INNOVATION IN THE PROBLEMATICS OF TURNING WITH A LINEAR CUTTING EDGE
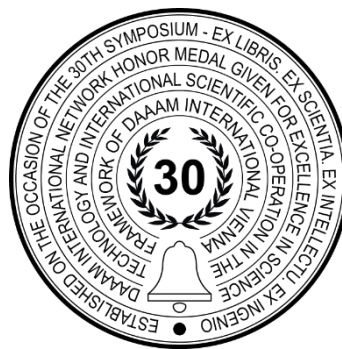
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Abstract

Thermal spray technology is a developing trend in the surface treatment of workpieces. This makes it possible to produce a very hard, abrasion-resistant, and corrosion-resistant surface while maintaining a tenacious core. There are several application methods of thermal spraying, which are not technologically demanding, but the final quality of the surface of the applied layer is not good. The surface is rough and dimensionally and geometrically inaccurate. So, it is necessary to machine it further. The current method of machining thermal sprays is grinding, which is quite slow and, in some cases, unnecessarily precise, which is increasing costs. Therefore, other machining methods are being developed, such as turning using a tool with a linear cutting edge. A significant advantage of this method is a significant reduction in machining times and the possibility of using the entire cutting edge of the insert. To accurately set the position of the cutting edge in the machine, a program was created in the Python programming language, which determines the number of possible cuts on the cutting edge depending on the depth of cut and the angle of the cutting edge.

Keywords: linear cutting edge; python programming; thermal sprays; depth of cut; inclination of the cutting edge

1. Introduction

Nowadays, when all technologies are moving forward, the requirements for machine parts are necessary to keep up with this. With this trend, the technology of applying thermal sprays is also increasing. This technology allows the application of a thin layer that will ensure increased resistance to mechanical wear, corrosion, and oxidation while leaving a tough core. The roughness Ra of the thermal spray after application to the surface is around 7 µm. Such a low-quality surface is not suitable for the functional purposes of the sprayed surface. In order to achieve smaller surface roughness and dimensional and geometric accuracy, subsequent processing of the thermal coating is necessary [1] [2] [4].

The principle of thermal spray technology is that a primarily molten powder is applied to the pre-prepared surface of the workpiece, which adheres to the surface and forms a layer of the desired properties. Thermal sprays are mainly used in the automotive and aerospace industries, where they are applied to internal combustion engine parts and act against wear at elevated temperatures. Those parts are, for example, various pistons, pins, cylinders, pistons, valves, crankshafts, and others. Furthermore, they are used significantly for turbine blades in the energy industry, as a thermal barrier and protection against corrosion and cavitation. In engineering, various types of thermal spraying are applied to components of pumping and hydraulic technology [3] [6] [7].

As far as machining is concerned, the vast majority of used thermal sprays are classified as hard-to-machine materials due to their composition. The composition contains many hard-to-machine elements such as nickel, tungsten, and vanadium. These elements increase the hardness and form very hard carbides in the microstructure together with carbon. That increases the wear of the cutting-edge during machining. Thermal sprays are currently machined using grinding technology for these reasons [3] [4] [5]. This method of processing achieves high machine times and unnecessary high-quality surfaces on certain types of products. This unnecessarily increases costs. For this reason, other machining methods are being developed, which will reduce the quality of the surface but will significantly reduce machining times. One method is, for example, turning with a tool using a linear cutting edge [1]. The main goal of this work is to devise and create a method for calculating the cross-section of the cut layer during machining with a linear cutting edge.

2. Linear cutting edge

When turning with a linear cutting edge is no tip present in the cut. Tools that do not have a cutting tip produce relatively smooth surfaces when cutting at speeds significantly higher than conventional tools [8]. The minor cutting-edge angle is zero and the inclination of the cutting angle is very positive or negative. The following figure (Fig. 1) shows a model to give an idea of the position of the insert depending on the workpiece. The insert, which is square positive, is yellow and the workpiece is grey. The image (Fig. 2a) shows a tool with a positive inclination of the cutting edge, and the image (Fig. 2b) shows a tool with a negative inclination of the cutting edge.

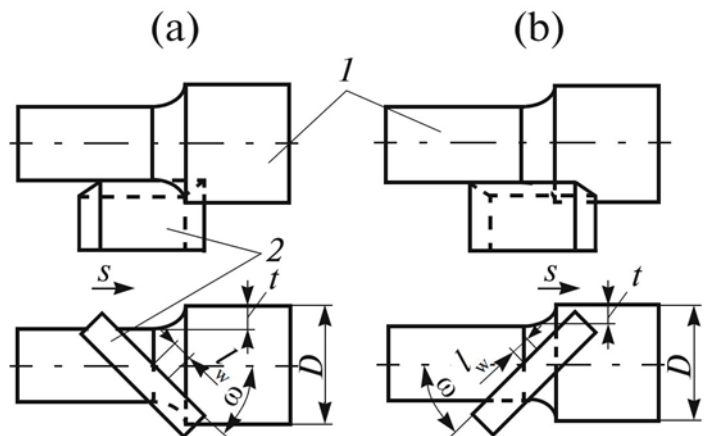Fig. 1. Position of the cutting edge relative to the workpiece

Fig. 2. Positive (a) and negative (b) inclination of the cutting-edge angle [8]

This principle of machining with tools with a linear cutting edge or otherwise with tools without cutting tips was dealt with earlier in 2016 by Filippov et al. He stated that theoretical analysis of turning by tipless tools with linear and curved cutting edges indicates that the basic parameters that determine the shaping by such tools are as follows: the cutting depth, the tool supply, and the tool inclination. He and his team conducted several experiments where they varied these parameters and measured the cutting forces. In the thesis, he presents a preliminary overview and states that this issue needs to be investigated even more thoroughly [8]. Due to this, our scientific team started to investigate it and decided to apply this method of machining with a linear cutting edge to the machining of hard-to-machine thermal sprays.

The advantage of this machining principle is that the tip in which heat accumulates is not present in the cut. It is generally known from machining theory that the depth of the cut layer should not be less than the corner radius because the surface is formed rather than machined. Because when machining with a linear cutting edge, only the cutting-edge radius is in the cut. This radius is significantly smaller than the radius of the tips, so it is possible to machine very small depths of cut. In this way, it is possible to make the coating layer thinner, thus saving the cost of coating. Only a small part of the total length of the cutting edge is used with a small depth of cut. This linear cutting-edge technology makes it possible to use the entire length of the cutting edge by moving the tool to the Y-axis of the machine. This is another great advantage of this method. For example, if one edge of a square insert is used 3 times, the total number of cuts on one insert is 12. The cross-section of the cut-off layer has the shape of an elliptical segment in turning with a linear cutting edge. This changes with a change in the depth of cut, the diameter of the workpiece, and especially with a change in the inclination of the cutting angle. As this angle decreases, the ellipse expands, and thus the line section of the segment increases. So, for example, to maintain the same number of cuts on the cutting edge, when reducing the inclination of the cutting angle setting, it is necessary to reduce the depth of the cut. During the change of the shape of the ellipse section, the centre of the line section moves, which needs to be known to set the tool on the Y-axis, so that the cuts on the cutting edge do not overlap. To speed up and facilitate the determination of the size of the cut-off layer in the shape of an ellipse section and the determination of the coordinates of the tool settings, it was advisable to invent a solution that would allow this. A solution that also evaluates the area of the cut layer. It is, for example, suitable for calculating cutting resistances.

3. Problem solving

The first solution was to create a model in a modelling program that evaluates the required parameters when the criteria are changed. With correctly set bonds, it was possible to achieve in the model to evaluate the cross-section of the cut layer when changing the diameter of the workpiece, the depth of cut, and the inclination of the cutting angle. However, the process of entering and evaluating parameters was not very user-friendly. In addition, this solution method requires a complex licensed CAD program to obtain the required values. The model for determining the cross-section of the cut layer is shown in the next figure (Fig. 3). In the picture, the colors correspond to those in the picture (Fig. 3). The cross-section of the cut layer has a purple color.
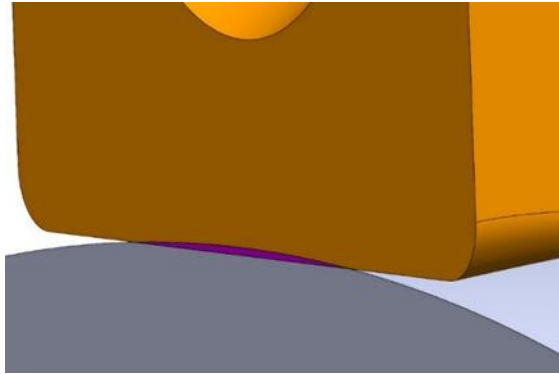

Fig. 3. Model for determining the cross-section of the cut layer

The second solution was to make a program in some software such as MATLAB or Python. Python was chosen because it is free and open-source software. Specifically, the Spyder program was chosen for programming. To create the program, it was convenient to draw what needed to be calculated. The images below show the task in graphical form. The figure (Fig. 4) shows a circular workpiece with a cut A-A that corresponds to the setting angle of the blade inclination λs. This angle with the workpiece radius is the variable criterion that will vary depending on the actual settings required. In section A-A, the depth of cut parameter and other dimensions needed for the equation are also displayed. They are the width of the ellipse a and its height b, which corresponds to the radius of the workpiece r, half of the line section Xn and lastly the cross-section area A. The cut depth parameter is the next and last input condition.
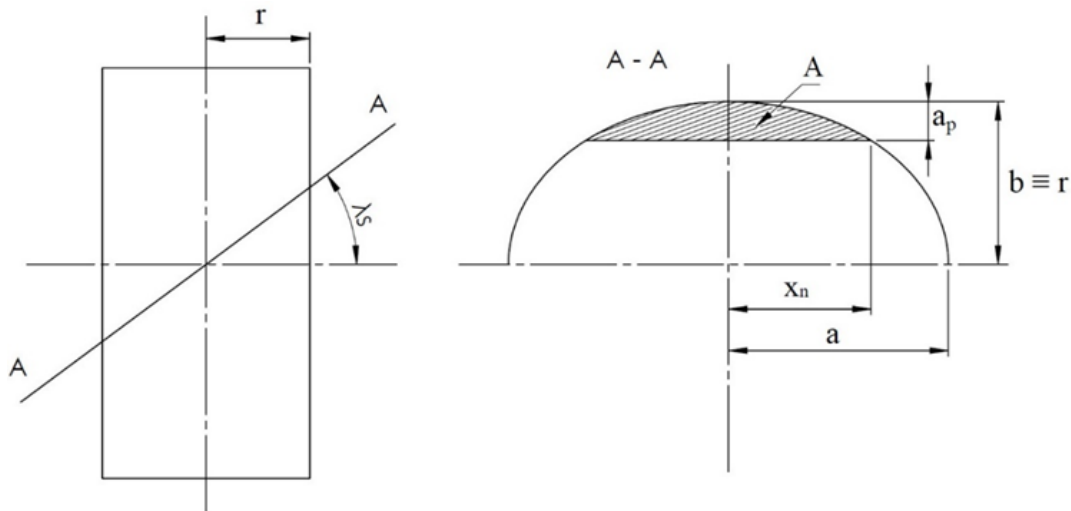

Fig. 4. Graphical definition of the task

The next picture (Fig. 5) is a division of the areas so that it is possible to define the required A area. This area is crosshatched in black in the picture. Another red area shows an ellipse from zero to xn. Last is the rectangular green area. To calculate the cross-section of cut layer A, it is necessary to integrate the red area and then subtract the green area from it. After further reflection, it was found that the calculation of area A could be done in another simplified way. This is such that when the ellipse is tilted ninety degrees to the vertical position, the cross-section of the finished surface can be calculated directly, without the need to subtract other areas. This variant is shown in the figure (Fig. 6). Using this expression, the calculation became more precise. Therefore, the following equation will be expressed just for this variant.
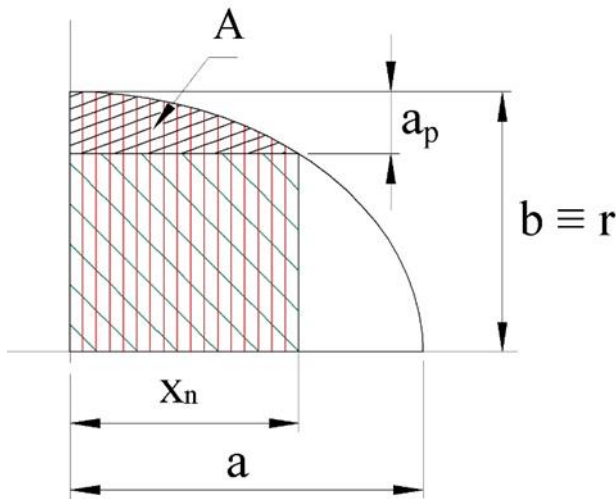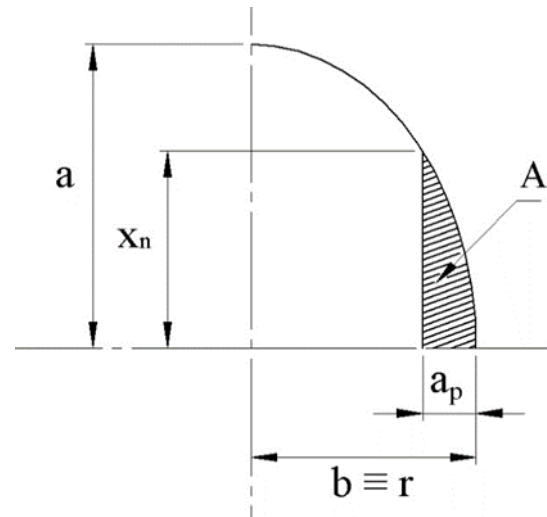
Fig. 5. The first variant of the calculation

Fig. 6. The final variant of the calculation

The integral used to calculate the cross-section of the cut layer in the tilted variant is given in equation (1) below. In the integral x is the unknown, a is the height of the ellipse, and b is the width of the ellipse. Parameter X changes depending on the setting of the inclination of the cutting angle, parameter b on the change in the radius of the workpiece, and, of course, the parameter ap on the setting in the depth of cut. The whole integral is multiplied by two since it is calculated only for half the cross-section of the cut layer.

$$A(x) = 2 \int_{b-a_p}^{b} a \sqrt{1 - \frac{x^2}{b^2}} \, dx = a \left[x \sqrt{1 - \left(\frac{x}{b}\right)^2} + b \cdot \sin^{-1}\left(\frac{x}{b}\right) \right]_{b-a_p}^{b} \tag{1}$$

By entering all the necessary equations into the Python program, it was achieved that when the required parameters were entered, the program evaluated the area of the cut layer. Both numerically and graphically. This can be seen in the graph in the picture (Fig. X). In the graph, the ellipse is shown in blue, and the straight line shows the edge in orange. The graph in the picture corresponds to the specified values of $r = 40$mm, $ap = 0.05$ mm and $\lambda_s = 60°$.
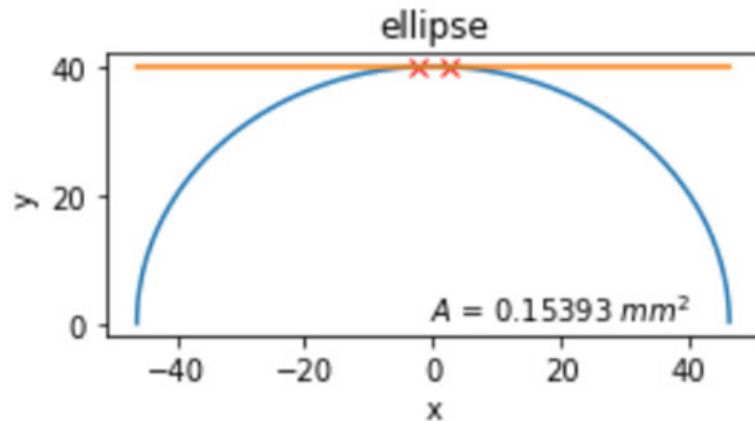

Fig. 7. Numerical and graphical evaluation of the cross-section of the cut layer

Furthermore, the program evaluates the depth of cut that must be set to fit n number of cuts on the cutting edge. For this, it is necessary to enter the number of cuts and the depth of the cut layer into the program. This can be seen in the graph in the figure (Fig. X), where the width of the blade L in mm is indicated on the X-axis and the depth of cut ap in mm on the Y-axis. The graph also shows the coordinates of the centres of the cross sections of the cut layers for setting the tool in the Y axis of the machine. The graph in the picture corresponds to the specified values of $r = 40$ mm, $\lambda_s = 60°$, $L = 12$ mm, and $n = 4$.
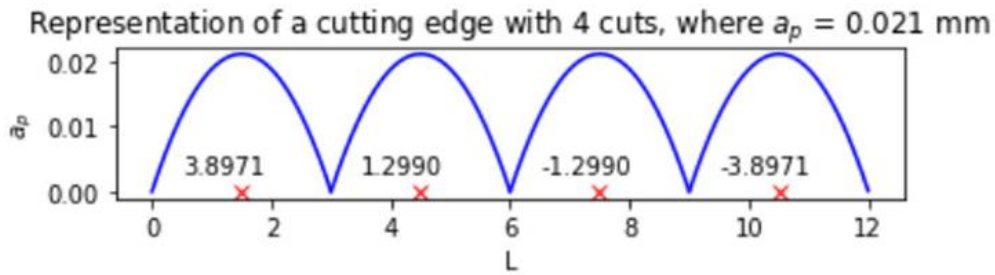
Fig. 8. Evaluation of ap for a certain number of cuts

There was also an inverse problem programmed into the program, which solves how many cuts n can be made on the cutting edge when a certain depth of cut is entered. The graph in the picture corresponds to the specified values of $r = 40$ mm, $\lambda s = 60°$, L = 12 mm, and $ap = 0.05$ mm.
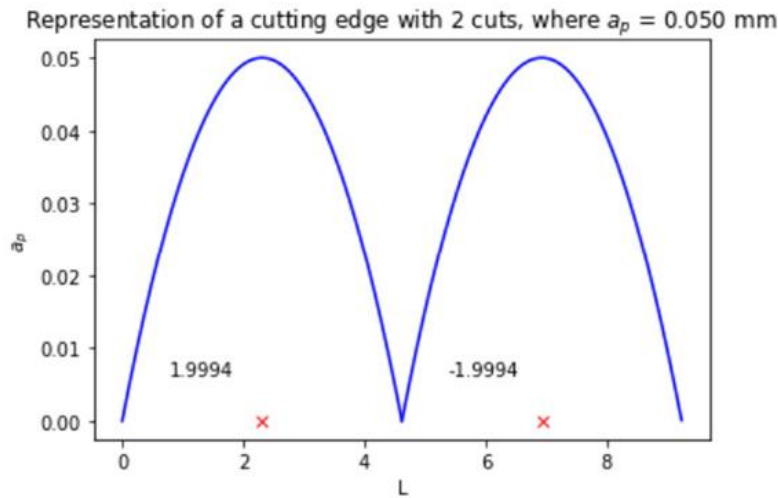

Fig. 9. Evaluation of the number of cuts for a certain a_p

4. Conclusion

This work aimed to create a program for calculating the area of the cut layer when machining with a linear cutting edge or otherwise with a tool without cutting tips, depending on the change in the depth of cut, the diameter of the workpiece, and the angle of the main cutting edge. In our case, for the machining of hard, difficult-to-machine hot sprays, but also for the machining of common materials. Because one of the main advantages of a linear cutting edge is the possibility of using the entire cutting edge, i.e. it is possible to move the tool in the Y axis so that the worn part of the tool gets outside the next cut on the same cutting edge. Therefore, one of the other requirements was to use the program to determine the coordinates of the centers of the cut layers to determine the coordinates in the Y-axis. This is so that the individual cuts on the blade do not overlap. Furthermore, the calculation of the depth of cut for a certain number of cuts on the cutting edge and vice versa. Thus, the inverse problem for determining the number of cuts for the required depth of cut. The Spyder software and the python programming language were chosen to create this program. The created program expresses the required values both numerically and graphically. All these values determined by the program can be used in practice.

A functional model was also created for this issue, but it turned out to be unsatisfactory for quickly determining the values. However, it can also be used to evaluate other parameters, such as the theoretical roughness of the machined surface at a certain displacement. The python program cannot solve this so far. This is another future research plan. Extend the Python program so that it evaluates the theoretical roughness of the surface using the cross-section of the cut layer and the displacement.

5. Acknowledgments

6. References

[1] Zatloukal, T., Řehoř, J., Fulemová, J. & Povolný, M. (2020) Optimization of the machining process of NiCrBSi thermal spraying. In Annals of DAAAM and Proceedings of the International DAAAM Symposium. Vienna: DAAAM International Vienna, s. 632-637. ISBN: 978-3-902734-29-7, ISSN: 1726-9679

[2] Hoesel, D.; Wertheim, R.; Haenel, T. & Thurner, S. (2011). Milling of Cast Material and PTA-Hard-Facing Layers of the Cobalt-Base-Alloy Stellite 12, Annals of DAAAM for 2011 & Proceedings of the 22th International DAAAM Symposium, Published by DAAAM International, Vienna, 2011, ISBN 978-3-901509-83-4

[3] Cesanek, Z. (2015). Thermally Sprayed Coatings Used in Corrosive Environments, Ph.D. Dissertation, ZCU, FST, Pilsen, Czech Republic

[4] Houdkova, S., Vostrak, M. (2013). Comparison of NiCrBSi Coatings, HVOF Sprayed, Re-melted by Flame and by High-Power Laser. Available from: http://metal2013.tanger.cz/files/proceedings/12/reports/1407.pdf, Accessed: 2020-08-08

[5] Zaman, H. A.; Sharif, S.; Kim, D. W.; Idris, M. H.; Suhaimi, M. A. & Tumurkhuyag, Z. (2017). Machinability of Cobalt-based and Cobalt Chromium Molybdenum Alloys - A Review, Procedia Manufacturing, Volume 11, Pages 563-570, ISSN 2351-9789, Available from: https://doi.org/10.1016/j.promfg.2017.07.150.

[6] https://www.triboing.cz/zarove-nastriky.html, (2018). Thermal sprays, Tribo Engineering, Accessed: 2020-08-08

[7] https://www.plasmametal.cz/pouzite-technologie, (2019). Thermal spraying. Plasmametal, Accessed: 2020-08-08

[8] Filippov, A.V., Filippova, E.O. & Chazov, P.A. (2016) Cutting-force components in turning by tools with no cutting tip. Russ. Engin. Res. 36, 1040–1043. Available from: https://link.springer.com/content/pdf/10.3103/S1068798X16120066.pdf