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The Role of Robot in Flexible Manufacturing Systems

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Preliminary note

The analysis of existing manufacturing capacities indicates that machining is to a large degree being done in a traditional manner, on universal machines. This way a universality of process is achieved — a large assortment of mechanical elements can be machined. On the other hand, preparation time is long, capacity usage small, highly qualified labour needed. This paper presents the WCMA 25 manufacturing system in order to compare its operation with hitherto existing way of manufacture and show the advantages of robotized manufacturing systems. WCMA 25 is dedicated to metal manufacturing industry for higher complexity and accuracy work pieces made of cast iron, engineering steel and welded steel elements. By providing insight into results achieved by the system, this paper shows its advantages. Techno–economic indicators voice its ability to earn profit at limited-quantity production, because change of manufacturing programme does not imply any hardware change in the system. Its control unit has a data base big enough for machining a large variety of mechanical elements. The paper shows product price over quality ratio obtained on this system as a function of production quantity size and the tolerances chosen.

Keywords
Manufacturing
Robot
System

Ključne riječi
Proizvodnja
Robot
Sustav

Uloga robota u fleksibilnim proizvodnim sustavima

Prethodno priopćenje

Analiza postojećih kapaciteta ukazuje na to da se u velikoj mjeri obrada obavlja na klasičan način (na univerzalnim strojevima). Na ovaj način postiže se univerzalnost procesa (moguća je obrada velikog asortimana strojarskih elemenata). Sa druge strane pripremno vrijeme je veliko, iskoristivost kapaciteta mala, potrebna je visoko kvalificirana radna snaga. U radu je prikazan proizvodni sustav WCMA 25. s namjerom da se njegov rad usporedi sa dosadašnjim načinom proizvodnje i predoče prednosti robotiniziranih proizvodnih sustava. Postrojenje je namijenjeno metalo prerađivačkoj industriji za obradu radnih predmeta od lijevanog željeza, konstrukcijskih čelika i zavarenih elemenata od čelika, veće složenosti i točnosti. Sagledavanjem rezultata koje sustav ostvaruje, u ovom radu su pokazane njegove prednosti. Tehno-ekonomski pokazatelji govore o njegovoj isplativosti pri malim serijama, jer izmjena programa obrade nije praćena nikakvim hardverskim promjenama u sustavu. Upravljačka jedinica sadrži dovoljnu bazu podataka potrebnih za obradu velikog broja različitih strojnih elemenata. Prikazan je odnos cijene i kvalitete proizvoda u zavisnosti od veličine serije i izabranih tolerancija dobiven na ovom sustavu.

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1. Introduction

Previous experience indicates that many manufacturing organization problems have remained unsolved. Justified are all efforts aimed at finding new organizational and techno-engineering solutions for a new type of manufacturing, which is to bring about suitable, economical and rational manufacturing [1].

Analyses of buyers' needs show that market conditions and requirements are such that the existing manufacturing philosophy cannot address them appropriately. Rigid manufacture with inadequate organization has made existing types of manufacturing uneconomical and inflexible, i.e. unadaptable to very severe market conditions. Flexible manufacturing has come about as an answer to the new state of the market and the new requirements. These demands primarily indicate that ever growing number of products have to be manufactured in different variants, with consumer demands becoming more exclusive all the time. Mass manufacturing and sale of products is a thing of the past. Only those products will succeed that can adapt to market requirements and in a short time at that [2], Figure 1.

Flexible manufacturing systems as a new form of manufacturing philosophy are expected to absolve the most important manufacturing dilemmas. In order to apply the newest practices, one also has to comprehend all the elements comprised by such systems. As a part of the new technology, robots successfully come to terms with requirements placed before them. Their machining

Symbols/Oznake

p	- rejection rate, % veličina škata	k	- empirically constant - eksperimetalna konstanta
c	- price coefficient - koeficijent cijene		

qualities are good, while at the same time lowering manufacturing costs. Since design requirements of industrial robots are becoming more and more complex regarding manipulative abilities, speed of movement, accuracy and repeatability, adaptability, energy efficiency, manufacturing costs etc., it becomes necessary to gain a deeper insight into industrial robots' control problems, tightly related to contemporary electronics.

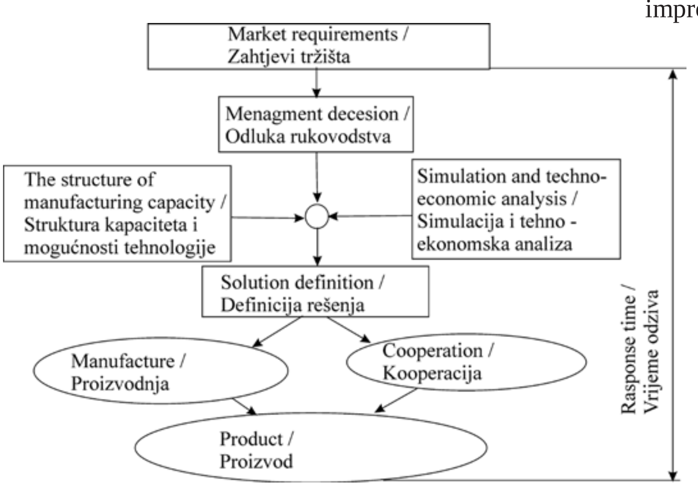

Figure 1. The way to organize manufacturing

Slika 1. Način organiziranja proizvodnje

Flexible manufacturing systems of various ratings and purposes represent a contribution to automation and a raise of the product quality level. Their fundamental engineering components are numerically controlled machines and industrial robots. Automation in all areas of manufacturing, especially the one implemented in terms of flexible manufacturing systems, stands also for multiple increase of accuracy and more precise execution of operations in all work phases. That means enhancement of the final product quality.

2. The properties of contemporary manufacturing

Continous development of new and improvement of existing products requires and often increases the quota of piecewise and limited-quantity production. One of the most important characteristics of contemporary manufacturing could be called „indulging the market" (i.e. the buyer). This is achieved through limited-quantity production and a large number of models and their variants. Engineering progress and product quality are interrelated categories. Engineering progress acts towards permanently increasing product use value, while on the other hand in its implementation implies utilisation of work objects of ever greater quality. Here lies the contribution of automation, as the most pronounced form of the contemporary engineering progress, in constantly improving the means of production.

The developed industrial systems show different degrees of manufacturing process automation i.e. ratio of automated operations to overall number of operations. Around 2005, leading automobile manufacturers had 90 % as that percentage ratio in the operation of car body welding, 70 % in the operation of car body spray painting, and only 15 % during final assembly. Via introducing new manufacturing systems with computer integrated and organized functions, it is forecast that by year 2020 this percentage ratio for the operations of car body welding will reach 100 %, for the operations of car body spray painting 85 %, and 30 % in the final assembly [3].

Any manner of manufacture without robot is nowadays almost unthinkable. The robot represents one of the most cardinal elements of automation. In various ways it makes the manufacturing cheaper and more profitable. Robots and artificial inteligence go together, so it is hard to conceive of a modern robot having no artificial intelligence. According to experts, by 2040 robot will attain the intelligence of man and will certainly become much more intelligent than many of us. Robots and artificial intelligence will lengthen man's lifespan and improve his life in its entirety.

The main objective of contemporary manufacturing is the maximum engagement of all available capacities throughout the environment, in order to make the advantages at our disposal bear fruit. This does amount to a huge effort, but if one is to stay in competition, one has to meet the challenges brought about by the contemporary way of doing business. Such ways of manufacturing most often require rousing all available potentials in the shortest time possible. One must keep in mind that everything takes place in real time now. The market is very *mobile* and some new rules will most probably hold good in the next timespan.

3. WCMA 25 Manufacturing cell

This system (Figure 2) designed by GOŠA Institute comprises three machines (two numerical lathes and one miller) and a local repository-palettes exchanger of proprietory design, whose job is to eliminate queueing, provide the cell with required work pieces and exchange them with already finished ones. All three machines are products of HAAS Automation**.** A FANUK "Multipurpose Measurement System" performs the role of the measurement & control unit. The design of the robot is antropomorfic; it was designed in collaboration with School of Mechanical Engineering. The purpose of the cell is to machine positions which do not require rotation and weigh from 2 to 18kg, measuring from 100x100x100 mm to 350x350x600 mm.

A band conveyor couples this machining unit with the rest of the manufacturing process. The conveyor has a horizontal grasp, suitable for organizing line manufacturing. The planar receiving part is suitable for grasping palettes. Machining objects are manually piled on palettes, which are transported by the band conveyor and fed the machining system via exchanger. Machined parts are returned to the system in much the same way, but in reverse order.

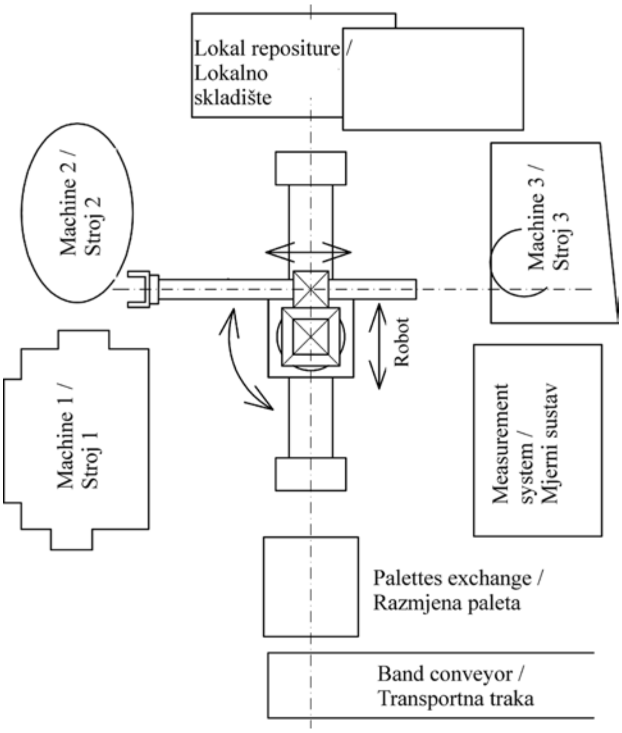

Figure 2. WCMA 25 system structure

Slika 2. Struktura sustava WCMA 25

Market analysis established the need for high productivity manufacturing of diverse types of constructions, i.e. of a large variety of high quality mechanical elements. This system is offered the potential buyer along with all its advantages that turn up on comparison with the previous way of manufacturing. Given enough employment, the system can pay itself off and than create profit. Engineering indicators reveal that 12 % of mechanical elements demanded by the market cannot be machined in a traditional way [3].

Robot **RW25** has five degrees of freedom (two rotations and three translations) and resembles a jointed quadrangle hand. It moves along the rails, enabling it to service all its devices and also machines without tool exchangers of their own. It also services chippings removal devices, which every machine has. Its control system has position and velocity feedbacks, making for even running and more flexible setting of desired positions of all system segments. It is fitted out with digital inputs/outputs for coupling with peripheral devices and is driven by AC motors with controlled position and velocity. Axes are balanced pneumatically and by weights. Encoders serve as positional transducers. Robot's kinematical structure is given in Figure 3.

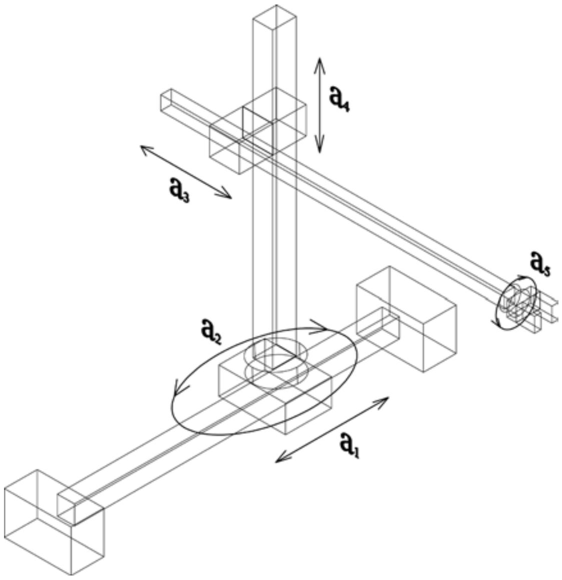

Figure 3. The kinematical structure of the RW25 robot

Slika 3. Kinematska model robota RW25

The control structure of the robot subsystem is schematically given in Figure 4.

Cell control unit is completely computer oriented and integrated. All system (subsystem) elements act as functional units in a concerted effort to perform a designated manufacturing task. Program library disposes of a large number of programs defining cell operation during various manufacturing tasks. Flexibility is provided by the available equipment (hardware) and control program support (software). Two modes of operation are provided for – the system can operate either as an independent whole or as a part of a bigger configuration, if need be.

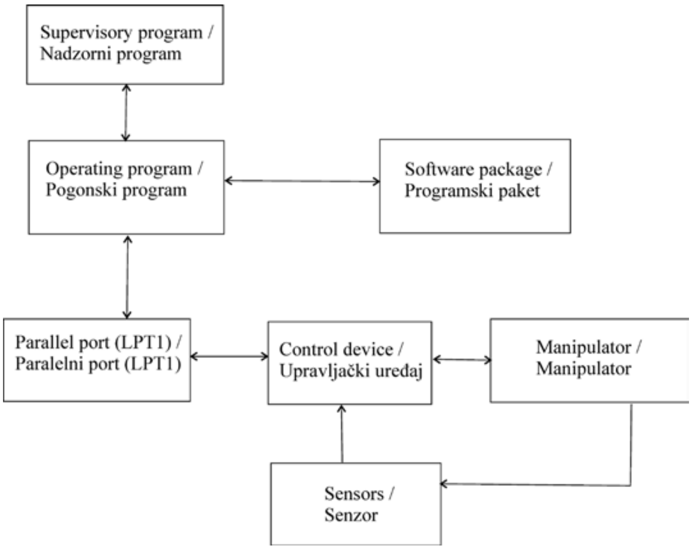

Figure 4. Robot RW25 subsystem control structure

Slika 4. Struktura upravljanja podsustava robota RW25

The programming software of this flexible manufacturing unit is convenient for implementing machining tasks. Inclusion of a robot and the total automation in the production process brings about a train of advantages in comparison to previous manual procedure. It shortens machining time significantly, thus substantially increasing productivity. It gives higher and evener product quality. It rationalizes the manufacturing process. It provides for greater safety of the work process, as well as substantial advancement regarding humanization of workplace conditions.

Our research has yielded the product price over product quality ratios (Table 1). It is up to the manufacturer to estimate what brings profit at any given moment, so long as it results in a product of desired characteristics.

Table 1. Product price over (product) quality ratio

Tablica 1. Odnos cijena i kvalitete proizvoda

Production quantity / Veličina serije, no. of pieces / komada	Price / Cijena, %	Quality / Kvaliteta, %
less than 10	+ 548	+ 45
10 to 80	+ 113	+ 67
80 to 200	- 36	+ 69
200 to 1000	- 268	+ 72
1000 to 5000	- 580	+ 74
over 5000	- 730	+ 75

All calculations are based on spring 2009 market prices in Serbia.

4. Influence of tolerances on the machining price and the rejection rate

Profitability analysis of such a system yields many factors bearing an influence upon it [4]. One of the most prominent is the optimal usage of capabilities of all machines and their relationships. Correct cell operation affects the overall price of the product, that must find its place in the market. Calculations were performed and recommendations given in order to maximize the rationality of usage of the system designed. Next table (Table 2) is earmarked for calculating the change in the cost price of the machined piece subject to selection and the change of the tolerances arrived at during design and later during manufacture.

According to their surfaces to be machined, all pieces machineable on this flexible manufacturing system have been divided into several groups:

1. outer cylindrical surface of a piece that can rotate
2. inner cylindrical surface of a piece that can rotate
3. surface surrounding apperture on a piece that can rotate
4. inner cylindrical surfaces of a piece that cannot rotate
5. surface surrounding apperture on a piece that cannot rotate
6. inner surface next to a measuring point (or a gear wheel apperture) on a piece that cannot rotate
7. planar surfaces next to a measuring point on a piece that cannot rotate

Table 2. Price coefficient as a function of tolerance

Tablica 2. Veličina koeficijenta cijene ovisno od tolerancije

Group no. / Broj grupe	Tolerance / Tolerancija, mm						
	0,300	0,150	0,075	0,040	0,020	0,010	0,005
5	0,56	0,70	1,02	2,00	4,43	5,55	7,06
6	0,18	0,26	0,37	1,98	2,88	3,46	5,48
4	0,57	0,76	1,07	1,51	2,31	3,32	5,05
7	0,15	0,31	0,38	0,86	1,16	2,56	3,84
3	0,33	0,38	0,44	0,55	0,68	1,90	4,32
2	0,19	0,24	0,29	0,38	0,50	1,07	2,37
1	0.06	0.06	0,07	0,20	0,21	0,24	0,47

Rejection rate p is a function of the price coefficient c, while k is an empirically obtained constant.

$$p = f(c) = kc \tag{1}$$
$$k = 0{,}98$$

It is the designer's task to correctly choose properties of each component, thereby determining the reliability and the price of the final product [5].

5. Conclusion

The paper shows that this kind of manufacturing is altogether suitable for addressing new market demands. Swift appearance of new products, profitable manufacturing of several variants of the same product, limited-quantity production while maintaining high quality, low costs, all are but a few characteristics of this kind of production.

Robotized manufacturing, efficiency/thriftiness, adaptability to quick changes in the market, all of these result from using the newest technologies, the most up to date technical achievements and contemporary methods of work organization. Flexible manufacturing stands for contemporary techno-engineering and organizational solution completely in line with market demands and environment changes nowadays. Organizing work this way calls for big investments, but they are presently justified and profitable in the long term. Control of all manufacturing parameters is achieved by constant techno-economic analysis, utilised here to prove the advantages of this system with respect to the traditional manner of manufacturing. All indicators speak for profitability of this system even at limited-quantity production, because changes of machining programme are not fraught with any hardware changes in the system. With a great certainty one can claim that automation nowadays represents a safe investment and a reliable direction of development.

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