# PLANNING AND SELECTION OF OPTIMAL ASSEMBLY SEQUENCE

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**Abstract**: In this paper some assumptions of a new method of assembly design process were presented, adapted to synchronous product design, taking into consideration assumptions of "design for assembly". The algorithm of setting units of possible assembly sequence, which is a constituent of the computer program designed to support the whole assembly process.

## INTRODUCTION

"Assembly is more than putting parts together. Assembly is the activity in which all the upstream processes of design, engineering, manufacturing, and logistics are brought together to create an object that performs a function." (D.Whitney).

The above presented quotation indicates the importance of the assembly process in the product development and its launch into the market. Assembly itself influences the costs and time of product manufacture but also on its quality in a significant way. Therefore, the design process should include planning of assembly process. Only within the time of design it is possible to shape the construction which could optimally take into account the requirements of the assembly. Due to the fact, that generally, the parts have to be joined in different ways, one should search for the most convenient order of assembly operations. The issue of pointing out the set of possible assembly sequences leads towards difficult combinatorial tasks. Its proper solution has a great practical significance for each assembly process, especially for automatic or computerized assembly. The issue of pointing out the assembly sequences has been so far analysed by plenty of authors [1,2,3,4,], however, always with an assumption of fixed product construction. From this point of view performing any construction alternations in order in order to improve the assembly process is possible only by noticing outstanding faults of the construction. Actually, there is no place for a conscious shaping of the assembly process in the course of construction design process. Because of a great number of possible combinations of the issue, one is not able to solve this without computer systems usage. Only on that condition simulation and analysis of the assembly sequence will be possible in the design stage.

Setting the most favorable assembly sequence is one of the most significant steps while planning assembly process and have a valid impact on the rest of the sub-pocesses (fig.1) realized while assembly design.

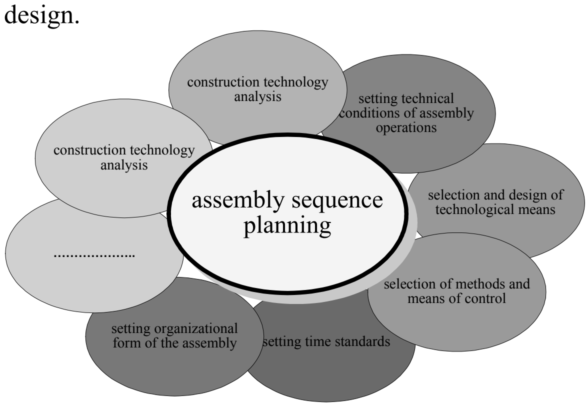


Fig.1. *One of more essential constituents of the assembly*

This report constitutes an introduction into the examination process heading for integration of main three stages of product making process, as design, design for assembly, and assembly itself.

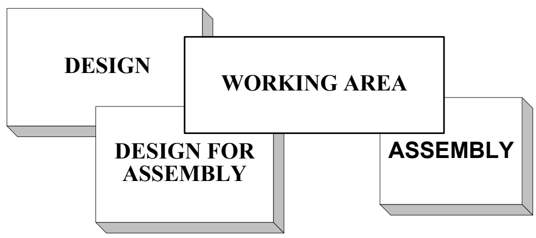


Fig.2. *Work problematic area*

Work problematic area definitely results from a postulate of simultaneous taking into consideration requirements of three processes presented in figure 2 and subordinating them to the product realization process.

# 1. CONCEPTION OF DESIGN OF OPTIMAL ASSEMBLY SEQUENCE DESING METHOD.

The concept of introduction of the design of the most favorable assembly sequence for design process were described in the former publications [5,6]. According to this conception the algorithm of generating an assembly sequence is a part of the system supporting synchronous product design, and advisable by the literature the rules of design for assembly will be placed in the knowledge data. This system, in assumption, is aiming at helping constructors and designers in shaping the constructive body of the product, in such a way to ensure the most beneficial course of the process of the target assembly. The knowledge data should contain information about proper shaping of the joined parts in the assembly process and tips to limit the number of generated variants of the assembly order. Early constraint of the number of the assembly sequences is important due to the fact of acceleration of algorithm activity. As an example, while defining the touch-type relation A-B of two elements of screw-type connection one may describe the basic part, to which the second part will be screwed in or on. In such a way, thanks to setting the order of joining A and B parts, in further analysis they can be regarded as one part.

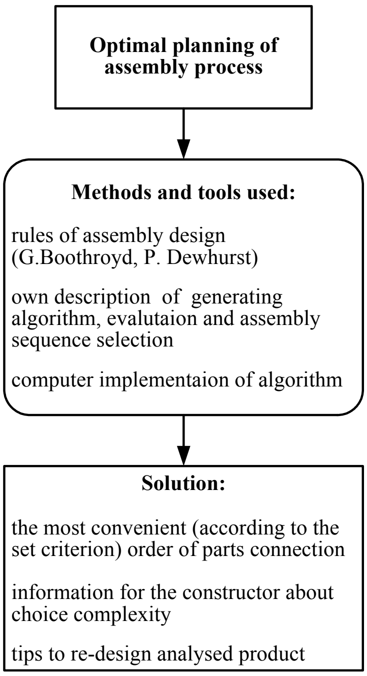


Fig.3. *Aims of the method-employed means-results*

To sum up, conception of design of optimal assembly sequence design method (fig.3) is directed towards:

- gaining the most convenient (according to the accepted criterion) the order of joining parts.
- supplying the designer information about the complexity of the product and possibilities of its reduction.
- supplying the designer tips concerning possibilities and/or purposfulness of the construction alternations of the designed target.

## 1.1. Assignation of assembly sequence

Assignation of feasible (possible to perform) assemble sequences belongs to such combinatorial problems, which altogether with the increase of the elements number they number, experience so called “combinatorial explosion”. The number of possible combinations increases then so rapidly that their review seems to be a problematic issue even for computer programs, not to mention for a human being. That is why, the primary significance constitutes already described problem of quick reduction of the number of combinations to such sequences which have practical value.

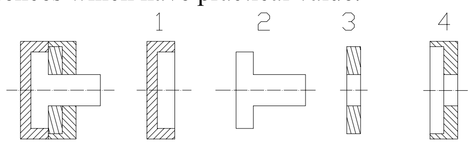


Fig.3. *Simple assembly sub-unit*

For example, for a sub-unit presented in picture 3, which consists only from four elements, there are theoretically 24 possible assembly sequences, presented in figure 4.

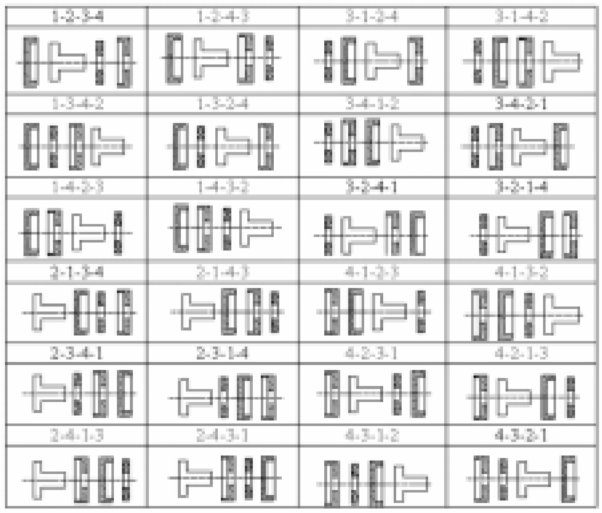


Fig.4. *Possible assembly sequences of 4-part sub-unit.*

However, among all the presented 24 solutions in picture 4 (4!=24), there are only 8 possible solutions, and the rest 16 constitute inappropriate ones. This trivial example indicates a great significance of elimination of unnecessary assembly sequences, sequences being only the results of combinatorial operations. In the following point of this paper a new algorithm of generating possible assembly sequences was described, taking into consideration mentioned postulates.

### 1.1.1. Algorithm of generating possible assembly sequence.

The general scheme of algorithm of setting assembly order is shown in figure 5.5.

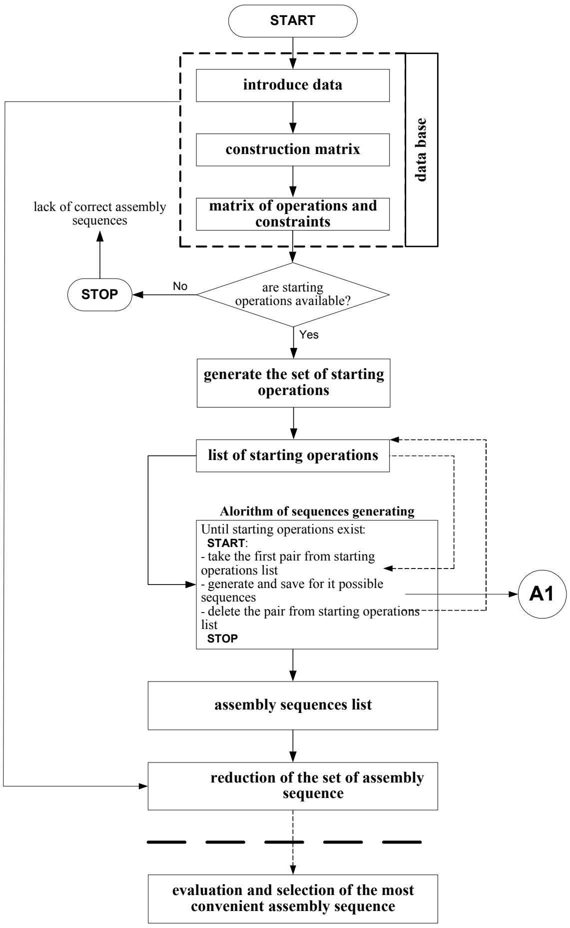


Fig.5. *Algorithm of assembly sequence assignment*

Basic data of complexity of the construcion (list of parts, touch-type relations) and preferences concerning the order of assembly operations are introduced into a block: INTRODUCE DATA. They are saved on three matrixes: construction, operation, and constraints. In the second block – GENERATE UNIT OF STARTING OPERATIONS, on the basis of already defined constraints we point out a unit of initial assembly process – connections of constituents, which can be performed at the beginning of the assembly process. If such operations exist, then algorithm starts generating the unit of assembly sequence. Algorithm A1 of this process was characterised and described in a former publication [6,7]. If the initial operations cannot be defined, which means there are no possibilities to start the assembly, then the algrotihm brings its activity to the end.

The most characteristic operation of the algorithm A1 is the selection of the first assembly operation form the list of starting operations and joining to a unit, already made of the following parts (with regard to constraints and order relations), until the parts unit of the set up object are run out. The algorithm generates all possible orders of the assembly beginning from this starting operation. The sequences created in this process are saved, and the used starting operation is deleted form the set of starting operations. Then, the algorithm selects the following starting operations and the process of sequence construction is repeated. After the run-out of whole set of starting operations, a set (unit) of all possible assembly sequences is made. This set depends upon the complexity of the designed object and can be very numerous. Therefore, a possibility of additional constraints introduction was considered, limiting some sequences containing less convenient parts connections and redundancy sequences and/or those slightly different. Usage of these constraints leads towards a significant reduction of the assembly process variants. Thanks to this, a selection of the most appropriate and favorable assembly order will be less complex.

## 2. COMPUTER IMPLEMENTATION OF THE METHOD – ACTUAL CONDITION.

The computer program designed in Delphi environment is an implementation of the algorithm described in 1.1.1. of this paper. In figure 6 one presented some commands available in the main menu of the program. Currently, the program consists of four main flaps: PROJECT, MATRIX OF CONSTRUCTION, MATRIX OF OPERATION, SEQUENCE GENERATING. The commands in the flap: PROJECT are generally employed in programs of WINDOWS-type and do not require any description.

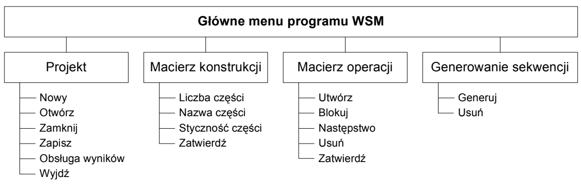


Fig.6. *Main menu of the programe*

Three remaining flaps of the program: matrix of construction, matrix of operation, Sequence generating are briefly depicted on the example of previously presented simple 4-element-sub-unit. In figure 7 a dialogue window with an active flap- Matrix of construction was shown.

In this matrix the areas on the crosscut of the line (i) and column (j) describe relation of constructive touch between the parts represented by i-line and j-column. In such a way the construction structure and relations between the parts of the constituents are saved. In the sub-unit presented in picture 4 every single parts touches every another part so, there are 6 touch-type surfaces. Because the matrix of the construction is symmetrical (if part A touches part B, then part B also touches A), there are 12 touch-type relations saved.

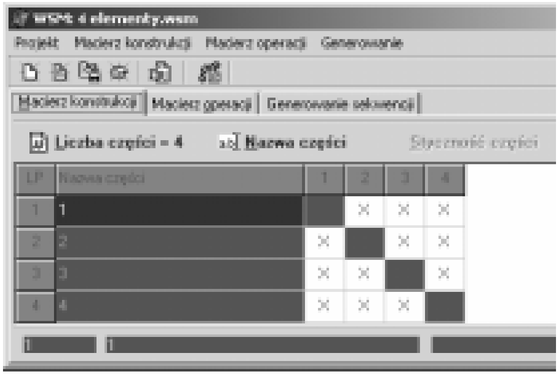


Fig.7. *Matrix of the construction*

On the basis of the touch-type relations saved in the Matrix of the construction, the program automatically makes a unit (collection) of theoretically possible operations and fill the areas of the Matrix of the operation (fig.8).

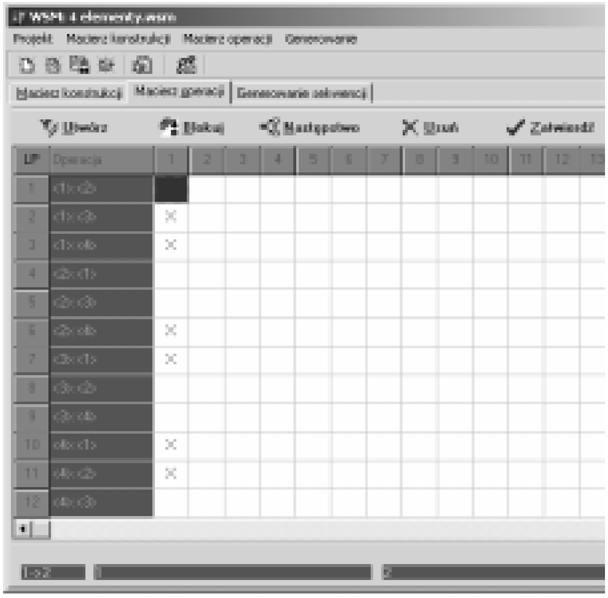


Fig.8. *Matrix of the operation.*

The core issue of the programe user is to implement the conditions: describing the order relations (option- the Sequence) and exclusion of undesirable starting operations (option-Block). A starting operation is an operation beginning the assembly process. In this example one has to block 6 operations: 1-3; 3-1; 1-4; 4-1; 2-4; 4-2. These operations performed as primary ones, would make it impossible to set up the sub-unit.

After the fulfillment of the matrix constraints, in the flap Matrix of operations there are some possibble starting operations generated. Every starting operation potentially makes the family (group) of assembly sequences. The program itself points out these sequences and shows them in the flap: "Sequence generating" (fig.9). In the dialogue window presented in figure 9, the program generated 8 variants concerning the order of the assembly of the sub-unit made of 4 constituents. While setting these sequences only constraints resulting from blocking starting operations were taken into account.


Fig.9. *Sequence generating flap*

In order to decrease the number of gained solutions, the user, having received the set of assembly sequence may use the following commands: Delete and/or Don't duplicate in the flap: Sequence generating. The command Delete is used to remove the sequences containing unfavorable operations. For instance, we may suppose that the order of 2-1 is unfavorable, then the command Delete reduces all of these sequences of operations, in which assembly operation 2-1 appears. Performing this command reduces the set of solutions up to four sequences. Usage of the command Don't copy reduces the number of solutions up to 6 by removing similar sequences i.e. sequence 2-3-1-4 is similar to sequence 2-3-4-1, and sequence 3-2-1-4 is similar to 3-2-4-1.

In algorithm of sequence assignation there is also a possibility of defining the order of chosen assembly operations. Introduction of such types of conditions may significantly limit the number of variants offered by the programe.

If the user did not employ any constraints, then the program would show all the permutations of the 4-element-sub-unit, what in consequence gives 24 assembly sequences. Obviously, in this unit there are forbidden operations, and their usage would make the assembly of some sub-units impossible. The usage of the described algorithm makes it possible to eliminate forbidden combinations. In this simple example already described there were 16 such combinations.

## 3. AN EXAMPLE OF METHOD APPLIANCE

This example concerns the assignment of assembly sequence of the sub-unit of bearing cone wheel. This sub-unit constructed of 10 parts, is presented in figure 10.

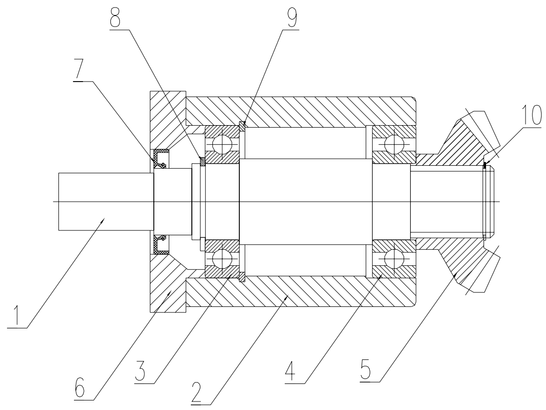


Fig.10. *Driving sub-unit*

Specification of the constituents of the sub-unit:
1 – shaft, 2 – cover, 3 – m bearing , 4 – d bearing, 5 – cone wheel, 6 – lid, 7 – seal, 8 – safety ring 1, 9 – safety ring 2, 10 – safety ring 3.

The further stages of generating the unit of possible assembly sequences are presented in a shortened form below. In the first step, on the basis of relations of construction touches, the touch-type matrix is fulfilled - figure 11. In this matrix 32 touch-type relations were defined.

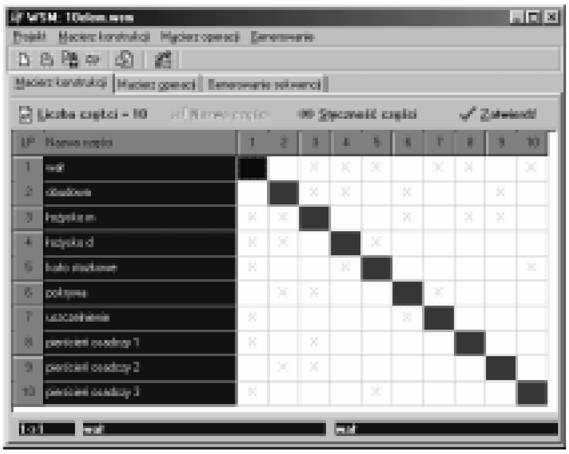

Fig.11. *Matrix of the construction of driving sub-unit*

In the second stage the matrix of starting operations is automatically generated. In this matrix one should define the constraints concerning order. The order relations are defined in the following way:

- For every single operation represented by appropriate line in the Matrix of operation, one should define the operations that ought to be performed before this operation. It results from the possibility of mutual blocking of these operations which means that earlier performance of some operations would make it impossible to perform the following operations, what in consequence would lead to impossibility of entire and proper performance of the assembly of the concerned driving sub-unit.

The defined relations were presented in the figure below (fig.12).

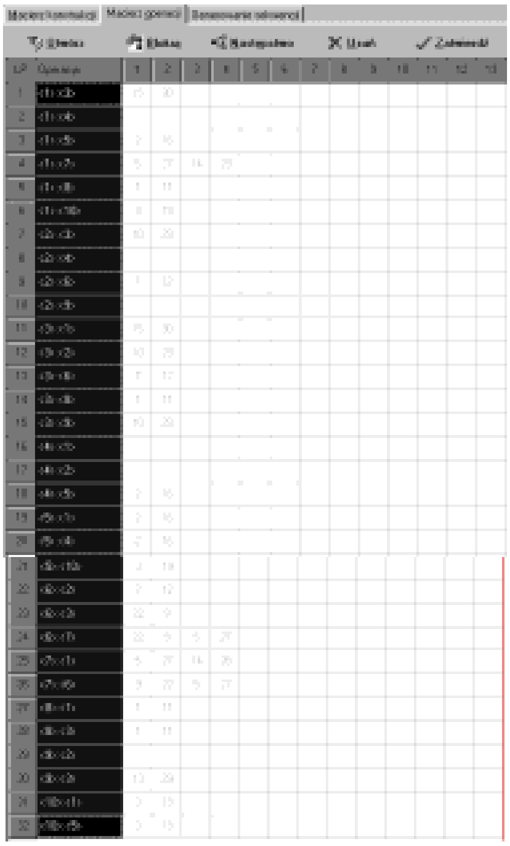

Fig. 12. *The matrix of the operation and limitations for the driving sub-unit*

For such defined order constraints 236 of possible assembly order variants were obtained, of which :

- 3 sequences begin from operations 1-4-5-10-2-9-3-...
- 3 sequences begin from operations 2-4-1-5-10-9-3-...
- 60 sequences begin from operations 2-9-3-1-...
- 36 sequences begin from operations 2-9-3-4-...
- 16 sequences begin from operations 2-9-3-6-...
- 3 sequences begin from operations -1-5-10-2-9-3-...
- 3 sequences begin form operations 4-2-1-5-10-9-3-...
- 60 sequences begin from operations 9-2-3-1-...
- 36 sequences begin from operations 9-2-3-4-...
- 16 sequences begin from operations 9-2-3-6-.....

The set of achieved sequences may be decreased by blocking of unwanted operations.

Below (Table 1) the set of sequences beginning from sub-sequences 2-9-3-1 is presented.

If we delete sub-sequences 1-4 i 1-6 then unfavourable series of operations will be excluded and the number of analysed sequences will be reduced to 20. (from nr 47 to 66). Next, if we would like to have the entire left part of the sub-unit set up in the first step, then one has to reduce the actual unit of sequences by deletion incorrect sequences.

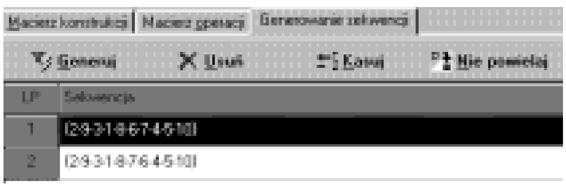

Fig.13. *Resultant assembly sequences for driving sub-unit*

In a consequence we will rapidly receive only two correct, according to this criterion, assembly sequences – figure 13.

Table 1. *The set of generated sequences containing sub-sequences 2-9-3-1.*

| *60 sequences beginning from operations 2-9-3-1-...* | | | |
|---|---|---|---|
| 7 | {2-9-3-1-4-5-10-6-8-7} | 21 | {2-9-3-1-4-6-5-8-7-10} |
| 8 | {2-9-3-1-4-5-10-8-6-7} | 22 | {2-9-3-1-4-6-8-5-10-7} |
| 9 | {2-9-3-1-4-5-10-8-7-6} | 23 | {2-9-3-1-4-6-8-5-7-10} |
| 10 | {2-9-3-1-4-5-6-10-8-7} | 24 | {2-9-3-1-4-6-8-7-5-10} |
| 11 | {2-9-3-1-4-5-6-8-10-7} | 25 | {2-9-3-1-4-8-5-10-6-7} |
| 12 | {2-9-3-1-4-5-6-8-7-10} | 26 | {2-9-3-1-4-8-5-10-7-6} |
| 13 | {2-9-3-1-4-5-8-10-6-7} | 27 | {2-9-3-1-4-8-5-6-10-7} |
| 14 | {2-9-3-1-4-5-8-10-7-6} | 28 | {2-9-3-1-4-8-5-6-7-10} |
| 15 | {2-9-3-1-4-5-8-6-10-7} | 29 | {2-9-3-1-4-8-5-7-10-6} |
| 16 | {2-9-3-1-4-5-8-6-7-10} | 30 | {2-9-3-1-4-8-5-7-6-10} |
| 17 | {2-9-3-1-4-5-8-7-10-6} | 31 | {2-9-3-1-4-8-6-5-10-7} |
| 18 | {2-9-3-1-4-5-8-7-6-10} | 32 | {2-9-3-1-4-8-6-5-7-10} |
| 19 | {2-9-3-1-4-6-5-10-8-7} | 33 | {2-9-3-1-4-8-6-7-5-10} |
| 20 | {2-9-3-1-4-6-5-8-10-7} | 34 | {2-9-3-1-4-8-7-5-10-6} |
| 35 | {2-9-3-1-4-8-7-5-6-10} | 49 | {2-9-3-1-8-4-5-6-10-7} |
| 36 | {2-9-3-1-4-8-7-6-5-10} | 50 | {2-9-3-1-8-4-5-6-7-10} |
| 37 | {2-9-3-1-6-4-5-10-8-7} | 51 | {2-9-3-1-8-4-5-7-10-6} |
| 38 | {2-9-3-1-6-4-5-8-10-7} | 52 | {2-9-3-1-8-4-5-7-6-10} |
| 39 | {2-9-3-1-6-4-5-8-7-10} | 53 | {2-9-3-1-8-4-6-5-10-7} |
| 40 | {2-9-3-1-6-4-8-5-10-7} | 54 | {2-9-3-1-8-4-6-5-7-10} |
| 41 | {2-9-3-1-6-4-8-5-7-10} | 55 | {2-9-3-1-8-4-6-7-5-10} |
| 42 | {2-9-3-1-6-4-8-7-5-10} | 56 | {2-9-3-1-8-4-7-5-10-6} |
| 43 | {2-9-3-1-6-8-4-5-10-7} | 57 | {2-9-3-1-8-4-7-5-6-10} |
| 44 | {2-9-3-1-6-8-4-5-7-10} | 58 | {2-9-3-1-8-4-7-6-5-10} |
| 45 | {2-9-3-1-6-8-4-7-5-10} | 59 | {2-9-3-1-8-6-4-5-10-7} |
| 46 | {2-9-3-1-6-8-7-4-5-10} | 60 | {2-9-3-1-8-6-4-5-7-10} |
| 47 | {2-9-3-1-8-4-5-10-6-7} | 61 | {2-9-3-1-8-6-4-7-5-10} |
| 48 | {2-9-3-1-8-4-5-10-7-6} | 62 | {2-9-3-1-8-6-7-4-5-10} |
| 63 | {2-9-3-1-8-7-4-5-10-6} | | |
| 64 | {2-9-3-1-8-7-4-5-6-10} | | |
| 65 | {2-9-3-1-8-7-4-6-5-10} | | |
| 66 | {2-9-3-1-8-7-6-4-5-10} | | |

## 4. CONCLUSION

Taking into consideration essential influence of the assembly process on costs and quality of machines and other mechanical tools and appliances, the constructor should be given an opportunity to choose the most convenient order of the assembly operations. Therefore, he needs a good evaluation tool to estimate the designed construction taking into account assembly requirements, and which could enable the constructor to design for assembly for on-going designing process. Such a tool shall make it able to design construction which simple and cheap assembly process is an advantage.

In this paper a conception, algorithm and prototyped computer program generating the set of appropriate order variants of mechanical appliances assembly have been presented. The core of the concept states that the program should support the user in appointing the most convenient assembly sequences by constraints already defined in the first steps of shaping the construction of the product.

The program of further going works mainly provides for extension of the possibilities of the computer program about the elements of evaluation and choice of variants of assembly sequences. Elaboration of knowledge data including manual rules of “design for assembly” and specific technological conditions of the production plant. The computer program and knowledge data will be exploited by a user (constructor, programmer) in the course of construction as well as while elaboration of technological operations of assembly. .

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