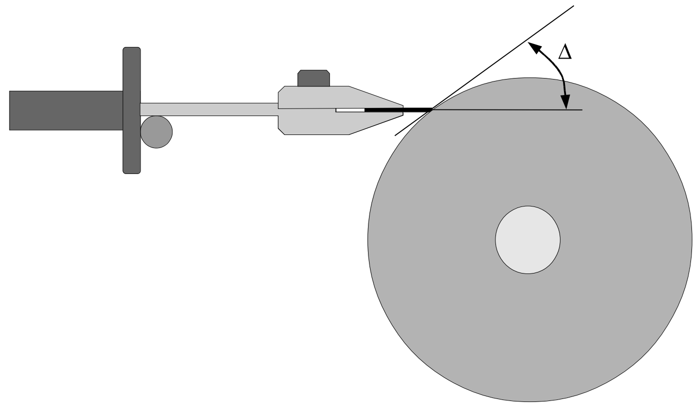
More Math

for the
adjustable knife-jig



on the

Tormek grinder

by Ton Nillesen

More Math for the adjustable knife-jig on the Tormek grinder

by Ton Nillesen © 2018

Contents

Acknowledgement

I am very grateful to Ken Schroeder for the interest he has shown for my development and his contribution to improvements and alternatives. I would also like to thank the following members of the Tormek forum for their inspiring contributions: "Wootz" (Vadim), "cbwx34" (Curtis) and "Jan"

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1. Introduction

In 2013 I bought a Tormek grinder and after some experimenting and grinding of the available knives, blades, scissors etc. it became clear to me that the reproducibility of the grinding angles was rather poor if the adjustment was done according to the procedure described in the handbook. Good reproduction can be obtained if the bevel is coloured with a marker pen and the support is adjusted until the stone clears the bevel.

That method however is not fast and easy. I wanted a simple method which could be realized by measuring and adjusting the position of the universal support and the length of the adjustable jig. That resulted in the development of the following formulas.

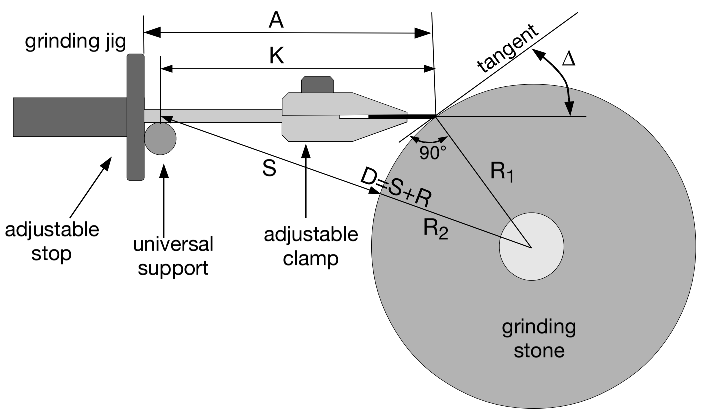

Figure 1: Original diagram for jig adjustment

Consider the triangle determined by the knife jig, via R_1 to the centre of the stone and via the long side D (=R_2+S) back to the jig on the universal support.

The angle opposite side D (=S+R) is equal to 90°+Δ because the grinding angle Δ is equal to the angle between the knife blade and the tangent to the stone while the radius R_1 is perpendicular to the tangent.

With the cosine-law we get $D^2 = K^2 + R_1^2 - 2*K*R_1*\cos(90° + \Delta)$

which can be simplified to: $D^2 = K^2 + R^2 + 2*K*R*\sin(\Delta)$ [F0]

So the grinding angle Δ is determined by: $\Delta = \arcsin\left(\frac{D^2 - K^2 - R^2}{2*K*R}\right)$ [F1]

and D should be adjusted to $D = \sqrt{(K^2 + R^2 + 2*K*R*\sin(\Delta))}$ [F2]

If D is fixed, then the grinding angle can be adjusted by changing the distance K with the adjustable stop.

For easy application, the method was described in a document with tables for settings at different stone diameters and for a range of grinding angles. [1] (See chapter "References" on page 15) That document will be further referred to as "***Doc1***".

9. References

[1] "Simple and accurate Grinding Angle Adjustment"
Document "***Doc1***" on knife-jig adjustment, December 2013
https://bit.ly/2yX9dUC

[2] "Simple adjustment of the grinding angle"
topic on Tormekforum, April 14, 2014
https://www.tormek.com/forum/index.php?topic=1849.0

[3] "Thanks, Ton ("Dutchman")"
topic on Tormekforum, September 12, 2014
https://www.tormek.com/forum/index.php?topic=2240

[4] "Knife setting tool"
topic on Tormekforum, May 25, 2015
https://www.tormek.com/forum/index.php?topic=2510

[5] "Matching grinding wheels of different diameter"
Introduction of Wootz method, March 28, 2016
https://www.tormek.com/forum/index.php?topic=2969

[6] "A new way to calculate knife jig set up"
Introduction of Wootz applet
https://www.tormek.com/forum/index.php?topic=3365.0

[7] "Wootz" website
http://knifegrinders.com.au

[8] "How to get razor-sharp knives on Tormek" by "Wootz"
https://www.tormek.com/forum/index.php?topic=3661.0 topic on Tormekforum
https://youtu.be/ZDPXqAK9Xr0 Movie-1
https://youtu.be/UckPmizlIk0 Movie-2

[9] Jan's Excel script
Discussions about accuracy
https://www.tormek.com/forum/index.php?topic=3365.msg20593#msg20593

[10] "Re: kenjig modification for paring knives"
About reference points
https://www.tormek.com/forum/index.php?topic=3320.msg19875#msg19875

[11] The "cbwx34-fix", on Tormekforum
Re: Machine Set-up related to carpal tunnel/repetitive motion injuries
https://bit.ly/2Hy5Vb7

[12] "Homemade Knife Rest HK-50" by Herman Trivilano
https://www.tormek.com/forum/index.php?topic=1592

[13] "Tormek-T7 grinder" folder with several documents
https://bit.ly/2lHaR3m on DropBox
https://bit.ly/2KpROFg on OneDrive

8. Documentation

The spreadsheet is titled "***USB adjustment table.ods***" and is made in the free and open source office package LibreOffice. It can be downloaded from the public folder "Tormek-T7 grinder" on DropBox and OneDrive. [13]
Downloaded versions will open and run in Excel. If you upload your own version to the cloud, then it opens and runs also in the online version of Excel. The same holds for the spreadsheet which is used for the tables in ***Doc1***: "***Grinding angle adjustment table.ods***" which also can be found in the same folder.
The contents of the folder [13] are:

- ***Doc1***: initial document about mathematical adjustment of the knife jig
  - "Grinding angle adjustment A5 serial.pdf", serial version for tablet
    "Grinding angle adjustment Booklet.pdf", A5 booklet to be printed on A4
  - "Grinding angle adjustment table.ods", spreadsheet for tables in ***Doc1***
  - "Measuring distance 'S'.JPG", picture of simple measurement of USB-to-stone distance
- ***This document:***
  - "More math for the Tormek grinder A5 serial.pdf", serial version for tablet
  - "More math for the Tormek grinder booklet.pdf", A5 booklet to print on A4
  - "USB adjustment table.ods", spreadsheet to generate the new table

2. Further developments

In April 2014, after some experimenting on several knifes, I decided to introduce the method on the Tormek-forum. [2]
The first reaction about the application of this method came from Ken Schroeder in September 2014. [3] He became a promoter of this method and even developed a further simplification so that the adjustment could be done without the need for a table look-up. He called his design the "Ken-jig"[4] . Several forum-members adopted his ideas and created a variety of improvements and alternatives.
In March 2016 the method was adapted by "Wootz" (Vadim) by measuring the distance from the top of the support bar to the base of the grinder rather than the distance to the stone. That measurement is easier to reproduce. For that purpose he designed a "frontal vertical base" for sharpening away from the wheel. See Figure 2.

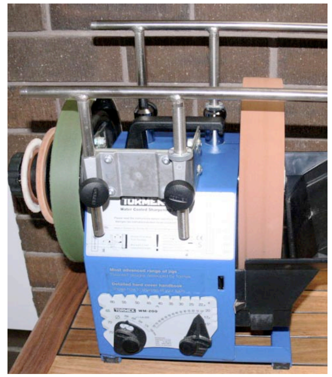
Figure 2: frontal vertical base applied to the grinder

Furthermore he developed a computer program to calculate the correct height.[5] He now applies his method to his grinding and polishing machines in his workshop and made an applet commercially available. It is reviewed and discussed in [6] . In that topic he also introduces a simple and accurate jig length measuring/setting block including images with construction details.
His grinding results are of unprecedented precision, as stated on his website [7] :

> *"… the cutting edge we deliver has at or under 0.1 micron edge apex width, and usually near 0.05 micron for high-end knives, sharper than a razor."*

He expressed his satisfaction in a message to me in which he clearly described the benefits:

> *"After I scripted your formulas, my sharpening turned from guess and approximation into a scientific precision.*
> *Since then I've never failed to set exact edge angle, will it be keeping the factory angle or by customer's whim.*
> *If not for your formulas, I wouldn't be able to keep exact edge angle as I move the blade I sharpen from stone to stone of different diameters, from T7 to T8, and then to paper wheels for honing.*
> *Only thanks to you I now have every edge apex width under 1 micron, typically 60-90 BESS, within 3-5 minutes."*

I could not wish for better recognition, and moreover he also sent me a copy of his frontal vertical base as a present.

Meanwhile, five years after introduction, it gets widespread attention as a "***method***" including instruction movies on youtube. [8]

3. Comparison with the “Anglemaster”

The distance ‘S’ between the stone and the jig’s center above the USB is one of the parameters for the adjustment.
Figure 3 gives an example how a distance of 85mm is set for the center of the USB. About the inaccuracy of this adjustment of ‘S’ a discussion arose on the forum.
“Jan” made a calculation on the error in grinding angle if this “wrong” measurement is done. For a particular set-up this error appears to be 0.6°, according to his calculations.[9] Document ***Doc1*** however (as seen in Figure 1) refers to the correct reference point which I emphasized in the following note:[10]

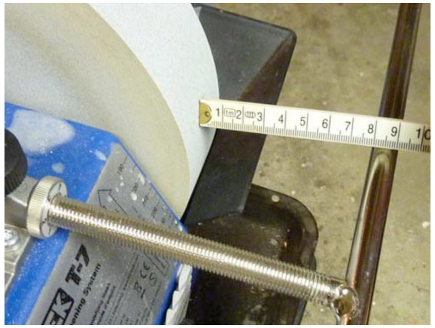

Figure 3: Measuring distance 'S'

> *“The distance is measured NOT to the top NOR the center of the support. It is part of the triangle through the knife in the jig. So it should be measured to the heart of the jig just above the center of the support. Measuring the distance to the top of the support however will give a negligible error.*
> *Please keep in mind that this subject [i.e. method] is not an academic item, but a proposal to simplify the jig-setting.”*

The distance K is determined via distance A (Figure 1) by measuring the distance from knife edge to the adjustable stop. That is the correct distance as intended. The distance 'S' is measured by me in practice between the stone and the middle of the USB, as shown in figure 3. To get an impression of the resulting error, for a few settings the computed angle was compared with the angle set with the "Anglemaster".

Measuring set-up

Figure 4 gives an illustration of the measuring set-up. As “knife-jig” a steel ruler was used with a thickness of 1mm. The (dark) steel ruler is resting on the USB and touches the stone with its end. The distance of the USB to the stone is set with the white ruler. The steel ruler is then shifted, forward or backwards while touching the stone and the USB, until the angle setter fits on the ruler. That is checked by viewing backlight passing between ruler and angle setter.

Practice makes perfect?

The intention was to measure angles of 10°, 20° and 30°. At the angle of 10° it turned out to be very difficult to accurately position the steel ruler at the right length. There was then a range of about 10 mm in which the angle appeared to be correctly set. Therefore measurements have been done for angles of 20° and 30° only, with USB distances to the stone of 65, 80 and 95 mm.
The anglemaster must be placed close to the end of the ruler during adjustment.

7. New tables

Since the usage of a table is faster and easier than entering the parameters in an app or formula, I have designed a spreadsheet for generating a table based on formula F9. The table gives the USB-to-stone distance as a function of the jig-length JG in columns and the desired grinding angle ∆ in rows. See figure 11.
The user can set the following parameters:

- **System parameters**
  these parameters are independent of the knifes to be sharpened and must rarely be changed
  - Stone diameter AS
  - Offset JC between the jig’s shaft-centre and USB-centre
- **Table parameters**
  these parameters determine the start and increment of the rows and columns of the table
  - minimum value for JG, which is in the first column
  - increment between columns of JG
  - minimum value for the grinding angle ∆, which is on the first row
  - increment between rows of ∆

Simple adjustment of the grinding angle (∆)

See report "Grinding angle adjustment" and report "More math for the Tormek grinder"

System parameters (to be measured and preset by user)

Stone diameter (mm) Ø= 240 mm ---> Radius=SA=AG= 120 mm

Jig-center to USB-center offset (mm) JC= 12 mm

USB to stone distance (=S=CS) as function of ∆ with jig-length (JG) as parameter

Table parameters (to be preset by user)

JG-minimum (left column)= 120 mm

JG-increment (between columns)= 2 mm

∆-minimum (first row)= 10 °

∆-increment (between rows)= 1 °

Adjustment table

Jig-length K to knife edge (mm)	JG=	120	122	124	126	128	130	132	134	136	138	140
USB-center to knife edge (mm)	CG=	121	123	125	127	129	131	133	135	137	139	141
Angular offset (°)	∂_k=	5,7	5,6	5,5	5,4	5,4	5,3	5,2	5,1	5,0	5,0	4,9
	∆ (°)	USB-center to stone distance (=S=CS)										
Grinding angle	10	56	58	60	61	63	64	66	68	69	71	73
	11	58	59	61	63	64	66	68	69	71	73	74
	12	59	61	62	64	66	67	69	71	72	74	76
	13	61	62	64	66	67	69	70	72	74	76	77
	14	62	64	65	67	69	70	72	74	75	77	79
	15	63	65	67	68	70	72	73	75	77	78	80
	16	65	66	68	70	71	73	75	76	78	80	82

Figure 11: Screenshot of (upper part of) adjustment table

6. Usage of existing tables

Previous considerations concerning the choice of the reference point '*C*' lead to a different approach to the use of the tables in ***doc1***. With a different choice of that reference point, a correction must be made for the angle ∂_k (Figure 10), which then increases the grinding angle with respect to the calculated value.

Determining 'offset-angle' ∂_k

If the reference point '**C**' is chosen at the ***contact point*** where the jig rests on the USB, then the distance JC will equal to 6 mm. With the reference point at the center of the USB, the distance JC will equal 12 mm. For the ***"cbwx34-fix"*** the distance JC equals 24 mm.
The length JG is variable with the adjustable stop of the knife-jig. The length A in figure 1, between the adjustable stop and the clamp edge, is adjustable from 108 to 125 mm. The width of the knife adds another variable. So let's consider an example as given in ***Doc1***:

Example: (from ***Doc1***)
Consider a cooks knife with a width of 45mm. The jig can grip the knife to a depth of 14mm. As a consequence the knife edge extends 31mm from the clamp.
Thus the distance between the knife edge and the adjustable stop can be varied between 108+31 and 125+31 mm, that is from 139mm to 156mm.

The distance JG in figure 10 equals distance K in figure 1 which is 6 mm less than the distance A in figure 1. Hence distance JG under these conditions will range from 133 to 150 mm. The following table can then be calculated for the values of ∂_k:

∂_k as function of JC and JG		JC 6 mm	JC 12 mm	JC 24 mm
JG	133 mm	2.6°	5.2°	10.2°
	150 mm	2.3°	4.6°	8.8°

This leads to the conclusion that the grinding angles in the tables of ***Doc1*** have to be corrected by 2.5° if the measuring point is not chosen on the centerline of the jig but on the ***contact point*** where the jig rests on the USB.

The maximum error of 0.2° can clearly be neglected. If the reference point is chosen at the center of the USB, then an offset angle of 5° should be taken into account. The ***"cbwx34-fix"*** gives an offset of 9.5° with a variation of 0.7° at maximum over the variable range.
This justifies the final conclusion that, with a simple correction, the tables of ***doc1*** are useful for alternative measurements of the stone distance.

The distance S is determined with a caliper and the ruler is provided with a slider as adjustable stop so that both distances were measured with the USB edge as reference. The radius of the USB, i.e., 6 mm, was subtracted from the measured results to give the distance to the USB center.

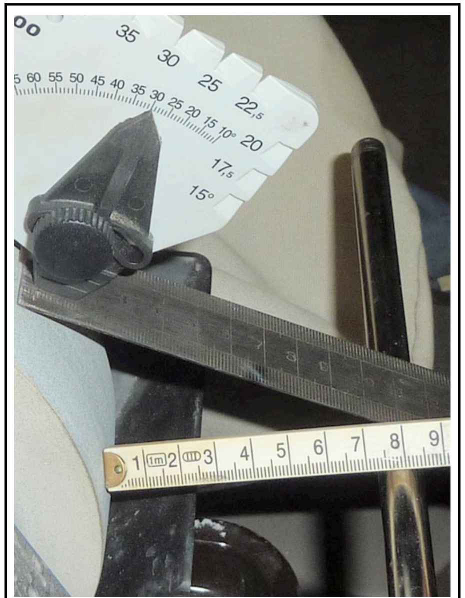

Figure 4: The anglemaster applied to a steel ruler

Results

The results are listed and evaluated in the following table. Distances R, S, and K refer to Figure 1.
The first two columns in the table contain the adjusted parameters. The angle is the adjustment for the angle-setter of the anglemaster and S is the distance from the stone to the center of the USB.
The shaded columns contain the measured and derived values. Column K contains the distance from the end of the ruler touching the stone to the point where it rests on the USB. With these parameters the grinding angle Δ can be calculated according to formula F1, in which D=S+R. The difference with respect to the preset angle of the anglemaster is shown in the last column.

Stone diameter=240mm → R=120

Adjusted		Measured	Calculated	
Angle	S (mm)	K (mm)	Δ (F1)	Δ-Angle
20	65	107	19.04	-0.96
	80	126	18.76	-1.24
	95	144	18.72	-1.28
30	65	96	27.42	2.58
	80	115	25.86	3.36
	95	131	27.8	2.2

The measuring accuracy is about 1mm. It has to be noted that a measuring error of 1mm results in an angular error of 0.8°. Nevertheless, the results are disappointing and the errors are so great that an analysis is needed to arrive at a better understanding of the correct adjustment.

4. Error analysis

A lot of measurements have been made to find out where the measurement errors could come from. For a long time there was apparently a systematic error. The error turned out to be dependent on the thickness and the sharpening angle. The smaller the angle and the thicker the material the larger the error. I finally discovered that by grinding wood with a thickness of 6 mm. After grinding several pieces with different angles, the cause of the error became clear.

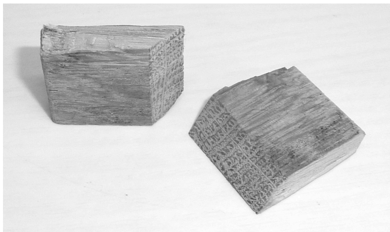

Figure 5: Sharpened wood

Understanding why thickness matters

The distance K was measured before sharpening, so with a blunt instead of a sharp piece of material. As a consequence the tip of the blade will sink to the stone during sharpening, thereby changing the angle with respect to the stone. This is illustrated in Figure 6.

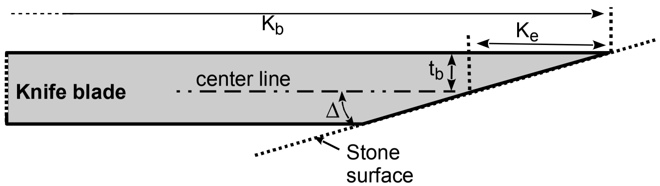

Figure 6: Knife blade positioning on the stone

The error is made by adjusting the length K or JG to the edge of the blunt testing blade. In the figure this length is indicated with K_b. During the grinding, the tip of the blade sinks over a distance t_b to the stone, causing the grinding angle to change. To compensate this, the setting distance should be shortened by a value K_e. That value is dependant on the blade thickness $2*tb$ and the grinding angle Δ.

The equation $\tan(\Delta)=\frac{t_b}{K_e}$ leads to the formula: $\boxed{K_e=\frac{t_b}{\tan(\Delta)}}$.

The following table gives an overview of the values of K_e (on grey background) for some combinations of blade thickness and grinding angle. It is clear that this can cause a major error, for example 8.5 mm at a grinding angle of 10° and blade thickness of 3 mm.

Resulting grinding angle Δ

An expression for the grinding angle Δ can directly be derived from formula F9. The first step is squaring, to eliminate the square root, and then rearrange the terms:

$$2*CG*AG*\sin(\Delta-\arctan(JC/JG))=CA^2-CG^2-AG^2$$

Separation of the trigonometric function gives:

$$\sin(\Delta-\arctan(JC/JG))=\frac{CA^2-CG^2-AG^2}{2*CG*AG}$$

That leads to the inverse trigonometric function:

$$\arctan(JC/JG)=\Delta-\arcsin\left(\frac{CA^2-CG^2-AG^2}{2*CG*AG}\right) \qquad [F12]$$

and rearranging the terms results in the function for Δ:

$$\boxed{\Delta=\arctan(JC/JG)+\arcsin\left(\frac{CA^2-CG^2-AG^2}{2*CG*AG}\right)} \qquad [F14]$$

Usage with other reference points

The reference point ‘**C**’ in figure 10 is chosen as being the center of the USB. However, the formulas remain the same if the reference point is chosen elsewhere, for example on the top of the USB or the point where the knife-jig rests on the USB, the ***“contact point”***. Of course, different distances will then change, but as long as the rectangular angles remain intact, the formulas remain valid.
If the reference point ‘**C**’ is chosen at the center of the knife-jig as in figure 1, then the distance JC reduces to zero and formula F14 reduces then to formula F1.
As a consequence the tables in ***Doc1***, which are related to formula F1, can also be applied with an offset JC if a correction is made for the ‘offset-angle’ ∂_k in figure 10 which equals the term arctan(JC/JG) in formula F14.

micro-height-adjustment of the universal support bar.
Angle ∂_k can be derived from the expression $\tan(\partial_k) = JC/JG$. Hence ∂_k equals:

$$\partial_k = \arctan(JC/JG) \quad [F7]$$

Angle α_1 can be derived with the cosine rule as:

$$CA = \sqrt{(CG^2 + AG^2 - 2*CG*AG*\cos(\alpha_1))}$$

which can be simplified with $\alpha_1 = 90° + \alpha_2$ to:

$$CA = \sqrt{(CG^2 + AG^2 + 2*CG*AG*\sin(\alpha_2))} \quad [F8]$$

As $\Delta = \alpha_2 + \partial_k$ this can be rewritten with F7 to:

$$CA = \sqrt{CG^2 + AG^2 + 2*CG*AG*\sin(\Delta - \arctan(JC/JG))} \quad [F9]$$

in which:

$$CG = \sqrt{JC^2 + JG^2} \quad [F10]$$

Adjustment of USB to stone distance

With formula [F9] the correct position of the USB can be calculated for a certain grinding angle Δ at a fixed setting of the distance JG. The Ken-jig [4] is an example of such an application. It could also be useful for other equipment parts:

- the "Tool Rest" SVD-110
- the "Scissors jig" SVX-150

and not least:

- the "Homemade Knife Rest" HK-50 designed by Herman Trivilano [12] .

These tools have in common that they are set up close to the stone with a fixed distance to the USB and a certain offset JC.
Instead of the distance CA it is easier to measure the distance CS to the stone, as in the initial method: $CS = CA - AG$

Adjustment of USB height

For Vadim's frontal vertical base the height of the USB can be calculated by applying the Pythagoras' theorem on the triangle ABC which gives: $BC = \sqrt{CA^2 - BA^2}$.

Adjustment of knife jig

My favourite approach however is to adjust the distance CG via the adjustable stop on the knife-jig with a preset for the USB-parameter CA c.q. CS. To this end, formula F9 must be converted to a formula for JG as a function of the parameters.
However, I have not succeeded in developing a closed formula for this, because JG is not only part of the arctan function but also part of the expression for the distance CG. See formula F10.
As a consequence the knife-jig distance JG has to be chosen and then the USB-distance to the stone has to be adjusted according to formula F9.
Another solution, though not exact, is given in chapter 6: "Usage of existing tables" on page 12.

	Blade thickness 2∗tb (mm)					
Δ (°)	1	2	3	4	5	6
10	2.8	5.7	8.5	11.3	14.2	17.0
15	1.9	3.7	5.6	7.5	9.3	11.2
20	1.4	2.7	4.1	5.5	6.9	8.2
25	1.1	2.1	3.2	4.3	5.4	6.4
30	0.9	1.7	2.6	3.5	4.3	5.2

Reduction K_e of jig-length as function of blade thickness t_b and angle Δ

It will be clear that these considerations are related to single sided grinding. For double sided grinding the values K_e and t_b will increase with 50% for grinding the first edge. Furthermore this error is not present or negligible with sharpened blades.

Error by incorrect reference point

Figure 7 is a schematic representation of the measuring set-up of Figure 4. It shows where the K and S rulers rest on the USB. Line K indicates the steel ruler which measures distance 'K' of Figure 1 and line S refers to the distance 'S' to the stone, towards the center of the stone.
In this set-up the distances S and K are measured from points S_t and K_t respectively. However, these distances must both be measured from point K_t in order to get an exact result from formula F1.
The distance between Kt and St will in normal circumstances be a few millimeters and thus cause a non-negligible error in the stone distance.

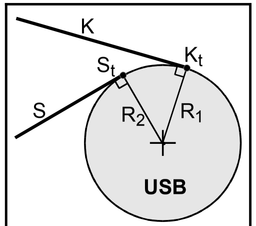

Figure 7: Rulers K and S touching the USB

Changing the reference point for the stone distance

Both distances can be recalculated to a distance from the center of the USB. Both line segments together with the radius to their tangent point form a rectangular triangle as displayed in Figure 8 in which R_u is the radius of the USB.
The hypotenuses of these triangles are the distances K_r and S_r with their common

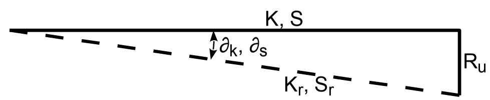

Figure 8: "Real" distances K_r and S_r as hypothenuse of rectangular triangles

reference point on the center of the USB. The angle ∂_k is the angular offset with respect to the original line segment K and is the offset with respect to the grinding angle determined by K_r and S_r.

So in principle the grinding angle could be determined by applying the cosine rule with distances K_r and S_r, but then the angle to be set must be reduced by the offset ∂_k. In addition, there is also an extra offset because the centerline of the jig is 6 mm above the USB.
Another reason to pay more attention to the "offset" between the jig and the USB was the development of a robust attachment of the knife-jig to the USB by forum member "cbwx34". [11] . I call it after the developer's forum-name "***cbwx34-fix***". It is displayed in Figure 9.

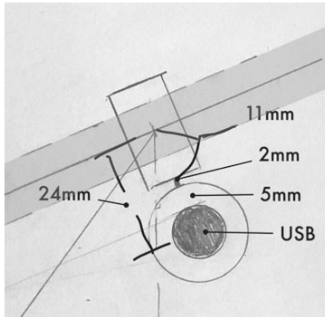

*Figure 9: the "**cbwx34-fix"** on the USB and its major dimensions*

5. Grinding angle adjustment for the "cbwx34-fix"

In his method with "the frontal vertical base" (Figure 2) "Wootz" sets the USB-height with respect to the grinder-base. According to his information, the applet for the adjustment takes the offset into account. As the math behind this correction was not published on the forum, "cbwx34" (Curtis) contacted me for help on the adjustment of the jig in his "***cbwx34-fix***".
The adjustment formula will be derived with reference to the following figure which is a schematic representation of the ***"cbwx34-fix"*** as displayed in Figure 9.

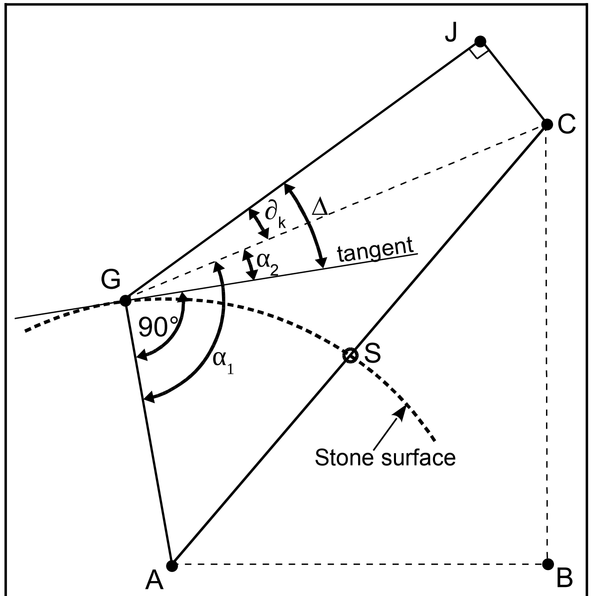

*Figure 10: Schematic set-up of the **"cbwx34-fix"***

A = **A**xis-center of stone
B = **B**ase-point for height measurement of USB
C = **C**enter of USB (universal support bar)
G = **G**rinding edge
S = **S**tone **S**urface at intersection with CA
JC = **J**ig centerline offset to **C**

The numbering of the formulas is a continuation of the numbering in ***Doc1***.
The angle Δ is the grinding angle and equals
Angle ∂_k is adjustable via the length JG with the adjustable stop of the knife-jig.
Angle α_2 equals $\alpha_2 = \alpha_1 - 90°$ in which α_1 is adjustable via the length BC with the