CUTTING PROCCESS OPTIMIZATION ON THE BASE OF CNC ADAPTIVE PROGRAMMING

Alexander SHARMAZANASHVILI Dr Professor
Georgian CAD/CAM Engineering Center
Tbilisi, Georgia
Lasha.Sharmazanashvili@cern.ch
www.cadcam.ge

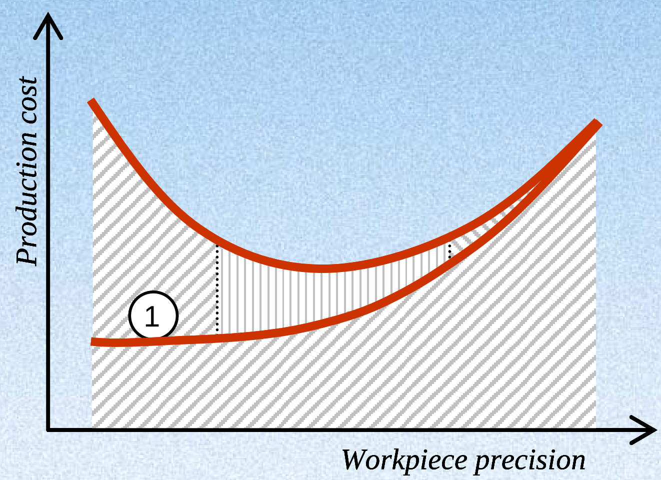
TMCE 2008 April 21 – 25 Izmir, Turkey

Total production cost

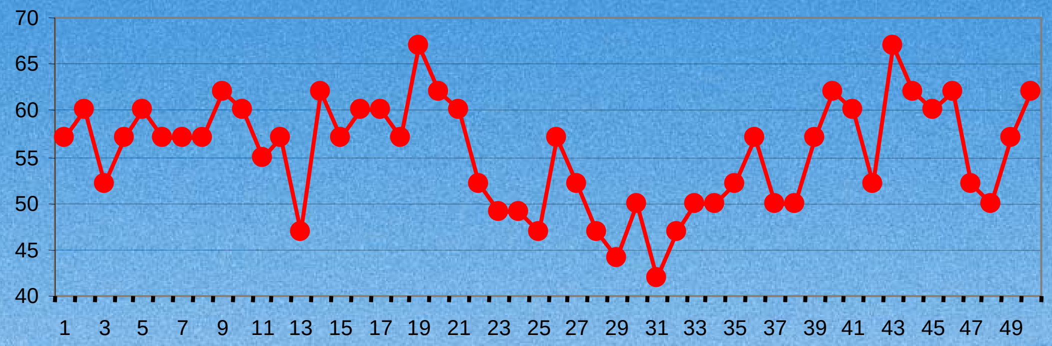
$$Q_{\Sigma} = Q_W + Q_M$$

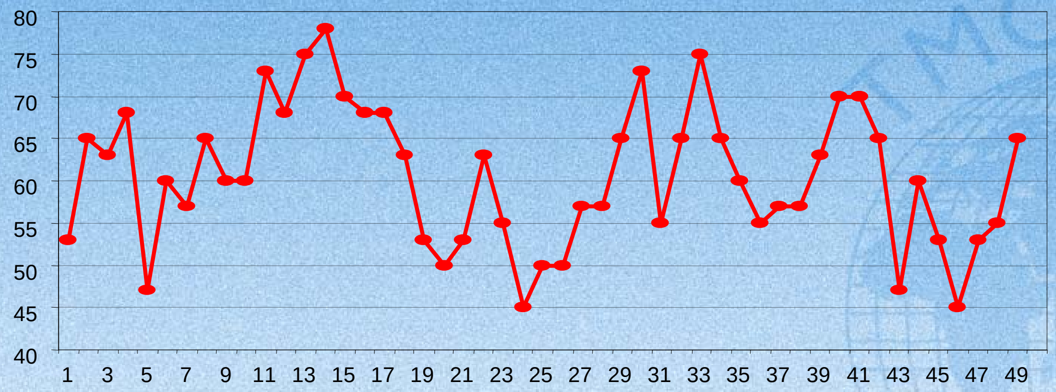
Q_W - cost of workpiece

Q_M - cost of machining



Dispersion of Workpiece Hardness:





Deviation from average is for:

- Iron alloys – 46%
- Aluminum alloys – 48%

Dispersion of Workpiece Dimensions:

Engineering hand books

Types	$(R_z)_1$ (mm)	h_1 (mm)	$(\Delta_\Sigma)_1$ (mm)			$(Td)_1$ (mm)	ε_1 (mm)
CASTING	0.2	0.1	0.28			4	2.6
PUNCHING	0.2	0.25	Δ_κ: 0.084	$\Delta_б$: 1	1.1	5	4
ROLLING	0.32	0.4	2.1			3	4.32
WELDING	1.5	-	Δ_κ: 0.06	$\Delta_б$: 1	1.06	5.5	5.3

Manufacturing experience

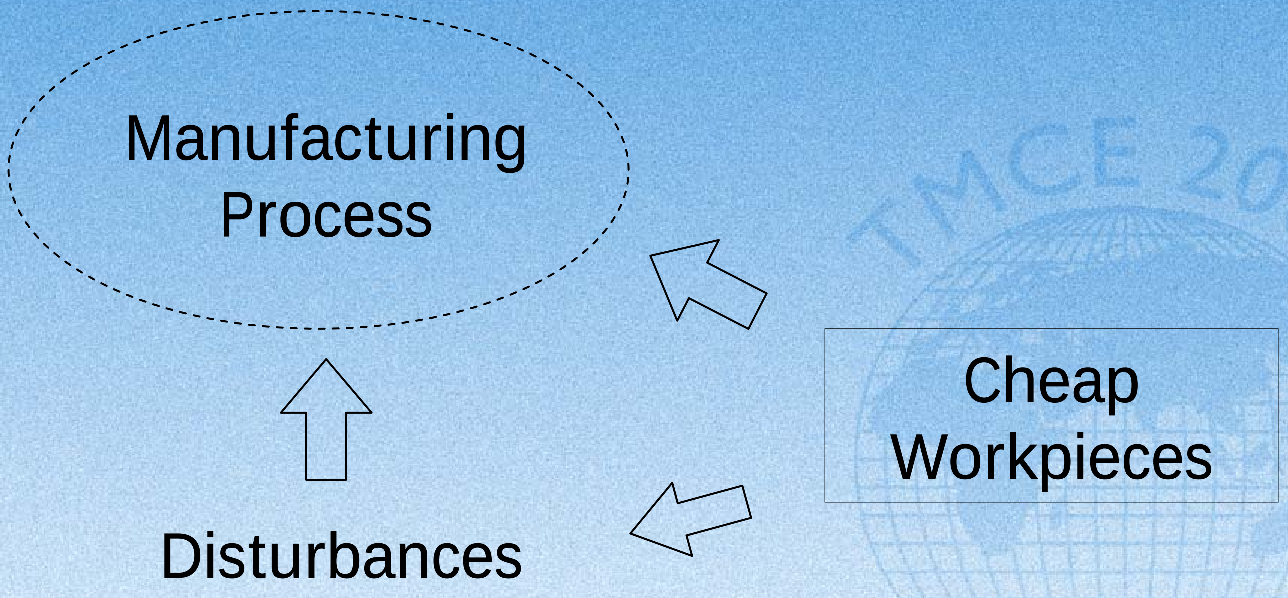
Types	$(R_z)_1$ (mm)	h_1 (mm)	$(\Delta_\Sigma)_1$ (mm)	$(Td)_1$ (mm)	ε_1 (mm)
CASTING	$(R_z)_1$	h_1	$(\Delta_\Sigma)_1$	4	2.6
PUNCHING	$(R_z)_1$	h_1	$(\Delta_\Sigma)_1$	4.2	3.7
ROLLING	-	-	-	-	-
WELDING	$(R_z)_1$	h_1	$(\Delta_\Sigma)_1$	11	8.1

Literature sources

Types	$(R_z)_1$ (mm)	h_1 (mm)	$(\Delta_\Sigma)_1$ (mm)	$(Td)_1$ (mm)	ε_1 (mm)
CASTING	$(R_z)_1$	h_1	0.21	2.6	1.8
PUNCHING	0.2	1	$(\Delta_\Sigma)_1$	2.4	3.5
ROLLING	$(R_z)_1$	0.75	$(\Delta_\Sigma)_1$	$(Td)_1$	4.7
WELDING	-	3.5	5.6	15.3	16.8

	Hand-Books ε_1 (mm)	Experience ε_2 (mm)	Sources ε_3 (mm)
CASTING	2.6	2.6	1.8
PUNCHING	4	3.7	3.5
ROLLING	4.32	-	4.7
WELDING	5.3	8.1	16.8

Disturbance is the difference between the designed and existing values of workpiece parameters



Methods of Parametrical Optimization

Without considering of expences of tools

With considering of wear of tools

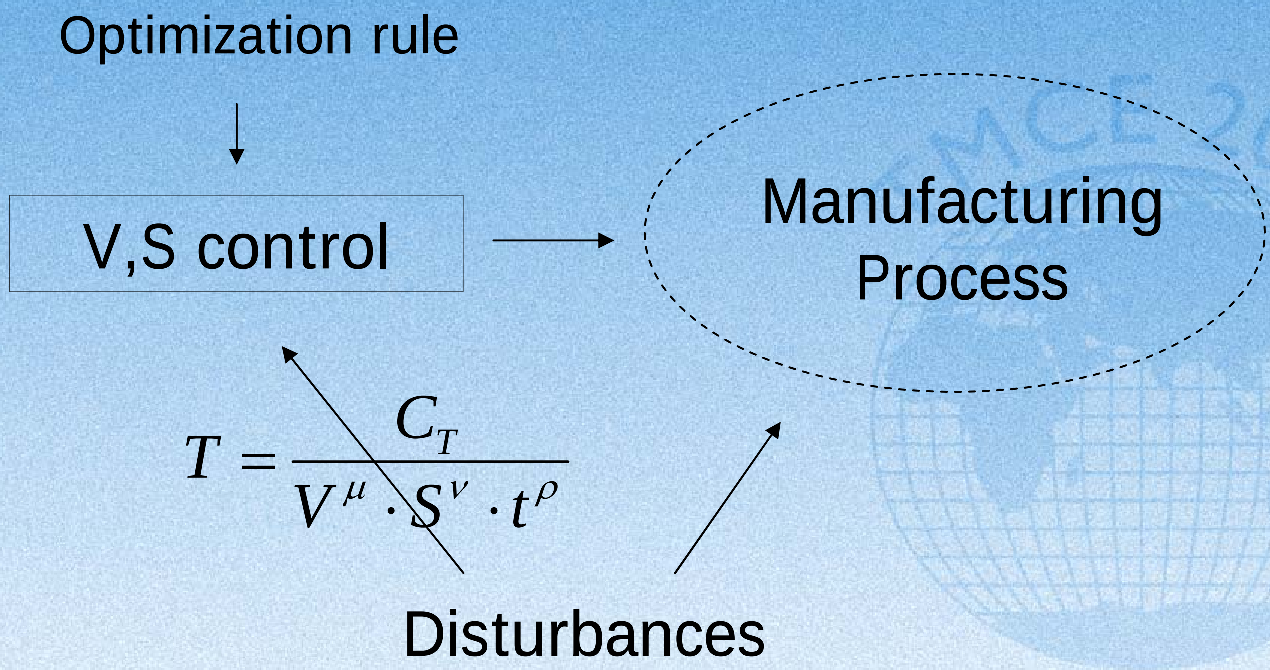
$$T = \frac{C_T}{V^{\mu} \cdot S^{\nu} \cdot t^{\rho}}$$

V - *Cutting speed*

S - *Feedrate*

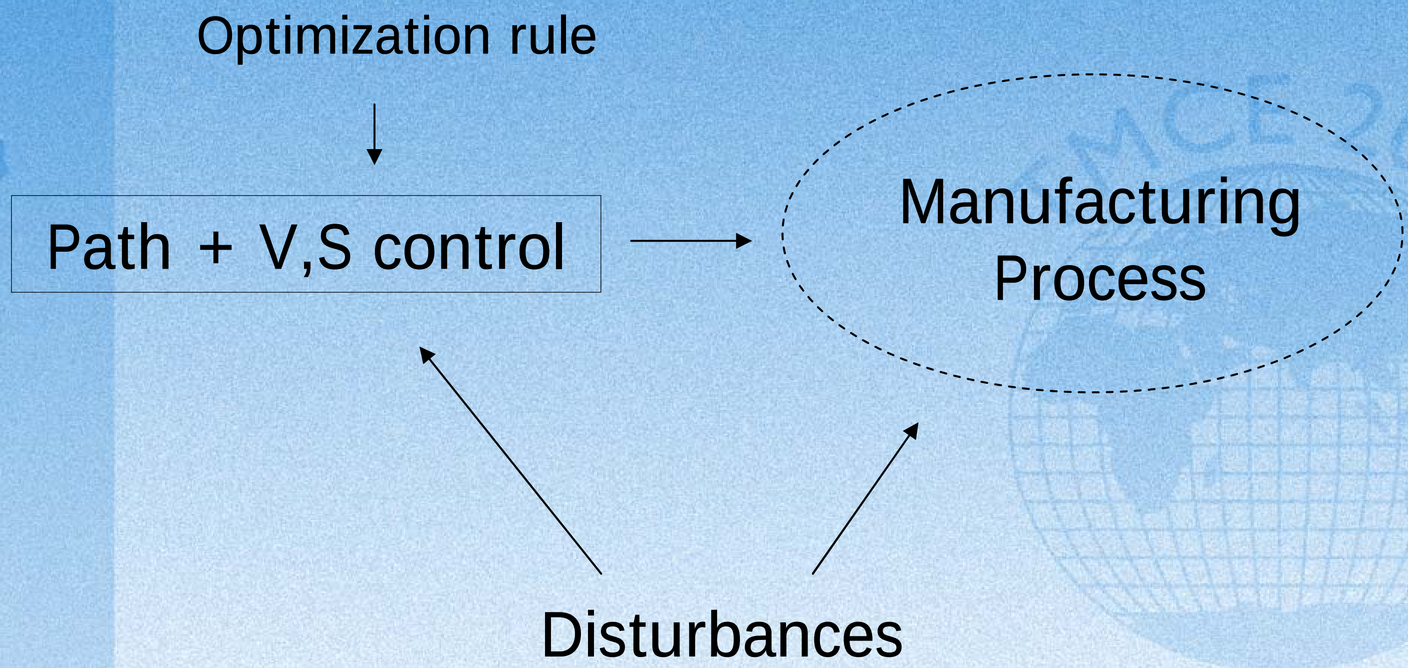
t - *Depth of cut*

Adaptive Real Time Control



$$T = \frac{C_T}{V^{\mu} \cdot S^{\nu} \cdot t^{\rho}}$$

Adaptive Part Programming (APP)



$$T = \frac{C_T}{V^{\mu} \cdot S^{\nu} \cdot t^{\rho}}$$

Research Concept

Optimization Criteria

$$Q = \left(\tau_M + \frac{\tau_I}{N} \right) \cdot Q_T + \frac{Q_I}{N}$$

$$Q = \ell \cdot Z \cdot Q_T \cdot \left(\frac{1}{V \cdot S \cdot t} + \frac{\tau_I + {Q_I}/{Q_T}}{V \cdot S \cdot t \cdot T} \right)$$

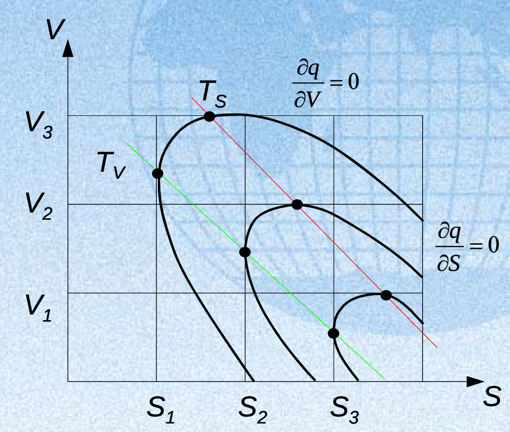
$$q = \frac{1}{V \cdot S \cdot t} + \frac{\gamma}{C_T} \cdot V^{\mu - 1} \cdot S^{\nu - 1} \cdot t^{\rho - 1}$$

$$\gamma = \tau_I + \frac{Q_I}{Q_T}$$

$$\frac{\partial q}{\partial V} = 0 \qquad \frac{\partial q}{\partial S} = 0 \qquad \frac{\partial q}{\partial t} = 0$$

$$V^* = \left(\frac{C_T}{\gamma \cdot (\mu - 1) \cdot S^{\nu} \cdot t^{\rho}} \right)^{\frac{1}{\mu}}$$

$$S^* = \left(\frac{C_T}{\gamma \cdot (\nu - 1) \cdot V^{\mu} \cdot t^{\rho}} \right)^{\frac{1}{\nu}}$$



Research Concept

Optimization Criteria

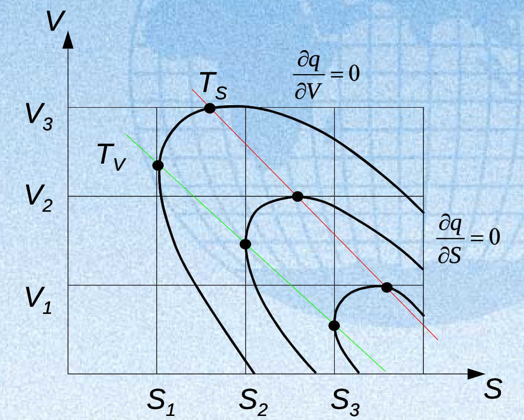
$$Q = \left(\tau_M + \frac{\tau_I}{N} \right) \cdot Q_T + \frac{Q_I}{N} \qquad Q = \ell \cdot Z \cdot Q_T \cdot \left(\frac{1}{V \cdot S \cdot t} + \frac{\tau_I + Q_I / Q_T}{V \cdot S \cdot t \cdot T} \right)$$

$$q = \frac{1}{V \cdot S \cdot t} + \frac{\gamma}{C_T} \cdot V^{\mu-1} \cdot S^{\nu-1} \cdot t^{\rho-1} \qquad \gamma = \tau_I + \frac{Q_I}{Q_T}$$

$$\frac{\partial q}{\partial V} = 0 \qquad \frac{\partial q}{\partial S} = 0 \qquad \frac{\partial q}{\partial t} = 0$$

$$V^* = \left(\frac{C_T}{\gamma \cdot (\mu - 1) \cdot S^{\nu} \cdot t^{\rho}} \right)^{\frac{1}{\mu}}$$

$$S^* = \left(\frac{C_T}{\gamma \cdot (\nu - 1) \cdot V^{\mu} \cdot t^{\rho}} \right)^{\frac{1}{\nu}}$$



$$T = \frac{C_T}{V^{\mu} \cdot S^{\nu} \cdot t^{\rho}} \qquad q = \frac{1}{V \cdot S \cdot t} + \frac{\gamma}{C_T} \cdot V^{\mu-1} \cdot S^{\nu-1} \cdot t^{\rho-1}$$

Research Concept

Optimization Criteria

$$C_{m_i} \cdot V^{\alpha} \cdot S^{\beta} \cdot t^{\gamma} = M_i \leq [\Pi_i]$$ - *Boundary conditions*

$$\downarrow$$

$$\begin{bmatrix} H = C_H \cdot V^{\alpha_H} \cdot S^{\beta_H} \cdot t^{\gamma_H} \\ \Phi = C_{\Phi} \cdot V^{\alpha_{\Phi}} \cdot S^{\beta_{\Phi}} \cdot t^{\gamma_{\Phi}} \end{bmatrix} \longrightarrow q = a \cdot t^{\eta} + \frac{\gamma}{C_T} \cdot b \cdot t^{\lambda}$$

$$a = \frac{\left\{[H] \cdot C_H^{-1}\right\}^{\left(1/\beta_H\right) \cdot \left(\beta_{\Phi}/\alpha_{\Phi} - 1\right)}}{\left\{[\Phi] \cdot C_{\Phi}^{-1}\right\}^{1/\alpha_{\Phi}}} \qquad b = \frac{\left\{[\Phi] \cdot C_{\Phi}^{-1}\right\}^{(\mu-1)/\alpha_{\Phi}}}{\left\{[H] \cdot C_H^{-1}\right\}^{\left(1/\beta_H\right) \cdot \left(\beta_{\Phi} \cdot \mu/\alpha_{\Phi} - \beta_{\Phi}/\alpha_{\Phi} - \nu - 1\right)}}$$

$$\eta = \frac{\gamma_{\Phi}}{\alpha_{\Phi}} + \frac{\gamma_H}{\beta_H} - 1 - \frac{\gamma_H \cdot \beta_{\Phi}}{\gamma_{\Phi} \cdot \beta_H} \qquad \lambda = \left(\frac{\gamma_H \cdot \beta_{\Phi}}{\alpha_{\Phi} \cdot \beta_H} - \frac{\gamma_{\Phi}}{\alpha_{\Phi}}\right) \cdot (\mu - 1) - \frac{\gamma_H}{\beta_H} \cdot (\nu - 1) + \rho - 1$$

$$T = \frac{C_T}{V^{\mu} \cdot S^{\nu} \cdot t^{\rho}} \qquad q = \frac{1}{V \cdot S \cdot t} + \frac{\gamma}{C_T} \cdot V^{\mu-1} \cdot S^{\nu-1} \cdot t^{\rho-1}$$

Research Concept

Optimization Rules

$$N = \frac{1}{6120} \cdot V \cdot C_{P_Z} \cdot S^{\beta_Z} \cdot t^{\gamma_Z} \cdot HB^{n_Z}$$

$$M = 0.5 \cdot 10^{-3} \cdot D \cdot C_{P_Z} \cdot S^{\beta_Z} \cdot t^{\gamma_Z} \cdot HB^{n_Z}$$

$$\left| \begin{array}{l} V_M \le V_{\max} \\ S_M \le S_{\max} \end{array} \right|$$

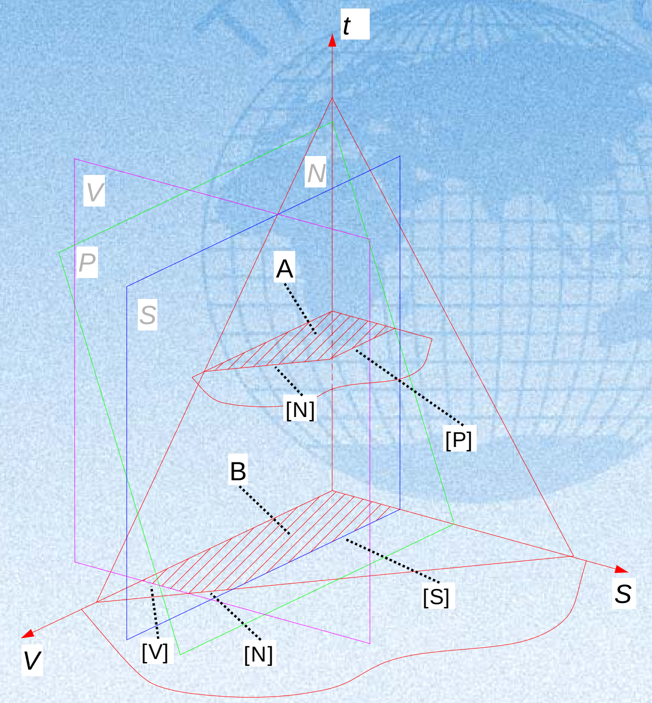
$$R_z = \left[\frac{S_o \cdot t^{\gamma_z} \cdot (\varphi \cdot \varphi_1)^{z_c}}{C_s \cdot r^u} \right]^{\frac{1}{\gamma_s}}$$

$$T_0 = \gamma \cdot \left(\frac{\alpha \cdot \nu - \beta \cdot \mu}{\alpha - \beta} - 1 \right)$$

$$P_x = C_{P_x} \cdot S^{\beta_x} \cdot t^{\gamma_x} \cdot HB^{n_x}$$

$$P_z = C_{P_z} \cdot S^{\beta_z} \cdot t^{\gamma_z} \cdot HB^{n_z}$$

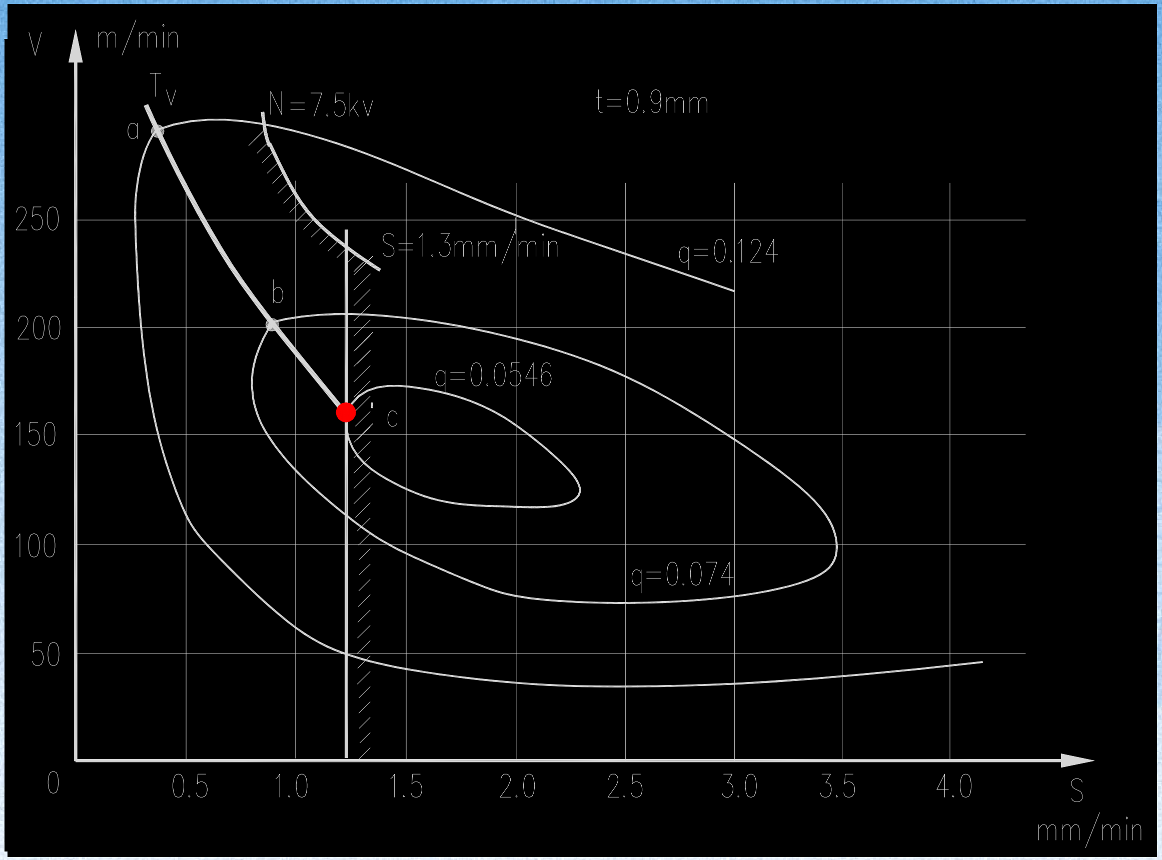
$$P_y = C_{P_y} \cdot S^{\beta_y} \cdot t^{\gamma_y} \cdot HB^{n_y}$$



$$T = \frac{C_T}{V^{\mu} \cdot S^{\nu} \cdot t^{\rho}} \qquad q = \frac{1}{V \cdot S \cdot t} + \frac{\gamma}{C_T} \cdot V^{\mu-1} \cdot S^{\nu-1} \cdot t^{\rho-1}$$

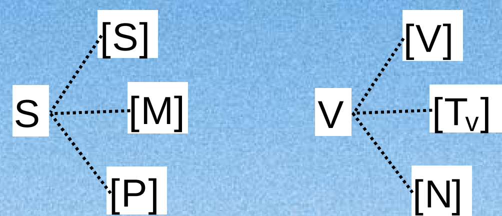
Research Concept

Optimization Rules



Research Concept

Optimization Rules



↓

$$[PV]\,[SV]\,[PT]\,[ST]\,[SN]\,[PN]\,[MV]\,[MN]\,[MT]$$

$$T=\frac{C_T}{V^{\mu}\cdot S^{\nu}\cdot t^{\rho}} \qquad q=\frac{1}{V\cdot S\cdot t}+\frac{\gamma}{C_T}\cdot V^{\mu-1}\cdot S^{\nu-1}\cdot t^{\rho-1} \quad [PV][SV][PT][ST][SN][PN][MV][MN][MT]$$

Research Concept

5 Typical cases of machining:

Workpiece - P20HB180; Cutting tool – GC415;
$\tau_I =$ 2min; Q_I =6.7cent; $[P_z]$=30n; $\lfloor P_y \rfloor$=4n;
$[R_z]$=0.002mm

Workpiece - K20HB260; Cutting tool – GC43
$\tau_I =$ 2min; Q_I =6.7cent; $[P_z]$=30n; $\lfloor P_y \rfloor$=7

$[R_z]$=0.002mm

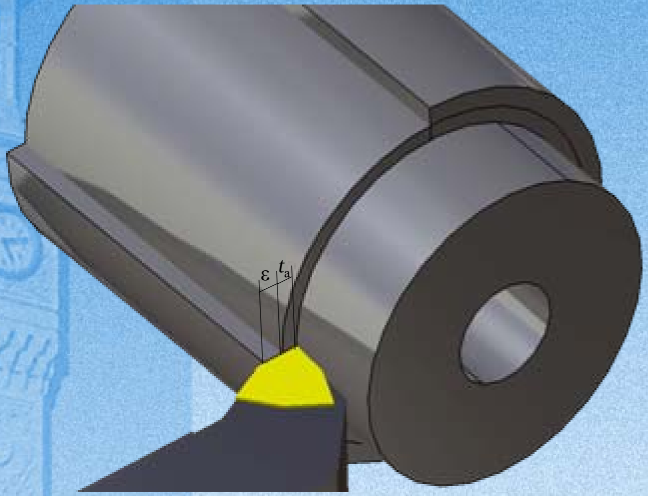
Workpiece – P30HB200; Cutting tool – GC415;
$\tau_I =$ 2min; Q_I =6.7cent; $[P_z]$=30n; $\lfloor P_y \rfloor$=7n;
$[R_z]$=0.002mm

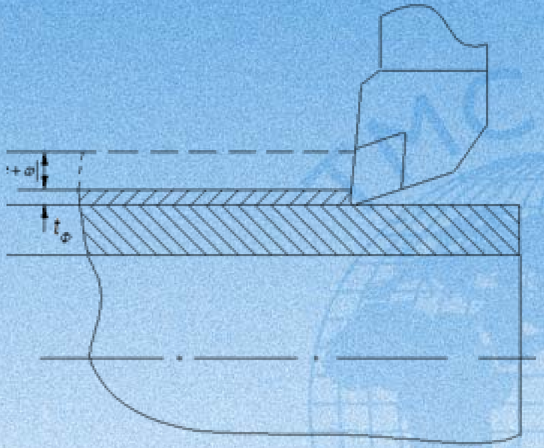
Workpiece – P01HB100; Cutting tool – GC415;
$\tau_I =$ 2min; Q_I =6.7cent; $[P_z]$=30n; $\lfloor P_y \rfloor$=7n;
$[R_z]$=0.002mm

Workpiece - M20HB170; Cutting tool – GC435;
$\tau_I =$ 2min; Q_I =6.7cent; $[P_z]$=25n; $\lfloor P_y \rfloor$=7n;
$[R_z]$=0.002mm

$$T = \frac{C_T}{V^{\mu} \cdot S^{\nu} \cdot t^{\rho}} \qquad q = \frac{1}{V \cdot S \cdot t} + \frac{\gamma}{C_T} \cdot V^{\mu - 1} \cdot S^{\nu - 1} \cdot t^{\rho - 1} \qquad [PV][SV][PT][ST][SN][PN][MV][MN][MT]$$

Analysis of Adaptive Control

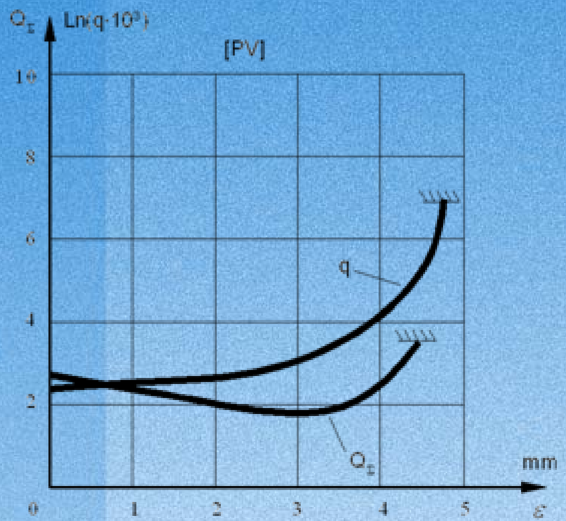




$$T = \frac{C_T}{V^{\mu} \cdot S^{\nu} \cdot t^{\rho}} \qquad q = \frac{1}{V \cdot S \cdot t} + \frac{\gamma}{C_T} \cdot V^{\mu-1} \cdot S^{\nu-1} \cdot t^{\rho-1}$$

[PV] [SV] [PT] [ST] [SN] [PN] [MV] [MN] [MT]

Analysis of Adaptive Control

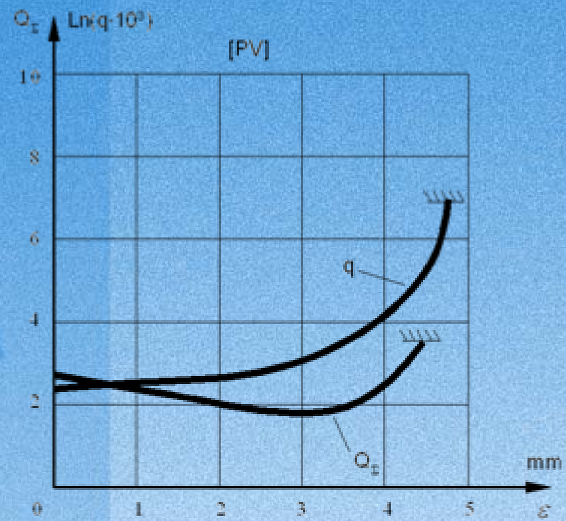


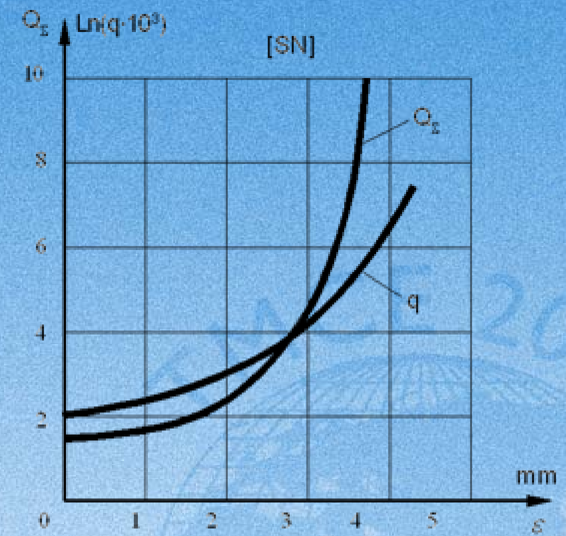
$$q \rightarrow Q_W$$

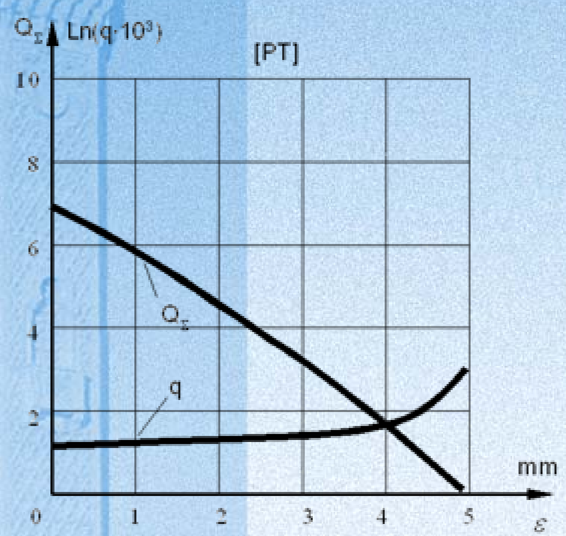
$$q = \frac{1}{V \cdot S \cdot t} + \frac{\gamma}{C_T} \cdot V^{\mu-1} \cdot S^{\nu-1} \cdot t^{\rho-1}$$

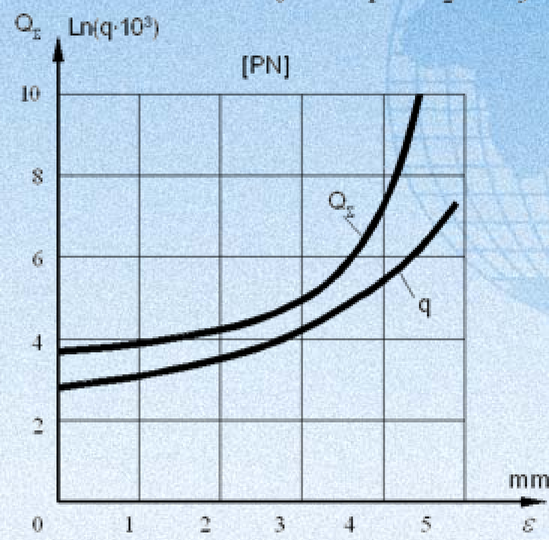
$$T = \frac{C_T}{V^{\mu} \cdot S^{\nu} \cdot t^{\rho}} \qquad q = \frac{1}{V \cdot S \cdot t} + \frac{\gamma}{C_T} \cdot V^{\mu-1} \cdot S^{\nu-1} \cdot t^{\rho-1} \qquad [PV][SV][PT][ST][SN][PN][MV][MN][MT]$$

Analysis of Adaptive Control



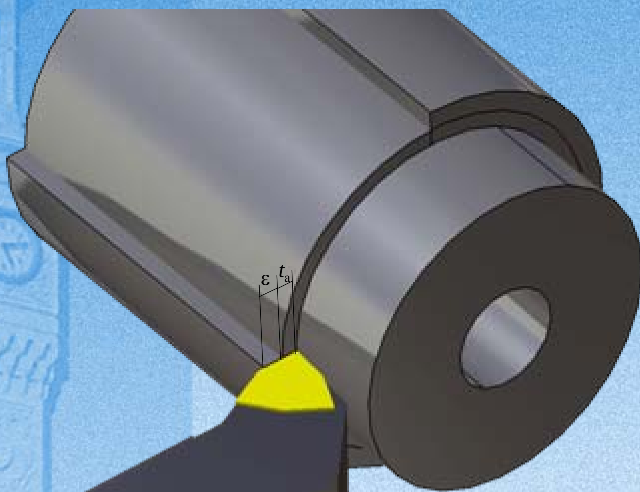


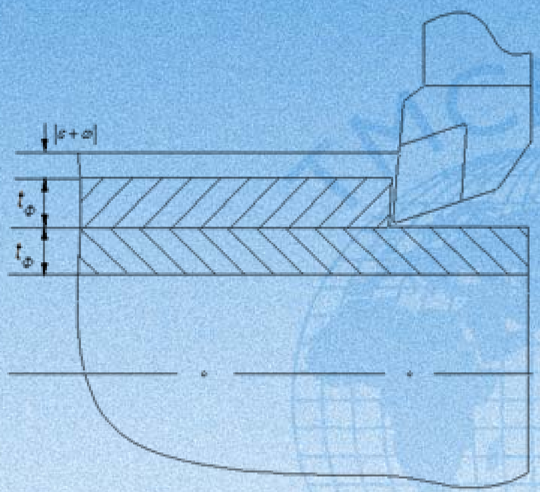




$$T = \frac{C_T}{V^{\mu} \cdot S^{\nu} \cdot t^{\rho}} \qquad q = \frac{1}{V \cdot S \cdot t} + \frac{\gamma}{C_T} \cdot V^{\mu-1} \cdot S^{\nu-1} \cdot t^{\rho-1} \quad [PV][SV][PT][ST][SN][PN][MV][MN][MT]$$

Analysis of Adaptive Part Programming



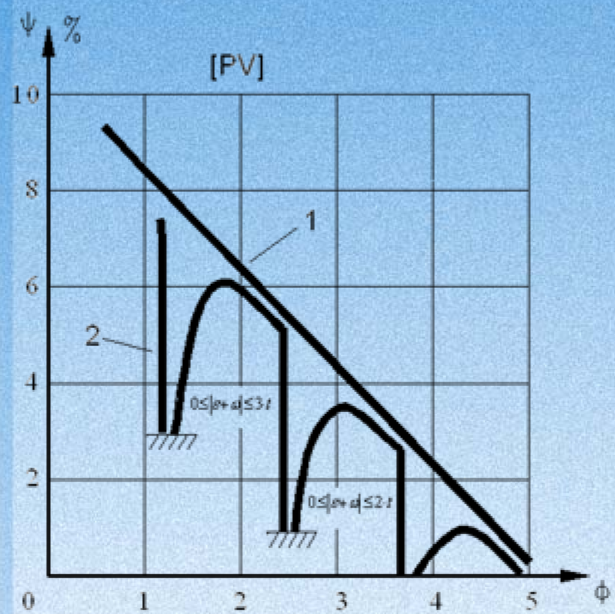


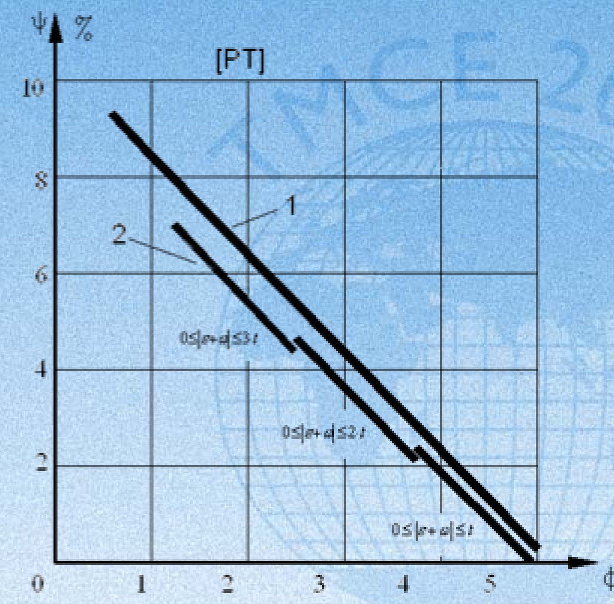
$$T = \frac{C_T}{V^{\mu} \cdot S^{\nu} \cdot t^{\rho}} \qquad q = \frac{1}{V \cdot S \cdot t} + \frac{\gamma}{C_T} \cdot V^{\mu-1} \cdot S^{\nu-1} \cdot t^{\rho-1}$$

$[PV][SV][PT][ST][SN][PN][MV][MN][MT]$

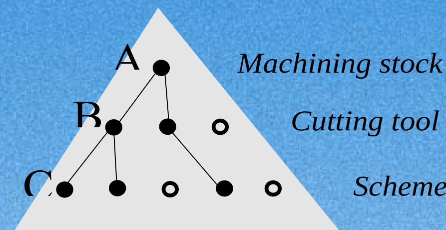
Analysis of Adaptive Part Programming

$$\psi = \left(\frac{Q_0}{Q_a} - 1 \right) \cdot 100\%$$



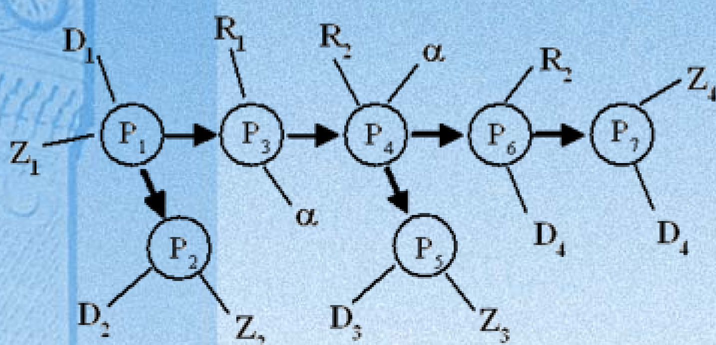


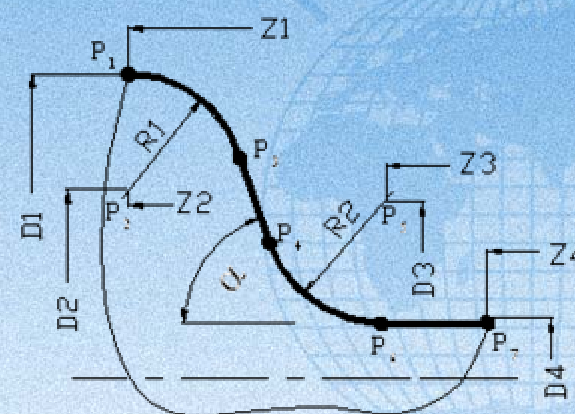
Realization of APP



$$M_2 = \{A_1 - B_2 - C_4\}$$

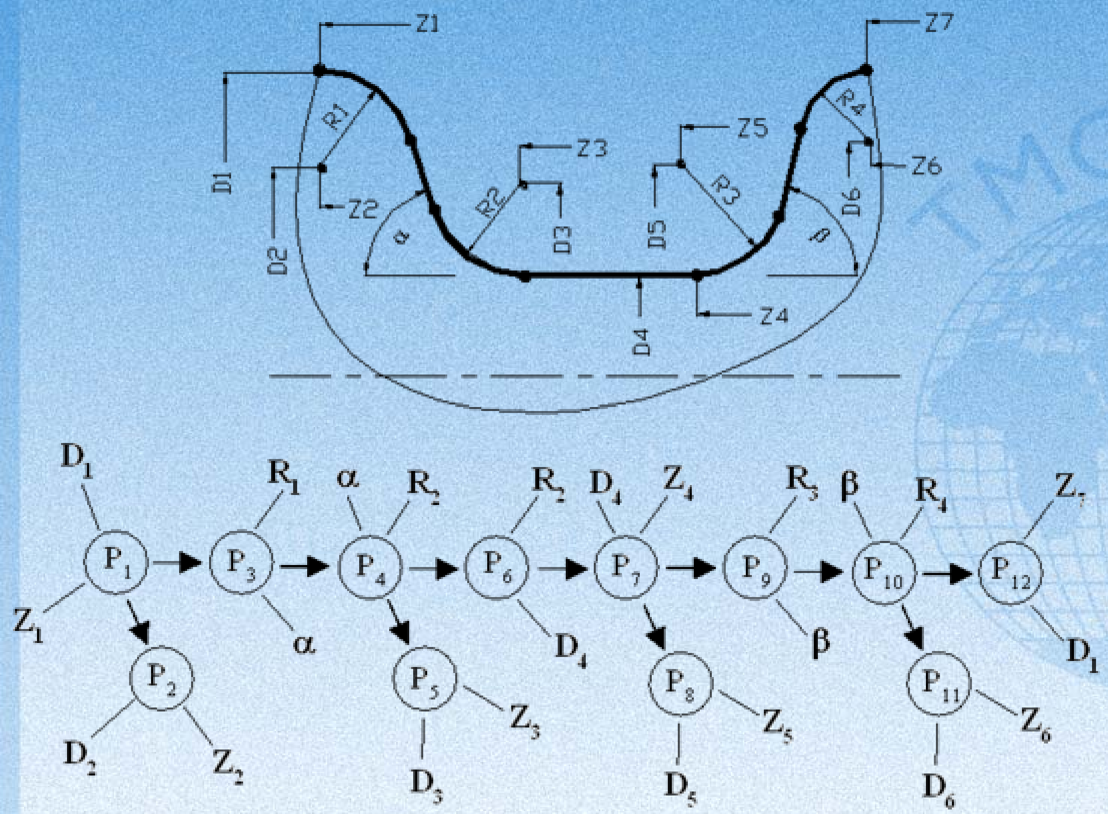
STHO Structure





Realization of APP

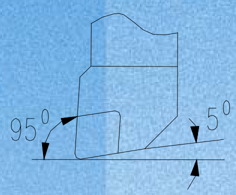
STCL Structure



Realization of APP

Model Formalizm for STHO

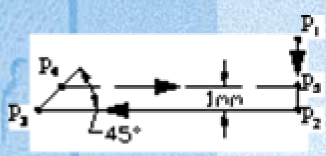
T_{1HO}

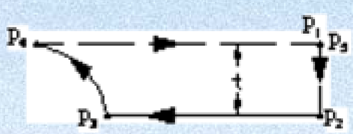


$$
\left| \begin{array}{l}
Z_{HO}^{E} \rightarrow T_{1HO}^{E} \rightarrow M_{1-1}^{L} \\
Z_{HO}^{E} \rightarrow T_{1HO}^{E} \rightarrow M_{1-1}^{D} \\
Z_{HO}^{E} \rightarrow T_{1HO}^{E} \rightarrow M_{1-2}^{L} \\
Z_{HO}^{E} \rightarrow T_{1HO}^{E} \rightarrow M_{1-2}^{D}
\end{array} \right|
$$

M_{1-1} –“Fast->Feedrate->Fast->Fast”

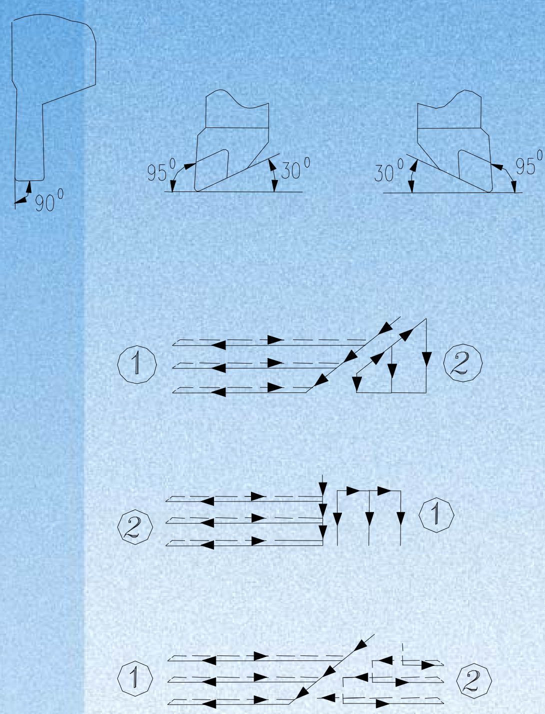
M_{1-2} – “Fast->Feedrate->Feedrate->Fast”





Realization of APP

Model Formalizm for STCL



$$
\left|
\begin{array}{l}
Z^{E}_{CL} \rightarrow T^{E}_{1CL} \rightarrow M_{3} \\[6pt]
Z^{E}_{CL} \rightarrow \begin{array}{l} T^{E}_{2HO} \rightarrow M_{1-1} \\ T^{E}_{1CL} \rightarrow M_{3} \end{array} \\[6pt]
Z^{E}_{CL} \rightarrow \begin{array}{l} T^{E}_{1CL} \rightarrow M_{3} \\ T^{E}_{1HO} \rightarrow M_{1-1} \end{array} \\[6pt]
Z^{E}_{CL} \rightarrow \begin{array}{l} T^{E}_{2HO} \rightarrow M_{1-1} \\ T^{E}_{2CL} \rightarrow M_{1-1} \end{array}
\end{array}
\right|
$$

CNC Custom Software Development

Sinumerik MS2-300 Heidenhain Co.

Contact Probe *Marpos*

Adaptive Control Unit Promess – [M] [V]

$$N\ldots\{A_i\}\{X_j\}\{H_k\}\{Y_m\}$$

A_i - is array of subroutine names – 5 names L71÷L75 were reserved for this array

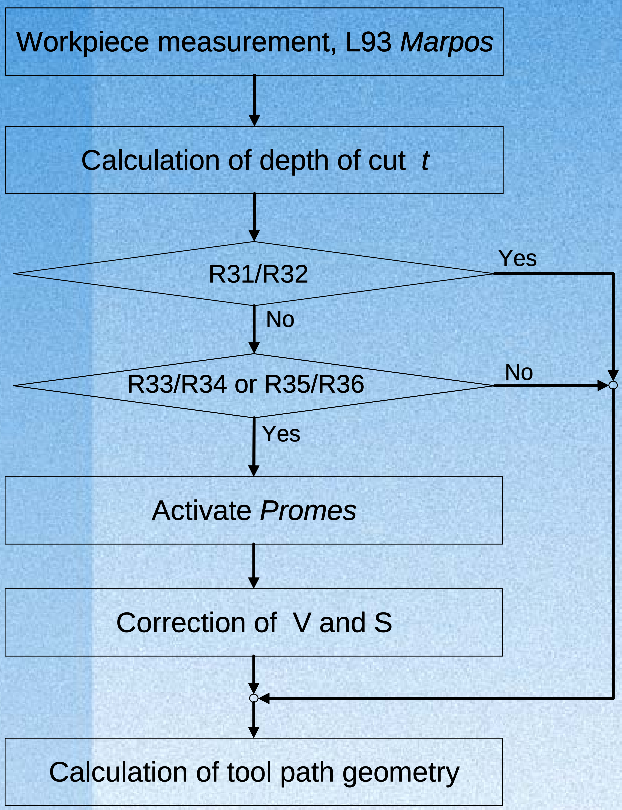
X_j - array of geometrical parameters of STHO/STCL; 19 parameters R11÷R30 were reserved

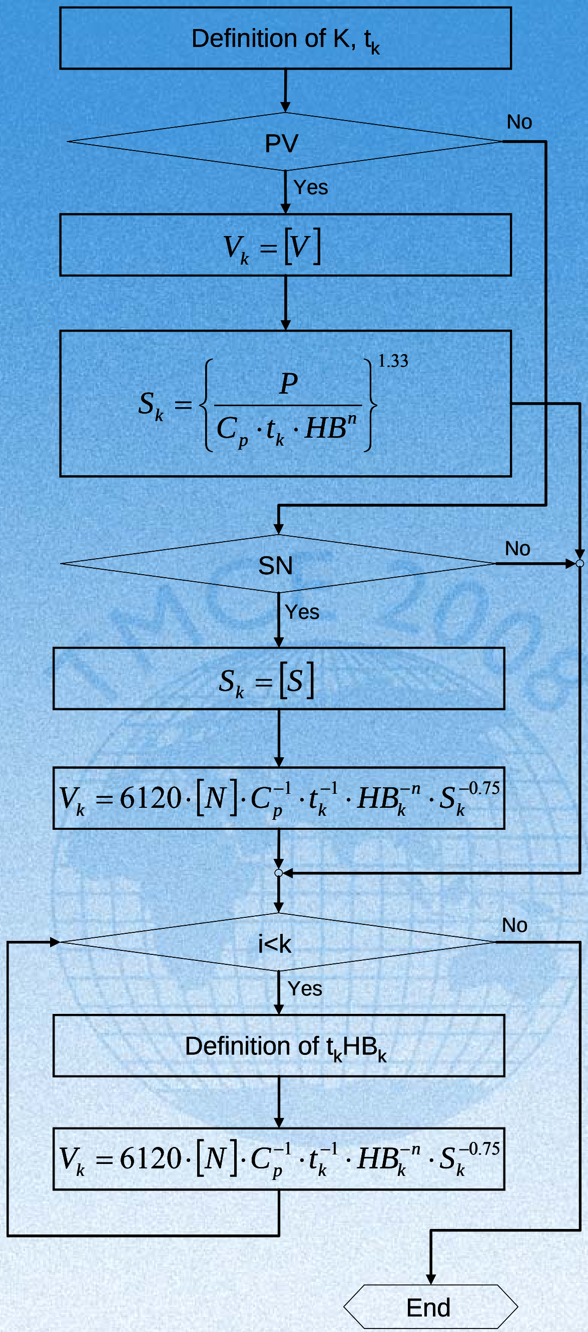
H_k - array of machining parameters, optimization rules and constants – 9 parameters R31÷R40 were reserved

Y_m - array of entry control parameters - 9 parameters R41÷R50 were reserved.

CNC Custom Software Development

Correction Algorithms





Conclusions

1. For rough cutting conditions it is identified that correction of tool path geometry according to actual value of workpiece dimensions brings enhancement of fixed rule adaptive control for $[PV]$, $[SN]$, $[PN]$, $[MV]$, $[MN]$ control.

2. For limitations concerning with cutting tool life period (rules $[PT]$, $[MT]$), correction of tool path geometry is not necessary.

3. Adaptive Part Programming approach can be realized through the customization of the standard cycle's library of CNC.

Thanks a lot !