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AUTOMATION OF THE CASTING PROCESS BY THE USE OF SIMULATION SOFTWARE

Peter Trebuňa, Miriam Pekarčíková, Jana Kronová

Technical University of Košice, Faculty of Mechanical Engineering, Institute of Management, Industrial and Digital Engineering, Slovak Republic

Corresponding author:
Miriam Pekarčíková
Technical University of Košice
Faculty of Mechanical Engineering
Institute of Management, Industrial and Digital Engineering
Park Komenského 9, 040 01 Košice, Slovak Republic
phone: (+42155) 602 32 44
e-mail: miriam.pekarcikova@tuke.sk

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Abstract
Technological development offers a wide range of new possibilities for implementation of production processes. Continual production development is the main key to success and competitiveness improvement, labour productivity and image-building for all manufacturing companies. The article deals with designing of new workplace with implementation and utilization of automated robot for faster and safer handling of cast stock. The new layout of workplace is created in software Process Simulate.

Keywords
analysis, process, automation, model, simulation.

Introduction

The aim of each production in company is to achieve the highest profit with quality products. Correctly selected production process leads to the achieving the positive economic results. To achieve the best results, companies use wide range of mathematical models, production or optimization software. Using these models, production can be adjusted for satisfaction requirements of the market and size of financial, commodity and raw material sources. Furthermore, it depends on effective work of individual departments and production workers; the management of goods, raw material resources and marketing; the location of customers and the amount of transportation costs; the environment in which it is located, as well as other factors [1–3].

Development of optimization models become an integral part of production processes. There is still a lot of start-up that does not work with the required effect. Next part of article deals with solution of optimizing the production process and the results are possible to apply in manufacturing process of flanges [4–6].

One of the possibilities of optimization, which has a high application especially in the manufacturing engineering, is the automation of production. But automation of business processes alone is no longer sufficient to respond to modern challenges. The present time and especially near future, is affected by the phenomenon of Industry 4.0 [7, 8].

Automation and robotization of casting process is difficult. The casting process requires workers' skills in particular. Intelligent robot must be able to recognize and accurately respond to changes in conditions in the process of casting. Replacing physically demanding and harmful work with robots is one of the ways forward. Integrating robots into the production process is primarily about increasing the quality, accuracy, efficiency, flexibility and speed of production processes [7, 9, 10].

The main advantages of introducing robotization into the company in addition to the above are:
- reduction of operating costs (especially reduction of energy consumption),
- production increase,
- reduction of error and waste,
- improving health and safety at the workplace,

- saving space in production halls,
- increasing the volume and flexibility of production: enabling nonstop production to increase production quotas and complying with the delivery date of the products to the customer, off-line programming the production of new products and processes.

The digitization of production through modeling and simulation allows predicting behavior of an investigated system that is influenced by external and internal factors. The greatest advantage of digitization is the creation of a dynamic digital model that allows applying instant changes and comparing designs with simulation outputs. Less costly is error detected in simulations, as the error detected during the implementation of production system [11, 12].

Each company will be sooner or later forced to transform from the current structure into a new one that will respond to modern market demands. The analyzed company also belongs to a group of companies that gradually consider introducing modern technologies in production process. Digitization is faster and more accurately way to prepare business processes for their implementation into real production. Modelling, simulation and optimization are means of eliminating additional cost and time-consuming changes without interfering with ongoing production. For this reason, the module Tecnomatix Process Simulate was applied to solve the problem of the case study [11, 12].

Analysis of production process in company

Selected company is concerned with production of aluminum castings, using a top technology of casting under pressure. Company does not produce forms for high pressure discharge, the forms are ordered by mold manufacturers. Each cast is specific – it has a different shape, dimensions and characteristics. Production of form is complex. The company produces series production of complex castings (flanges, compressor cylinder heads, electromotor shields, etc.) with excellent surface quality, which workers provide for subsequent machining.

Orders are made according to the inventory, it means whenever it is needed, e.g.: once a week, once every two weeks, monthly. Material consumption for production depends on number and size of orders in company, also it depends on spoilt goods and casts that were not sold. Foundry casts is cast stock from 98% of pure aluminum which is purchased from various suppliers in the form of bricks. There are also needed: granules, which are used to remove impurities from the molten metal and specific material for refining.

The basic structure of material flow in company forms a material that is transported by forklift truck on gitterboxes or cup. Whole material flow is influenced by several factors: the volume and type of production, the level of complexity and segmentation of individual processes, the number of operations for the individual products and the distance between them, the mode of transport between workplaces [10, 12].

Company produces a wide range of castings for various companies, which use them as individual components for final products. In this case, the flange to the washing machine is selected product for optimalization and automatization of production process.

Production process of flange

According to the technological process, the product is called a short flange. Materials used: Al Si 9 Cu 3 (Fe) EN 1676 EN-AB 46000 (DIN 226) (2,0%-4,0%Cu) and Al Si 12 Cu 1 (Fe) EN 1676 EN-AB 47100 (DIN 231) (0,7%-1,20%Cu) [13].

Material must be recasted in the smelter, after that it is tapped to transport containers, which are transmitted to machines for casting under the pressure. Short flange is casted four times in the machine MW 550. It means 4 casts are made by one process of casting, Fig. 1.

Fig. 1. Casts in four-time form [13].

The control must be made two times: firstly, at the beginning according to the parameters of adjusting card and later once during the shift. The first good package passes to inspection for approval.

Molder gives every two hours one piece for checking [13].

At the beginning of casting, it is necessary to clean the mold cavity by compressed air. Extensive pollution are removed by scraper. Subsequently, the required parameters are set on the machine and press is closed by pushing the button. Casting cycle starts by blanking a piston, then continues dosing of liquid metal, compression molding and solidification of casts. The machine automatically opens and casts can be taken from the casting mold. Casts are placed on the handling table. In the process of next cycle the molder performs visual control of casts and then a package is put on handling wooden pallets.When the pallet is full, it is proceed to the next workplace. Net weight of product is 0.102 kg.

In the next step it is necessary to carry out trimming of gating system. This is implemented on presses where the package is placed and two-hand lowering for trim the casts is carried out. It is necessary to remove and store the gating system into the pallets. Individual casts are taken form machine and they are stored on pallets.

After this operation, pallets with casts are transported to the workplace of drilling and thread cutting. For this type of cast it is necessary to drill a hole with a diameter of 4.9 mm. It is important to control each product. Finally, casts are transported to the wokplace of tumbling. Products with open bubbles are discarded. Good casts are stored on pallets.

Control is very important during whole production process. It is necessary to observe the following factors which affect the accuracy and quality of products:

- structural and technological – stiffness and machine strength, geometrical and working accuracy, correctness of setting,
- material – material formability, tolerance, roughness,
- influence of the human factor – correctness of the setting, control on the output,
- impact of the environment – temperature, dustiness.

Each cast must fulfill the parameters and it has to satisfy requirements of customer, Fig. 2.

Fig. 2. Final product – short flange [13].

Recent production time

In the process of production any type of cast, the most important aspect is time and quality. In all areas of processing, it is necessary to take into account production time, time delays caused by machine failures, missing orders and insufficient number of staff [10, 12].

In the process of making an agreement between company and customer, it is necessary to negotiate terms and conditions of duration individual production activities [13]:

- **Remelting process:**
  melting process of material: 10 min.,
  bar gauge to crucible, about 200 kg of hot melt = bar gauge + refining: 5 min.,
  total time = 15 min.
- **Casting:**
  pouring of material to the container of casting machine = 3 min.,
  cycle of one casting (4 casts) = approximately 40 seconds,
  casting of 1 pallet, i.e. 210 packages = 8400 sec. = 140 min., i.e. 210 packages = 8400 sec. = 140 min.,
  total time = 143 min.
- **Trimming:**
  trimming of 1 pallet (210 packages, i.e. 840 casts) = 70 min.
- **Drilling:**
  drilling of 1 piece = 7.2 sec.,
  drilling of 840 casts = 6048 sec. = 100.8 min,
  in one palette: 2500 pieces = 18000 sec. = 300 min.
- **Thread cutting:**
  thread cutting of 1 piece = 8.4 sec.,
  thread cutting of 840 pieces of casts = 7 056 sec. = 117.6 min,
  in one palette: 2500 pieces = 21000 sec. = 350 min.
- **Tumbling:**
  tumbling of 1 piece = 3.36 sec.,
  tumbling of 840 pieces of casts = 2822.4 sec. = 47.04 min.,
  tumbling of one pallet (2500 pieces) = 8400 sec. = 140 min.
- **Checking:**
  checking of 1 piece = 3 sec.,
  checking of 840 pieces of casts = 2520 sec. = 42 min,
  checking of one pallet (2500 pieces) = 7500 sec. = 125 min.
- **Transit times of material and casts to the work stations:**
  movement of material between all departments = 15 min.

The manufacturing process of 840 pieces of cast flanges takes about 598 minutes, what is less than 10 hours. It results from adding all operations of material – it means from the beginning to the final cast. Production is continuously in progress. Production standards for individual sites are planned by company: seven hours, deducted break is 30 minutes, down time is 20 minutes and 10 minutes for time loss.

For comparison, the conversion is calculated according to the above mentioned period of production activities at the specific workplace. The resulting data are shown in the Table 1, below.

The calculations show that workplace of casting and trimming does not fulfill standards of production capacities.

Optimization and automation of production process of flange in the software program Process Simulate

One disadvantage in production process of flange and other cast is arrangement of individual departments. One of them is: transfer of material, unloading of casts from pallet, process of trimming, storage of casts back to the pallet and their transfer to other sites. The second problem is that company does not fulfill production capacity in the workplace of casting and trimming.

The solution is arrangement of a new plant and purchase of robot, so the process will be automated and controlled continuously. For preparation of such workplace it is necessary to make a proposal, create a simulation in software and compare simulated production with actual situation.
Robot description:

Control System "E42" Kawasaki equipped with a main 32-bit CPU, type Celeron M for management of extremely quick and accurate process, programming keypad with colored 6.5" LCD screen and multiple functions by the type of menu, software aimed at pressure outflow, Fig. 3.

Fig. 3. Colosio PF01000 with robot Kawasaki [13].

Description of software module Tx Process Simulate

The software product Process Simulate is one of the modules of the Tecnomatix software package from Siemens PLM Software (Plant Simulation, Process Designer, RobCAD, FactoryCAD, FactoryFlow, Jack and Jill). It is a simulation tool for planning manual and robotic production systems (simulation of production – assembly and handling operations, simulation of production processes for robotic applications, simulation of human movement). It consists of large number of elements through which it is possible to verify the virtual plans on the assembly line before the start of production and mitigate potential risks.

Using simulated 3D environments can create realistic robot simulations, create simulations of production processes and optimize them. Introduction of complex production processes into operation is faster and in higher quality [14, 15].

Table 1
Comparison of standard, real and automatized production.

Short flange		Short flange (calculations of actual production)		Short flange (calculations of automatized production)	
Process	Pieces/7 hours	Process	Pieces/7 hours	Process	Pieces/7 hour
Casting	2600	Casting	2130	Casting	2800
Trimming	4800	Trimming	4200	Trimming	5000
Thread cutting + drilling	2600	Thread cutting + drilling	2630	Thread cutting + drilling	2830
Tumbling	7000	Tumbling	7020	Tumbling	7020
Checking	7000	Checking	7050	Checking	7050

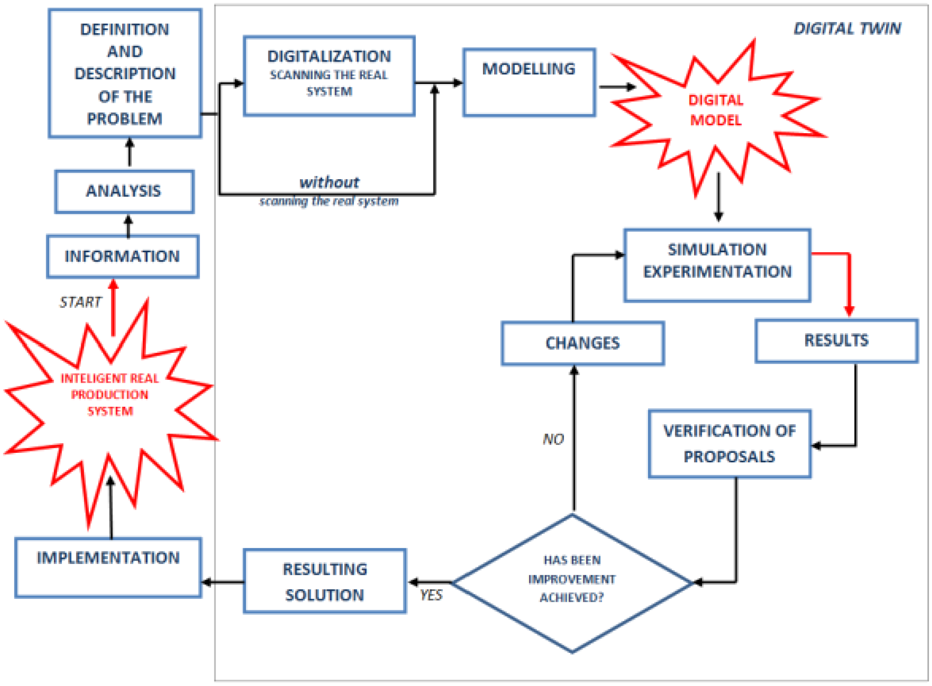

Fig. 4. Flow-chart of the methodology.

Creating simulations in the program leads to a reduction of risk in production before its start, reduce costs associated with the design of the product, reducing the time of planning, the election of the best method of production, ensuring an ergonomically safe processes. The big advantage is that this module is fully integrated with the Teamcenter platform. This allows technicians and designers to reuse data that has been used in past designs and re-create, validate, edit, and use processes data throughout their life cycle [14, 15].

Flow-chart of the methodology of modelling and simulation in solving the case study is shown in Fig. 4.

The company doesn't dispose of 3D laser scanning, so the workplace was created by 3D modelling using software SolidWorks and imported the objects into Tx Process Simulate environment and also was used objects from software library.

The aim of modelling and simulation in the Process Simulate module is to visualize the new layout of the workplace and to estimate the running time of castings when the new robot KUKA kr350/240 robot is deployed.

Case study solution

Molder needs to set an automatic cycle of casting on pressure machine and run production. After the casting, the signal is transmitted to robot which catches gating system with casts that must be chilled. Subsequently casts have to be placed on the further handling. After that process the casts are thrown into the gitterbox. The waste falls into the prepared pan located under the trimming press. The number of cycles of casting is set on casting machine, so the exchange of gitterbox can be realized. This cycle represents 210 outflows, i.e. 840 pieces of casts.

Trimmed parts fall down into the container. They are replaced by caster and transported for remelting into the smelter. The course of the simulated process must fulfill all standards of TPV flange. Any activity can not be missed or skipped.

The measured values of the automated processes are:

- **Remelting process:**
  melting process of material: 10 min.,
  bar gauge to crucible, about 200 kg of hot melt = bar gauge + refining: 5 min.,
  total time = 15 min.
- **Casting:**
  pouring of material to the container of casting machine = 3 min.,
  cycle of casting a single packages (4 casts) = approximately 20 seconds,
  casting of 1 pallet, i.e. 210 packages = 4200 sec. = 70 min.,
  total time = 73 min.
- **Handling:**
  gripping of casts by robot in the machine and its cooling = 6 sec.,

gripiing of 210 packages = 1260 sec. = 21 min.,
embedding of 1 package of casts into the stripping press = sec.,
embedding of 210 packages of casts into the stripping press = 630 sec. = 10.5 min.,
total time = 31.5 min.

- **Trimming:**
rimming of 1 pallet (210 packages, i.e. 840 casts) = 60 min.
- **Drilling:**
drilling of 1 piece = 7.2 sec.,
drilling of 840 casts = 6048 sec. = 100.8 min.
- **Thread cutting:**
thread cutting of 1 piece = 8.4 sec.,
thread cutting of 840 pieces of casts = 7056 sec. = 117.6 min.
- **Tumbling:**
tumbling of 1 piece = 3.36 sec.,
tumbling of 840 pieces of casts = 2822.4 sec. = 47.04 min.
- **Checking:**
checking of 1 piece = 3 sec.,
checking of 840 pieces of casts = 2520 sec. = 42 min.
- **Transit times of material and casts to the work stations:**
movement of material between all departments = 8 min.

Production process of automated workplace for 840 casts of flanges takes about 495 minutes, it means 8.25 hours. New layout of workplace created in Process Simulate is on Fig. 5.

Production of 840 pieces of finished casts during ongoing production is 598 minutes, in automated production with the new deployment of production machines it is about 495 min.

Efficiency of production process:

$$\frac{598 \text{ min}}{495 \text{ min}} = 1.21. \tag{1}$$

The production of casts by the process of automation increased about 21%.

Calculations evaluate the effectiveness of automated production compared to the automated and standardized production of casts in the various activities of production process. The input information for comparison of standardized, actual and automated production is processed in the following Table 1 (values from 1nd and 2nd columns concern Standards valid from 1.3.2015).

Casting process:

$$\frac{2800}{2600} = 1.08. \tag{2}$$

Trimming process:

$$\frac{5000}{4800} = 1.04. \tag{3}$$

Thread cutting and drilling process:

$$\frac{2830}{2600} = 1.09. \tag{4}$$

Tumbling process:

$$\frac{7020}{7000} = 1.003. \tag{5}$$

Checking:

$$\frac{7050}{7000} = 1.007. \tag{6}$$

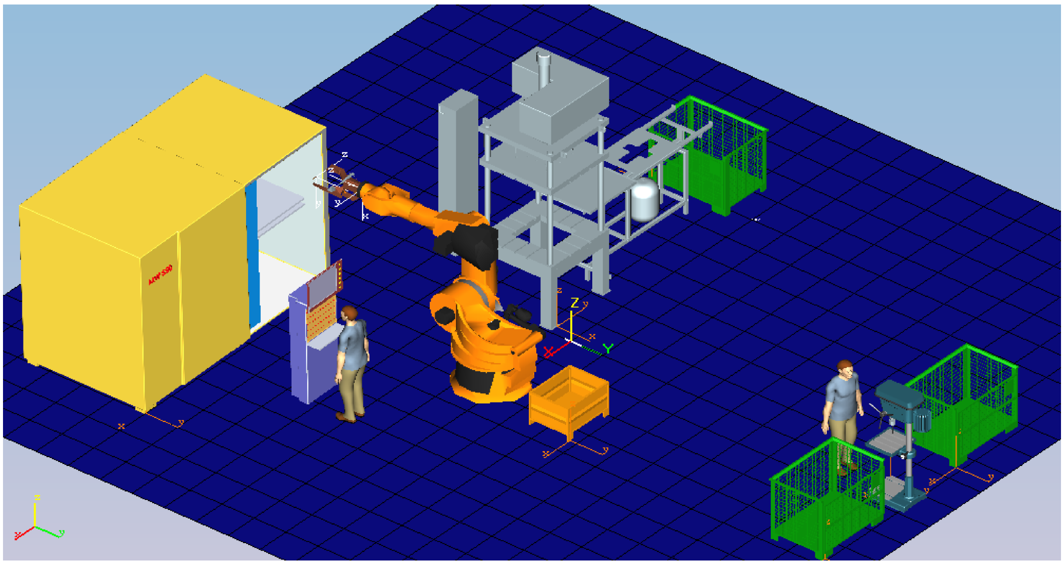

Fig. 5. New layout of workplace created in process.

The establishment of an automated workplace enables to increase the production capacity of casting process by 8%, trimming process by 4%, the process of thread cutting and drilling about 9%, the process of tumbling about 0.3% and process of cheking of 0.7%.

On the base of calculations it is possible to realize the evaluation of effectiveness of automated production and the actual state of castings in various activities of production process. The evaluation:

Casting process:

$$\frac{2800}{2130} = 1.31. \tag{7}$$

Trimming process:

$$\frac{5000}{4200} = 1.19. \tag{8}$$

Thread cutting and drilling process:

$$\frac{2830}{2630} = 1.08. \tag{9}$$

Tumbling process:

$$\frac{7020}{7020} = 0. \tag{10}$$

Checking:

$$\frac{7050}{7050} = 0. \tag{11}$$

Table 2 shows comparing time values from recent production time and time after optimization resulting from case study solution.

Table 2
Comparison recent state vs. state after optimization.

Production activities	Time (minute)	
	Recent state	State after optimization
Remelting process:	15	15
Casting	143	73
Handling	–	31.5
Trimming	70	60
Drilling	300	100.8
Thread cutting:	350	117.6
Tumbling	140	47.04
Checking	125	42
Transit times of material and casts to the work stations	15	8
SUM	1158 min.	494.94 min.
TOTAL REDUCTION	about cca 43%	

The evaluations of calculated results points not only to increased production, but also to operations of casting and trimming, that could be shortened by installed robot KUKA kr350/240. Manipulation with the robot in the production process will allow faster movement of material from the casting process to the trimming process. Individual operations also involve material handling that needs to be done through the robot. The result is shortening the transfer time of castings between workplaces.

The establishment of an automated workplace compared with actual production capacity can increase casting process by 31%, trimming process by 19% and cutting and drilling process about 8%.

The greatest risk in this project is financial budget overrun, delay in delivery of production equipment, badly planned project and improperly prepared interior. These components are most important, beacause the project price is 78 019.50 € for a very short time. Its plan and course of implementation must be strictly adhered, so company should produce larger amounts of casts and thus attain financial resources. Proposed arrangements to reduce the risk: control during the duration of project, careful monitoring of financial flows within the project, correct compliance of all points of project.

Conclusions

Future development of machine production is closely linked by automation, through which it is possible to produce larger quantities of products, accept large amount of orders and increase labour productivity. The most important reason of process automation of injection molding is removal of a person from operations that may endanger his health. For that reason it is important to optimize processes and focus on future technology development because its progress is developed and improved daily in each area.

The creation of simulations has led to the visualization of alternative solutions, reduction of production risk before its start-up, reduction of costs associated with product design, shortening of automation implementation planning times, improvement of ergonomic conditions and improvement of work safety.

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