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## Profiling of Screw Compressor Rotors by Use of Direct Digital Simulation

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### ABSTRACT

A standard feature of AutoCAD software enables a rotor to be 'cut' from a given blank and then generate a meshing rotor profile from a given primary profile template for practically all existing screw compressor rotor profiles. Three examples are presented, namely, a roots blower to demonstrate two-dimensional meshing, a twin screw compressor to demonstrate 'two and one half' dimensional generation and a single screw compressor rotor and hobbing tool to show full three-dimensional profile generation. Rotor profile points can be generated by this procedure from which the compressor displacement, the sealing line points and the blow-hole area can be estimated. Furthermore, the derived results can be integrated into a software suite for use as a design tool to predict compressor performance and related operating characteristics.

### 1. INTRODUCTION

The design of screw compressor rotor profiles has been long considered to be a specialist area, requiring expert knowledge, based mainly on the use of the envelope meshing condition, used in gear design, either in its original or derived form, such as in the Willis gearing procedure, Wu and Luo, 1992 and the Euler-Savary method for planar and spatial application. Other examples are Ito and Takahashi, 1999 and Dooner and Seireg, 2007. All of them resulted in the generation of a set of gear or rotor profile points from which gear characteristics like contact force, contact stress and relative sliding velocity could be calculated as well as screw compressor characteristics, like the working volume and volume gradient, the sealing line and the blow-hole area.

Recently, as shown by Kapelevich, 2007, it was concluded that in gearing practice it was necessary to profile gears directly from each other rather than by the traditional method of generating them from a convenient tool or a simple straight line template rack. This was because the traditional methods are not sufficiently precise for modern gear design. The new practice ensured, in advance, that gears would meet the requirements for low contact stress, affordable sliding velocity and controlled undercut, which were not possible with previous methods. As a result, gears would be able to operate with extremely low oil content or in extreme cases even without oil. Successful application of this practice has been reported recently by Kapelevich and McNamara, 2005. It is worth noting that as summarized by Stosic, 1998 the design of screw compressor rotor profiles used this, practice from the start due to the large lobe depth required.

Recently several papers, such as that of Goldfarb, Lunin and Trubachev, 2003 and 2004 and a pioneering textbook, Goldfarb, Lunin and Trubachev, 2004-2 described the synthesis of gear profiles by the use of CAD (Computer Aided Design) software to generate the profile points and other required profile and surface characteristics. They called the procedure Direct Digital Simulation, or DDS. By its use, gear profiles could be generated without any expert knowledge or expensive, specialist software. A similar approach is shown in this paper. However, as shown by Capatto, 2007, DDS may already be used in industry to design screw compressor rotors.

A standard intrinsic feature of perhaps every existing design software package is to extract the overlapping areas of planar shapes or volumes of spatial bodies. It can be conveniently used to find a corresponding profile from a given profile. This subtraction may either be static, when the overlapping elements are extracted from the stationary assembly, or dynamic, when the subtraction is performed for a sequence of succeeding positions to give a generated profile or body over a complete cycle. All kind of relative motion can be imposed between the elements, thus a variety of gear pairs can be designed on parallel, intersecting or nonintersecting and nonparallel axes. Therefore, spur, helical bevel, hypoid or worm forms can be created equally well. Either rotation or translation or both can be applied. A known profile will therefore cut the required shape from a 'blank' with an arbitrary starting shape. However it needs to be sufficiently large to cover all successive positions of the original profile or body.

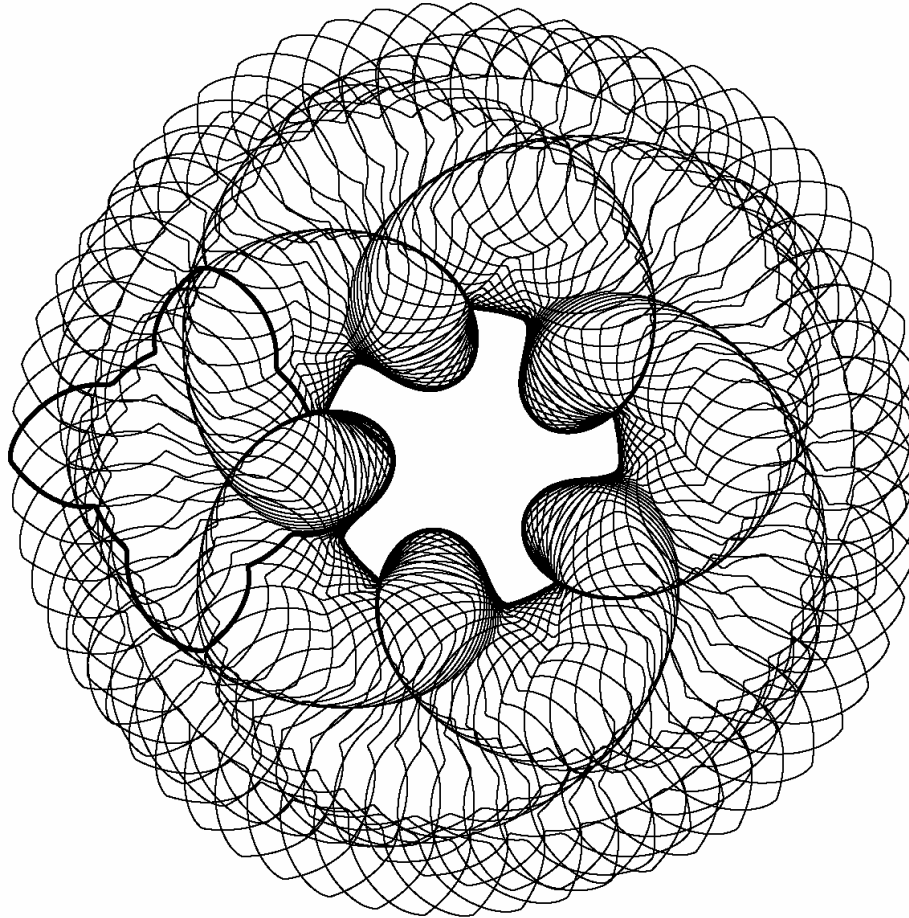


Figure 1: Example of a female rotor enveloped by its male counterpart, shown by a bold line on the left

An illustration of such a procedure is presented in Fig 1 where the male rotor of a screw compressor was used as a template to generate the female rotor. The relative motion in this case is the orbiting of the male rotor by rolling along its pitch cylinder over the female stationary rotor pitch cylinder to envelope the female rotor. This is a planar problem with parallel axes and it represents the simplest possible case in a screw compressor application.

Since there is no limitation in the use of this procedure in two- or three-dimensional cases, practically all rotor profiles of the existing twin or single screw compressors may be conveniently generated. Three examples are presented in this paper, a Roots blower as an example of two-dimensional meshing, a twin screw compressor as an example of 'two and half' dimensional generation and a single screw compressor rotor and hobbing tool as examples of full three-dimensional profile generation.

The material cut-off from the blanks by this means is obviously the rotor displacement volume. Additionally the rotor profile points are generated with its sealing line points and, if it exists, the blow-hole size and shape are estimated. Furthermore, the procedure has been integrated into a software suite which calculates the compressor performance and other compressor characteristics to form a very convenient engineering tool. Therefore, direct digital simulation may be used to predict contact area and contact movement between the parts, to design the cutting tools, to calculate the manufacturing settings, to calculate sliding, rolling and efficiency of the gear or rotor set, to estimate the contact and bending stresses and to create CAD models of the gears, rotor profiles, cams or similar items, as well as to inspect the profiles and identify the geometrical properties of the meshing pairs.

## **2. CONTROL OF CAD FOR ROTOR MESHING**

AutoCAD software was conveniently used in this project, from which the elements required for direct digital simulation of the shapes in screw compressor practice are given in this paper. The generation process is automated by developing user programs which control the CAD application. This was done in the Visual Basic for Application programming language. The user programs are based on a modular principle which consists of the selection of modules, which are separated for the blank and cutter parts, then the motion modules which define the part translation and two- or three-dimensional rotation, then boolean modules for the part subtraction, intersection and union, as well as the control modules.

The data and CAD objects are managed through part templates, which are the blank part as well as a CAD template of the part to be cut off, the cutter part as a CAD template part designated for cutting and CAD layers containing different template and working parts. Three elements of the CAD automation system used in this project. 1. the CAD document - drawing and part, assembly. This may be created by use of any appropriate CAD system, as for example AutoCAD, MDT, Inventor, ProEngineer, Solid Works, CATIA. CAD application is used as core system to perform generation of the corresponding part. 2. A user program is developed to perform different automated tasks on the exposed objects inside of the CAD application on the application and document level. 3. Application programming interface (API) based on either ActiveX objects or Java classes is used to access any exposed objects of CAD application. The most important are the blank and cutter part which correspond to different events from the user program changing its properties or executing different methods such as part motion, boolean operations, selection or similar.

Once established, the user functions can be shared among users to form an extensive library of procedures that may significantly enhance the use of standard CAD packages.

## **3. APPLICATION EXAMPLES**

A series of DDS example application to screw compressor rotors is presented in this section.

A purely two-dimensional case of a pair of Roots blower rotors is presented in Fig 2. Since the rotors of a typical Roots blower are symmetrical and equal, a guessed profile was used to start the generation and the resulting profile was adjusted to conform with the requirements until two equal rotors were generated. This procedure is so different from the traditional one, that none of the constraints, usually present in traditional profiling, were required. This gave additional freedom in creating profiles and resulted in flexible rotor profiles which offer a new approach to the design of Roots blowers. It may be worthwhile to point out that extending from straight to twisted rotors is direct and requires only one of the motion parameters to be adjusted. This then becomes a, so called, two and one half dimensional example.

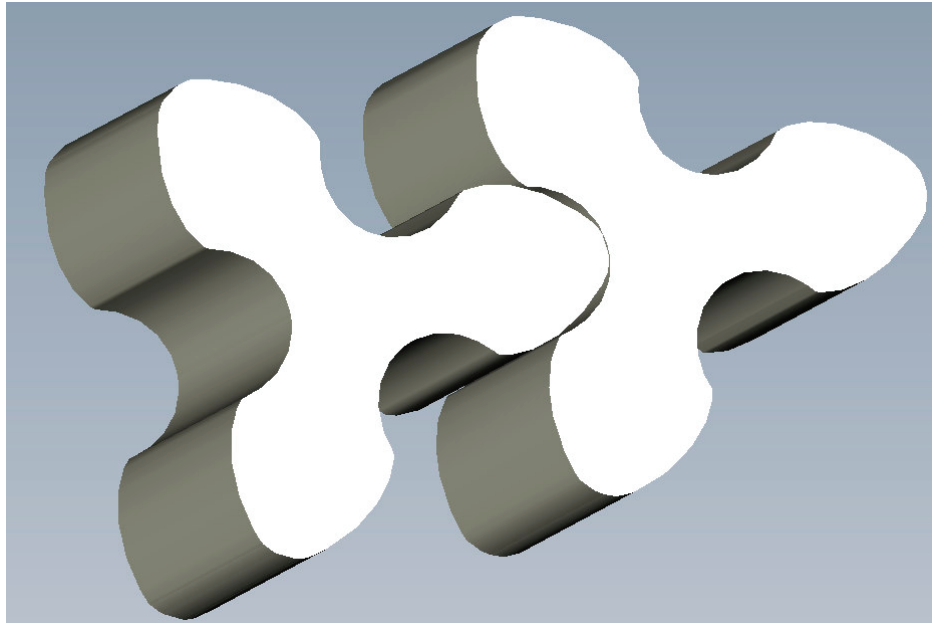


Figure 2: Example of Roots blower rotors generated by DDS procedure constrained by the equality of the rotors

A similar example is given in Fig 3 where a female rotor of a twin screw compressor is generated from a blank, cut by the male rotor which was previously created by use of a generation procedure presented in Figure 4, where a rack was used to create the male rotor of a screw compressor.

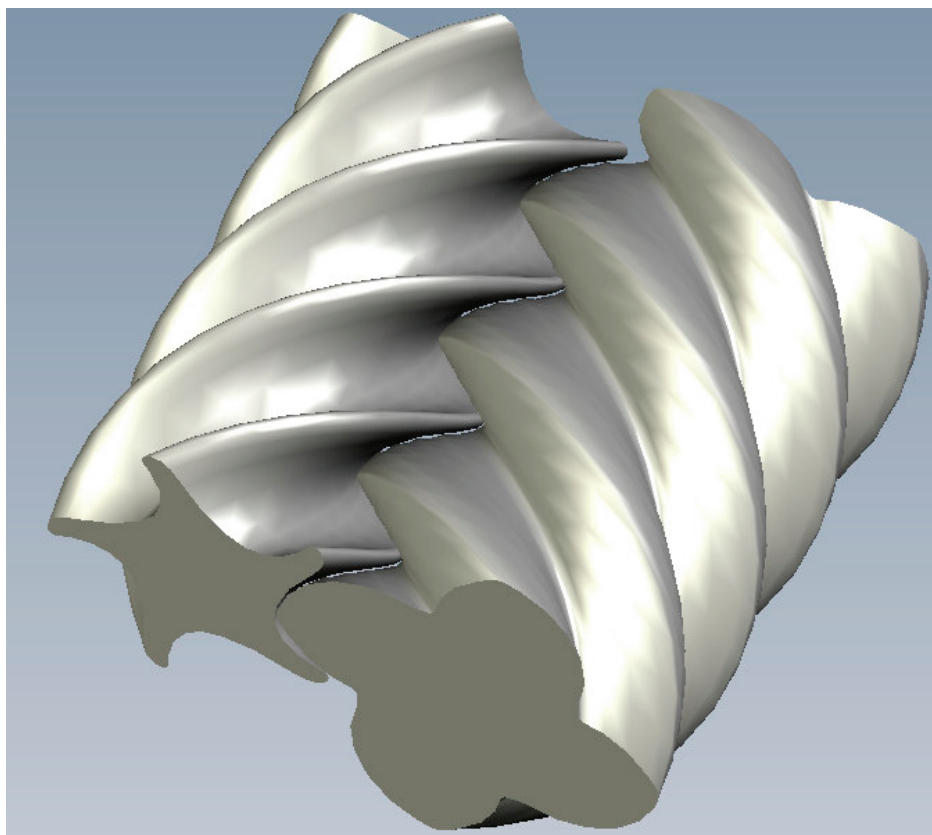


Figure 3: Example of generation of a female rotor from its male counterpart

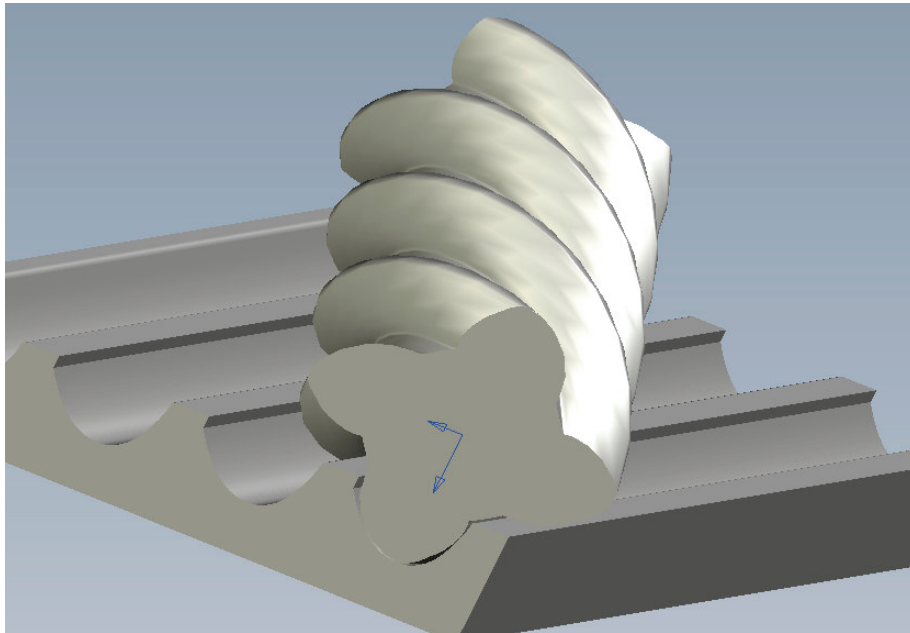


Figure 4: Example of generation of a male rotor from its rack

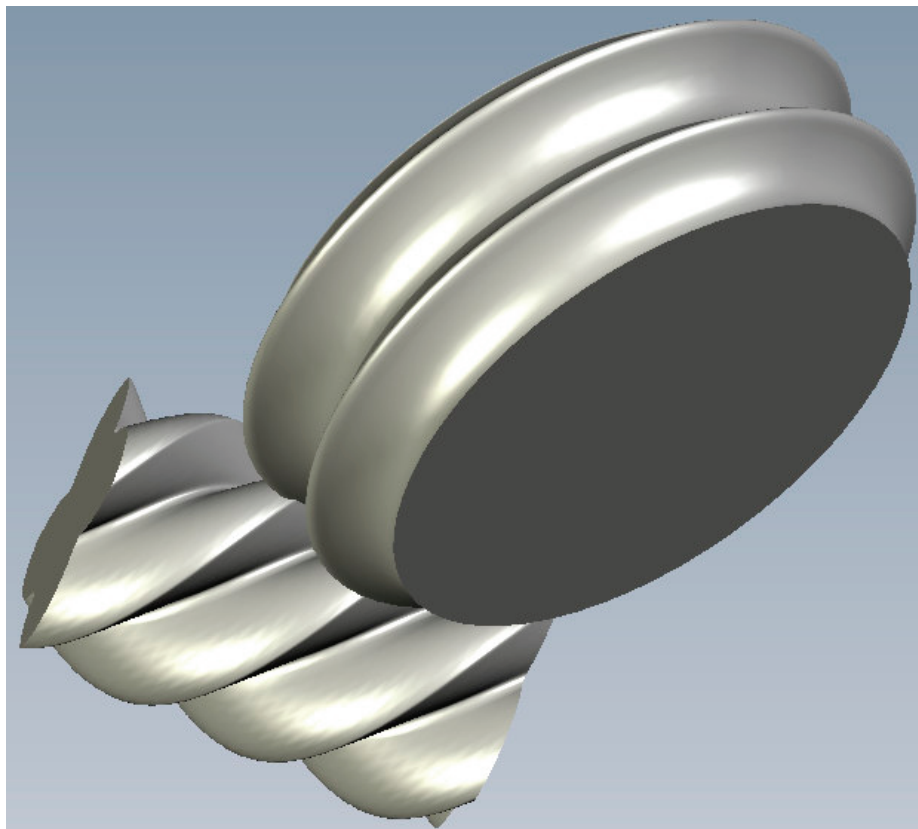


Figure 5: A formed milling or grinding plate tool generated from the male rotor template

The following three examples are for full three-dimensional generation. The synthesis of a formed tool for milling or grinding from a template male rotor is presented in Fig 5, while a hobbing tool which may be used either for milling or for grinding is presented in Fig 6. The rotor and tool axes are non-intersecting in these cases and at an arbitrary angle. The difference between the formed and hobbing tool is in the lead of the tool.. The lead comprises a zero and a finite value respectively. The difference between the milling or grinding tool is the cutting gashes required for milling. The last example is presented in Fig 7 and represents the synthesis of a single screw rotor from its star rotor. In this case, the rotor axes are non-intersecting and orthogonal.

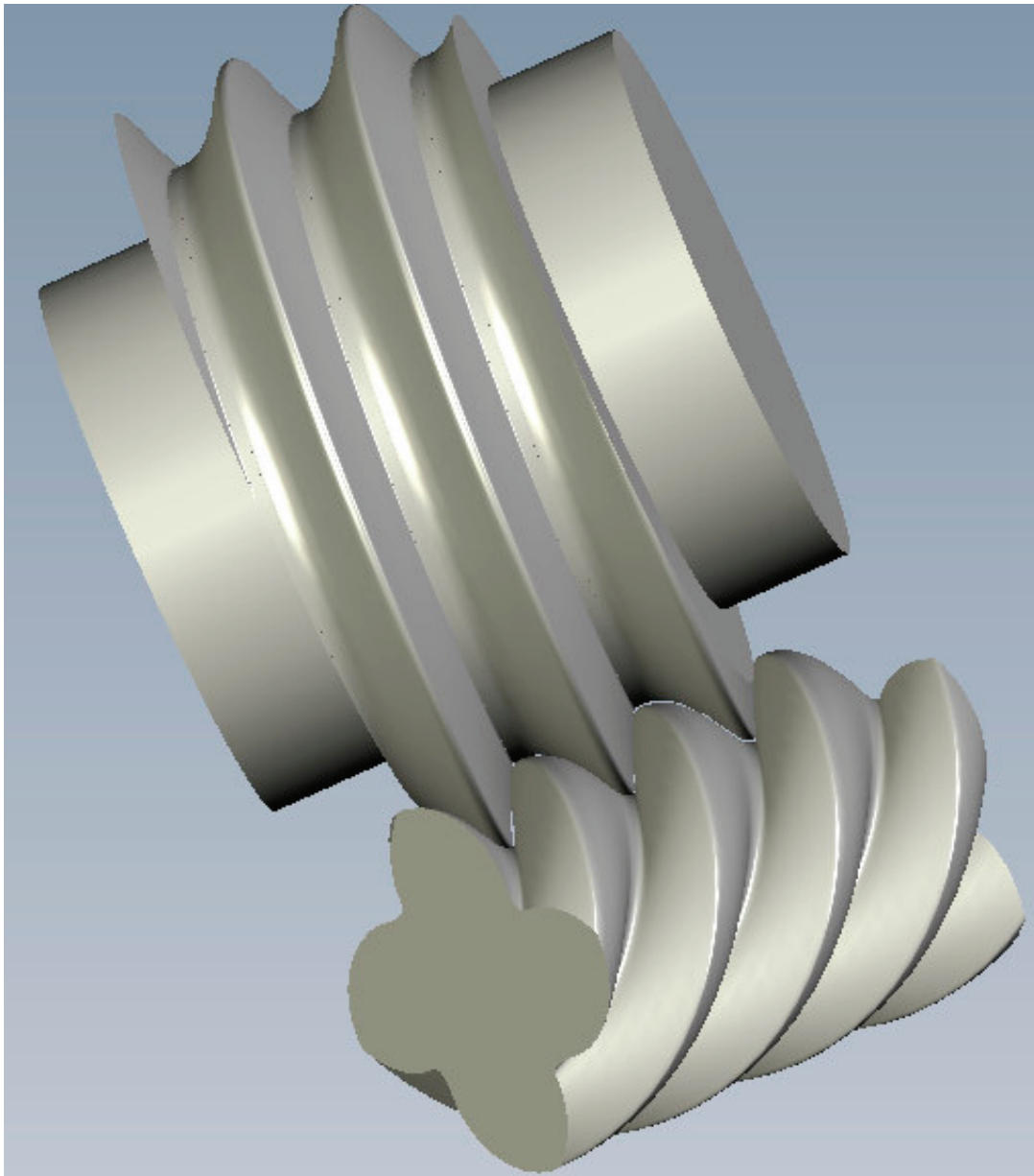


Figure 6: Hobbing tool for milling or grinding generated from a male rotor template



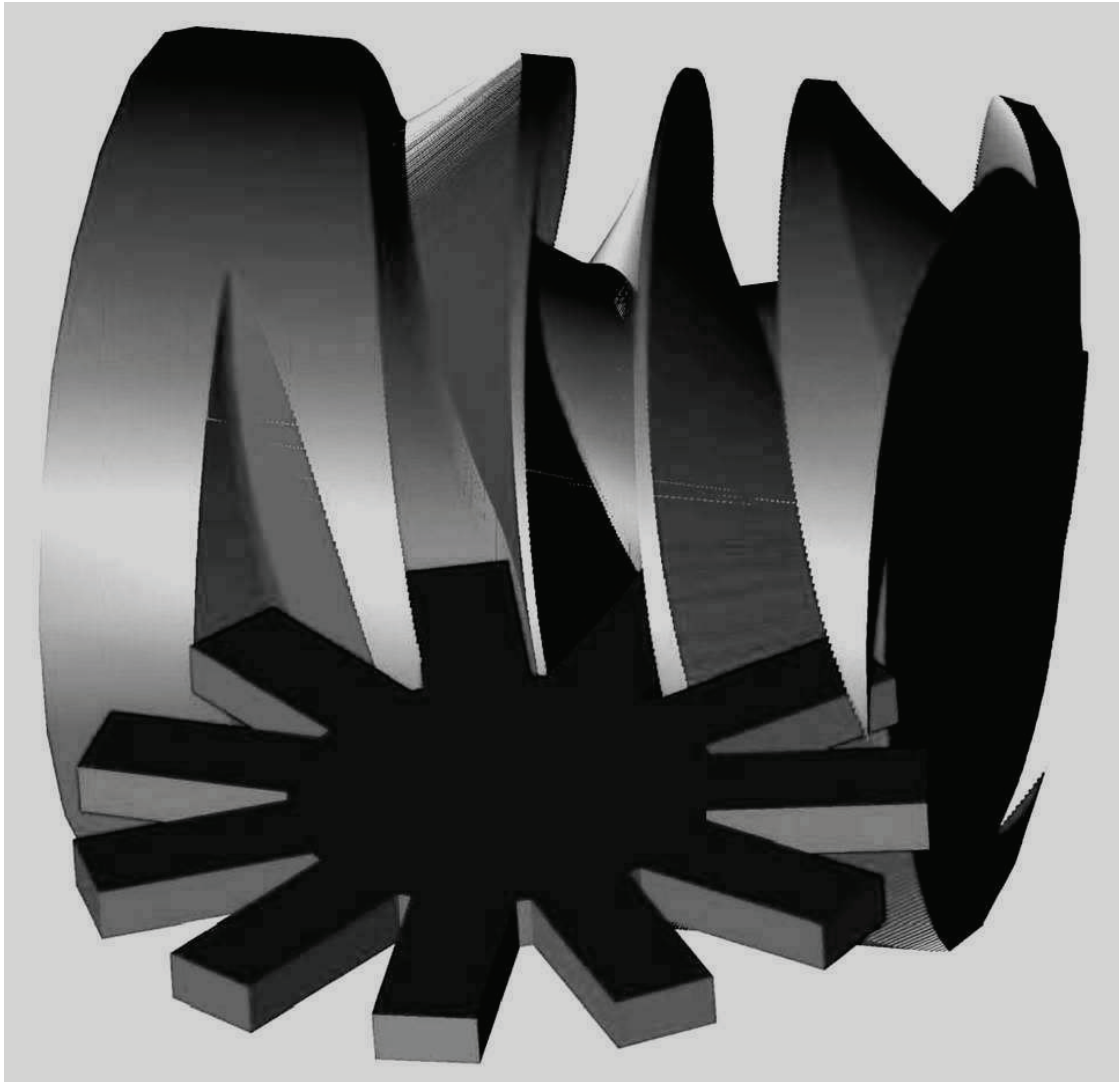


Figure 7: A single screw rotor generated from its star rotor

#### 4. CONCLUSIONS

Direct digital simulation can be applied to generate screw compressor rotors and their tools and confirms the flexibility, applicability and usefulness of this procedure. By this means engineers, who are not specialists in gearing, can design their own rotor profiles. The examples presented show that little intervention is required in the user to create a variety of rotor profile shapes. Such a convenient procedure opens a new approach to screw compressor rotor profiling which, since it may be acquired by an increased number of researchers, will certainly result in new profile shapes. These may be very difficult to imagine being created by traditional generation methods. Moreover this procedure can be acquired anyone who has access to CAD software suites, the use of which is nowadays becoming more routine and commonplace.



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