„Automation for Time Consuming Workpiece Installations on Machine Tools“

Siemens ES64F4

Dr Eng. Axel Stegen - Operation & Development of Machine Tools

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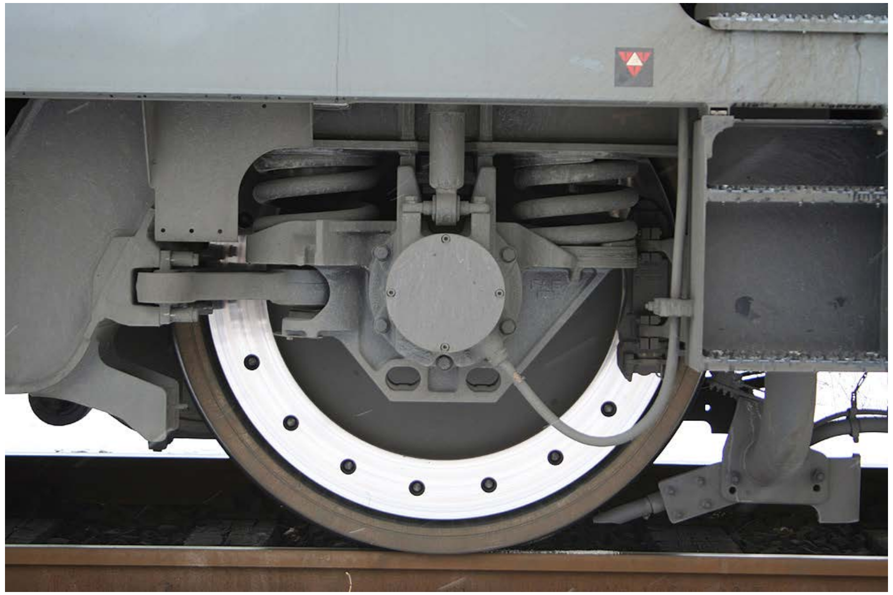
Structure

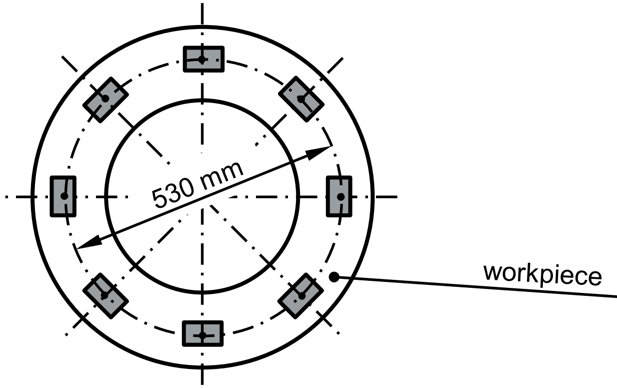


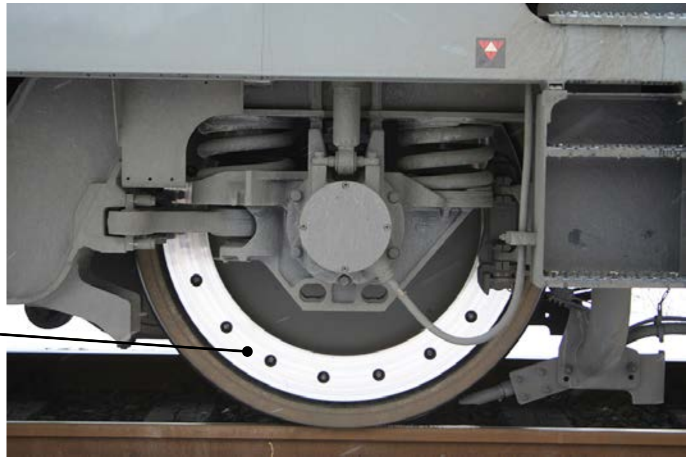
Source: S. Terfloth

- Introduction
- Manual Adjustment
- Automation Level I
- Automation Level II
- Adjustment Model
- Cost-effective Analysis
- Summary

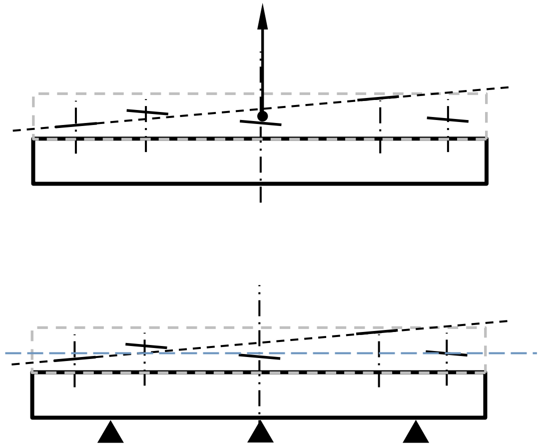
Structure

Application Example: Machining of Brake Disc for Railways (flange type)





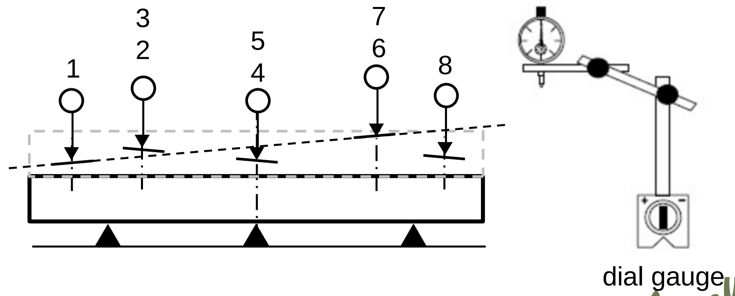
Quelle: S. Terfloth

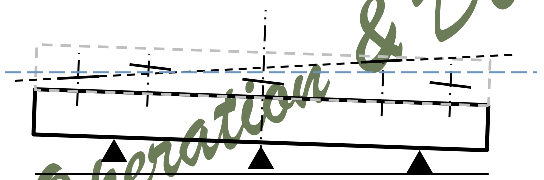


- **Workpiece :**
  brake disc for railways (casting)
  8 manufacturing areas
  diameter of the pitch circle ø 530 mm
- **Set-up :**
  problem of time consuming
  workpiece installations

Structure

No Automation: Manual Adjustment by Dial Gauge





manual adjustment: nearly 2 h
machining by the machine tool : nearly 10 min

- the position of the machining surfaces have to be controlled during the adjustment by 8 dial gauges
- after the adjustment, a 3-axis machine tool can be used for machining
- adjustment has to be repeated for every workpiece
- time relation: 12:1

Structure

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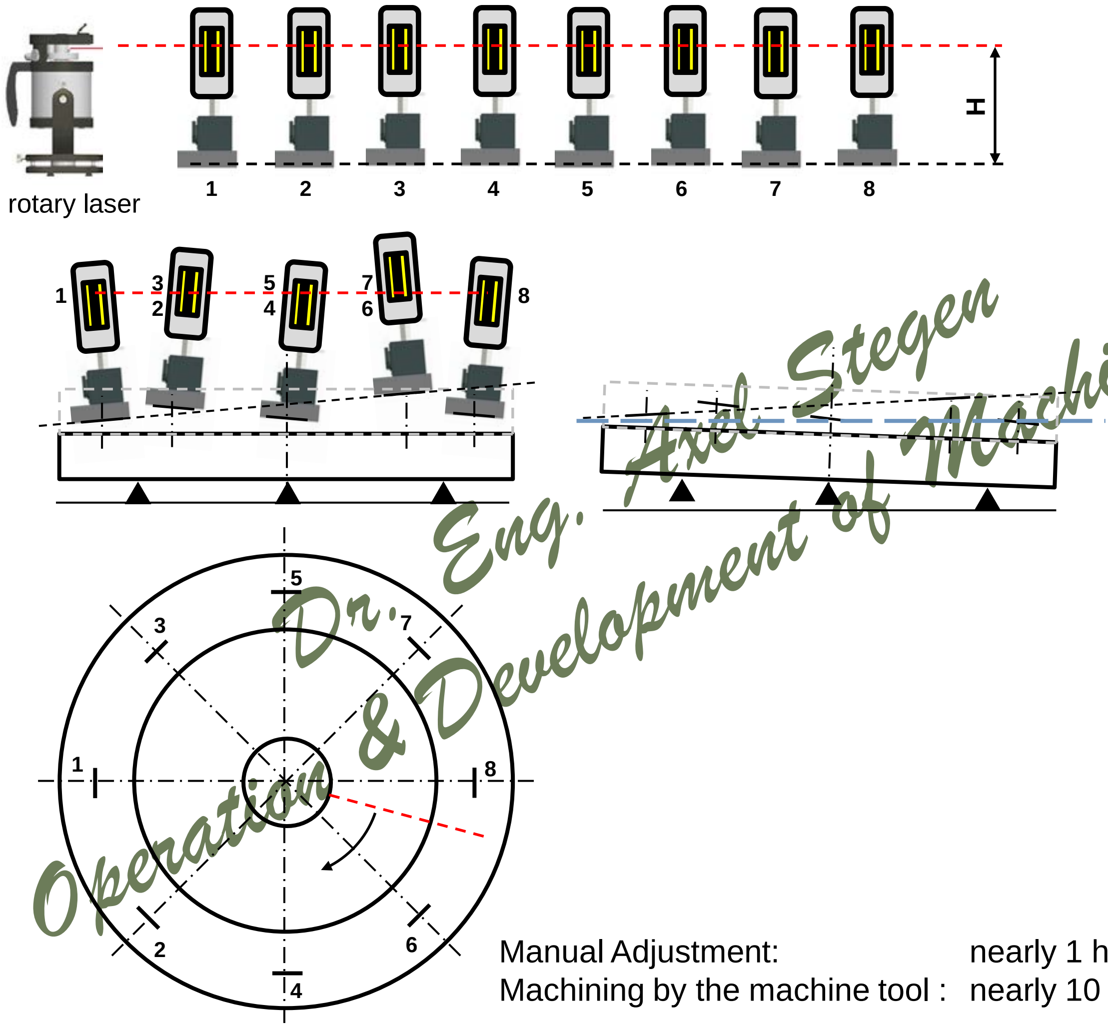
Level I : Manual Adjustment by Position Sensitive Device (PSD) & Rotary Laser

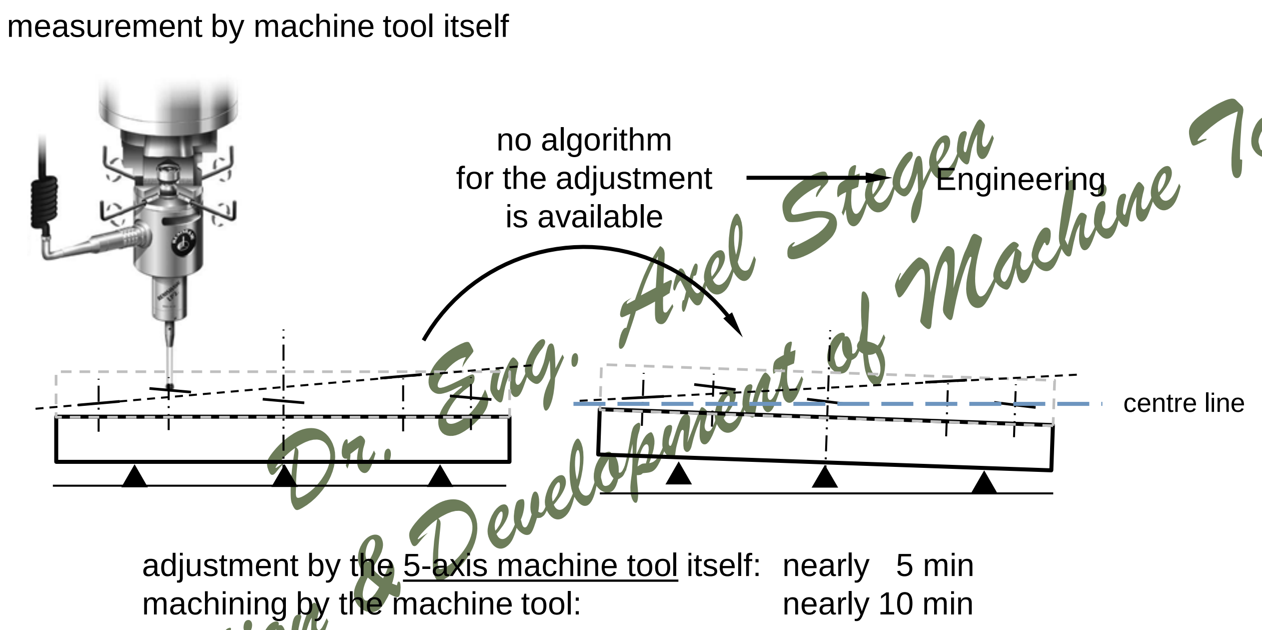


Manual Adjustment: nearly 1 h
Machining by the machine tool : nearly 10 min

- adjustment of the 8 PSD in the equal height
- bring the PSD into the position of the workpiece
- install the rotary laser in the middle of the workpiece & fix the laser with the table of the 3-axis machine tool
- the workpiece can be adjusted by the adjusting elements by observing the signals of the 8 PSD on the display
- time relation: 6:1

Structure

Level II : Measurement, Adjustment & Machining by Machine Tool



- measurement by the machine tool itself with a tactile measurement sensor
- adjustment by the 5-axis machine tool itself
- no algorithm is available
- but a big economic advantage is reachable
- engineering costs divide on all workpieces
- engineering is cost-saving!
- time relation: 1:2

Structure

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Engineering Procedure: Automatic Adjustment

Development of the model (analytical)

↓

Set-up of the workpiece

↓

Exchanging the measuring head

↓

Touching the machining surfaces

↓

Saving of the measuring points

↓

Model (analytical geometry 12th class of the secondary school)

↓

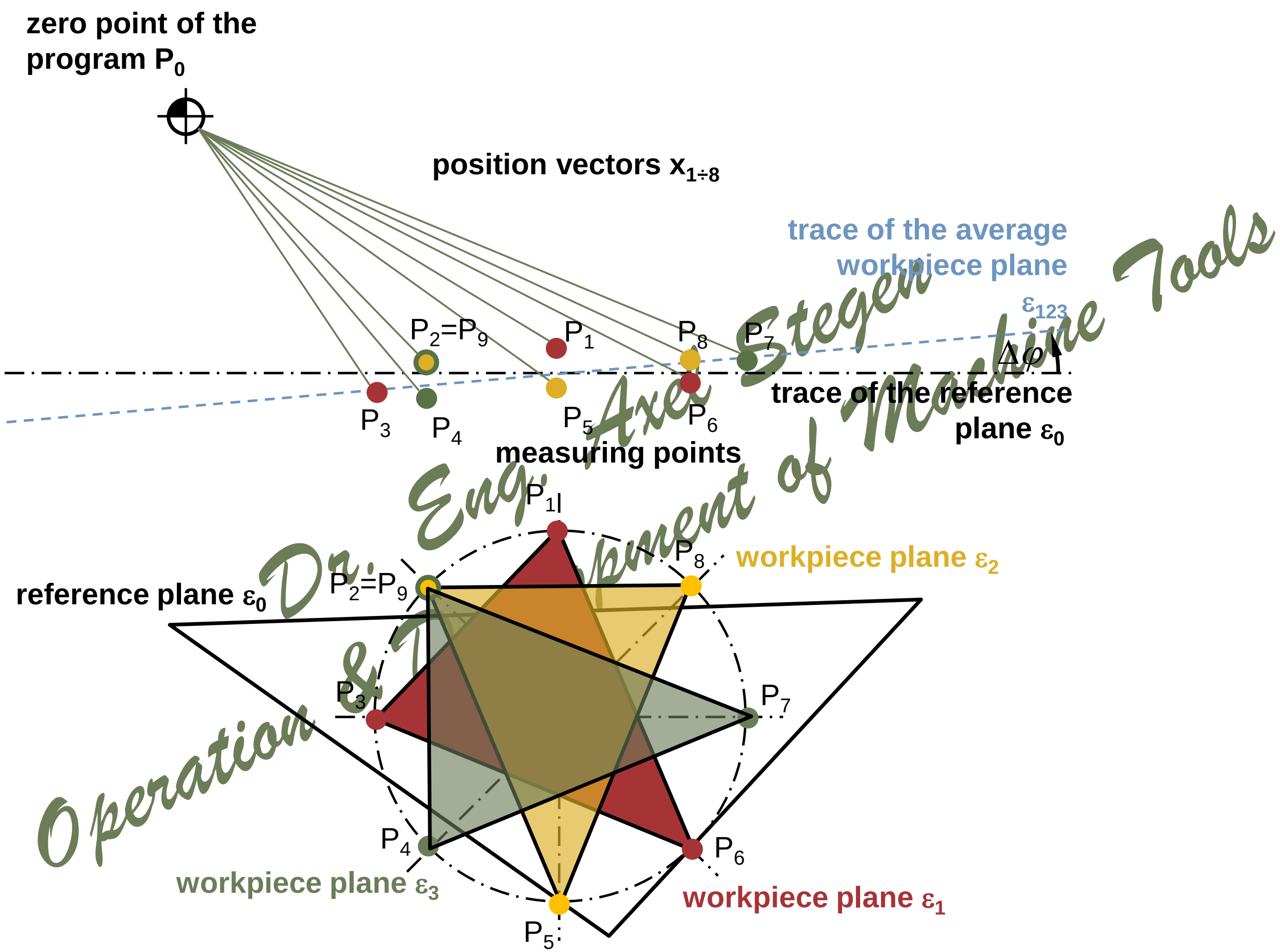
Calculation of the correction angles $\Delta\varphi_A$ and $\Delta\varphi_C$!

↓

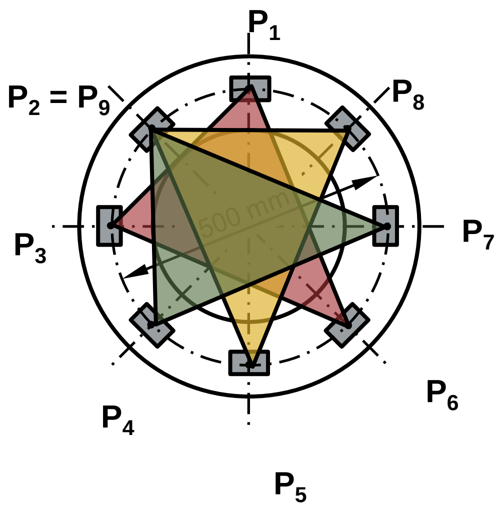
Machining of the workpiece by minimum time investment!

- procedure of activities
  (process chain)

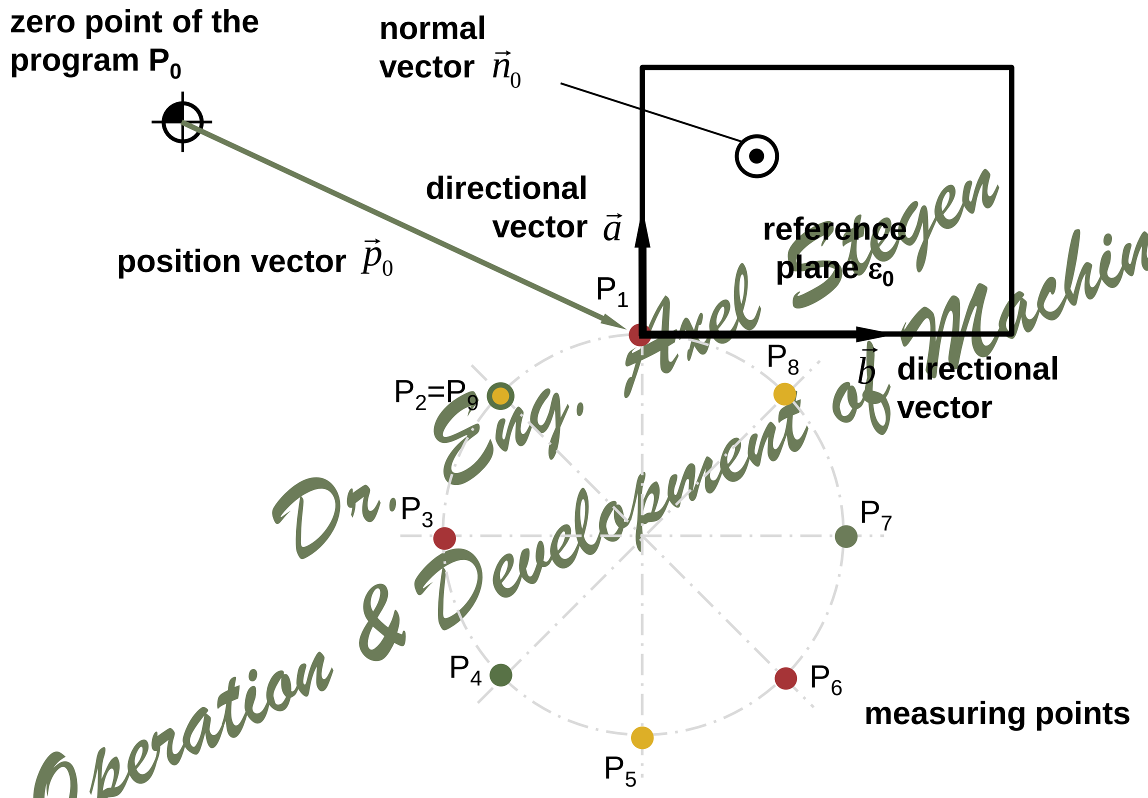
Measurement Procedure: Model Idea



- principle of an inclination table
- overview of the model
- 3 planes defined by 3 points
- 1 point has to be used twice
- averaging by normal vectors



Model Development: Reference Plane of the Working Table

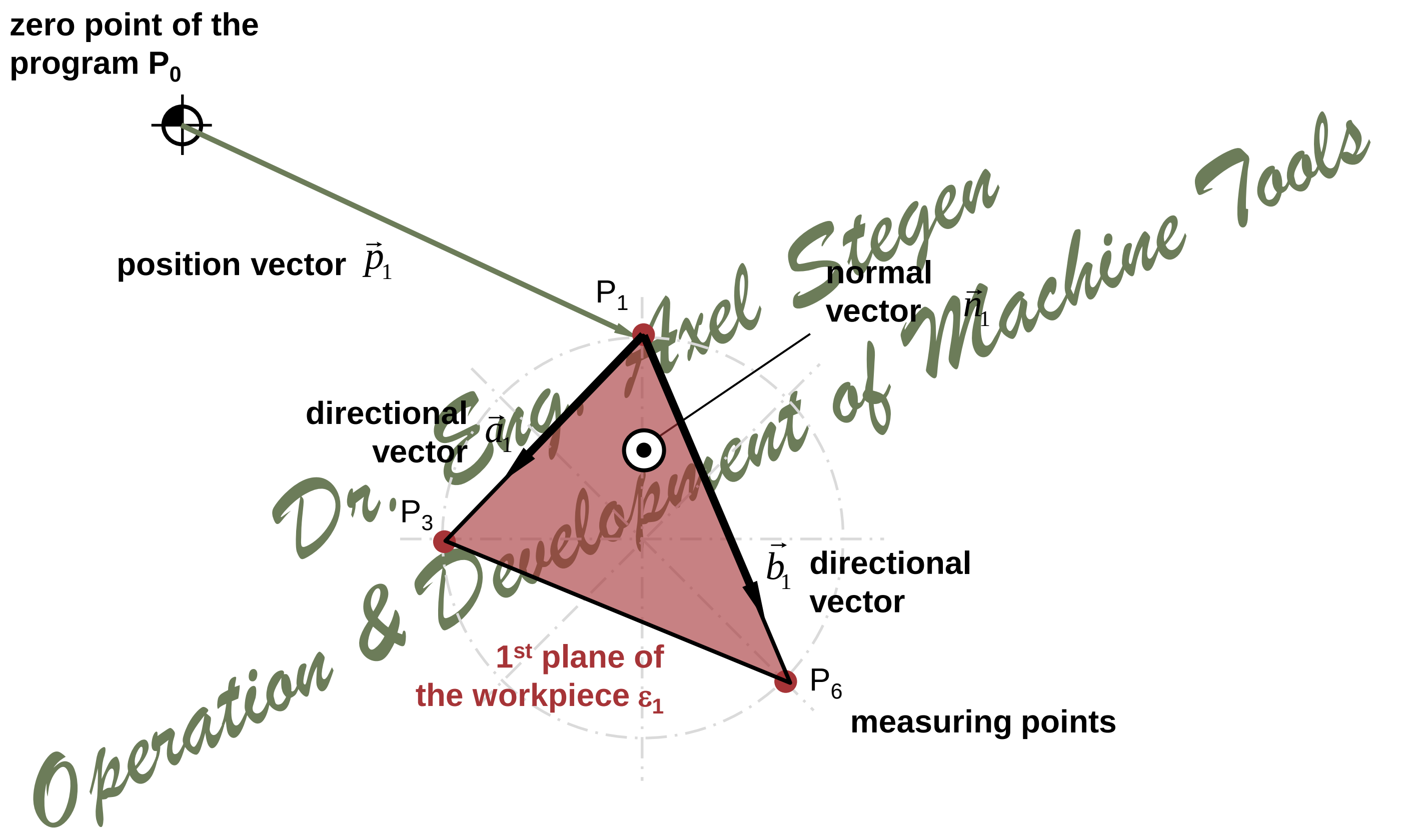


- determination of the position vectors
- determination of the equation of the reference plane

$$\varepsilon_0: \quad \vec{x} = \vec{p}_0 + s_0 \cdot \vec{a}_0 + t_0 \cdot \vec{b}_0$$

- determination of the reference plane's normal-vector $\vec{n}_0$

Model Development: 1st Plane of the Workpiece

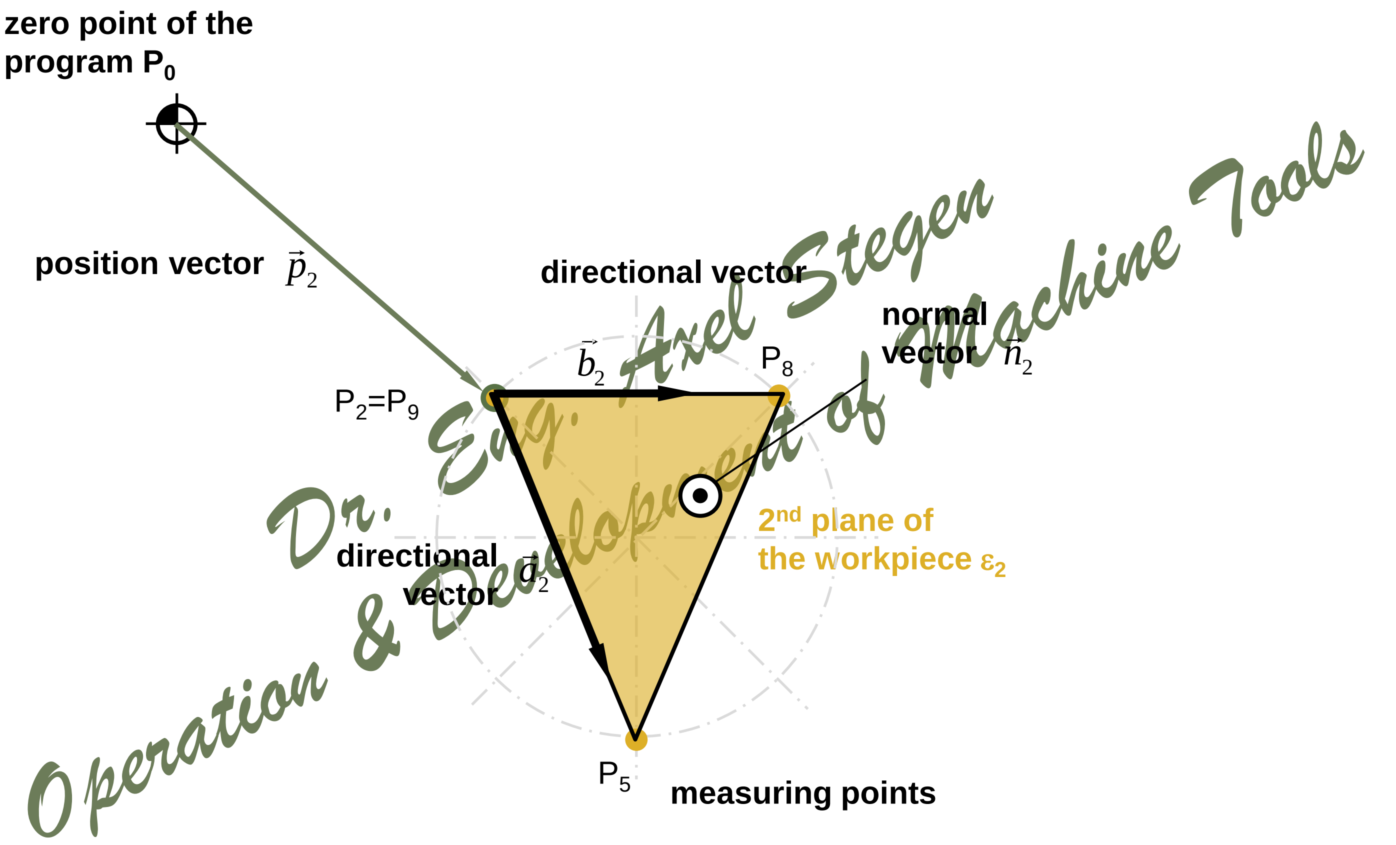


- determination of the position vectors
- determination of the equation of the 1st plane of the workpiece

$$\varepsilon_1 : \quad \vec{x} = \vec{p}_1 + s_1 \cdot \vec{a}_1 + t_1 \cdot \vec{b}_1$$

- determination of the normal-vector of the 1st plane of the workpiece $\vec{n}_1$

Model Development: 2nd Plane of the Workpiece

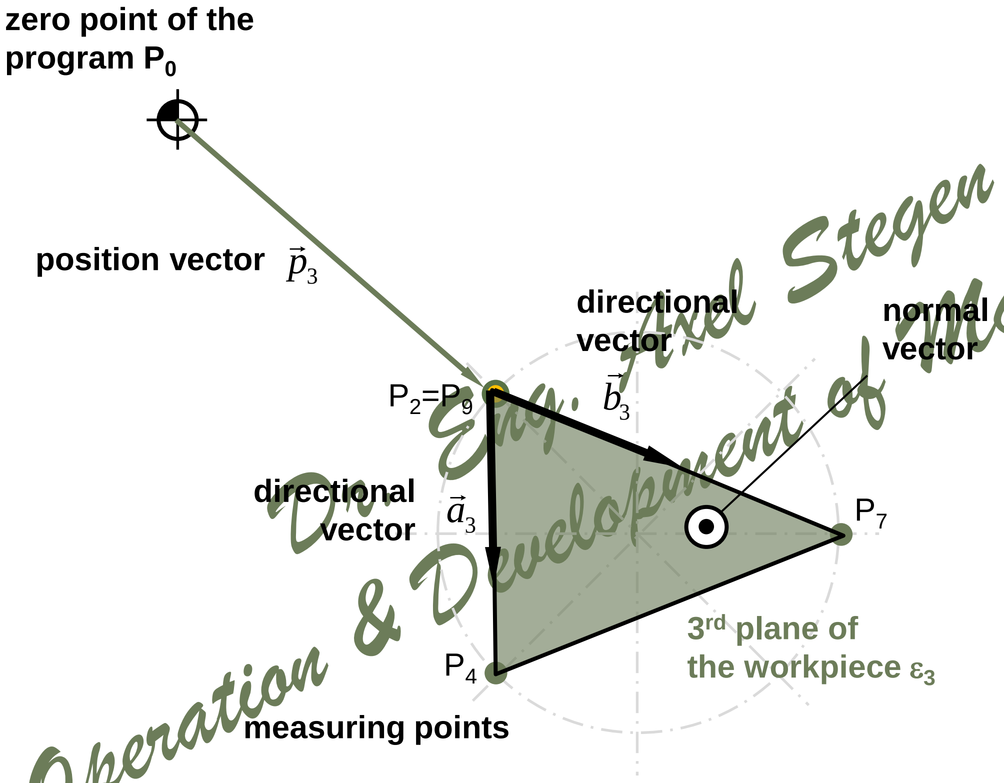


- determination of the position vectors
- determination of the equation of the 2nd plane of the workpiece

$$\varepsilon_2: \quad \vec{x} = \vec{p}_2 + s_2 \cdot \vec{a}_2 + t_2 \cdot \vec{b}_2$$

- determination of the normal-vector of the 2nd plane of the workpiece $\vec{n}_2$

Model Development: 3rd Plane of the Workpiece

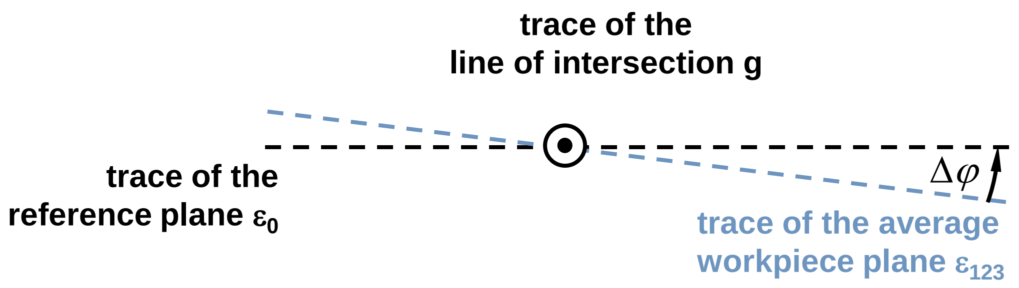


- determination of the position vectors
- determination of the equation of the 3rd plane of the workpiece

$$\varepsilon_3: \quad \vec{x} = \vec{p}_3 + s_3 \cdot \vec{a}_3 + t_3 \cdot \vec{b}_3$$

- determination of the normal-vector of the 3rd plane of the workpiece $\vec{n}_3$
- averaging of the normal-vectors of the 3 planes of the workpiece $\vec{n}_{123}$

Fundamental Task: Intersection Plane - Plane



- intersection of set-up plane & average plane of the workpiece
- line of intersection:

  $g: \quad \vec{x} = \vec{p}_g + t_g \cdot \vec{c}$
- determination of the total correction angle $\Delta\varphi$ (A,C)
- determination of the correction angles $\Delta\varphi_A$ (A) & $\Delta\varphi_C$ (C) !
- axis of rotation is the line of intersection g !
- only the directional vector of the line of intersection is relevant

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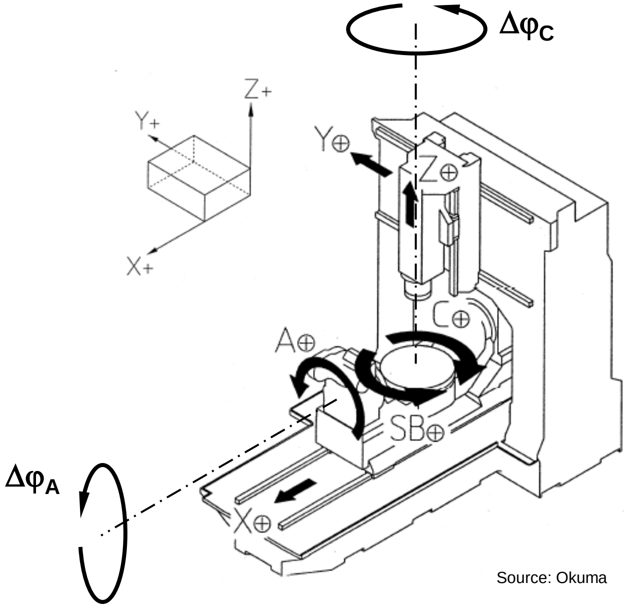
Analysis of the Developed Model



- unique development of the model
- numerous applications of the model
- digital application of the model
- simple & inexact set-up of the workpiece
- correction of the angle by a push button
- extensive savings of set-up times
- only one NC-program
- smart use of the machine tool !!!

Application Example: Adjustment of a Disc Brake

Table for Corrections of the Workpiece Adjustment by oblique Surfaces

(Principle "Inclination Table")

Table 1 : Measurement input and preanalysis

P1 :	x_{p1}	=	265,0000	P1 :	265,0000
	y_{p1}		0,0000		0,0000
	z_{p1}		65,5520		65,5520
P2 :	x_{q1}	=	187,3833	P3 :	0,0000
	y_{q1}		187,3833		265,0000
	z_{q1}		66,3250		64,2340
P3 :	x_{r1}	=	0,0000	P6 :	-187,3833
	y_{r1}		265,0000		-187,3833
	z_{r1}		64,2340		66,4890
P4 :	x_{p2}	=	-187,3833	P2 :	187,3833
	y_{p2}		187,3833		187,3833
	z_{p2}		65,0530		66,3250
P5 :	x_{q2}	=	-265,0000	P5 :	-265,0000
	y_{q2}		0,0000		0,0000
	z_{q2}		64,1290		64,1290
P6 :	x_{r2}	=	-187,3833	P8 :	187,3833
	y_{r2}		-187,3833		-187,3833
	z_{r2}		66,4890		66,5520
P7 :	x_s	=	-187,3833	P4 :	-187,3833
	y_s		-265,0000		187,3833
	z_s		66,0070		65,0530
P8 :	x_t	=	187,3833	P7 :	-187,3833
	y_t		-187,3833		-265,0000
	z_t		66,5520		66,0070
				P2 :	187,3833
					187,3833
					66,3250

total allowance of the heigth Δz : 2,423 mm

Correction Angle φ_A : -0,22 °

Correction Angle φ_C : 47,81 °

average of the heigth : 65,6296

- input table
- blue numbers are changeable
- black numbers calculate automatically
- right side: re-orientation of the measuring points for processing to planes

Application Example: Equations of the Planes

Equation of the reference plane ε_0 :

$$\varepsilon_0 : \quad \mathbf{x}_0 = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 265{,}000 \\ 0{,}000 \\ 65{,}630 \end{bmatrix} + s_0 \cdot \begin{bmatrix} -265{,}000 \\ 265{,}000 \\ 0{,}000 \end{bmatrix} + t_0 \cdot \begin{bmatrix} -452{,}383 \\ -187{,}383 \\ 0{,}000 \end{bmatrix}$$

Equation of the workpiece plane ε_1 :

$$\varepsilon_1 : \quad \mathbf{x}_1 = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 265{,}000 \\ 0{,}000 \\ 65{,}55[illegible] \end{bmatrix} + s_1 \cdot \begin{bmatrix} -265{,}000 \\ 265{,}0[illegible] \\ -1{,}318 \end{bmatrix} + t_1 \cdot \begin{bmatrix} -452{,}383 \\ -187{,}383 \\ 0{,}937 \end{bmatrix}$$

Equation of the workpiece plane ε_2 :

$$\varepsilon_2 : \quad \mathbf{x}_2 = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 187{,}383 \\ 187{,}383 \\ [illegible]6{,}325 \end{bmatrix} + s_2 \cdot \begin{bmatrix} -452{,}383 \\ -187{,}383 \\ -2{,}196 \end{bmatrix} + t_2 \cdot \begin{bmatrix} 0{,}000 \\ -374{,}767 \\ 0{,}227 \end{bmatrix}$$

Equation of the workpiece plane ε_3 :

$$\varepsilon_3 : \quad \mathbf{x}_3 = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} -187{,}383 \\ 187{,}383 \\ 65{,}053 \end{bmatrix} + s_3 \cdot \begin{bmatrix} 0{,}000 \\ -452{,}383 \\ 0{,}954 \end{bmatrix} + t_3 \cdot \begin{bmatrix} 374{,}767 \\ 0{,}000 \\ 1{,}272 \end{bmatrix}$$

- analytical description of the reference plane ε_0
- analytical description of the workpiece planes ε_1, ε_2 and ε_3

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Application Example: Normal Vectors of the Planes

Normal vector of the reference plane n_0 :

$$n_0 = \begin{bmatrix} x_a \\ y_a \\ z_a \end{bmatrix} = \begin{bmatrix} 0,000 \\ 0,000 \\ 169.538,147 \end{bmatrix}$$

Normal vector of the workpiece plane n_1 :

$$n_1 = \begin{bmatrix} x_{n1} \\ y_{n1} \\ z_{n1} \end{bmatrix} = \begin{bmatrix} 1,334 \\ 844,546 \\ 169.538,147 \end{bmatrix} \qquad |n_1| = 169.540 \text{ mm}$$

Normal vector of the workpiece plane n_2 :

$$n_2 = \begin{bmatrix} x_{n2} \\ y_{n2} \\ z_{n2} \end{bmatrix} = \begin{bmatrix} -865,523 \\ \text{[illegible]} \\ 169.538,147 \end{bmatrix} \qquad |n_2| = 169.540 \text{ mm}$$

Normal vector of the workpiece plane n_3 :

$$n_3 = \begin{bmatrix} x_{n3} \\ y_{n3} \\ z_{n3} \end{bmatrix} = \begin{bmatrix} -575,432 \\ 357,527 \\ 169.538,147 \end{bmatrix} \qquad |n_3| = 169.540 \text{ mm}$$

Average normal vector of the workpiece plane n_{123} :

$$n_{123} = \begin{bmatrix} x_{n12} \\ y_{n12} \\ z_{n12} \end{bmatrix} = \begin{bmatrix} -479,874 \\ 434,922 \\ 169.538,147 \end{bmatrix}$$

- description of the normal vector of the reference plane
- description of the normal vectors of the workpiece n_1, n_2 and n_3
- description of the average normal vector of the workpiece

Application Example: Result

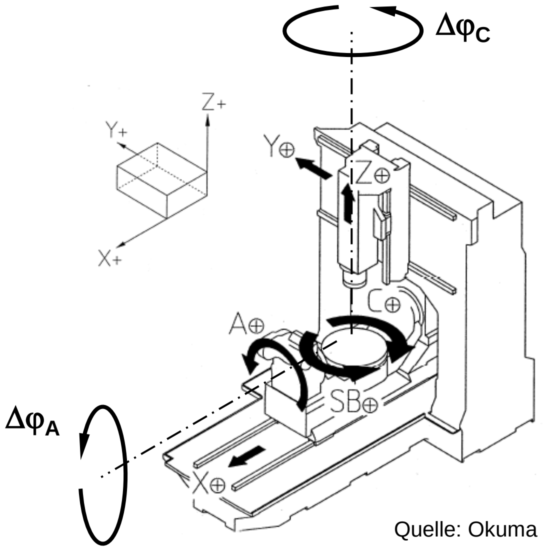
Line of intersection g by ε_0 and ε_{123} :

$$g: \quad \mathbf{x} = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} + t \cdot \begin{bmatrix} 0{,}906 \\ 1 \\ 0 \end{bmatrix}$$

Angle of intersection

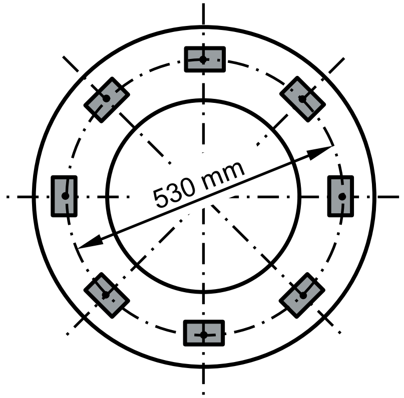
angle of intersection $\Delta\varphi_g$:	0,219	°
Correction angle $\Delta\varphi_A$:	-0,219	°
Correction angle $\Delta\varphi_C$:	47,813	°

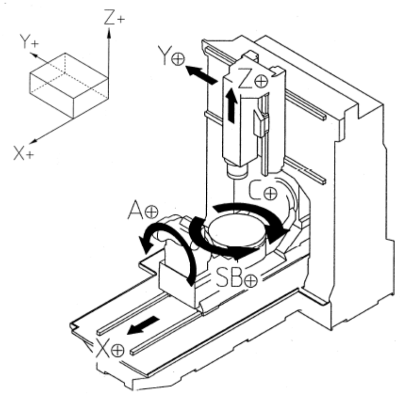
- analytical description of the line of intersection
- result: two correction angles

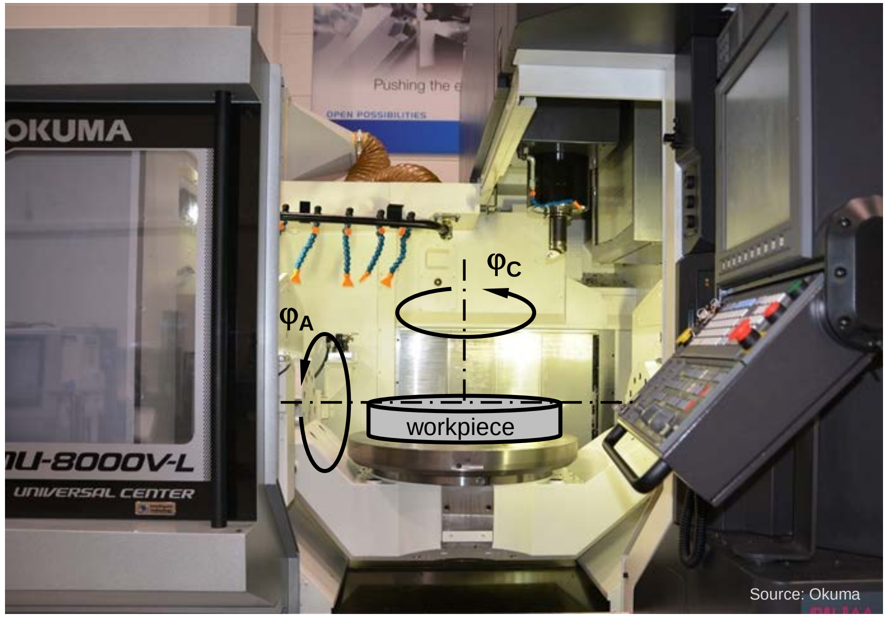


Quelle: Okuma

Application Example: Smart Cutting of Brake Disc (flange type)

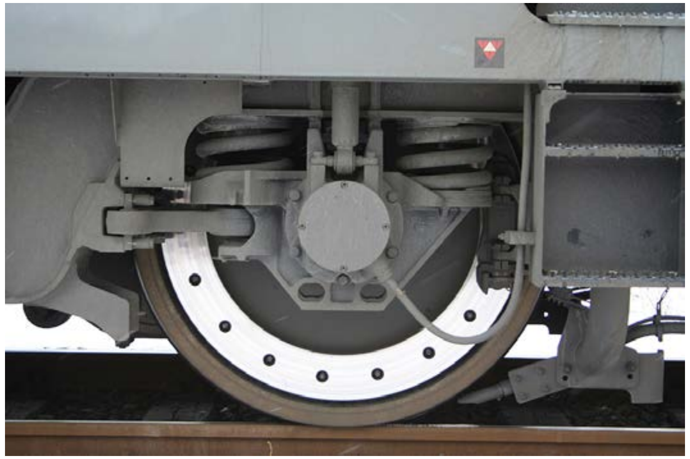




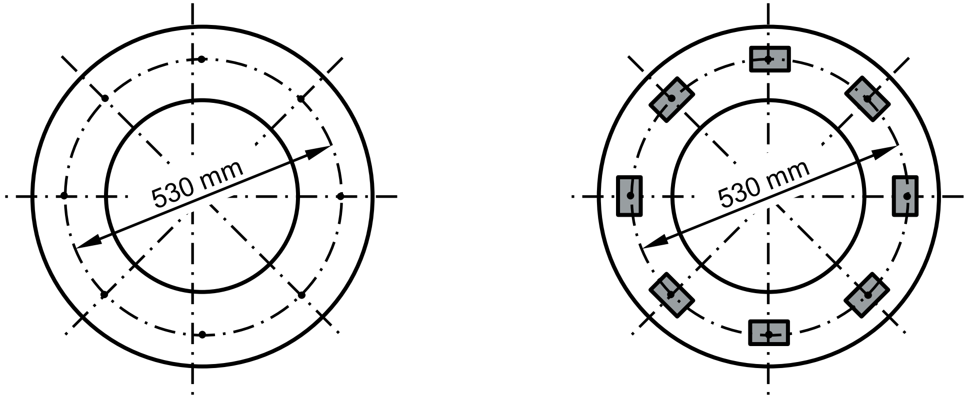


- **Workpiece :**
  brake disc for railways (casting)
  8 Manufacturing areas
  diameter of the pitch circle ø 530 mm
- **Measuring Head :**
  Renishaw QMP 60
- **5-Axis Machine :**
  Okuma MU 8000V-L
- **Set-up :**
  problem of time consuming
  adjustments is solved

Impressions of the Test Cut



Quelle: S. Terfloth

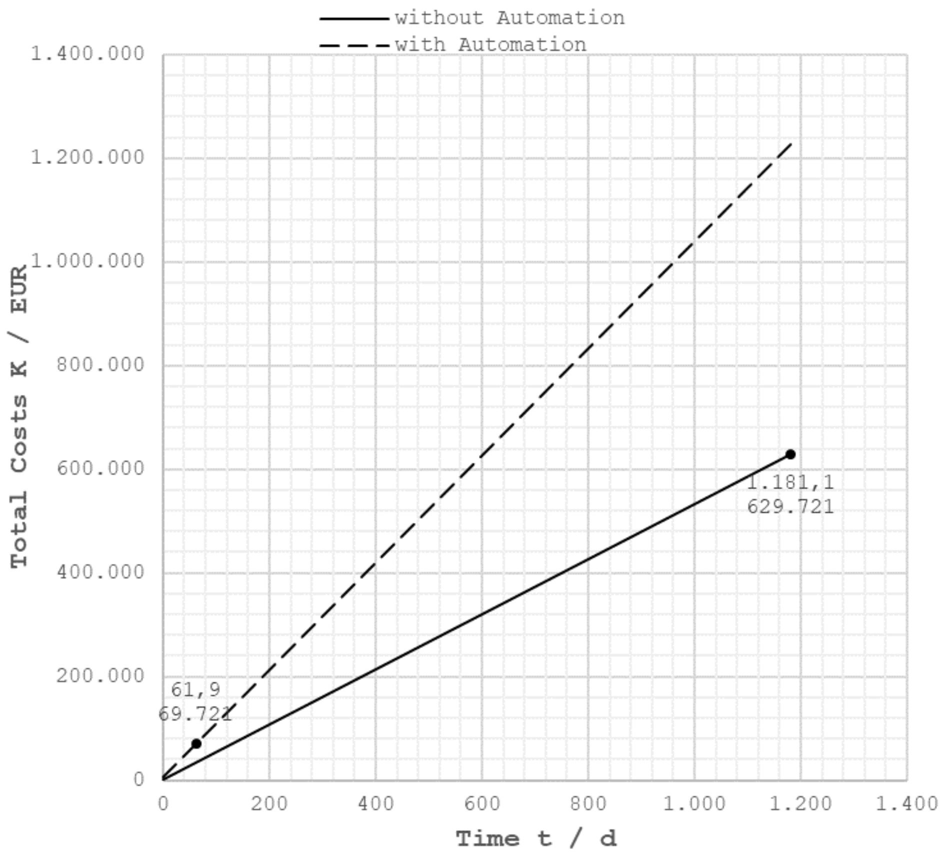


front side **back side**

- delegation is standing round the machine tool
- operator starts the process
- the machine tool is twitching twice
- the delegation was whispering
- cutting process is running
- result: top quality

Structure

Cost-effective Analysis



- analysis of the costs
- automation system is more expensive than the non automated system – time by time.
- consider: the output of the system is relevant
- the costs per piece have to be calculated

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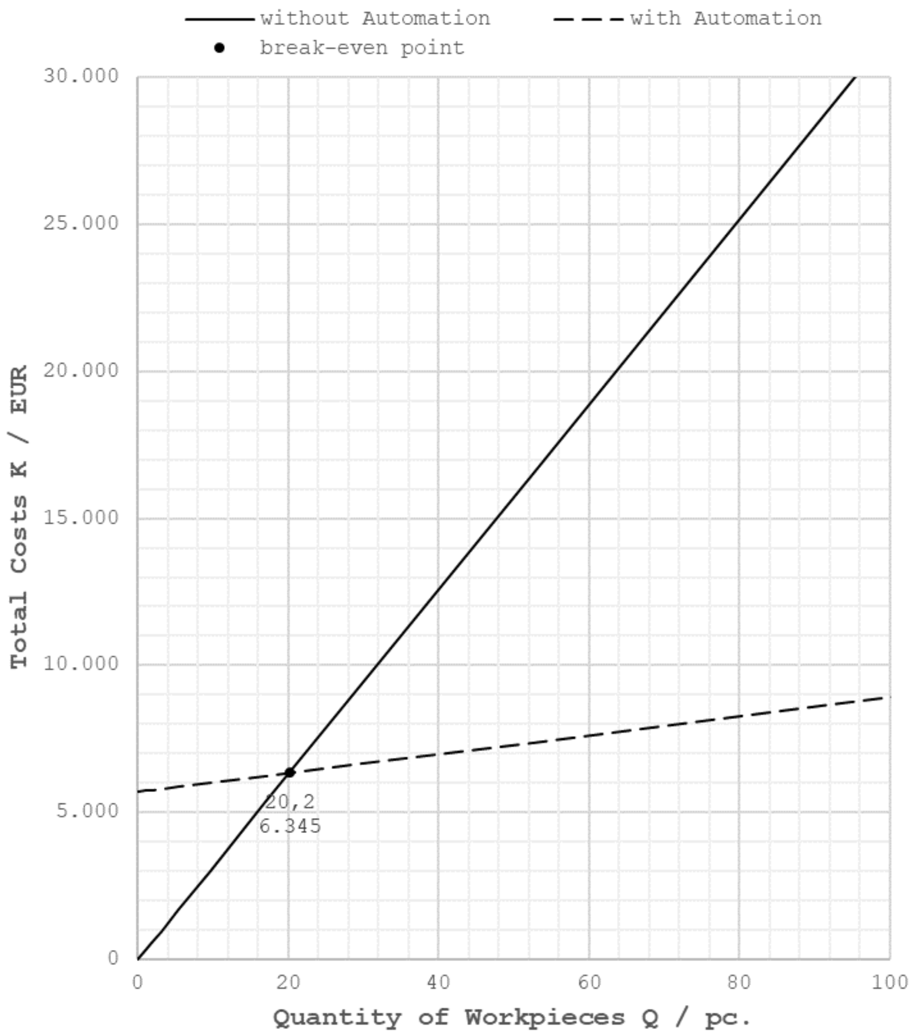
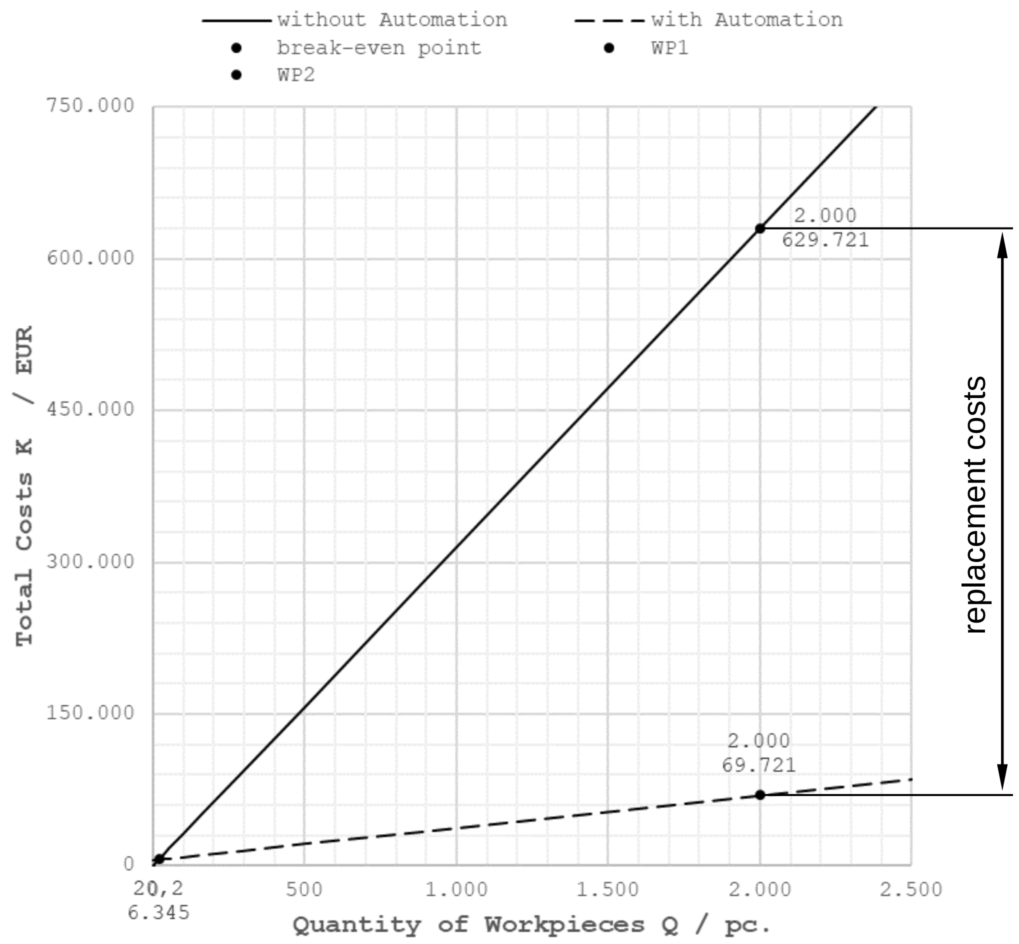
Cost-effective Analysis: Cost Comparison Method - linear



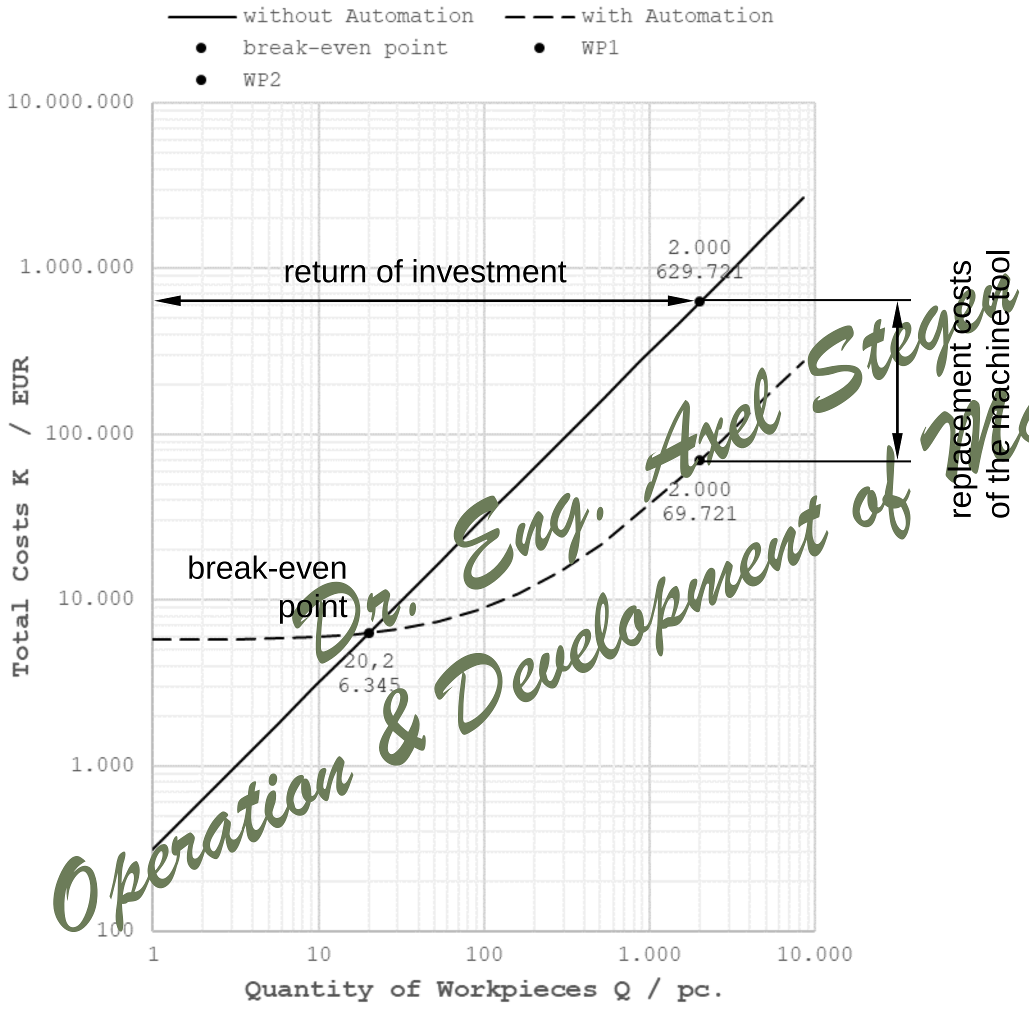
- here you see that the total costs depend on the output of workpieces
- the break-even point is sketched in
- it is visible, that the total costs of the automation system are bigger than before, but the progression of the output of workpieces is bigger than the progression of the total costs.
- This is the principle of automation!

Cost-effective Analysis: Cost Comparison Method - linear



- investment is returned after 2.000 workpieces
- this is realised after a quarter of a year
- by comparation with the conventional production, the automation gives the possibility of addition of 19 machine tools! (if the market demands of these workpieces)

Cost-effective Analysis: Cost Comparison Method - logarithmical



- For a better costs overview it is necessary to use logarithmic scaling of the system.
- So, break-even point and return of investment are visible!
- The potential of 5-axis machine tools are not only in the field of 5-axis simultaneous cutting!

Structure

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Summary

- manual adjustment
- automation level 1
- automation level 2
- model was explained
- The workpieces have been shown.
- The automation have been analysed economically.
- cost-effective advantages are very visible, if the origin system works on a low automation level!