ROBOTIZATION OF THE PROCESS OF REMOVAL OF THE GATING SYSTEM IN AN ENTERPRISE FROM THE AUTOMOTIVE INDUSTRY

Robotyzacja procesu usuwania układów wlewowych w przedsiębiorstwie z branży motoryzacyjnej

Magdalena BUCIOR ORCID: 0000-0002-1081-5065
Rafał KLUZ ORCID: 0000-0001-6745-294X
Andrzej KUBIT ORCID: 0000-0002-6179-5359

DOI: 10.15199/160.2020.1.2

Abstract: Cleaning and removal of components of the gating system, and finishing of castings are the most labor-consuming and damaging to health foundry processes. This paper presents the results of an analysis of labor consumption of the process of removal of gating systems of aluminium castings, which were carried out in a conventional manner using a band saw and a boring machine, and using an industrial robot. In the final part of this paper the analysis of occupational hazard of work-stands is presented. It has been shown that the use of robotization leads to an increase both the productivity of the process and work safety. The use of an industrial robot allows to reduce the labor consumption of the process of removal of gating systems by 29,5% in relation to the non-robotized stand. Furthermore, on the robotized stand almost all the time needed for the process of removal of the gating system is connected with the machining. It represents 98.7% of the production cycle. In the case of non-robotized stand, the machining takes 79% of the total time required for treatment of one piece of the casting.
Keyword: automation and robotics in foundry, product development, removal of gating systems, work safety

Streszczenie: Oczyszczanie, usuwanie elementów układu wlewowego oraz wykańczanie odlewów należą do najbardziej pracochłonnych, szkodliwych dla zdrowia oraz niebezpiecznych procesów odlewniczych. W pracy przedstawiono analizę pracochłonności procesu usuwania układów wlewowych odlewów aluminiowych, realizowanego w sposób konwencjonalny z zastosowaniem pilarki taśmowej i wytaczarki oraz z zastosowaniem robota przemysłowego. W końcowej części pracy dokonano analizy ryzyka zawodowego stanowisk pracy i wykazano, że wprowadzenie robotyzacji procesu prowadzi do zwiększenia jego wydajności oraz bezpieczeństwa pracy. Zastosowanie robota przemysłowego umożliwia zmniejszenie pracochłonności procesu usuwania układów wlewowych o 29,5% w stosunku do stanowiska niezrobotyzowanego. Na stanowisku zrobotyzowanym, niemalże cały czas potrzebny na realizację procesu usuwania układu wlewowego jest poświęcony na obróbkę właściwą. Stanowi ona 91% cyklu produkcyjnego. W przypadku stanowiska niezrobotyzowanego, obróbka właściwa zajmuje 80% całego czasu potrzebnego na obrobienie jednej sztuki odlewu.
Słowa kluczowe: automatyzacja i robotyzacja w odlewnictwie, projektowanie wyrobów, usuwanie układów wlewowych, bezpieczeństwo pracy

Introduction

Modern industrial robots are very universal. They have been successfully used in such different areas as welding, painting, assembly and casting. The market of industrial robots in Poland and in the world is continuously growing, and the number of robots in production plants is systematically increasing. However, an increase in the use of industrial robots is influenced by a number of advantages, such as its high efficiency, ensuring repeatability of processes, the ability to work in hazardous environments, operating with heavy loads, optimal use of workspace. Furthermore, robots have a number of safeguards to protect the health and life of employees. Due to these advantages, the production plant can increase the variety and quality of manufactured products, and thus it becomes more competitive on the market [1]. The effect of the use of robots in casting processes is an increase of productivity and reduction of the number of defective castings, and reduction of the cost of the product by increasing efficiency [3, 5].

Robots are used both in the pressure die-casting and gravity casting. The use of robots most often is limited to [2, 4, 6, 8, 9]:

- applying of separating medium on the surface of mould joints,
- pouring the pressure casting dies,
- removing the solidified castings from the pressure casting die,
- cooling the castings by immersing them in a cooling tank,
- transfer of the casting from the cooling tank to the automatic edging stand,

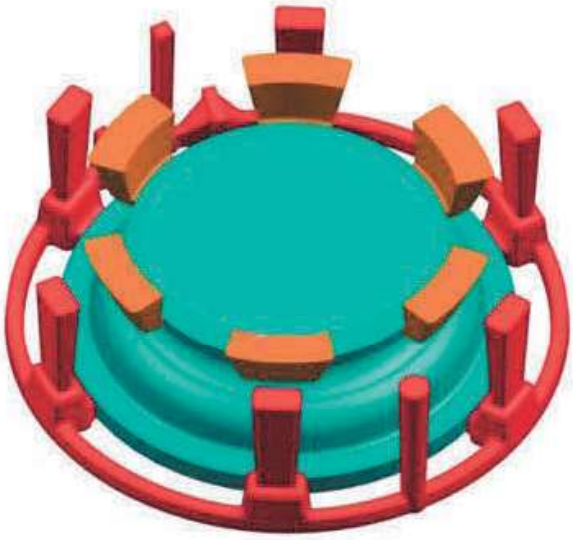


Fig. 1. The casting with the elements of the gating system

– removal of the gating system,
– location of steel inserts inside the pressure casting die,
– inspection of castings dimensions.

Cleaning, removal of components of the gating system and the finishing of castings are the most labour-consuming, harmful and dangerous foundry processes [7]. Estimated duration of cleaning and finishing of casting is from 20 to 50% of the total labour consumption of their manufacturing. Despite the large mechanization, the share of manual work during cleaning, removal of elements of the gating system and finishing of castings is very high and it ranges from 40 to 90%.

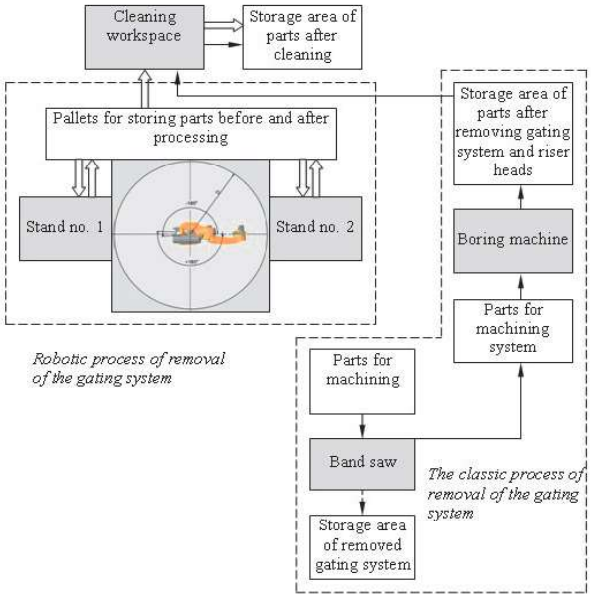


Fig. 2. Scheme of the arrangement of the stands

Despite the existence of beneficial conditions associated with the use of robots in the process of removal of gating systems, many entrepreneurs believe that robotization of their company will not be profitable. As a result, entrepreneur does not see the need to install industrial robots and manipulators in their plants. Therefore, the aim of this paper is to compare the labour consumption and work safety of the process of removal of gating systems realized in the conventional manner using a band saw and boring machines, and by using industrial robots. The obtained results can underlie the decision about robotization of analyzed process.

Analysis of labour consumption

The subject-matter of the analysis was the process of removal of the gating system and process of cleaning of AC-47100 aluminum alloy casting (Fig. 1).

In the process of removing the gating system realized in a conventional manner with the casting with the gating system and riser head is transported from the part store using the foundry crane to the band saw. The removing process is carried out manually. Therefore, the accuracy of the process realization depends on an employee who manipulates cast attached to the foundry crane.

Next the casting with the removed gating system is pushed by using a crane on a manual hand track, which is transported by an employee operating the saw band on the boring machine stand. The distance between the band saw and the boring machine was approximately 30 meters. The casting is clamped by an employee on the boring machine using the foundry crane. On the boring machine the remaining riser heads are removed and one of the flanges is roughened. After that, the casting was transported by the crane to the cleaning stand, where it was subjected to abrasive blasting.

The schematic arrangement of the stands in the present process is shown in Fig. 2. In the case of robotization process, the removal of elements of the gating system (except cleaning) is carried out by using an industrial robot KUKA. The industrial robot KUKA KR 120 R2500 PRO shown in Fig. 3 (workspace graphics) and Fig. 4 (with a mounted circular saw), is an industrial robot with a compact design, high rigidity and high power. It is resistant to high temperatures and impurities. In order to ensure the efficient realization of the process of gating system removal, the robot is equipped with twelve-positional store of tools. Basic technical specifications of the robot are given in Table 1.

In the robotized process of removing the casting gating system, the casting is transported with the foundry crane into the robot's workspace. Then the casting is secured by the employee in the three-jaw chuck located

Table 1. Technical specification of KUKA KR 150 R2700-2 robot

Weight (excluding controller)	1072 kg
Rated payload	150 kg
Maximum reach	2701 mm
Number of axes	6
Positioning repeatability	±0.05 mm
Temperature during operation	+10°C to +55°C

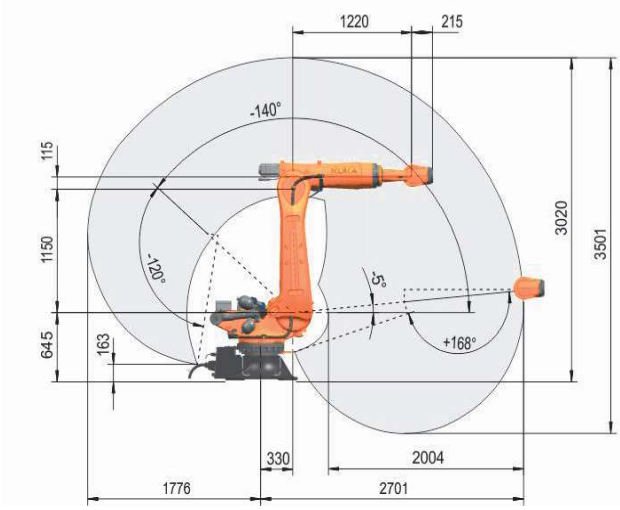


Fig. 3. Workspace graphic

Fig. 4. Industrial robot KUKA KR 150 R2700-2

on the turntable. The following operations are realized on the robotized position:

- removing the gating system using a saw blade with a diameter of Ø 250 mm (Fig. 5),
- cutting off of riser heads with a saw blade Ø 120 mm,
- planning of the flange surface using a faze milling cutter in order to reduce the labor consumption of the process of casting cleaning.

Fig. 5. Cutting off of the gating system by a robot

In order to compare the labour consumption of the process of removing the gating system realized in a conventional manner and using a robot, the chronometrial investigations that involve the measurement of the duration of all operations were carried out within the processes. The measurement was repeated three times, and then the average value of the obtained results was determined. Test results were presented in Tables 2 and 3.

The results of investigations showed that the duration of machining of the casting in the case of robotized stand (40 min 50 s) takes about 1013 seconds (16.88 minutes) shorter than machining without the use of an industrial robot (57 min 13 sec). Assuming that the working shift in the production plant takes 27 000 seconds (7.5 hours - minus 30 minutes break), the plant with the help of an industrial robot can produce 3 casts more per working shift. Assuming a two-shift work per month the usage of robot can increase productivity by 29,5%.

On the robotized stand almost all the time needed for the process of removal of the gating system is connected with the machining. It represents 91% of the production cycle (Fig. 6a). In the case of non-robotized stand, machining takes 80% of the total time required for finishing of one piece of castings. The remaining 20% of the time involved such operations as transport, clamping and unclamping of the casting (Fig. 6b). The use of the robot to process the removal of gating systems allowed a significant reduction in the length of transport paths (Fig. 2) and reducing the handling steps. The time wasted on transport and manipulation was reduced by 58.1%.

Due to the use of an industrial robot, the times of operations such as transport and casting clamping do not extend the casting transition time through the production process. This is because the industrial robot has two workspaces. When the industrial robot is working, the employee has time to prepare the next part for processing in the second workspace. This additionally shortens the production cycle (by 6.8%). Due to the high repeatability of the robot, the surface after the cut off elements of the

Table 2. Removal of the gating system without the help of a robot

Action	Description	Tool	Tavg [s]
1	Casting transport	gantry	52
2	Cutting the gating system	gantry, band sawing machine	514
3	Putting the parts on the trolley	gantry, hand truck	20
4	Cut of the gating system remaining on the band sawing machine	band sawing machine	32
5	Transport to the boring machine	hand truck	141
6	Clamping of the casting	gantry	146
7	Boring	boring machine	753
8	Unclamping of the casting	keys	111
9	Transport to the work-in-progress store	gantry	43
10	Transport of the casting to the cleaning station	gantry	31
11	Casting cleaning	cleaning tools	1 560
12	Transport to the store	gantry	30
			3 433

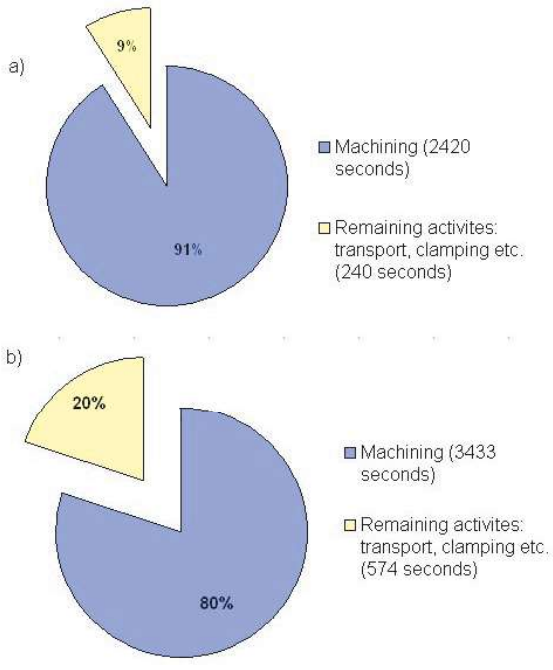
Table 3. Removal of the gating system using a robot

Action	Description	Tool	Tavg [s]
1	Clamping of the casting	gantry	105
2	Cutting the gating system	industrial robot	416
3	Cutting the feeder	industrial robot	509
4	Milling	industrial robot	315
5	Unclamping of the casting and transport to the work-in-progress store	gantry	76
6	Transport of the casting to the cleaning station	gantry	29
7	Casting cleaning	cleaning tools	1 180
8	Transport to the store	gantry	30
			2 660

gating system is processed more accurately, which allows reducing casting cleaning time by 23.9%.

In the case of machining of the casting without the help of an industrial robot, the setup time (Tpz) and the time necessary for waiting for the foundry crane, which supports several workstations should also be taken into account. The setup time Tpz is the time which occurs when the production plant changes the type of the produced casting. If necessary it is a need to adjust the milling fixture to the new casting. It takes about 420 seconds (7 minutes), which significantly increases the time of the casting flow in the production cycle. In the case of the foundry crane the situation is similar. The foundry crane that operates a few neighbouring workstations can be busy at the given time and the employee must wait to use it. In this case the expected time is in the range of 30 - 240 seconds, what also increases the production cycle. In the case of processing the position of robotic casting, preparation time is virtually unnoticeable, because it takes a few seconds. If it is necessary to process another type of casting, the employee approaches the control panel and selects the appropriate, previously written machining program. For this position, the employee must also wait

Fig. 6. The percentage share of duration of processing on the non-robotized (a) and robotized (b) workstand



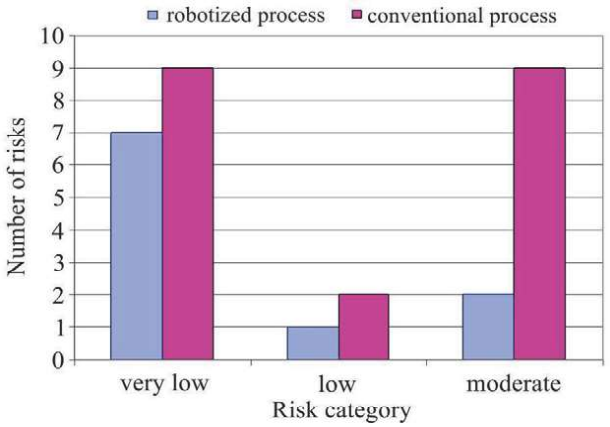


Fig. 7. Types of hazards and their categorization in the process of removing the gating systems

for the gantry to be released, but the industrial robot has two work stations, which allows the employee to perform all auxiliary activities during his work.

Analysis of work safety

When removing elements of the gating system on the non-robotized workstation a number of safeguards located on the machines are used. The main safeguards are warning signs, safety switches or protective casings. However, the safeguards may not be sufficient, because the moment while employee is careless can lead to an accident. The employee that works on a workstation or a random person in the vicinity of the workstation can be injured.

Removing elements of the gating system on the robotized workstation leads to avoiding dangerous situations that occur during its cutting using the saw band or boring machine. However, using an industrial robot we cannot eliminate the possibility of an accident, but its probability is much smaller. To estimate the occupational hazard of workstations the Risk Score indicator method is used.

The assessment of occupational hazard "R" is determined by multiplying three parameters:

$$R = SEP \tag{1}$$

where: S - potential effects of the event,
E - exposure to risk,
P - probability of risk occurrence.

After determination of the R indicator, the results should be interpreted according to Table 4, which contains the degree of occupational hazard in a given workstation and indicates when the appropriate actions should be taken to reduce the risk.

Conducted risk assessment has shown that the use of the industrial robot in the process of removing the gating systems significantly reduces not only the number of types of hazards, but also reduces the risk category (Fig. 7).

In the conventional process, 20 different types of hazards were identified, and 45% of which represent hazards with a moderate risk (70≤R <200). These risks need to take additional actions to increase the occupational safety. Robotization of the process enabled a reduction of 77% of risks characterized by a moderate level of risk. Most of them were shifted to the range in which the value of risk is low (20≤R <70) or very low (R <20). Therefore, it enabled an increase of the level of occupational safety.

Conclusions

The investigations of labour consumption of removal of gating systems of aluminum castings showed that the use of an industrial robot leads to reduction of the labor consumption of the process by 29,5%. In the case of the conventional method of removing the gating systems it should be noted that the transport routes are much longer, and the process required a larger number of workstations.

Table 4. Results of evaluation of occupational hazard using R indicator

R-value	Risk category	Necessary actions	Risk assessment
R<20	Very low	Advisable inspection	Acceptable
20≤R<70	Low	Necessary inspection	Acceptable
70≤R<200	Moderate	Necessary improvement	Tolerated
200≤R<400	High	Necessary immediate improvement	Untolerated
R≥400	Very high	Advisable work stoppage	Untolerated

Additionally, the waiting time for a foundry crane is not constant and employees often need to stop work to wait for the crane. Such stop affects process capability and leads to a significant extension of the duration of casting processing. Robotized stands occupy less space on the production hall, allow shortening the processing time, the time lost in transport and manipulation (about 57%) improve occupational safety and increase the accuracy and repeatability of casting process. The usage of robots in the production plant causes that manufacturer is more flexible to new market requirements.

References

[1] Brogardh T. 2007. „Present and future robot control development — An industrial perspective". Annual Reviews in Control 31(1): 69-79. DOI: 10.1016/j.arcontrol.2007.01.002.

[2] Brussel H.V., Persoons W. 1996. „Robotic deburring of small series of castings". CIRP Ann.-Manuf. Techn. 45(1): 405-410. DOI: 10.1016/S0007-8506(07)63091-1.

[3] Campbell J. 2015. Properties of castings. In J. Campbell (Ed.), Complete casting handbook (2nd ed.). Waltham, MA: Butterworth-Heinemann.

[4] Jaworski J., Kluz R., Trzepieciński T. 2014. „Investigation of stability of fabrication system of casting parts". Arch. Foundry Eng. 14(1): 5-8.

[5] Kluz R. 2012. „Analysis of the repeatability positioning of the assembly robot". Arch. Mech. Techn. Autom. 32(3): 59-68.

[6] Kosler H., Pavlovčič U., Jezeršek M., Možina J. 2016. „Adaptive robotic deburring of die-cast parts with position and orientation measurements using a 3D laser-triangulation sensor". Stroj. Vestn.-J. Mech. Eng. 62(4): 207-212. DOI: 10.5545/sv-jme.2015.3227.

[7] Stefanescu D.M. 2015. Science and Engineering of Casting Solidification. (3rd ed.). Heidelberg: Springer.

[8] Syrcos G.P. 2003. „Die casting process optimization using Taguchi methods". J. Mat. Proc. Technol. 135(1): 68-74. DOI: 10.1016/S0924-0136(02)01036-1.

[9] Trebuna P., Pakarcikowa M., Kronova J. 2018. „Automation of the casting process by the use of simulation software". Management and Production Engineering Review 9(1): 82-89.

Dr. inż. Magdalena Bucior
Rzeszow University of Technology, Department of Manufacturing and Production Engineering
e-mail: magdabucior@prz.edu.pl

Dr. inż. Rafał Kluz
Rzeszow University of Technology , Department of Manufacturing and Production Engineering
e-mail: rkktmiop@prz.edu.pl

Dr inż. Andrzej Kubit
Rzeszow University of Technology , Department of Manufacturing and Production Engineering
e-mail: akubit@prz.edu.pl