Framework of consideration productivity for assembling operations in sheet metalworking

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1. Introduction

The manufacturing environment during past ten years has changed and competition among organizations has increased unprecendently. In the most design and manufacturing organizations today, there is often a great disparity in the use of computer tools achieving higher productivity. The software and hardware they have acquired over the years can at best be described as firm wares stand – alone compute islands [1]. The level of integration across departments is very poor in particular marketing - design – manufacturing chain. Sheet metal design is very sensitive to the designer decision for product geometrical form and joint of separate parts in assembly unit with the possibilities of manufacturing division. There are many methods of sheet metal parts production because today the companies have various facilities from mechanical or hydraulical presses and dies to various CNC machines for cutting, bending and punching [2].The main problem exist how to choose the facility which could help to increase the productivity of work from the beginning stage of a new product design to the delivery to customer with minimum manufacturing cost and time.

The main objective of this research is to develop a productivity consideration framework in assembling operations of sheet metalworking. Assembling operations of sheet metalworking in most cases are carried out manually with the small and seldom exceptions. It is related with the lack of assembling machines and appropriate robotics and, therefore, the productivity level depends on the right selection of the feasible assembling methods and machines. The framework developed can help the designer to make the best decision and save the cost of metal consumption and assembling time.

Research novelty of this paper is grounded on the creation of intelligent functional knowledge based models of new products manufacturing cost optimization at the early design stage. The framework can change the traditional work of engineer and help to quicken the delivery of new products to the marketplaces.

2. Productivity calculation methodology in sheet metalworking

Different requirements of productivity are fixed for the production of sheet metal prototypes and the products for batch production. New prototype of the sheet metal product design is devoted for the negotiations among customers, designers and manufacturers. In this area of sheet metalworking the delivery time dominates and the requirements for cost and productivity level are not so high. Quite another situation is in batch or mass production of sheet metal products when product prototype is chosen. Overall productivity definition as the value of cumulative gain or loss [1] is used. A higher level of productivity in one specific department or discipline is not a good measure. Productivity means creating concepts that positively impact the whole system - both the upstream and downstream operations. The overall productivity N is expressed

$$N = O / E \tag{1}$$

where O is throughput of an organization, Lt; E is the operating expenses, Lt.

The main possibility to increase the productivity of a company activity is engineering resource automation [3].The positive result of productivity is when

$$\begin{aligned} &N > 1 \\ &O \to max \\ &E \to min \end{aligned}$$

Throughput in this context is defined as useful outputs, that customers can use, i.e. end product or services completed in a given period of time. In other words, scrap or waste is not a measure of productivity. Throughput O is calculated

$$O = \sum_{i=1}^{n} \left(P g \right)_i \tag{2}$$

where P is a product worth, Lt; g is the production volume in a given period of a time; n is the number of production variety.

The target of each organization is to achieve the condition $O \to max$. It is available producing small vol-

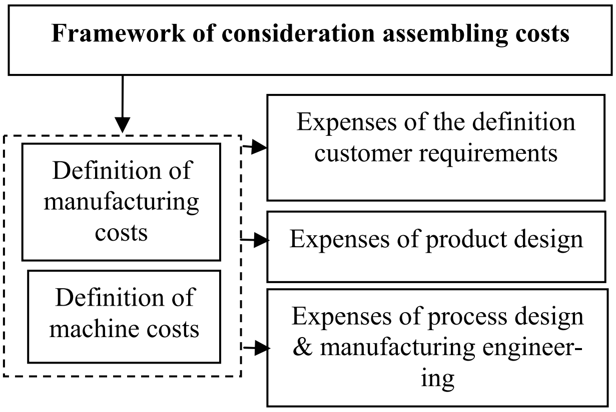

Fig. 1 Framework structure of assembling costs consideration in sheet metalworking

ume products which worth is high or simple products when production volume is big. On the other hand mix production combination is available, but both above-mentioned possibilities demand many efforts of manufacturers: high worth products often are complex and demand scrupulous design and manufacturing engineering, while high volume manufacturing - effective production process and perfect management of a work. These conditions are related with high investments and many problems arise achieving other condition $E \to min$. In the first step E can be expressed as an abstraction function

$$E = f_1(t_1, t_2, t_3, t_4, t_5) \quad (3)$$

where t_1 is the expenses of customer requirements definition; t_2 is the expenses of product design; t_3 is the expenses of process design and manufacturing engineering; t_4 is the expenses of machine costs; t_5 is the expenses of manufacturing costs.

Our object is the consideration of t_4 and t_5 costs for assembling jobs in sheet metalworking. The values of the rest members in equation (3) which are conditionally constant have been acquired from companies DB. The framework for the consideration of assembling cost of sheet metal design has been developed (Fig. 1).

The objective of the framework is to help designer to design low cost products of sheet metal. The framework has been developed on the base of our previous investigation [4] and common work with the industry. The focus is paid on assembling operations in sheet metalworking because many alternatives of available methods and machines exist and designers often can not define the priorities in particular at the early design stage.

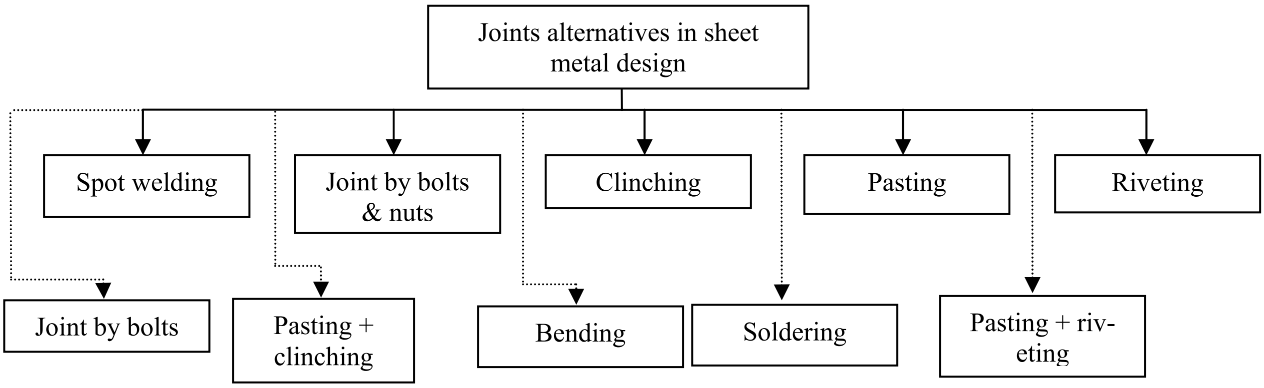

Fig. 2 Classification of assembling methods in sheet metalworking

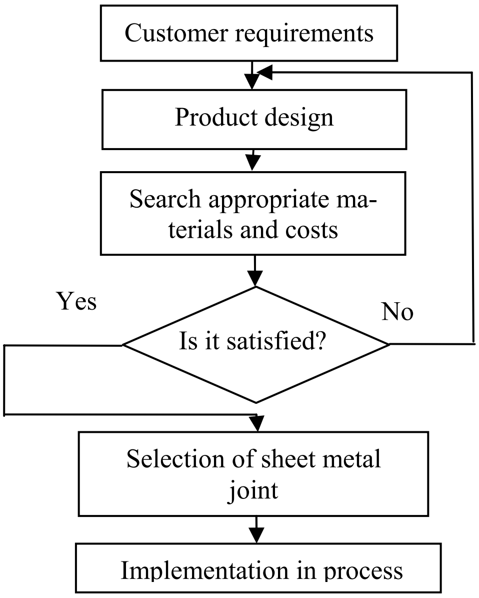

Fig. 3 Algorithm for assembling costs calculation in metalworking

The intelligent part of the framework for assembling costs definition in sheet metalworking consists of three modules: 1) classification of assembling methods (Fig. 2) with their advantages and disadvantages; 2) practical evaluation of each assembling method (Table 1);
3) intelligent algorithm and appropriate software for the calculation of assembling costs (Fig. 3).

There are different practical solutions to join two metal sheets. All these solutions have similar function, but assembling costs are totally different. Spot welding, joining by bolts and nuts, bending, riveting and clinching are widely used for mechanical components, and pasting and soldering – in electronics production. The analysis of available joining methods in sheet metalworking showed many advantages of clinching [5]. It is practicable for joint sheet metal parts of complex geometrical form in high volume production, but it does not fit for the parts of big dimension [6].

The production volume, used material, product size and geometrical form define the priorities selecting the possible alternatives. Later from the selected 2, 3 alternatives, the best solution according to assembling costs index is chosen. Manufacturing costs in Global Manufacturing (GM) is one of the main factors to win orders [7]. Tables 1 and 2 show practical evaluation and recommendation of assembling methods in sheet metalworking and electronics industry. We have developed an intelligent functional model for integrated design of sheet metal products and processes using DFX (design for parameter X) approach taking into account our early research [8, 9]. It is assigned to the early design stage of a new sheet metal product. The product should be optimized at an early design stage not only in terms of the parameters of its performance and functions, but in terms of its effortless low – cost manufacture and also its assembly. The developed model is integrated in the framework of productivity consideration of the assembling operations in sheet metalworking (Fig. 1).

Calculation algorithm of assembling costs in metalworking used in the developed intelligent model is presented in Fig. 3. Parametrical functions for forecasting assembling time of one sheet metal joint have been developed in Table 3. Coefficients k_1-k_5 of loading – unloading time per assembling unit depend on used assembling time and dimensions of joined parts. We have considered and classified the joined parts into 2 groups: 1) until 750x750mm and 2) more than 750x750, and joining methods as well as into two groups: 1) clinching & spot welding and 2) screwing & riveting. The value of some Lithuanian sheet metal design companies loading – unloading data and available analogues data in other sources [2, 10] for statistical processing of value the coefficients k_1-k_5 have been used. The results of a statistical processing are presented in Table 4. The definition of assembling time for various joint methods in metalworking is presented in Fig. 4. The investigation outcome with some external sources [10] was compared.

Table 1

Practical evaluation and recommendation of assembling methods in sheet metalworking

Joint Material	Clinching	Spot welding	Joint by bolts & nuts	Pasting	Riveting
Aluminum	Yes	No	Yes	Yes	Yes
Copper	Yes	Not	Yes	Yes	Yes
Low carbon steel	Yes	Yes	Yes	Yes	Yes
Stainless steel	Yes	Not	Yes	Yes	Yes
Thickness, mm: 0.80	Yes	Yes	No	Yes	Yes
1.00	Yes	Yes	Maybe	Yes	Yes
1.25	Yes	Yes	Yes	Maybe	Yes
1.50	Yes	Yes	Yes	No	Yes
2.00	Yes	Yes	Yes	No	Yes
Sheet: Painte	Yes	No	Yes	Maybe	Yes
Galvanized	Yes	No	Yes	Maybe	Yes

The parametrical function using abstraction (3) for cost definition $E1$ of assembling operations has been developed

$$E1 = \sum_{i=1}^{n} \left(At \right)_i + \sum_{j=1}^{m} W_j + D \tag{4}$$

where A is the equipment depreciation and maintenance costs per hour, Lt; t is metal sheet product assembling time, h; W is assembling labour cost, Lt; D is additional cost of assembling materials.

Parametrical functions (1), (2) and (4) are included in the developed framework. According to this framework the intelligent model of productivity consideration of assembling operations in sheet metalworking is created on the software level with appropriate KB.

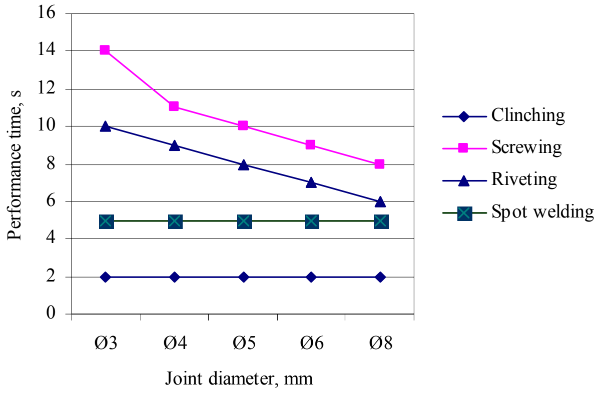

Fig. 4 Assembling time of one joint point

Table 2

Properties and additional requirements of various joint methods in sheet metal design

Joint Properties	Spot welding	Joint by bolts & nuts	Clinching	Pasting	Riveting
Corrosion	High	Little	Little	None	Little
Edges-burring	None	Edges	None	None	None
Process combined to pasting	Poor	Possible	Optimum	--------	Possible
Joining consumables required	None	Nuts, bolts, roves	None	Glue	Rivet
Additional working processes	Surface cleaning	Drilling, screwing	None	Pressing	Drilling
Energy consumption	Very high	Very high	Very little	High	High
Cost per joint	High	Very high	Very little	High	Very high

For generating the productivity indices the knowledge base (KB) structure of assembling operations with the part of rules has been developed. The first version of software has been programmed using Microsoft Excel program. The model generates a productivity index of each product assembling alternative.

The developed intelligent model has been tested both in laboratory and industry. The model has generated a number of alternatives of the assembling plan for various products. The verification and validation tests for the developed model have been conducted in the laboratory. Some results of model work are presented in the next paper section.

3. Case study

Testing of the developed framework testing for various joint methods in sheet metalworking was carried out. Fig. 5 presents assembling time distribution while Fig. 6 – assembling cost distribution of 1000 joint points for different joint methods.

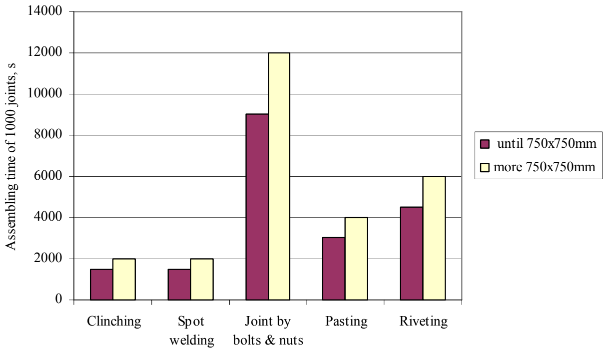

Fig. 5 Assembling time distribution for different assembling methods

The dependencies of productivity of different assembling methods for two types of product complexity and the number of joint points are presented in Fig. 7. It illustrates that clinching productivity is highest while riveting productivity has smallest value for the selected products.

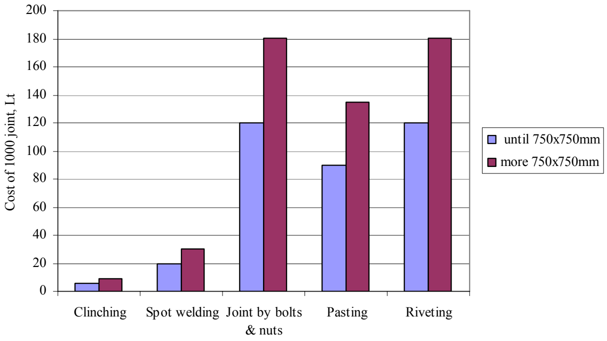

Fig. 6 Assembling costs distribution for different assembling methods

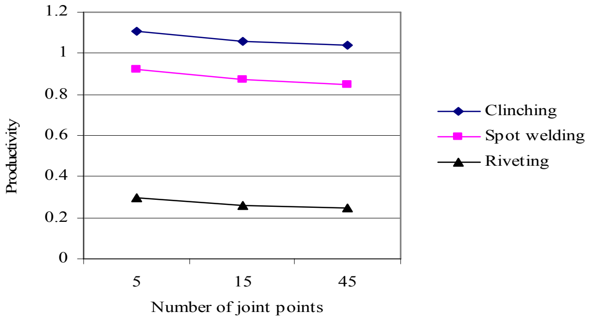

Fig. 7 Productivity dependencies on different number of joint points

Table 3

Assembling time of one sheet metal joint

	Joint	Assembling time of one joint	Notes
1	Spot welding	$t_{suv}*n*k_1$	t_{suv}-spot welding time n- spot number t_{sk}-drilling time t_{sus}-screw time t_{cl}-clinching time t_{nuv}-cleaning time for pasting t_{kl}-pasting time t_{su}-grip time z-processing area t_{kn}-riveting time k_1-k_5-coefficients of loading-unloading time per unit
2	Joint by bolts & nuts	$(t_{sk}*n+t_{sus}*n)*k_2=(t_{sk}+t_{sus})*n*k_2$	
3	Clinching	$t_{cl}*n*k_3$	
4	Pasting	$(t_{nuv}*z+t_{kl}*z+t_{su})*k_4$	
5	Riveting	$(t_{sk}*n+t_{kn}*n)*k_5$	

Table 4

The value of coefficients k_1-k_5

Assembling operation & coefficients k_1-k_5	Part dimensions	
	Until 750x750 mm	More 750x750 to 1500x1500mm
Clinching, k_1	1.4-1.6	1.9-2.1
Spot welding, k_2	1.3-1.5	1.8-2.0
Screwing, k_3	1.7-1.9	2.3-2.5
Pasting, k_4	1.1-1.3	-
Riveting, k_5	1.6-1.8	2.2-2.4

4. Further research

We are planning to investigate and to upgrade the structure of KB including more assembling processes types and data for sheet metalworking. The definition of the consumption time and resources for more precise customer requirements formulation and new product / process development are in our further research plan also.

5. Acknowledgement

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6. Conclusion

1. It was defined that minimum assembling cost has clinching and spot welding methods and maximum –

assembling by bolts & nuts, riveting and pasting.

2. The highest productivity has been fixed for clinching and spot welding methods, and lowest – for riveting joint of middle size (not more 750-750 mm) metal sheet design.

3. The diameter of joint point does not influence on assembling time while for riveting and joining by bolts & nuts assembling time decreases when the diameter increases.

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METALO LAKŠTŲ RINKIMO OPERACIJŲ NAŠUMO TYRIMO STRUKTŪROGRAMA

Reziumė

Analizuojami sukurtos struktūrogramos metalo lakštų surinkimo operacijų našumui tirti ypatumai ir metodologija. Išnagrinėtas kniedijimo be kniedžių, taškinio suvirinimo, tradicinio kniedijimo, klijavimo, varžtais ir veržlėmis sujungimo metodų našumas ir priemonės jam didinti.

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FRAMEWORK OF CONSIDERATION PRODUCTIVITY FOR ASSEMBLING OPERATIONS IN SHEET METALWORKING

Summary

The paper deals with the developed framework of productivity consideration for assembling operations in sheet metalworking peculiarities and methodology. Productivity and factors for its increase in clinching, spot welding, riveting, pasting, bolts and nuts joint methods are considered.

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СТРУКТУРА ИССЛЕДОВАНИЯ ПРОИЗВОДИТЕЛЬНОСТИ СБОРОЧНЫХ ОПЕРАЦИЙ В МЕТАЛО ЛИСТОВОМ ПРОИЗВОДСТВЕ

Резюме

В статье анализируются особенности и методология развитой структуры для рассмотрения производительности сборочных операций в работе с листовым металлом. Исследована производительность и факторы ее увеличения для сборочных операций клепки без заклепок, точечной сварки, приковывания, клепки, болтовых соединений.

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