovetbayev@mail.ru. ORCID: https://orcid.org/0009-0007-3605-515X.

Kirill Ozhmegov – PhD, Department of Production Management, Technical University Czestochowa, Poland; e-mail: kvozhmegov@wp.pl. ORCID: https://orcid.org/0000-0002-7103-2945.

Altair Bilyalov*– Master's Student of the Educational Program 7M07104 – «Mechanical Engineering», Shakarim University, Republic of Kazakhstan; e-mail: Altshok@bk.ru.

Aslan Nurbekovich Nurbekov – Bachelor of the Educational Program 6B07108 – Digital Technologies in Mechanical Engineering, Shakarim University, Republic of Kazakhstan; e-mail: aslannurbekov2@gmail.com.

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