PLANNING AND ANALYSIS OF MECHANICAL ASSEMBLY SEQUENCES IN DESIGN ENGINEERING – PART II: APPLICATION

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In the first part of the article, a method of assembly sequence planning and analysis of construction of the designed product parts allowing for principles of "designing for assembly" has been presented. This article presents a computer programme which constitutes the implementation of this method and its application is presented on a real-life, industrial example. The article presents the way how to use the computer programme in order to select the set of allowable assembly sequences and choose the most beneficial one as well as to apply the programme to analyse and design the parts construction in such a way that these parts are characterised by "easy and cheap" assembly.

Keywords: assembly sequence planning; computer program; design for assembly; engineering design

Planiranje i analiza toka operacija montaže u projektiranju – Dio II: Primjena

U prvom je dijelu rada predstavljena metoda planiranja operacija montaže i analiza konstrukcije projektiranih dijelova proizvoda uzimajući u obzir principe "konstruiranje za montažu". U ovom se dijelu predstavlja računarski program za implementaciju te metode, a njena je primjena predstavljena na industrijskom primjeru iz stvarnog života. Prikazan je način primjene računarskog programa u svrhu izbora niza mogućih operacija montaže i odabira najprihvatljivije te primjena programa za analizu i projektiranje konstrukcije dijelova na način da te dijelove karakterizira "laka i jednostavna" montaža.

Ključne riječi: planiranje toka operacija montaže; projektiranje za montažu; računarski program; tehnički projekt

1   Introduction

Each decision made during the process of designing, constructing, assembly planning (as well as many other processes) is based on individual knowledge of the person performing certain designing operations. Such a person makes a number of decisions aiming at obtainment of a compromise solution fulfilling all the designing limitations and guidelines and preserving certain functions of the designed product at the same time. In case of complex processes, among which there are certainly designing, constructing, assembly, the required knowledge is not generated automatically but comes from the experts in a particular field. The accumulated knowledge should improve the designing process meaning its quick elaboration allowing for e.g. construction, technology, assembly, etc. requirements [1 ÷ 3].

The practical application of the principles of design for assembly is often limited to the intuitive consideration of these requirements during the development of the project. It is commonly known that manufacturing costs constitute the major part of the implementation process, while the installation costs can be even 30 ÷ 50 % of the cost of manufacturing the product. Therefore, design for assembly is one of the most important methods in the wide field covered by the general name of DfX [4 ÷ 8].

In the literature, it is possible to find different approaches of computer-aided assembly sequence planning [9 ÷ 11].

Taking the above into account, the author has elaborated the integration of basic engineering knowledge that enables to require the effective parts assembly in the early stage of construction design and to select the most beneficial assembly sequence of the designed products at the same time [11, 12].

2   Presentation of EASYASSEMBLE programme

The result of computer implementation of the method (thoroughly described in part I of the article) is EASYASSEMBLE programme. Four tabs of the programme are presented in Fig. 1. In the first tab, *Structure Matrix*, the user defines relations between the parts and assigns their constituent values (h_p, f_p) of the grade indicator q_a [13]. In the next tab, *Start Sequences*, the programme generates the set of allowable operations out of which the user has the possibility of selecting the operations of "start" and "ignore" type (characteristics of these types of operations have been presented in part 1 of the article). In the *Blocking Sequences* tab, there are limitations of "OR" and/or "AND" type. All the information defined in the first three tabs is saved in a file with *.asp filename extension (abbreviation of assembly sequence planning). In the last tab, *Run Process*, an algorithm generating allowable assembly sequence according to previously defined *.asp file is performed. The user has the possibility of reviewing the results and saving them to a text file (*.txt) as well as to obtain the information concerning particular steps of the algorithm.
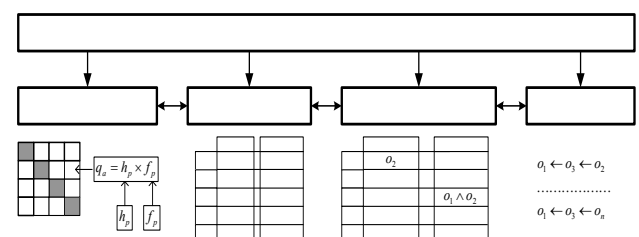

Figure 1 EASYASSEMBLE programme tabs

Fig. 2 presents selected dialog boxes of EASYASSEMBLE programme. Previously characterised tabs are presented in the form of dialog boxes.
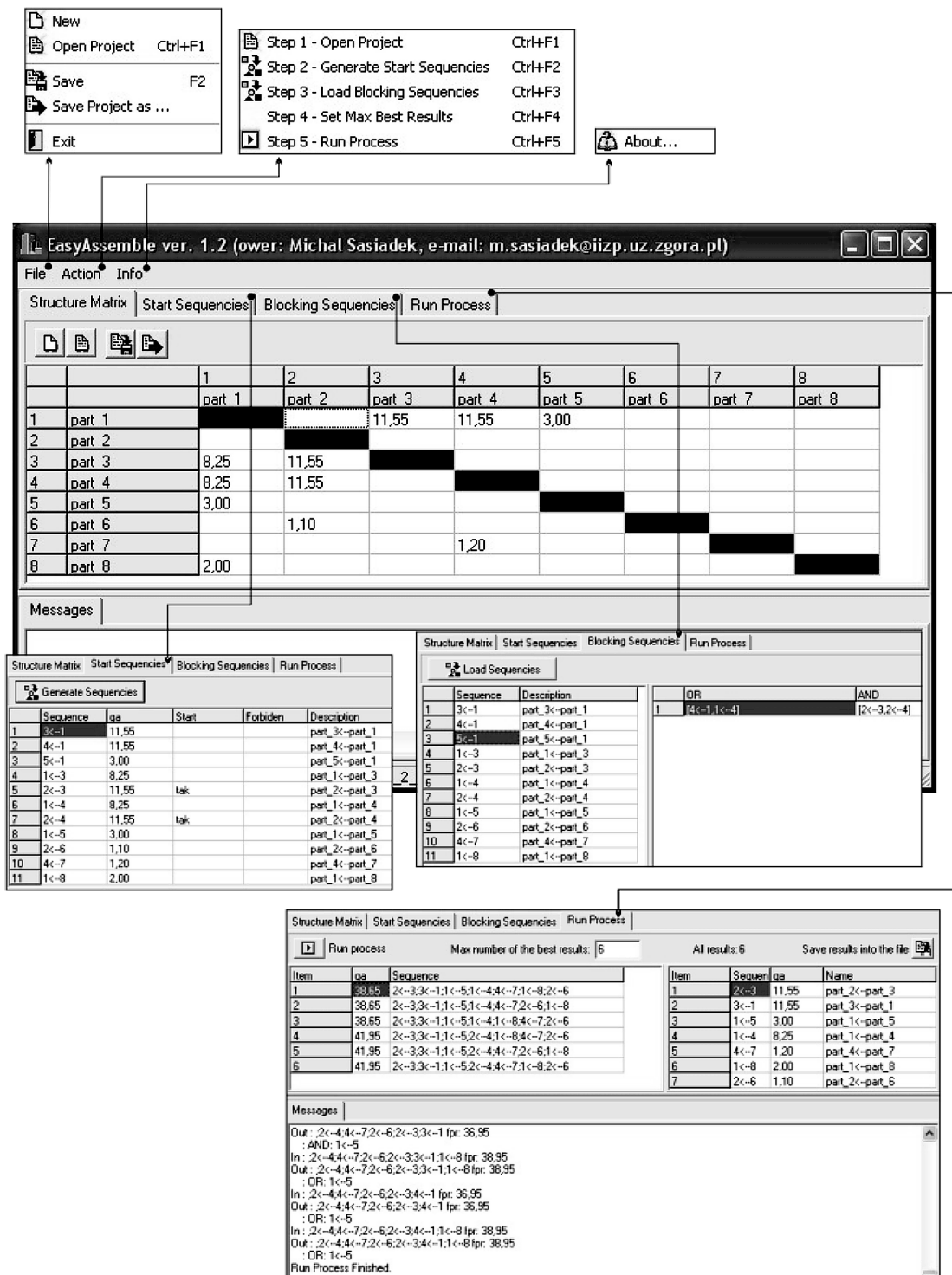
Figure 2 EASYASSEMBLE dialog boxes

3   Application of the programme in a real live example

In this chapter, a set of possible assembly sequence for selected subassemblies of a pneumatic rotary and self-aligning servo-motor is going to be determined. On the basis of the generated set, the most beneficial sequences of joining its constituent parts are going to be presented as well as analysis of its construction aiming at assembly simplification is going to be carried out. On the basis of the assembly drawing documentation, the servo-motor has been decomposed into 5 subassemblies and 5 independent parts. Due to limited volume of the article, in its further part the analysis of selecting the assembly sequence for two subassemblies of the servo-motor (subassembly of front cap and piston-rod) is going to be carried out. Furthermore, the analysis of construction of these subassemblies allowing for the principles of "designing for assembly" is going to be presented.

3.1 Evaluation of parts joining process

Front cap presented in Fig. 3 constitutes subassembly 1. It is composed of 6 parts: 1 – Front cap body, 2 – Pilot sleeve, 3 – Sealing-scraping ring, 4 – Packing gland, 5 – OS gasket/sealing, 6 – ON gasket/sealing.
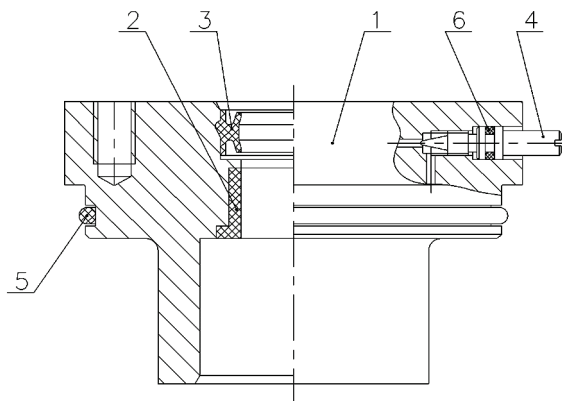
Figure 3 Servo-motor front cap

Possible assembly connections have been defined on the basis of "construction contact" relation and with the assumption that parts 4 and 6 constitute a subassembly directly mounted to the body 1. The set of theoretically possible 12 assembly connections has been reduced to 4 connections presented in table 1. Furthermore, it has been assumed that the assembly of part 2 (pilot sleeve) in the body 1 is going to be the start connection in the assembly sequence. In this example none of limitations in the form of blocking connections have been defined. Each of the connections presented in table 1 has been graded with q_a

indicator – informing about difficulty in realization of the connection due to requirements of the assembly process (lower value of the indicator means connection easier to realize).

Table 1 Juxtaposition of connections and limitations for the servo-motor front cap

No.	Assembly connection	Start connection	Blocking connections	
			"OR"	"AND"
1	1←2	xx	--	--
2	1←3	--	--	--
3	1←4-6	--	--	--
4	1←5	--	--	--

In each tab of the programme (marked in Fig. 4 with rectangular framing and numbers from 1 to 4), there have been defined the following:
- In tab 1 (*Structure Matrix*) – assembly connections,
- In tab 2 (*Start Sequences*) – start connections,
- In tab 3 (*Blocking Sequences*) – blocking connections (in subassembly 1 no connections of this type have been defined).
- Tab 4 (*Run Process*), which is the result dialog box, presents the set of generated allowable assembly sequences of subassembly 1.
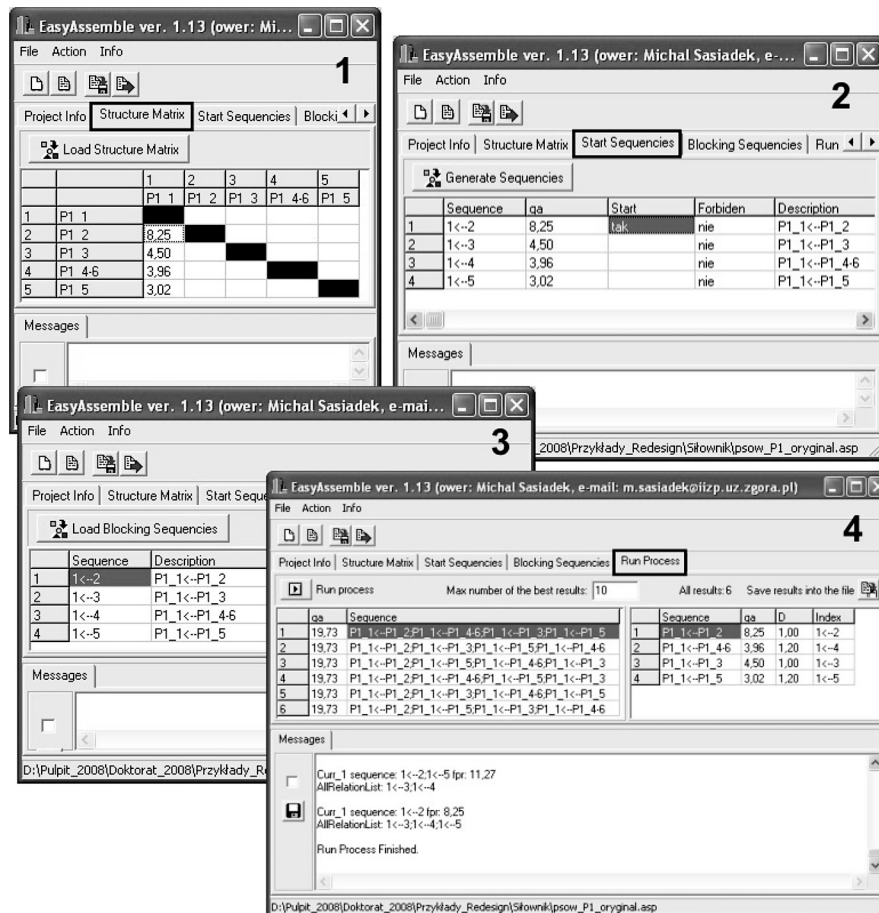

Figure 4 Dialog boxes of the programme presenting the solution for the front cap

Six assembly sequences equally evaluated (q_a=19,73) have been obtained. They all begin with the connection of parts 1 and 2. They differ from one another with successively connected parts. It is caused by the fact that the parts number 2 and 3 and the subassembly consisting

of parts 4 and 6 may be assembled in an optional order. In case of changing the value of redirection factor from the value 1,0 to 2,0, diversified values of the selected 6 sequences are obtained, which is presented in figure 5 in the 2 dialog box. Redirection factor allows for changes of

the assembly directions and enables selection of such a sequence in which these changes are limited to minimum.
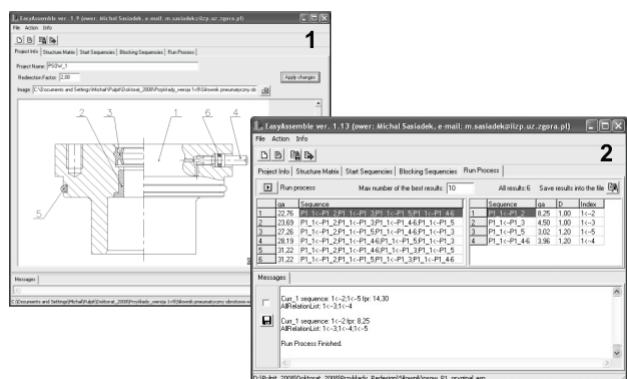

Figure 5 Result dialog box 2 for the front cap of the servo-motor

The second subassembly analysed and presented in this article is the subassembly 3 constituting piston-rod unit, presented in figure 6. It consists of 11 constituent parts: 1 – Piston-rod, 2 – Muffler front sleeve, 3 – Muffler rear sleeve, 4 – Front gland ring, 5 – Rear gland ring, 6 – Piston, 7 – U1 sealing, 8 – M4×10 screw, 9 – Tab washer, 10 – Piston sealing.
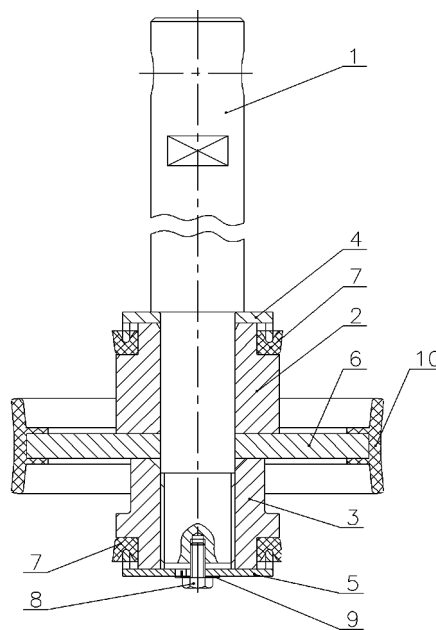

Figure 6 Piston-rod unit

Similarly to the case of the front cap, there have been defined and evaluated assembly connections and limitations (blocking and start connections) in the piston-rod unit. Result dialog boxes of the programme are presented in Fig. 7 – 8 assembly sequences visible in the dialog box no. 4 have been obtained.
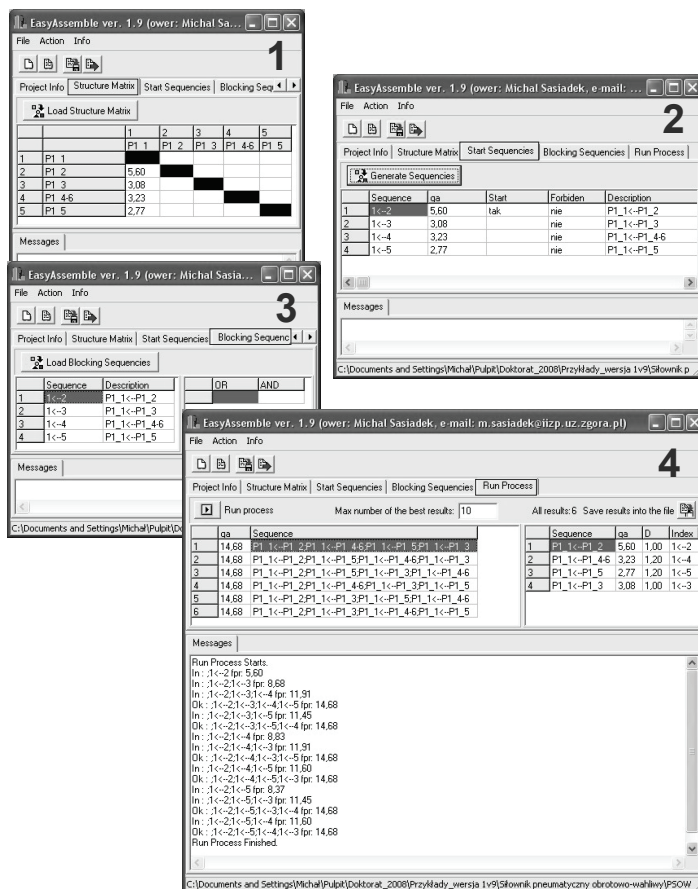

Figure 7 Result dialog boxes of the servo-motor piston-rod unit Dialog

3.2 Analysis of the servo-motor subassemblies construction

As a result of analysis of obtained solutions of the servo-motor subassemblies (specified above), construction changes of constituent parts of two

subassemblies have been proposed. These changes simplify the construction due to the assembly process requirements, which, in turn, leads to increase of its efficiency. The proposed changes consider front cap subassembly (subassembly 1) and piston-rod unit (subassembly 3). They are specified below.

In the front cap, subassembly construction changes in the pilot sleeve (2) as well as modification of the front cap corpus (1) deriving from these changes have been proposed. The pilot sleeve and its proposed modification are presented in Fig. 8.
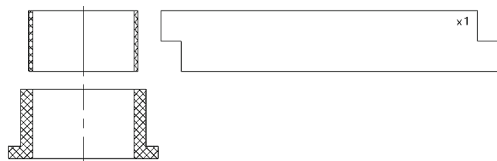

Figure 8 Sleeve construction changes

The original as well as the proposed sleeve plays the role of a slide bearing for the piston-rod unit and it is made of PTFE polymer (Teflon). The proposed sleeve is made of a 1 mm thick stripe and unfolded is presented in the left side of the figure. This change causes simplification of the sleeve assembly in the corpus and leads to decreasing of the execution costs of the sleeve as well. Moreover, the change of the sleeve forced re-designing of its seat in the corpus.

Similarly to the former selecting of the set of allowable assembly sequences, no order relations have been defined for this subassembly and connecting part 2 to part 1 (1←2) has been defined as the start connection. Evaluation of the start connection has changed. As a result of the algorithm, with the redirection factor defined as d=2, 6 allowable solutions have been obtained. Result dialog box is presented in Fig. 9. The most beneficial sequence is the same as the original one (before the changes) but its evaluation indicator equals q_a=15,61, which implies the construction improvement when compared to the original solution.
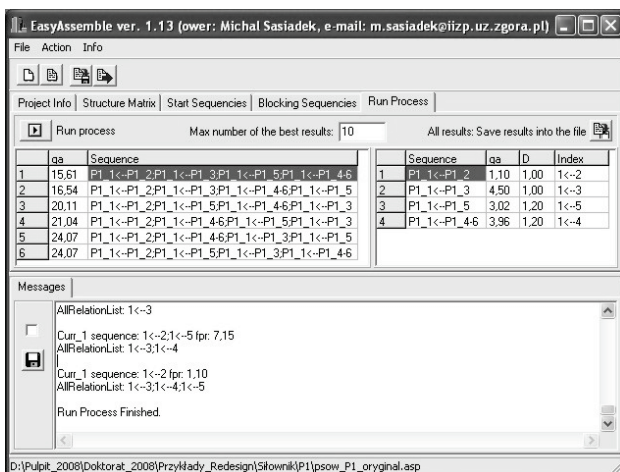

Figure 9 Result dialog box of the re-designed front

On the other hand, parts reduction has been suggested in the piston-rod unit. Instead of parts 2, 6 and 3, a solution aggregating the replaced parts into one has been proposed. In Fig. 10, there is the solution with three separate parts presented on the left side of the figure

whereas one part playing the role of a piston in the analysed subassembly is presented on the right side of the figure.
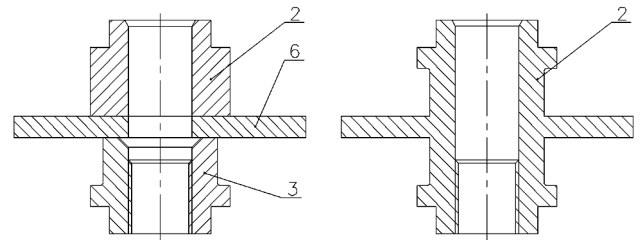

Figure 10 Construction change of part no. 2, 3 and 6 of the piston-rod unit

Due to the implemented changes in the construction of the piston-rod unit (subassembly 4), the set of allowable assembly sequences has been re-selected. Result dialog box for the re-designed piston-rod unit is presented in Fig. 11. One sequence evaluated with the indicator q_a=13,60 has been obtained.
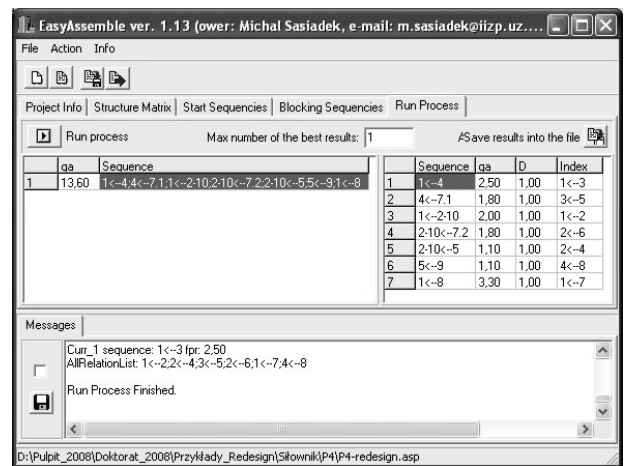

Figure 11 Result dialog box of the re-designed piston-rod unit

4   Summary and conclusion

The article presents practical application of the EASYASSEMBLE programme. The programme has been used in order to select assembly sequence for pneumatic rotary and self-aligning servo-motor composed of 38 constituent parts. First, the subassemblies have been separated on the basis of the documentation. Later on, allowable assembly sequences have been successively selected and evaluated. After selecting allowable assembly order of the selected subassemblies of the servo-motor, the analysis aiming at their construction modification in order to improve its efficiency indicator has been carried out. Changes in the construction of these subassemblies (front cap and piston-rod unit) have been proposed. In case of the front cap, the pilot sleeve (2) and its seat in the corpus (1) have been modified. As a result, the value of the best sequence has been decreased from 22,76 to 15,61, which implies the construction improvement.

Reduction of the number of constituent parts of the piston-rod unit (subassembly 3) by replacing three parts (no. 2, 3 and 6) with one has been proposed as a result of the analysis of this piston-rod unit. This led to the decrease of the generated sequences from 8 to 1 as well as

to the improvement of the sequence evaluation from 16,1 to 13,6.

Further work is required to complete the method according to the author's entire idea. The background knowledge for comprising the whole body of information about the "design for assembly", that can be found in the professional literature sources, is under preparation. A tool for taking into account specific manufacturing terms of an individual manufacturing company is also going to be added to the computer programme.

The author is looking for a computer tool which would consistently include design for assembly into concurrent engineering. It is expected that such a tool will prevent the designer's team from violating requirements of the design for assembly principles and that it will contribute to find out the best trade-off for many conflicting design specifications.

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