ISSN 1392 - 1207. MECHANIKA. 2011. 17(6): 637-642

Research of solidity and reliability of mass customised products in a competitive manufacturing system

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crossref http://dx.doi.org/10.5755/j01.mech.17.6.1007

1. Introduction

1.1. Product customization in modern manufacturing system

The manufacturing of 21st century is globalized and integrated in development of products, processes and production delivery. The compliance of various technologies and activities are oneness of different manufacturing organizations, which are fighting for survival in globalized markets and competitive manufacturing environment. The competitive manufacturing organization must enhance the variety of product types, production flexibility and quality, and decrease the manufacturing cost and production volume also finding other ways to understand the customer wishes. The customizing products and services are among the most critical means to deliver true customer value and achieve superior competitive advantage. The challenge is not to customize products and services in itself – but to do it in a profitable way [1]. The more effective tool of mass customization is a product configuration system of achieving and implementing this in practice and offering a reduction of the lead time for products and quotations. It also achieves faster and more qualified responses to customer inquires, fewer transfers of responsibility and fewer specification errors, a reduction of the resources spent for the specification of customised products, and the possibility of optimising the products according to the customer requirements.

The involvement of customers in this procedure as soon as possible in the early development stage can help to activate the products customization process. Leaving the product open to customization will allow customers to change the design content of the item for their own purchase. Customer customization of a producer's products does not impact the design content of the originally posted item. It simply allows for the customer to create a personalized variation of the initial product design for different users. Products customization is based on their modular design and development of configuration systems. The art of design the customized items is the capability to create a large number of product alternatives applying developed modules of basic seller's products and not limited number of standard components. This procedure involves analysis of product range, object-oriented modelling of product conception structure and design of itself product, implementation and maintenance. The solidity and reliability of customised products have more problems in manufacturing and quality control procedures comparing with products of unique design structure because they are becoming more complicated in both cases point of view applying technology and management. The process and tooling though become more complicated in the latter case but customized products market shearing is bigger and steadier.

1.2. Requirements of products solidity and reliability

The main purpose of manufacturing improvement is to satisfy the customers' requirements developing new innovative products and processes through satisfying the requirements of quality and safety standards. The survive of competitive organization is manufacturing of required product with low cost, which can be reduced, when the product is qualitative and is provided to customer without need of rework or condemn it to market.

The products safety evaluation in Lithuania is performed according to regulations of Product safety law. There is indicated that if the product is produced for the market, it must be safe. Every product's group has specific methods for their solidity and reliability evaluation at the testing laboratory according to the requirements of appropriate European standard. European standards for transport means testing including bicycles are used as Lithuanian standards and they are provided with status of national standards [2 - 4]. The manufacturer can chose more testing methods and means for safety warranty, which are noted at the directive 2001/95/EB of European Union for common product safety.

The objective of this paper is development of a methodology for mass customized products solidity and reliability testing, when products have been produced with minimal cost and high quality. The appropriate manufacturing network for competitive customized products has been created and case study of bicycles solidity and reliability testing methodology and results has been illustrated.

2. Development of a manufacturing network for competitive customized products

The strategical and structural creation of competitive hybrid manufacturing systems (HMS) network as a small / large size approach for development and production of innovative mass customized products is created (Fig. 1). It uses high skilled humans (engineers and operators), CNC machine tools, software and hardware and appropriate interfaces. New HMS structure based on improved collaborative tasks between humans, robotics and machines versus flexible machine stations (FMS) has better future perspective looking for indices of competitiveness and productivity. HMS is able to develop, produce and delivery products and components with competitive price and quality, because it has a high flexibility index and processes capability. Created HMS network is able to apply *make or buy* strategic approach and seek an excellence of operational performance in manufacturing because network partners have high specialization level, experience, skill and effective interfaces. At the centre of a network is products' assembling company, which collaborates with products developers, suppliers of products' original parts, standard parts and assembling process materials, research centres and universities and customers of developed and produced products.

A developer of products being in created network applies concurrent engineering approach [5] and seeks better communication and partially overlapped activity with customers, product's parts and material suppliers, and research centres and universities. The interfaces for this aim are created and used. They help to use product's modular design and design for manufacturability and easier assembling (DFMA) methods. Every design feature (DF) of a product must be examined at the early product and process development stage on a focus of customer, designer and manufacturer because they have different point of view. Designer creates product properties and characteristics applying various DF and seeking different variety, dimensions, size, volume and qualitative-quantitative parameters while manufacturer looks for competitive process. There are, therefore, some conflicts and trade-offs, which must be solved during early design stage of product and process employing integrated collaborative work approach among various HMS network partners. Going to mass customization of a product is very urgent correct modular product design principle, which is essential in collaborative design because it helps:

- to clarify customer requirements,
- to select and find technical solutions,
- to generate and evaluate concepts
- to improve an every module.

The systematic approach instead well known trials and errors method has been used for innovative products and processes development in generated HMS network. The knowledge base (KB) structure for acquiring best practice, facts and rules for conclusion formulation is created. The relation between man and unmanned work was classified and criteria proposed. New products developers collaborating with University Technological Experiments Centre originated rules and proposals when robotics or assembling machines are better to use versus a manual work. These rules and guidelines were created in virtual environment operating with technological models and appropriate mathematical formalization [6] when several assembling processes, their alternatives and machines have been examined and data systematized. For optimal utilization of a material aim function was developed that has been used for optimising the consumption of various materials

$$k = \frac{\sum_{i=1}^{n} (M)_i \; p}{\sum_{j=1}^{m} N_j} \rightarrow 1.0 \qquad (1)$$

where k is the coefficient of material consumption; M is the mass of work piece, kg; p is the number of work pieces; N is the mass of raw materials used for production of M, kg.

Materials consumption rate is closely related with product properties and characteristics; when the aim is getting an easier mass product with sufficient solidity and reliability, it is necessary to use better materials or vice-versa. These problems are to be solved at the early new product development stage with customers' discussions also taking into account product manufacturing cost.

Make or buy strategy requires an effective supplier selection process for created HMS network. As a supplier selection function the qualitative-quantitative factors has been used and a trade-off between tangible and intangible factors as essential techniques in selecting the best supplier were exploited [7]. Applying these criteria, the available suppliers of parts and materials have been ranked and their data base (DB) was created. Wide collaboration with customers in different countries and organizations, moreover, their involvement in base product customization process at the early product development stage helped to increase products types' variety and new ideas finding.

The solidity and reliability of mass customized products are very urgent for transport means, as driving safety is the most important requirement. The case study of this paper examines Lithuanian bicycles manufacturer *X* as typical representative of HMS, which collaborating with University Technological Experiments Centre and other partners created competitive and innovative company.

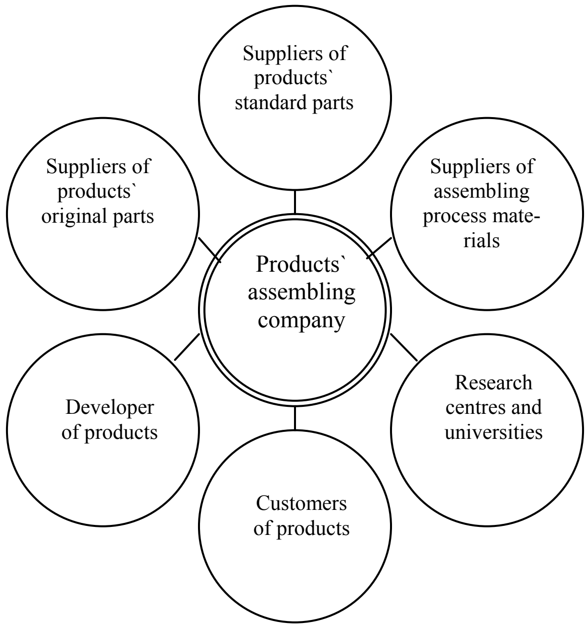

Fig. 1 Network of a competitive hybrid manufacturing system

3. Research results

3.1. Research methodology

The research presented in this paper pertains to the manufacturing science which is the applied research aiming at the contribution to both theoreticians and practitioners. The latter usually do not care of the research approaches used, as long the results help them solve practical problems. The methodology used in this paper is an exploration how well fit the theoretical model of manufacturing system in practice and creation of the methods and tooling for testing solidity and reliability of products.

The performed research is closely linked with the activity of a large Lithuanian enterprise *X* that produces bicycles. Peculiarity of this enterprise is that bicycles are assembled, painted, tested and validated in Lithuania, but most of the materials, parts and components are purchased from suppliers located in various companies and countries mostly outside of Lithuania. It produces now close to 3000 various types of bicycles including bicycles for children, urban and tourist, mountain bicycles and even special bicycles for sport race. The yearly output of bicycles at the enterprise is more than 40.000 units. Most bicycle types are made in small batch volumes according to the customers' orders.

As things stand the shareholders of the company *X* decided systematically analyze the nonquality and manufacturing cost problems inside and outside of the company, and initiated close collaboration with academia. The Technological Experiments Centre at the Siauliai University was established for well-rounded experiments of bicycles and their parts and components. All tests of quality control are performed according to the requirements of standards [2-4]. Tests are accomplished on more responsible parts of bicycles from every supply lot of products according to the quality management requirements [8]. These tests showed which parts, sections, assembling units and so on are improper and where risk of breaking can appear. An appropriate stands for testing solidity and reliability of mass customized bicycles and their parts have been developed and implemented.

3.2. Testing results

Part of tests, accomplished at the Technological Experiments Centre during the period 2008-04-01 – 2011-01-01 is presented in Table. The data of only weakest parts of bicycle, where the risk of breaking is the highest according to test results are presented in this Table. Parts of bicycles, which didn't break during the tests detected that these parts are substantial, reliable and quality is quite enough. Table shows most vulnerable spots of bicycles.

Table

List of tests with bicycle parts and assembled products

Name of test	Number of tests	Below standards
Dynamical tests of assembled bicycle	84	38
Tests of brakes	70	31
Dynamics tests of pedals	14	2
Dynamics tests of carriers	52	24
Tests of front fork	44	12

Total quality of the assembled bicycle depends on reliability and quality of all parts of bicycle [9]. As shown in the Table, the weakest parts of tested bicycles are brakes, carriers and front fork. The different suppliers of HMS network deliver original and standard parts for bicycle assembling company *X*. It permanently does quality control and analysis of reliability the every supplier in accordance of standard deviation average of errors and defects [10]. The suppliers are ranked on this index and worst of them are rejected from HMS network.

Brakes of a bicycle are one of the most important parts to ensure safety of bicyclist, so this testing is very important to ensure, that brakes of bicycle will work properly.

The visual and functional evaluation of brakes is performed. This is performed for assembled bicycle (Fig. 2). Handle of the handbrake is loaded with 300 N for min 15 seconds. This load is concentrated 25 mm from the end of break handle. The test is repeated for 10 times.

Fig. 2 Test facility for brake testing

The footbrake test is also performed for assembled bicycle. When the footbrake is used, the angle between drive and brakes near the pedal can not exceed 60°, when the tree of pedal is load with torque of 14 N.

Parts of drive and bicycle systems can not disengage or break during the testing. A pedal in horizontal position is loaded with vertical force of 1500 N every other second. Such testing is performed 10 times.

The special attention for the quality of braking has been paid designing brakes. Generally, for brakes design lever transmissions with the optimized transmission ratio and number of parts have been used. Ratio of the transmission must be high and the number of parts must be low. Analysis of different lever constructions exhibited that the most effective is "V-Brake" design – ratio of the transmission for this design is the highest in comparison with other lever design alternatives. The most effective design is pointed in Fig. 3.

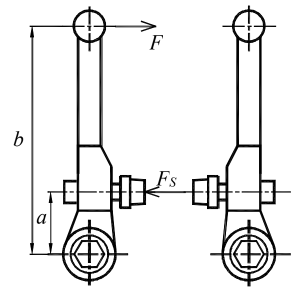

Fig. 3 V-Brake design; F is a force from brake handle, N; F_s is a force of lever transmission, N

Ratio of the transmission for this design is high: $K = b/a = 3.0 - 3.5$. Also the number S of parts in this design is not high, $S = 15$. It was stated, that such design is simple, but works effectively.

Another reason of brakes nonquality is material, used for the brake slipper. Influence of the brake slipper for the quality of braking is very high. Frictional force F_{fr} (N), between the brake slipper and wheel rim

$$F_{fr} = F_S \ \mu \tag{2}$$

where F_S is force of lever transmission, N; μ is coefficient of friction.

F_s depend on the force from brake handle F and on the transmission ratio K. Investigation of the contact between hard surface (wheel rim) and elastic surface (brake slippers) was performed. Elastic surface is pressed to the hard surface with force F_s. Resilience upstarts in the area of contact between elastic surface and hard surface. The value of this resilience depends on average strain σ (MPa), which can be determined

$$\sigma = \frac{F_S}{A} \tag{3}$$

where A is total area of the contact, m^2.

When brake slippers are slipping on wheel rim at the fixed speed, frictional force will be composed of two components

$$F_{fr} = F_{adg} + F_{hyst} \tag{4}$$

where F_{adg} is adhesive component and F_{hyst} is hysteresis component.

Adhesive component is clear defect of the surface and hysteresis component is volumetric expression, which depends on elastic features of elastic surface. The equation (4) is divided by force of lever transmission F_S, then it can be written

$$\mu = \mu_A + \mu_H \tag{5}$$

where $\mu_A = \dfrac{F_{adh}}{F_S}$ is adhesive friction coefficient;

$\mu_H = \dfrac{F_{hyst}}{F_S}$ is hysteresis friction coefficient.

Both of these components are the result of energy loss. This energy raises temperature in the line of two bodies contact. Conditions during the experiment have a big influence on coefficients μ_A and μ_H. When the wheel rim is very smooth and the brake slippers are not very elastics, the hysteresis component is going down. Adhesive component is reduced by the water, which is passed into friction zone. For the most effective breaking the brake slippers must be made from two different materials with different hardness to secure sufficient frictional coefficient during the braking on dry way and on sloppy way as well.

When effectiveness of the brakes is tested, the deceleration of braking is calculated according to the equation

$$a = F_{Br} / m \tag{6}$$

where a is value of the braking deceleration, m/s^2; F_{Br} is force of the braking, N; m is mass, kg.

For testing of adults bicycles is used 100 kg mass, for childish bicycles – 60 kg.

Tests of the braking in dry and wet conditions are performed. Fig. 4 shows variation of performances of braking during the testing of front wheel in dry conditions.

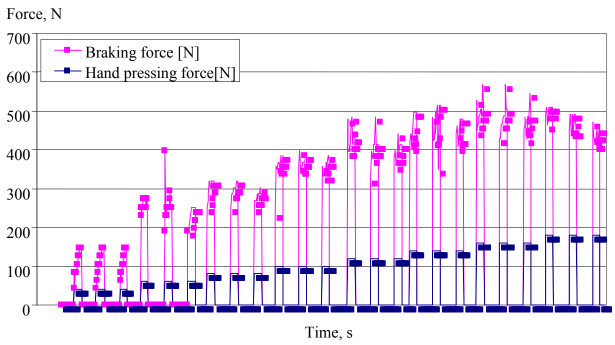

Fig. 4 Variation of braking force during the brake testing in dry conditions

The results of braking force testing of the same wheel in wet conditions are shown in Fig. 5.

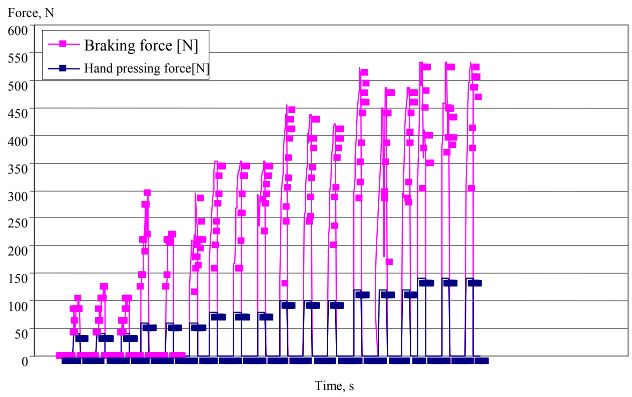

Fig. 5 Variation of braking force during the brake testing in wet conditions

The value of breaking performances in dry conditions must be more than 3.4 m/s^2 for front wheel and more than 2.2 m/s^2 for back wheel. In wet conditions this meaning must be respectively 2.2 m/s^2 and 1.4 m/s^2.

Testing of carriers is performed loading it with 25 kg in the middle of carrier. Cycle is repeated 100.000 times. Different breaks were noticed after testing: one side of support snapped of after 82394 cycles of testing.

Another carrier was broken after 44370 cycles - the horizontal part of front support break down. One more the carrier was broken after 13552 cycles – the upper part of the carrier break down. The main reason of carrier either any other part failures which has applied welding during solidity and reliability testing is nonqualities during welding process, as wrong welding facility, work regimes and human errors seeking less manufacturing cost and high productivity [11]. The ways avoiding welding process errors and defects seeking quality, productivity and least manufacturing cost is proposed in many research papers; one of them is presented in research works of Lappeenranta University of Technology, which is a partner of Lithuanian industry and academia in manufacturing science field [12].

The testing-bench for dynamical testing of front fork is shown in Fig. 6. The front fork of bicycle is loaded with the force of 600 N, for 100.000 cycles. If there appear any cracks or fork breaks during the testing, it can not be used for assembling of the bicycle. Similar testing is performed for all main parts of the bicycles.

Fig. 6 The front fork on the testing-bench

Front fork is tested using the load of 600 N, this is repeated for 100.000 cycles. Different breaks were noticed after the testing: fork was broken after 65057 cycles of dynamical testing with 600 N load (Fig. 7). Break of the front fork in this part was noticed most often during the testing of nonquality forks, which do not stand during the testing. Differs only the number of cycles – a part of forks was broken after a long time of testing, another does not stand for a long time of loading. The number of cycles differs from 27647 to 88741 cycles during the period of testing.

Fig. 7 The fork after 65057 cycles of testing with 600 N load

In the other cases front fork achieves different cracks after the testing. Cracks are noticed in one or both sides of the fork (sometimes cracks are noticed when testing is finished, sometimes – after different number of testing cycles).

When a part of the bicycle is broken during the testing, it is replaced with another one and it is tested repeatedly. When testing results are satisfactory, after the testing the part can be used for assembling of a bicycle.

Dynamical testing for assembled bicycle is performed according to DIN plus program for different bicycles. Different parts of assembled bicycles are loaded with appropriate loads and the bicycle starts to run on the stand with reels. All parts are watched during the testing and places of cracks are fixed (Fig. 8).

Fig. 8 Break of both frame tubes after riding of tourist bicycle distance of 230 km on stand with reels

4. Discussions and conclusions

The research in this paper presents a network of HMS for mass customized products development, production, assembling, testing and validation. Particular attention has been made on creation of testing methodology, testing tooling and techniques for solidity and reliability of transport means, in particular bicycles. The new innovative product and process design is the essential task of the manufacturing organization that defines its productivity and effectiveness. Cross-discipline and inter-departmental collaboration inside and outside of a HMS is an effective way finding new innovative solutions and ideas for products and processes development.

The methodology of HMS net creation and solidity and reliability testing of products that has been described in this paper accomplishes the objective of this research. It has several advantages: the originated testing stands for customized products have been developed and validated. The created testing methodology is able to estimate the solidity and reliability of itself product and its parts. Briefly it is conclude as follows:

1. The created manufacturing network for competitive customized products is able to develop and produce competitive mass customized products with less production cost.
2. The created product's solidity and reliability of testing methodology and facilities help to disclose the regularity of design and manufacturing errors and defects; the combination of applied materials, design features of parts and customized product type diminish manufacturing cost and increase quality.
3. New human-robot interactive cooperation in advanced HMS with motivated employees and their satisfaction of work can increase quality and productivity and reduce manufacturing cost.

4. Knowledge-based innovation in HMS processes, products and deep collaboration is a new alternative going from cost cutting to knowledge acquisition and value adding.

Acknowledgment

This research was partially supported by contracts with industry No. 06351, 2008; No. 06164, 2009 and No. 0626, 2010.

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MASIŠKAI PRITAIKYTŲ INDIVIDUALIAM VARTOTOJUI GAMINIŲ STIPRUMO IR PATIKIMUMO TYRIMAS KONKURENCINĖJE GAMYBOS SISTEMOJE

R e z i u m ė

Straipsnyje aprašytas gaminių, masiškai pritaikytų individualiam vartotojui, stiprumo ir patikimumo tyrimas konkurencinėje gamybos sistemoje. Sukurta hibridinės gamybos sistemos (HMS) struktūra, padedanti užtikrinti gamybos kokybę mažiausiomis sąnaudomis. Atlikti dviračių bei jų dalių tvirtumo ir patikimumo bandymo įrangos bei metodologijos tyrimai ir gautos atitinkamos išvados. Išvystyta tyrimo metodologija ir įranga yra patvirtinta gamybos įmonėje.

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RESEARCH OF SOLIDITY AND RELIABILITY OF MASS CUSTOMIZED PRODUCTS IN COMPETITIVE MANUFACTURING SYSTEM

S u m m a r y

This paper deals with research of solidity and reliability of mass customized products in a competitive manufacturing system. The network of hybrid manufacturing systems (HMS) for production quality products with least cost is developed. A case study as methodology and testing facility for bicycles and their parts research of solidity and reliability is illustrated and appropriate conclusions are made. The developed testing methodology and tooling are validated in industrial company.

Received February 02, 2011
Accepted November 30, 2011