# THE PROGRAMMING PECULIARITIES OF BENCHES IN CONTEMPORARY AGRICULTURAL MECHANICAL ENGINEERING BUSINESSES

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**ABSTRACT.** *Businesses producing and repairing agricultural technology still largely use NC-led benches – mostly lathes. Benches with technically outdated NC control system are still being used for the simple and CNC-led benches for handling the complicated surface geometry. Such a work division provides a more economic usage of the CNC-led bench resource. Programming NC-led benches is far more complicated when compared to that of CNC-led benches – even for handling the simplest surface geometry (phases, cones), a blueprint needs to be compiled with the CAD programme. According to the change in the measurements of the detail, a new blueprint needs to be compiled each time. Compiling the blueprint could be renounced when a mathematical model would be compiled for the corresponding surface element – it would help to find the coordinates of certain points required for programming. The present article describes the mathematical model for calculating the coordinates necessary for programming phases and cones with different measurements. The model has been compiled on the basis of MS Excel, as this programme (or analogues) are used in most of the mechanical engineering businesses.*

***Keywords:*** *cutting treatment, phase, cone, main measurements of the instrument, insert nose radius, mathematical model.*

## Introduction

In agricultural machine building ventures with a number-led bench park it is both technologically and economically wise to divide machining operations with a different level of complexity according to the capability of benches. The capability of number-led benches is primarily the simplicity of their programming and the number of different types of works done with them. Differences in the capability of benches are shown most accurately when NC- and CNC-led lathes are compared.

From the programming point of view a complicated surface geometry consists of straights combined at angles (tilts, phases), circular arches or other more difficult type lines (ellipse, parabola). Thus a simple surface geometry consists mostly of straight lines (also at an angle). Programming possibilities for complicated surface geometry for NC-led lathes are much more limited and complicated (Устойства..., 1982) than it is the case with CNC-led benches (Siemens Sinumerik, 2000). Contemporary CNC-led lathes are equipped with living instruments with which it is possible to carry out both drilling and milling tasks. NC- led benches do not have living instruments.

Depending on the complexity of surface geometry and the technological capacity of the bench, the different machining operations of one detail are divided between NC- and CNC-led lathes as follows – a more complicated surface geometry is handled on the CNC-led bench, a simpler one on the NC-led bench. The main advantage of this work division is the maximum use of the more capable bench. During the time when the NC-led bench is working on a simple surface geometry, the CNC-led bench can already be used in machining on the next complicated detail.

The complexity of programming NC-led lathes stems both from the limited mathematical possibilities of the control system, the difficulties in determining the main measurements of the instruments and thus programming difficulties with them. Determining the main measurements of an instrument (Figure 1) does not take place with standard measuring tools (measuring microscope, height calliper), but by taking off thin levels from the prototype detail and additional calculations.
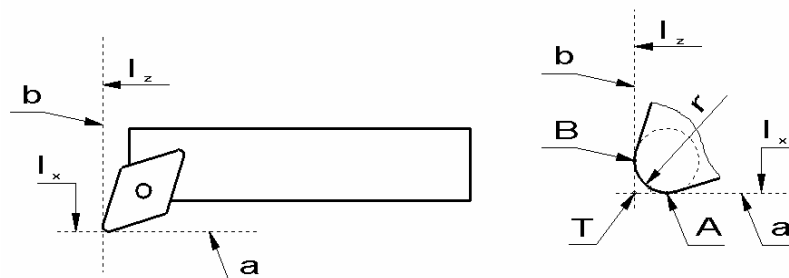


**Figure 1.** Main measurements of the lathe tool: A, B – touching points of the nose radius of turning insert; T – peak of the lathe tool; a – straight line parallel with bench Z-axis; b – straight line parallel with bench X-axis; r – nose radius of the insert; $l_x$ – lathe tool X-axis directional length; $l_z$ – lathe tool Z-axis directional length

Figure 1 projects the internal working blade with the most common shape (in German *Bohrstange*) that consists of the shrank holder DPDH 132R and an insert DNMG 150612-MH (Mitsubishi Gesamtkatalog, 2004–2005) attached to it. The present scheme shows a horizontal straight, marked with a, which is parallel with the Z-axis of the bench, but the vertical straight, marked b, is parallel with X-axis. In the figure, $1_x$ marks the measure of the lathe tool on the X-axis direction and $1_z$ marks the Z-axis measure. Dimensions $1_x$ and $1_z$ are determined by separating levels from the prototype detail, but the nose radius of the insert r from a corresponding catalogue. The crossing point T of straights a and b is called the peak of the lathe tool, or a point by which the moving of the instrument takes place during the machining process. Figure 1 shows that the lathe tool peak T is not at the actual edge of the insert, the arch with end points A and B, but at a certain distance from it, outside from the insert (lathe tool). Due to such a location of point T it is fairly difficult to program even the simpliest working of surface geometry without previously compiling a blueprint with the CAD programme.

## Description of the object

For determining the coordinates of the characteristic points necessary for programming the simple surface geometry works, it is useful to compile the mathematical models by calculations from programmes (Mathcad, Excel). The main advantage of mathematical models in comparison with blueprints compiled with the CAD programme is their flexibility. If the measurements of the detail change, a new scheme needs to be compiled each time also – in case of mathematical models only the preliminary data needs to be changed. The main requirement for compiling models is the little amount of required preliminary data – preliminary data necessary for achieving the end result needs to be specified only in the detail scheme, and other freely determined amounts. No preceding calculations need to be carried out for determining preliminary data.

An example is a mathematical model compiled on the basis of MS Excel for calculating necessary coordinates for handling different phases and cones. MS Excel was chosen as the application as it is part of each MS Office pack that most industrial ventures have. MS Excel files can also be opened without any alterations for example in the freeware Open Office Calc application (analogue to MS Excel). In case of the given model the Excel calculation formulas have been used (Mägi, 1994) which are based on algebraic calculations carried out with the help of cells. As preliminary data, the sizes determined from the scheme, such as the measure of the phase (length of the phase – f and the angle of the phase with the horizontal α°) and, depending on the location of the phase or the tilt, the outer diameter of the shaft-shaped detail $D_v$ or the internal diameter of the pipe-shaped detail $D_s$, the round radius of the insert determined from the lathe tools catalogue r and technologically determined removing distances $e_{KA}$ and $e_{KB}$ are being used. The mathematical model of the described allows to calculate the phase of the shaft-shaped detail end (hereinafter the outer phase), the internal phase of the pipe-shaped detail (hereinafter the pipe's internal phase) and the internal phase reaching the bottom of the clogged hole (hereinafter the clogged hole phase) necessary for handling the coordinates (Figure 2).
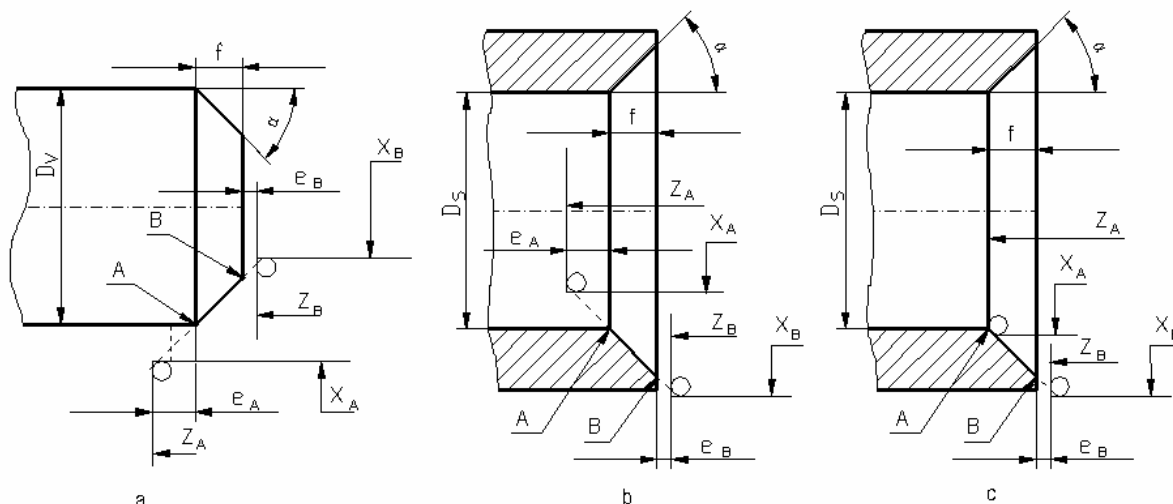


**Figure 2.** Calculated phases: a – outer phase, b – pipe's internal phase, c – clogged hole phase, A, B – end points of the phase, f – length of the phase, α – phase tilt angle, $X_A$, $Z_A$ – point $T_1$ coordinates, $X_B$, $Z_B$ – point $T_2$ coordinates, $D_v$ – external diameter of the shaft; $D_s$ – internal diameter of the shaft; $e_{KA}$, $e_{KB}$ – removing distances in points A and B

## External phase

Technologically it is necessary that the forward movement starts and ends in a specific distance from the detail (Poluhhin *et al.*, 1969). To achieve that, in source data, sizes $e_{KA}$ and $e_{KB}$ have been defined, which can be called removal distances from the end points of the phase (points A and B). Considering the position of the top of the lathe tool relating to the edge of the insert and also sizes $e_{KA}$ and $e_{KB}$, the coordinates of top of the lathe tool T in

points $T_1$ and $T_2$ which are necessary for phase treatment are found by using the following mathematical model. Coordinates of the lathe tool top T in point $T_1$ are $X_A$ and $Z_A$ accordingly and in point $T_2$ $X_B$ and $Z_B$ (Figure 3).
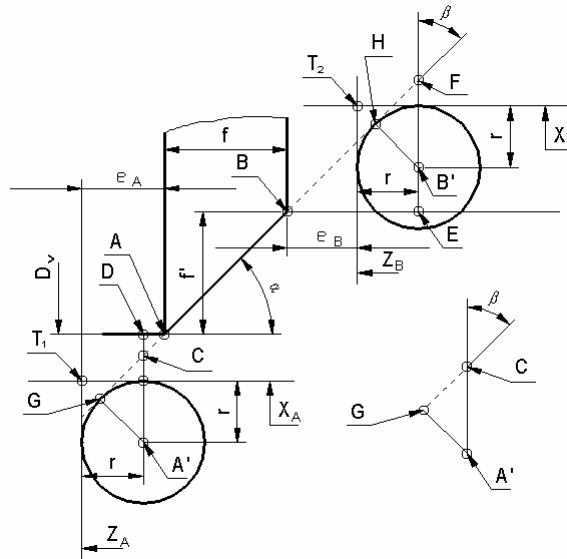


**Figure 3.** External phase: A, B – the end points of phase; A', B' – the centre points of nose radius; C, D, E, F, G – end points of characteristic sections; α – rake angle of phase; β – characteristic angle, $T_1$, $T_2$ – top of lathe tool in corresponding points A and B; $X_A$, $Z_A$ – point $T_1$ coordinates; $X_B$, $Z_B$ – point $T_2$ coordinates; $D_v$ – outside diameter of shaft; $e_{KA}$, $e_{KB}$ – removal distances from the end points A and B

The source data for this model is based mostly on measurements directed towards Z-axis of the bench, which help to find the X and Z coordinates for points $T_1$ and $T_2$. It is not expedient to show the lathe tool in its full size, because for calculations, only the position of its insert's nose radius and its numerical size are needed. This is why the lathe tool is shown on technological drawings as well as in this article only as a circumference that has an equal radius to the radius of insert's nose radius. Phase and its motional extension is tangent to the insert's nose radius. Essentially, finding the X-coordinates to point $T_1$ means calculating the distance between the horizontal line going through that point and the edge of detail. In Figure 3, it can be seen that the line through point $T_1$ is also tangent to the nose radius. In order to find this distance, the length of the section between the tangent of nose radius and point C, must be calculated. However, on the basis of the source data of this model, that would prove to be too complex a mathematical task. Several right-angle triangles must be constructed for that, which, in turn, would make the model too complicated (too many elements). Basically similar mathematical tasks must be solved when calculating the X-coordinate of point $T_2$. This is why the X-coordinate of points $T_1$ and $T_2$ is found indirectly by using a seemingly unnecessarily complex method. When calculating the coordinates for points $T_1$ and $T_2$, the sizes used in algorithms are all geometrical and their meaning is most clear from Figure 3. All the formulae are shown in the following table (Table 1).

**Table 1.** Formulae used for calculating coordinates for points characteristic of external phase

| Point $T_1$ | Formula No. | Point $T_2$ | Formula No. |
|---|---|---|---|
| $\beta = \dfrac{\pi}{2} - \left(\dfrac{\alpha \cdot \pi}{180°}\right)$ | 1 | $\overline{BE} = e_B + r$ | 8 |
| $\overline{A'C} = \dfrac{\overline{A'G}}{\sin \beta}$ | 2 | $\overline{EF} = \overline{BE} \cdot \tan\left(\dfrac{\alpha \cdot \pi}{180°}\right)$ | 9 |
| $\overline{AD} = e_A + r$ | 3 | $\overline{B'F} = \dfrac{\overline{B'H}}{\sin \beta}$ | 10 |
| $\overline{CD} = \overline{AD} \cdot \tan\left(\dfrac{\alpha \cdot \pi}{180°}\right)$ | 4 | $\overline{B'E} = \overline{EF} - \overline{B'F}$ | 11 |
| $\overline{A'D} = \overline{CD} + \overline{A'C}$ | 5 | $f' = f \cdot \tan\left(\dfrac{\alpha \cdot \pi}{180°}\right)$ | 12 |
| $X_A = D_v + \left(\overline{A'D} - r\right) \cdot 2$ | 6 | $X_B = D_v - \left(f' + \overline{B'E} + r\right) \cdot 2$ | 13 |
| $Z_A = \left(f + \overline{AD} + r\right) \cdot (-1)$ | 7 | $Z_B = e_B$ | 14 |

The coordinates for X and Z of point $T_1$ are found with corresponding formulae 6 and 7. In formula 6, the calculation in parenthesis describes the distance of the instrument's edge from the detail. The section in parenthesis is multiplied by two, because in case of numerically controlled lathes there is an option to determine the diameter targeted details, *i.e.* X-coordinates by either the radius or the diameter. The numerical value of X-coordinate written in programme is a number that is equal either to radius or to diameter. Mostly it is programmed by using the diameter of the detail, because in that case the numbers shown in the drawings can be used and no additional calculations are necessary.

In formula 7, parenthesis are multiplied with minus one, because the zero point of detail's coordinates is usually set so that all the material side coordinates that are directed to Z-axis are negative. However, all the point coordinates that are necessary for aided movements and distancing from the material are positive due to this kind of zero point placement. Using differently marked Z-coordinates makes the programmes clearer (Siemens Sinumerik, 2000).

The X- and Z-coordinates of point $T_2$ are found with formulae 13 and 14, respectively. The numerical value of the X-coordinate of that point is also programmed according to its diameter (formula 13). The Z-coordinate of point $T_2$ is positive compared to point $T_1$ because it is outside of detail's frontal surface (formula 14).

## Internal phase

During the internal phase (Figure 2, b) as well as clogged hole phase (Figure 2, c) of the pipe, calculating the X and Y coordinates of point $T_2$ outside of material is done by using basically the same formulae (formulae 8 to 12 and 14) the same as when calculating the external point bearing the same name. Using the numeration of formulae used for calculating the external phase, the only difference is in formula 14, or the calculation formulae for the X-coordinate of point $T_2$. The formula for calculating X-coordinates for point $T_2$ (both internal phases) is as follows:

$$X_{\mathbf{B}} = D_s + \left( f' + \overline{B'E} + r \right) \cdot 2$$ (15)

The difference in formulae 14 and 15 is in the multiplication with 2 and addition to pipe's internal diameter $D_s$ of the size which depends on phase height f', removal distance $e_{KB}$ and insert's nose radius r. For external phase, this size is subtracted from the detail's external diameter $D_v$.

Since the calculation formulae for the coordinates of point $T_2$ in clogged hole phase as well as in internal phase of the pipe are the same, only point $T_1$ formulae are shown in Table 2.

**Table 2.** Calculation formulae for coordinates of point $T_1$

| Clogged hole phase | Formula No. | Pipe's internal phase | Formula No. |
|---|---|---|---|
| $\overline{A'D} = \dfrac{\overline{A'E}}{\sin \beta}$ | 16 | $\overline{DF} = \left( e_A - r \right) \cdot \tan \alpha$ | 21 |
| $\overline{DC} = \overline{AC} \cdot \tan\left( \dfrac{\alpha \cdot \pi}{180°} \right)$ | 17 | $X_A = \left[ D_s - \left( \overline{DF} + \overline{DC} + \overline{A'C} \right) \cdot 2 \right] + 2 \cdot r$ | 22 |
| $\overline{A'C} = \overline{A'D} - \overline{DC}$ | 18 | $Z_A = (f + e_A) \cdot (-1)$ | 23 |
| $X_A = \left( D_s - 2 \cdot \overline{A'C} \right) + 2 \cdot r$ | 19 | | |
| $Z_A = f \cdot (-1)$ | 20 | | |

The calculation formulae for the coordinates of point $T_2$ in clogged hole phase as well as in internal phase of the pipe are essentially the same up to a certain point. The calculation formula (formula 1) for the value of angle β is universal – it can be used for external phase as well as for $T_1$ and $T_2$ points of both internal phases.

Also for both internal phases, the same formulae can be used for calculating the lengths of sections $\overline{A'C}$ and $\overline{CD}$ (formulae 17 and 18). Thus, for the purpose of keeping the mathematical model simple, the formulae for these values have been written out only for the clogged hole phase calculations. Since the X- and Z-coordinates of point $T_1$ in clogged hole phase are the same as the actual coordinates of the bottom of the hole or the end points of the phase, the value for removal distance $e_{KA}$ is zero (Figure 4). However, for the regular internal phase, it is possible to give the removal distance $e_{KA}$ a suitable numerical value. The principle for Z-coordinates of both internal phases is the same as for the external phases.

In case of clogged hole phase, the insert's nose radius has two tangents at once – one with a phase and the other with a clogged hole bottom. Because of two touch points, there is always a curvature between the clogged hole bottom and the changeover of phase with a radius which is equal to the insert's nose radius. So there is no need to specifically program the machining of curvature.
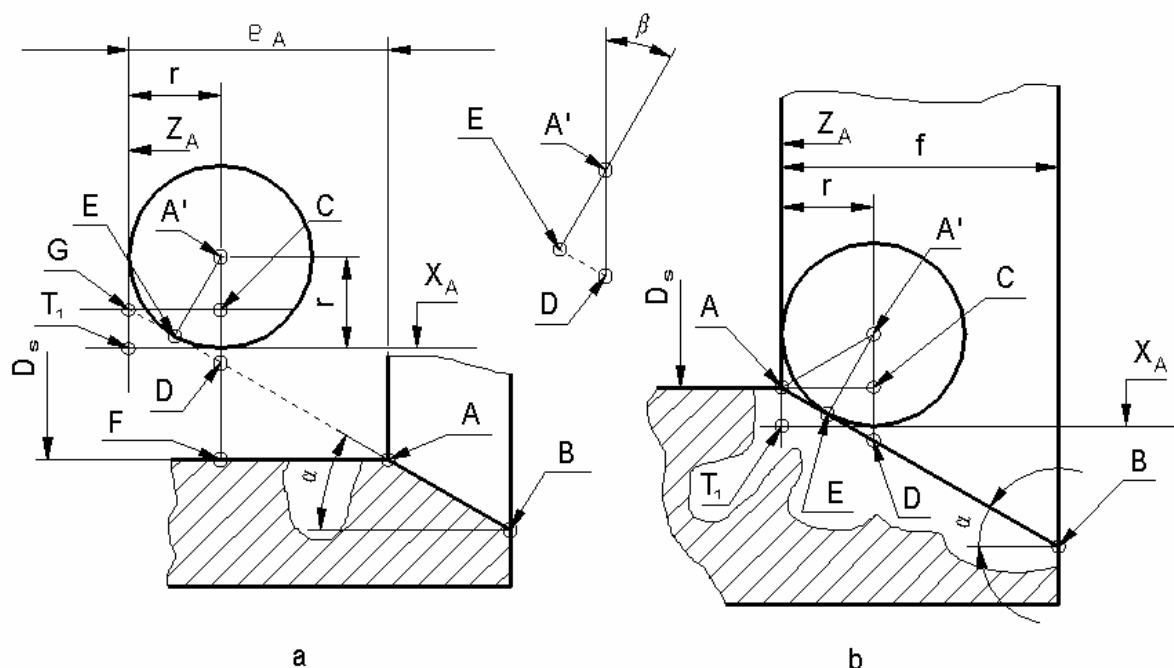
**Figure 4.** Internal phases: a – pipe's internal phase, A, B – the end points of phase, A', B' – the centre points of nose radius, C, D, E, F, G – end points of characteristic sections, α – rake angle of phase; β – angle characteristic of phase; $T_1$ – top of lathe tool in point A, $X_A$, $Z_A$ – point $T_1$ coordinates; $D_s$ – inside diameter of shaft; $e_{KA}$ – removal distances from the end point A, b – clogged hole phase; f – the length of the phase

## Application

Work distribution, where more complicated surface geometry is machined with CNC control lathes and easier with NC control, is practical for an enterprise that manufactures as well as repairs agricultural machinery. Agricultural machinery has a number of details that have simple surface geometry, and have to be manufactured in great numbers at once. These kinds of details are for example the reeling spikes or blueberry harvester's harvest comb spikes. The cutting operations of these spikes are performed before pressure treatment (bending). The cutting treatment of spikes means the phasing of both parts and it is practical to perform it on NC controlled benches.

All the poppet valve head working surfaces of gasoline and diesel engine distribution gear are under an angle (usually 45°) in relation to the symmetry axis of the valve. If the work surfaces have been made of hard alloy material, then it is possible to treat them during the repairs only with lathe tools compiled of hard alloy inserts. In both cases, it is recommended to use the mathematical model given in this article for the calculation of point coordinates necessary for phase or angle machining.

## Summary

Although the NC control system is essentially obsolete, the benches supplemented with that system are widely used in Estonian metal-working enterprises thanks to their simple construction and high reliability. While CNC controlled work benches can be programmed, using CAM programmes, NC benches have no such option. That is why this mathematical model was created. This model can be used for all benches with NC31 and NC81 type control system. The model allows to calculate the needed point coordinates for all cones (also internal cones), internal and external phases, and the entire necessary source data can be found on detail drawings. This model can still be developed; regular formulae can be replaced with a compact macro. For those macros, programming language Visual Basic is used in MS Excel environment. When using macros, MS Excel's display is used only for entering source data, displaying end results and starting the macro that performs the calculations.

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