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Assessment of design manufacturability in assembly processes by modified Boothroyd & Dewhurst DFA method

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Paper presents the problem of evaluating manufacturability of product design. The issue was described from the point of view of course of assembly operations implementation criterion (Design for Assembly – DFA). Technological assessment of the complex product structure flow is given using Boothroyd & Dewhurst method. Presented flow of the proceedings is illustrated by an example.

KEYWORDS: assembly processes, design manufacturability

Introduction

Determining the consequences of design decisions is critical in assessing the efficiency and effectiveness of designing production processes and systems [7]. Various methods are used to assess assembly efficiency [1-7, 9]. In the automotive industry, DFA (design for assembly) methods have gained recognition. The use of DFA methods allows for a simpler construction with fewer components [6, 7, 10]. The most common methods are Lucas DFA and Boothroyd & Dewhurst (B&D) DFA [2, 3, 8]. The Lucas DFA method is described in publication [7]. The study presents possibilities of applying and modifying the B&D method.

Boothroyd & Dewhurst DFA method

The B&D method was developed at the end of 1970. In the following years, it was improved due to new methods and analysis techniques. The analysis is not used to develop the project, while it is used to evaluate and improve the existing structure of the designed product. Most often, it is used to assess the prototype before putting it into production [2].

The B&D method has eight guidelines for the design of the assembly process:

- reducing the number of components (assemblies, parts),
- elimination of corrections after assembly operations,
- designing the largest possible number of product components (assemblies, parts) for self-positioning and self-assembling,
- providing adequate access and unrestricted view,
- ensuring easy assembly of components,
- minimizing the need to reorient components during assembly,
- maximizing the number of components that cannot be installed incorrectly,
- maximizing the number of components that are symmetrical (if possible) or (if not) clearly asymmetrical.

However, it should be noted that reducing the number of components of the product may lead to an increase in their complexity and increase in their manufacturing costs.

At the first stage of the assembly analysis, two characteristic parameters are determined for each part: thickness and size – figs. 1 and 2.

Fig. 1. Determination of thickness (diameter) and size (length) [2]

Fig. 2. Determining the ALPHA and BETA angles [2]

Thickness is the length of the shortest side of the smallest cuboid that surrounds the item. Size is the length of the longest side of the smallest cuboid that can surround the part [2].

In fig. 2, the angles BETA and ALPHA are marked. The ALPHA angle determines the symmetry of the part about the axis perpendicular to the insertion direction. BETA angle - symmetry of a part about an axis parallel to the insertion direction [2]. Based on the values of thickness and size as well as angles, indicators of handling time and setting time in assembly operations are determined. To this end, tables prepared by Boothroyd and Dewhurst are used.

Handling time indicator is determined depending on the following features and parameters of the assembly process in progress [2]:

- A component (assembly or part) is a solid or unstable part of the assembly process. An assembly is considered a part if it is assembled as a whole.
- "Required holding" means that the part being mounted is unstable when placed, inserted, or during subsequent operations and will require re-gripping and alignment or holding.
- The part is easy to assemble and determine the position if its construction form has features that facilitate assembly, e.g. by designing the chamfers on sharp edges.
- Resistance encountered while inserting parts.
- Standard tightening time includes extra time to raise the power tool, lower the screw or nut, and start the tool.

When determining the time index of manipulation, it must be assessed whether the manipulation can be carried out: with one hand, one hand with an auxiliary handle, two hands, two hands with mechanical assistance. Time for placing parts is considered for three situations:

- the part is mounted but not connected,
- the part is mounted and connected,
- the part is assembled after additional operation.

For each of these situations, the embedding indicator is determined based on indicator tables. The next stage of the analysis is to check the possibility of eliminating the part. A diagram of the course of proceedings regarding the elimination of parts is shown in fig. 3 (assessment of the possibility of the occurrence of several parts in the form of one whole).

The following course of action was developed for large-scale production. The final stage is the calculation of: the sum of the number of operations, total time of the operation, total cost of the operation, theoretical minimum number of parts and the DFMA production index:

$$S_{lo} = \sum O_i \quad (1)$$

where: S_{lo} - sum of the number of assembly operations [2]; O_i - i -th assembly operation.

Fig. 3. Elimination scheme for B&D DFA components [2]

$$T_{op} = \sum T_{mau} + \sum T_{mov} \quad (2)$$

where: T_{op} - total time of assembly operations [2]; T_{mau} - time of the assembly operation with the u -th manipulation time indicator; T_{mov} - assembly time with v -th embedding time indicator.

$$DFMA_{wp} = \frac{(3 \cdot S_{lo})}{T_{op}} \quad (3)$$

where: $DFMA_{wp}$ - index of structure efficiency before assessment [2].

$$DFMA_{wpo} = \frac{(3 \cdot S_{lpo})}{T_{opo}} \quad (4)$$

where: $DFMA_{wpo}$ - structure efficiency index after analysis [2]; S_{lpo} - sum of the number of assembly operations after the analysis; T_{opo} - theoretical minimum assembly operation time after analysis.

An attempt was made to modify this method and its application also for serial and small-lot production. The B&D method, due to its simple construction compared to other methods (e.g. Lucas DFA [6, 7]), according to the authors, may be susceptible to such modification. In the organization of production, the unification and standardization of product components is important, which can be determined by the index of component unification:

$$DFMA_{\text{wUNK}} = \frac{(3 \cdot S_{\text{UNK}})}{T_{\text{op}}} 100\% \quad (5)$$

where: $DFMA_{wUNK}$ - index of structure efficiency after analysis for unified and standardized components; $SUNK$ - sum of unified and standardized assembly components after analysis.

From the point of view of machining costs, the use of group machining plans and operations that do not require retooling work stations, the improvement of process efficiency due to the increase in production series can be determined by the index of unification of performed operations:

$$DFMA_{\text{wOG}} = \frac{(3 \cdot S_{\text{OG}})}{T_{\text{OP}}} \cdot 100\% \quad (6)$$

where: *DFMAwOG* - construction efficiency index after analyzing the construction of components enabling the implementation of group machining; *SOG* - sum of components after analysis, possible to implement using group processing technology.

Example

According to the B&D DFA method, the design of a single-stage gear prototype was analyzed (fig. 4).

First, the assembly process was defined, an example of which is shown in the table. S_{lo} , T_{op} , $DFMA_{ip}$, $DFMA_{ipo}$ values were specified for each assembled part and for each defined assembly process step

$$\text{Indicator } S_{i0}: S_{i0} = \sum O_i = 113 \quad (7)$$

$$\text{Indicator } T_{\text{op}}: T_{\text{op}} = \Sigma T_{\text{mau}} + \Sigma T_{\text{mov}} = 683,19 \quad (8)$$

$$\text{Indicator } DFMA_{wp} = \frac{(3 \cdot S_{10})}{T_{op}} = 3 \times 113/683,19 = 0,496 (\sim 50\%) \quad (9)$$

In order to improve the gear assembly technology, consideration should be given to analyzing:

- the use of a new construction form (casting),
- the use of a new assembly structure - by assembling the assemblies, e.g. shaft with mounted gear, bearings, the use of tooling, visibility and easy manipulation of the value of physical loads during assembly, etc. [2].

After changing the gear structure and performing another analysis of the structure's efficiency, the following indicator values were obtained:

- after changing $Swpo = 22$,
- after unification $Swpo = 37$ including 27 unified elements,

after determining the group processing $Swpo = 42$ including the number of components subject to group processing: 19, indicator $DFMA_{wpo} = \frac{(3 \cdot S_{ipo})}{T_{ino}} = 3 \cdot 22/244,59 = 0,26 \sim 26\%$

Fig. 4. Diagram of the analyzed gearbox

Based on the given index values, other coefficients were determined for the changed design of the designed transmission: (10)

$$\text{Indicator } S_{\text{UNK}}: S_{\text{UNK}} = \Sigma O_i = 27$$

$$\text{Indicator } T_{\text{UNK}} = \Sigma T_{\text{mau}} + \Sigma T_{\text{mov}} = 372 \quad (11)$$

$$\text{Indicator } DFMA_{\text{wUNK}} = \frac{(3 \cdot S_{\text{UNK}})}{T_{\text{UNK}}} \cdot 100\% = 3 \cdot 27 / 372 = 0,217 (\sim 22\%) \quad (12)$$

$$\text{Indicator } S_{\text{OG}}: S_{\text{OG}} = \Sigma O_i = 19 \quad (13)$$

$$\text{Indicator } T_{\text{OG}} = \Sigma T_{\text{mau}} + \Sigma T_{\text{mov}} = 421 \quad (14)$$

$$\text{Indicator } DFMA_{\text{wOG}} = \frac{(3 \cdot S_{\text{OG}})}{T_{\text{OG}}} \cdot 100\% = 3 \cdot 19 / 421 = 0,135 (\sim 14\%) \quad (15)$$

TABLE. Results of the analysis of gear assembly manufacturability from fig. 4.

DFMA Analysis record																
Product data			Components assembly details					Manipulation		Embedding		Operation time index	Theoretical minimum number of parts/operations			
No.	Description	Initial process assumption	Number of repetitions	Thickness (t mm)	Size (s mm)	Rotation Alpha (degrees)	Rotation Beta (degrees)	Code	Time index [min]	Code	Time index [min]		Relative movement [min]	Other material	Separation of parts	Do you need
1	Body	download	1	120	309	360	360	30	1.95	0	1.5	3.45	N	N	T	1
2	Bearing 16	body pressing	1	17	72	180	0	0	1.13	31	5	6.13	N	T	T	1
3	Bearing 17	body pressing	1	20	90	180	0	0	1.13	31	5	6.13	T	T	T	1
4	Toothed shaft	bearing pressing 16	1	37	194	360	0	88	6.35	41	7.5	13.85	T	N	T	1
5	Slow speed roller	download	1	28	216	360	360	30	1.95		0	1.95	T	N	T	1
8	Spacer sleeve 14	mounting on shaft assembly	1	4	60	180	0	0	1.13	1	2.5	3.63	N	N	N	0
9	Heating	gear heating up to180	1						0	99	12	12	N	N	N	0
10	Roller assembly	bearing pressing 17	1	136	216	360	360	30	1.95	51	9	10.95	T	T	T	1
11	Cover	download	1	25	288	360	360	30	1.95		0	1.95	N	N	Y	1
12	Bearing 16	cover pressing	1	17	72	180	0	0	1.13	31	5	6.13	T	T	T	1
13	Bearing 17	cover pressing	1	20	90	180	0	0	1.13	31	5	6.13	T	T	T	1
18	Spring washer 28.2	screw mounting	10	4	14	180	0	5	18.4	6	55	73.4	N	N	N	0
19	Screw with washer	screwing cover to the body	10	4	20	360	0	10	15	38	60	75	N	N	N	0
22	Spring washer 28.2	screw mounting	4	4	14	180	0	5	7.36	6	22	29.36	N	N	N	0
23	Sealant Monolith	sealing	1						0	99	12	12	N	T	N	1
24	Screw with washer	screwing cover 5 to the body	4	4	14	180	0	10	6	38	24	30	N	N	N	0
Sum of parts/operations - Before change - 113			113						Sum of operations times -before change - 683.19			683.19	Theoretical minimum numer of parts/operations			22
- after change - 22. - after unification - 27. - number of components subject to group machining - 19 - after change - ~244.59; after unification - ~372; - after analysing the possibilities of grup machiny-~421																

Summary

The B&D method, by analyzing the obtained values of the parameters of assembly efficiency assessment:

- allows for reducing the time, eliminating errors, reducing the process costs, taking into account, in addition to assembly, many other factors, e.g. availability of spare parts, production series, production conditions in the form of equipment types, available assembly techniques, level of automation or the scope of external cooperation orders. The method can be used for smaller production runs;
- assessment of the machinability of the structure arouses designers' creativity; The assessment of the efficiency in the form of given indicators and coefficients should be carried out by experts with extensive production experience.

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