

Design, Modeling and Manufacturing Analysis of a New Rotary Combustion Engine

László Dudás

Department of Information Engineering
University of Miskolc
Miskolc, Hungary
iitdl@uni-miskolc.hu

Pálma Kapitány

Department of Information Engineering
University of Miskolc
Miskolc, Hungary
kapitanypalma@gmail.com

Abstract—The paper introduces the steps of development of a patented rotary internal combustion engine. First reviews the advantageous features of the novel construction. Then it presents the model structure, the CAD modeling of the prototype and the working simulation using Surface Constructor kinematic modeling and simulation software application. The third part of the paper deals with the modeling and analysis of manufacturing of the most complicated elements, the rotor and the rotary chamber. In the simulation of the grinding procedure of the rotor a patented grinding machine and grinding technology are taken into consideration. The closing part synthesizes the results of the full modeling and simulation process.

Keywords—combustion engine, design, working simulation, rotor, rotary chamber, manufacturing analysis

I. INTRODUCTION

Though electric cars represent the future [1], cars and other machines will use internal combustion engines in special environments [2]. These high-speed motors having only rotary parts and made from industrial ceramics [3], like the patented invention of the author [4], have new properties that justify the necessity of deeper analysis of such machines. Fig. 1 shows the sketch of the innovative engine that has three rotating parts only, as marked in the figure. There is an e eccentricity between the rotation axes.

The closed cavities that are formed between the rotor and the rotary chamber moves from left to right and due to the changing pitch of the threads realize the four cycles of an internal combustion engine: intake, compression, explosion and exhaust. These working cycles are marked with different colors in the figure. The followings can be mentioned among advantages:

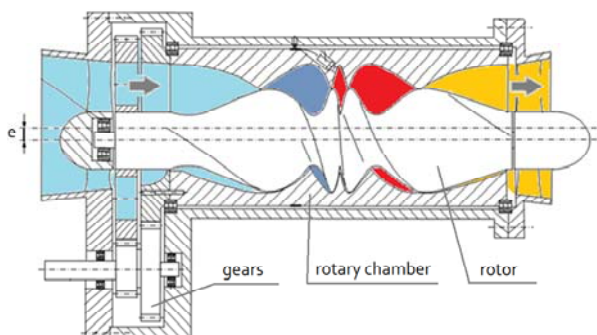


Fig. 1. Rotary internal combustion engine

- Mixture and exhaust fumes are isolated perfectly.
- There are only well balanced rotating parts – there is no vibration.
- The function of the changing pitch of the helicoidal rotating parts can be set according to the compression and explosion needs.
- Due to ceramic materials very high temperatures are possible.
- Water cooling is not required.
- The friction between the rotor and the rotary chamber decreases drastically, as there is a very small gap between them.
- Very high rotation speed can be achieved: 40 000 rpm.

A. Applied Tools for Modeling and Simulations

For the design of the prototype motor, the Autodesk Inventor® CAD software system was applied. For the modeling of the complex 3D helicoids of the rotor and rotary chamber and for the simulation of their motions the workmanship of the author, the Surface Constructor (SC) computer program was used. This software that can determine surfaces generated by enveloping with other surface (see [5, 6]) was used advantageously for modeling the rotor surface and for generating the internal surface of the rotary chamber. Moreover this tool was applied for the determination of the surface of the grinding wheel for machining the rotor in the modeling and simulation tasks of manufacturing analysis. This software also helped the analysis of forming process of the internal cavities and the motion simulation of the engine parts to determine the special features of the working cycles. As this software application played central role in the research covered by this paper, a short introduction will be given here. The SC is mainly intended for determination of an unknown surface generated by a given one. This task arises usually in development and improvement tasks of gears. The functional levels of the software are demonstrated in Fig. 2, where the top level represents the given surface $F1$ and the relative motions ($Fi1$, $Fi2$) between the surfaces $F1$ and $F21$ or $F1$ and $F22$ with symbolic expressions. The Zeta, Rho and Tau variables are used by the enveloping process when $F21$ and $F22$ surfaces will be determined. To get the real form of the modeled 3D objects that can be displayed in animations the value entering and calculation steps are required. In the lower level can be visualize the selected 3D objects and animate and investigate their motion. In our case $F1$ is the rotor surface, the surface

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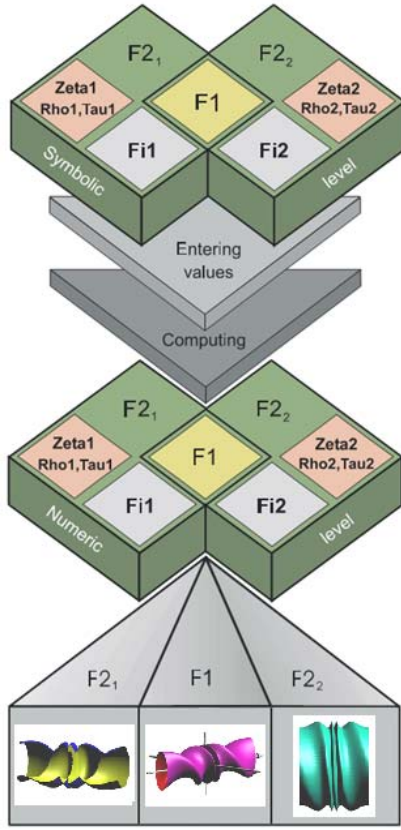


Fig. 2. Structure of SC

of the rotary chamber F21 and the surface of the grinding wheel F22 for grinding the rotor are the generated surfaces. For more detailed explanation of SC see [7].

II. DESIGNING A MOTOR PROTOTYPE

The final goal of the development is to make a ceramic prototype of the engine. However, considering the real possibilities the first goal is to create an aluminum version. The development process took into consideration the replacing of metal parts to ceramic ones. The steps of the constructional development were the followings:

- Determination of the rotor and rotary chamber surfaces with proper cross sections and pitch function.
- Modeling and analysis of the formation of the cavities and the simulation of the motions.
- Creation of the 3D CAD model of the prototype.

For the two first steps the SC kinematical modeling tool was used, while in the third step the Autodesk Inventor CAD software helped the work.

A. Determining the Rotor Surface

The rotor surface is a swept surface, the generating curve is an ellipse given in the perpendicular plane to the axis of the rotor. Moving it with a helical motion where the constant pitch

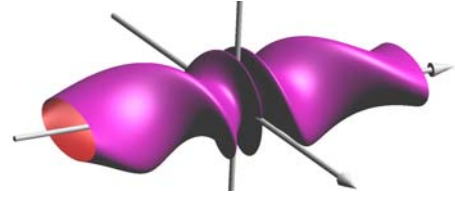


Fig. 3. The rotor surface

function is modified with a cubic function the surface can be get easily in the SC software. The resulted surface is shown in Fig 3.

B. Determining the Rotary Chamber Surface

The generation of the rotary chamber inner surface needs the special capability of the SC software. In this enveloping process the rotor surface generates the chamber surface in the relative motion. The ratio of the rotation of the chamber and the rotation of the rotor is 2:1. Fig. 4 shows an opened form of the generated chamber surface.

C. Analysis of the Formation of the Cavities

Because the axes of helicoids are parallel in this process, the generating movements can be analyzed in planes perpendicular to the axes. In every plane along the axes the same ellipse envelops a curve having cardioids-like shape. This demonstrated in Fig. 5 where the contacting ellipses and cardioids-like curves are in different locations along the engine length and these figures are assigned to the appropriate location of the rotor with numbers. Using these contacting planar curves the formation of the 'slug' form spatial cavities can be analyzed. The grey regions can be interpreted as consecutive intersections of the same 'slug'. Such a 'slug' form cavity moves linearly along the motor parallel to the axes and changes its length in axial direction as a spring, realizing the volume alteration that required for the compression and for the expansion. This motion and the simultaneous alteration in axial direction were animated by the SC software.

Another method to check the formation and extent of the cavities was the visualization of their borders emphasizing the contact lines between the rotor and the chamber surface. To realize this, the size of the rotor was enlarged a bit. The alteration of the accentuated contact lines can be seen in Fig. 6. Using the animation capability of SC the wandering and the changing of these border curves could easily be studied. Additionally it is easy to open the cavity and analyze its formation and alteration from the inside. The results of these

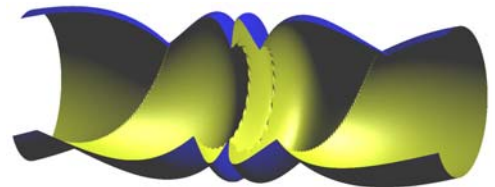


Fig. 4. The rotary chamber surface

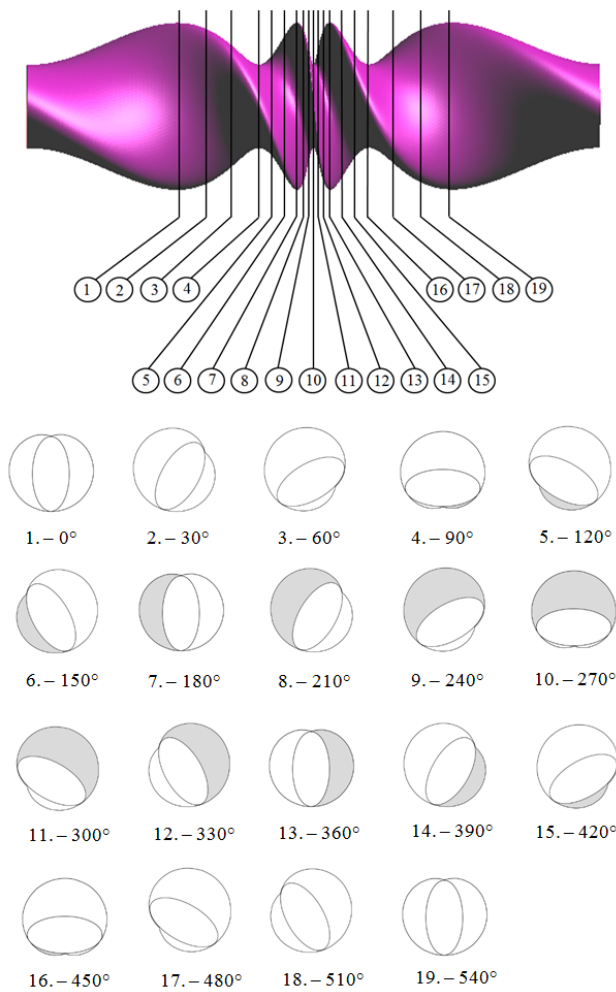


Fig. 5. Analysing the intersection regions of the cavities

investigations can be concluded as follows:

- The rotary housing and the rotor have different starts: one and two, respectively.
- The pitch of the rotary housing is the half of the rotor pitch.
- A cavity length on the rotor is half of the length on the rotary housing: 540 grad and 1080 grad, respectively.
- The cavities start at every half rotation of the rotor and at full rotation of the rotary housing.
- The minimum length motor needs a rotor with three full threads. The intake cavity closes after one and a half turnings, then the compression and expansion need 0.75 – 0.75 turnings. Finally the cavity opens.
- Ignition occurs for every turning of the rotary housing that is for every half turning of the rotor.
- There are three closed filled cavities in a six threads housing at a moment.

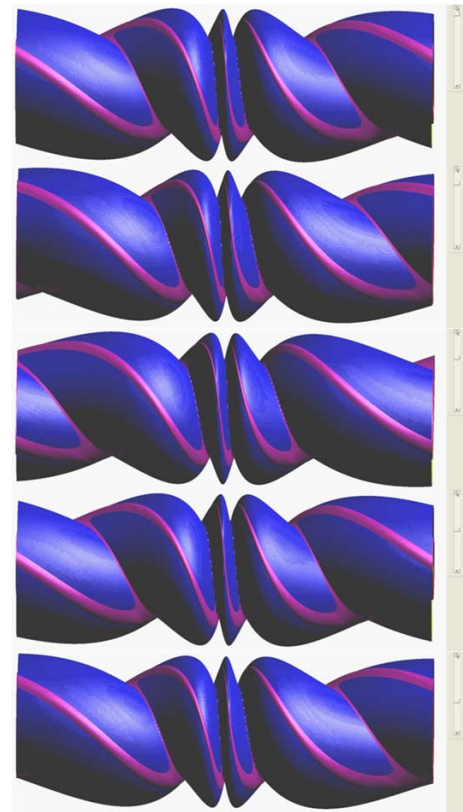


Fig. 6. Wandering of the cavities and the border lines

D. Creation of the CAD Model of the Prototype

The next step of the construction process is to design a 3D CAD model that can be made. More variants were developed and investigated in this phase, one of the possible constructions is shown in Fig. 7.

The CAD model makes possible conducting kinematical analysis, dynamic modeling and flow simulations and provides the fundamentals of production.

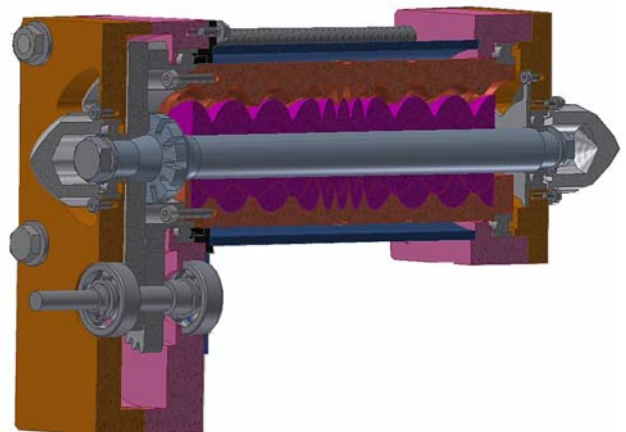


Fig. 7. A possible variant of the prototype engine

III. MANUFACTURING ANALYSIS

Similarly to the construction process the planning of the manufacturing of the motor also raises interesting problems. The technologically most complex issue is the machining of the rotor and the rotary chamber due to the changing pitch helicoids. The possibilities of manufacturing were analyzed also considering the possible assembling and disassembling requirements in more detailed form [8]. A summation of the performed research is given in the following.

A. Rotor Manufacturing

For manufacturing of the rotor two technologies were analyzed. The technologies need CNC milling machine and CAM software for generation of the precise NC code for the controller. The first cutting technology was the free form milling with ball nose end mills. This technology is advantageous mainly for roughing, but the analysis proved that using 1 mm diameter ball nose end mill for the finishing in the most critical deepest and tightest valleys the rotor can be cut precisely. For the roughing and precise finishing a series of milling tools with decreasing radii is planned. The hardest problem that arose is solving the undercut. The rotor has to be manufactured in two setups and the determination of the suitable dividing face to avoid undercut regions is essential. The solution can be given by determining the surface points having horizontal normal vectors. Fig. 8 shows the rotor with this theoretical dividing face that limits the area that can be machined in one setup. Additionally this figure shows the 1 mm diameter ball nose end mill in the tightest valley.

The second investigated milling technology applies disk shaped milling cutter. This technology is advantageous for finishing mainly because the two setups can be avoided and the smaller forces at finishing do not cause problematic deflection of the rotor that is fixed at its one end. For the finishing the used convex cutter has toroidal form. This cutting method arises two problems: the tilting of the rotor in horizontal plane is limited by the outer diameter of the disk shaped cutter. It would be advantageous to turn the rotor to the helical angle of the deepest and tightest valley but it results in problematic intersection curve (shown in the left part of Fig. 9) due to the given minimum outer diameter of the disk shaped tool. Decreasing the angle of the rotation to 2.5 degree the intersection curve (shown in the middle of the figure) has suitable form for correct manufacturing. The right side of the figure shows the tool in the critical locations. The investigations are proved, that the finishing can be achieved

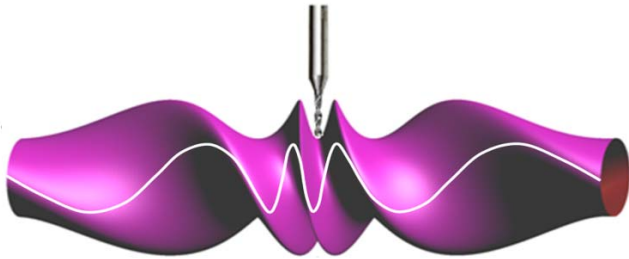


Fig. 8. The rotor with the borderline of the area that can be milled in one setup and the ball end nose milling tool

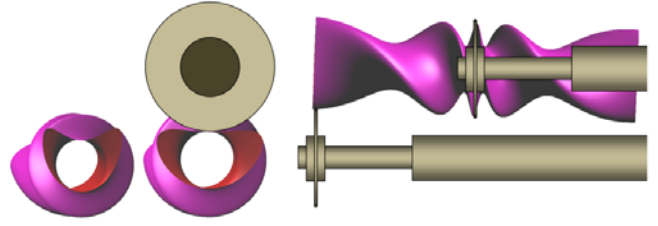


Fig. 9. To the left: 5 degree rotation. In the middle: 2.5 degree rotation. To the right: Top view of cutting.

correctly.

B. Rotary Chamber Manufacturing

The manufacturing of the internal helicoids of the rotary chamber raises more complex problems. Because of the changing internal helicoids surface the milling with disk shaped tool is practically impossible, can be imagined only as finishing operation when the allowances and consequently the cutting forces are very small. Therefore the chamber has to produce from two assembled halves. The question is the form of the dividing face. The accomplished investigations proved that the chamber can't be divided into two halves without undercut regions. This can be followed in Fig. 10 where letters a and b mark undercut regions. As there are intervals along the length of the chamber where the surface points having horizontal normal vectors form doubled contours the clean-cut dividing face can't be determined. The possible solution is applying an intermediary contour in the intervals and trying to minimize the depth of the undercut. But fortunately the undercut half surface can be milled precisely if the technology applies ball end milling tool having thinned shank.

C. Grinding of the Rotary Parts

The grinding of the working surfaces of the rotor and the chamber would be important because the effectiveness of the motor depends on the size of the gap between these parts [9].

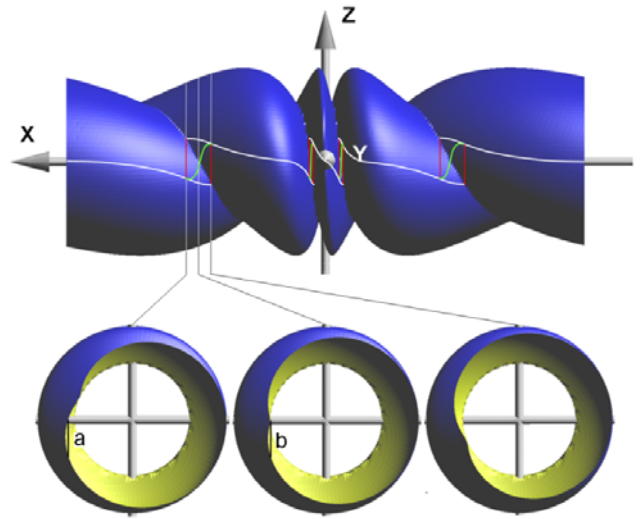


Fig. 10. Optimising the dividing face shape against undercut

Geometrically the grinding of the rotor surface and the inner surface of the chamber can be made with toroidal grinding wheels similarly to the finish milling of these parts with convex disk shaped milling tools.

The grinding of the rotor in case of mass production can be made using an innovation. The invention [10] of L. Dudás that can be studied in [11, 12], suggests a new grinding machine construction and a novel technology for grinding quasi helicoids surfaces. This solution applies a 1:1 rotational ratio between the complex, not surface of revolution grinding wheel and the grinded workpiece. See Fig. 11. In this method, the wheel surface and the workpiece surface are conjugate surfaces, so the wheel surface can be generated by the workpiece surface using enveloping. This task can be modeled with SC software and the grinding motions can be simulated. The snapshot of the SC software application in the midst of the grinding wheel generation and the simulation of the grinding process are shown in Fig 12. It is important that such grinding machine and grinding wheel is very expensive so the technology is suggested for mass production of the rotors.

As the rotor surface is very complex, the possible undercut makes the grinding of the rotor questionable. In case of worm grinding it is well known that the suitable tilting angle for the surface of revolution grinding wheel is the largest helical lead angle that can be found at the deepest point of the thread. For the rotor such critical lead angle value can be found at the

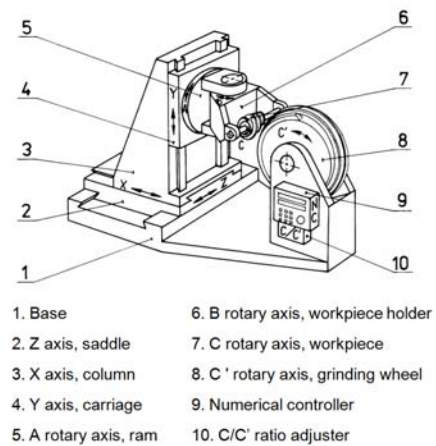


Fig. 11. Grinding machine for grinding quasi helicoid surfaces

middle of the rotor in the bottom of the thread. For the generation of the grinding wheel of the rotor the SC tool is applied with this tilting angle. This tool can be used because the rotor surface and the wheel surface are conjugate surfaces in this technology. As the rotor surface is very curved the possibility of undercut is large. To check the generated wheel surface against undercut the contact line visualization method

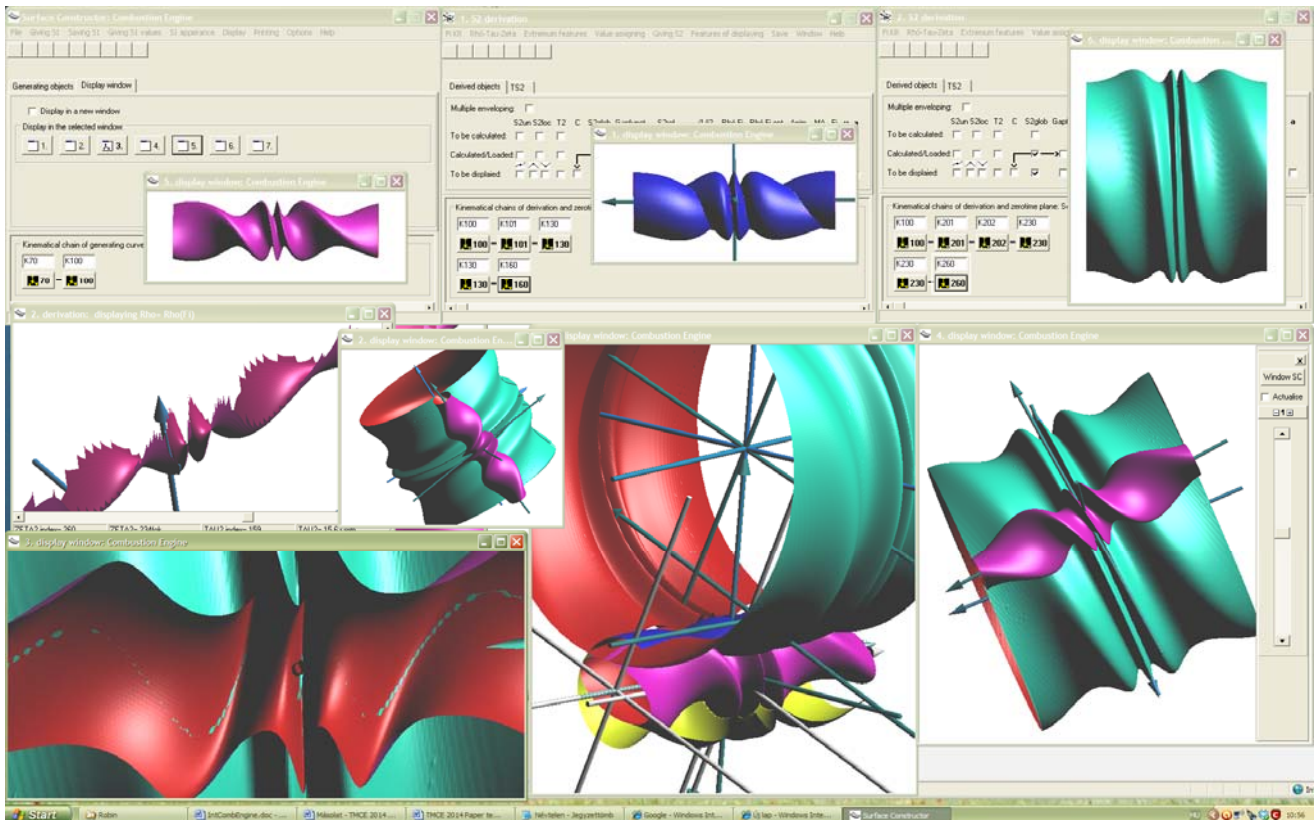


Fig. 12. The SC software with animation windows of grinding simulation

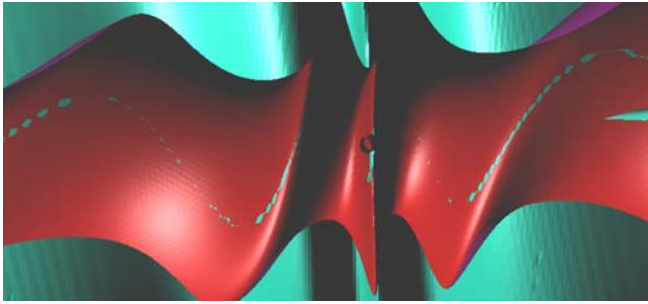


Fig. 13. Checking against undercut using the meshing line

was applied. With this method the contact of the two surfaces is checked visually in many locations of the generated surface. If the contact line is continuous in every moment of the grinding then the grinding wheel surface is undercut-free. Such an inspection moment is shown in Fig. 13. If the contact line is not continuous there is undercut, so the generated grinding wheel cannot reproduce the rotor surface. As the user interface of SC is very comfortable, the inspection for a given setting can be accomplished in seconds. Practically the inspection has to be made in the machine coordinate system with opened rotor surface and the relative rotary motion has to be carried out manually with the time slider button. During the motion the visual checking of the contact line continuity can be performed easily. For this the zoom factor and other settings can be made with mouse. But this investigation has to be performed almost every position accurately for a full rotation. Owing to this the process is time consuming. Finishing the investigation the results proved that the generated grinding wheel has not undercut at the set tilting angle. For the grinding of the rotor the same machine settings have to be applied. The feed can be made in radial direction. To avoid vibration during the grinding the rotor and the grinding wheel need static and dynamic balancing.

IV. CONCLUSIONS

The paper presented the results of a longer development process that intends to create the prototype of a new rotary internal combustion engine. The overview introduced the main characteristics of the patented construction, delineated the steps of the design process that resulted in a 3D CAD model. Then the technological aspects of the realization were discussed, mainly for the manufacturing of the rotor and the rotary chamber using milling and grinding. Every phase of this development process was aided by the innovative SC kinematical modeling and simulation tool. The CAD model

makes possible accomplishing mechanical and flow analyses with FEM tools. The final goal is to manufacture the prototype of the engine and carry out the motor tests.

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