ANALYSIS OF THE FLANGE TURNING OF ALUMINIUM AEROSOL CANS BASED ON TOOL EDGE GEOMETRY

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Abstract
In recent years, the cosmetics industry, as the largest user of aerosol packaging, has been growing at an accelerating pace, requiring the production of aerosol cans with an increasing number of design elements. In the production of aluminium aerosol cans, the final shape is formed in several steps from a disc-shaped blank by back-rolling, and a so-called flange cutting (turning) operation is usually carried out after the flange of the can has been formed. Experience has shown that this operation often results in difficult-to-handle flowing chips, which in some cases can lead to a poor-quality product. In this paper, the material and edge geometry of the insert bit used in the flange turning operation are investigated and edge geometry modification recommendations are made to avoid unfavourable machining conditions.

Keywords: *aerosol can production, flange turning, cutting tool edge geometry*

1. Introduction

Aluminium cans are mainly produced through various cold plastic forming processes (Bay, 1997; Kores et al., 2016; Niemiec et al., 2017). The literature also analyses this production process primarily from the side of plastic forming (Dessie et al., 2021; Farhoumand et al., 2016; Gönczi et al., 2019). However, in some cases, it is also necessary to process cans in different states of their production by cutting (Lukács, 2019). A typical operation of this kind is the cutting of can flanges formed by rolling, which is used to finish the mating surfaces of the flange. In this case, a flat surface perpendicular to the axis of rotation of the can, or a conical surface at an angle to it, is formed on the rolled rim. The length of the bottle is also formed with a cutting operation after necking, thereby eliminating the unevenness of the length created during necking (Fitryk et al., 2018). During our investigations, we analysed the turning process of the flat surface of the rolled rim of the can perpendicular to its rotational axis (Figure 1).

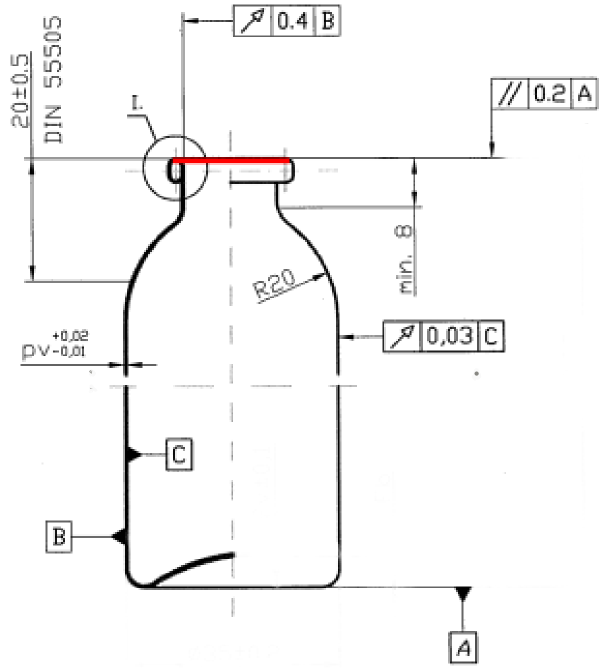

Figure 1. *Flange turning by creating a flat surface perpendicular to the rotational axis*

2. Turning operation during can production

In the theoretical and experimental study of the cutting process, a number of neglections have to be made for the reasons to be explained below. The can is flanged by cutting at the necking station. The cutting tool itself, including the inserts, is mounted on one of the workstations of the forming drum of this workstation, together with a motor that rotates the tool (Figure 2).

Figure 2. *Detail of the shaping drum and the cutting tool with inserts*

The feeding motion of the tool is provided by the alternating motion of the drum. The cutting tool cuts at the end of the stroke, at which point the drum slows down until it comes to a complete stop. Thus, the feed rate (327 mm/s) calculated from the set stroke rate of the drum (1200 strokes/min) at the moment of cutting can be much lower than the theoretical value. This phenomenon was neglected when conducting the cutting experiments. Also, there was a limitation in the size of the adjustable speed (cutting speed).

Under operating conditions, the tool rotates at 9600 rpm, while in the research experiments the maximum revolution of the tool that could be set was 4000 rpm. Thus, we could only draw conclusions about the effect of speed in terms of its nature. To analyse the specificities of the cutting, we first examined the material and edge geometry of the cutting insert.

3. Material of the cutting insert bit

For machining aluminium, there are three basic tool materials:

- *High speed steel (HSS)*. R1, R2, and R3 classic high speed steels with 18% W alloy are suitable for making cutting tools (e.g. turning tools);
- *Carbide*. The ISO-N marked carbide grade combines excellent friction wear resistance and cutting edge sharpness for roughing and smoothing aluminium alloys;
- *Polycrystalline diamond (PCD)*.

The most outstanding tool material in terms of material and technological properties is polycrystalline diamond (Pattnaik et al., 2018). When machining aluminium, there is virtually no wear, and the sharpest edge can be produced on that.

It has a low coefficient of friction and a low coefficient of thermal expansion, making it extremely dimensionally stable. However, it has the disadvantage that tool manufacturers only sell it in certain insert shapes, which are not suitable for all tasks. Furthermore, their effective rake angle is zero or less than 3-6 degrees, which is not sufficient for the highly ductile pure aluminium.

Carbide grades are also high performing, but with pure aluminium, the edge quality is not always sufficient to perform a correct cut and like diamond inserts, they are only available in certain shapes (Songmene et al., 2011). Ordering custom inserts for both diamond and carbide inserts would be practically uneconomical.

In terms of its properties, high-speed steel is the least favourable of the three tool materials. However, it can be used to form any edge geometry and can be produced in-house with acceptable edge quality. It can also be used to form quite large positive rake and clearance angles, which is essential for machining the highly ductile pure aluminium.

For the machining process under consideration, the inserts are made of R2 high-speed steel, which is the best possible choice for the above reasons.

4. Angles determining the position of the cutting edge

This chapter deals with the edge geometry of the insert bit used in the flange cutting of the front surface (face) of aluminium cans and to study of the systems required for this purpose. This is necessary because the edge geometry determines the force and power requirements, tool life, surface quality, chip formation and the dynamics of the cutting process (Abdalrahman et al., 2020; Horváth et al., 2015; Rico et al., 2010).

When designing the cutting edge angles of special cutting tools, care must be taken to ensure that the requirements of the tool are met. Cutting edges must be positioned in a way that is appropriate to the workpiece in order to be able to remove material from the workpiece. Care must also be taken to ensure that the cutting edge is able to withstand the required load without distortion.

To describe the edge geometry of tools and to determine the angles of the cutting tool, spatial coordinate systems are needed, which must be chosen and fixed to take account of the movements during cutting. The combination of these coordinate systems is the defining system (tool defining system, working defining system). For cutting tools, the edge angles - the edge geometries - specified in the tool definition system change in the moving system during operation, so the edge geometries of the tool in operation can be examined in the working defining system (Leskó, 1983).

In the production of the insert bit, the initial size is Ø20.5 mm x 100 mm, which is milled down to a block of material with a 0.2 mm allowance, when the size is 10.4 mm x 6.4 mm x 100 mm. The component drawing of the insert bit used for flange turning is shown in Figure 3.

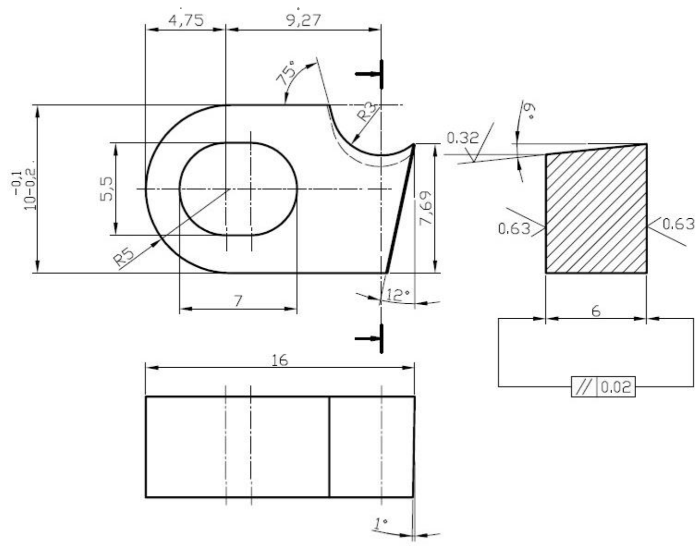

Figure 3. *Drawing of the flange turning insert bit*

The R5 radius is prepared on the block end-to-end with a peripheral milling cutter and then cut-off to a width of 6.4 mm. The given radius R3 is prepared one by one in each piece with a milling disc, where the machine head is tilted at 6° with a 0.2 mm allowance, and then, after the groove Ø5.5 mm is made, the 12° angle is formed on a milling machine with a 0.2 mm grinding allowance. After heat treatment, both sides are machined to the required 6 mm width on a surface grinding machine. The radius R3 is formed on a tool grinder using profiled discs (R3 and 75°). When grinding the clearance face on the tool grinder, the 6° and 1° inclinations are set using a sine vice.

Based on the 2D model of the insert bit, a 3D theoretical model of the cutting part of the insert can be constructed, the characteristic angles of which are shown in Figure 4.

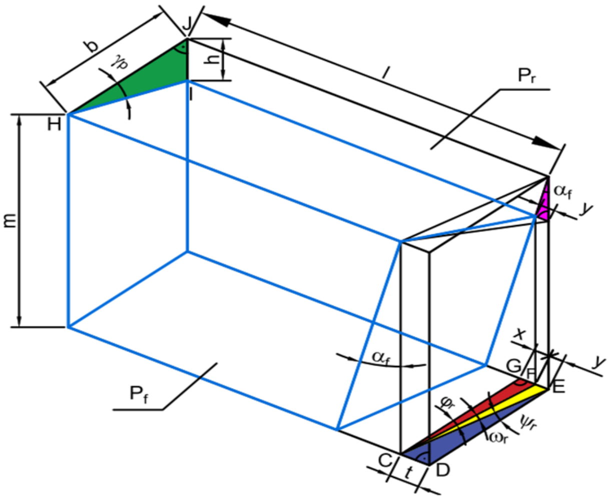

Figure 4: *Edge geometry and characteristic angles of the cutting tool*

The data in Figures 3 and 4 can be used to write the following equations:

from triangle *CFG*: $tan\,\varphi = \frac{x}{b}$

from triangle *CDE*: $tan\,\psi_r = \frac{t}{b}$:

from triangle *LMK*: $tan\,\alpha_f = \frac{y}{h}$

from triangle *HIJ*: $\tan\gamma_p = \frac{y}{b}$

The angles (α, γ, ω, ψ, φ) required for the edge geometry analysis can be determined using the following formulas:
from triangle *CDE*:

$$tan\,\psi_r = \frac{t}{b}\text{, thus: } t = b \cdot \tan\psi_r \tag{1}$$

The drawings of the tool bit on Figures 3 and 4 show that:

$\psi_r = 1°$, the edge angle of the tool bit;

$b = 6\;mm$, width of the tool bit.

On this basis:

$$t = \tan\psi_r \cdot b = \tan 1° \cdot 6 = 0.1047\;mm \tag{4}$$

From the *HIJ* triangle:

$$\tan\gamma_p = \frac{h}{b}\text{, from that: } h = b \cdot \tan\gamma_p \tag{5}$$

Also from the tool bit drawings (Figures 3 and 4), it can be seen that
$\gamma_p = 6°$, rake angle of the tool bit
This means that:

$$h = b \cdot \tan \gamma_p = 6 \cdot \tan 6° = 0.6306\, mm \quad (7)$$

From the *LMK* triangle:

$$tan\, \alpha_f = \frac{y}{h}, \text{ thus: } y = h \cdot tan\, \alpha_f \quad (8)$$

Where:

$\alpha_f = 12°$, flank angle of the tool bit

Based on these data:

$$y = h \cdot \tan \alpha_f = 0.6306 \cdot \tan 12° = 0.1340\ mm \quad (10)$$

From the *CFG* triangle:

$$tan\, \varphi = \frac{x}{b} \quad (11)$$

Based on Figure 3, Figure 4 and the results of the calculations carried out so far, the distance "x" can be given by the following relation:

$$x = t - y = 0.1047 - 0.1340 = -0.0293\, mm \quad (12)$$

From Equation 11 it follows that:

$$\tan \varphi = \frac{x}{b} = \frac{-0.0293}{6} = -0.00489 \quad (13)$$

Consequently, the angular value sought is:

$$\varphi = -0.279° \quad (14)$$

The negative value of the angle φ indicates that the projection of the edge (distance *CF*) is in the opposite direction to the assumed one, i.e. the point *F* is to the left of point *G*, not to the right. If φ were set to zero, the projection of the edge would be parallel to the *DE* section, i.e. the edge position angle would be exactly 90°, and thus the edge would be perpendicular to the direction of the feed. This is what would be required to make an accurate cut.

The results show that the edge angle $\psi_r = 1°$ given in the drawing should preferably be 1.279° instead of 1°. In other words, based on the presented calculations, it can be seen that more emphasis must be placed on the design of the right edge angles during the production of the tool bit, and efforts must be made to produce the given turning tool according to the dimensions given on the drawing with the modifications we propose, otherwise the turned surface (flange face) will have a deformation error (taper).

5. Study of the cutting edge angles in the tool-in-use system

Under the real cutting conditions, the actual direction of movement differs from the assumed direction of movement due to the complex movement of the tool. Since the tool angles are based on the assumed movement directions, these angles change very often during cutting, so the angles interpreted in this way are called angles in the tool-in-use system. The working angles affect the cutting work of the tool (the cutting process) because these angles can change from point to point along the edge (even in the case of a straight edge). Therefore, the position of the base plane also changes during the cutting, and as a result, the actually operating angles also change.

For the angles in the tool-in-use system can be calculated and analysed, the needed rake angle must be determined (γ_f) which is shown in Figure 5.

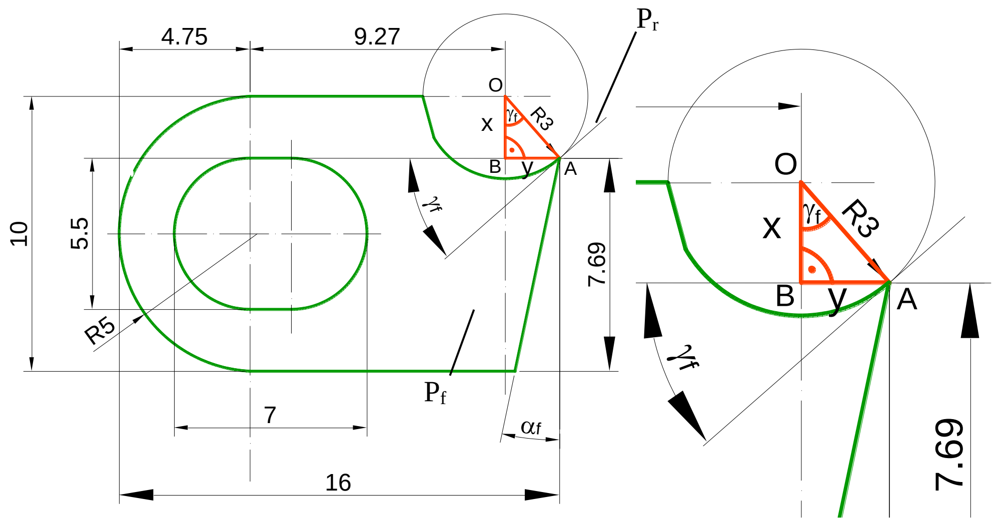

Figure 5. *Determination of the rake angle (γ_f) in the tool-in-hand system*

Taking into account the dimensions specified and resulted during the production of the turning tool, the γf rake angle is defined from the OBA triangle by a cosine function.

From the OBA triangle:

$$\cos\gamma_f = \frac{x}{R3} \tag{15}$$

where γ_f = rake angle of the cutting edge

R3 = given radius

x = OB distance

Additionally, the "x" distance can be calculated by the following equation as it can be seen in Figure 5:

$$x = 10 - 7.69 = 2.31\ mm \tag{16}$$

From this the following can be written:

$$\cos\gamma_f = \frac{x}{R3} = \frac{2.31}{3} = 0.77 \tag{17}$$

Therefore:

$$\gamma_f = 39.646° \tag{18}$$

The angles in the tool-in-use system can be studied based on the tool bit, its mechanical drawing and Figure 5. The effect of the tool position on the working angles can take several forms. The angles referred to the basic situation (where the tool nose is in the symmetry plane of the workpiece) can be changed even in a standing but raised or rotated tool. The question therefore arises as to what tool angles we must count on in a certain examined position of the tool. The definition of working angles is shown in Figure 6.

The angles in the tool-in-use system are especially important in relation to the flank angle since the tool is not capable of cutting in the case of a negative flank angle. It can be seen that the higher the deviation of the tool setting compared to the centre line of the workpiece and the smaller the diameter of the workpiece, the deviation of the working angles of the tool from the production angles will be higher.

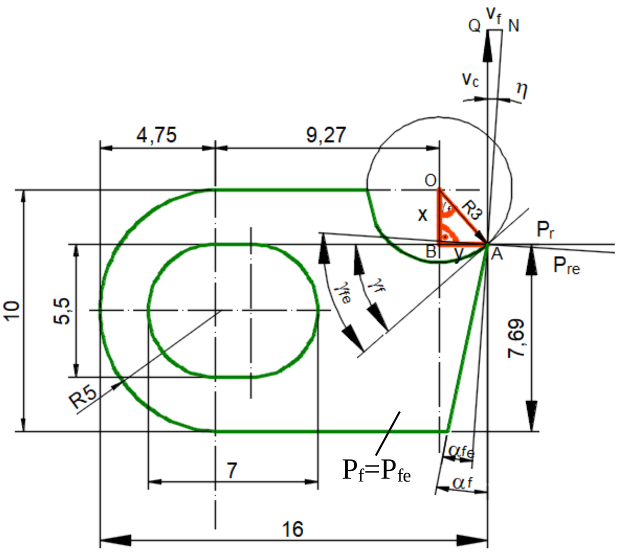

Figure 6. *Study of the cutting edge angles in the tool-in-use system*

The operating angles and other geometrical characteristics change from point to point along the cutting edge, even with a straight edge tool. If the edge face or back (tip of the tool) is rounded, or the edge is curved, you must work with tangent planes. The operating angles and planes we examined are denoted in Figure 6 by α_{fe} (operating flank angle), γ_{fe} (operating front angle), P_{fe} (operating assumed working plane). The position of the resulting cutting direction can be determined by knowing the speed v_f and v_c, that is, the inclination angle (η) of the resulting cutting direction at the examined point can be calculated, so the position of the tangent plane can be determined mathematically in every case.

The working angles of the cutting edge and other geometric attributes change from point to point along the cutting edge, even with a straight edge tool. Therefore, it is necessary to set which point the planes of the working determination system refer to (point A), because the geometry of the tool can only be determined clearly in this way. If the flank face or rake face is rounded or the cutting edge is curved, we must work with tangent planes. The angles and planes analysed by us in Figure 6 are noted as α_{fe} (working flank angle), γ_{fe} (working rake angle), P_{fe} (assumed working plane in the tool-in-use system). The position of the resulting cutting direction can be determined by knowing the feed rate (v_f) and the cutting speed (v_c), hence the inclination angle (η) of the resulting cutting direction at the examined point can be calculated, so the position of the tangent plane can be determined mathematically in every case.

According to the process parameters in the manufacturing of the bottle, the revolution of the tool is 9600 rpm (n), the applied feed rate is 327 mm/s (v_f) hence the feed per revolutions is 2 mm/rev. (f).

Since the worst value of the flank angle is needed, the outer diameter of the turned surface on the bottle must be taken into consideration.

Figure 7 shows the geometric design of the analysed bottle flange.

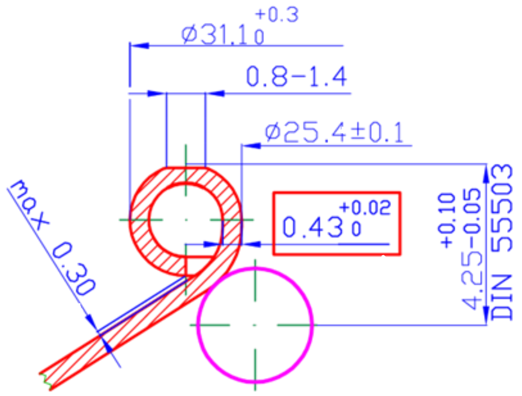

Figure 7. *Geometric relations of the flange design*

The cutting speed can be calculated from the geometric relations as the following:

$$v_c = d\pi n \tag{19}$$

where: v_c: major cutting speed

d: outer diameter of the flange turned surface

n = 9600 1/min, revolutions per minute

the maximum width of the turned surface: 1.4 mm

$$d = \frac{31.1+25.5}{2} + 0.7 = 29\ mm \tag{20}$$

Based on this:

$$v_c = d\pi n = 29 \cdot \pi \cdot 9600 = 875619.39\ mm/min = 14576.98\ mm/\sec \approx 14577\ mm/sec \tag{21}$$

From the ANQ triangle in Figure 6:

$$tan\,\eta = \frac{v_f}{v_c} = \frac{327}{14577} = 0.02243 \tag{22}$$

Therefore:

$$\eta = 1.285° \tag{23}$$

Based on the conducted calculations, the value of the working flank angle (α_{fe}) and working rake angle (γ_{fe}) can be determined by the η angle:

$$\alpha_{fe} = \alpha_f - \eta = 12° - 1.285° = 10.715° \tag{24}$$

$$\gamma_{fe} = \gamma_f + \eta = 39.6461° + 1.285° = 40.9311° \tag{25}$$

Therefore, the working angles examined at the given point, calculated with the given technological data, are as follows:

flank angle $\alpha_f = 12°$, while working flank angle $\alpha_{fe} = 10.715°$

rake angle $\gamma_f = 39.646°$ while the working rank angle $\gamma_{fe} = 40.931°$

It can be seen from the above, that although the tool flank angle (α_f) must be chosen carefully, the working flank angle (α_{fe}) - during the turning of this surface, examined at a given point - does not change to such an extent that the cutting conditions during machining would deteriorate significantly.

6. Summary

The following conclusions can be drawn based on the analysis of the flange turning in aluminium bottle manufacturing:

- Given the specifics of aluminium cutting, the R2 grade high-speed steel tool material can be applied for the machining of suitable, large rake and flank angles and thus for performing the machining in a suitable quality.
- The geometric analysis of the tool bit showed that the edge angle (ψ_r) should be changed from 1° to 1.279°, because the position of the cutting edge would be perpendicular to the direction of the feed in the base plane in this case, which results in a better surface quality.
- Based on the analysis of the working tool edge angles, it can be concluded that their change is not significant compared to the tool-in-hand system, so it does not significantly affect the quality of the machined surface.

The examination of flange turning of aluminium bottles can be continued partly with the help of finite element analyses, and partly with the help of cutting experiments that ensure their validation. We would like to continue our research in this direction in the future.

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