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O POTRZEBIE ZMIAN KRYTERIÓW OCENOWYCH W PRODUKCJI MONTAŻOWEJ

Jerzy ŁUNARSKI

Procesy montażowe należą do jednych z najpowszechniej stosowanych w różnych sektorach wytwórczości, jednak ich specyfika znacznie zależy od takich czynników, jak: materiały i gabaryty montowanych elementów, potrzeby zachowania dokładności i sterylności procesów, przeznaczenia produktów i skali ich produkcji, niezawodności i bezpieczeństwa wyrobów oraz warunków w jakich mają być eksploatowane.

Mimo tej różnorodności procesów montażowych dotychczasowe kryteria ocen tych procesów przeważnie dotyczyły zapewnienia bezpieczeństwa, wykonalności, minimalizacji kosztów i pracochłonności, a niekiedy również takich kryteriów, jak: produktywności, wydajności, trwałości eksploatacyjnej, funkcjonalności i in.

Wzrastająca aktywność współczesnych społeczeństw w zakresie gospodarki, konsumpcji, globalizacji, wykorzystywania nieodnawialnych zasobów itp. wywołały szereg globalnych zmian, których narastanie może stanowić zagrożenie dla istnienia przyszłych pokoleń (zmiany klimatu, wyczerpywanie zasobów, wymieranie gatunków fauny i flory, degradacja gleb, wylesianie, wzrastające zanieczyszczenia środowisk odpadami (stałymi, ciekłymi, gazowymi, w tym o dużej szkodliwości dla zdrowia itp.) stwarzają konieczność wprowadzenia radykalnych zmian w systemach gospodarczych, politycznych, społecznych, etycznych i in.

Produkcja montażowa nie należy do liderów generujących powyższe negatywne skutki, lecz konieczna jest zmiana podejścia do procesów projektowania, wytwarzania i eksploatowania systemów montażowych i obiektów montowanych.

Zmiany te powinny dotyczyć wyboru kryteriów ocen i ich rang w trakcie formułowania założeń projektów, nadzoru nad ich realizacją i końcowej ich weryfikacji i walidacji. Można tu przytoczyć kilka przykładowych, ważniejszych zaleceń, które w konkretnych działaniach mogą być znacznie rozszerzone, uszczegółowione i dostosowane do specyfiki montowanych produktów i stosowanych w tym celu systemów montażowych, tzn.:

1. Preferowanie stosowania materiałów nie deficytowych, łatwych do ponownego wykorzystywania i recyklingu, z których elementy byłyby łączone sposobami łatwymi do demontażu, zaś sposoby ich ponownego wykorzystania byłyby mało energochłonne.

2. Stosowanie rozwiązań i połączeń montażowych umożliwiających maksymalne ograniczenie, w procesach wytwarzania i eksploatacji, generowania odpadów nie znajdujących wtórnego zastosowania lub wykorzystania w odrębnych procesach.

3. Wykorzystywanie metod i rozwiązań zapewniających maksymalizację sprawności energetycznej, mechanicznej, cieplnej i in. dzięki czemu możliwym będzie lepsze, dłuższe i efektywniejsze wykorzystywanie wyrobów i urządzeń systemów montażowych.

4. Preferowanie rozwiązań modułowych (w konstrukcji, technologii, organizacji) umożliwiających łatwe przeprowadzanie modernizacji i rewitalizacji wyrobów i systemów w trakcie ich eksploatacji, bez konieczności fizycznej likwidacji i wydłużających ich przydatność eksploatacyjną, produktywność, bezpieczeństwo i in.

5. W rozpatrywaniu różnych wariantów rozwiązań konstrukcyjnych i technologicznych celem ich optymalizacji, oprócz kosztów, pracochłonności i bezpieczeństwa, należy uwzględniać również takie, jak: energochłonność, materiałochłonność, ilość generowanego dwutlenku węgla oraz ilości generowanych odpadów (zwłaszcza niebezpiecznych i nie podlegających utylizacji) i inne.

Istnieje już obszerna literatura naukowa, normatywna i prawna wskazująca na preferowane kryteria postępowania, lecz jest ona w ograniczonym stopniu wykorzystywana w procesach projektowania. Do ważniejszych można zaliczyć następujące: norma ISO 26000 (o społecznej odpowiedzialności biznesu), wytyczne ONZ w sprawie tzw. czystszej produkcji (CP), normy serii ISO 14000 (systemy zarządzania środowiskowego), zasady szczupłego zarządzania i wytwarzania (LM, LP), wiele różnych aktów prawnych dotyczących poszczególnych działań i in.

Redakcja TiAM oraz jej czytelnicy będą szczególnie zadowoleni jeśli Autorzy opracowań naukowych prezentowanych w TiAM naszego kwartalnika będą w swoich pracach uwzględniali powyższe wytyczne. Globalne znaczenie postępujących zmian degradacyjnych wymaga powszechnego zaangażowania i kreatywności – wiele małych i drobnych inicjatyw może sumować się w istotne efekty, z pożytkiem dla naszej cywilizacji.

HEURISTIC METHOD OF ASSEMBLY SCHEDULING OF MULTI-OPTION PRODUCTS FOR ASSEMBLY LINE WITH INTERMEDIATE BUFFERS

Heurystyczna metoda harmonogramowania montażu wielowariantowych produktów linii montażowej z buforami międzyoperacyjnymi

Евристический метод чередования сборки многовариантных изделий в сборочной линии с межоперационными магазинами

Marek MAGIERA

Abstract: The method intended to build the possibly shortest assembly schedules is presented in the paper. The method is constructed for assembly lines without parallel machines. The intermediate buffers are located between the assembly machines. A flow of products of different types is unidirectional in the assembly line. The proposed method is a heuristic because the fixed tasks are characterized by a large size and considerable computational complexity. It is a relaxation heuristic. The linear mathematical model is used in the mentioned heuristic method. The method is constructed for assembly scheduling for multi-option products. Assembly of various types of products in different variants is the reply to the contemporary challenges faced by the manufacturers, who try to satisfy the demands of individual customers. The planned downtimes of machines are regarded in the method, for example downtime of machines connected with maintenance. The results of computational experiments with proposed heuristic method are presented. The described heuristic method is compared with optimal method based on the integer programming. The fixed makespans and computational fixed times using heuristic method and optimal method are compared.
Keywords: heuristic, relaxation, assembly line, optimization, scheduling, linear programming

Streszczenie: Przedstawiono metodę przeznaczoną do budowy najkrótszych harmonogramów montażu produktów w liniach montażowych bez maszyn równoległych. Konfiguracja linii montażowej uwzględnia obecność buforów międzyoperacyjnych pomiędzy maszynami. Przepływ równocześnie montowanych produktów różnych typów jest jednokierunkowy. Ze względu na rozmiary rozwiązywanych problemów i związaną z tym złożoność obliczeniową metoda jest heurystyką. Jest to heu¬rystyka relaksacyjna, w której wykorzystano model zadania programowania liniowego.Metoda dotyczy produktów wielowariantowych. Produkty danego typu mogą różnić się warian¬tami wykonania – specyficznymi cechami, uwzględniającymi wymagania odbiorców. Metodę wyróżnia także uwzględnienie planowanych przestojów maszyn, np. przeznaczonych na konserwację. Zaprezentowano wyniki eksperymentów obliczeniowych, za pomocą których oceniono jakość opracowanej metody. Długości harmonogramów wyznaczanych za pomocą przedstawionej metody porównano z długościami harmonogramów optymalnych, znanymi dzięki zastosowaniu modelu zadania programowania całkowitoliczbowego. Porównano także czasochłonność obliczeń.
Słowa kluczowe: heurystyka, relaksacja, linia montażowa, optymalizacja, szeregowanie operacji, programowanie liniowe

Introduction – the reasons for construction of heuristic

The method for construction of assembly scheduling, as suggested in the present paper, may be assigned to the approximate methods; it is the heuristics. The term heuristic originates in Greek language, it comes from the word *heurisko*, that means *I find*, *I discover*. The heuristics are employed first of all in the cases where the complete algorithms are too expensive due to technical reasons [2]. The mentioned expensiveness – in the case of the submitted method – concerns the dimensions of the problems to be solves and the computational complexity.

In construction of the possibly shortest assembly scheduling, the multi-option products were considered. The products of a given type that are assembled in various variants differ in respect of their distinguishing features, e.g. additional componental parts (e.g. handlers), shape and dimensions of case, or other factors affecting their external appearance and utility properties. The consideration of individual requirements of customers, being the undoubted advantage of the developed method, results in relatively great extent of the problems to be solved. The extent of the problem is understood as integer number, being a measure of the quantity of input data which characterize a given problem [6]. The input data include, *inter alia*, parameters concerning various variants of the products and, also, parameters of assembly line. The extent of the problem has an influence on the quantity of computer resources, being necessary for solving the problem, that is, computational complexity. The mentioned resources include memory (memory complexity) and time (time complexity).

In connection with the above, in case of the problems of a great extent, the search for the optimum solution is often unprofitable. Due to this reason, the heuristic method was constructed owing to which it is possible

– in a relatively short time – to find the solutions which may be charged with a certain deviation from optimum. It is significant in the case of the necessity to repeat the scheduling – to determine a new scheduling in a short time.

The examples of the application of heuristics in the assembly scheduling may be found in the research papers [1], [3] and [6]. The method suggested in the present study is distinguished by the consideration of multi-option products and, also, the planned downtimes.

The heuristic method was described in chapters 2 and 3. The successive chapter is dedicated to the evaluation of the discussed heuristic – the comparison of the set optimum solutions and the heuristic ones.

Formulation of the problem and the concept of its solution

Unidirectional assembly line without parallel machines is given. Between the machines, there are intermediate buffers with limited capacities where the products may wait for performance of the successive operations. In the assembly line system, we may have simultaneously assembled multi-option products of different types. Some machines may be omitted by the product. The exemplified configuration of assembly line which the developed method is referred to is illustrated in Fig.1.
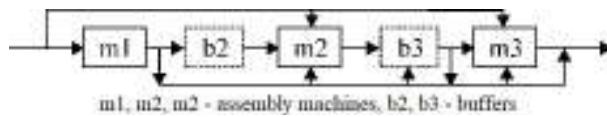

Fig. 1. Unidirectional assembly line with intermediate buffers
Rys.1. Jednokierunkowa linia montażowa z buforami międzyoperacyjnymi

In case of the above assembly line, the shortest scheduling of performing the assembly operations should be constructed.

The method concerning the solution of the described problem is based on the monolithic approach. The assignment of operations to machines and distribution of operation in time is performed simultaneously. The block diagram of the discussed method is given in Fig.2.
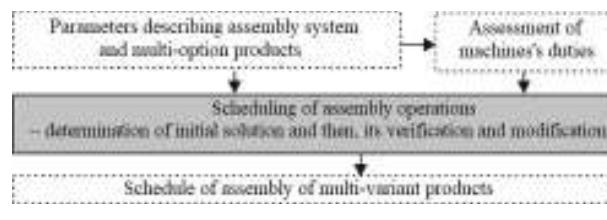
Fig. 2. Block diagram of the heuristic method
Rys.2. Schematy blokowy heurystycznej metody

Table 1. Summary of sets, parameters and variables
Tabela 1. Zestawienie oznaczeń zbiorów, parametrów i zmiennych

Sets:	
I	– Set of assembly machines: $I = \{1, ..., M\}$;
J	– Set of types of assembly operations: $J = \{1, ..., N\}$;
K	– Set of types of assembled products: $K = \{1, , W\}$;
L	– Set of time intervals: $L = \{1, ..., H\}$;
S	– Set of indices of multi-variant products;
I_j	– Set of machines capable of performing the operation $j \in J$;
J^1	– Set of basic operations, $J^1 \in J$;
J^2	– Set of additional operations (rendering the specific features to the multi-option products), $J^2 \in J$;
J^C	– Set of assembly operations consisting in additional assembly of a part, taken from feeder, $J^C \in J$;
O^1	– Set of pairs (k, j), in case of which the basic operation $j \in J1$ concerns the product of $k \in K$ type;
O^2	– Set of pairs (s, j), in case of which additional operation $j \in J2$ concerns $s \in S$ product;
R^1	– Set of ordered triples (k, r, j), in which performed successively basic operations $r, j \in J^1$ concern product of k type;
R^2	– Set of ordered triples (s, r, j), in which successively performed operations $r, j \in J$ concern product s and at least one operation belongs to set J^2;
T	– Set of ordered pairs (s, k), where product s is of k type;
Parameters:	
a_{ij}	– Working space of machine i utilised for performing operation of j type;
b_i	– Working space of machine i, where feeders of componential parts may be placed;
d_i	– Capacity of intermediate buffer placed before machine i;
$g_{\tau i}$	– Time of product's transport between machines τ and i;
p^1_{jk}	– Time of performing basic operation $j \in J^1$ concerning product of k type;
p^2_{js}	– Time of performing additional operation $j \in J^2$ concerning s product;
n_{il}	= 1, if machine i is available in time interval l, otherwise nil = 0;
Variable, the values of which are determined in the particular iterations e:	
x^e_{ij}	= 1, if type of operation j is assigned to machine i, otherwise x^e_{ij}
q^e_{ijsl}	= 1, of in time interval l operation j concerning product s is performed in machine i; otherwise q^e_{ijsl};
y^e_{isl}	= 1,if in time interval l product s is found in intermediate buffer placed before machine i, otherwise $y^e_{isl} = 0$;
w^e_{is}	– Time of commencing performance of operations concerning product s in machine i;
z^e_{is}	– Time of completing the performance of operations concerning product s in machine i;

Fig.2 shows that the parameters, describing machine ark and multi-option products, are utilized in the procedure, intended for assessment of machine duties. It results from the consideration of the planned downtimes of machines. In the heuristic destined for solving the problem, the linear mathematical model, constructed by the author of the present paper, concerning the scheduling of assembly line with intermediate buffers was employed. In the discussed model, the conditions of integer numbers of decisive variables were omitted. It is a characteristic of relaxation heuristics. In the developed method, the rules of rounding of variables, informing on

assignments of particular assembly operations to the machines in given time intervals, were specified. The discussed method includes also procedures of verification and modification o the schedule to be constructed, e.g. those ones concerning behaviour of sequence limitations (performance of operations in accordance with each sequence, in unidirectional assembly line), lack of collision in assembly (in a given moment on a specified machine there is no more than one operation performed; in the case of the product, also, in a given moment no more than only one assembly operation assigned to this product is performed).

The detailed description if the method is given in the next chapter. Omitting of the conditions of integer numbers of variables in mathematical model affected very positively the time consumption of the calculations what was indicated in chapter 3 concerning the computational experiments, carried out on the developed method.

Mathematical description of relaxation heuristic

In the relaxation heuristic, the sets and parameters compiled in Tab.1 were considered.

The parameters described in Tab.1 are the input data considered in the heuristic algorithm. The values of variables, being defined in the mentioned table, determined in the last iteration are the solution. Here we have the relaxation heuristic:

- -

Step 1. Linear relaxation of mathematical model, initial solution

Apply the procedure for determination of the number of time intervals H, as published in the paper [5]. Adopt the number of iteration $e = 1$ and solve the task formulated in linear mathematical model which the function of aim concerns (1) and constraint (2) – (20).

Minimize:

$$\sum_{i\in I}\sum_{j\in J}\sum_{l\in L}\sum_{s\in S} lq_{ijsl}^{e} \tag{1}$$

Subject to:

$$\sum_{i\in I}\sum_{j\in J} q_{ijsl}^{e} \leq 1; \quad l\in L; s\in S \tag{2}$$

$$\sum_{j\in J}\sum_{s\in S} q_{ijsl}^{e} \leq n_{il}; \quad i\in I; l\in L \tag{3}$$

$$\sum_{i\in J_j}\sum_{l\in L: n_{il}=1} q_{ijsl}^{e} = p_{jk}^{1}; \quad j\in J^1; (s,k)\in T: (k,j)\in O^1 \tag{4}$$

$$\sum_{i\in J_j}\sum_{l\in L: n_{il}=1} q_{ijsl}^{e} = p_{js}^{2}; \quad j\in J^2; s\in S: (s,j)\in O^2 \tag{5}$$

$$q_{ijsl}^{e} + q_{\tau jsf}^{e} \leq 1; \quad \tau, i\in I; j\in J; l,f\in L; s\in S; \tau \neq i \tag{6}$$

$$lq_{ijsl}^{e} - fq_{\tau rsf}^{e} \leq \sum_{\eta\in L: f<\eta<l}\left(q_{ij\tau\eta}^{e} + q_{irs\eta}^{e}\right) + 1 + (H+1)(1 - q_{ijsl}^{e})$$

$$i,\tau\in I; (s,k)\in T; l,f\in L; (k,r,j)\in R^1 \vee (s,r,j)\in R^2 \tag{7}$$

$$x_{ij}^{e} \geq q_{ijsl}^{e}; \quad i\in I; j\in J; l\in L; s\in S \tag{8}$$

$$x_{ij}^{e} = 0; \quad i\notin I_j; j\in J \tag{9}$$

$$a_{ij} x_{ij}^{e} \leq b_i; \quad i\in I; j\in J^c \tag{10}$$

$$iq_{ijsl}^{e} \geq \tau q_{\tau rsf}^{e} - (H+1)(1 - q_{ijsl}^{e}); i,\tau\in I; (s,k)\in T; l,f\in L; (k,r,j)\in R^1 \vee (s,r,j)\in R^2 \tag{11}$$

$$lq_{ijsl}^{e} - fq_{\tau rsf}^{e} \geq 1 + g_{js} - (H+1)(1 - q_{ijsl}^{e})$$

$$i,\tau\in I; f,l\in L; \left((s,k)\in T; (\kappa,r,j)\in R^1; \kappa=k\right)\vee (s,r,j)\in R^2 \tag{12}$$

$$w_{is}^{e} \geq lq_{ijsl}^{e} - \sum_{f\in L}\sum_{r\in J} q_{irsf}^{e} + 1 - (H+1)(1 - q_{ijsl}^{e}); \quad i\in I; j\in J; l\in L; s\in S \tag{13}$$

$$w_{it}^e \leq lq_{ijsl}^e + (H+1)(1 - q_{ijsl}^e); \quad i \in I; \ j \in J; \ l \in L; \ s \in S \tag{14}$$

$$z_{it}^e \geq lq_{ijsl}^e - (H+1)(1 - q_{ijsl}^e); \quad i \in I; \ j \in J; \ l \in L; \ s \in S \tag{15}$$

$$lq_{ijsl}^e - fq_{\tau ksf}^e - 1 \leq g_{\tau i} \sum_{\delta \in L: f < \delta < l} \left(q_{ijs\delta}^e + q_{\tau ks\delta}^e \right) + \sum_{\delta \in L} y_{isl}^e + (1+H)(1 - q_{\tau ksf}^e)$$

$$\tau, i \in I; \ \tau < i; \ (s,k) \in T; \ f, l \in L; \ f < l; \ (k,r,j) \in R^1 \vee (s,r,j) \in R^2 \tag{16}$$

$$l y_{lsl}^e \geq z_{\tau s}^e + 1 + g_{\tau i} - (H+1)(1 - y_{isl}^e); \quad \tau, i \in I; \ l \in L; \ s \in S; \ \tau < i \tag{17}$$

$$l y_{isl}^e \leq w_{is}^e - 1 + (H+1)(1 - y_{isl}^e); \quad i \in I; \ l \in L; \ s \in S \tag{18}$$

$$\sum_{r \in S} y_{irl}^e \leq d_l; \quad l \in L; \ v \in V; \ i > 1 \tag{19}$$

The presented model is intended for determination of the shortest schedules owing to minimization of sum (1). The constraints concerning the discussed model ensure: (2) – performance in a given moment of no more than one assembly operation concerning a defined product; (3) – performance of no more than one operation by assembly machine in a given moment if the machine is available in this moment; (4) and (5) – distribution of basic (4) and additional (5) operations into machines; (7) – indivisibility during the operations concerning a given product, performed in a specified machine; (8) – determination of the assignment of types of operations to the machines; (9) – elimination of the assignment of operations to the wrong machines; (10) – preservation of the limited working space of each of machines: (11) – unidirectional flow of products throughout the assembly line; (12) – consideration of sequence limitations in performing the operations and ensuring the time for transportation of the products between the machines: (13) and (14) – determination of the times of commencing the performance of operations concerning the specified products in the particular machines and (15) – determination of the times of completing the performance of these operations; (16) – determination of time intervals in which the assembled product must remain in buffer during the time period, preceding the next operation – owing to relation (17) and after transportation to this machine – owing to condition (18) with consideration of limited capacity of buffers what ensures dependence (19).

In the described model, the integer number conditions were omitted. To determine the initial solution, the auxiliary variables have been introduced:

v_{ijs}=1, if operation j concerning product s is performed in machine j, otherwise $v_{ijs} = 0$;

t_{sij}^e, c_{sij}^e - times of: commencing, completing of operation j for product s, performed in machine i

To determine values of the mentioned variables, assign v_{ijs} to the mentioned machine i capable of performing operation j concerning product s, in the case of which value $\sum_{l \in L} q_{ijls}^e$ is the highest one. If value of this sum is the same in case of few machines, choose the machine capable of performing operation j with lower index i.

Assume number of iteration e: = 2. Make acc. to (20) rounding of the variables, determine the times of commencing the operations (21) and times of completing the operations (22).

$$q_{ijls}^e = \text{round}(q_{ijls}^{e-1}); \quad i \in I; \ j \in J; \ l \in L; \ s \in S \tag{20}$$

$$t_{ijs}^e = v_{ijs} \cdot \min_{l \in L, \tau \in I}(lq_{ijls}^e); \quad i \in I; \ j \in J; \ s \in S \tag{21}$$

$$c_{ijs}^e = \begin{cases} t_{ijs}^e + p_{jk}^1 - 1 & i \in I; \ j \in J^1; \ (s,k) \in Z: (k,j) \in O^1 \\ t_{ijs}^e + p_{js}^2 - 1 & i \in I; \ j \in J^2; \ s \in S: (s,j) \in O^2 \end{cases} \tag{22}$$

Assume $e: = e + 1$ and remember loads of particular machines in the particular l periods, using 23 and go to step 2.

$$q_{ijlt}^e = \begin{cases} 1, \text{gdy } t_{ijs}^{e-1} \geq l \leq c_{ijs}^{e-1} \\ 0, \text{inaczej} \end{cases} ; \ i \in I; \ j \in J; \ l \in L; \ s \in S \tag{23}$$

Step 2. Verification of direct succession of operations performed in a given machine concerning the same product

a) Check whether in the case of each pair of successively performed operations r, j, concerning s product of k type where $(k, j, r) \in R^1$ or $(s, r, j) \in R^2$ performed in the same machine, the equation (24) is satisfied. If so, go to step 5; if not – go to step 5b.

$$t_{irs}^e - c_{ijs}^e = 1; \ i \in I; \ (s,k) \in T; \ r, j \in J; \ v_{ijs} = v_{irs} = 1 : (k,r,j) \in R^1 \vee (s,r,j) \in R^2 \tag{24}$$

Let $e: =e + 1$. Remember each product s' (mark it in such a way) that does not satisfy condition (24) in case of machine i' (mark it in such a way) and then, determine the set of operations performed in this machine, mark it as J'. Mark with j' the first operation, performed in machine i' concerning s' product. The times of commencing and completing of these operations, in the case of which the equation (24) is satisfied remain unchanged and are remembered owing to (25) and (26). In the case of i operations of the products which have not met the constraint (24), there are determined acc. to (27) and (28) such times of beginning and ending the operations as to satisfy constraint (24)

$$t_{ijs}^e = t_{ijs}^{e-1} \text{ dla } \left(i \in I \setminus \{i'\}; \ j \in J \right) \vee \left(i = i'; \ j \in J \setminus J' \vee j = j' \right); \ s \in S \tag{25}$$

$$c_{ijs}^e = \begin{cases} t_{ijs}^e + p_{jk}^1 - 1 \text{ dla } \left(i \in I \setminus \{i'\}; \ j \in J^1 \right) \vee \left(i = i'; \ j \in J^1 \setminus J' \vee j = j' \right); \ (s,k) \in T \\ t_{ijs}^e + p_{js}^2 - 1 \text{ d/a } \left(i \in I \setminus \{i'\}; \ j \in J^2 \right) \vee \left(i = i'; \ j \in J^2 \setminus J' \vee j = j' \right); \ s \in S \end{cases} \tag{26}$$

$$t_{ijs}^e = c_{irs}^e + 1 \text{ dla } i = i'; \ r \in J'; \ j \in J' \setminus \{j'\}; s = s'; \left((k,r,j) \in R^1 \wedge (s,k) \in T \right) \vee (s,r,j) \in R^2 \tag{27}$$

$$c_{ijs}^e = \begin{cases} t_{ijs}^e + p_{jk}^1 - 1 \text{ dla } i = i'; \ j \in J' \setminus \{j'\}; \ (s,k) \in Z; \ s = s' \\ t_{ijs}^e + p_{jk}^2 - 1 \text{ dla } i = \hat{i}; \ j \in J' \setminus \{j'\}; \ s \in S; \ s = s' \end{cases} \tag{28}$$

Update acc. to (29) information on loading of machines. Then, undo denotation of machines, operations, products and set of operations (i', j', s', J') and go to step 3.

$$q_{ijls}^e = \begin{cases} 1, \text{gdy } t_{ijs}^e \geq l \leq c_{ijs}^e \\ 0, \text{inaczej} \end{cases} ; \ i \in I; \ j \in J; \ l \in L; \ s \in S \tag{29}$$

Step 3. Verification of collision-free condition of performing the operations

a) Let machine index $i : = 0$. Go to step 3b.
b) Let $i : = i + 1$ and index of time interval $l : 0$. Go to step 3 c.
c) Let $l : l + 1$. If the condition (30) is met, i.e. in a given period l, machine i performs no more than one operation, go to step 4; if not, go to step 3 d.

$$\sum_{j \in J} \sum_{s \in S} q_{ijls}^e \leq n_{il} \tag{30}$$

d) Choose only one product s which meets the equation $q_{ijls}^e = 1 \ (j \in J)$ and determine s' while making the choice of this product according to lexicographic order: 1) the product which met the equation $q_{ijls}^e = 1 \ (j \in J)$ in the previous iteration and was not marked with s'; 2) the product with the lowest value $t_{ijs}^e \ (j \in J)$; 3) the product with the highest value $\sum_{j \in j} \sum_{l \in L} q_{ijls}^e$; 4) the product with the lowest index s.

Determine j' operation concerning s' product, performed in the l period in i machine. Assume $e := e + 1$. When applying (31), determine the number of time intervals b, in which j' operation requires load of machine i in the period from l until completion of the discussed operation.

$$b = c_{ijs'}^{e-1} - l + 1 \tag{31}$$

On the base of (32), determine element of D set – ordered pairs (s, j) where j operation concerns s product. Set D includes products and their relating operations in the case of which it is necessary to make modification of scheduling – ascribe the later time of performing the operations for these products (prolongation of the scheduling by b periods).

To ensure the collision free condition of assembling, modify the scheduling acc. to (33). Update the times of commencing and completing the performance of operations in accordance with the equations (21) and (22). Undo the denotation of operations and products (j', s') and go to step 4.

$$D = \left\{ (s, j) : s \in S; \ j \in J \setminus \{j'\}; \ q_{ijs}^{e-1} = 1; \ f \in \langle l, l+b-1 \rangle \right\} \tag{32}$$

$$q_{\tau ijs}^{e} = \begin{cases} q_{\tau ijs}^{e-1} & \text{dla } ((\tau \in I \setminus \{i\}; (s, j) \in D) \vee (\tau = i; j \in J; (s, j) \notin D)) \\ q_{\tau ijf}^{e-1} & \text{dla } \tau = i; (s, j) \in D; \rho \geq l+b, \ f = \rho - b \end{cases} ; \rho \in L; s \in S \tag{33}$$

Step 4. Verification of behaviour of limitations concerning the sequence of performing the operations

a) If the verified constraint (34) concerning the sequence limitations is satisfied for j operation performed in i machine and its predecessor – operation r, performed in τ machine, go to step 5, otherwise, go to step 4b.

$$t_{ijs}^{e} - c_{\tau rs}^{e} - 1 \geq g_{\sigma}; \ \tau, i \in I; \ s \in S; \ t_{ijs}^{e} \leq l; \ ((k, r, j) \in R^{1} \wedge (s, k) \in Z) \vee (s, r, j) \in R^{2} \tag{34}$$

b) Mark operation which does not satisfy constraint (34) with letter j', and mark the product relating to the discussed operation with letter s'. Determine b – minimum number of periods by which value $t_{ij's'}^{e}$, should be increased as to preserve limitation (34). Assume $e := e + 1$ and modify scheduling acc. to (35). Update the times of commencing and completing the operations concerning products acc. to (21) and (22). Undo the denotation of operations and products (j', s') and go to step 5.

$$q_{\tau ijs}^{e} = \begin{cases} q_{\tau ijs}^{e-1} & \text{dla } ((\tau \in I \setminus \{i\}; j \in J) \vee (\tau = i; j \in J \setminus \{j'\})), \rho \in L; s \in S \\ q_{\tau ijf}^{e-1} & \text{dla } \tau = i; j = j'; \rho \in L; \ \rho \geq l+b; \ f = \rho - b; s = s' \end{cases} \tag{35}$$

Step 5. The condition of halting for the so-far existing stages of verification and improvement of scheduling

If $l < \max_{\tau \in I, j \in J, s \in S} c_{\tau js}^{e}$, go to step 3c, otherwise check: $i < M$ (M – number of machines). If the relation is satisfied, go to step 3b; otherwise go to step 6.

Step 6. Verification of utilizing intermediate buffers and availability of machines

Assume $e := e + 1$ and solve the system of inequalities (13) – (19) in order to determine the loads of intermediate buffers. When analyzing the successive time intervals and loads of machines and loads of intermediate buffers as well as a limited availability of machines (checking the constraint (3)), verify and modify a scheduling in such a way as to have the admissible number of products in the particular buffers in a given moment and the machines loaded in the periods of their availability. In the successive iterations, analogically as in the case of equation (31) in step 3, determine the number of time intervals b, by which the operations which do not satisfy the described constraints, should be "shifted". If a few products do not meet the mentioned constraints (in a given iteration), employ lexicographic order, as being described in step 3 in order to choose one product. Modify the scheduling analogically to constraint (33) and update the times of performing operations, applying (21) and (22).

The times of commencing and completing the performance of the particular operations, as determined in the last iteration – on the grounds of equations (21) and (22) are the solution.

- -

The computational experiments – relaxation heuristic and the accurate method

The submitted heuristic algorithm (algorithm H) has been subjected to verification. The determined schedules, using the mentioned algorithm were compared to the scheduling constructed with the use of the precise method (method M). In the accurate method, there was solved a task, formulated in mathematical model (1) – (19), supplemented by the constraints, ensuring the binarity of decision variables – thus, the integer programming was employed.

The computational experiments included 4 groups of test tasks. In the case of each of the groups, 25 test tasks were solved. In the computation, GUROBI [6] was used. The parameters of the groups of test tasks and the results of the experiments were presented in Tab.2. In the mentioned table, there were presented the mean values of 2 indicators, defined in the equations (36), indispensable for evaluation of heuristic: f_1 – destined for comparison of the length of scheduling, and f_2 – for comparison of the computation times using heuristic method H and accurate method M. in the mentioned equations C_{max} is a length of the scheduling and CPU represents the time of computations.

$$f_1 = \frac{C_{max}^{H} - C_{max}^{M}}{C_{max}^{M}} \cdot 100\%, \quad f_2 = \frac{CPU^{H}}{CPU^{M}} \cdot 100\% \quad (36)$$

Tab.2. Parameters of groups of tasks and the results of computational experiment

Group of tasks	Parameters of group of tasks					The results of experiments	
	M	N	W	S	H	f_1 [%]	f_2 [%]
1	3	10	3	6	16	3,5	0,37
2	4	12	4	8	18	3,7	0,33
3	4	14	5	10	20	3,6	0,27
4	5	16	6	12	22	4,3	0,26

Number of : M – machines, N –types of assembly operations, W – types of products, S – products, H – time intervals

The mean values of indicators f_2 show multiple abbreviation of the time of computations in the case of applying hierarchic method for solution of test tasks – the schedulings were determined by 270 – 380 times quicker than in the case of the application of accurate method. The discussed abbreviation of the time of computations had however certain deviation from optimum, amounting to 3.5 – 4.3 % what is shown by the values of f_1 indicators.

Final remarks

The unquestionable advantage of the presented method consists in consideration of multi-option products, in the assembly schedulings, constructed in a relatively short period of time. A quick solution of the formulated problem has been reached owing to the application of relaxation technique. This relevant favourable feature of the presented method has, however, certain deviation from optimum what is characteristic of the approximate methods. The conducted computational experiments allowed measuring of defects and advantages of the suggested method.

Owing to the described above features, the presented method is recommended mainly for the operational planning in the case of assembly of the products which consider the individual requirements of customers. It is also suitable in the case of re-scheduling – when there is a necessity to construct a new scheduling in relatively short time.

Mathematical model, as presented in this paper, and supplemented by the conditions of integers of decision variable, may be utilized in construction of optimum schedulings, especially in the case of solving the small dimension problems.

The discussed model may be modified, adopted to the varying conditions of the assembly process and employed in innovative operations in automated assembly [4].

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ROBOTIC EXECUTION OF HOLES FOR WELDING IN LARGE-SIZED CYLINDRICAL BLANKS

Zrobotyzowane wykonywanie otworów montażowych w cylindrycznych wielkogabarytowych półfabrykatach

Роботизированное выполнение отверстий под сварку в цилиндрических крупногабаритных заготовках

Asia GORELOVA, Mark KRISTAL,
Vladislav MARTYNENKO, Jurij BAZHENSKY

A b s t r a c t : The design of the shell and tube heat exchanger includes a tube-like shell with holes to which an inlet and outlet pipes are welded. Radial and tangential holes are produced manual-ly by means of plasma cutting with the use of specialized tools, which determines high labo-riousness of heat exchangers production. An automatic device is proposed to reduce the labo-riousness of this operation. To produce the hole in the heat exchanger shell, two reversible motions are superimposed: linear motion of the cutter along the longitudinal axis of the shell and the shell rotary motion. A mathematical model of the required cutter motion is proposed, which describes the relative trajectories of the plasma cutter and the shell in parametric form. To verify theoretical premises, a prototype of the device was produced using a 3D pro-totyping technology, a ball screw for the reversible linear motion of the cutter and a stepper motor for the reversible rotary motion of the shell. The shell is fixed by means of a collet chuck and rests on the pipe roller support.

K e y w o r d s : robotic execution, welding, cylindrical blanks

S t r e s z c z e n i e : Przedstawiono metodę przeznaczoną do budowy najkrótszych harmonogramów montażu produktów w liniach montażowych bez maszyn równoległych. Konfiguracja linii montażowej uwzględnia obecność buforów międzyoperacyjnych pomiędzy maszynami. Przepływ równocześnie montowanych produktów różnych typów jest jednokierunkowy. Ze względu na rozmiary rozwiązywanych problemów i związaną z tym złożoność obliczeniową metoda jest heurystyką. Jest to heu¬rystyka relaksacyjna, w której wykorzystano model zadania programowania liniowego.Metoda dotyczy produktów wielowariantowych. Produkty danego typu mogą różnić się warian¬tami wykonania – specyficznymi cechami, uwzględniającymi wymagania odbiorców. Metodę wyróżnia także uwzględnienie planowanych przestojów maszyn, np. przeznaczonych na konserwację. Zaprezentowano wyniki eksperymentów obliczeniowych, za pomocą których oceniono jakość opracowanej metody. Długości harmonogramów wyznaczanych za pomocą przedstawionej metody porównano z długościami harmonogramów optymalnych, znanymi dzięki zastosowaniu modelu zadania programowania całkowitoliczbowego. Porównano także czasochłonność obliczeń.

S ł o w a k l u c z o w e : heurystyka, relaksacja, linia montażowa, optymalizacja, szeregowanie operacji, programowanie liniowe

ВВЕДЕНИЕ

Среди различных конструкций нефтехимического оборудования имеется большое количество крупногабаритных изделий, диаметры цилиндрических обечаек которых варьируются в диапазоне 800…4000 мм, а толщины – 10…100 мм. Одной из операций при их производстве является изготовление центральных и тангенциальных отверстий под сварку с патрубками диаметром от 200…1000 мм. Эту операцию выполняют вручную с помощью плазменной резки и дополнительных приспособлений, что достаточно трудоёмко. Поэтому автоматизация процесса обработки отверстий под патрубки в заготовках корпусов ТА является актуальной задачей. В связи с серийным типом производства, необходимо, чтобы устройство, реализующее рассмотренную операцию, было способно к переналадке на различные типоразмеры заготовок, к регулированию скорости резания, в зависимости от материала и толщины металла заготовки, а также к возможности исполнения, как центральных, так и тангенциальных отверстий (рис. 1).. Для снижения капитальных затрат целесообразна не полная, а частичная автоматизация, где вспомогательные переходы, такие как: установка заготовки относительно базирующих элементов, подвод инструмента к сечению заготовки, где должно быть выполнено отверстие, выставление рабочего зазора между поверхностью заготовки и торцом сопла газового резака, выполняют операторы.

Для минимизации количества приводов устройства предложено траекторию перемещения инструмента реализовать сложением двух реверсивных движений: резака вдоль образующей заготовки в плоскости осевого центрального продольного ее сечения и заготовки вокруг ее собственной оси.
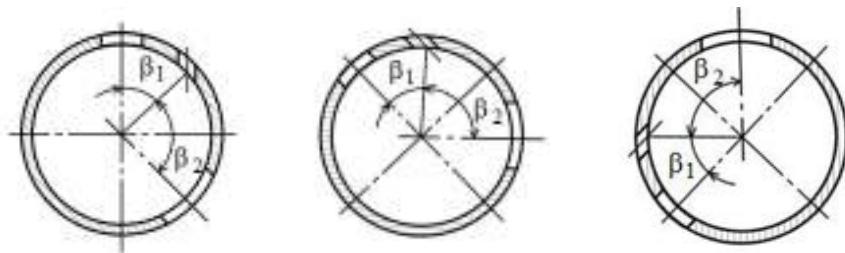
Рис. 1. Расположение отверстий в заготовке теплообменного аппарата
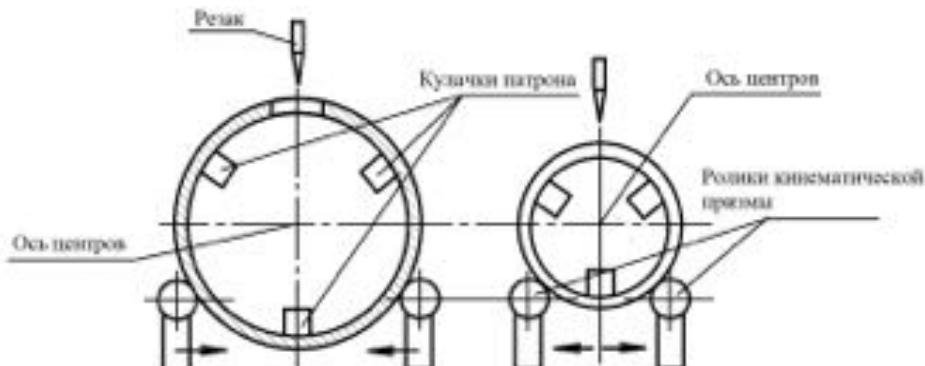
Рис. 2. Базирование обечаек заготовок различного диаметра

В зависимости от того, какое отверстие требуется вырезать, заготовку в начальный момент необходимо повернуть вокруг ее продольной оси таким образом, чтобы начальная точка выполнения отверстия лежала на центральной оси поперечного сечения обечайки. Для обработки заготовок разного диаметра с неизменным положением оси центров предложено использовать трехкулачковый патрон в сочетании с раздвигаемыми роликовыми опорами кинематической призмы (рис. 2).

Такая схема базирования позволяет перейти к формированию математической модели, описывающей относительное перемещение инструмента (резака) и заготовки.

МАТЕМАТИЧЕСКАЯ МОДЕЛЬ ФОРМИРОВАНИЯ ОТВЕРСТИЙ

В общем случае отверстие смещено на величину   относительно вертикальной оси обечайки теплообменного аппарата (рис. 3).
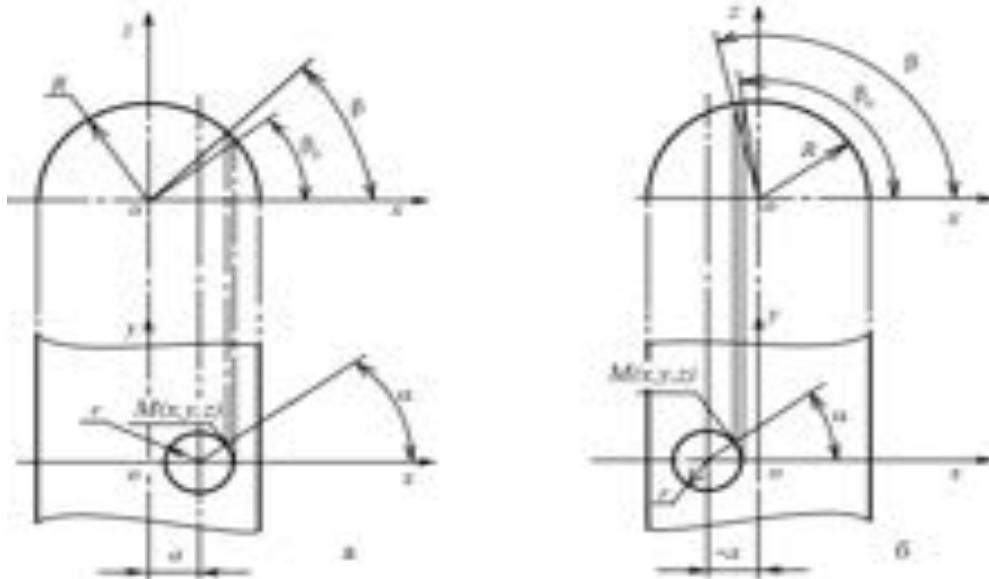
Рис. 3. Образование отверстия в заготовке: а, б – возможные положения тангенциальных отверстий относительно осевого центрального продольного сечения

Система уравнений связи движение в двух плоскостях zox и yox имеет вид [1]:

$$\begin{cases} x = a + r\cos\alpha, \\ y = r\sin\alpha, \\ z = \sqrt{R^2 - (a + r\cos\alpha)^2}, \end{cases} \quad (1)$$

$$z = x\,\mathrm{tg}(\beta) \quad (2)$$

где R – радиус корпуса теплообменного аппарата; r – радиус отверстия; a – смещение оси отверстия от вертикальной оси; β – угол, под которым в каждый момент времени находится секущая плоскость отверстия в плоскости zox; α – угол, под которым в каждый момент времени находится секущая плоскость отверстия в плоскости yox.

В частном случае, когда центр отверстия находится на вертикальной оси сечения заготовки величина $a=0$, а система уравнений (1) приобретает вид:

$$\begin{cases} x = r\cos\alpha, \\ y = r\sin\alpha, \\ z = \sqrt{R^2 - r^2\cos^2\alpha}, \end{cases}$$

Тогда элементарные приращения координат z и y могут быть представлены как:

$$dz = \frac{-Rr\sin\alpha\,d\alpha}{\sqrt{R^2 - (a + r\cos\alpha)^2}}; \quad dy = r\cos\alpha\,d\alpha \quad (3)$$

Исходя из (3), элементарное приращение траектории относительного перемещения заготовки и газового резака:

$$dl = \sqrt{(dz)^2 + (dy)^2} = r\left(\sqrt{\dfrac{1 - \left(\dfrac{a}{R} + \dfrac{r}{R}\cos\alpha\right)\cos^2\alpha}{1 - \left(\dfrac{a}{R} + \dfrac{r}{R}\cos\alpha\right)^2}}\right)d\alpha. \quad (4)$$

Тогда, с учетом того, что $\alpha = \omega t$, из выражения (4) следует, что скорость перемещения резака вдоль траектории реза будет равна:

$$V = \frac{dl}{dt} = \frac{dl}{d\alpha}\frac{d\alpha}{dt} = r\omega\left(\sqrt{\dfrac{R^2 - (a + r\cos\alpha)^2\cos^2\alpha}{R^2 - (a + r\cos\alpha)^2}}\right) \quad (5)$$

Поскольку выражение (5) представляет собой непрерывную функцию, то можно определить параметр ω, который в точке $\alpha=0$ приводит уравнение (6) к виду:

$$V = \pm r\omega.$$

Аналогичное выражение получаем при значении параметра $\alpha=0$ в выражении (3):

$$V = \frac{dy}{d\alpha}\frac{d\alpha}{dt} = r\omega\cos\alpha. \quad (6)$$

Разделив уравнение (4) на величину R, получим элементарное приращение угла β:

$$\frac{dl}{R} = d\beta = \frac{r}{R}\left(\sqrt{\dfrac{1 - \left(\dfrac{a}{R} + \dfrac{r}{R}\cos\alpha\right)\cos^2\alpha}{1 - \left(\dfrac{a}{R} + \dfrac{r}{R}\cos\alpha\right)^2}}\right)d\alpha \quad (7)$$

Тогда для угловой скорости изменения угла поворота заготовки β, получим:

$$\frac{d\beta}{dt} = \frac{d\beta}{d\alpha}\frac{d\alpha}{dt} = \frac{r\omega}{R}\left(\sqrt{\dfrac{1 - \left(\dfrac{a}{R} + \dfrac{r}{R}\cos\alpha\right)\cos^2\alpha}{1 - \left(\dfrac{a}{R} + \dfrac{r}{R}\cos\alpha\right)^2}}\right) \quad (8)$$

Полученные выражения (6) и (8) позволяет реализовать законы управления реверсивными движениями: линейным – резака, вращательным – обечайки цилиндрической заготовки.

Следовательно, полученные выражения позволяют разработать такой принцип управления процессом обработки отверстий, который обеспечит поддержание результирующей скорости V резака постоянной в автоматическом режиме.

МАКЕТ РОБОТИЗИРОВАННОГО УСТРОЙСТВА.

Предложенный макет, изготовлен с применением $3D$ – прототипирования [2, 3]. Он содержит цанговый зажим, в который закреплена трубчатая заготовка, базирующаяся в кинематических призмах с возможностью реверсивного вращения вокруг его продольной оси. Модуль инструмента для плазменной резки имеет возможность продольного перемещения вдоль заготовки.
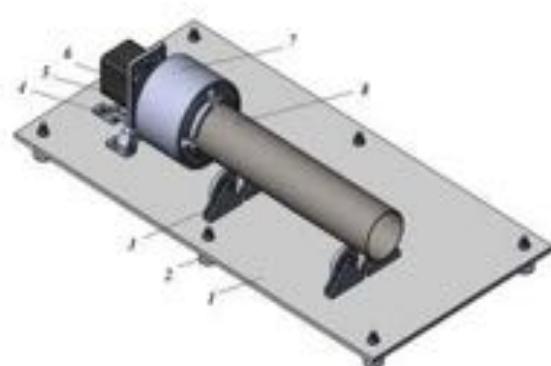

Рис. 4. Узел вращения заготовки: *1* – основание; *2* – регулируемые опоры; *3* – роликовые опоры; *4* – держатель для привода; *5* – привод; *6* – узел подшипниковый; *7* – цанговый зажим; *8* – заготовка

Установка содержит два привода: вращения и линейного перемещения, которые, работая совместно, позволяют получить требуемые траектории и скорости перемещения резака, необходимые для выполнения отверстий разного диаметра и различного положения на поверхности обечайки.

Узел реверсивного вращения заготовки, представлен на рис. 4.

Заготовку 8 закрепляют в цанговом зажиме (7) и приводят во вращение приводом (рис. 3). Узел вращательного движения (рис. 1) выполнен следующим образом. Основание (1) установлено на регулируемых опорах (2) для его выставления в горизонтальном положении. Трубчатая заготовка (8) устанавливается в цанговый зажим (7), закрепленный на валу привода (5), и опирается на роликовые опоры (3). Привод (5) установлен на кронштейне (4). Вал привода (3) установлен в подшипниковом узле (6).

Модуль продольного перемещения рабочего органа (рис. 5) установлен на опоры (3), основания (1). Привод (4) установлен в держателе (5). Через муфту (7) вращения от привода передается на шариковинтовую передачу (8), приводящую в движение по цилиндрическим направляющим (11), закрепленными в кронштейнах (6) и (13), узел рабочего органа (9). Оба кронштейна установлены на опорах (3). Вал шариковинтовой передачи (8) установлен в подшипниках (12). В макете, в качестве инструмента использован маркер (10) закреплённый в узле рабочего органа (9).

Работа описанного устройства смоделирована в инженерном программном комплексе, где для двух двигателей заданы законы движения и получена результирующая траектория движения (рис. 6). Реальный макет представлен на рис. 7.
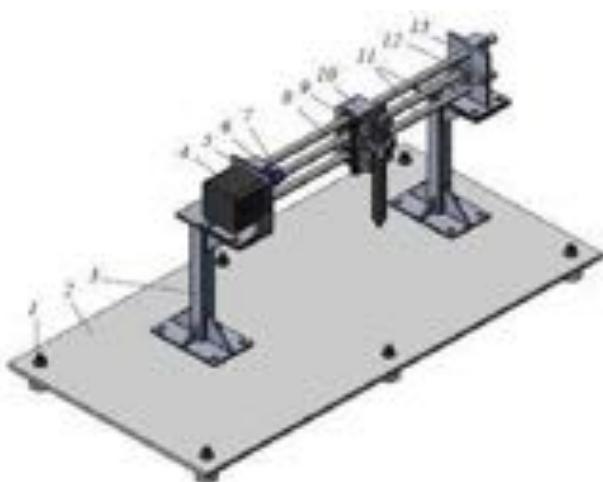

Рис. 5. Узел продольного перемещения рабочего органа макета роботизированного устройства для обработки отверстий: 1 – регулируемая опора; 2 – основание; 3 – опоры; 4 – привод; 5 – держатель для привода; 6 – узел подшипниковый; 7 – муфта; 8 – шпилька резьбовая; 9 – узел рабочего органа; 10 – маркер; 11 – направляющие цилиндрические; 12 – упор подшипниковый; 13 –крепление для подшипникового упора

Рис. 7. Разработанный и изготовленный макет экспериментальной установки

УПРАВЛЕНИЕ РОБОТИЗИРОВАННОЙ ОБРАБОТКОЙ ОТВЕРСТИЙ

В зависимости от марки и толщины разрезаемого материала заготовки, технологами назначается требуемая скорость резания, зазор между заготовкой и резаком. По величине скорости вычисляют параметр ω.
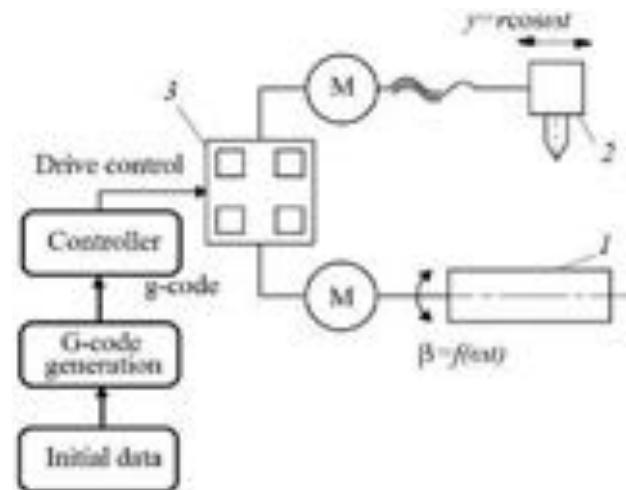
Рис. 8. Схема управления процессом обработки отверстия: 1 заготовка; 2 резак; 3 плата с драйверами

Затем, в соответствии с исходными данными: положением и размерами выполняемого отверстия, и полученными выше параметрическими зависимостями координат и скоростей перемещения инструмента, выходные параметры преобразуют в так называемый G-Code. G-Code ¬ это набор команд, содержащий информацию о перемещениях рабочих органов, которая загружается в память контроллера. Далее контроллер передает управляющую программу драйверам исполнительных механизмов, которые приводят систему обработки отверстий в действие (рис. 8).

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AUTOMATED UNIT FOR NAIL AND THIN-WALLED WASHER ASSEMBLING

Zautomatyzowane stanowisko do montażu gwoździa w cienkościennej podkładce

Роботизированное выполнение отверстий под сварку в цилиндрических крупногабаритных заготовках

Konrad KLUSEK, Janusz KOBIAŁKA, Marcin WELC

A b s t r a c t: In the paper, the automated unit for nail-washer assembling has been presented. The nails with the same diameter and different lengths are inserted to the thin metal washer.
K e y w o r d s: automated machine design, assembly process, joining elements, washer, weldable nail

S t r e s z c z e n i e: W artykule przedstawiono w sposób syntetyczny zautomatyzowane stanowisko do montażu wybranego typoszeregu metalowych gwoździ (o tej samej średnicy i różnych długościach) w metalowej, okrągłej i cienkościennej podkładce
S ł o w a   k l u c z o w e: stanowisko montażowe, proces montażu, łączenie elementów, podkładka, gwóźdź zgrzewalny

Introduction

The contemporary times have charged the humanity with a special duty of taking care of the environmental protection. We segregate the rubbish; we leave the waste electronic and electric equipment at the special points, or we run organic cultivations in our household gardens.

Also, in the field of industry, we try to reduce the energy losses, when applying different types of thermal insulation. We limit the emission of vibrations and noise to the environment by insulation of their sources, as well. The most popular insulating materials, as employed in a form of mats, rollers and coatings (Fig.1) must be fixed to the protected objects.

Assembling with the application of nails (Fig.2 and 4), struds (Fig.3), and mandrels from weldable wire are a relatively new and more and more popular method for fixing the insulating layers in the case of metal casing of the objects.

Demand on such assembly elements is constantly increasing; hence, there is a need of their mass production. Responding to the request of NEWIR Company with the seat in Warsaw, which supplies the assembling, and constructional accessories and pre-fabricated products for construction of ventilation, heating and air-conditions equipment, Institute of Mechanized Construction and Rock Mining undertook the work on development and performance of automated unit for assembly of weldable nail and thin-walled washer.

Additionally, there was designed and started up the unit for punching of metal sheet in a form of tape. The punching unit consists of the following elements:

Rys. 1. Maty, rolki i otuliny izolacyjne (źródło: materiały firmy NEWIR [1])
Fig. 1. Mats, rollers and insulating coatings (source: NEWIR [1])

Rys. 2. Mata izolacyjna zamocowana do kanału wentylacyjnego przez zgrzewalny gwóźdź, wyposażony w dodatkową podkładkę izolacyjną (źródło: materiały firmy NEWIR [1])
Fig. 2. Insulation mat attached to the ventilation duct by a weldable nail equipped with an additional insulating pad (source: NEWIR [1])

- Eccentric press with pneumatic conveyor of tape, the task of which is to shift the tape under the stamp, with the constant stroke of the tape (Fig. 5),
- Mechanism, allowing to unwind the tape of steel sheet (Fig.6),
- System of buffer of the unwound tape (Fig.7) together with the sensors of the tape situation

Rys. 3 . Szpilki służące do mocowania poprzez zgrzewanie lub spawanie izolacji termicznych i akustycznych na powierzchniach stalowych - głównie kotłów, zbiorników (źródło: materiały firmy NEWIR [1])
Fig. 3. Struds for fixing by welding thermal and acoustic insulation on steel surfaces - mainly boilers, tanks (source: NEWIR [1])

Rys. 4. Gwóźdź zgrzewalny z klipsem samozaciskowym wykorzystywany w instalacjach wentylacyjnych, grzewczych i klimatyzacyjnych do mocowania na gładkich powierzchniach (źródło: materiały firmy NEWIR [1]).
Fig. 4. Weldable nail with self-locking clip used in ventilation installations, heating and air conditioning for fixing on smooth surfaces (source: NEWIR [1])

The punching unit supplies the washers to production of ready connector in the automated unit.

Analysis of the existing solutions of the automated machine for assembly of weldable nails

The weldable nails have been known in the industry for many years and in spite of this fact, in general literature concerning production automation as well as in publications of nail producers, any information on automated assembly units serving for production of such type of product has not been found. From available information, it is followed that manufacture of weldable nails takes place most frequently in the manual work sites or in semi-automated units. It is connected with many problems relating to the automation of the discussed process.

The problem itself concerning combination of the object of roller type and another object, possessing the roller-like opening is widely met in the industry [2}. For example, there are automatic devices for assembling the

Rys. 5 . Prasa mimośrodowa z pneumatycznym podajnikiem, przesuwającym taśmę w przyrządzie narzędzia wykrawającego podkładki, z lokalnym pulpitem sterującym (źródło: własne)
Fig. 5. Eccentric press with pneumatic conveyor, for moving the tape in the instrument of a washer punching tool, with a local control panel (source: own)

Rys. 6. Odwijak taśmy blachy stalowej z lokalnym pulpitem sterującym (źródło: własne)
Fig. 6. Belt sheet unwinder with a local control panel (source: own)

The assembly of the nails with the washer may be investigated in the device, presented in Fig.8 and in the materials of the producers [4], [5]. It is a special machine, destined for production of paper nails, the so-called umbrella nails. The nails are made of a wire which is wounded by the system of rollers. Flat washers with opening, placed in vibrating conveyor are then stacked in a pile from where a single washer falls down to matrix. The washer is nailed on a cut piece of wire and then a part of head of the nail is formed. Next, the wire conveyor pulls out the wire with washer in appropriate distance which is a set length of the nail and after it, there is a movement of two lateral scissors which shape the edge of the nail and, also, cut off the shaped nail which falls down to a storage bin. Subsequently, the washer is driven on the cut part of a wire and the process is cyclically repeated. The performance of automates of the discussed type is $50 \div 70$ [pcs/min.] [2], depending on the length of the nail. The presented process is easy in respect of automation because the details have an uncomplicated shape – a drawn wire and relatively high washer and with a small external diameter. Owing to such solution, the detailed parts are quickly and perfectly oriented and by this, all units of the machine may be driven from one engine, using a set of gears and cams. Control consists only in change of rotary speed of the engine. The washer is driven in the end of the nail having a length of several millimeters and is formed in the shape of umbrella, with the simultaneous forming of the end of the nail. It is probably connected with a smaller force necessary for joining than in the case of pushing out the whole length of the nail throughout the washer because the processes of friction and punching of the washer's material do not occur in such length. Generally, the force required for such type of joint is dependent on mutual relation of diameter of the nail and diameter of a hole in the washer and on the materials from which these elements are produced.

nails and washer, for molder's sprigs, for applicators with caps or for expansion bolts. The dimensional specificity of the defined detailed parts causes that the discussed processes may run with a different speed; the methods for solving the basic assembly problems are similar.

In spite of the fact that the presented below automated assembly units produce the detailed parts with a somewhat different shape and dimensions as compared to those required ones, their constructors had to solve many similar problems, beginning from supply and addressing the details, ensuring the appropriate quality of joining, separation of the correctly joined details from the defective ones and receipt of the finished details.

Another example of automate which implements similar tasks is machine for assembling paper nails (Fig.2) described in publication [1]. The mentioned automat joins

Rys. 9. Automat do montażu gwoździ papowych z podkładką. Po lewej: widok z przodu, po prawej: widok na strefę montażu (źródło: własne) Automatic machine for tar paper nail and washer assembly.
Fig. 9. On the left: front view, on the right: view of the assembly zone (Source: own)

the nails of the length up to 36 [mm] and the washers of diameter of 30 [mm].

The nails and washers are oriented and conveyed to buffer strips using vibratory feeders. The cluster, driven by pneumatic servo-motor contains two sockets which are alternatively positioned under the mechanism of a single dispensing of washers. After taking a correct position, the washer falls down to the socket of the cluster. At the same time, a single nail falls down into the centering head, being situated above the socket. After positioning of these two details, there is a movement of stamp, causing joining of nail and washer together. Then, the cluster is shifted into another extreme position and the extractor situated under the socket throws the linked detail from the socket away. At the same time, in the neighboring socket, the simultaneous process of assembly is carried out, owing to which the capacity of the machine is equal to 2 pieces per second.

In the both presented above automates, the nail-washer joint is assured by flanging of the sheet on the nail. For the plate of 1÷2 [mm] thickness, the discussed type of joint is durable. In the case of weldable nails, the washers are very thin, they have 0.5 [mm] thickness; due to this fact such type of joint cannot be performed. The joining is obtained, therefore, by appropriate formation of the bottom of the nail which is tightened on the both sides on the opening of the washer.
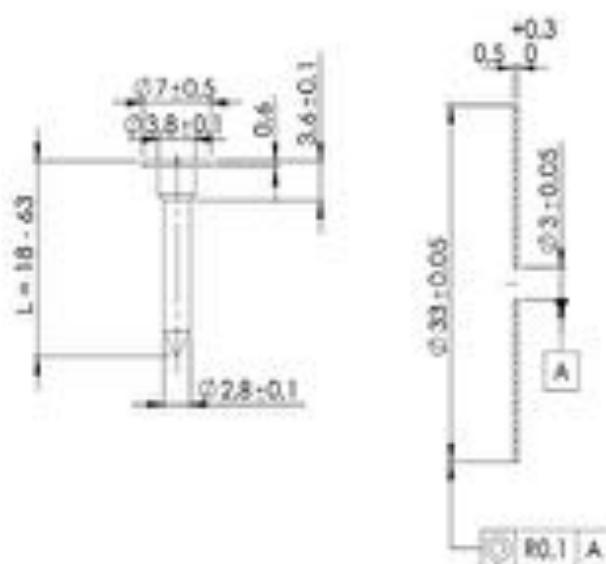
A thin washer causes also many other problems. A small thickness of the metal plate excludes a series feeding of the washers, one next to another. A small weight causes that the process of inserting the washer to the socket must run slower and more precisely; it is not enough to base upon the gravitation forces or compressed air.

The assumptions to development and performance of the automated assembly unit

The assumptions concerning details intended for assembly

A view of the nail and washer and their basic dimensions are given below in Fig. 10.

The joint between the nail and washer should be durable and aesthetic. The nails should not lose a permanent contact with the nail during their packaging into cartoons and during transportation. The nail should be positioned rectangular to the surface of the washer with tolerance of ±5 [o] in relation to the axis of the washer. The embossed head of the nail should be faced with the front surface of the washer. It is allowed to flange the edge of the washer during the assembly.

Rys. 10. Widok gwoździa i podkładki (źródło: własne)
Fig. 10. View of the nail and washer (source: own)
The nails differ in length which is found within the interval of 18 – 63 [mm]. The washers are flat, not moulded.

The assumptions of the construction of automated work stand for assembly of the nail and washer

Construction of the automating device has been based upon the multi-position, indexing-rotary table on which the sockets will be fixed in a constant distance each other. The table will perform, each time, the rotation by one position, carrying the detailed parts for further operations. By this, the time for performance of one complete detail piece will be a sum of performing the longest operation and the change of the table position into the successive one. The operations to be performed in the successive working positions include:

- Delivery of washers to the sockets of the table – the washers will be manually placed in the vibrating feeder, from where they will be stacked in a tube of buffer; the buffer will be equipped with two tubes: the empty tube will be filled from the vibrating feeder and from the full tube, the single washers will be selected and inserted with the manipulator to the socket in the indexing-rotary table,
- Preliminary association of the washer and nail (putting the nail in the washer) – the nails will be manually fed to the vibrating feeder of nails where they will oriented and directed to the buffer strip of the nails; the guiding part of the feeder may be utilized for the nails in the total range of their length, without the necessity of rearming or additional regulation; at the end of buffer strip, there will be a mechanism of single release of a nail the task of which will be to pick up a single nail from the strip and put it in the opening in the washer; to simplify the service, it was assumed that the association of all types of the nails with the opening in the washer will be performed with the use of the same servo-motor with the constant stroke,
- Formation of joint of the nail and washer – the stamp of the pneumatic-hydraulic actuator will perform the tightening of the nail and the washer,
- Release (pushing out) of the ready assembled detail from the socket matrix – the pneumatic actuator will perform the release of the detail from the socket by breaking the friction forces of the detail in relation to the socket matrix,
- Removal of the detail from the socket - the manipulator will take a final detail from the socket and throw it to the container of good products.

The additional assumptions

Between the particular working positions of the table, a series of sensors, supervising the correct functioning of the machine in the particular positions will be installed.

In the case of discovering the irregularities, the operation will be informed about the existing problem by a light and sound signal.

All mobile elements of the machine will be protected in accordance with the obligatory rules and good engineering practice, with assurance of a free access to subunits of the equipment.

All actuators, being present in the equipment, as well as manipulators will possess pneumatic or electric drive.

The automated assembly station for assembly of the weldable nail and thin-wall washer and the selected problems occurring during its performance

After approval of the assumptions of the project of the working unit by the Orderer, i.e. NEWIR Company, the implementation of the project was commenced.

At the beginning, the time was dedicated to designing of the model of assembly sockets with matrixes and after a series of the trials, the appropriate type and shape of the matrix was selected. In the situation of thin-wall washer and the set shape of the nail head, the construction of such matrix that would ensure – after assembly – the stable inseparable joint of the nail and washer was a big problem. It is very important for the later process of welding the nail to the metal surface e.g. of the insulated reservoir or ventilation system. The mentioned joint must ensure as small as possible resistance for the current during the welding process. It became successful.

The shape of matrix was so selected that after performance of the joint, the detailed part may be removed from the matrix without the necessity of its opening and, at the same time, not causing any damages of the detail itself.

It allows time saving and decreases the costs of constructing the machine.

The successive challenge included transport of the separated washers between the cylindrical vibrating feeder and the tube of their buffer. Due to zinc coating of the washers, their flow on the transporting gutter was difficult. The problem was however solved owing to the passage of the details of the air cushion.

A lot of time was also dedicated to the appropriate modelling of mechanism of a single release of the nail. Selection of its shape and geometric parameters requires especially much work. A capture of a single dispatched mail by the magnetized prism and its introduction to centring jaw head occurred to be a helpful operation. The mentioned head facilitates placement of the nail in the central hole of the washer – the preliminary association of the nail and the washer.
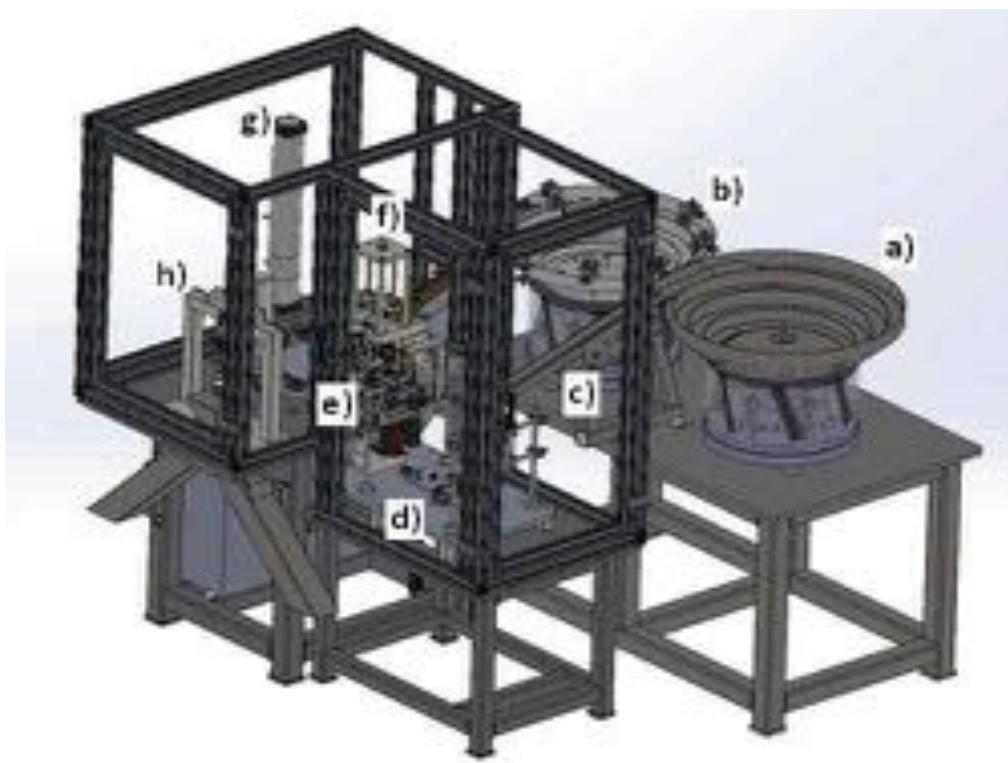
Owing to, inter alia, the mentioned above operations it was possible to give a final shape to the device (Fig.11 and 12).

Conclusions

The described work caused construction of the automated station for assembly of the weldable nail and thin-wall washer for the most frequently sought series of types of the nail lengths i.e. from 188 mm to 63 mm. The capacity of the machine is equal to 1.5 seconds up to 1.6 seconds per one piece. During constructional and implementing stage it was possible to develop such shape of matrixes which guarantees the repeatability.

The unit for cutting the washers as the auxiliary device, supplying the detailed parts to the process of the assembly of the nail and the washer is working with the output not lower than one piece per second. It cuts out the washers from galvanized steel tape of 0.5 mm thickness using fours-socket device from the tape of the 70 mm width and six-socket unit from the tape of 102 mm width. The both devices are adapted to the work with the press stroke equal to 20 mm and stroke of the tape feeder equal to 33 mm.

Rys. 11. Widok zaprojektowanego zautomatyzowanego stanowiska montażowego składającego się z: podajnika podkładek, podajnika gwoździ, rynny transportującej rozseparowane podkładki, bufora podkładek z magazynkami tubowymi, stacji pobierania podkładki z tuby bufora do gniazda stołu obrotowego, stacji wydania pojedynczego gwoździa i umieszczenia go w podkładce, prasy montującej gwóźdź z podkładką, stacji zdejmowania gotowego detalu ze stołu obrotowego (źródło: własne)

Fig. 11. A view of designed automated assembly station - washer feeder, nail feeder, gutter for transporting separated washers, washer buffer with tube magazines, unit for collecting washers from buffer, and placing in rotary table socket, unit for the release of a single nail, and placing it inside the washer, the press for nail and washer assembling, unit for removing finished part from the rotary table (source: authors)

Rys. 12. Widok wykonanego zautomatyzowanego stanowiska montażowego (źródło: własne)
Fig. 12. A view of automated assembly station (source: authors)

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E-CAR'S DOOR BEAM OPTIMIZATION

Optymalizacja belki bocznej drzwi kabiny pojazdu elektrycznego

Оптимизация боковой балки дверей кабины электромобилья

Andrzej BARSZCZ, Mirosław CHŁOSTA

Abstract: The design of the shell and tube heat exchangr includes a tube-like shell with holes to which an inlet and outlet pipes are welded. Radial and tangential holes are produced manual-ly by means of plasma cutting with the use of specialized tools, which determines high labo-riousness of heat exchangers production. An automatic device is proposed to reduce the labo-riousness of this operation. To produce the hole in the heat exchanger shell, two reversible motions are superimposed: linear motion of the cutter along the longitudinal axis of the shell and the shell rotary motion. A mathematical model of the required cutter motion is proposed, which describes the relative trajectories of the plasma cutter and the shell in parametric form. To verify theoretical premises, a prototype of the device was produced using a 3D pro-totyping technology, a ball screw for the reversible linear motion of the cutter and a stepper motor for the reversible rotary motion of the shell. The shell is fixed by means of a collet chuck and rests on the pipe roller support.

Keywords: passive safety, simulations, FEM

Streszczenie: Bezpieczeństwo bierne pojazdów jest jednym z ważniejszych problemów konstrukcyjnych. Rozwiązuje się go poprzez zastosowanie odpowiednich materiałów, głównie stali o bardzo wysokiej wytrzymałości i odpowiednie ukształtowanie elementów konstrukcyjnych. Niniejsze opracowanie przedstawia wyniki optymalizacji belki drzwi kabiny pojazdu N-Truck, projektowanego w ramach programu INNOMOTO, projekt nr: POIR.01.02.00-00-0194/16. Jako kryterium przyjęto graniczne wartości dopuszczalnych odkształceń elementów usztywniających oraz wartości naprężeń.

Słowa kluczowe: bezpieczeństwo bierne, symulacje, MES

Introduction

Steels with miscellaneous mechanical properties are the basic construction materials of the modern passenger cars body structure. The construction elements of the passenger car body are shown by the types and grades of their material on the Fig.1. The main construction material in the automotive industry is steel, despite the increasing use of aluminium alloys, magnesium, composite materials and plastics. This is mainly due to economic factors and the possibility of changing the properties of steel in a wide range. This helps to reduce vehicle weight and thus reduce fuel consumption while providing passengers with an adequate level of car passive safety. The hot and cold rolling stainless steels are common used in car body manufacturing. Annealing and normalizing after forming leads to ferritic steel structure. On the other hand the new steel generation needs the innovative forming process to get the more complex structure.

The traditional spot-welding technology is most popular until today, meanwhile laser welding and soldering, hybrid laser gluing, riveting technologies growing up [1].

Despite the expansion of technologies such as welding and laser soldering, hybrid laser, gluing, riveting and crimping resistive spot welding remains the main method of assembling the car bodies [1].

The steels used in the automotive industry can be divided into the following groups:

I. mild, plastic, low carbon steels (DQSK, IF) with an ultimate strength of Rm below 300 MPa and elongation A of 30 ÷ 60%;
II. Conventional steels with high strength HSS (BH, C Mn, IF with microadditives, HSLA) of 300 < Rm < 700 MPa and reduced A compared to the previous group;
III. Steels with very high strength AHSS (Rm above 700 MPa, up to 2000 MPa) and elongation range of 5 ÷ 30%, with the increase in strength goes with the reduction of plasticity;
IV. High manganese steel TRIP/TWIP with very heavy strength up to 1200 MPa and very high plasticity.

The first two groups, known for many years, are materials used to build self-supporting car bodies on a mass scale manufacturing, due to good plastic properties. The steels of group III and IV are successively implemented into manufacturing and their share is steadily increasing, mainly in the passive safety elements.

The body structure consists of different profiles. By selecting their sections, shapes and materials, a controlled crushing zone accumulating the impact energy is obtained. A car body stiffness shall ensure the survivability of passengers. Guidelines for structural work
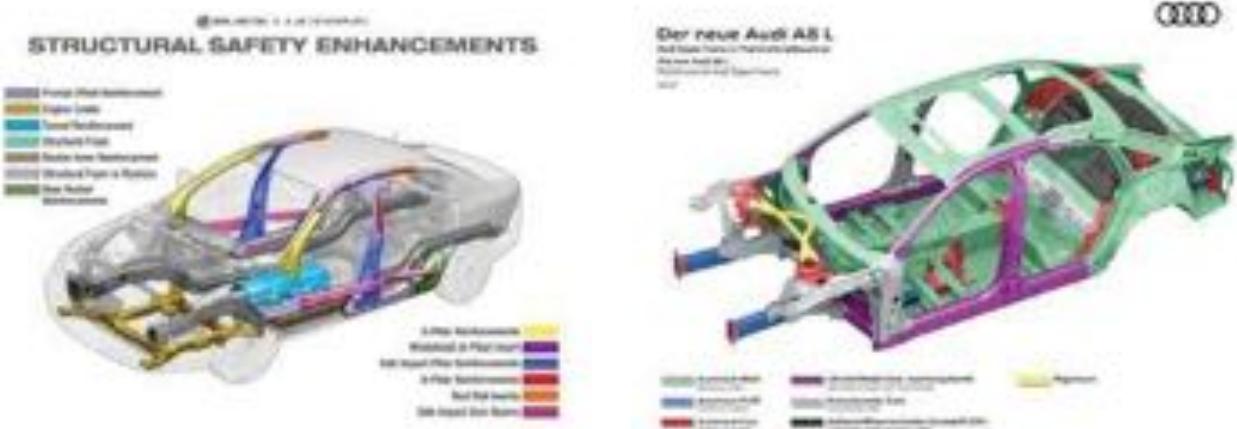
Fig. 1.The main structuralmaterials of the cars bodiesparts [3].
Rys. 1. Materiały konstrukcyjne użyte do produkcji istotnych elementów nadwozia pojazdu
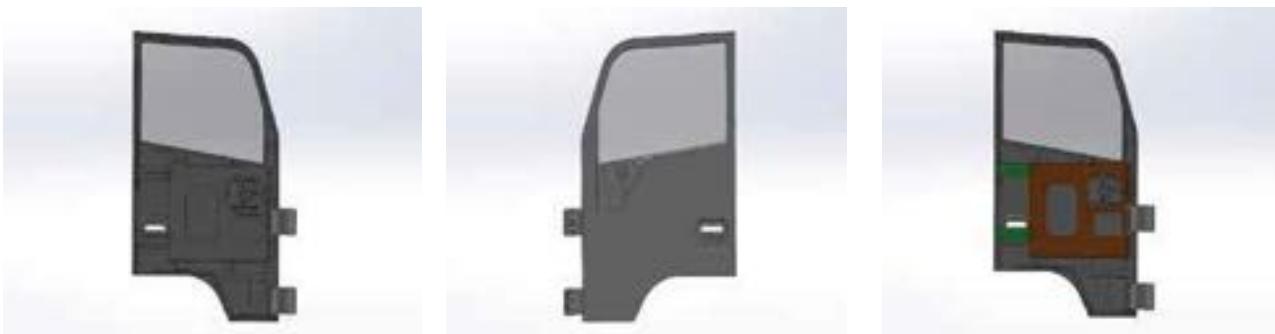
Fig. 2. Left doors of the N-Truck car and reinforce elements
Rys.2. Drzwi lewe kabiny pojazdu N-Truck oraz element wzmacniające

are obtained of crash test results. Their methodology and evaluation criteria have been determined by the NCAP organization since 1996, which aims to harmonize the criteria used globally. It contains frontal, lateral and pedestrian impact tests. The results are announced to them after the completed attempts.

Verification test procedures

Spot tests and crash tests are the final verification of the solutions adopted. The General Motors' procedures have been adopted as guidelines for calculation methodology and criteria for assessing their performance in this work [6]. Vertical displacement f of the stamp at a constant speed of v< 12.7 mm/s (0.5˝/s) is inflicted on the final value fk = 152.4 mm (6˝). For displacements value fmax = 115 mm, the beam reaction force F should be greater than F(fmax) = 10 kN. The maximum beam strength (Fmax) and the mean force (fav), calculated as the ratio of the field under the F(f) curve to fk, shall also be determined. The simulation studies described below in the study are intended to shorten the time of finding the optimum shape and stiffness of the beam. In this work, the elastic modeling of the door frame was omitted due to lack of data.

Scope of the work

The work is carried out in the POIR. 01.02.00-00-0194/16 grant aiming to develop the design and manufacture of a prototype of an electric modular vehicle, with a DMC 3.5 t for transport in urban and industrial areas. This vehicle is temporarily named N-Truck.

Simulation works

Reinforce elements

The N-Truck door model was developed by MELEX and delivered as a step file to IMBiGS. The door view is shown in Fig. 2.

The possibility of mounting additional safety elements in the door space has not been provided, due to limited space. Therefore, the functions of the safety beam must be taken over the other parts, such as the window guide brackets and the door lock. These are shown in Fig. 2 by selecting green and brown.

Material properties

The each element of the beam were made of 2 mm thick Strenx 700 MC steel sheet. This is a hot rolled structural steel, with a minimum yield strength of ReH = 700 MPa, dedicated for cold forming, enabling the more

| Yield strength () min [MPa]	Ultimate strength Rm [MPa]	ElongationA80min % Probe thickness t < 3mm	Elongation A5min % Probe thickness t <3mm
700	750 - 950	10	12
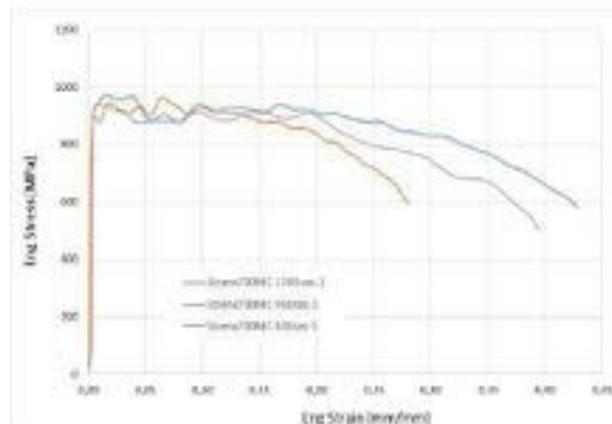
Fig. 3. Strenx 700 MC steel characteristic [5] and its model for simulation
Rys. 3. Charakterystyka stali Strenx 700 MC oraz model przyjęty do obliczeń.

powerful and lighter structures manufacturing. Strenx 700 MC meets and even exceeds the requirements for steel S700MC as in EN 10149-2 standard. The mechanical properties and the model of this steel adopted for the calculations are shown in tab. and in Fig. 3

MELEX beam simulation
Load

The door frame stiffness has not been taken into the model due to the lack of sufficient information. Due this, the fixed hinge and the fixed geometry were applied as the model constrains. The simulations were done for the conditions described in point "Simulation works". Such a model has been applied in the other cases concerned in this paper. The boundary conditions were worse than the real.

Results of simulation

Results of simulation were shown below.

The calculation results shown above show that the MELEX beam carries higher than recommended loads in the GM test. Unfortunately, its stiffness is too small, which is illustrated in two consecutive drawings.The stiffness criterion does not meet. Too little force was reached for 115 mm punch displacement. Its value is 1 740 N, which is more than 6 times less than required.

Conclusion

The door beam proposed by MELEX does not meet the requirements of these types of car components. First, it is not a technologically optimal design. It introduces additional operations to the manufacturing process, increasing its time and material intensity and thus the cost of manufacturing. Second, the results of the calculations carried out that the safety components made of STRONX 700 MC steel are capable of transferring higher than normative loads but do not meet the stiffness condition, which should eliminate them from the use. For this


Fig.4. MELEX beam. Stress distribution (Huber-Mises) and displacement
Rys. 4. Belka MELEX. Naprężenia zredukowane wg hipotezy Hubera-Misesa oraz przemieszczenia
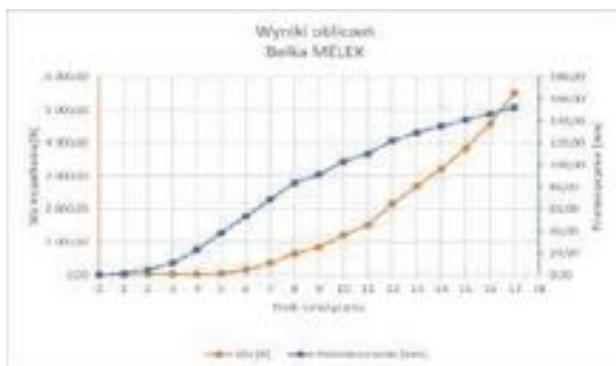
Fig. 5. MELEX beam. Displacement and reaction force in following calculation steps and force vs displacement
Rys. 5. Belka MELEX. Przemieszczenia i wypadkowa siła reakcji w kolejnych krokach obliczeń oraz siła w funkcji przemieszczenia

reason, change their shape is necessary . The goal is to achieve more optimal stress distribution and improve the technology of the parts. In this second aspect it is about restrict the number of welding operations and replacing them with plastic machining or bending.

Beam optimizing. Beam No. 1.
Geometric model

The N.Truck door beam was based on a windshield lifting mechanism. As previously stated, additional space for reinforcing elements was not included. Therefore, they must fulfill a dual role: to protect the driver's space from lateral impact and to act as a support function for the mechanisms located inside the door (lock, windshield lifting mechanism, etc.). An additional assumption was the variability of the beam dimensions and the fixing points (Fig.6.). Therefore, the beam was made as a monolithic element of a steel sheet with 2 mm thickness. This parameter has a fixed value because it is the smallest thickness available at the supplier of the sheet.
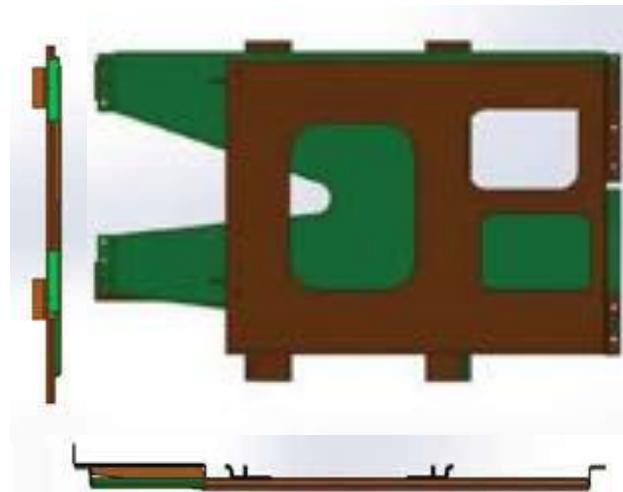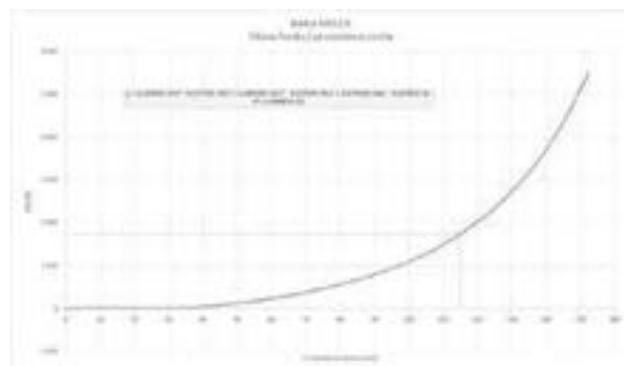
Fig. 6. The new shape of the beam, the primary in the background
Rys. 6. Nowy kształt (kolor zielony) belki wzmacniającej na tle pierwotnej

The first concept of solution against the MELEX in the background is shown in Fig.6. The new reinforcement elements are marked with green color.

Simulation results

Results of simulation were shown below on Fig. 7.
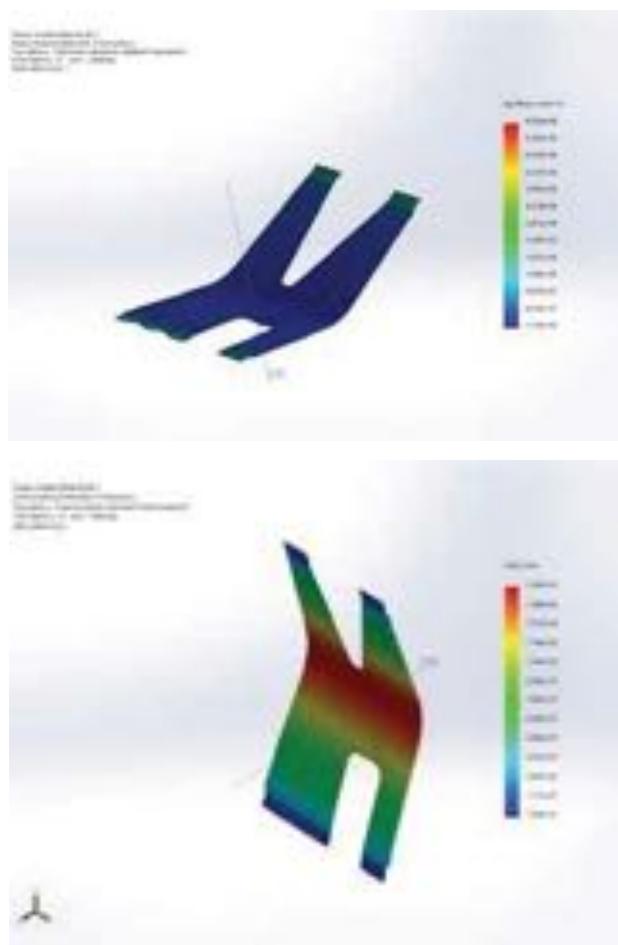
Fig. 7. Stress value. Stress distribution (Huber-Mises) and displacemant
Rys. 7. Naprężenia zredukowane wg hipotezy Hubera-Misesa oraz przemieszczenia

Force and displacement variation in time were show on Fig 8.
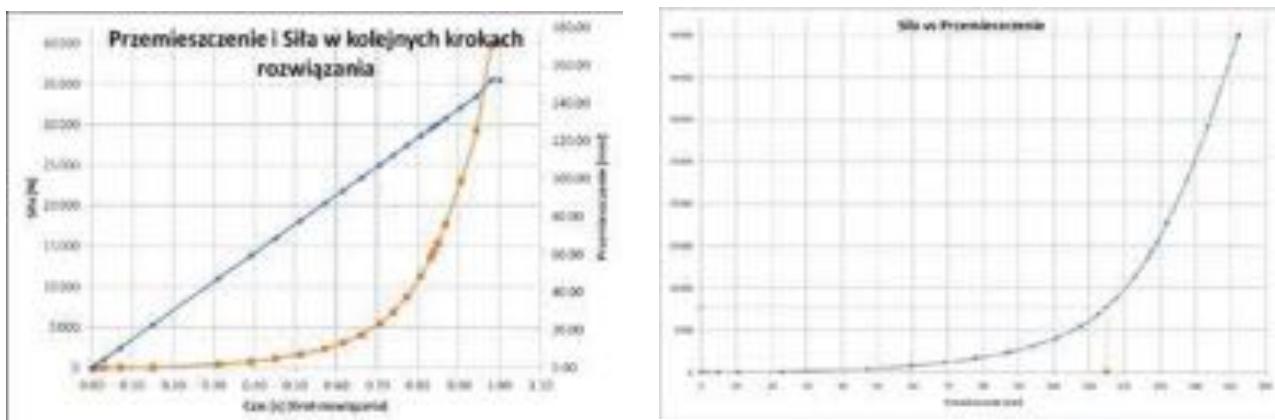
Fig.8. Displacement and reaction force in following calculation steps and force vs displacement
Rys. 8. Zmienność siły i przemieszczenia w kolejnych krokach rozwiązania (czasu) oraz siła w funkcji przemieszczenia

Conclusions

The simulation results presented above show that the beam carries loads greater than those recommended in the GM test. Unfortunately, beam stiffness is too small, as illustrated in Fig. 8. The stiffness criterion is therefore not met. Force value at the 115 mm punch displacement is approx. 7 800 N, i.e. representing 78% of the minimum required value.

Beam optimizing. Beam No 2.
Geometric model

The optimization first step conclusions are used to new beam shape design. The goal is to make lower the beam cross section to obtain the plastic deformation at the smaller displacement values. A basic dimensions of the beam were shown on Fig. 9.
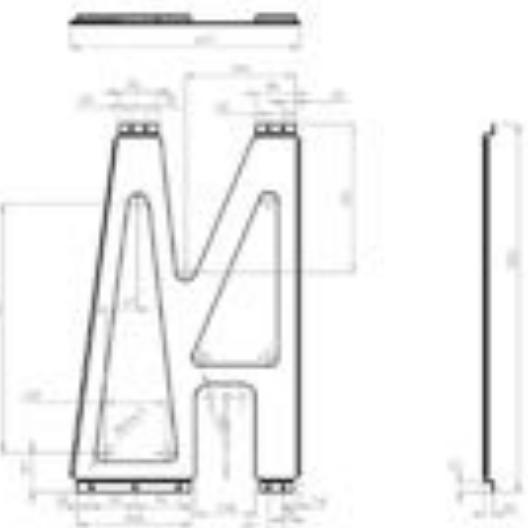
Fig. 9. Main beam dimensions – version 2
Rys. 9. Podstawowe wymiary belki bocznej – wersja 2
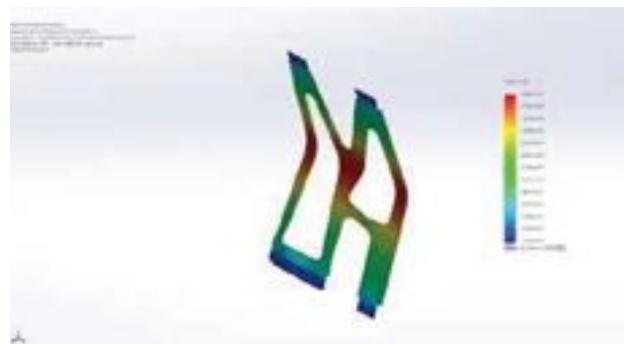
Fig. 10. Beam 2. Stress distribution (Huber-Mises) and displacement
Rys. 10. Belka 2. Naprężenia zredukowane wg hipotezy Hubera-Misesaoraz przemieszczenia

Results

Force and displacement variation in time were show on Fig 11.
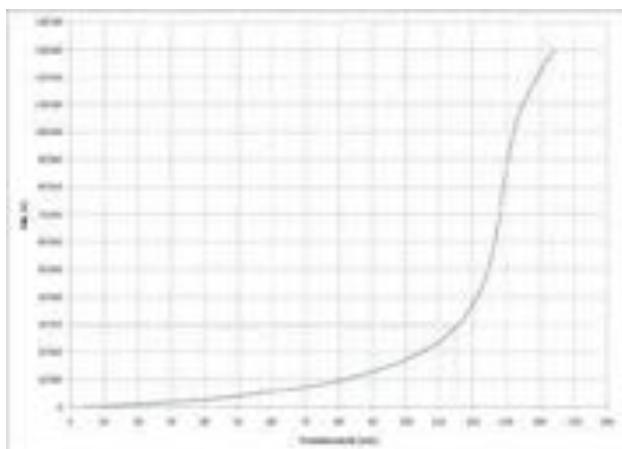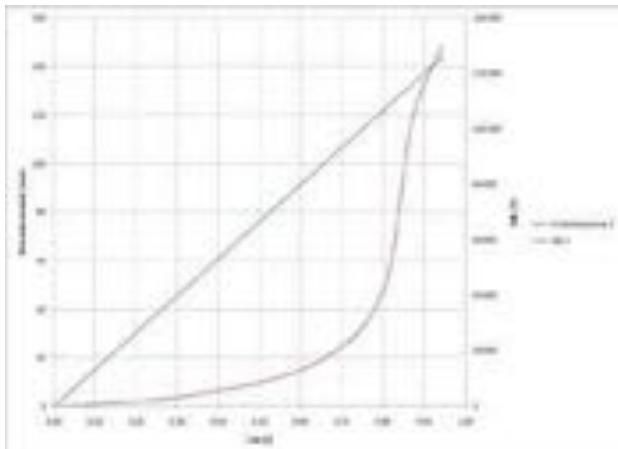
Fig. 11. MELEX beam. Displacement and reaction force in following calculation steps and force vs displacement
Rys. 11. Zmienność siły i przemieszczenia w kolejnych krokach rozwiązania (czasu)

Conclusions

The simulation results, as illustrate above, show that the "Beam 2" does not meet the strength requirements. Although for the punch displacement of 115 mm, the force value exceeds the minimum (almost threefold), however, the maximum strain is not achieved. The beam is destroyed before the 152.4 mm displacement value. The concentration of stresses with the highest values occurs at the beam fixing points. Hence it is necessary to redesign this beam area. It seems, the clamps are the critical part of beam.

Beam optimizing. Beam No 3.
Geometric model

Using the conclusions of the second optimization step, a new shape in the beam fixing area was designed. It was primarily driven by a change the damage mechanism of the element from the buckling to bending. Thus, the reinforcement of the upper surface (stiffening) was introduced by a 600 mm ball rolling of the with R = 7, 5 mm radius in two beam areas and a 450 mm ball rolling with a radius of 10 mm, and a change of the tilt angle of the fastening feet from 90o up to 100o. A drawing with basic dimensions is shown below.
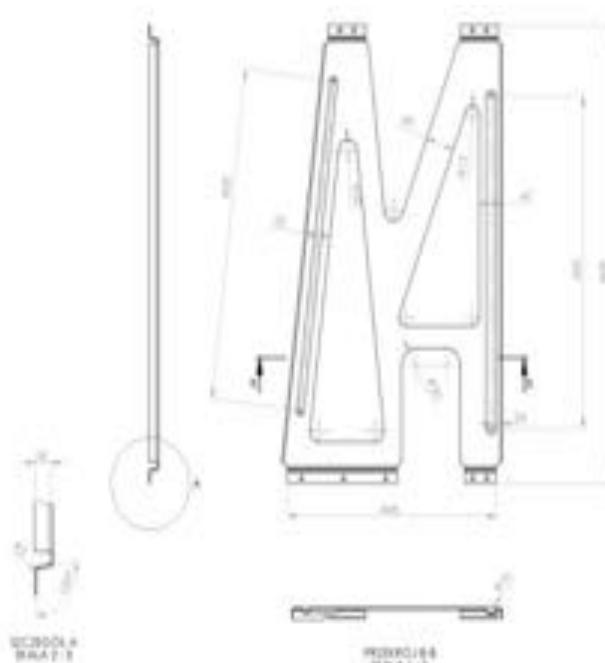

Fig. 12. Main dimension of the beam – version 3.
Rys. 12. Podstawowe wymiary belki bocznej – wersja 3
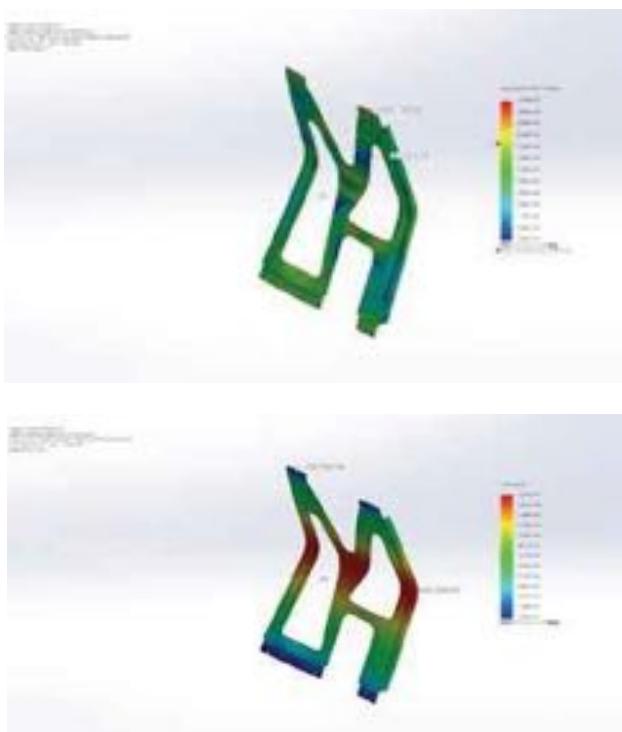
Fig. 13. Beam 3. Stress distribusion (Huber-Mises) and displacement
Rys. 13. Belka 3. Naprężenia zredukowane wg hipotezy Hubera-Misesaoraz przemieszczenia
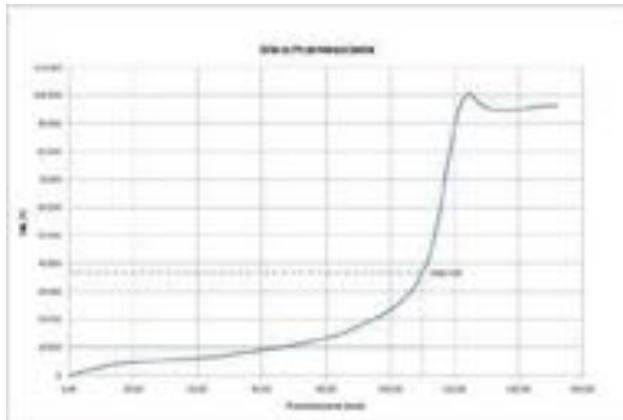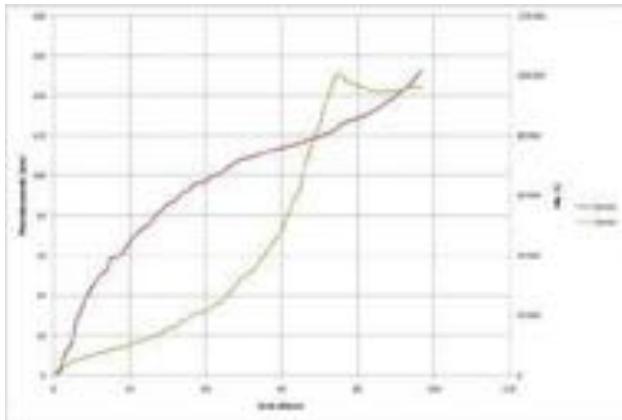
Fig. 14. Displacement and reaction force in following calculation steps and force vs displacement
Rys. 14. Zmienność siły i przemieszczenia w kolejnych krokach rozwiązania (czasu) oraz zmienność siły w funkcji przemieszczenia

Simulation results

Stress and displacement distribution of the "beam 3" are shown on Fig.13.

Force and displacement variation in time are shown on Fig 14.

Conclusions

The calculation results shown that the "Beam 3" meets the strength requirements. As foreseen, the concentration of the stresses highest values occurs at the beam fixing holes. Tensile strength has been exceeded in the beam anchorage area. This can be caused by:

1. mesh errors, due to incorrect shape coefficient of elements generated near holes;
2. shell elements using instead of volumetric elements.

Thus, the final verification must take place on the stand tests.

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A COMPARATIVE STUDY OF THE MECHANICAL PROPERTIES OF A CONSTRUCTION TOOL HANDLE

Badania porównawcze właściwości mechanicznych uchwytu ręcznego narzędzia budowlanego

Сравнительные исследования свойств межанического захвата ручного строительного инструмента

**Stanisław KOZIOŁ, Tomasz SAMBORSKI,
Andrzej ZBROWSKI**

Abstract: The article presents a method and the results of a comparative study related to the mechanical properties of a construction manual tool handle, namely, the mason trowel. The study was conducted on behalf of Comensal, a tool manufacturer, and it was a part of the process to improve and modernize the construction and manufacturing technology of the product. In the study, strength tests were conducted for three different constructions of the handles, which were made of different materials, and for the connections between the handles and the working plate of the tool. The results of the study and the manufacturer's information on the production cost and manufacturing conditions became the basis in the decision making process to implement the most advantageous solution and to purchase appropriate manufacturing equipment.

Keywords: manual construction tools, destructive tests, strength tests, strength

Streszczenie: W artykule przestawiono metodykę oraz wyniki badań porównawczych właściwości mechanicznych uchwytów rękojeści ręcznego narzędzia budowlanego - packi tynkarskiej. Badania wykonane na zlecenie firmy Comensal - producenta narzędzi, były częścią procesu doskonalenia i modernizacji konstrukcji i technologii wytwarzania produktu. Przeprowadzono badania wytrzymałościowe trzech różnych konstrukcji uchwytu wykonanych z różnych materiałów oraz wytrzymałości ich połączenia z płytką roboczą narzędzia. Wyniki badań oraz posiadane przez producenta dane dotyczące kosztów i warunków wytwarzania, stały się podstawą do podjęcia decyzji o wdrożeniu najbardziej korzystnego rozwiązania i zakupie odpowiedniego wyposażenia technologicznego.

Słowa kluczowe: ręczne narzędzia budowlane, badania niszczące, badania wytrzymałościowe, wytrzymałość

Introduction

The aim of the studies was to analyze the possibility of replacing the plastic or mixture of plastics which would allow replace the aluminum alloy, used for manufacture of supporting parts of construction tools. The range of the work included determination of the strength parameters of the tool elements, manufactured from the selected materials and a comparative analysis of the obtained results of the tests [5, 6].

The object of the tests concerned the handles of the mason trowels, produced by Comensal company. The mentioned trowel consists of a flat working plate, made of stainless sheet, the fixed holder of the handle and the handle. The holder of the handle is fixed with the application of press-fitting connection on four pegs welded to the working plate (Fig.1). The handle is pressed into the end of the holder with the appropriate pressure as to ensure the carrying over of the work loads.

Comensal Company, the Orderer of the tests, is a producer of mason trowels, in which there are employed the holders of the handle, which are pressure die cast of aluminum alloy (Fig.2 a) or, alternatively,

Fig. 1. Using welded pegs for a press-fitting connection of the handle with the plate
Rys. 1. Zastosowanie kołków zgrzewanych do wciskowego połączenia uchwytu z płytką

made of pressed polystyrene (Fig.2 b). In commercial practice of Comensal, the aluminum holders are characterized by high manufacturing costs that make the market competition difficult. Their replacement with

the polystyrene pressed holders has caused a significant change in a shape, resulting from the necessity of ensuring the required strength of the tool. The new shape, in spite of the approvable manufacturing costs, does not find, however, the recognition of the customers due to insufficient stiffness and strength, making the effective and comfortable work of the craftsman difficult.

a)

b)

c)
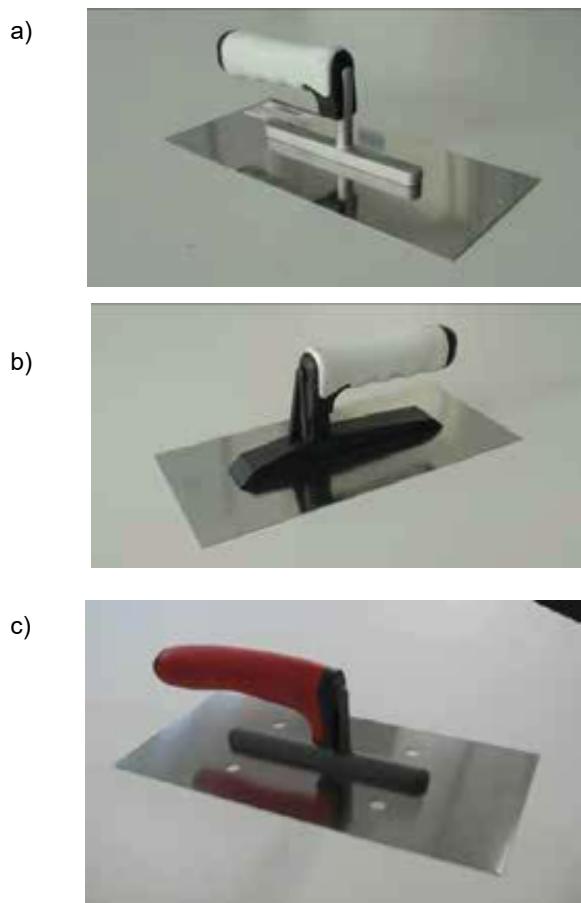
Fig. 2. Mason trowels: a) with the handle made of aluminum alloy, b) with the handle made of pressed polystyrene, c) with the handle made of polyamide
Rys. 2. Packa tynkarska: a) z uchwytem rękojeści wykonanym ze stopu aluminium, b) z uchwytem prasowanym z polistyrenu, c) z uchwytem prasowanym z poliamidu

When bearing in mind the market requirements, Comensal Company decided to consider the possibility of replacing the so-far employed solutions by the handle, made of pressed polyamide (Fig 2 c). The trowel with the polyamide handle has a shape and construction traditionally approved by the market, similarly as in the case of aluminium handle.

The main purpose of the tests was to compare the strength parameters of the handle, as being performed using three mentioned above technologies. The results of the tests were the basis for undertaking the decision on the change of the technology producing the handles, employed in the Comensal Company.

The research method

The strength tests of the handles of the mason trowels were carried out with the utilization of the strength testing machine INSTRON 5582 which facilitates:
- Performance of the tests with the application of measuring heads, range : 2 kN and 100 kN,
- Measurement of load and elongation in accuracy class 0.5

In the trials, the following measuring procedures, reproducing the working loads of the tool, were employed:
- Bending and compression trials with the load, directed perpendicularly to the working surface of the trowel (Fig.3),
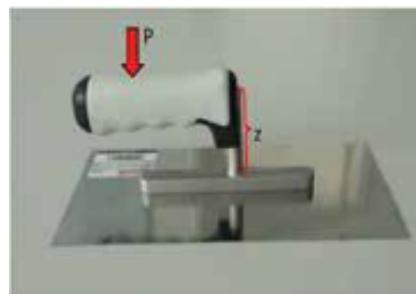
Fig. 3. A diagram of the load during a bending and compression trial with the load directed perpendicularly to the working surface of the trowel: P - load, z –the fragment of the handles with normal stress [2, 4].
Rys. 3. Schemat obciążenia podczas próby zginania ze ściskaniem przy obciążeniu skierowanym prostopadle do płaszczyzny roboczej packi: P - siła obciążająca, z - fragment uchwytu, w którym występują naprężenia normalne [2, 4]

- Bending and torsion trial with the load directed parallel to the working surface of the trowel (Fig.4)

Fig. 4. A diagram for the load during a bending and torsion trial with the load parallel to the working
Rys. 4. Schemat obciążenia podczas próby zginania ze skręcaniem przy obciążeniu skierowanym równolegle do płaszczyzny roboczej packi: P - siła obciążająca, x-x - przekrój uchwytu, w którym występują największe naprężenia zredukowane [2, 4]

The trials consisted in the application of the load P (Fig. 3 and 4) with preliminary value equal to 30 N and its increasing at the speed of deformation amounting to 10 mm/min. The software of the testing machine registered the diagram of relationship of the load and the sample deformation. The trial was stopped at the moment of damage of the sample (breaking of the holder of the handle) or obtaining the highest possible deformation, resulting from the construction conditions.

The first trials were conducted when applying the load to the handle of the trowel, as it was illustrated in Fig.3 and 4. It was found that it caused the uncontrolled changes in a real load, resulting from the destruction of the material of the handle due to a high stress concentration in the site of the quasi-point application of strength and instability of the contact of the loading element and surface of the handle at the great deformations of the sample.

As a result of the conducted preliminary trials, the research procedure was changed. The change consisted in the removal of the handle from the handle and application of the load directly to the mandrel on which it was mounted. To ensure the stability of the contact of the loading element connected with the testing machine and the surface of the sample, a special mandrel with the fork-shaped termination was performed (Fig.5).

For the both measuring procedures, three series of the tests for each procedure were carried out; the trials included three mason trowels in each series, with the handles made from the particular materials.

The run of the trials and the recorded results

Fig. 5 shows the photographs of the illustrating the method of loading and mechanism of destruction of the handle holders during the bending and compression trial, with the load directed perpendicularly to the working surface of the trowel.

The tested tool was mounted on the table of the testing machines in a strictly determined position, ensuring the repeatable distance of the point of the load application from the neutral axis of vertical segment of the bent cross-section of the handle.

Fig.6 shows the example of the diagram of the relationship between the load of the tested handles and the deformation. The vertical segment of the diagram is the end of the trials as a result of the destruction of the tested sample.

Fig.7 presents the photographs showing the way of loading, mounting of the samples and Fig.8 contains the images of destruction of the handles during bending and torsion trial, with loading directed parallel to the working surface of the trowel. The tested tool was mounted on the vertical surface of a special holder, combined with the table of the testing machine in a strictly determined position, ensuring the repeatable distance of the point of the load application from the neutral axis of the segment of cross-section of the handle perpendicularly directed to the working surface.

a)

b)

c)

d)

Fig. 5. The bending and compression trial with the load directed perpendicularly to the working surface of the trowel: a) the mounting of the trowel and load application, b) the destruction image of the aluminum handle, c) the destruction image of the polyamide handle, d) the destruction image of the polystyrene handle

Rys. 5. Próba zginania ze ściskaniem przy obciążeniu prostopadłym do płaszczyzny roboczej packi: a) sposób zamocowania packi i przyłożenia obciążenia, b) obraz destrukcji uchwytu ze stopu aluminium, c) obraz destrukcji uchwytu poliamidowego, d) obraz destrukcji uchwytu polistyrenowego

Fig.6. Diagram of the relationship between the load in the tested handles and the deformation registered for the load perpendicular to the working surface of the trowel

Rys.6. Wykresy zależności obciążenia badanych uchwytów od odkształcenia zarejestrowane przy obciążeniu prostopadłym do płaszczyzny roboczej packi

Fig. 7. Bending and torsion trial with a load parallel to the working surface of the trowel (polyamide handle): a) the mounting of the trowel and the load application, b) termination of the trial – handle breaking

Rys. 7. Próba zginania ze skręcaniem przy obciążeniu równoległym do płaszczyzny roboczej packi (uchwyt z poliamidu): a) sposób zamocowania packi i przyłożenia obciążenia, b) koniec próby - złamanie uchwytu

Fig. 8. Images of the trowel handle destruction during the bending and torsion trial with the load parallel to the working area of the trowel: a) and b) aluminum alloy handle, c) polyamide handle, d) polystyrene handle

Rys. 8. Obrazy destrukcji uchwytów rękojeści packi przy próbie zginania ze skręcaniem przy obciążeniu równoległym do płaszczyzny roboczej packi: a) i b) uchwyt ze stopu aluminium, c) uchwyt poliamidowy, d) uchwyt polistyrenowy
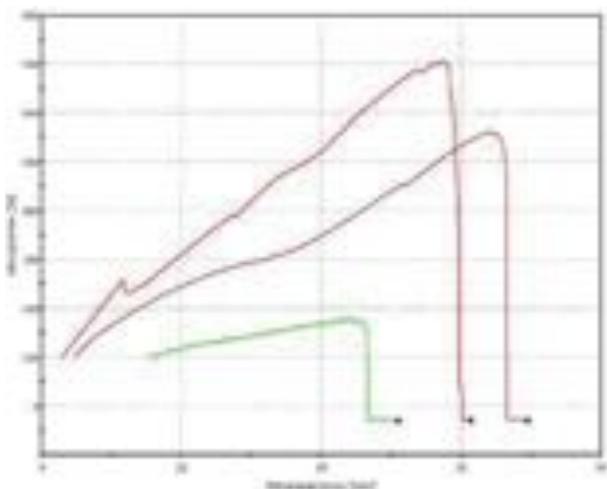
Fig. 9. Diagrams of the relationship between the load in the tested handles and the deformation registered for the load perpendicular to the working surface of the trowel

Rys.9. Wykresy zależności obciążenia badanych uchwytów od odkształcenia zarejestrowane przy obciążeniu równoległym do płaszczyzny roboczej packi

Fig.9 shows the examples of diagrams of the relationship between the load of the tested trowels and the deformation. The vertical segment of the diagram is the end of the trial as a result of the destruction of the tested sample.

The comparative analysis of the strength parameters

Table 1 and 2 contain a summary and the calculated mean values of the results of the measurements, carried out during the strength trials

When analyzing the obtained results, the run of the trials and mechanisms of destruction of the particular handles of the tested tools, the following conclusions have been formulated:

1. The handle made of aluminum alloy by the method of pressure die casting is characterized by the best strength properties. The mean destructive load in the bending and compression trials is equal to more than 3 kN what exceeds more than 3 times the load

Table 1. A summary of the measurements obtained for bending and compression trials with the load directed perpendicularly to the to the working area of the trowel

Tabela 1. Zestawienie wyników pomiarów otrzymanych w próbie zginania ze ściskaniem przy obciążeniu skierowanym prostopadle do płaszczyzny roboczej packi

Test with load perpendicularly directed to working surface of the trowel	Maximum load [N]	Mean maximum load [N]	Destructive displacement [mm]	Mean destructive displacement [mm]
Aluminum handle	2 661		4,1	
	3 502	3 136	5,9	4,8
	3 244		4,4	
Polyamide handle	2 068		3,8	
	1 953	1 915	3,9	4,0
	1 723		4,2	
Polystyrene handle	2 135		18,7	
	2 098	2 117	20,3	18,8
	2 118		17,3	

Table 2. A summary of the measurements obtained for the bending and torsion trial with the load directed parallel to the to the working area of the trowel

Tabela 2. Zestawienie wyników pomiarów otrzymanych w próbie zginania ze skręcaniem przy obciążeniu skierowanym równolegle do płaszczyzny roboczej packii

Test with load parallel directed to working surface of the trowel	Maximum load [N]	Mean maximum load [N]	Destructive displacement [mm]	Mean destructive displacement [mm]
Aluminum handle	706,1		30,7	
	576,0	643,8	23,6	25,8
	649,3		23,0	
Polyamide handle	560,8		34,7	
	524,5	521,0	36,5	34,9
	477,7		33,6	
Polystyrene handle	176,5		25,5	
	172,1	175,5	24,3	24,9
	177,8		24,9	

of average man. The destructive deformation in the discussed trial results from the limited plastic properties of the cast and is comparable with the deformation of polyamide handle. In the bending and torsion trial, the aluminum handle is also characterized by the highest strength and a big recorded destructive displacement is caused by pulling out of the pegs linking it with the sheet of the working part of the trowel (Fig.8a). The tendency to pull the pegs out during the trial results from a small width of the handle's foot adjacent to the sheet what causes the generation of a great pulling out force, caused by lateral load. Defective structure of the cast, caused most probable by utilization of a cheap, recycled alloy with non-identified composition and doubtful purity does not affect negatively the strength properties of aluminum handles as compared to the remaining constructions (Fig.10).

Fig. 10. Internal structure of the aluminum alloy
Rys. 10. Struktura wewnętrzna odlewu aluminiowego

The manufacturing costs are a defect of aluminum handles. Brittleness of the cast alloy [1, 3] limits also the possibility of regulating the bearing capacity of the press-fitting connection and peg connectors that could be increased by the change in pressing or imposing of plastic deformation e.g. by knurled pegs.

2. The handle made of polyamide by pressing method is characterized by good strength properties. The mean destructive strength in the bending and compression trial is equal to almost 2 kN what is value being quite sufficient for use of the trowel during typical plastering and bricklaying work. The results of the measurements of destructive load and deformation as obtained in the bending and torsion trial are very similar to the parameters of aluminum handle. The material of the handle contains filler which improves its strength what limits the susceptibility to deformations. The advantage of the handle includes the increased cross-section at the basis as marked in Fig. 4 as x-x. It causes a considerable increase of its strength in the site of incidence of the highest reduced stress, caused by operating lad. The advantage resulting from the discussed solution gives a lower cost and lower energy consumption of the process of the manufacture of the discussed elements by the method of pressure injection of plastics.

3. The handle made of polystyrene by the pressing method is characterized by the worst strength properties. It is mainly determined by low destructive load in the bending and torsion trial. There is a concern that in the case of certain typical operations during construction work e.g. removal of dried glue remnants or of mortar, the resistance of the handle will be insufficient. The handle is characterized by a high formability on bending and compression trial what results from the application of ribs, increasing the resistance to bending in the plane of the trowel's symmetry. A high susceptibility to deformation does not give any practical advantage. The construction of the polystyrene handle indicates distinctly the action of constructor whose purpose was to stiffen the product in the plane of the tool's symmetry; it did not however bring a similar result as in the case of being endangered to other operating loads. The disadvantage of the polystyrene handle includes a higher amount of plastic being indispensable for its manufacture as compared to the polyamide handle.

Summing up

As a result of the conducted work, the possibility of improving the innovativeness of the products, manufactured by Comensal Company and the innovative character of technological processes of their production has been confirmed.

In manual construction tools, produced by Comensal (mason trowels), the so-far applied aluminum or, alternatively, polystyrene element joining the stainless working plate of the trowel with the handle should be replaced by the handle made of polyamide. The pressed polyamide handle is characterized by good strength parameters, comparable with the parameters of the best aluminum handle. It is more resistant than the employed alternatively handle, made of pressed polystyrene.

Apart from the revealed good strength, the polyamide handle has the following advantage, being significant form the viewpoint of the tool producer and user which decide on its innovativeness:
- Smaller cost of manufacture as compared to aluminum handle;
- Shape consistent with the tradition of the market of construction tools;
- Possibility to produce the handles in the own factory;
- Positive effect of technology on implementation of the principle of the sustainable development of economy via limitation of the energy consumption in manufacture and elimination of material (Al alloy) the obtaining of which is especially burdensome for the environment.

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properties. The steels of group III and IV are successively implemented into manufacturing and their share is steadily increasing, mainly in the passive safety elements.

PREDICTION OF ADHESIVE JOINTS STRENGTH BASED ON THE MODIFIED DE BRUYN METHOD USING THE NUMERICAL METHODS

Przewidywanie wytrzymałości połączen klejowych w oparciu o modyfikowaną metodę De Bruyna z wykorzystaniem metody numerycznej

Прогнозирование прочности клеевых соединений на основе модифицированной методы Де Брёйне с использованием номерического метода

Jacek DOMIŃCZUK

Abstract: The paper presents a numerical model, based on artificial intelligence, to predict the strength of adhesive joints on basis of the modified De Bruyn method. The model was built using the results of research on destructive force of adhesive joints of steel sheets. Input variables for the model were: the thickness of the materials to be joined, the length of the overlap, the geometrical development of the surface and the thickness of the adhesive layer. The obtained model was tested on correctness of representing of the impact of individual variables on the strength of the joint, represented by the value of stress from the destructive force of the adhesive joint in the combined material. Based on the obtained results, it was possible to extend this forecasting method with further factors affecting the strength of adhesive joints, including energy parameters.

Keywords: joint strength, adhesive joint, numerical model

Streszczenie: W artykule przedstawiono model numeryczny oparty na sztucznej inteligencji służący przewidywaniu wytrzymałości połączeń klejowych w oparciu o modyfikowaną metodę De Bruyna. Model ten zbudowano posługując się wynikami badań laboratoryjnych pomiaru siły niszczącej połączenie klejowe blach stalowych. Jako zmienne wejściowe przyjęto grubość łączonych materiałów, długość zakładki, rozwinięcie geometryczne powierzchni i grubość spoiny klejowej. Uzyskany model poddano ocenie poprawności odwzorowania wpływu poszczególnych zmiennych na wytrzymałość połączenia reprezentowaną przez wartość naprężenia w łączonym materiale pochodzącego od siły niszczącej połączenie klejowe. W oparciu o uzyskane wyniki stwierdzono możliwość poszerzenia tej metody prognozowania o kolejne czynniki mające wpływ na wytrzymałość połączeń klejowych w tym o parametry energetyczne.

Słowa kluczowe: wytrzymałość połączenia, połączenie klejowe, model numeryczny

Introduction

Technology of glue bonding plays a very big role in development of modern constructions. In many cases, it is an alternative to the so-far employed methods of joining, sealing or regeneration of parts of machines. Gluing creates the new possibilities in respect of combining materials with different physical and geometrical properties; it allows also linking the parts with different dimensions what contributes repeatedly to the simplification of their construction. Combination of gluing and other technologies e.g. riveting or welding allows obtaining joints with different properties, favourable for improvement of bearing capacity or tightness of joints. Such wide possibilities of adhesive bonding application cause the necessity of seeking for the optimum conditions for implementation of the discussed process and determination of factors, affecting significantly the resistance of adhesive joints.

The so-far employed single-factor models do not give a full image of the influence of independent variable on dependent variable, i.e. joint strength. The complexity of the discussed problem in combination with the

expectations of the constructors causes the necessity of constructing a model which would consider the effect of the particular properties, relating to the way of formation of the upper layer state, including the energy properties as well as constructional parameters.

We still seek for better methods for forecasting the adhesive joint strength based upon the set of constructional and technological factors. The developed and published formulas of relationships between the independent parameters affecting the quality of joint, as obtained on the basis of empirical analyses, consider greater and greater number of factors. They are limited, however, by the interval of the values of variables in which they may be utilized. The alternative to such approach includes application of numerical methods, based on the artificial intelligence. The mentioned method gives a lot of new possibilities in respect of conducting the complicated analyses and construction of prognostic models. The ability of appropriate describing the state of the joint gives the possibility to improve the quality of the products as well as affects the lowering the cost of their manufacture owing to the limitation of technological operations to the indispensable minimum and their optimal selection. Apart

from this, the application of numerical methods gives the possibility of constant improvement of the model.

The described above factors have caused that the attempts were undertaken to construct a prognostic model of joint strength based upon the modified De Bruyn method, with the consideration of the following initial parameters: length of the adhesive lap, thickness of adhesive joint, thickness of the joined materials, the square mean of coarseness profile ordinates.

Numerical analysis of the adhesive lap joints

A quick method for determination of the adhesive joints strength is facilitated owing to the modified De Bruyn method, presented in the paper [3]. As a result of the method's modification, the nomographs of the bearing capacity of the lap joints were created on the grounds of the experimental trials. In the submitted studies, the samples were made from the sheets of different thickness. They were joined, using different lengths of the laps and then, the level of tensions in the joined elements was determined at the moment of destruction of the joint ($\sigma_0 = P/\delta b$), (where: P- force, d –thickness of sample, b-width of sample) (Fig. 1.) [3].
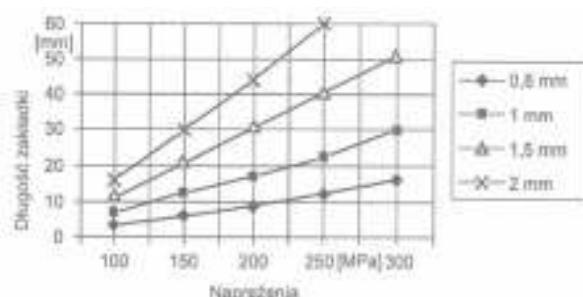

Fig. 1. Nomograph of single lap joints strength of PA7 sheets of four different thickness, joined using Epidian57 resin, cured by TECZA hardener at 328 K during 1,5 hour (surface of sheets cleaned with abrasive cloth, 80 Grit) [3]
Rys. 1. Nomogram nośności jednozakładowych połączeń blach z materiału PA7 o czterech grubościach, klejonych Epidianem 57 utwardzanym TECZA w temperaturze 328 K w czasie 1,5 h (powierzchnia blach czyszczona płótnem ściernym o ziarnistości 80) [3]

Nomograph in such form is true for the specified species of adhesive, the determined conditions of hardening the adhesive lap, the determined type of the joined material and a specified way of preparing the surface for joining as well as for the specified type of joint.

The set of the initial factors of the analysis of the adhesive joints strength was determined based upon the experimental data, as presented in the publications [5, 2, 6, 7, 8, 9, 13] and the noticeable relationship of the dispersive part of a free surface energy, determined by Owens-Wendt method [5, 14] and the strength of the joint.

To obtain the input data for construction of the numerical model, serving the forecasting of short term strength of adhesive joints, the trials of resistance of the lap adhesive joints to shearing force were carried out. The plan of the studies was based on the complete set,

constituting a combination of the mentioned below input factors. Five repetitions of the strength measurement in the system were conducted. The tests were carried out on the basis of PN-EN 1465:2003 [11]. The joined elements included steel sheets, made of the steel 1.0330. The shape and dimensions of the samples, used in the tests are given in Fig.2.

Fig. 2. Shape and dimensions of the test samples
Rys. 2. Kształt i wymiary próbek stosowanych do badań.

For the analysis of the obtained results and construction of the model, the artificial neuron nets were used. As a result of the conducted analysis of the effectiveness of the network's functioning it was found that the best prognostic model was obtained in the case of MLP network – Multilayer Perceptron with a structure (4:4-11-1:1). The mentioned network was learnt with utilization of algorithm CG - Conjugate Gradient Descent, with logistic function of activating neurons of the hidden layer and linear with the saturation with function of activation the input layer and output layer with the application of linear function of postsynaptic potential [1, 12].

The schematic plan of the model's construction is given in Fig.3.
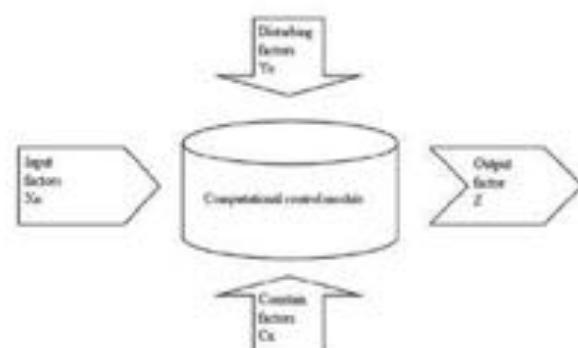
Fig. 3. Diagram of mathematical model of predicting strength of adhesive joint, based on modified De Bruyn method
Rys. 3. Schemat planu budowy modelu numerycznego do przewidywania wytrzymałości połączenia klejowego w oparciu o modyfikowaną metodę De Bruyna

Where:
Input factors:
X_1 – length of the lap (l – 5, 10, 15 [mm]),
X_2 – degree of geometrical development of surface (characterized by parameter R_q- 2.4, 1.9, 1.8, 2.4 [μm]),
X_3 – thickness of adhesive joint (δk – 0.06, 0.11, 0.17, 0.24 [mm]),
X_4 – thickness of joined materials (δ - 1, 1.5, 2 [mm])

Output factor:
Z – normal stress in the joined material ($\delta 0$ [MPa]).
Constant factors:

C_1 – type of joined material,
C_2 – time of hardening (72h)
C_3 – type of the applied adhesive (Epidian 57/PAC-100/80),
C_4 – type of degreaser Loctite 7061

Disturbing factors:
Y_1 – unrepeatability of the measurement conditions
Y_2 – unrepeatability of technology of joint performance
Y_3 – inaccuracy of measurements stands
Y_4 – inaccuracy of measurement

The conducted own studies allowed building – based upon the neural networks – of the multi-parameter model in a form of implicit function. When assuming the homeostasis of the selected input parameters, the discussed model gives also a possibility of constructing the three-dimensional nomographs. Such approach allowed extending the range of analysis and considering the effect of the changes in stereometric parameter Rq and thickness of adhesive layer δk on the adhesive joint strength.

Table 1 shows the results of regression statistics of MLP network, as given in Fig.4. Value of a strength, destructing P joint ([N] was presented here as an input variable.

Uc, P, Wa, P, Te, P – Information concerns, successively, the following sets: training dataset, validation data set and testing dataset, connected with the analysis of the destructive strength value P [N]

Tab.1. Regression statistics of destructive strength value for MLP network (4:4 – 11 – 1:1)
Tab. 1. Statystyki regresyjne wartości siły niszczącej P dla sieci MLP (4:4-11-1:1).

	Uc. P	Wa. P	Te. P
Mean	4668	4628	4418
Standard deviation	1914	1957	2139
Mean error	-6,6	41,9	-102,1
Error deviation	746,1	739,9	883,9
Mean absolute error	538,9	525,8	651,7
Deviation quotient	0,39	0,38	0,41
Correlation	0,92	0,93	0,91

Where:
Mean: the mean value of the input variable, calculated on the basis of the set values of the discussed variable, collected – respectively – in training dataset, validation dataset or test dataset.
Standard deviation: standard deviation, calculated for the set values of the input variable
Mean error: mean error (understood as module of difference between the expected value and the obtained output value
Standard deviation of error: standard deviation of errors for the output variable

The mean absolute error: the mean absolute error (difference between the set value and the obtained output value) for input variable
Quotient of standard deviations: quotient of standard deviations for the errors and the data. It is the main indicator of the quality, constructed by the network of regression model
Correlation: standard correlation of R Pearson correlation for the set value and the obtained output value

Fig.5 shows the surfaces of the responses if the net, as illustrated in Fig.4. The mentioned surfaces represent the stress in the joined material, corresponding to the stress destructing the adhesive joint, with the consideration of the changes in the length of the lap and the changes of the remaining input parameters.
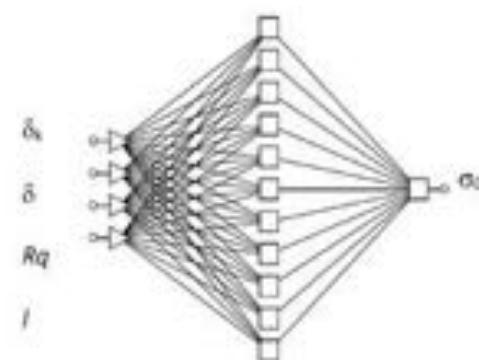

Fig. 4. MLP structural diagram (4:4-11-1:1)
Rys. 4. Schemat strukturalny sieci MLP (4:4-11-1:1)
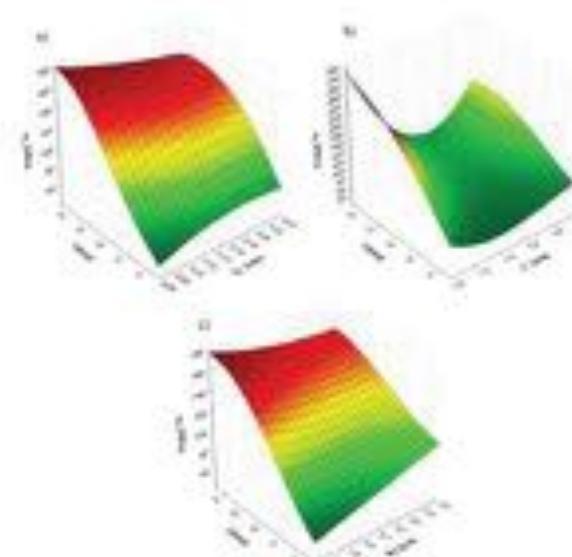
Fig. 5. Predicted change of stress in joined material depending on a) dk – l, b) d – l, c) Rq-l
for dk=0,1 [mm], d=2 [mm], Rq=2 [mm]
Rys. 5. Prognozowany przebieg zmian naprężenia w łączonym materiale w funkcji:
a) dk – l, b) d – l, c) Rq-l. Przypadek chwilowy dk=0,1 [mm], d=2 [mm], Rq=2 [mm]
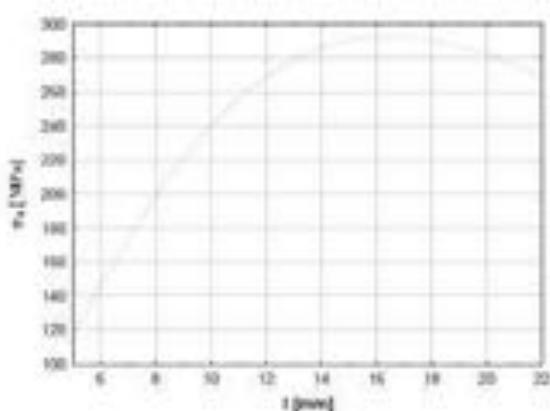
Fig. 6. Nomograph of single lap joints strength of d=1 [mm] thick sheets, where thickness of adhesive layer dk=0,1 [mm], parameter Rq=1,7 [mm], joined using Epidian 57/PAC/100:80
Rys. 6. Nomogram nośności jednozakładowych połączeń blach stalowych o grubości d=1 [mm], grubości spoiny klejowej dk=0,1 [mm], parametr Rq=1,7 [mm], klejonych klejem Epidian 57/PAC/100:80

The analysis of the mutual relations between the thickness of the joined elements and the length of the lap based upon the De Bruyn coefficient (4) does not impose any limitations concerning the increase of the lap's length. It has been revealed, however – as it is followed from the diagram on fig.6 – that the increase of the lap's length above a certain limitary value is aimless. It does lead to the increase of the joint strength. The obtained numerical model is deprived of the errors, resulting from the theory of Volkersen [10] which assumed omitting the deformations, resulting from the bending of the joined elements and the resulting normal stress.

Summary

From the presented effects of the model functioning, it is followed that the introduction of modifications in De Bruyn method gives the possibility of conducting the analysis of the strength of the lap adhesive joints as well as forecasting of their strength, described by normal stress, generated in the joined material, with the consideration not only of the lap's length and thickness of the joined materials but also including the thickness of the adhesive layer and geometric features of the joined surfaces. The run of the relationship, as being presented in the model corresponds to the current state of the knowledge on the effect of the analysed variables on value of the joint strength. When designing the adhesive joints, the consideration of the effect of the changes of the particular factors and their noticeable non-linear influence on bearing capacity of the joint gives the possibility to improve the quality of the joints as well as allows more precise forecasting of their strength.

Based upon the conducted analyses, we may formulate the following cognitive conclusions:

1. In the case of the length of the lap, the thickness of the joined materials as well as thickness of the adhesive layer, the non-linear effect of the mentioned factors on the strength of the adhesive joint has been revealed; the nature of the mentioned effect and by this, the run of the relationship function is changing together with the change of each of the input parameters.

2. The threshold length of the lap should not be determined with omitting of the geometric (stereo) features of surfaces of the joined materials in the site of joint. The results of analysis, using the artificial intelligence show that the real threshold length of the lap is higher than that one determined with the utilization of the known strength equations which are charged with the errors, resulting from the simplifications, adopted in the theory of Violkersen.

3. There is a possibility of optimizing the strength of the lap adhesive joint due to the thickness of adhesive layer, its length, geometric status of the surface for a specified adhesive (glue) and the joined material, with the set thickness of the joined materials and width of the joint.

The presented model may be further modified and improved owing to introduction of the successive parameters affecting the strength of the joint. Based upon the conducted research work, it may be supposed that the improvement of the quality of the model may be reached via introduction of the energy parameters, describing the state of the surface layer of the joined materials [5] as well as compositional elements of a surface free energy of the adhesive substance.

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ADHESIVE MIXING AND APPLYING DEVICE

Установка для смешивания и накладки клеев

Anna RUDAWSKA

A b s t r a c t: The aim of the present article is to present the design concept of a specialized device for mixing and applying adhesives (one and two-component ones) intended for unit production or laboratory use. The paper presents the initial assumptions of the device design, such as the type of production, application method and adhesive properties. Technological requirements for the adhesive mixing and applying device were enumerated. The technological requirements will include the characteristics of the method of adhesive application. The construction requirements of the designed device are also presented. The design of this device has been presented in the form of a 3D model, made with use of the SolidEdge software. The advantages and limitations of the concept of the designed device were also presented.

K e y w o r d s: bonding, device, mixing, application, adhesive

S t r e s z c z e n i e: Celem niniejszej pracy jest przedstawienie koncepcji projektu specjalizowanego urządzenia do mieszania i nakładania klejów (jedno- i dwuskładnikowych), przeznaczonego do produkcji jednostkowej lub do zastosowań laboratoryjnych. W pracy przedstawiono założenia wstępne projektu urządzenia, takie jak: rodzaj produkcji, sposób nakładania oraz właściwości kleju. Przedstawione zostaną także wymagania technologiczne stawiane urządzeniu do mieszania i nakładania kleju. Wśród wymagań technologicznych wymienia się m.in. sposób nakładania kleju. Przedstawiono także założenia konstrukcyjne zaprojektowanego urządzenia klejarskiego. Projekt tego urządzenia został przedstawiony w formie modelu 3D, wykonanego za pomocą programu SolidEdge. Zaprezentowano także zalety oraz ograniczenia koncepcji zaprojektowanego urządzenia.

S ł o w a   k l u c z o w e: klejenie, urządzenie, mieszanie, nakładanie, klej

Introduction

The process of bonding technology includes a series of operations aimed at obtaining an adhesive joint with specific characteristics [3, 6, 7]. The bonding technology process includes the following operations: surface preparation, adhesive preparation, adhesive application, fixing and bonding the elements, curing the adhesive joint, joints control, finishing operations [5, 8, 13]. The bonding technology process described in the aforementioned operations also includes several indirect activities, and the whole process is carried out with use of various tools and devices (often the specialised ones) that are necessary to make a proper adhesive joint [9, 10, 11].

The stages of the bonding process analysed herein are the adhesive mixing and applying, whereas they may be analysed both separately and together. Due to this fact it is possible to enumerate both the tools and devices dedicated to specific operations of the bonding technology process and those that combine the functionalities of mixing and applying the adhesives [4, 10, 12].

The adhesive preparation process is a key stage of the bonding technology process. The appropriate mixing of the adhesive components plays a vital role in the bonding process [4, 5, 7]. In case of the two-component adhesives it is important to make sure that all the components (added in proper amounts, often based on the stoichiometric ratio of some components) are mixed properly and thoroughly so that the adhesive mixture obtained is homogenous [2, 5]. Also, it is necessary to ensure that the adhesive compound does not contain any air bubbles as it may result in improper bonding of the joined materials and affect the adhesive joint's strength. In this type of operation both the manual and mechanical methods are used. Both of them require proper tools and devices, though. In order to obtain a proper adhesive joint, it is necessary to apply the appropriate adhesive layer on the bonded surfaces. For different types of production (piece or batch), the process of applying the adhesive may be automated by using proper devices, tools or appliances [4, 5, 8, 11].

There are lots of devices used in the operations of adhesive preparing and applying. They are offered by different producers (in most cases the producers of adhesives). Also, they are sometimes designed especially for the purposes of a specific bonding process [1, 2, 8, 9, 12].

The present article is aimed at elaborating a concept of the project of a specialised device for mixing and applying adhesives (one and two-component ones) aimed at piece production and laboratory work, based on the existing construction solutions.

The concept of the adhesive mixing and applying device

• Technological, construction and performance assumptions

The condition for the proper design of the adhesive mixing and applying device is to meet numerous construction and technological requirements affecting the correctness of the adhesive application process. The designed device should serve the specified functions, as well as enable to obtain the repeatability of the adhesive application process. The following technological and performance assumptions were made:

- the possibility of mixing two components of an adhesive (e.g. resin and curing agent in case of epoxy adhesives),
- precise dosage of the prepared (mixed) adhesive,
- the repeatability of the adhesive application process,
- the possibility of applying the adhesive on the surfaces of irregular shapes,
- the possibility of changing the way of applying the adhesive (tracks, drops),
- the possibility of a quick adhesive refill,
- the possibility of quick cleaning the adhesive containers after the application process, due to the use of additional "inserts" in the form of disposable containers placed in the adhesive containers,
- ease and speed of maintenance.

The assumptions presented hereinabove enable to elaborate the concept of design of a device that, when used properly, will improve and rationalize the adhesive application process. Setting a proper amount of the adhesive compound to be applied, as well as shorter application time will enable to apply the adhesive mass properly in the form of drops or tracks.

• Construction assumptions

A 3D model of the adhesive mixing and applying device presented in Figure 1 was designed based on the construction of devices produced by ABM [1], specialised in, among others, construction and production of devices for the bonding process. The basic elements of this specialised tool are presented in Figure 2. The concept elaborated included some changes in terms of dimensions and construction of containers for the adhesive's components (or the adhesive itself in case of one-component adhesives). Also, there were some changes in the construction of the mixing-dosing nozzle and the possibility of two variants of the adhesive application on the surface was added.

The construction assumptions of the adhesive mixing and applying device included, among others, the overall dimensions of the device (Fig. 2), i.e.:

- total height: 410 mm,
- base dimensions: 300 x 400 mm,
- adhesive containers total spacing: 327 mm,

The adhesive containers are made of stainless steel (1.4301) and contain additional "inserts" in the form of disposable containers placed inside of them. In addition,
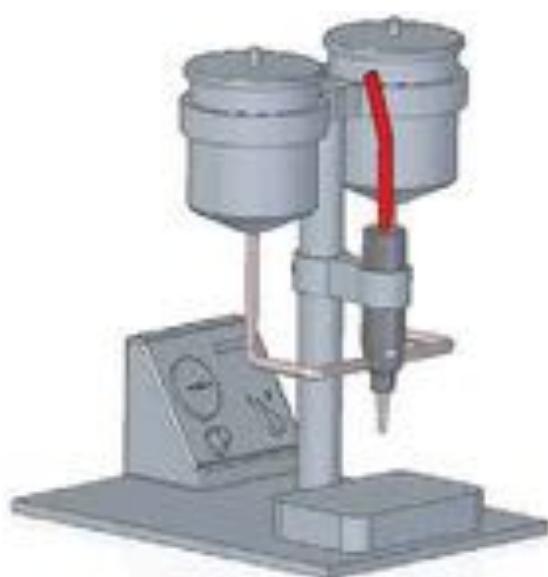
Fig. 1. A 3D model of the adhesive mixing and applying device
Rys. 1. Model 3D urządzenia do mieszania i nakładania kleju
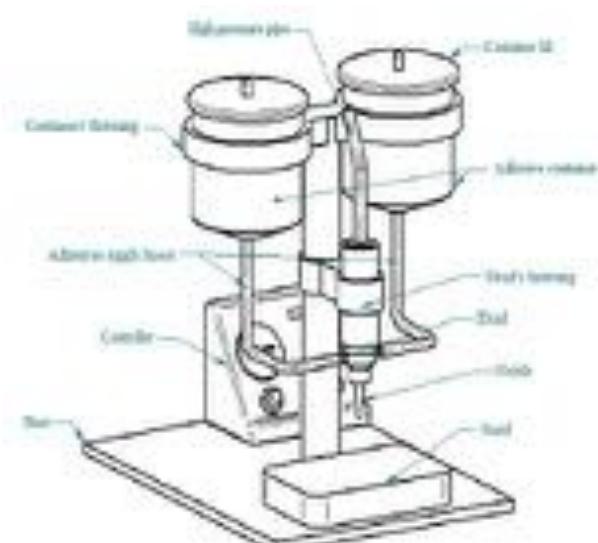
Fig. 2. General arrangement diagram of the adhesive mixing and applying device
Rys. 2. Schemat ogólny urządzenia do mieszania i nakładania kleju

they are equipped with lids protecting the adhesive from external conditions and impurities (e.g. dust). The containers' capacity is 1.5 l.

The device's base is equipped with a special work table (stand) that can be used to place the objects being covered with the adhesive firmly and directly under the dosing head.

The head's fastening is made of stainless steel (1.4301). The hole made in the fastening together with the knob enable to adjust the head's height in order to cover the objects of bigger dimensions with the adhesive.

The hoses supplying the adhesive are made of silicone with the diameter of 10 mm, which makes them more flexible. The compressed air pipe with a diameter

of 12 mm is a universal pipe aimed at pneumatic devices with the operating pressure of up to 1.5 MPa, made of combination of rubber with polyvinylchloride (SBR + PVC). It is characterised by high wear and bending resistance.

• Description of adhesive mixing and applying

The process of adhesive mixing in the designed device takes place in the dosing nozzle. Its special construction allows for proper mixing of the two-component adhesives directly before the operations of dosing and applying the adhesive on the bonded surfaces. Thanks to that it takes much less time to bond the elements as an additional operation of preparing the adhesive is eliminated. The adhesive that flows off from the containers is forced through by a small piston located in the head. It is driven by compressed air supplied from the compressor to the head. When the proper pressure is obtained, the adhesive flows into the dosing-mixing nozzle where it is mixed by a mixer located in the dosing nozzle.

The designed device is equipped with a proper dosing-mixing head (Figure 2), which, with use of a proper controller, enables to adjust the amount of adhesive and the way of its application on the bonded surface. The dose of the adhesive is strictly related to the amount of the compressed air supplied, which steers the small piston in the dosing head. The piston opens, i.e. feeds the adhesive and, at the same time, pushes it out through the nozzle onto the bonded surface. When the piston closes it makes it impossible to supply an undesirable dose of adhesive and, as a result, eliminates so called dripping.

The component parts of the adhesive spreader that is the key element of the adhesive mixing and applying device are presented in Figure 3, whereas the 3D model is shown in Figure 4.

Such construction of the adhesive head enables to apply the adhesive in two possible variants presented below:

Fig. 4. A 3D model of the adhesive spreader's head
Rys. 4. Model 3D głowicy nakładarki do kleju

- in the form of single adhesive doses (drops) - Figure 5a, application of adhesive in the form of single drops enable to bond, among others, small objects,
- in the form of a uniform stream (track) - Figure 5b.

The designed device is equipped with a controller with a manometer that controls the device. The controller enables to regulate the operating pressure in the adhesive spreader's head pneumatic system and prevents from deviations related to the pressure decrease and the change of the adhesive dose. Thanks to the manometer used in the device it is possible to observe the pressure in the pneumatic system that steers the head and to set a proper dose of adhesive. The device control switch enables to set the right dose of adhesive from two ranges: 25 ml and 50 ml.

Fig. 3. Construction of the adhesive spreader's head
Rys. 3. Budowa głowicy nakładarki do kleju

a)   b)
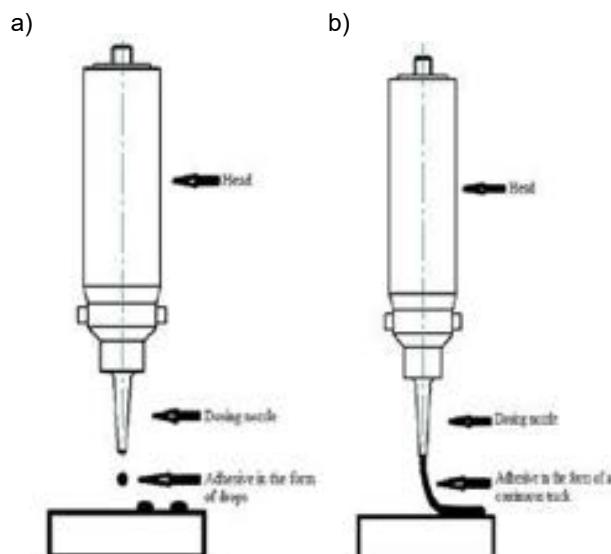
Fig. 5. Adhesive's application: a) in the form of single drops, b) in the form of a continuous track (stream)
Rys. 5. Aplikacja kleju: a) w postaci pojedynczych kropel, b) w postaci jednostajnego strumienia

• Advantages and limitations of the device

The advantages of the adhesive applying device concept described herein include:
- the possibility of dosing adhesive from two ranges: 25 ml and 50 ml,
- simple and functional construction,
- the possibility of changing the way of applying adhesive (tracks, drops),
- simple and user-friendly interface,
- dosing accuracy,
- the possibility of applying two-component adhesives without the need of mixing them beforehand,
- stable and durable device base,
- small dimensions,
- the construction made of stainless steel to eliminate possible corrosion of different elements,
- a standard adhesive container capacity for multiple dosing without the need of refilling the adhesive,
- the use of disposable nozzles to shorten the cleaning time after finishing the bonding process,
- shorter time of adhesive application thanks to the use of a mixing-dosing nozzle,
- simple construction for faster cleaning of the whole device,
- the possibility of setting the head height for bonding the elements of different dimensions.

The limitations of the adhesive mixing and applying device are the following:
- the overall dimensions of the elements covered with adhesive depend on the dimensions of the work table,
- the possibility of applying the adhesive only in two specified doses,
- no possibility of heating up the adhesive during application,
- no possibility of connecting the device to external sources for feeding the adhesive,
- limitations related to using fillers.

Summary

The concept of device presented herein allows for mixing and applying both one and two-component adhesives. Thanks to the use of a special head, two variants of adhesive application are possible - in the form of tracks and drops. The possibility of regulating the adhesive application variant enables to increase the possibilities of the device' usage in the bonding process. Applying the adhesive in the form of single drops makes it possible to bond small elements precisely as the adhesive dose is small and accurate. In turn, applying the adhesive in the form of tracks (stream) enables to bond bigger and much longer elements. Precise dosing of the adhesive compound prevents from different issues related to insufficient bonding. It is due to the fact that the adhesive fed in the form of tracks through the dosing nozzle is applied in a continuous way, which eliminates the shortages that result from improper dosing.

The small overall dimensions of the designed device are its considerable advantage as it takes up very little space in properly managed workshop and production spaces.

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1. Assembly tolerance analysis based on the Jacobian model and skin model shapes

Authors: Ting Liu, Yan-Long Cao, Qijian Zhao, Jiangxin Yang, Lujun Cui

The purpose of this paper is to carry out an assembly tolerance analysis by means of a combined Jacobian model and skin model shape. The former is based on small displacements modeling of points using 6 × 6 transformation matrices of open kinematic chains in robotics. The latter easily models toleranced features with all kinds of geometric deviations.

This paper presents the procedure of performing tolerance analysis by means of the Jacobian model and skin model shape for assemblies. The point cloud-based discrete representative is able to model the actual toleranced surfaces instead of the ideal or associated ones in an assembly, which brings the simulation tools closer to reality.

The proposed method has the advantage of skin model shape which is suitable for geometric tolerances management along the product life cycle and contact analysis of kinematic small variations, as well as, with the Jacobian, enabling transformation of locally expressed parts deviations to globally expressed functional requirements. The result of the case study shows the accuracy of the method.

The proposed approach has not been developed fully; other functional features such as the pyramid are still ongoing challenges. It is an effective method for supporting design, manufacturing and inspection by providing a quantitative analysis of the effects of multi-tolerances on the final functional key characteristics and for predicting the quality level.

2. Modeling of assembly systems with complex structures for throughput analysis during transients

Authors: Yukan Hou, Yuan Li, Yuntian Ge, Jie Zhang, Shoushan Jiang

The purpose of this paper is to present an analytical method for throughput analysis of assembly systems with complex structures during transients.

Among the existing studies on the performance evaluation of assembly systems, most focus on the system performance in steady state. Inspired by the transient analysis of serial production lines, the state transition matrix is derived considering the characteristics of merging structure in assembly systems. The system behavior during transients is described by an ergodic Markov chain, with the states being the occupancy of all buffers. The dynamic model for the throughput analysis is solved using the fixed-point theory. This method can be used to predict and evaluate the throughput performance of assembly systems in both transient and steady state. By comparing the model calculation results with the simulation results, this method is proved to be accurate.

This proposed modeling method can depict the throughput performance of assembly systems in both transient and steady state, whereas most exiting methods can be used for only steady-state analysis. In addition, this method shows the potential for the analysis of complex structured assembly systems owing to the low computational complexity.

3. An adaptive ball-head positioning visual servoing method for aircraft digital assembly

Authors: Hua Liu, Weidong Zhu, Huiyue Dong, Yinglin Ke

To gain accurate support for large aircraft structures by ball joints in aircraft digital assembly, this paper aims to propose a novel approach based on visual servoing such that the positioner's ball-socket can automatically and adaptively approach the ball-head fixed on the aircraft structures.

Image moments of circular marker labeled on the ball-head are selected as visual features to control the three translational degrees of freedom (DOFs) of the positioner,

where the composite Jacobian matrix is full rank. Kalman–Bucy filter is adopted for its online estimation, which makes the control scheme more flexible without system calibration. A combination of proportional control with sliding mode control is proposed to improve the system stability and compensate uncertainties of the system.

The ball-socket can accurately and smoothly reach its desired position in a finite time (50 s). Positional deviations between the spherical centers of ball-head and ball-socket in the X-Y plane can be controlled within 0.05 mm which meets the design requirement.

The proposed approach has been integrated into the pose alignment system. It has shown great potential to be widely applied in the leading support for large aircraft structures in aircraft digital assembly.

4. Energy efficient modeling and optimization for assembly sequence planning using moth flame optimization
Authors: Arif Abdullah, Mohd Fadzil Faisae Ab Rashid, S.G. Ponnambalam, Zakri Ghazalli

Environmental problems in manufacturing industries are a global issue owing to severe lack fossil resources. In assembly sequence planning (ASP), the research effort mainly aims to improve profit and human-related factors, but it still lacks in the consideration of the environmental issue. This paper aims to present an energy-efficient model for the ASP problem.

The proposed model considered energy utilization during the assembly process, particularly idle energy utilization. The problem was then optimized using moth flame optimization (MFO) and compared with well-established algorithms such as genetic algorithm (GA), particle swarm optimization (PSO) and ant colony optimization (ACO). A computational test was conducted using five assembly problems ranging from 12 to 40 components. The results of the computational experiments indicated that the proposed model was capable of generating an energy-efficient assembly sequence. At the same time, the results also showed that MFO consistently performed better in terms of the best and mean fitness, with acceptable computational time.

This paper proposed a new energy-efficient ASP model that can be a guideline to design assembly station. Furthermore, this is the first attempt to implement MFO for the ASP problem.

5. A self-adaptive alignment strategy for large components based on dynamic compliance center
Authors: Fuzhou Du, Ke Wen, Hao Yu

Aiming at the problems of geometric precision misalignment and unconsidered physical constraints between large components during the measurement-assisted assembly, a self-adaptive alignment strategy based on the dynamic compliance center (DCC) is proposed in this paper, using force information to guide alignment compliantly.

First, the self-adaptive alignment process of large components is described, and its geometrical and mechanical characteristics are analyzed based on six-dimensional force/torque (F/T). The setting method of DCC is studied and the areas of DCC are given. Second, the self-adaptive alignment platform of large components driven by the measured six-dimensional F/T is constructed. Based on this platform, the key supporting technologies, including principle of self-adaptive alignment, coordinate transfer, calculation of six-dimensional F/T and alignment process control, are illustrated. Using the presented strategy, the position and orientation of large component is adjusted adaptively responding to measured six-dimensional F/T and the changes of contact states are consistent with the strategy. Through the setting of DCC, alignment process runs smoothly without jamming.

This strategy is applied to the alignment experiment of large components muff coupling. The experimental results show that the proposed alignment strategy is correct and effective and meets the real-time requirement.

6. Vision and laser fused SLAM in indoor environments with multi-robot system
Authors: Haoyao Chen, Hailin Huang, Ye Qin, Yanjie Li, Yunhui Liu

Multi-robot laser-based simultaneous localization and mapping (SLAM) in large-scale environments is an essential but challenging issue in mobile robotics, especially in situations wherein no prior knowledge is available between robots. Moreover, the cumulative errors of every individual robot exert a serious negative effect on loop detection and map fusion. To address these problems, this paper aims to propose an efficient approach that combines laser and vision measurements.

A multi-robot visual laser-SLAM is developed to realize robust and efficient SLAM in large-scale environments; both vision and laser loop detections are integrated to detect robust loops. A method based on oriented brief (ORB) feature detection and bag of words (BoW) is developed, to ensure the robustness and computational effectiveness of the multi-robot SLAM system. A robust and efficient graph fusion algorithm is proposed to merge pose graphs from different robots. The proposed method

can detect loops more quickly and accurately than the laser-only SLAM, and it can fuse the submaps of each single robot to promote the efficiency, accuracy and robustness of the system.

Compared with the state of art of multi-robot SLAM approaches, the paper proposed a novel and more sophisticated approach. The vision-based and laser-based loops are integrated to realize a robust loop detection. The ORB features and BoW technologies are further utilized to gain real-time performance. Finally, random sample consensus and least-square methodologies are used to remove the outlier loops among robots.

7. Track-based analysis for profile generation on globoidal cam in automatic tool changer of CNC machining center
Authors: Kuldeep Verma, R.M. Belokar, Vinod Kumar Verma, Klimis Ntalianis

This paper aims to propose an elementary approach towards the measurement of a globoidal cam profile used in an automatic tool changer (ATC) of computer numerical control (CNC) machines.

A simple and unique online method has been designed for the profile metrology of the cam. This simple methodology will replace the traditional methodology of profile metrology of cam by coordinate measuring machine (CMM). A globoidal cam with an indexable turret and roller follower (rotating in an enclosed track) has been evaluated in our analysis. This analysis plays a significant role in the performance determination of the cam as well as the ATC of CNC machines.

A novel model has been designed and implemented to investigate the profile of a globoidal cam. The proposed methodology becomes an enhancement over the old methodology, i.e. measurement through CMM. Theoretical analysis and practical implementation prove the significance of the method.

An enhanced methodology to effectively measure the globoidal cam profile has been proposed. The practical implication of the proposed methodology remains for the CNC machine tool and ATC manufacturers. Finally, analytical explorations have been carried out to prove the validity of the proposal.

8. Assembly error propagation modeling and coordination error chain construction for aircraft
Authors: Feiyan Guo, Fang Zou, Jian Hua Liu, Qingdong Xiao, Zhongqi Wang

Manufacturing errors, which will propagate along the assembly process, are inevitable and difficult to analyze for complex products, such as aircraft. To realize the goal of precise assembly for an aircraft, with revealing the nonlinear transfer mechanism of assembly error, a set of analytical methods with response to the assembly error propagation process are developed. The purpose of this study is to solve the error problems by modeling and constructing the coordination dimension chain to control the consistency of accumulated assembly errors for different assemblies.

First, with the modeling of basic error sources, mutual interaction relationship of matting error and deformation error is analyzed, and influence matrix is formed. Second, by defining coordination datum transformation process, practical establishing error of assembly coordinate system is studied, and the position of assembly features is modified with actual relocation error considering datum changing. Third, considering the progressive assembly process, error propagation for a single assembly station and multi assembly stations is precisely modeled to gain coordination error chain for different assemblies, and the final coordination error is optimized by controlling the direction and value of accumulated error range. Based on the proposed methodology, coordination error chain, which has a direct influence on the property of stealthy and reliability for modern aircrafts, is successfully constructed for the assembly work of the jointing between leading edge flap component and wing component at different assembly stations.

9. Variation propagation modeling and analysis of automotive body outer cover panels assembly systems
Authors: Wenwu Han, Qianwang Deng, Wenhui Lin, Xuran Gong, Sun Ding

This study aims to present a model and analysis of automotive body outer cover panels (OCPs) assembly systems to predict assembly variation. In the automotive industry, the OCPs assembly process directly influences the quality of the automobile body appearance. However, suitable models to describe variation propagation of OCPs assembly systems remain unknown.

An adaptive state space model for OCPs assembly systems is introduced to accurately express variation propagation, including variation accumulation and transition, where two compliant deviations make impacts on key product characteristics (KPCs) of OCP, and the impacts are accumulated from welding process to threaded connection process. Another new source of variation from threaded connection is included in this model. To quantify the influence of variation from threaded connection on variation propagation, the threaded

connection sensitivity matrix is introduced to build up a linear relationship between deviation from threaded connection and output deviation in KPCs. This matrix is solved by homogeneous coordinate transformation. The final deviation of KPCs will be transferred to ensure gaps and flushes between two OCPs, and the transition matrix is considered as a unit matrix to build up the transition relationship between different states.

The model can be used to predict assembly variation or potential dimension problems at a preliminary assembly phase. The calculated results of assembly variation guide designers or technicians on tolerance allocation, fixture layout design and process planning.

10. A coordination modelling approach for assembly of multi-constrained objects based on measured skin model
Authors: Yifan Jiang, Xiang Huang, Shuanggao Li, Zhengping Deng

The purpose of this paper is to propose an assembly coordination modelling approach based on measured data for assembly quality control of multi-constrained objects in aircraft assembly. This approach aims to establish a high-precision digital mirror of physical assembly system in the virtual environment, with which the assembly process in the virtual environment can be performed synchronously with that in the physical world.

This paper presents a realistic geometrical representation model based on measured point cloud, as well as the multiple constraints modelling methods for local and global constraints with the proposed representation model. For the assembly target optimization, a novel optimization method based on the evaluation of multi-dimensional tolerance zone is proposed, where the particle swarm optimization and simulated annealing algorithm are combined to calculate the optimal solutions.

As shown in the validation results, the minimum easiness value for easiness model in global optimization is 3.01, while the best value for weighting model by adjusting weights for more than 10 times is 1.94. The results verify that the proposed coordination modelling approach is effective to the assembly of multi-constrained objects, and the optimization model has an obvious advantage over the traditional weighting method.

11. A discrete fireworks optimization algorithm to optimize multi-matching selective assembly problem with non-normal dimensional distribution

Authors: Zhenyu Liu, Zhang Nan, Chan Qiu, Jianrong Tan, Jingsong Zhou, Yao Yao

The purpose of this paper is to apply firework optimization algorithm to optimize multi-matching selective assembly problem with non-normal dimensional distribution.

In this paper, a multi-matching selective assembly approach based on discrete fireworks optimization (DFWO) algorithm is proposed to find the optimal combination of mating parts. The approach introduces new operator with the way of 3-opt and also uses a stochastic selection strategy, combines the discrete selective assembly problem with firework optimization algorithm properly and finds the best combination scheme of mating parts with non-normal dimensional distributions through powerful global search capability of the firework optimization algorithm.

The effects of different control parameters, including the number of initial fireworks and the coefficient controlling the total number of sparks generated by the fireworks on the evolution performance, are discussed, and a promising higher performance of the proposed selective assembly approach is verified through comparison with other selective assembly methods.

The best combination of mating parts is realized through the proposed selective assembly approach, and workers can select suitable mating parts under the guidance of the combination to increase the assembly efficiency and reduce the amount of surplus parts.

12. The shortest-path spanning tree of assembly dimension and its application
Authors: Youli Wang, Liming Dai, Xueliang Zhang, Xiaohui Wang

The purpose of this paper is to obtain the reasonable dimensioning for each part and a full-dimension model of assembly dimensions.

The relational path graph of assembly dimension, the shortest-path spanning tree of functional dimension and a revised spanning tree are established in this paper.

The proposed method can obtain reasonable dimensioning of parts and establishment of dimension model in an assembly. The proposed method can easily realise by computer and be more suitable to automatic dimensioning and establishment of dimension model of parts.

70 lat
WYDAWNICTWA SIGMA-NOT

Minęło właśnie 70 lat działalności oficyny wydawniczej Naczelnej Organizacji Technicznej, od czterdziestu lat znanej jako Wydawnictwo Czasopism i Książek Technicznych SIGMA-NOT. Rodowód oficyny sięga 1949 roku, kiedy to w dniu 12 lipca, po II Walnym Zjeździe Delegatów NOT, powołano do życia Administrację Czasopism Technicznych NOT, z której wywodzi się SIGMA. Z dzisiejszej perspektywy decyzję tę należy ocenić jako doniosłą — ponieważ zintegrowała ona różnorodne, rozproszone działania wydawnicze, podejmowane przez stowarzyszenia inżynierskie jeszcze w drugiej połowie XIX wieku oraz wyszła tu ogromnemu zapotrzebowaniu na dokształcanie fachowe i informacje techniczne po zakończeniu II wojny światowej.

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70 lat
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