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ECONOMIC ASPECTS OF APPLICATION OF ROBOTS FOR MEASUREMENT AND INSPECTION

Summary. The use of modern measuring techniques is steadily growing. However, problems arises when it comes to economic assesment of the CMM or measuring robot investment. This paper presents one of the possible approaches to the economic aspect of CMM and measuring robots application for inspection tasks.

Each manufacturing process can be analysed as a dynamic system consisting of three main groups of elements, namely:

1. technological operation i.e.:
- preparatory and manufacturing processes,
- inspection and measurement processes.
2. resources of information, energy and materials necessary for the manufacturing,
3. flow of information, energy and materials between elements of the 1-st and 2-nd group and an environment.

The final product should feature required quality. $W \leq Wo$ or the equivalent inequality $MW \leq MWo$ where: M is the measure of the product resources, W is the product defectiveness, Wo is the limit acceptable defectiveness. Due to the great variety and complexity of manufacturing processes and because of the increasing product quality and reliability requirements it is necessary to lay a particular emphasis on a quality inspection and an optimal selection of measurement tools and methods. Economic and technical analysis and choise of the measurement methods the best suited for a given manufacturing process is a must since the quality control costs constitute 12-20% of the total manufacturing costs. The Coordinate Measuring Machines (CMM) and Measuring Robots are the most modern measuring machines, often fully automated, computer controlled both when carrying out a measuring process and processing obtained data. The versatility of the CMM and Measuring Robots created a new problem: a prospective buyer must be able to choose an appropriate machine from the wide range of them offered on the market. "Accuracy, flexibility, speed and cost" - this is the set of demands for optimisation procedure in case of purchasing any measuring machine. The term "accuracy" contains the overall measurement error together with the external influences. The ISO standards define length measurement error parallely to the axis and in any position in the machine space, the external conditions being stated.

"Flexibility" has two meanings : referring to the measured parts and referring to the application of the machine. The latter implies unlimited application range for various measuring tasks in the laboratory or on the shop floor.

"Speed" is most often referred to the real time of operations : from part fixture till its removal after measurement (and obtaining a report).Graphical illustration of the above relations is shown on fig. 1

Introduction of new techniques and technologies is often based on difficult to evaluate economic criteria. It often occurs that introducing new techniques is induced by achieving (or exceeding) performance limits of the machines being used. There are two basic analysis criteria groups :

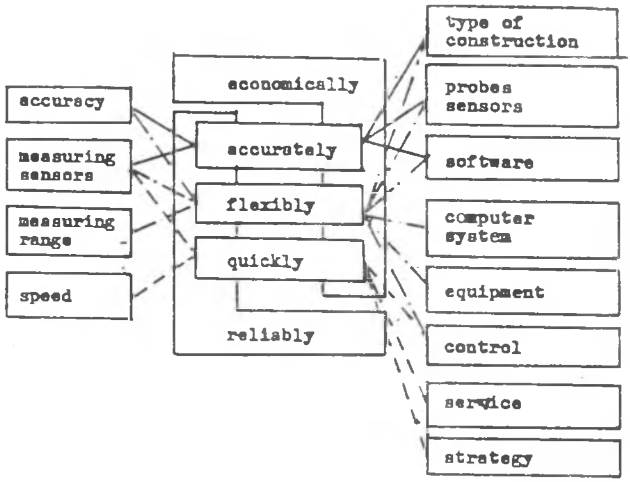

Fig . 1. Graphical illustration of the relations between quality inspection parameters

-qulitative criteria,
-quantitative criteria.

Qualitative criteria take into consideration the following issues:

-measurement of the various parts as the whole manufacturing process inspection,
-machines quality assessment,
-special parts 100 % inspection,
-favourable conditions for introduction of the new technologies,
-possibility of classifing and sorting of the parts.

Quantitative criteria show the amortization of the instrument through replacing many special instruments with one only:

-reducing costs thanks to existing software libraries,
-avoiding expensive hardware investments,
-inspection costs reduction,
-reducing down-time costs during the change of production profile,
-reducing the number of rejects and costs of processing.

It is essential to carry out an economic analysis of the measuring machine prior to its introduction into the manufacturing process. One of the possibilities is to make use of the minimum inspection time criterion. For example, the annual cost of the inspection process can be calculated as following :

$$Kr = Ka + Ku + Kp \qquad (1)$$

where:

Kr - annual cost of performed inspection operations,

Ka - annual amortization cost,

Ku - machine annual maintenance cost,

Kp - annual machine operation cost,

The addends of the annual inspection cost are given by the following formula:

$$Ka = \frac{Z(t)}{n} * C + Kn \qquad (2)$$

where:

C - cost of the measuring machine,

Z(t) - wear in time function,

Kn - servicing costs.

n - number of series a year

$$Ku = Ke + Ko \qquad (3)$$

where:

Ke - operation, periodical inspections and regulation costs,

Ko - air conditioning and working space maintenance costs,

$$Kp = \sum [Q + O + Kj + (Ki + Ks)\ x] \qquad (4)$$

where:

Q - measuring software cost for a given type of parts,

O - instrumentation cost for a series of parts,

Kj - measurement instrumentation adjusting costs,

Ki - energy costs,

Ks - manpower costs,

x - batch quantity,

Annual cost of inspection is a batch quantity linear function, whereas the cost of inspection referred to one part is the exponential fun - ction (fig. 2) .

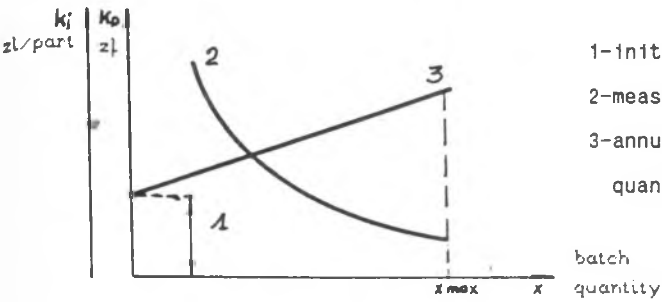

Fig. 2. Inspection cost diagram vs batch quantity

Analyzing annual inspection costs for different measuring devices depending on annual production size, it is necessary to study the above mentioned equations in order to determine their parameters for the considered measuring devices (fig. 3).

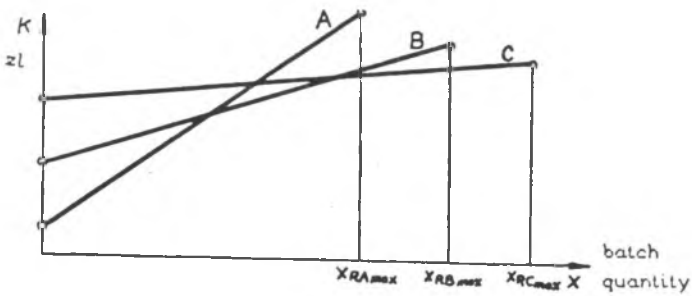

Fig. 3. Graphical presentation of economic efectiveness of three measuring devices : A, B, C.

Technical and economic aspects of CMM and robots application were compared and the analysis of their suitability for the mass and piece production was made.

In mass production the most desired kind of inspection is the active one, though sometimes not feasible. In that case custom made measuring system or a versatile measuring robot is the only reasonable solution. There is also a possibility to apply fully automated measuring machines, which working in a feedback loop, directly affect the production process.

The application of the automated measuring machine and measuring robots ensure satisfactory measuring accuracy, speed and reliability. The efficient measuring software for data collection and analysis is necessary, both on-line and off-line techniques are to be used.
Table 1 depicts the profits made by application of the modern measuring techniques. The measured part was the combustion engine body [2].

Tab. 1.

Measurement time (min.)

	Hand-operated measuring tools, conventional strategy	hand-operated measuring machine, individual strategy	CMM, CNC-control-service	Robot with laser measuring head, CNC-control
Preparatory work	10 min/part	8 min/part	10 min/part	15 min/series
Measuring software	-	-	30 min/series	40 min/series
Fixing	8 min/part	1 min/part	1 min/part	
1st part measurement	155 min	45 min	18 min	5 min
X-th part measurement	130 min	37 min	17 min	3,5 min
measurement of 100 part	-	250 min	95 min	30 min
communication with the production process	manual	manual	atomatic	automatic
random error %	15	8	negligible	

Presented data clearly show the time savings arising from the application of the modern measuring techniques. Graphical analysis of the general measuring costs depending on the batch quantity is shown on fig. 4.
This graph was made on the basis of data from the firm Buick-USA [2] (front car door).

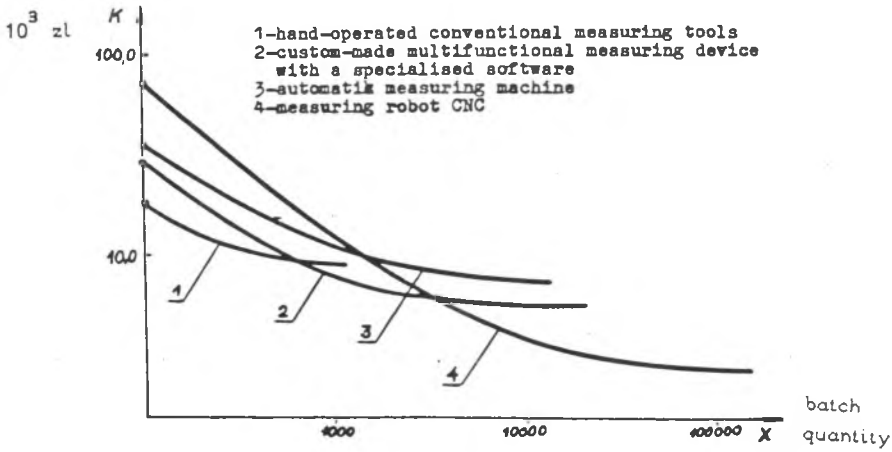

Fig. 4. Overall measurement cost as a batch quantity function

The conclusion is that manual measurements with the usage of traditional tools is no longer profitable ,and sometimes not possible (no data above 1000 parts). Good results are guaranteed by CMM and special measuring stands, especially for long series. The minimum cost, above 10000 parts, is ensured by measuring robots, which feature high versatility at medium series measurements and task changes (thanks to available metrological software). In case of the piece production many different metrological problems are encountered . This requires application of a wide range of measuring instruments. Therefore individual measurement progams should be elaborated on the basis of economic and time criteria. The analysis was made using a part with a complex shape and rather big dimansions : turbine rotor, 63 dia.,"dt.86", produced by Siecor Corp-USA [3]. There are four means of the inspection: manually on special prisms, with the CMM, on the automated measuring stand or with the metrological robot.

1 - Manual measurement is very time-consuming (520 min.) and despite proper instrumentation the random error level is up to 30 % .

2 - Computerised CMM:

- measuring time 170 min.,
- long preparations,

- necessity of the individual metrological program partly based on program library,
- no possibility of performing measurements in one fixing.

3 - Automated measuring stand:
- measuring time 110 min.,
- shorter preparations,
- necessity of the entirely individual control program,
- one fixing measurement.

4 - Metrological robot:
- measuring time 165 min ,
- very short preparations,
- robot programming necessary,
- necessity of preparing a measurement program basing on the available library.

The conclusion from the above is that the shortest measuring time is obtained on the specially designed measuring stand. Its cost, however, together with the software preparation, exceeds the robot price (it consisted of two robots equipped with a central control unit).

The introduction of CMM and robots is highly economicly justified, especially for mass production inspection. The advantages were presented in this paper : measuring time and costs reduction, and the possibility of eliminating various disturbances end errors occuring during the measurements. Consequently the number of rejects decreases, the production improves in respect of both the quality and efectiveness.

References:

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