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COMPUTER-AIDED DESIGN OF EMBOSSING TAPS

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Summary

The paper presents the development of an algorithm for computing the sizes of embossing taps. There are defined: the area of the software program encompassing the types and range of threads (metric and unified of the UNC, UNF, UNEF and G types), the design of the working portion (the conical and curvilinear shape of the forming portion, the number of lobes) and the overall dimensions and the profile type (incomplete or complete) of the thread to be formed. The general description and operation of the computer-aided design software program are given. Examples of designing embossing taps with the use of the developed program also are shown.

Key words: *computer-aided design software, embossing taps, metric threads, unified threads*

1. Introduction

Manufacturing high-plastic steel threads and threads made of some non-ferrous metals and their alloys is sometimes a very difficult engineering task. High ductility and elasticity are distinctive features of the mentioned group of materials. Problems which occur when rolling threads made of these materials by using the cutting method may result in a built-up edge which causes an increase in the cutting torque and generates additional heat. This all result in the faster wear of the wedges of cutting tools. Furthermore, the quality of the thread, its geometry and precision do not comply with legal standards. Plastic cold thread forming in metal greatly eliminates the above difficulties. For internal threading, the embossing method is applicable and for external threading, the thread rolling method is applicable. Plastic forming of threads increases mechanical and physical properties and threads have higher dimensional accuracy. Basically, the tools used for that technology have higher attrition resistance which results in much longer durability in comparison with the tools used for cutting. In spite of well-developed thread rolling machines and the technology of production instrumentation, the professional literature concerning improvements in tool design should be supplemented with novel findings.

Three basic areas can be distinguished in the development of embossing taps: tooling materials, design solutions and the problems related to the use of information technology.

Thanks to materials engineering, new grades of high-speed steel (along with powder high-speed steels) and sintered carbides have been introduced [1,2,3,4]. For improving the service properties of these steels, techniques of applying thin anti-wear layers in the form of various chemical coatings on their working surfaces are employed [5,6,7,8,9]. Materials design for improving the exploitation properties in a manufacturing process is a wide subject of interest because its proper application allows obtaining a high-quality product [10,11,12]. As our own [13,14,15] and foreign manufacturers' [9,16,17,18] practical experiences were gained, new design solutions were created, which concerned primarily the working (forming and sizing) of the portion that has a direct effect on the thread crest forming process and the operational properties of the embossing tap. The third area comprises the capabilities offered by information technology, for example the use of tooling computer-aided design software programs.

Long-term studies on the thread forming process include notably the analysis of its nature [19,20,21,22,23], which is the base for new design researches concerning the thread working part that forms the crest [24,25,26,27]. A significant part in this tool development has been played by companies FETTE, Wagner and Reed Rico [28,29,30,31], that have been producing threading heads which are used for rolling with the axial, radial or tangential method.

The possibilities offered by information technology are the subject matter of the present paper. The developed software program, described in the paper, is applicable to embossing taps designed for forming through and non-through metric threads and the three most commonly used types of unified screw threads.

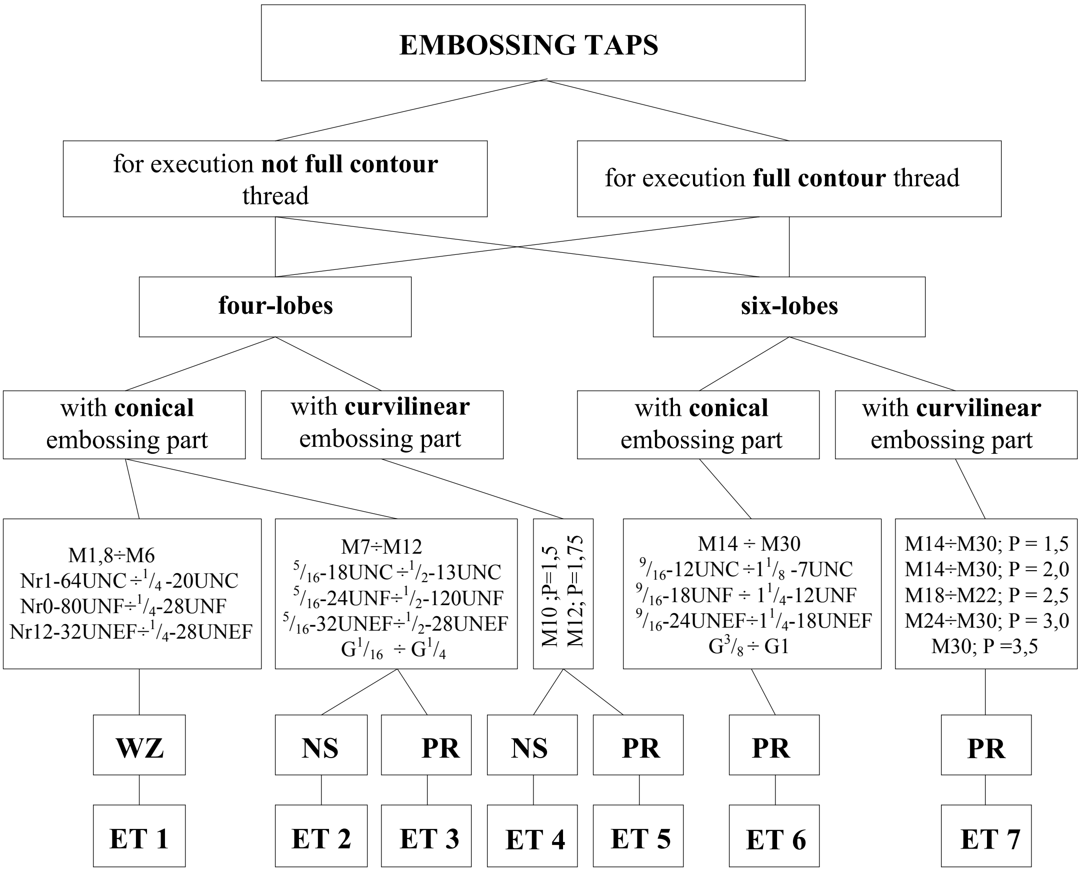
2. Problems and data covered by the software program

The computer-aided embossing tap design software program covers metric and unified screw threads, the design and overall dimensions of taps, types of the embossing portion and cross-section as well as types of the embossed thread profile. The starting point for developing an algorithm was a range of problems related to the design of taps (Table 1) and the block diagram shown in Fig. 1. The block diagram includes the selection of the embossed thread profile (complete or incomplete), the tap's working portion lobing (four-lobe or six-lobe) and the embossing portion axial profile shape (conical or curvilinear). In the subsequent part, the block diagram assigns gripping portion types and tap manufacturing drawings to specific thread sets.

Table 1 Factors taken into consideration in the computer program

TYPE AND DIAMETERS RANG OF THREADS	METRIC	UNC	UNF	UNEF	G
	M1,8 ÷ M30 common and fine	Nr.1- 64 UNC ÷ $1^{1}/_{8}$ – 7 UNC common	Nr.0-80 UNF ÷ $1^{1}/_{4}$- 12 UNF fine	Nr.12 – 32 UNEF ÷ $1^{1}/_{4}$ - 18 UNEF very fine	$G^{1}/_{16}$ ÷ G1
ACCURACY CLASS	5H, 6H, 6G, 7H	3B, 2B, 1B	3B, 2B, 1B	3B, 2B	-
DESIGN AND OVERALL DIMENSIONS	embossing tap with a ***reinforced grip***				
	embossing tap with a ***not through part***				
	embossing tap with a ***through grip***				
FORM OF THE EMBOSSING PART	embossing tap with a ***conical embossing part***				
	embossing tap with a ***curvilinear embossing part*** [1)]				
NUMBER OF LOBES - TRANSVERSE SECTION	***four-lobe*** embossing tap				
	six-lobe embossing tap				
EMBOSSING THREAD PROFILE TYPE	***not full profile thread***				
	full profile thread				
[1)] for metric thread: M10÷M30, P=1,5; M12, P=1,75; M14÷M30, P=2,0; M18÷M22, P=2,5; M24÷M30, P=3,0; M30, P=3,5					

The developed algorithm, shown in Fig. 2, includes in its structure the selection of specific design versions of tools for making a given type of thread. The formulae and relationships contained in the algorithm enable the calculation of the dimensions of taps that ensure a selected thread to be made in compliance with the requirements specified by relevant standards.



Grip type: **WZ** – reinforced; **WS** – not through; **PR** - through

ET 1 ÷ ET 7 – Design and dimensions Embossing Taps

Fig. 1 Simplified block diagram of the algorithm for embossing taps

The procedure for the order of calculation in a parallel selection of a design solution, defined in the algorithm, is as follows:

- calculation of the major diameter, d_N, and pitch diameter, d_{2N}, of the tap sizing portion,
- calculation of the minor diameter, d_{1N}, depending on the selection – either the complete or the incomplete profile,
- after the selection of the conical profile, the threads are divided into two groups, the first of which includes threads made with four-lobe taps, and the second, threads made with six-lobe taps,
- then, the tap thread crest rounding radius r_g, relieving pitch s_z, embossing portion angle of relief χ, tap head diameter d_{cN}, and the embossing portion length l_w are calculated,
- in the design of taps with a curvilinear profile, covering metric threads with $P \geq 1.5$ mm, similarly as in the situation described above, there is a division into four-lobe and six-lobe taps, for which r_g and s_z are calculated,

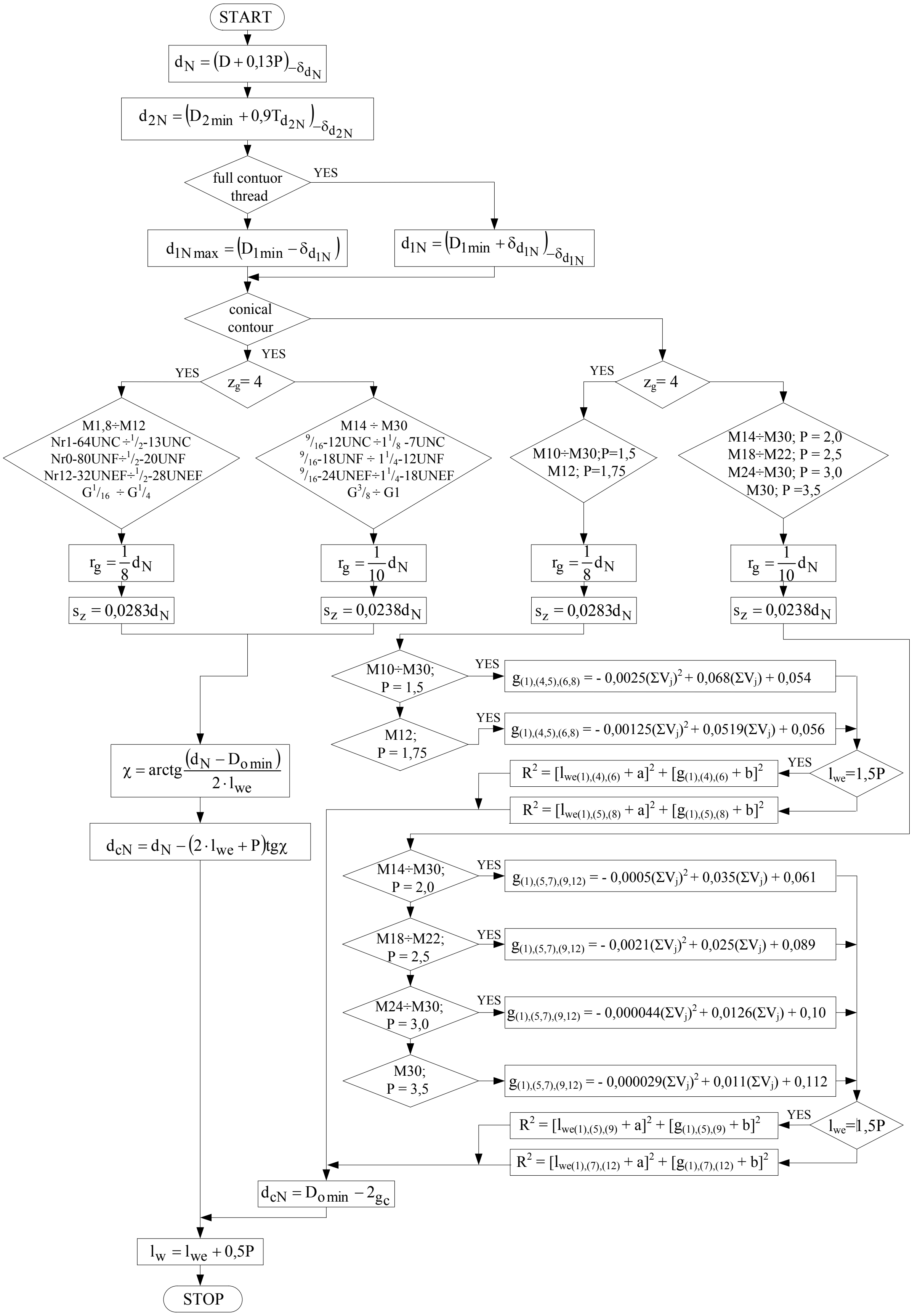


Fig. 2 Diagram of the algorithm for embossing tap dimensions calculation

- next, using the relationship between the successive edge sinkings and the displaced material volume, expressed in the form of $g_{(i)} = f\,[\Sigma V_{j(i)}]$, for one of the selected effective lengths l_{we} being equal to 1.5P or 2P, the embossing portion axial profile radius R and its coordinates a_R and b_R are calculated,
- the final calculations, the same as for the conical profile, are to determine the tap head diameter and the embossing portion length.

Stored in the database are all data necessary for carrying out calculations in accordance with the formulae and relationships contained in the algorithm, namely:

- the diameters D, D_{2min}, D_{1min} and P of metric and unified screw threads, depending on the accuracy class,
- the execution tolerances of the pitch diameter T_{D_2} of metric and unified screw threads, depending on the accuracy class,
- the execution tolerances of the major diameter δ_{d_N}, pitch diameter $\delta_{d_{2N}}$, minor diameter $\delta_{d_{1N}}$, the pitch δ_P and flank angle $\delta_{\alpha_{N/2}}$ of the tap thread working portion,
- the thread hole diameters D_{omin} and D_{omax} of metric and unified screw threads, depending on the accuracy class,
- the magnitudes of the displaced material volume V_j, depending on the thread size and the embossing portion length,
- the shape and overall dimensions of taps,
- the manufacturing drawings of four-lobe and six-edge taps, and
- templates of tables for the calculated tap dimensions.

3. The software program

3.1 A general description of the program

The software program has been designed so that each of its parts, i.e. calculations, accessing the database, communication with the user and displaying and storing the results in a file, is implemented as a separate whole.

The program has been written based on the libraries with an open source code, using generally available tools in the Java programming language [32,33]. For the program to run properly, the Java running environment in the JavaSE 7u6 version is required, which contains the JavaFX library [34] that was used for the programming of the part of the user's interface responsible for the selection of thread characteristics. In the program architecture, we can distinguish several parts, as shown in Fig. 3.

The user's interface is built based on the JavaFX library. Programs written with the use of JavaFX are platform-independent and allow the appearance of the components to be adjusted by using CSS styles.

The window for the thread parameter selection and calculation result display has been created by using the Java-Swing standard library. The manufacturing drawings themselves are stored in the SVG format, while for their display the Batik library is used [35]. Using vector format graphics allows the drawings to be scaled without the loss of quality. The computation module is responsible for the creation of a solution based on parameters chosen by the user and taken from the database.

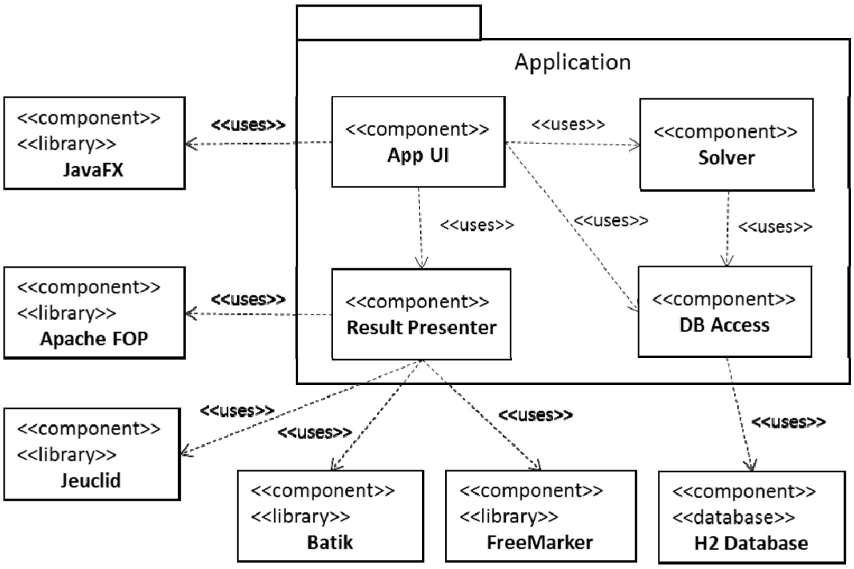


Fig. 3 Application architecture diagram

Computations are performed by following the route of the designed algorithm. After selecting the thread characteristics and parameters, appropriate data are taken from the database. Then, the template of the solution is prepared by using the FreeMarker library [36], complemented by the computed parameters. The so prepared document is then sent to the FOP module [37] which, depending on the selected option, generates a solution in the SVG or PDF format, which can then be displayed to the user, printed or stored in a file. The operation flow diagram is shown in Fig. 4.

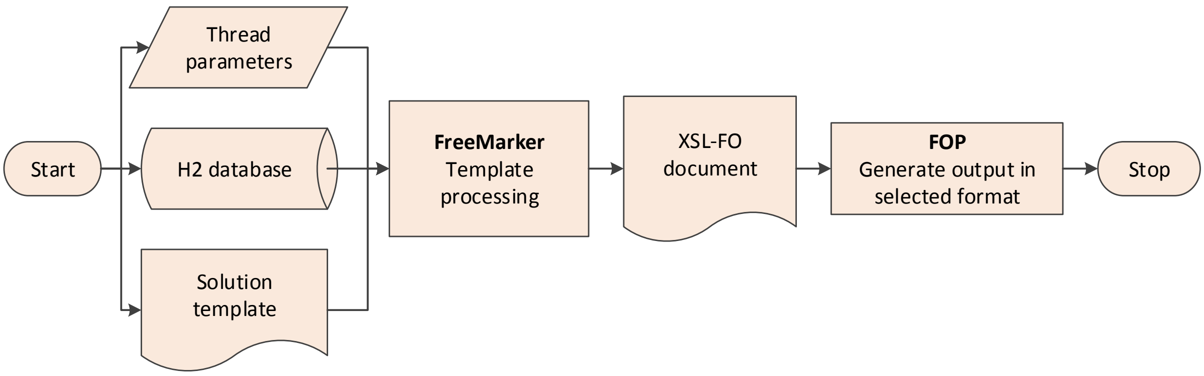


Fig. 4 Solver flow diagram

Figure 5 shows the schematic diagram of the database. The tables do not include the parameter columns. For storing data, the H2 database engine is employed [38]. This is a database with an open source code, written wholly in the Java language, which allows smooth integration with applications written in this language. Other advantages of the H2 database include the capability to run in the built-in mode, without having to run the database server.

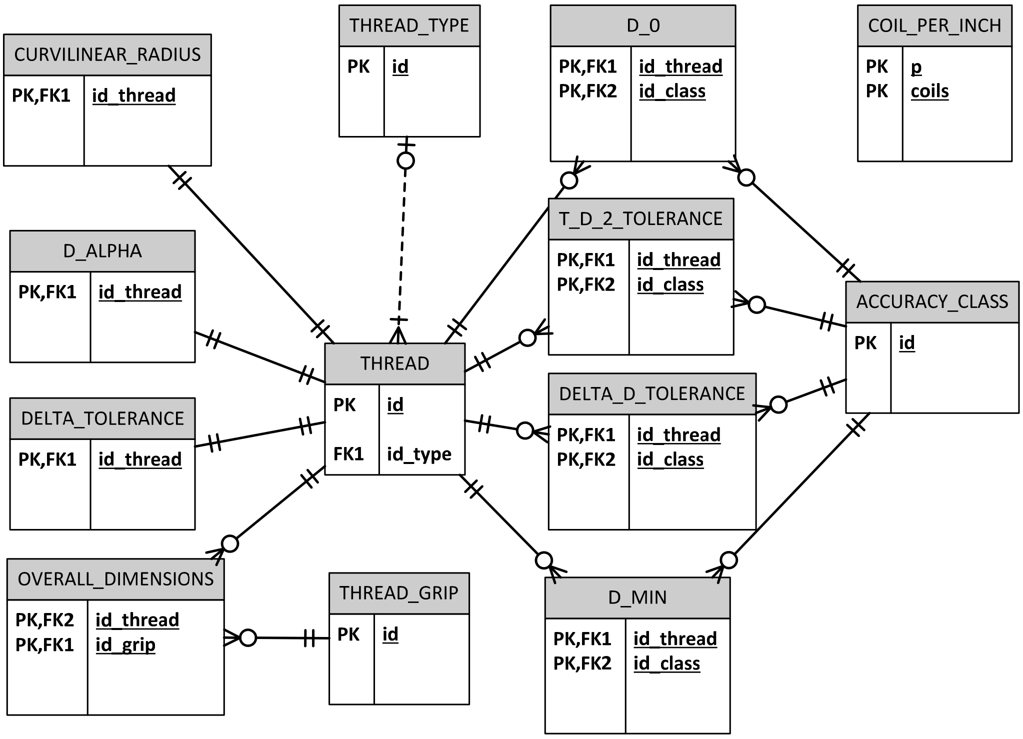


Fig. 5 Database schema

The designed application is a single-station application, therefore this database mode is used. Another advantage of the H2 database is the running speed. The tabulated data have been processed so that they could be entered in a relational database.

3.2 Program operation

After running the application, the selection of a respective tap is made, as shown in Fig. 6: for making thread with an incomplete profile – a four-lobe tap with a conical embossing portion and with a reinforced grip. After using the "Parameter Selection" option, the thread type (Fig. 7a), thread size (diameter) (Fig. 7b), pitch (Fig. 7c), the effective length of the embossing part (Fig. 7d) and the accuracy class (Fig. 7e) are selected. Enabling the "Compute" option (Fig. 7f) causes the program window to be displayed (Fig. 8) with the manufacturing drawing and the dimensions of the tap being designed. The window with the results and the manufacturing drawing contains a "menu" (Fig. 9) that enables the image to be stored in a PDF or SVG file and printed out.

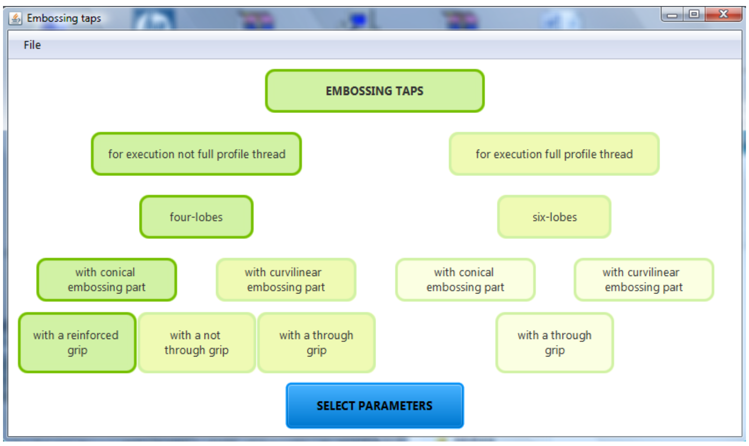


Fig. 6 Selection of embossing tap design

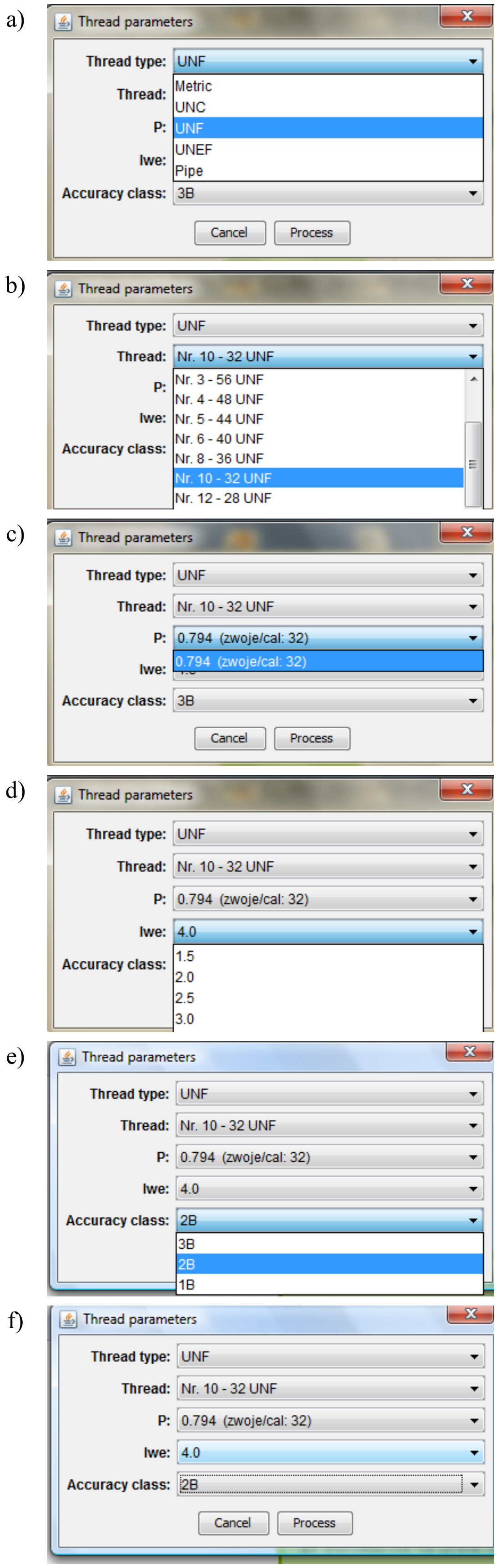
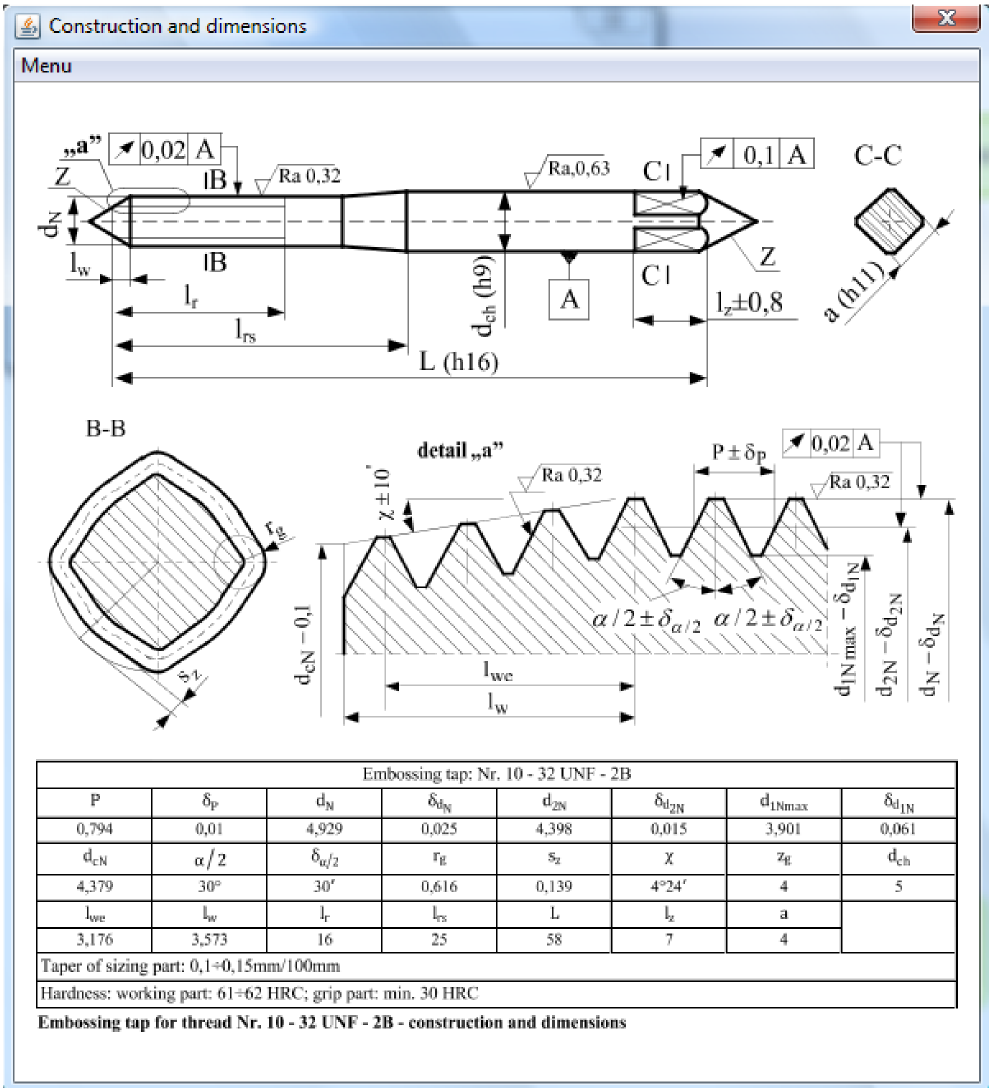


Fig. 7 The program windows enabling the selection of: a- type of the thread, b- diameter of the thread, c- pitch of the tap, d- length of the effective embossing tap, e- accuracy class of the thread, f- “calculate” button for the embossing tap dimensions calculation



Embossing tap: Nr. 10 - 32 UNF - 2B							
P	δ_P	d_N	δ_{d_N}	d_{2N}	$\delta_{d_{2N}}$	d_{1Nmax}	$\delta_{d_{1N}}$
0,794	0,01	4,929	0,025	4,398	0,015	3,901	0,061
d_{cN}	$\alpha/2$	$\delta_{\alpha/2}$	r_g	s_z	χ	z_g	d_{ch}
4,379	30°	30′	0,616	0,139	4°24′	4	5
l_{we}	l_w	l_r	l_{rs}	L	l_z	a	
3,176	3,573	16	25	58	7	4	
Taper of sizing part: 0,1÷0,15mm/100mm							
Hardness: working part: 61÷62 HRC; grip part: min. 30 HRC							

Fig. 8 Engineering drawing

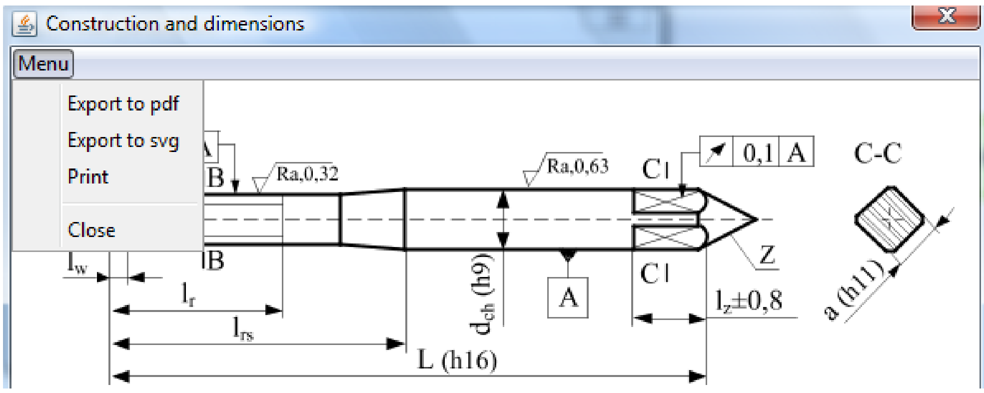


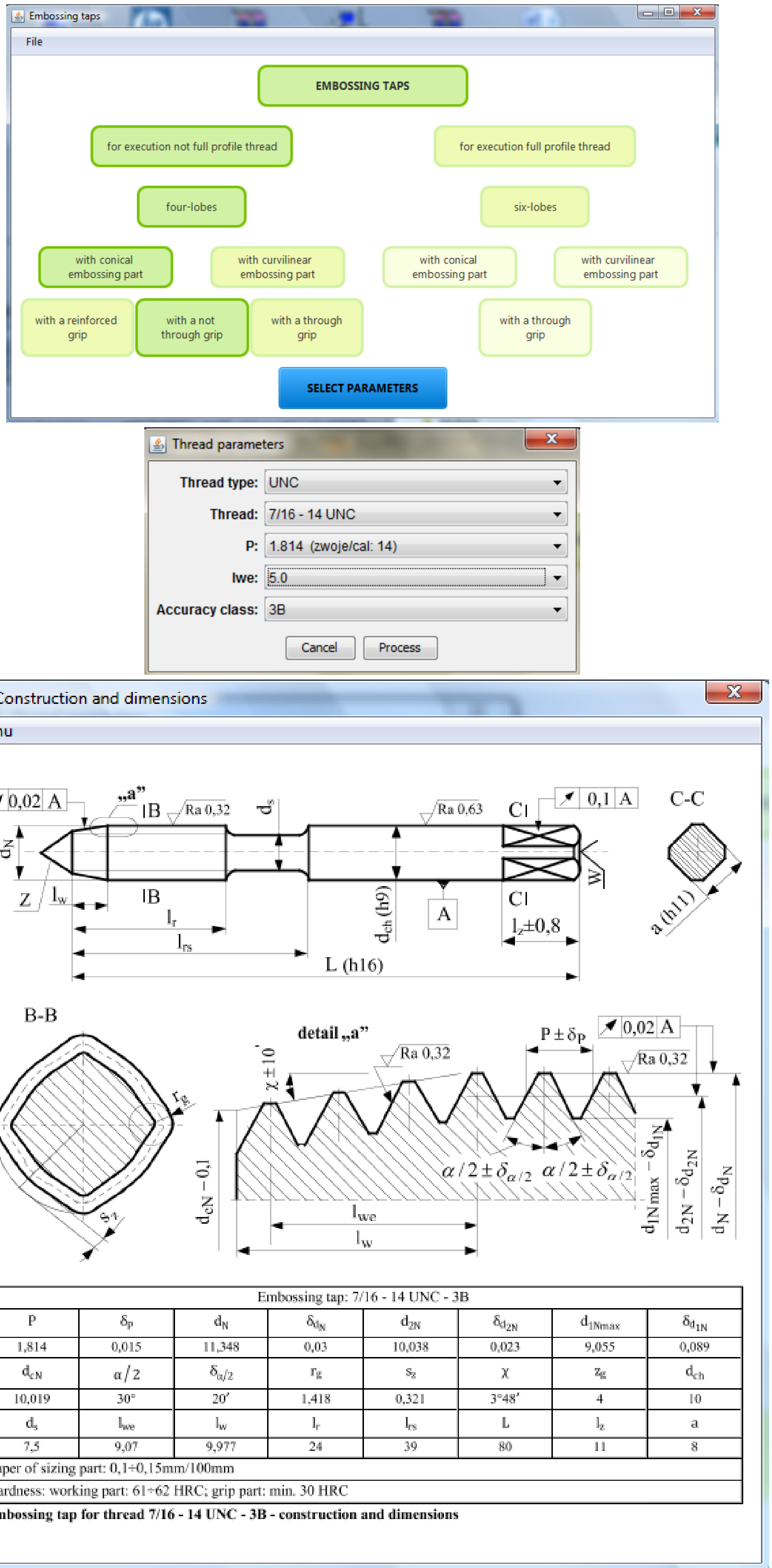
Fig. 9 Window for saving / printing of engineering drawing of designed tool

4. Examples

Figures 10, 11 and 12 provide the following examples of embossing taps designed by using the developed program:

- a four-lobe tap with a non-through grip, with a conical embossing portion for forming a $^{7}/_{16}$ – 14UNC – 3B unified screw thread with an incomplete profile,

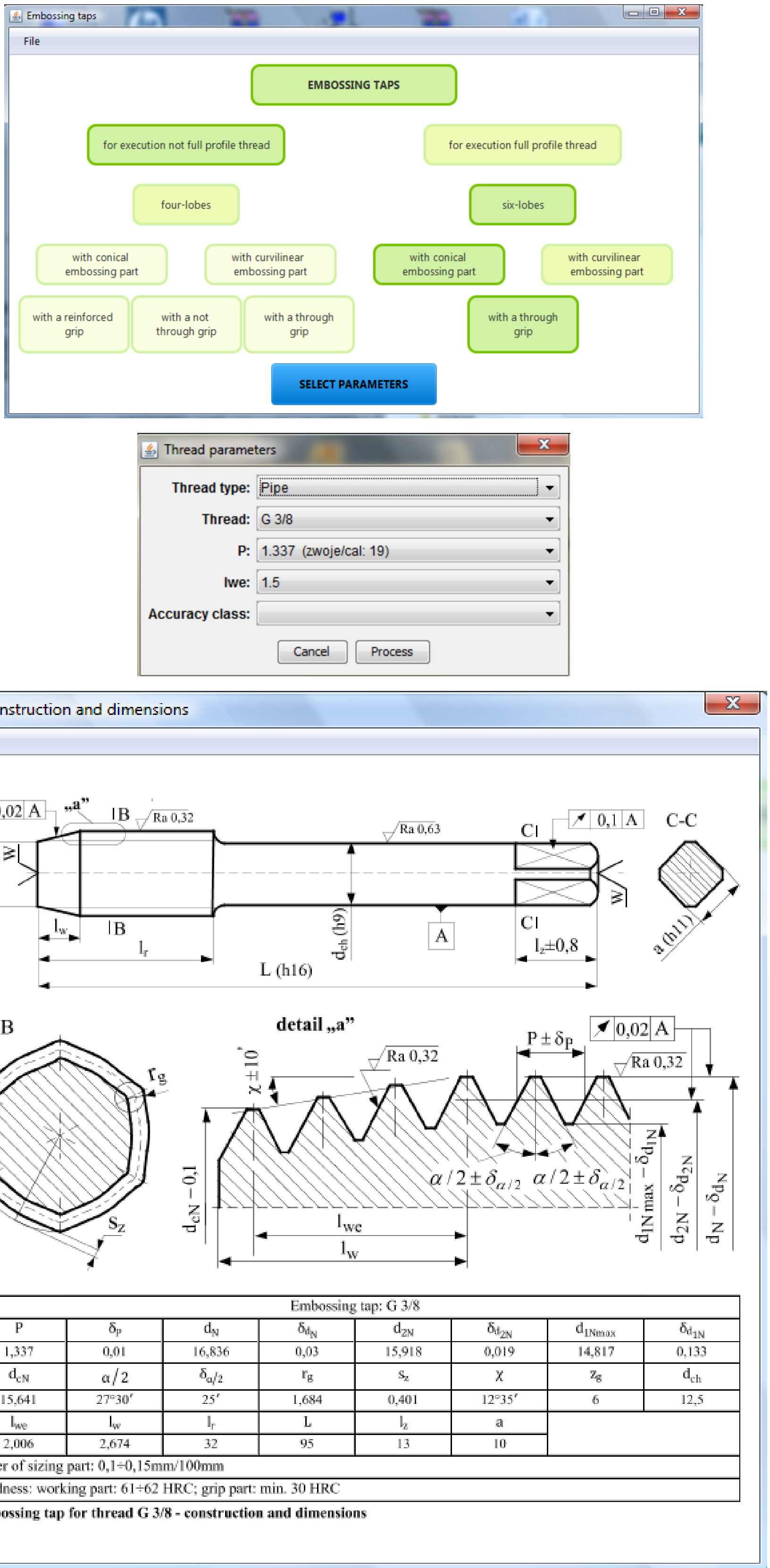
- a six-lobe tap with a through grip, with a conical embossing portion for forming a G $^{3}/_{8}$ unified screw thread with an incomplete profile,
- a six-lobe tap with a through grip, with a curvilinear embossing portion for forming an M27 – 6H metric thread with a complete profile.



Embossing tap: 7/16 - 14 UNC - 3B							
P	δ_p	d_N	δ_{d_N}	d_{2N}	$\delta_{d_{2N}}$	d_{1Nmax}	$\delta_{d_{1N}}$
1,814	0,015	11,348	0,03	10,038	0,023	9,055	0,089
d_{cN}	$\alpha/2$	$\delta_{\alpha/2}$	r_g	s_g	χ	z_g	d_{ch}
10,019	30°	20′	1,418	0,321	3°48′	4	10
d_s	l_{we}	l_w	l_r	l_{rs}	L	l_z	a
7,5	9,07	9,977	24	39	80	11	8
Taper of sizing part: 0,1÷0,15mm/100mm							
Hardness: working part: 61÷62 HRC; grip part: min. 30 HRC							

Embossing tap for thread 7/16 - 14 UNC - 3B - construction and dimensions

Fig. 10 Design and dimensions of embossing tap for inch common thread $^{7}/_{16}$ – 14UNC–3B execution



Embossing tap: G 3/8							
P	δ_P	d_N	δ_{d_N}	d_{2N}	$\delta_{d_{2N}}$	$d_{1N\max}$	$\delta_{d_{1N}}$
1,337	0,01	16,836	0,03	15,918	0,019	14,817	0,133
d_{cN}	$\alpha/2$	$\delta_{\alpha/2}$	r_g	s_z	χ	z_g	d_{ch}
15,641	27°30′	25′	1,684	0,401	12°35′	6	12,5
l_{we}	l_w	l_r	L	l_z	a		
2,006	2,674	32	95	13	10		
Taper of sizing part: 0,1÷0,15mm/100mm							
Hardness: working part: 61÷62 HRC; grip part: min. 30 HRC							

Fig. 11 Design and dimensions of embossing tap for inch pipe G $^3/_8$ thread execution

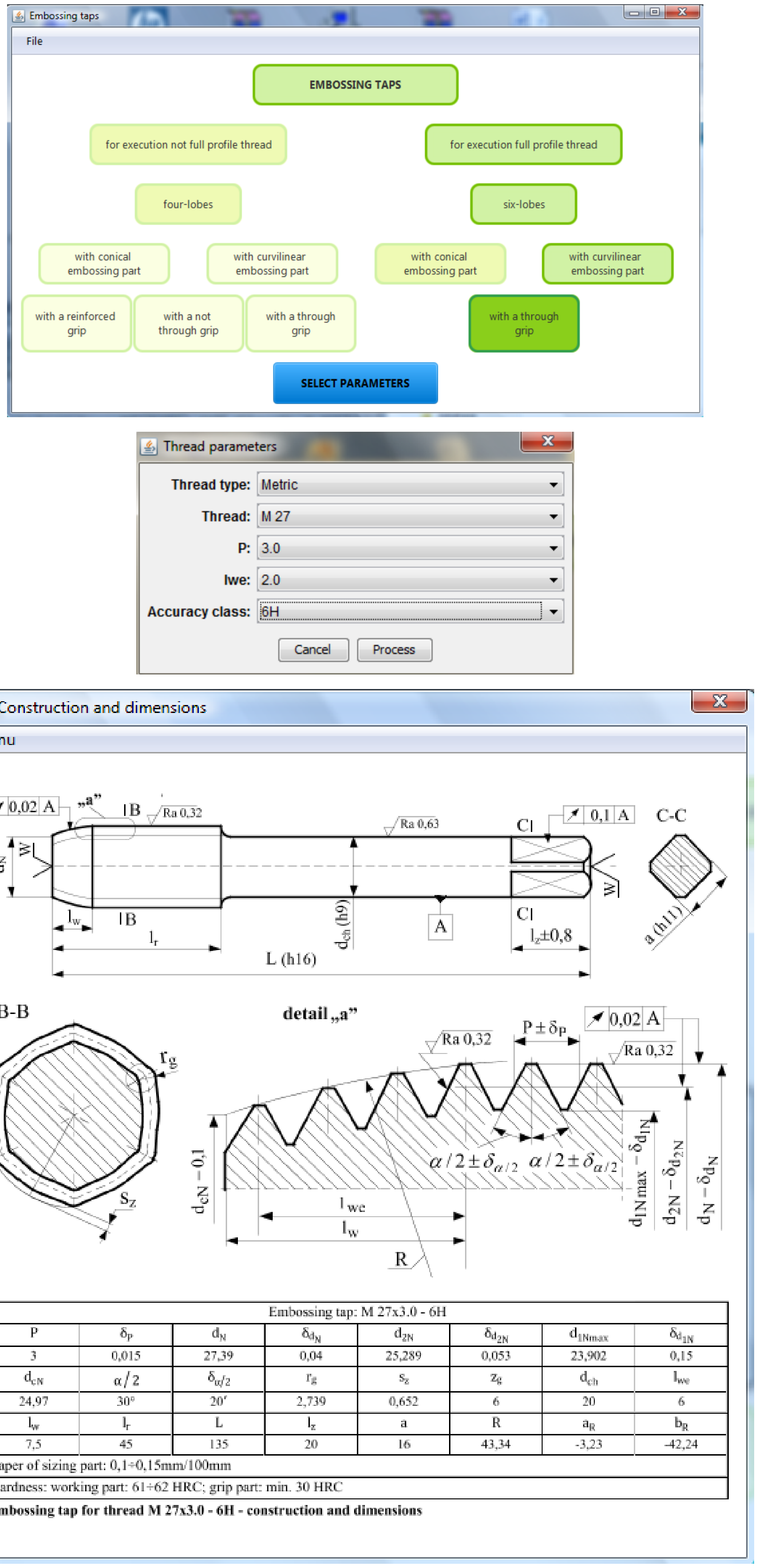


Fig. 12 Design and dimensions of embossing tap for metric M27 – 6H thread execution

5. Conclusions

The program presented in the paper is functional application software useful for designing embossing taps. On the basis of the analyses made in the paper the following conclusions can be made:

- The area covered by the program offers the possibility of designing the most common thread types applied in practice considering their shape, dimensions and particularly the working part of the tool body.
- The design of taps with a curvilinear embossing part is the innovative aspect shown in the paper.
- During the tap embossing the uniform allowance distribution to individual embossing edges occurs.
- While using a short embossing part the taps with a curvilinear profile have higher durability in comparison to taps with conical profiles.
- The large database source gives the opportunity to design a wide range of metric screw threads and four types of unified threads with various precision classes, and full and not full profile threads.
- The computer application has been designed so that it enables further development e.g. addition of successive types and dimensions of threads.
- This is user friendly software which has practical importance.

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