TOOL EDGE GEOMETRY FROM STRUCTURED LIGHT SCANNING

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INTRODUCTION

Structured light scanners are used to generate three-dimensional models of physical objects. These models can be measured and inspected for reverse engineering or quality control applications. Cutting tools, such as endmills or drills, can be scanned and measured to obtain tool specific geometry. For example, the edge profile for each tooth of a serrated endmill was measured and used to predict cutting forces and stability [1]. The objective of this paper is to demonstrate the capability of measuring the rake and relief profiles for a scanned endmill.

Keywords: 3D scanning, endmill, rake angle, relief angle

EXPERIMENTAL SETUP

The tool surface was prepared prior to scanning. An airbrush was used to spray the fluted end with a titanium dioxide coating, providing the surface with both a light color and diffuse reflection for optimal scanning (Fig. 1). Reference markers placed along the shank of the tool enabled multiple scans to be stitched together to create the final point cloud/3D model. Figures 2-3 display the scanning system and final 3D tool scan. The overall size of the scanned tool is displayed in Fig. 4. The GOM ATOS Capsule scanner and GOM Inspect software was used for this research.

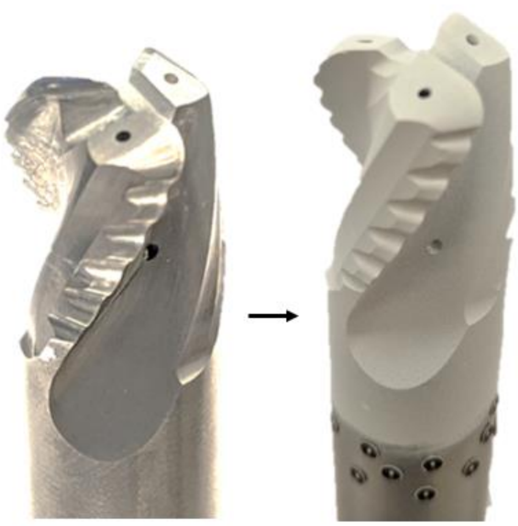

Figure 1. Tool prepared for scanning. Uncoated (left) and coated with reference markers (right).

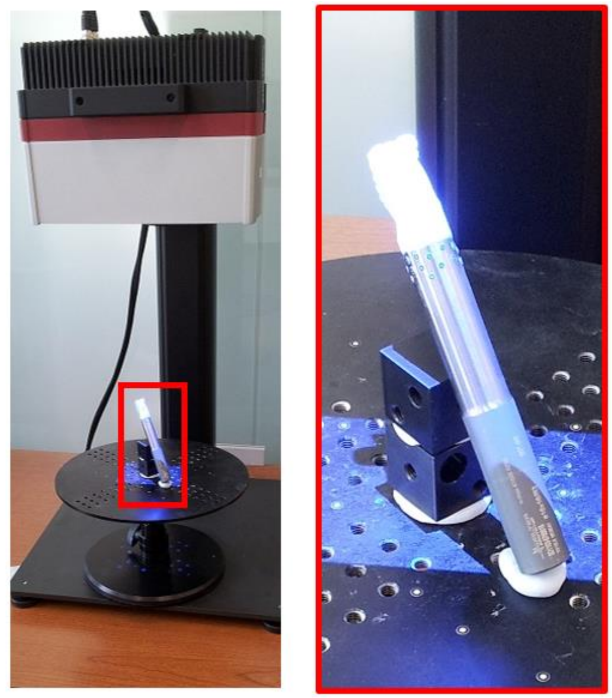

Figure 2. Setup on the GOM scanner.

Figure 3. Scanned 3D model.

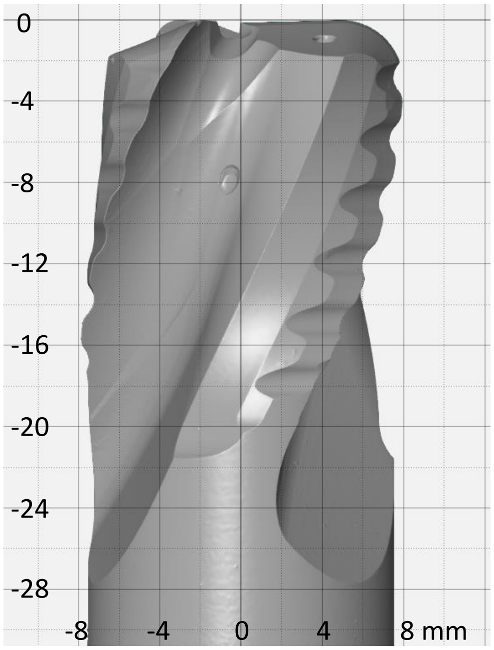

Figure 4. Scale for scanned endmill. The vertical axis is the z-axis.

DATA ANALYSIS

In order to perform geometric measurements, a coordinate system must be established on the tool. A cylinder was fit to the tool shank and a plane was created from the fluted end's extreme points. The intersection of the cylinder's axis and the plane was set as the origin of the coordinate system. Planar cross-sections were created along the z-axis of the tool. Each section contained the rake and relief profiles of each tooth at the corresponding axial location (Fig. 5). A simplified example of rake and relief angles is displayed in Fig. 6.

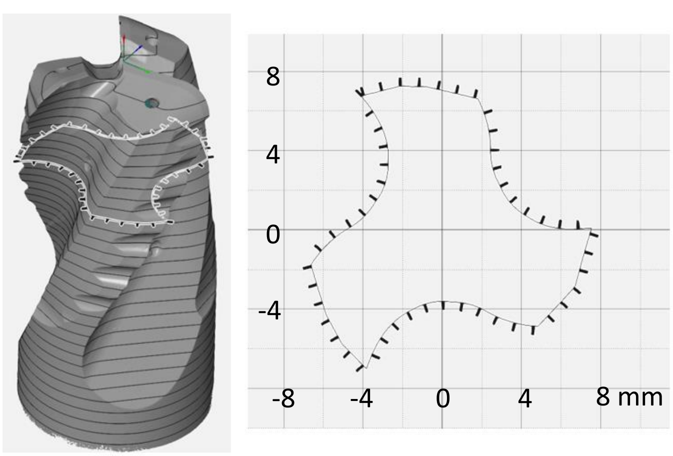

Figure 5. Planar cross-sections of 3D model (left) and z = -10 mm section (right).

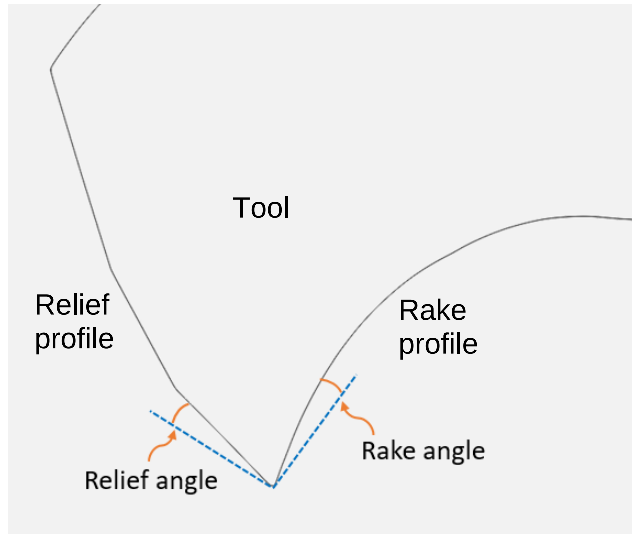

Figure 6. Example of rake and relief angles.

To calculate the rake and relief angles, equidistant points were placed along the rake and relief profiles (Fig. 7). The spacing between each point was 0.025 mm. Each point had an x,y,z coordinate and unit normal vector. A reference vector was created by connecting the origin of the section to the center of a best-fit circle at the tooth tip, where the rake and relief profiles meet (Fig. 8). To measure the rake angles, the unit normal vectors along the rake profile were rotated 90 deg clockwise to become unit tangent vectors. The rake angle was the angle between the tangent vector and reference vector. The same method was used to calculate the relief angles except the reference vector was now perpendicular (rotated 90 deg) to the original.

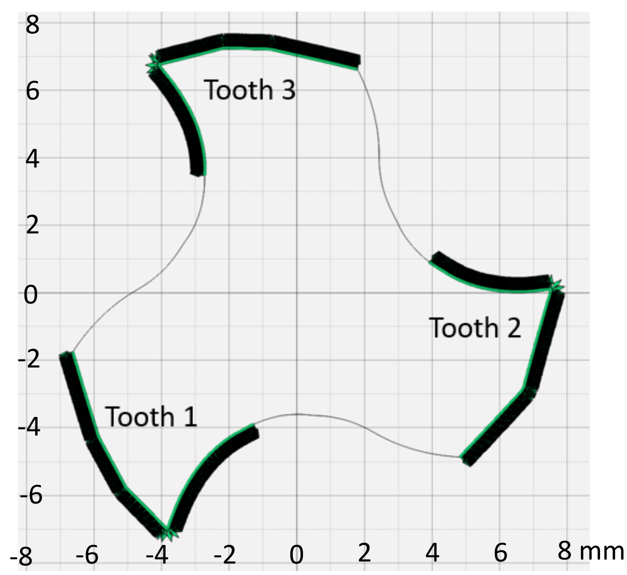

Figure 7. Rake and relief points for each tooth of the z = -10 mm section.

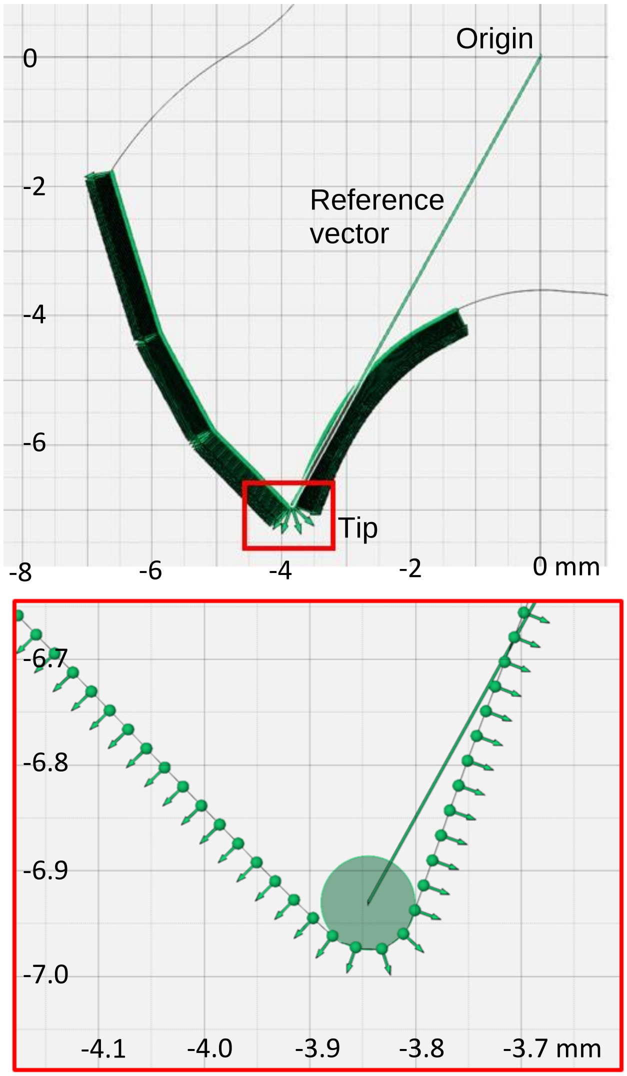

Figure 8. Reference vector (top) and tip details (bottom) for tooth 1 of the z = -10 mm section.

RESULTS

The rake and relief angles were plotted with respect to point distance, which is the distance traversed along the rake or relief profile from tip to point. A point at the tip was selected as the zero point so the distance of each subsequent point, moving away from the tip, could be calculated based on the equidistant point spacing. The rake and relief plots for tooth 1 are shown in Figs. 9 and 10. The rake angle is positive at the tip but flattens out and becomes negative as it moves further along the rake profile. The rake angle transitions linearly from positive to negative, which indicates that the rake profile is curvilinear. The relief angle plot shows three angles corresponding to the three flat sections along the relief profile.

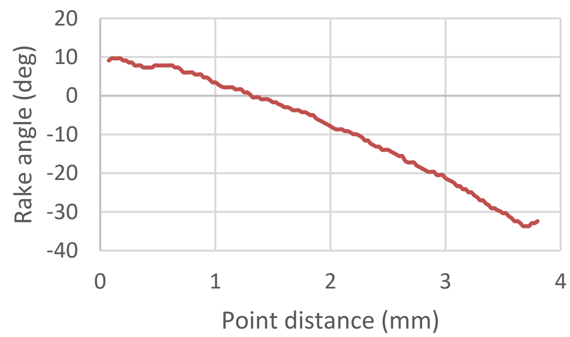

Figure 9. Rake angle measurements for tooth 1 of the z = -10 mm section.

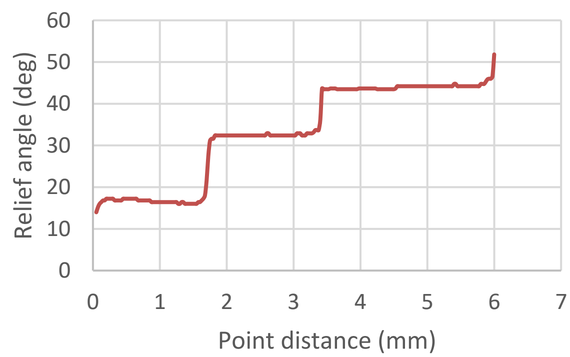

Figure 10. Relief angle measurements for tooth 1 of the z = -10 mm section.

The rake and relief angles were calculated for tooth 2 and tooth 3; the combined plots for all three teeth are shown in Figs. 11 and 12. The same trend can be seen in the combined rake angle plot; however, tooth 2 transitions from positive to negative slightly earlier than the other two teeth. Tooth 2 also differs in the combined relief angle plot (two vs. three angles).

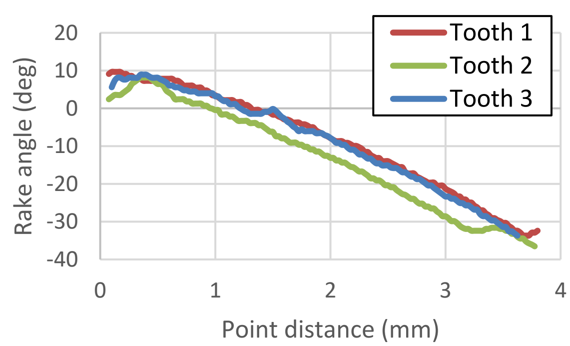

Figure 11. Rake angle measurements for all three teeth of the z = -10 mm section.

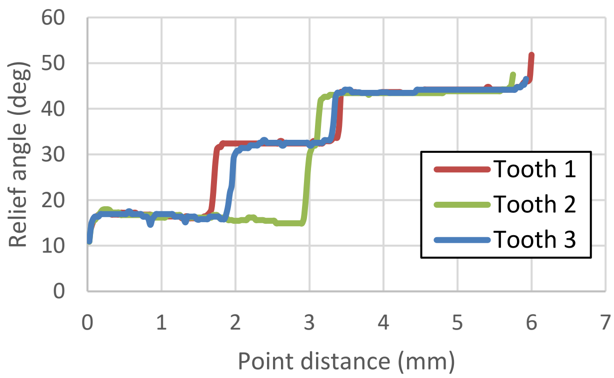

Figure 12. Relief angle measurements for all three teeth of the z = -10 mm section.

The previous plots compare the rake and relief angles of the three teeth at one z-section (-10 mm). The next set of plots compares one tooth (tooth 1) at multiple z-sections (Figs. 13 and 14).

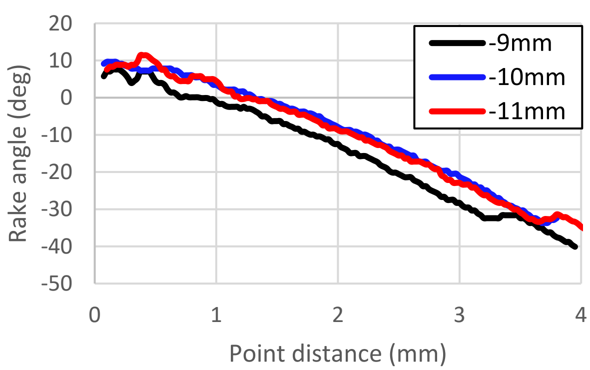

Figure 13. Rake angle measurements for multiple z-sections of tooth 1.

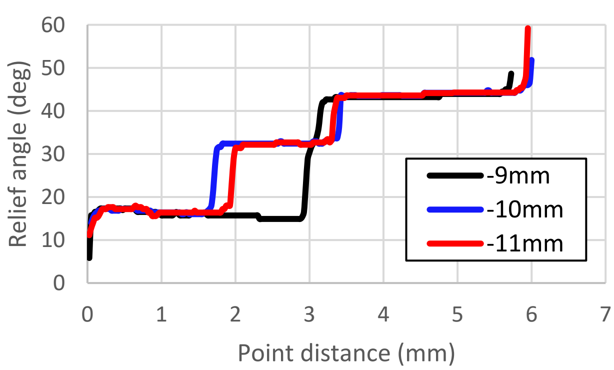

Figure 14. Relief angle measurements for multiple z-sections of tooth.

As seen in the previous figures, the rake and relief angle plots comparing multiple teeth of one section and multiple sections of one tooth are nearly identical. This is not a coincidence, but due to the design of the serrated cutting edges.

Figure 4 shows that the serration pattern along a single tooth repeats approximately every -3 mm (z). The serrated edge can be thought of as a wave with peaks and troughs. Any three consecutive, -1 mm z-sections along the serrated edge of a tooth have two peaks and one trough. The relief angles on a peak section have three distinct angles, while a trough section has only two. The rake angles have roughly the same profile, but the trough section has a shorter tip and transitions sooner from a positive to negative angle (e.g., Fig. 11: Tooth 2, z = -10 mm).

This pattern of two peaks and one trough repeats for the three teeth of one section due to the offset of the serrations between each tooth. For a given section, if a tooth is in a trough, then the other two teeth will be on a peak. Another way to visualize this is by looking at a planar view of multiple sections together. Figures 15 and 16 show the same z-sections, but now labeled A (-9 mm), B (-10 mm), and C (-11 mm). The three teeth are labeled as well.

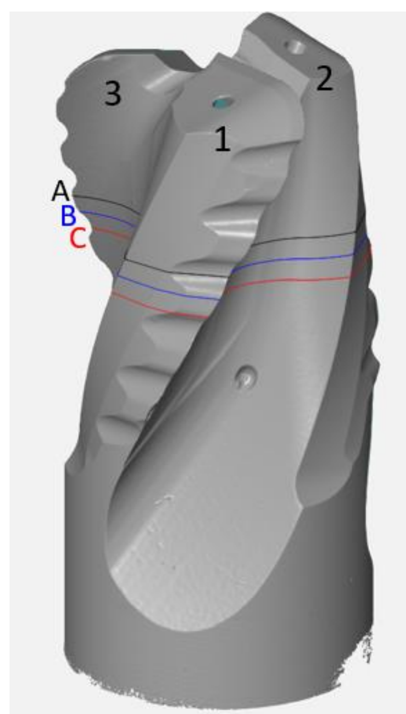

Figure 15. 3D view of consecutive z-sections.

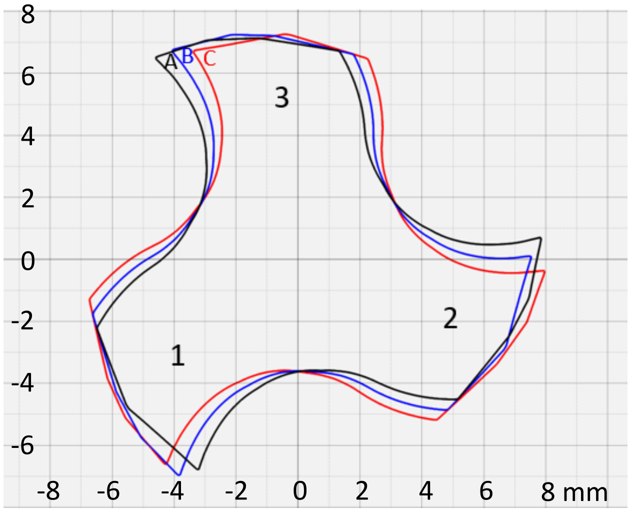

Figure 16. Top view of consecutive z-sections.

The shorter teeth in the trough sections were quantified by measuring the radius (distance from center to the tip) for each tooth; see Table 1. The measured values along a section or tooth follow the serration pattern.

Table 1. Radii measurements (all dimensions in mm) for section comparison.

		Tooth		
		1	2	3
Section	A	7.512	7.853	7.959
	B	7.957	7.512	7.862
	C	7.870	7.955	7.508

CONCLUSIONS

This paper demonstrates the capability of using structured light scanning for tool edge geometry measurements, specifically rake and relief angles. Once a coordinate reference frame was established, planar cross-sections were created, revealing the rake and relief profiles along the axis of the tool. Data points along each profile were extracted to calculate the rake and relief angles. The measurements show the serration pattern designed along and between each tooth for the selected non-standard edge geometry endmill.

REFERENCES

[1] No, T., Gomez, M., Copenhaver, R., Uribe Perez, J., Tyler, C., and Schmitz, T., 2019, Scanning and Modeling for Non-standard Edge Geometry Endmills, Procedia Manufacturing, 34: 305-315.