ANNALS OF THE ORADEA UNIVERSITY
Fascicle of Management and Technological Engineering
ISSUE #1, MAY 2013, http://www.imtuoradea.ro/auo.fmte/

OBJECTIFICATION OF QUALITY PARAMETERS IN ROBOT STRUCTURES BY CRITERION FUNCTIONS

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Abstract**—**Article describes the method of objective evaluation industrial robot quality, where is necessary to quantify chosen parameters, mathematically describes dependencies between physical values and express their value in non dimensional form. Presented theory of functional similarity was applied for comparison of three industrial robots construction. New method proposes more objective criterion of quality in comparison of physical similarity and is more general, because it does not demand geometrical similarity.

Keywords**—** Robot objectification, criterion functions, industrial robots, quality parameters.

I. Introduction

Quality is the comparative category that makes sense only when we are able to satisfy a given need comparing at least two products. Quality can be understood as a summary of expressing the ability of the product to perform the functions for which it is intended. At the same time taking into account economic indicators of the product, its accessories, equipment, spare parts and so on. As well as assumptions of manufacturer who produces the services associated with the use of the product. Quality of product is essential given's, which is different from the product with the same determination as to the utility value (level of performance). Product quality can be assessed only in relation to the product that meets the same or similar value. The concept of quality is understood here in its broadest sense as the quality of the philosophical sense as opposed to the quality of the production design. The quality of the production versions are expressed in terms of product quality conformity at the time of his final inspection of the quality prescribed in the technical documentation.

The quality of construction can also be assessed on the basis of indicators - quality parameters. Quality parameters can be divided into aspects (groups): functional, structural, technological, operational, economic and social.

Quality metrology is one of the theoretic of robotics, focusing on the theoretical basis for determining the quality of industrial robots and quantitative methods for evaluation of quality robots and also the use of these methods in the design, execution, and application of robots. Indicators characterizing the conditions of use of robots can be divided into groups:

a) Purpose (useful for the design of robotic workstations),
b) structure - the structure of mechanical assemblies,
c) economic.

Quality assessment for such views necessarily requires the classification of basic design and operational characteristics of the robot (the quantitative determination of the main characteristics of robots), allowing an objective assessment and comparison between different industrial robots kinematic structure of a particular structure type dimensions respectively. This effort to assess objectively the quality is usually not without susceptibility of introducing subjective opinions of assessed properties, respectively types of evaluation of design solutions. To objectively quantify the quality parameters of robot must therefore apply the method of mathematical modeling and experimental investigation, which are much more objective assessment.

One of the methods of quantifying industrial robots parameters is their optimization. Optimization of industrial robot construction can be performed from different aspects, from the weight aspect, from functional aspect or from economical aspect. Main aim of this optimization is improvement of construction (increase of utility parameters), of which increase of costs will correspond to economical viable quality. Here becomes problem in estimation of base classification markers and characteristics of industrial robots, which would quantify properties of industrial robots and allow objective classification and robot comparison of different construction. This evaluation process is very difficult and is carrying subjective view, the whole process can be corrupted. The only one reliable way of objectification of qualitative parameters is application of mathematical modeling methods and experimental monitoring.

According to the authors of works [1], [2], the construction of industrial robots can be assessed according to the characteristics grouped into groups according to various aspects. The group of parameters describing the quality of construction of an industrial robot can include [3]:

Functional parameters:

a) weight of manipulated object,
b) acceleration of end element,
c) handling space / size and shape,
d) kinematic structure and the number of degrees of freedom,
e) repeatability precision of positioning control system and sensory equipment,
f) weight of robot mechanical part,
g) type of drive,
h) degree of standardization and inheritance structures,
i) compatibility and so on.

Technological parameters:

a) Technological structures,
b) demands on precision execution,
c) demand for construction materials,
d) demands on transport and storage,
e) technological continuity of the current production.

Operating parameters:

a) Design versatility,
b) servicing requirements, software equipment, the number of programming steps,
c) mechanical reliability and control system,
d) environment resistance (system stability),
e) spatial complexity,
f) energy consumption and efficiency,
g) service.

Economic parameters:

a) Relation to complex automation,
b) economic efficiency and investment return,
c) operating costs for maintenance, repairs, training of personnel, and so on,
d) life cycle.

Other parameters:

a) Safety (active and passive),
b) environmental impact,
c) ergonomic parameters and design,
d) sociological aspects.

For objective quality evaluation of industrial robots, it is necessary to quantify monitored parameters, mathematically describe relations between physical values and express their value in non dimensional form. Theory of functional similarity, which was applied by author [1] to construction of industrial robots in work [2], proposes more objective criterions of quality in comparison to physical similarity, it is more general, because it does not demand geometrical similarity.

By theoretical analysis of industrial robot construction parameter objectification presented in works [2], [4] was obtained followed criterions:

a. Weight criterion

$$K_m = \frac{m}{\rho} \cdot \frac{\sigma_p}{Q \cdot a}^{\frac{3}{2}} \qquad (1)$$

b. Stiffness criterion

$$K_k = \frac{Q \cdot g}{E \cdot l \cdot p} \qquad (2)$$

c. Stiffness criterion from load aspect

$$K_Q = \frac{g}{p \cdot E} \cdot \sqrt{\frac{Q \cdot \sigma_p}{a}} \qquad (3)$$

d. Complex criterion

$$K_a = \frac{Q^2 \cdot V \cdot a \cdot g \cdot \rho}{l^3 \cdot m \cdot E \cdot p \cdot \varepsilon \cdot \sigma_p} \qquad (4)$$

Where :

Q is weight of manipulated object (kg)
a is reached acceleration ($m \cdot s^{-2}$)
V is manipulation space of robot (m^3)
m is weight of mechanical robot part (kg)
l is reference dimension (for example the length of robot arm) (m)
ρ is the density of construction material ($kg.m^{-3}$)
E is elasticity module (MPa)
p is precision of positioning (m)

Evaluation of mechanical construction part of industrial robot by theory of functional similarity, authors have been performed on constructions, which was available at university workplace, they had uniform drive, compliant cylindrical positioning system and discrete control system of movement sequence [5]. Main required parameters for analysis execution are presented in table 1. Types and manufacturers of monitored robots are not published from the reason commercial cause.

Computed values of separate criterions for monitored construction types are presented in table 2.

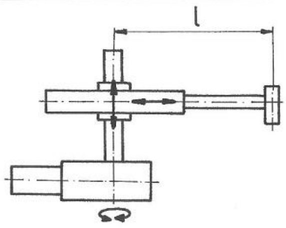
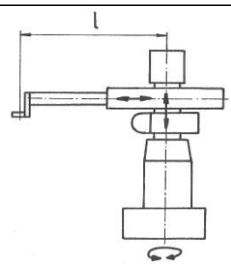
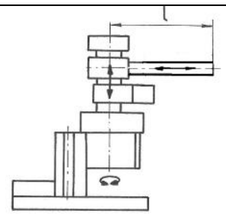
II. DISCUSSION

Weight criterion K_m indicates between weight of mechanical robot part and its load capacity. Higher quality of construction introduces its lower value. Order of evaluated robots is as followed: the best results are for construction No. I. The worst is construction No. III.

Stiffness criterion K_k gives value, which robot mechanical construction is the best from the aspect of stiffness. Its higher value means higher quality. Order of construction according to this criterion is as : the best values are reported in construction No. II. and the worst was construction No. III.

From table 2 results, that this order is corresponding to order of manipulators ordered by the criterion K_Q , which express the stiffness from the aspect of weight. Boundary or optimal values of $K_{m,}$ $K_{k,}$ K_Q criterions can be estimated by analysis of bigger amount manufactured manipulation robot construction in given kinematic structure and given type of drive.

TABLE I
ROBOT PARAMETERS

Monitored parameter	Construction of manipulation part		
			
	No. I.	No. II.	No. III.
m (kg)	40	340	742
Q (kg)	2	2x5	(2) x 6,5
l (m)	0,62	1,30	1,57
V (m^3)	0,026	2 x 0,07	(2) x 1,35

The whole quality of industrial robots is expressed by complex criterion K_a whose order is as: No. III, No. II and No. I.

To this corresponds also the order of industrial robots according to price: No. III- 0,0131 mil. EUR, No. II.- 0,00923. mil. EUR a No. I.- 0,00283 mil. EUR.

Complex criterion evaluates overall quality of robot, because of this it can happen, that the construction of appropriate robot is not the best from given set, but by given complex criterion is the best. This criterion happened in evaluation of robot No. III.

Complex criterion K_a can be supplemented by monitored parameters, which corresponds different specific characteristics of construction. This spreading automatically increases objectivity of own evaluation in fulfillment of condition to modify the criterion into non dimensional form.

TABLE II
CRITERION RESULTS

Construction of manipulation robot part	Criterion			
	weight K_m	stiffness K_k	stiffness from load aspect K_Q	complex K_a
No. I.	0,9501462	1,5069124	5,3262481	0,6147920
No. II.	0,7223603	1,7970020	8,4215370	1,0611368
No. III.	1,06350	0,96390	4,80102	4,411690

III. CONCLUSION

Contribution shows the possibility of objectification of decision-making processes. In this case, it is the determination of the criteria for determining the suitability of parameters Ki expressing a kinematic structure of industrial robots on employment. For work activities can be chosen following technological operations like coating, welding, installation and manipulation by the quality of industrial robots. Value of specified criteria express the quality of industrial robots. Designed criteria in dimensionless form allow quantify the suitability of any industrial robot kinematic structure for work destination and compare different types of robots among themselves. Future methods, of improving the technical parameters of industrial robots, are finding the optimal solutions. Optimization methods can be viewed from different perspectives, from the perspective of mass construction, operation, respectively economic efficiency of construction and so on. The paper described the optimization method, which improves the quality of construction of industrial robots to the extent the quality of industrial robots quality.

Quality assessment for such views, necessarily requires the classification of basic design and operational characteristics of the robot (the quantitative determination of the main characteristics of robots), allowing an objective assessment and comparison between different industrial robots, their kinematic structure, particular type of structure, dimensions, respectively this effort assess objectively the quality, trying to do so without susceptibility of introducing subjective opinions of properties, respectively types of evaluation and design solutions [6],[7]. To objectively quantify the quality parameters of robot must therefore it was applied the method of mathematical modeling and experimental investigation, which are much more objective assessment.

ACKNOWLEDGMENT

This work was created as a part of the Grant VEGA Ministry of Education no. 1/0274/11.

The article is dedicated to the memory of our teacher and later colleague prof. Eng. Frederick Vadovic, DrSc.

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