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Assembly Initiated Production as a Prerequisite for Mass Customization and Effective Manufacturing

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The paper deals with a review of a complex IPS-DFA methodology with a purpose of rating and improving design characteristics regarding the aspect of the assembly process. The approach has to be applied at the level of the product assortment, basic product structure and at the component level, aiming to achieve two primary goals: rationalization of the part count and the optimization of handling and fitting parts, through the developed tools for assembly suitability enhancement. Comprehensiveness of the methodology, especially at the product assortment level, simultaneously enables increasing suitability for mass customization. The paper provides an insight into the results of circular pumps product family application with a special emphasis on the consequences concerning mass customization.

Keywords: product design, design for assembly, mass customization, concurrent engineering

0 INTRODUCTION

Mass customization and personalization are strategies developed to address the challenge by producing goods and services meeting individual customer need's with near mass production efficiency [15] and [18]. Today's turbulent markets, growing product variety, and opportunities for e-commerce require efficient approaches, like Agile Manufacturing, Just-in-Time, Build-to-Order and Mass Customization. Mass customization comprises the whole spectrum of methodologies that can benefit companies and the inevitably one is DFA due to extreme importance of assembly process and well designed production varieties for quick response to individual customers needs.

The product design process definitely plays a major role when planning and implementing mass customization. Managing the variety in the design domain is a challenging problem for manufacturers. Designing a family of products using a common platform approach instead of designing single products has gained momentum in various industries. Product families and common product platforms should help mass customizing companies to ensure economies of scale while serving all customers differently. Design for assembly (DFA) techniques and methodologies have been in use since the early 1980s, started with three independent DFA tools, representing a systematic approaches in solving the problem of products' suitability for assembling.

These tools are:

- *Boothroyd-Dewhurst DFA* [5];
- *Lucas DFA* [12];
- *Hitachi Assembly Evaluation Method,* [13].

To this day, number of researches have been made in the field of assembly suitability rating and enhancement and/but each of them covers a part of the problem [1], [14] and[17]. The applicability factor of DFA methods also has received considerable attention. There are many factors, like modularizing the product to fit the strategy, adjusting the optimum product structure, minimizing the part variety with the help of group technology principles and determination the optimum level of automation of operations to accomplish production solutions. Flowchart methods which avoid extensive mathematical analyses have been presented, such as the design for automatic assembly (DFA2), and concurrent engineering methodologies have proposed supportive measures, but there still remains the distinct separation which exists, in most companies, between the design departments and production system [10].

The basic aim of the IPS-DFA integrated methodology is to completely encompass all relevant aspects of assembly suitability from the standpoint of product, process and system designing. The paper presents the methodology for implementation of all available knowledge about the **assembly process** *(organisation, process and resources)* into a new product or in

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an already existing product, enabling efficient and accurate assembly [3]. Built-in characteristics during the developing phase will lead toward the minimal expenses, short assembly times and working conditions suited to manual work. It has to be based on three principles IPS - *Integration, Parallelization and Standardisation,* generating the acronym of the full name **IPS-DFA methodology** [6]. Immediately follows the question, what does IPS-DFA methodology has to encompass. If the final goal is a **product designed for assembly** having all above-mentioned characteristics, it can be concluded that IPS-DFA methodology has to have three aspects of comprehensiveness:

- *The approach has to be applied at the level of the product assortment, structure of the complex product-representative and at the component level.*
- *The approach has to have complete mechanism for assembly suitability enhancement which consists of: developed analyses for design rating with the ability of weak point detection and the developed tools (procedures) for design improvement as a generator of ideas and suggestions.*
- *The approach has to be completely incorporated into the procedure of assembly process planning and system designing, therefore the conducted analyses and the results have to be adjusted to fit both needs.*

In addition, assembly is an operation that is executed relatively late in the manufacturing chain. Considering that most companies with large product variant numbers desire to give a product its final identity as late as possible in this chain, accomplishing this in the last operation that involves be a definite achievement. The final assembly is the last of the operations that involves making changes to the product itself would therefore be the natural choice for creating different variants of products.

Going from mass production to mass customization requires introduction a new strategy **AIP** *(Assembly-Initiated Production)* [9] providing short lead times through production. AIP is formed around the idea to assemble products from product modules on customer orders.

The total delivery time would be the time to process order + assembly time + shipping time. This gives a total delivery time considerably shorter than when manufacturing the entire product order.

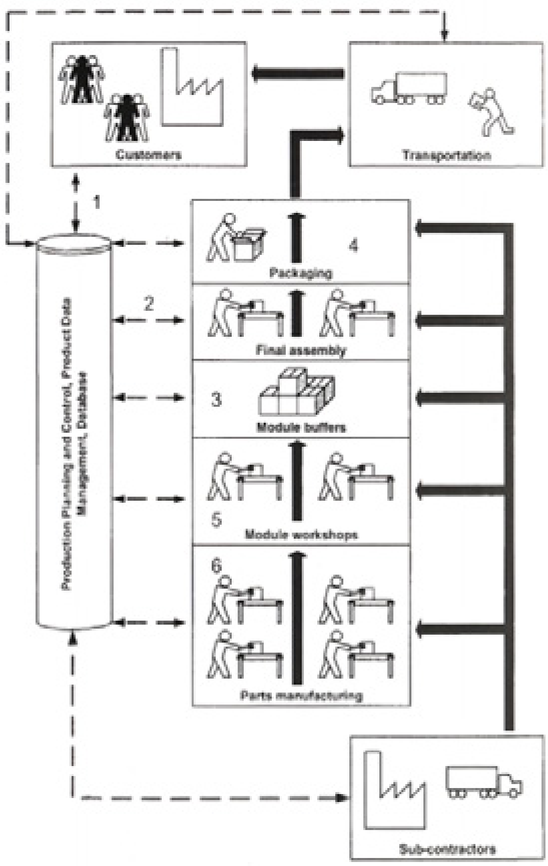

Fig. 1. *Assembly Initiated Production* [9]

Fig.1 describes the function of the AIP structure:

1. The customer order enters the computer system and is immediately available to the assembly.
2. The assembly will be able to see which orders there are in the system at an earlier stage. This will lead to a more responsive production with shorter lead-times.
3. One of the central concepts about AIP is the modularization of products. The modules and standard components will be stored close to the assembly. When an order is to be executed, components and modules will be taken from the storage and assembled into products.
4. The finished products are, after the assembly, packed and delivered to the customer. The process described so far will decide the lead time from order to delivery.

5. The module storage is set just before the module (assembly) working units. Modules are produced to keep the levels in the module storage at a preset value.
6. The demands placed upon manufacturing and ordering of components are basically the same as the ones placed upon modular working units.
7. The subcontractor's role in an AIP system will be evaluated in the scope of the project. Many of the demands set upon subcontractors will be generated by companies using AIP, regardless of what the final product is.

A modular product design is a part of the AIP strategy. Modularization is the decomposition of a product into building blocks (modules) with specified interfaces, driven by company specific reasons, called module drivers [7]. Analyzing module drivers, primary drivers for AIP are to be able to combine modules into products with different specification; different styling and that are sharing common units among variants. Basically, they are central building blocks of the AIP strategy. They make it possible to create product variants within the final assembly.

Second, to improve overall flexibility of the production, driver's carry-over of modules to new products, planned design changes, technical advancement during the product lifetime and the possibility to outsource are important. Standardization of parts that are not to be modules is included in the design process. There are also many different ways to easy production by designing the products to the specification of the manufacturing equipment. Use of design for X, including design for manufacturing and design for assembly methods will contribute to the overall flexibility and performance of the AIP system. **IPS-DFA methodology** provides answers on the most of the stated problems.

1 IPS-DFA METHODOLOGY

IPS-DFA methodology has been developed on the clearly defined principles stated in the introduction, which denote **comprehensiveness** of the methodology from three aspects, connecting *it with other IPS-DFX methodologies* in context of the wider concept of the IPS-DFX platform. The basic characteristic of the platform is the ***common data base*** in which the *integrated product and process development* starts and flows. It contains information about:

- *defined functional tasks,*
- *production system and environment,*
- *unique geometric model of the product*

as well as other necessary information which will be used during the developing phase.

Figure 2 illustrates the concept of comprehensive IPS-DFA methodology based on the principles within the frame of IPS-DFA platform, enabling simultaneous application of all available IPS-DFX methodologies.

IPS-DFA methodology transfers necessary data from the common data base, process them through developed procedure and returns the report with suggestions for corrections on the design. The integrated platform collates all returned suggestions for reconstruction from other methodologies, conforms them and equalizes existing differences, primarily on economic criteria but also on other general design evaluation criteria which could not be explicitly expressed through expenses.

Determined parameters are, according to the third aspect of *comprehensiveness,* ***integrated into the procedure of product planning and system designing,*** i.e. in documents that already exist enabling parallelism and **uniqueness.** After the application of the procedure for assembly suitability enhancement, the developed bases enable direct continuation of the process of product planning and system designing with significant shortening. The second aspect of comprehensiveness states that after the rating of the level of assembly suitability the obtained values be compared with the referent (margin) ones and to suggest concrete measures for assembly suitability enhancement, whereas all measures consist of formal procedures for enhancement, recommendations based on research work and knowledge base with examples, as an idea generator.

1.1. Assembly Suitability Indicators

In the context of the first aspect of **comprehensiveness,** detailed analysis of the influence of the production assortment, product structure and components on assembly process have been performed resulting in the list of necessary and sufficient number of indicators and parameters necessary for computing.

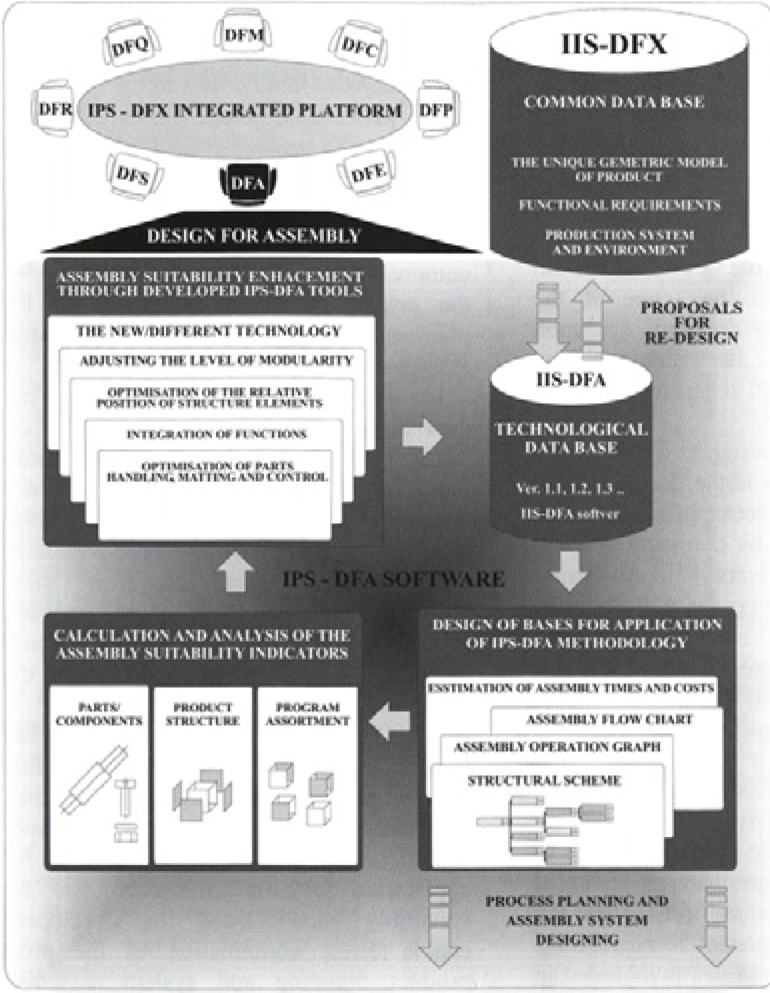

Fig. 2. *Concept of IPS-DFA methodology within the framework of IPS-DFX* [3]

1.1.1 Assembly suitability indicators at the production assortment level

A production program (assortment) is a group of similar products (p_1 - p_n) with the primary goal - fulfilment of a certain set of basic functional requirements (FRi), the most important background in the designing stage, as well as the fulfilment of the additional requirements as a result of the customers' individual demands, either technical or esthetical. The quality of designing, as a function of the production program structure, is generally defined as a maximum number of product variation p_1 - p_n that can be made with a minimum number of different parts N_{Ptot}. All parts that make various product variations have to go through the assembly system in the assembly process. If the structure of the production program is too wide, the possible level of automation and mechanization is lower, even the product representative itself is optimally designed.

After completing the research, four indicators of the assembly suitability are at first established,

Np_{tot} – total number of different parts in the production assortment,
P_v – suitability of product variant development,
P_a – automation suitability indicator,
P_m – number of modules,

capable of presenting the quality of certain production assortment and highlighting weak points that may require designers intervention.

1.1.2 Assembly Suitability Indicators at the Product Structure Level

From the point of the product structure suitability, the most important fact is minimisation of the number of parts and interconnections between them that would lead to the shortest assembly times and costs. The efficiency of the product structure is usually estimated by the following characteristics:

- *number of parts that make the subassemblies and assemblies,*
- *number and orientation of insertion axes,*
- *structural product scheme,*
- *joining techniques,*
- *modularity, standardization...etc.*

In order to calculate the next four indicators at the product structure level, it is necessary to make a structural scheme of the product, assembly operation list and possible assembly sequence graph.

N_P – number of parts of the basic product variant,
P_{fs} – functional suitability of a product,
$P_{ext.}$ – number of additional subass. movements,
P_{bas} – minimum number and sequence of assembly operations.

2.1.3 Assembly Suitability Indicators at the Component Level

The analysis at the component level (considers the geometry, physical and chemical characteristics of a part, and thus determines if a part is suitable for exclusion, handling, orientation and positioning. The main objective is to determine the time and costs of the assembly operations using various methods and techniques.

These estimates can be made for manual, robotized and automated assembling based on DFA handling and joining empirical cases [5]. Assembly suitability indicators at the component level

P_{gt} - suitability for group technology
Σt_{ii} - assembly operation time,
T_M - costs of assembling operation.

1.2. Tools for Assembly Suitability Enhancement

IIS-DFA methodology also includes developed tools for assembly suitability enhancement. Their primary goal is to reduce the part number as the most effective measure, eliminating the complete assembly operation. If further rationalization is not possible, there is a tool for part optimization from the point of handling, insertation and control operations. Having in mind the previous discussion,

Fig. 3 shows developed tools organized in five levels. Each tool consists of three parts:

- *formal (analytic) procedures for enhancement,*
- *recommendations based on research work and*
- *knowledge base with examples, as an idea generator.*

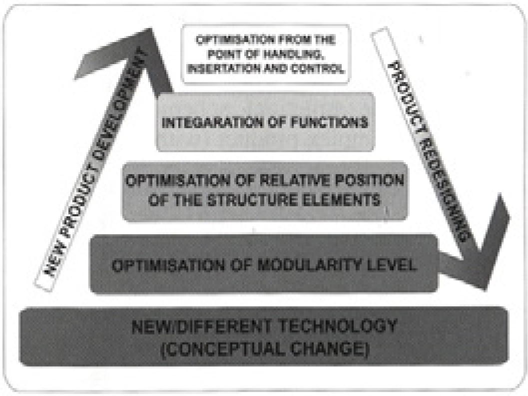

Fig. 3. *Application of the developed tools for assembly suitability enhancement in five levels*

The tools can be applied in process of new product designing or in process of redesigning the existing product.

2 APPLICATION OF THE IPS-DFA ON CIRCULAR PUMP'S PROGRAM VARIETY

Circular pumps production program consists of 14 basic product (Table 1). A total number of different parts in product assortment is 45.

Table 1. *Production program of circular pumps*

№	Product types	№	Product types
P1.	RS 15/50 P 130	P8.	RS 25/80 P 130
P2.	RS 15/60 P 130	P9.	RS 25/50 P 180
P3.	RS 20/50 P 130	P10.	RS 25/60 P 180
P4.	RS 20/60 P 130	P11.	RS 25/70 P 180
P5.	RS 25/50 P 130	P12.	RS 25/80 P 180
P6.	RS 25/60 P 130	P13.	RS 30/50 P 180
P7.	RS 25/70 P 130	P14.	RS 30/60 P 180

Fig. 4. *Circular pump representative – CAD model*

The basic variant, the one with the highest quantities is item No.3. RS 20/50 P130 consisting of 35 different positions (Figure 4).

Representing the whole production variety is of a vital interest, and it is enabled through creation of a structural scheme, with respect to the following rules. The structural scheme is generated for the most complex product (with the largest number of parts).

Initially generated structural scheme is progressively expanding, analyzing the whole assortment range from p_1 to p_n. During the process of structural scheme design regarding the whole production assortment, each part is classified into one of three groups:

- *Universal parts are parts that belong to each product variant (p1-p14),*
- *Poly-variant parts belong to the several product variants and*
- *Variant parts are explicitly addressed to one specific product variant.*

Figure 5 represents the structural scheme, generated for the circular pump's program variety.

According to IPS-DFA methodology (Figure 2), if the background documents are prepared and assembly suitability indicators calculated, the next step concerns an application of a specified number of iterations regarding the developed tools for design improvement - from Version 1 to Version 4.

In addition to, the structural scheme embracing the most needed parameters for assembly indicators calculation, the following backgrounds are also required: ASSEMBLY OPERATION GRAPH, ASSEMBLY FLOW CHART, ESTIMATION OF ASSEMBLY TIMES AND COSTS.

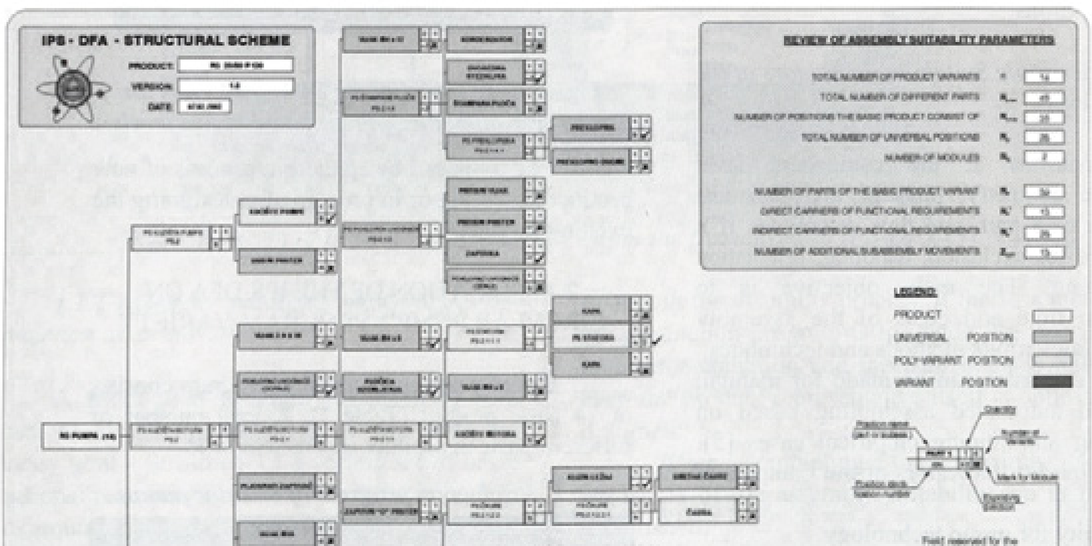

Fig. 5. *Structural scheme – representation of the product assortment*

2.1. Optimisation of Parts

The first measure for assembly suitability enhancement is a tool for optimisation of particular parts that are difficult to assemble, belonging to standard library parts or making the group of poly-variant parts. The results assume corrections on geometric features, material, surface quality, dimensions or tolerances (Figure 6).

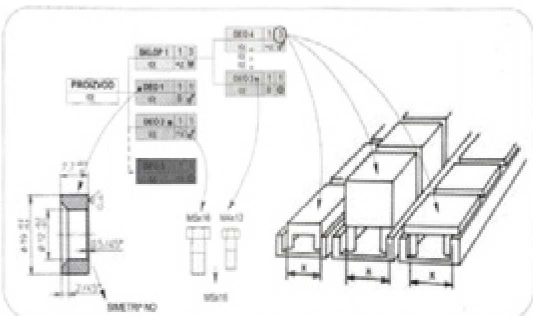

Fig. 6. *Optimization of parts*

The procedure starts with the identification of inconvenient surfaces on parts, concerning following operations *transport, orientation, positioning, joining, control, etc.*, and the main characteristic of the surfaces: functional (support, transfer forces, lead, etc.), connecting (touching or lying next to) or free (not functional or connecting) surfaces. The success of the procedure depends on a lot on the above mentioned surface character, allowing more or less freedom in making improvements toward assembly suitability and their acceptance (Figure 7).

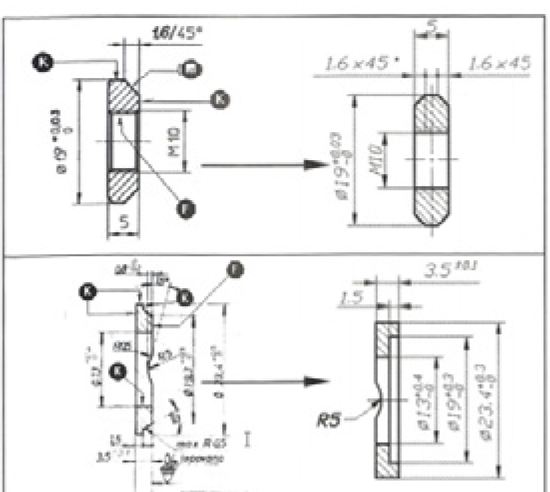

Fig. 7. *Examples of part optimisation*

2.2. Integration of Functions

The procedure prediction the possibility of making integration of two or more parts into one, depending on the efficiency of the given design solution. The integration is primarily related to parts *indirect carriers of functional requirements*, but can be applied without exception to parts *direct carriers of the functional requirements*. Although a strong line could not be drawn, the integration of functions is primarily related to the local (leaf) levels of the structures, to components or the simplest subassemblies. If the integration is successful, the *global structure of the product* will stay unaffected.

In order to make the integration of a certain number of parts, which will lead to elimination of assembly operation, a specific algorithm is developed for identification of parts suitable for integration (Fig. 8). Three fundamental reasons for differentiation have to be reconsidered of the given whole on the final number of elements. The creative thinking of the designer is stimulated through intentional and targeted questions for verification of each position in the design from the point of necessitation and justification for it's presence in the design. If passing through algorithm even one good reason is found for the existence of part as a separate entity, then it belongs to the group of elementary parts. On the contrary, the part belongs to a set of entities that's functions could potentially be transferred to part/parts in direct contact and perform the integration, physically eliminating it from the design.

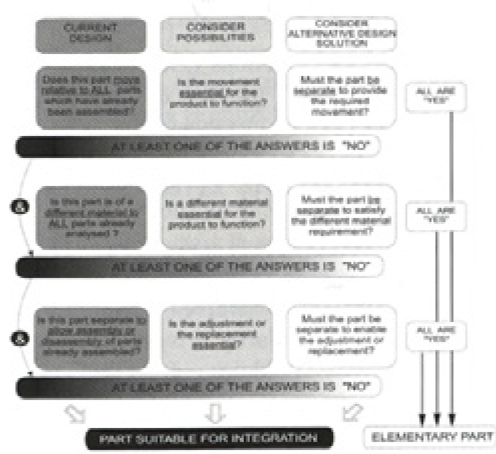

Fig. 8. *Algorithm for identification of parts suitable for integration*

Figure 9 shows the results obtained through integration of two or more parts in one.

2.3. Optimization of the relative Position of Structure Elements

The next step on the way to enhance assembly suitability is to vary the structure of the product, in order to optimise the relative position of elements (subassemblies). The achieved corrections will directly affect the structure: mating directions (±X, ±Y, ±Z), number of assembly flows, sequence of operations P_z, presence of the base component, the number of the extra operations P_{ext}, possibility of simultaneous performing the operations, minimum through output assembly time $t_{ct\ min}$, etc.

The procedure starts with the analysis of the structural scheme of the product and continues with the following:

- *Determination of the main assemblies and subassemblies through the desired level and symbolical representation,*
- *Symbolically represented main elements are varied in different spatial combinations,*
- *The most promising combinations that are not in collision with the defined functional requirements are going to be developed further,*
- *The choice of the optimum structure is based on the defined criteria,*

Figure 9 shows the reduction of few mating directions through changing the relative position of structure elements. Product shown on (Fig.9) (left) has 5 different matting directions (±X; ±Y; +Z), and after the reconstruction, the new design (Fig.9) (right) has only one matting direction (+X).

2.4. Optimization of the Modularity Level

Having in mind all disposable knowledge about the modularity and the consequences concerning assembly process, twelve basic features are highlighted as modularity drivers, if the existing number of modules is not satisfactory. The main features are organized in Table 2 to simplify the reconstruction of the product structure, recognizing and translating certain subassemblies into modules. The procedure starts with the matrix (Table 2) where the twelve modularity drivers are opposed to the complete product structure, including all building levels - subassemblies and parts.

Table 2. *Matrix of modularity drivers*

	ELEMENTS OF *STRUCTURE*	ASSEMBLY S-1	SUBASSEMBLY PS-1.1	SUBASSEMBLY PS-1.2	PART D-1	ASSEMBLY S-2	SUBASSEMBLY PS-2.1
	NAME	*	**	**	**	*	*
1	CARRY-OVER	●					
2	TECHNOLOGICAL EVOLUTION			○			
3	PRODUCT PLANNING			○	⊘		
4	TECHNICAL SPECIFICATION						
5	STYLING						
6	COMMON UNIT						
7	PROCESS/ORGANISATION REUSE		●		⊘		
8	SEPARATE TESTING OF FUNCTION					○	
9	BLACK BOX						
10	SERVICE & MAINTANANCE						
11	UPGRADING						
12	RECYCLING						

Note: ●-3 points, ⊘-2 points i ○-1 points

The matrix is filled with the given symbols illustrating the importance of certain features and the possibility that a given subassembly or component becomes a module. It is important to emphasise that the success of the procedure is tightly connected to defined functional requirements for the given product FRi, because the module generation is one of the earliest stages in product developing process, preceeding the detailed definition of structure. Elements of the structure having the highest number of points in total are separated as the most serious candidates for modules and it remains to be reconsidered if there is some design or technological constraints.

2.5. Application of the New / Different Technology

The last level of product enhancement is the most radical one, and if it can be technically accomplished, it brings the largest benefit. The application of the new/different technology is

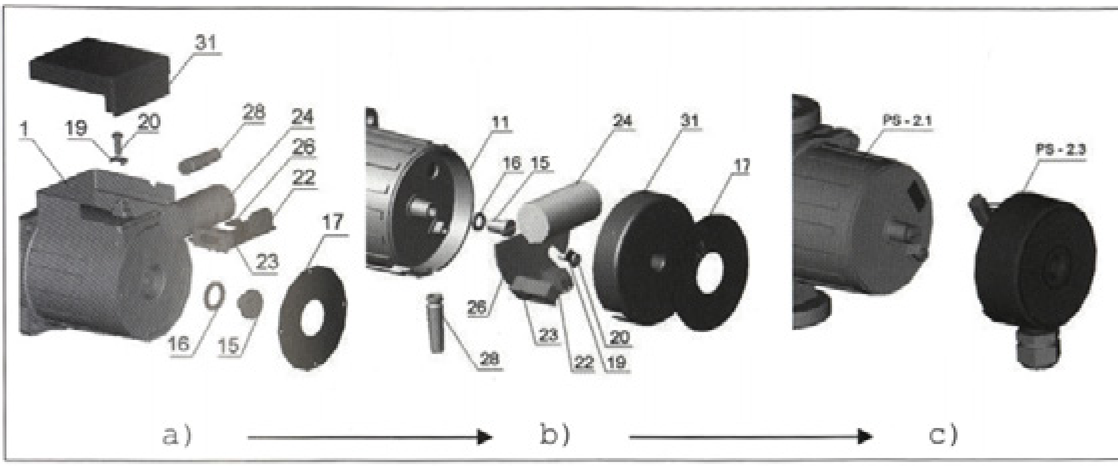

Fig. 9. *The results of applied tools for optimization of product structure and increasing the level of modularity*

connected to applied sciences as a result of the latest researches in fundamental sciences.

Morphological analysis is a methodology of a significant help in applying the new/different technologies. It is defined as an approach for systematical thinking and finding solutions for different problems. Morphological analysis enables the generation of possible developing alternatives in product designing.

2.6. Feedback Report - Proposals for Re-design

After the application of the developed tools for assembly suitability enhancement, it is to be expected that the number of proposals for re-design will follow. The proposals have to be clearly presented in the document "PROPOSAL FOR RE-DESIGN", where the expected savings in assembly times and costs are particularly highlighted. Further, the proposals have to be critically analyzed if they cause negative consequences in some other aspects of the design, and if so, the proposal has to be rejected avoiding the additional efforts of other experts in the DFX team.

If the DFA expert, according to his professional knowledge and experience does not see any obstacles for implementation of the suggestion, the proposal has to be transferred to be verified by the DFX team, where two different cases may occur.

- *The proposal for re-design is not delayed in any aspect, and can be directly implemented in product design;*
- *The proposal for re-design is delayed by the expert team, sent for a detailed cost-benefit analysis, and followed by a renewed discussion about verification.*

The DFX expert's team has to have as much iteration as necessary until none of participants has any objections to the proposal, so a consensus about the design reconstruction is achieved.

3 CONCLUSION

The developed IPS-DFA methodology completely came to the expectations, from the point of assembly suitability enhancement, since the established indicators connected with the developed tools enable a systematic improvement of certain detected weak points in the design, which has been confirmed in the number of case studies. After the process of re-designing has been completed, circular pump's program variety structural scheme (Figure 10) clearly indicates the achieved simplifications concerning the part count and part variety reduction – smaller yellow boxes with poly-variant parts. Continuously monitoring indicators through developed on three levels, enables one to track every single change in the design and the consequences it has on the assembly process.

Table 3 briefly summarizes the accomplished achievements with the given assembly suitability indicators after each iteration has been performed (ver.1-ver.4).

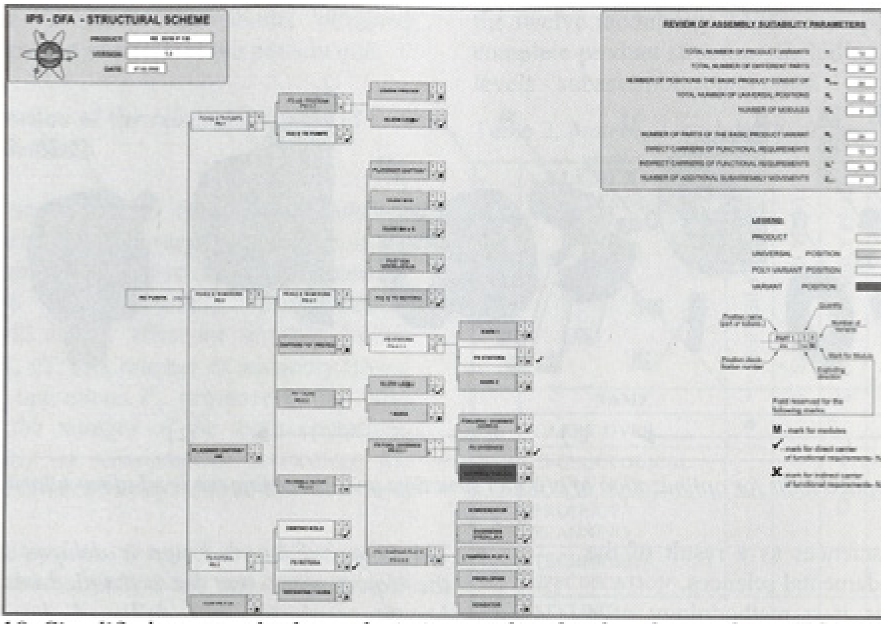

Fig. 10. *Simplified structural scheme depicting product family, after applying IPS-DFA*

Table 3. *Review of assembly suitability indicators after application of IPS-DFA*

No	SUITABILITY INDICATORS (Production Assortment)		Ver 1.4	Ver 1.3	Ver 1.2	Ver 1.1	Ver 1.0	Jed.
1.1	Total number of different parts in the production assortment	N_{du}	35	35	37	44	45	-
	Number of positions the basic product consist of	N_{pbas}	27	35	27	36	36	-
	Number product variants in the production program	n	14	14	14	14	14	-
1.2	Suitability of product variant development	$P_V=(N_{du}/N_{pbas})/n$	57%	71%	71%	71%	71%	-
	Total number of parts in the production program	N_U	23	18	20	28	28	-
1.3	Automation suitability indicator	$P_A=N_U/N_{du}$	66%	54%	64%	64%	62%	-
1.4	Number of modules	$P_M=N_M$	3	2	2	2	2	-
No	**SUITABILITY INDICATORS (Product Structure)**		**Ver 1.4**	**Ver 1.3**	**Ver 1.2**	**Ver 1.1**	**Ver 1.0**	**Jed.**
2.1	Number of parts of the basic product variant	N_P	29	28	30	39	39	-
	Direct carriers of functional requirements	N_P^I	13	13	13	13	13	-
	Indirect carriers of functional requirements	N_P^{II}	16	15	17	26	26	-
2.2	Functional suitability of a product	$P_{fu}=N_P^I/N_P$	45%	46%	43%	33%	33%	-
2.3	Number of additional subassembly movements	$P_{zd}=Z_{zd}$	7	9	11	13	13	-
2.4	Min. number and sequence of assembly operations	$P_{bo}=T_{cl,bo}/T_{cl}$	133/42%	150/54%	166/40%	197/45%	197/45%	-
No	**SUITABILITY INDICATORS (Component level)**		**Ver 1.4**	**Ver 1.3**	**Ver 1.2**	**Ver 1.1**	**Ver 1.0**	**Jed.**
	Number of the universal assembly tasks	m_u	18	16	19	22	22	-
	Total number of assembly tasks in basic product	m	20	18	21	24	24	-
3.1	Suitability for Group Technology	$P_{GT}=m_u/m$	90%	89%	90%	92%	92%	-
	Assembly handling time	Σt_h^A	80.76	50.91	61.89	79.94	81.50	sec
	Assembly inserting time	Σt_u^A	221.00	185.50	241.50	284.50	296.00	sec
3.2	Assembly operation time	$\Sigma t = \Sigma t_h^A + \Sigma t_u^A$	313.26	380.50	338.39	406.94	427.95	sec
	Costs of manual part handling	ΣT_h^R	3.96	3.56	4.03	5.20	5.31	din/kom
	Costs of manual part inserting	ΣT_u^R	14.30	12.75	15.72	18.63	19.40	din/kom
3.3	Costs of manual assembling operation	$T_M^R=\Sigma T_h^R+\Sigma T_u^R$	20.30	16.59	22.03	26.41	27.86	din/kom
	Costs of automated part handling	ΣT_h^A	20.72	17.67	29.61	29.30	27.72	din/kom
	Costs of automated part inserting	ΣT_u^A	38.60	34.08	47.77	46.94	44.67	din/kom
3.3	Costs of automated assembling operation	$T_M^A=\Sigma T_h^A+\Sigma T_u^A$	59.74	54.16	63.46	80.67	76.60	din/kom

At the program assortment level:

- *A total number of parts is decreased* $N_{du}^{IV} - N_{du}^{I} = 45 - 35 = 10$ or 23%,
- *Product variant development suitability is increased by 14%,*
- *The possible automation level amounts to 66%,*
- *The number of modules is increased by one.*

At the product structure level:

- *A total number of parts of the basic product* $N_{D}^{IV} - N_{D}^{I} = 39 - 29 = 10$ or 26%
- *Functional suitability of the basic product is increased by 45% - 33% = 12%,*
- *The number of additional assembly operations is decreased 13-7=5,*

- *The shortest possible assembly time of a product is also decreased from 197 s to 133 s*

At the component level:

- *The suitability for group technology application is very high 90%,*
- *The estimated manual assembly time is 427.95 s - 313.26 s =114.69s ≈ 2 min/item,*
- *The estimated manual assembly costs are decreased 0.43 €/item - 0.31 €/item = 0.12 €/item,*
- *The estimated automated assembly costs are decreased 1.18 €/item – 0.92 €/item = 0.26 €/item*

The achieved results concerning the IPS-DFA methodology application, in addition to the benefits regarding the assembly process, has another great impact on the production variety of circular pumps mass-customization. Figure 11 clearly indicates the obtained results at the production assortment level that mass customization can mostly benefit from. The 14 basic product variants now consist of less parts, component and variants. As a result, the desired customer order is easy to configure at the system entry.

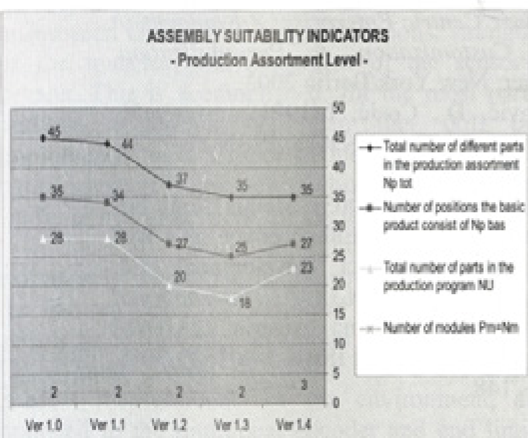

Fig. 11. *Increasing the program variety*

Additionally, the product is re-designed to be modular and the AIP concept can be easily applied to the production system designing, by forming three separate working units for subassembly of modules and one separate working unit for the final assembly (Figure 12). The automation level regarding final assembly can be manual or semiautomatic, while modules subassembly can be highly automated in separated assembly workshops. For example, the connecting box became a standardized module and it can be assembled with the highest automation level independently of the ordered variant.

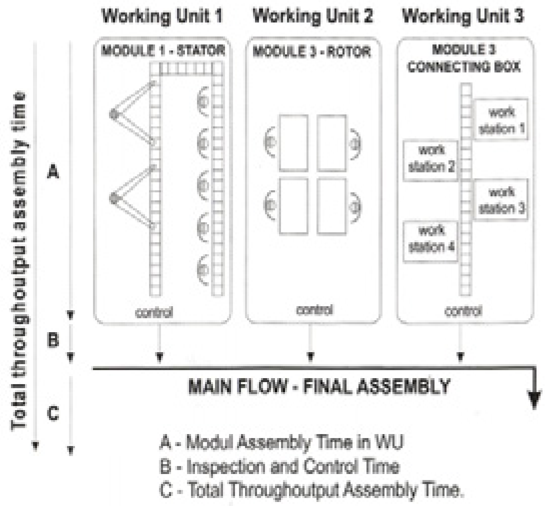

Fig. 12. *Circular pumps assembly system organized in separate working units*

It is important to emphasize in the conclusion, that IPS-DFA methodolgy and Mass Customization concept [4], [16] is directly in coordination with approach to design of *effective industrial system structures* [19], [20] based on principles of *group technology* and *product approach* in the designing of enterprise structure.

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