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Research of quality impact to the product design properties and characteristics

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1. Introduction

Quality impact research becomes an integral part of new product and process development. Customers require permanent improve of product properties and increase variety of types. Designers seeking the higher product value and better properties have to apply more complicated geometrical form and qualitative parameters. These challenges raise the probability of errors in both the product and process development, and manufacturing. Manufacturers avoiding errors have to increase the efforts to quality warrant, which raises the quality costs. The tendency in many organizations is to think of quality costs in terms of what is visible: scrap, rework, returns, warranty service, claims and the like [1].

The reasons of quality cost, however, often lie in the early stage of a new product and process development that are not visible, or are sorely to foresee it. This is very urgent in high variety and low volume manufacturing [2]. Developed new properties of a product can create quality problems during manufacturing, if designer had not solved them at the early product design stage. Impacts of a product modular design on agile manufacturing [3] emphasizing creation easiest of production and quality product alternative. The well-known Worst case and Root sum square models [4] and Tolerance allocation method [5] in low volume manufacturing is inadequate.

The research of this paper exams the quality affects to the new product design properties and characteristics in high variety and low volume manufacturing. It accented the factors causing errors and defects in product design and manufacturing. The new methodology verifying and estimating product quality in its life cycle phases is proposed and discussed in this research.

2. Quality impact to product development

The developed methodology to verify and estimate product quality in its life cycle phases is able to act and appraise the errors and their probability in product and process development, production stages and influence of the human factor on originate errors. Starting to appraise errors in product development and design procedure, organization can earlier make the necessary corrections and foresee the appropriate decisions in later activity steps. The virtual prototyping and rapid prototyping processes extended to the virtual reality technologies must be widely used in this stage. New product developer particular attention must pay to the user requirements, creating and applying specialized techniques for this aim [6]. On the other hand the designer has to check process cost [7] and quality cost [8] for the product developed at the early design stage.

Product production stage realizes requirements of finished product design and has a small influence on manufacturing and quality cost. The latter can increase and fluctuate over tolerances, when insufficiently operates quality management system in organization [1] or product and process design is imperfectly made. The probability for an error to occur in both the product and process design and manufacturing depends on many factors as product complexity, applied inter-discipline modules, human skills and experience, striving novelties and challenges in new product development and so on.

Acquirement of statistical data and errors probability in product and process development and manufacturing is very useful technique to quality impact research. A basic assignment of errors and defects probability and reasons can be conveniently characterized by the following functions that map the statistical distribution in different phases of product design and manufacturing

$$E1 = \bigcup_{i=1}^{n} D_i \qquad (1)$$

where $E1$ is the product's design error probability, D_i is the set of design factors influencing the errors and imperfections greatness.

Quite often, $E1$ specifies a percentage measuring level and is defined empirically or applying expert's knowledge. The knowledge base (KB) creates many best cases of design error probability for various products and sets of design factors. The Eq. (1) helps the designer to find a minimal number of errors and defects seeking higher product's properties and characteristics applying DFX methodology. The created analogous expressions of other phases are able to estimate their errors and defects.

$$E2 = \bigcup_{j=1}^{m} P_j \qquad (2)$$

where $E2$ is the product's process design error probability, P_j is the set of process design factors influencing to the errors and imperfections.

$$E3 = \bigcup_{k=1}^{p} M_k \qquad (3)$$

where $E3$ is the manufacturing factor of error probability, M_k is set of manufacturing factors acting to the product errors and defects.

The Eq. (3) helps managers of production divisions seeking higher productivity and products quality in managing divisions' activity.

$$E4 = \bigcup_{l=1}^{n} H_l \tag{4}$$

where $E4$ is the human factor of error probability, H_l is the set of human factors influencing the errors and defects in all phases of product development and manufacturing.

Eqs. (1-4) can separately estimate and forecast the errors probability of each phase of product development and manufacturing. The objective of mentioned equations is to specify the greatness of available errors and defects. They are valuable seeking minimum of each phase errors. In reality, developing and producing products, the interfacing of phases is fixed and errors from one phase mutates to the other increasing initial error. Considerations of sheet metal products development and manufacturing show that the value of $E1$-$E4$ fluctuates in the margins of 0-0.06 and depends on the product and process complexity and production volume. The evaluation of an aggregate error mutation among all product development phases is available as follows

$$E5 = \exists(E1)U(E2)U(E3)U(E4) \tag{5}$$

where $E5$ is aggregate factor of error probability in product development and manufacturing.

In an ideal case, $E5 = 0$, when $E1 = E2 = E3 = E4 = 0$ or is equal to wane small values; conversely, $E5$ fluctuates from 1 to 100%, i.e. when the product has defects or errors, or at least is totally unqualitative when errors and defects in separate product development and manufacturing stages are not eliminated. The $E5$ value probability in this case is calculated by the Evidence theory [9].

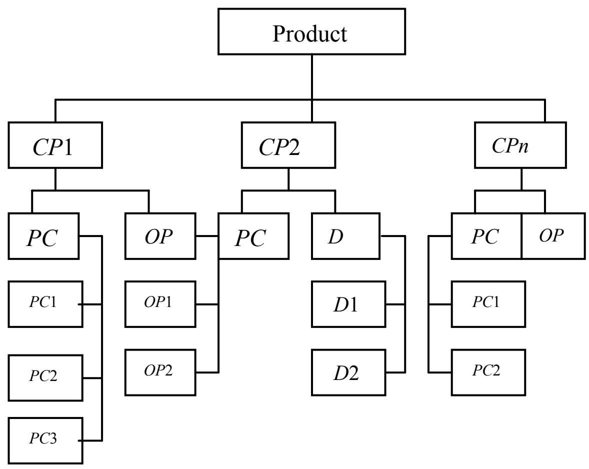

Fig. 1 Structural scheme of a first type product: where $CP1$, $CP2$, …, CPn is a number of first product type, $PC1$, $PC2$, …, PCm is a number of assembling units; $OP1$, $OP2$, …, OPp is a number of original parts and $D1$, $D2$, …, Dq is a number of design features

The developed methodology is suitable to consider the two types of products: 1) composed of some assembling units, original and standard parts and purchased components, and 2) original parts composed of various design features with different qualitative-quantitative parameters (Fig. 1).

The presented research has been made in both laboratory and industry. The theoretical aspects of quality impact to the first type product's design properties and characteristics have been created applying industry statistical data and mathematical modeling methods. The verification and validation tests for the developed research have been conducted in laboratory. Some companies of Lithuania took part conducting the acceptance tests of that research. Research results chapter illustrates how the developed methodology suits to the real industry problems.

3. Research results

A sequence of developed research experimental testing is shown. A typical mechanical product – a recuperator with various original and standard parts and purchased components has been taken. Lithuanian company X produces these products of different capacity and different purposes.

The main task of the recuperator is to clean, heat, to supply fresh air, and to exhaust used air. For heating of supplied air, the power of exhausted air is used. Air heaters of the considered air-handling units are electrical; the units have electronic communication fans with backward-curved impeller. More than 50 recuperators of different airflow capacity were investigated. The investigation of different recuperators (with maximum capacity requirements 400; 1500; 1900; 2000 m^3/h and other) was carried out. Analysis of characteristics – differential pressure Δp, output and input airflow productivity V was made. Dependences between characteristics and construction parameters of the product were determined.

Multiple nozzles in a chamber (Fig. 2) determine flow rate. The calculation of flow rate is made according to the methodology given in standard EN ISO 5167-1 [10]. The purpose of these calculations was to set up dependence of flow rate on differential pressure.

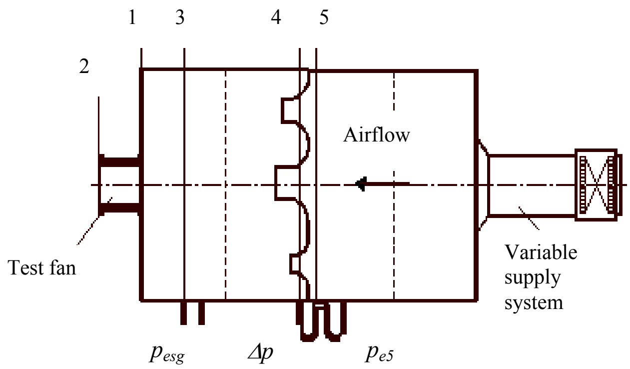

Fig. 2 Scheme of a test chamber: *1* – test fan inlet; *2* – test fan outlet; *3* – pressure measurement section in an inlet-side airway; *4* – throat or downstream tapings for Δp for an inlet-side measurement; *5* – upstream taping for Δp, p_{esg3} – constant pressure; Δp is differential pressure; p_{e5} – pressure upstream of the flow meter

Flow rate of the fluid is calculated as follows

$$V = 3600 \frac{q_m}{p_{sg1} / R_W \Theta_{sg1}} \tag{6}$$

where q_m is the mass flow rate, which passes the vent during the time unit; p_{sg1} is stagnation pressure; R_W is constant of humid air; Θ_{sg1} is air flow, passing the fan.

$$q_m = \alpha \varepsilon \pi \frac{d^2}{4} \sqrt{2\rho \Delta p} \quad (7)$$

where α is flow rate coefficient; ε is expansibility coefficient; d is diameter of the tap; ρ is air density; Δp is differential pressure.

$$p_{sg1} = p_{esg3} + p_a \quad (8)$$

where p_a is atmosphere pressure during the experiment.

The differential pressure Δp was changing from the maximum to minimum [10] meaning for the recuperator, which required airflow rate capacity V is 400 m^3/h. According to the calculation methodic of dependence between differential pressure and flow rate of the fluid, given in the standard, supply and exhaust flow rate V, m^3/h was estimated. The results are given in the Table 1.

Table 1

Flow rate capacity of the supply and exhaust air

Supply		Exhaust	
Δp, Pa	V, m^3/h	Δp, Pa	V, m^3/h
518	0	418	0
458	65	375	65
390	105	347	101
278	194	235	171
238	215	211	198
210	228	186	213
170	255	152	236
120	290	111	274
75	318	72	301
29	348	27	328
0	362	0	361

Analogical experiments were fulfilled with different recuperators with different requirements for the airflow rate capacity.

Experiments of different parameters, characteristics and assembly units influence on the supply and exhaust airflow rate capacity where fulfilled.

Characteristic of some recuperators with different airflow's rate capacity requirements were investigated. The dependence of airflow rate capacity on differential pressure was set. Influence of construction parameter's inaccuracy on the main recuperator characteristic (airflow rate capacity) was investigated.

Fig. 3 shows the range of airflow productivity when differential pressure is changing from maximum meaning to 0. Maximum airflow productivity is lesser the mark (400 m^3/h).

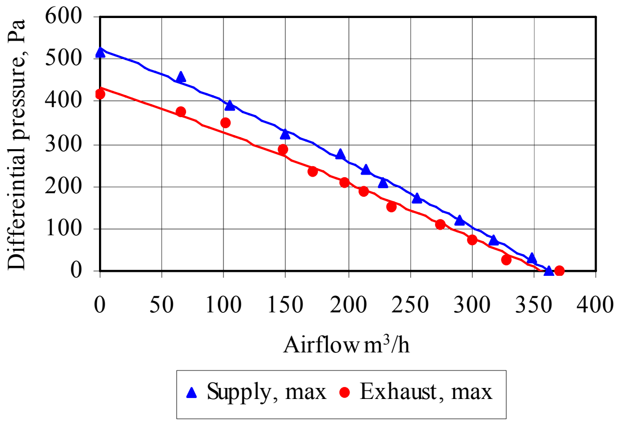

Fig. 3 Dependence between airflow rate and differential pressure (required max airflow rate 400 m^3/h)

Fifty measurements of airflow productivity were performed. They were grouped into clusters, completed of 5 individual measurements (Table 2). Fig. 4 shows the diagram of average airflow dimension before process correction. This diagram shows that the average airflow productivity is lesser the mark.

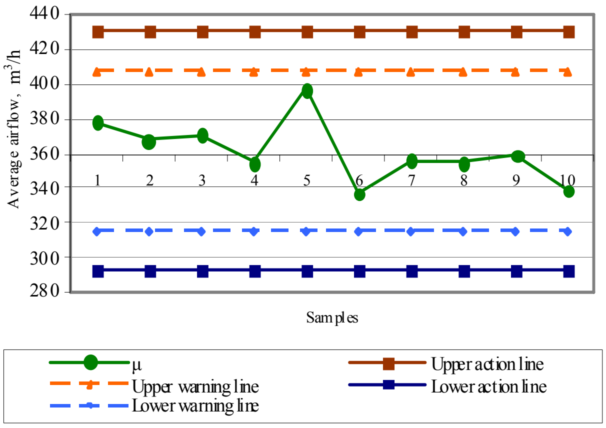

Fig. 4 Diagram of average output airflow productivity dimension before process correction

Average meaning of the airflow productivity must be 400 ± 20 m^3/h. Diagram of the average output airflow productivity shows, that the average meaning is 360 m^3/h. That means that these products are not working according to the requirements and are not suitable to be delivered for the customers.

Table 2

Maximum airflow rate capacity before process correction

	Nr.	1 sample	2 sample	3 sample	4 sample	5 sample	6 sample	7 sample	8 sample	9 sample	10 sample
400 m^3/h ±20 m^3/h T=40m^3/h	1	420.0	400.0	455.0	315.0	397.0	310.0	355.0	300.0	310.0	300.0
	2	390.0	310.0	400.0	410.0	398.0	355.0	345.0	325.0	325.0	315.0
	3	320.0	390.0	320.0	380.0	330.0	320.0	310.0	360.0	350.0	320.0
	4	340.0	330.0	330.0	360.0	400.0	400.0	380.0	400.0	450.0	410.0
	5	420.0	410.0	350.0	310.0	320.0	300.0	390.0	390.0	360.0	350.0
μ		378.0	368.0	371.0	355.0	369.0	337.0	356.0	355.0	359.0	339.0
R		100.0	80.0	135.0	100.0	80.0	100.0	80.0	100.0	140.0	95.0
σ		41.183	40.199	50.239	38.210	36.078	36.551	28.178	37.947	48.826	39.038

Fig. 5 presents dimension 400 ± 20 m^3/h range values before process correction. Testing results obtained are not suitable (point 5) because it is over warning line. Standard parts of the recuperators were changed and experiments were repeated. Meanings after displacement of standard parts show better result, but it is not proper.

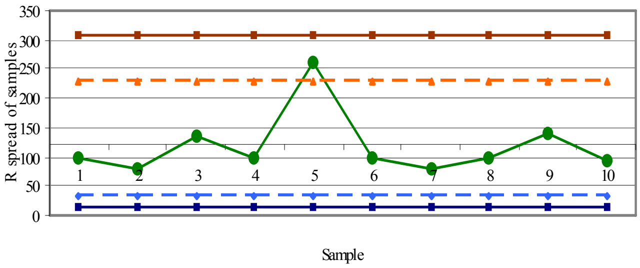

Fig. 5 Diagram of dimension 400±20 m^3/h range values before process correction

Fig. 6 presents the diagram of average airflow dimension after replacement of standard parts. It shows that the average meaning is good, but the process is not steady, meaning in point 10 reaches upper action line. After such correction, results are better, but not proper.

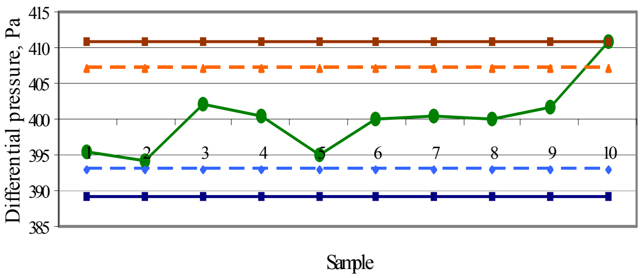

Fig. 6 Diagram of average output airflow productivity dimension after replacement of standard parts

Second step was precision investigation of recuperator construction parameters. Design features of recuperator's housings were examined. Holes of the recuperators' housing were measured. Diameter of the holes must be 7 ± 0.1 mm.

Fig. 7 illustrates the diagram of average diameter of the holes before process correction. It shows, that meanings are not satisfactory – meaning in point 4 is below the lower action line, meanings in points 5 and 8 – are over the warning lines. The process is not statistically controlled, so we suppose, that variance of constructional parameters has influence on airflow productivity of recuperators, because loses of airflow start up because of nonquality housing plates.

The means to improve airflow productivity were sought – other ones replaced standard parts, precision of construction parameters was investigated. The diagram of average airflow dimensions after process correction is shown in Fig. 8. The process after correction became statistically controlled – meanings are arranged in even distribution, average meaning is in the range of tolerance, values in different points do not exceed warning lines (Fig. 8).

The dependence between supply-exhaust airflow productivity and differential pressure of recuperators with required airflow productivity of 400 m^3/h after process correction is presented in Fig. 9.

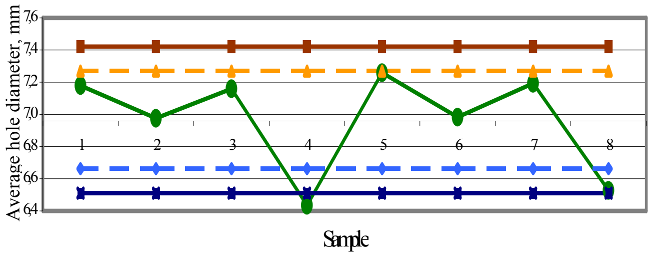

Fig. 7 Diagram of average holes' diameter of housing plates

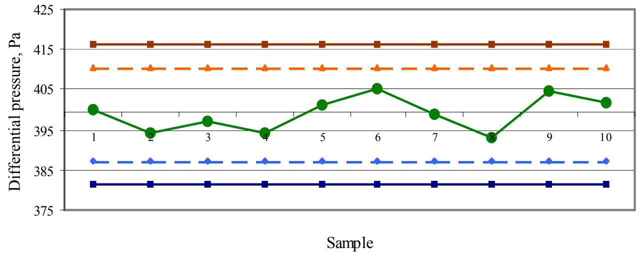

Fig. 8 Diagram of average output airflow productivity dimension after process correction

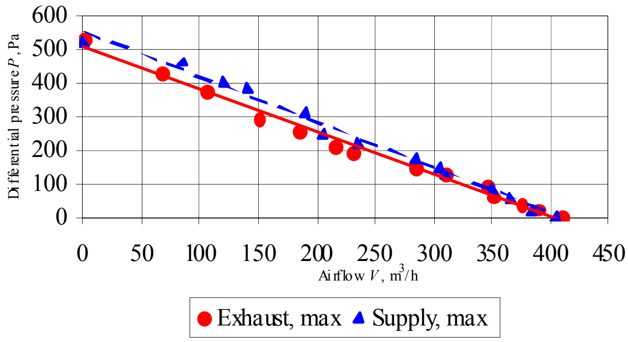

Fig. 9 Dependence between airflow and differential pressure recuperators (400 ± 20 m^3/h) after process correction

Airflow productivity, obtained after improving parameters of design features (holes for cramp of recuperator housing), meets the requirements.

4. Discussions and conclusions

The research in this paper presents quality impact to the product design properties and characteristics. New product development is a permanent solution at contradictions arising among product properties and manufacturing cost. Latter parameters destine the success of a developed product. Product development and manufacturing cost have a significant influence on the total product value. The developed methodology to verify and estimate product quality in its life cycle phases can help to improve product quality in early development stages.

The method that has been described in this paper accomplishes the objective of this research. However, this is not the only method currently available. It has its advantages and disadvantages. The advantages are several: the originated methodology simultaneously verifies errors and appraises their probability in product and process development and manufacturing stages. The mathematical formalization helps fixing errors probability in all product life cycles. The principal shortcoming of the developed methodology is intangible acquirement of product and process design factors influencing the errors and imperfections. Briefly, we can conclude as follows:

1. the created methodology to verify and estimate product quality in its life cycle phases helps to appraise errors at the early product development stage;
2. it is able to define errors and defects probability in product and process development and manufacturing phases that helps to avoid them;
3. the mathematical formalization of the developed methodology increases chance to implementation.

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KOKYBĖS ĮTAKOS KONSTRUOJAMO GAMINIO VERTEI IR CHARAKTERISTIKOMS TYRIMAS

R e z i u m ė

Straipsnyje pateikta metodologija, kuri leidžia nustatyti ir įvertinti gaminio kokybę kiekvienoje jo gyvavimo ciklo fazėje. Nustatomos ir įvertinamos klaidos ir jų atsiradimo tikimybė gaminio ir gamybos proceso kūrimo stadijose, taip pat žmogaus veiksnio įtaka klaidų atsiradimui. Sukurta matematinio formalizavimo metodika klaidų visumos kitimui visose gaminio gamybos stadijose įvertinti leidžia nustatyti klaidų kaupimosi įmonėje priežastis. Sukurtos metodikos efektyvumas patvirtintas eksperimentiniais tyrimais.

D. Čikotienė, A. Bargelis

RESEARCH OF QUALITY IMPACT TO THE PRODUCT DESIGN PROPERTIES AND CHARACTERISTICS

S u m m a r y

This paper deals with developed methodology to verify and estimate product quality in its life cycle phases. It is able to act and appraise the errors and their probability in product and process development and production stages, and influence of the human factor to originate errors. The developed mathematical formalization of an aggregate error mutation among all product development phases helps to find the reasons of errors accumulation in organization. The created research contains a case study.

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ КАЧЕСТВА НА СТОИМОСТЬ И ХАРАКТЕРИСТИКИ КОНСТРУИРУЕМОГО ИЗДЕЛИЯ

Р е з ю м е

В публикации представлена методология, позволяющая установить и оценить качество изделия на каждой фазе цикла его существования. Устанавливаются и оцениваются ошибки и вероятности их выявления на стадиях проектирования изделия и развития производственного процесса, а также влияние человеческого фактора на возникновение ошибок. Создана методика математической формализации изменения количества ошибок на всех стадиях развития изделия позволяет установить причины накопления ошибок на предприятии. Эффективность созданной методики подтверждена экспериментальными исследованиями.

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