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CAD MODELLING OF A MILLING INSERT

TAMÁS MAKKAI[1] – FERENC SARKA[2]
[1]*University of Miskolc, Institute of Manufacturing Science*
H-3515, Miskolc-Egyetemváros
[2]*University of Miskolc, Institute of Machine and Product Design*
H-3515, Miskolc-Egyetemváros
[1]*tamas.makkai@uni-miskolc.hu*, [2]*ferenc.sarka@uni-miskolc.hu*
[1]*https://orcid.org/0000-0002-7840-9856*
[2]*https://orcid.org/0000-0003-3136-4248*

Abstract: There is often a problem when using FEM software where the tool geometry needs to be specified for the cutting simulation, one or more dimensions are not known. In the article, we present how and with what methods we determined these unknown dimensions, how we created the three-dimensional CAD model of the cutting insert as input data for the FEM software. We report our experience gained during the measurement and model creation process.

Keywords: *CAD model, milling insert, FEM analysis*

1. INTRODUCTION, DESCRIPTION OF THE PROBLEM

The processes, during cutting, take place relatively quickly. For this reason, their observation with optical and mechanical devices is difficult, and even more difficult in the case of rotating tools. The deformation of the material, the formation of chips, the course of mechanical and energetic characteristics over time are important characteristics of the milling process. In addition to the difficulties of observation, the expensive tools and workpieces are also arguments for which the use of computer simulation software is extremely beneficial instead of real experiments. In many cases, the finite element method is used for the analysis in several mechanical engineering problem like in (Sarka, 2022), (Alzghoul, Sarka, & Szabó, 2022), (Jálics, 2017). Standard tools can be found in the simulation software, and it is also possible to use unique tool geometry. The dynamic effects of enter cutting was investigated with the position change (axial and radial rake angle) of an octagonal milling insert with FEM simulation by Sztankovics (Sztankovics, 2019). For this, he had to create the insert geometry individually in the software. Karpuschewski et al. investigated the changes in the components of temperature, torque, power and cutting force during face milling using two types of inserts (Karpuschewski et al., 2018). During the FEM simulation, in addition to the chip ratio, the angles of the tool (lead angle, axial and radial rake angle) were also variable. Borysenko et al. analysed the chip formation and the components of the cutting force with FEM simulation during face milling with a special tool (Borysenko, Karpuschewski, Welzel, Kundrák, & Felhő, 2019). In the case of indexable inserts, their manufacturers usually provide several geometric characteristics in their catalogues (e.g., insert thickness, edge length), but

there are some geometric dimensions that are not specified (e.g., rake angle, edge radius). If we want to use a tool of which geometrical data is unknown and cannot be found in the catalogue (e.g., older insert types), then these must be determined, and the CAD model must be created so that we can insert it into the simulation software. Hard turning experiments were carried out with a new octagonal cubic boron nitride (CBN) insert (Kundrák, Sztankovics, & Gévai, 2019) by Kundrák et al. For the FEM simulation, the rake angle of the insert was determined with a coordinate measuring machine. Felhő carried out face milling FEM simulation experiments to determine the components of the cutting force, he worked with a circular insert (Felhő, 2020). The edge radius of the insert is one of the important factors of chip separation, and he presented a new method to measure it. The measurement was carried out on a three-dimensional surface roughness measuring machine, and the value of the edge radius determined by this method was used in the FEM software, so that the simulation could be carried out such a tool geometry that is closer to the reality.

2. THE BRIEF HISTORY OF THE CUTTING INSERTS

After the First World War, diamond became very expensive, so the industry started looking for another material to replace it (as proper material as drawing die for non-sag tungsten wire). Scientists tried to convert the brittle carbide material into a plastic material by sintering, similar to tungsten. Schröter's first attempts to sinter WC (tungsten carbide) with Ni additions produced variable results. Then they experimented with the addition of cobalt powder, which proved successful, this metal-ceramic alloy was suitable for the production of drawing tools for tungsten wires. Schröter applied for a patent for his discovery, which received the number DRP 420.689 (Patent No. DE420689C, 1923). Then the patent went to the German Krupp Company, they started the production of the new material under the name WIDIA (Wie Diamant = WIDIA, like diamond). The development of carbides has led to a continuous increase in the production and use of carbide raw materials (Ortner, Ettmayer, & Kolaska, 2014). Pálmai et al. (Pálmai, Dévényi, & Szőnyi, 1991) presented in detail the characteristics of carbides, their production methods, and the manufacturing processes of various types of carbide tools. In the early days, carbide inserts were attached to the tool shank by soldering. The worn insert could be resharpened by grinding. The growing trend of automation in metalworking and the spread of numerical control led to the development of indexable inserts. Indexable inserts with complicated geometry and tight tolerances were thrown away and replaced with a new one after they were worn out. This made it possible to reduce tool costs and save human work and time spent on resharpening. The Swedish company Sandvik started the production of carbide tools in 1942 under the name Coromant. In 1943, the first carbide metalworking tools were manufactured. Ceramic cutting materials also appeared in the 1950s. In 1957, scrapers became the first tools to have mechanically clamped indexable inserts or throw-away inserts. This year, the T-Max holder appeared, and the use of indexable insert led to an increase in productivity. The world's first surface-coated carbide insert appeared, and in 1969 the heat-resistant gamma

coating (GC) was introduced, which further increased the performance of the inserts with its heat resistance (Sandvik, 2023). In addition to ceramics are also used in insert form. The more expensive raw materials, such as diamond (PCD) and cubic boron nitride (CBN), were placed on tip of the carbide inserts (as carriers).

3. BRIEF DESCRIPTION OF THE FEM PROGRAM

For the simulation analysis of cutting processes, we can choose software from several companies. In the following, we present what input data can be entered for a face milling simulation in the Third Wave AdvantEdge software. First, it is advisable to specify the geometric dimensions of the workpiece, i.e., width, length, and height, as well as the characteristics of the finite element simulation for the workpiece. In addition to the geometry, we can specify a standard material, but it is also possible to set individual material characteristics. The next step is to specify the geometry of the tool. We can choose to work with standard or unique edge geometry. When using a standard insert, you must select the exact type of insert, specify the cutter diameter and the number of edges. The position of the insert can be specified with various tool angles, these are the radial and axial rake angle, the relief angle, and the lead angle. The edge radius and the width of the insert (Tool Width) must also be entered. In case of individual insert design, the shape of the insert must be drawn in the base plane in the program's own editor. It is also possible to draw a unique cutting edge. This is followed by the selection of the material of the insert, if necessary, we can specify the number, thickness, and material of the coatings. After specifying the characteristics of the workpiece and the tool, the parameters of the cutting process must be specified. In the case of face milling, these are the spindle speed, feed per tooth, axial depth of cut, initial temperature, rotation angle, friction coefficient and cooling-lubrication characteristics. Finally, the parameters characteristic of the finite element mesh used during the simulation must be set. As a result of the simulation, we get the values of the following output characteristics over time: forces in the x, y and z directions interpreted in the Cartesian coordinate system, tangential and radial forces for a single cutting edge, cutting power, torque and temperature, the von Mises stress that can be measured on the tool, shear stress, pressure and temperature, as well as temperature rate, von Mises stress, plastic deformation rate and temperature that can be determined in the root of the chip. The software can also provide animation about chip formation. The results can be analysed immediately with the software called TecPlot, but they can also be saved in text format for further processing with an external application.

4. DETERMINATION OF THE GEOMETRIC DIMENSIONS OF THE INSERT

The examined insert was a parallelogram-shaped milling insert that can be attached to a face milling head. Its enclosure dimensions can be easily measured, even with a vernier calliper. However, the geometry of the boundary surfaces of the insert is much more complicated than it can be determined with simple hand tools. In order

to build the CAD model of the insert, we had to perform several different types of measurements. We present them in the next two points.

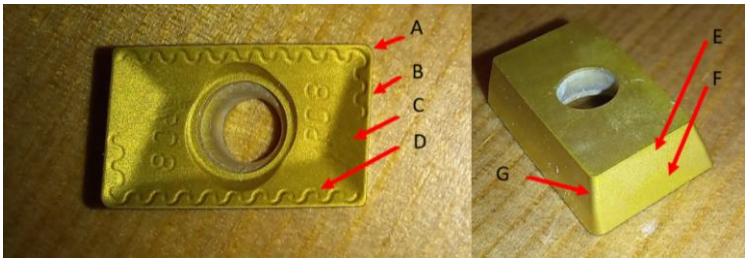


Figure 1. *Photo of the insert, marking the individual surfaces to be modelled*

We were able to determine the dimensions of the three inclusions of the insert using traditional hand measuring tools: its length, width and height. These are respectively 15.4 mm, 9.6 mm and 4 mm. The manufacturer of the insert specified the rounding radius of the cutting tip as 0.8 mm (it is also written on the insert), which we accepted when building the CAD model. The rounding radius is a very important data in terms of the roughness and the shape of the machined surface. The following figure shows a photo of the insert *(Figure 1)*. On this, we marked the individual surfaces, the modelling of them will be covered in the following points.

We continued the determination of the geometry with microscopic examination. We used a Zeiss Discovery v12 microscope and the accompanying ZEN software for the measurements. The measurements were performed at 20× magnification. Before the measurement, calibration was performed with a 2 mm thick gauge block. Using the microscope, we determined the width of the land. The value of the width was between 0.14–0.17 mm *(Figure 2)*.

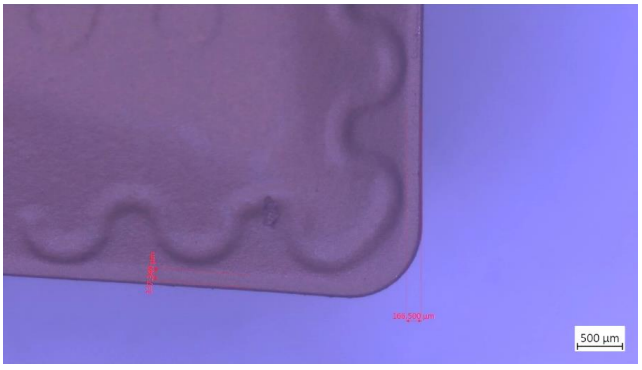


Figure 2. *Measuring the width of the land using a microscope.*

We could not determine the position of the surfaces marked C and D in *Figure 1* either on the basis of the microscopic image or with a hand-held protractor, so we had to look for some other method.

4.1. Results of scanners

We used a 3D scanner to determine the C and D surfaces of the cutting insert. First, we worked with a Roland Pix4 touch scanner. The advantage of this is that it can also digitize shiny metal surfaces. The scanning resolution was 0.05 mm in all three coordinate directions. The obtained result can be seen in *Figure 3* in the Dr. Picza3 program included with the scanner. With the help of the program, the coordinates of the scanned points can be queried, and the distance between two points can also be determined. The width of land can also be checked in the program, for this value the software gives is 0.15 mm [short red line in the figure *(Figure 3)*].

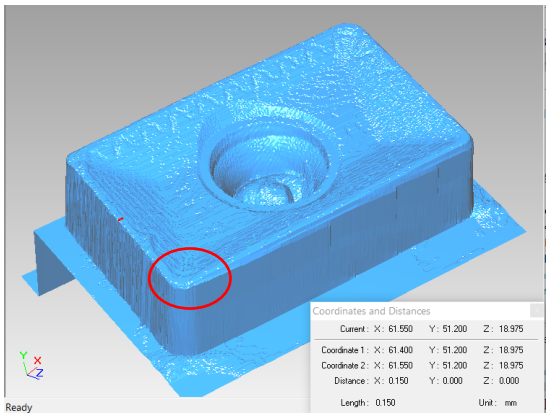


Figure 3. *The scanned image of the insert in the Picza3 program*

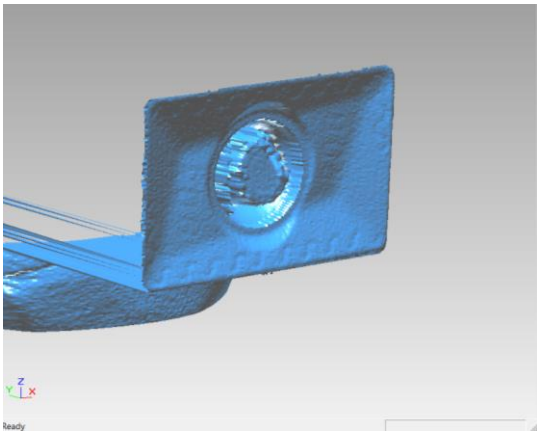


Figure 4. *Surface digitized by the laser scanner*

Based on the figure, we can see that the model made with the scanner has too bad surface and cannot be used in finite element simulations. That is why we continued the work, we painted the insert with a matte white colour (Mr. Hobby, MrFinishing Surfacer 1500 White paint at a thickness of about 30 μm with an airbrush gun) in

order to try to digitize the insert in a laser scanner. The type of the used laser scanner is Roland LPX-1200. The used resolution was 0.1 mm in all coordinate directions (this is the finest resolution that the scanner can handle). For the operation, we chose the planar scanning mode. The result is shown in *Figure 4*.

The digitized surface of the insert is much more accurate than the one obtained with the touch scanner, but it is still not good for finite element software. The obtained result was cleaned of unnecessary parts (they were used to install the insert in the scanner) and imported into the Solid Edge 2020 program, where we were able to determine the data required for editing the CAD model.

4.2. Building up the CAD model

The surface loaded into the Solid Edge program (cleaned of false parts) can be seen in the following figure *(Figure 5)*. The first step in determining the geometric data of the insert is to know the inclination angle of the planes marked C and D in *Figure 1* (the rake angle of the insert). Inclination angles must be measured in a plane perpendicular to the cutting edge. To do this, we first draw two straight lines on both cutting edges (drawn in black, marked by thick red arrows).

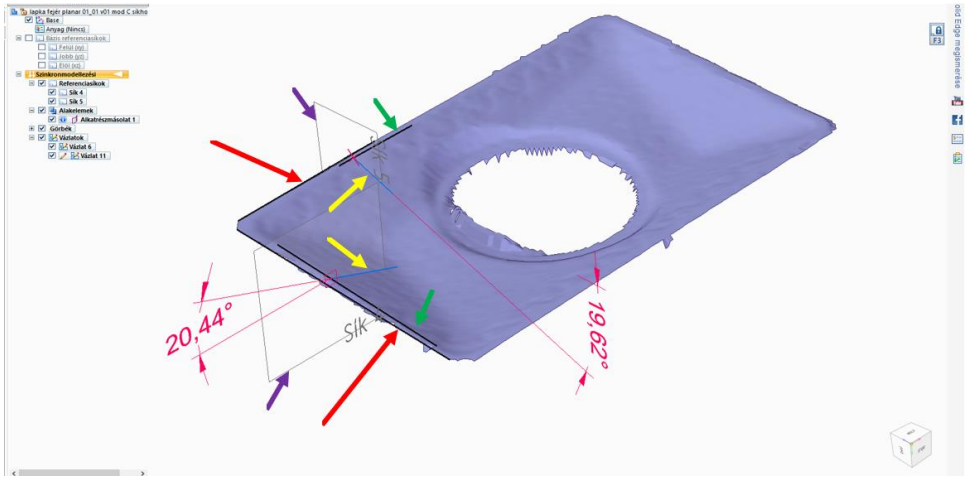


Figure 5. *Determination of the inclination angle of the planes marked C and D*

The lines were created by selecting two nodes of the scanned mesh to closely approximate the real edge of the insert. We made the planes labelled with plane 4 and plane 5 perpendicular to the two lines created in this way (indicated by purple arrows). The measurements will be carried out in these planes. We also need additional lines to determine the angle values we are looking for. Two of these are that edges of the land which facing to planes C and D (indicated by green arrows). It was created in a similar way as the straight lines of the cutting edges. These lines are needed because planes C and D start from here. Two more lines still needed for angle measurement are marked with yellow arrows. These lines run in the planes C and D

(approximately, within the accuracy of the scanner). They start from the punching points of the straight lines marked with green arrows and the recorded perpendicular planes (plane 4 and plane 5) and end at a point provided by the scanner. With this, we were able to set up the auxiliary lines that give the measurement. In the following figure *(Figure 6)* it is visible between which lines, and in which plane the measurement takes place. The straight lines are marked with yellow arrows. In the case of plane C, we obtained 20.44°. The method described above was also applied to the plane marked with D. The value of the inclination angle obtained here is 19.62° *(Figure 7)*.

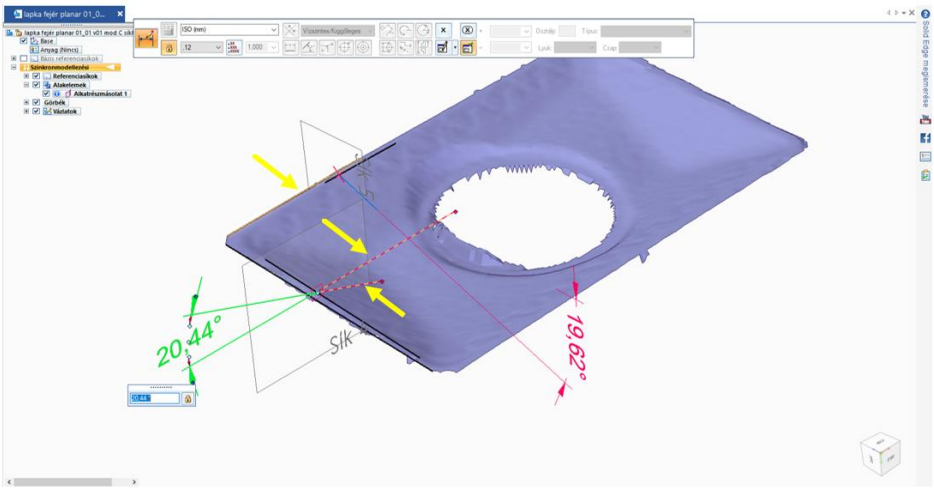


Figure 6. *The angle of inclination of the plane marked C with respect to the upper plane of the insert*

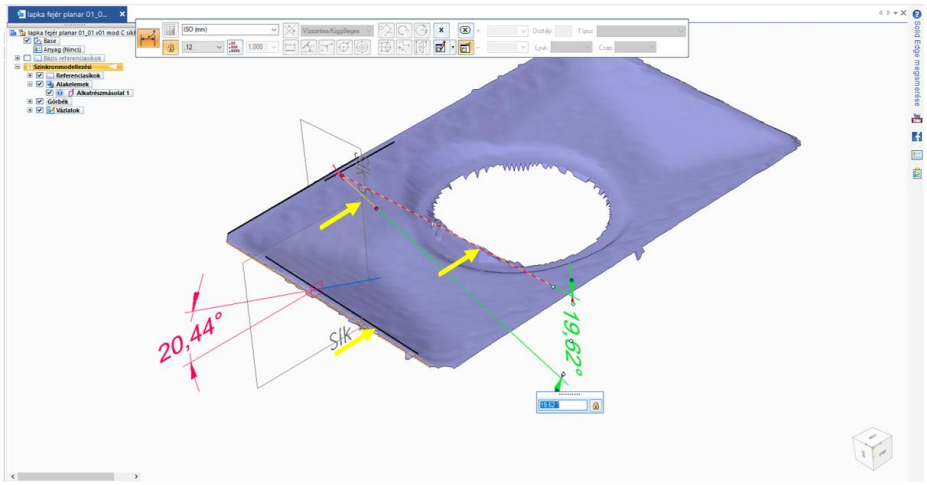


Figure 7. *Determination of the angle of inclination of the plane marked D*

When creating the CAD model, we rounded off the measured values and took the rake angle of the insert as 20° – in both directions. The error experienced in the measurement of the angles was primarily caused by the resolution of the scanner, the smallest value of the resolution is 0.1 mm (this was used). We still need additional data to create the CAD model. You should know the rounding of the outer edge of the land, the rounding between planes C and D, the data of the upper surfaces marked E, F and G. The missing data were determined using the methods described in the lines above, as well as with the help of a microscope and a three-dimensional roughness measuring machine, which are as follows:

- Edge rounding 0.05 mm, with a three-dimensional surface roughness measuring machine (method: [8]).
- The inclination angle of plane E is 18° (from the scanning result).
- The inclination angle of plane F is 11° (from the scanning result).
- The radius of the rounding marked G is 0.4 mm based on the microscope image.
- The rounding between planes C and D is given on the CAD model in such a way that it follows the R = 0.8 mm rounding of the tool tip in parallel.

After the measurements, microscopic examinations and scans, all data was available to create the CAD model. The finished model can be seen in the following figure *(Figure 8)*:

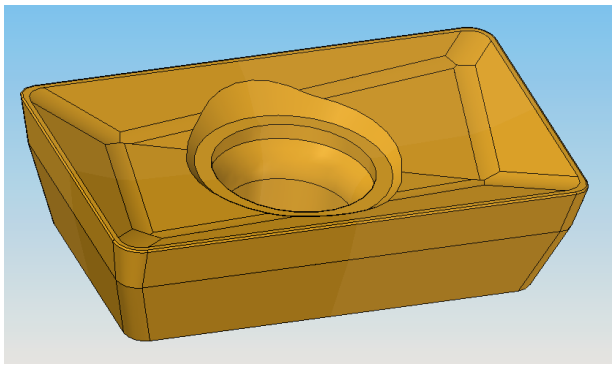


Figure 8. *The completed CAD model in the Solid Edge 2020 program*

5. INTEGRATING THE COMPLETED CAD MODEL INTO THE FEM PROGRAM

AdvantEdge software cannot directly read a model saved in Solid Edge's own file format. But it is possible to read some standard 3D CAD model file formats: stl, vrml and step. AdvantEdge best supports the step format, so the created model in Solid Edge must be saved in step format as well. We can import the tool model using the STEP Tool Import command of the AdvantEdge program. Inserts must be placed in the workspace as they appear in the milling head. The radial and axial rake angles, the lead angle, the cutter diameter, and the number of inserts (cutting edges) must be entered.

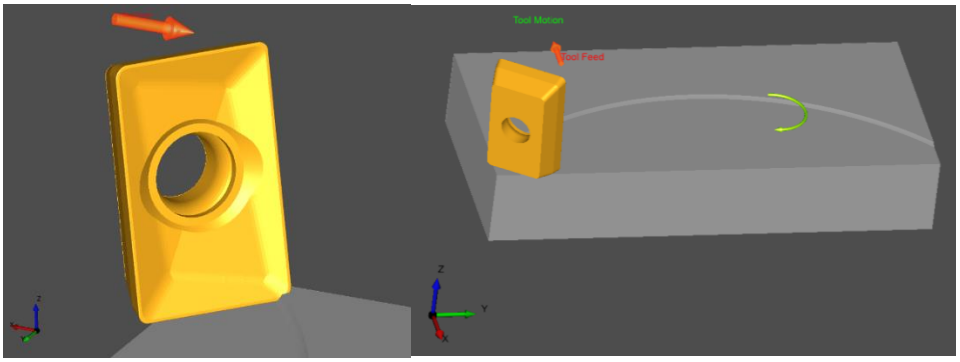


Figure 9. *CAD model of the insert in the AdvantEdge program*

The tool will then appear in the software workspace, and if necessary, it is possible to change the orientation of the tool. In the last step, we specify the necessary parameters for finite element meshing of the tool. With this, the imported insert model is ready to start the FEM face milling simulation *(Figure 9)*.

6. SUMMARY

With the help of the process presented in the points above, a CAD model of any existing cutting insert can be produced. The use of 3D scanners is essential in today's engineering research work. Unfortunately, its limitations are also clearly visible in the study presented. Scanners cannot create a precise edge geometry, which would be suitable in finite element programs used to model the cutting process, not least because of their resolution (inaccuracy). Therefore, there is no other option than building the inserts in CAD software. The CAD model also provides the opportunity to determine the tool's characteristic angles in the various system of tool designations, relatively easily and quickly by generating the appropriate sections.

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