PROCESS OPTIMIZATION FOR MACHINIG OF HARDENED STEEL MATERIALS

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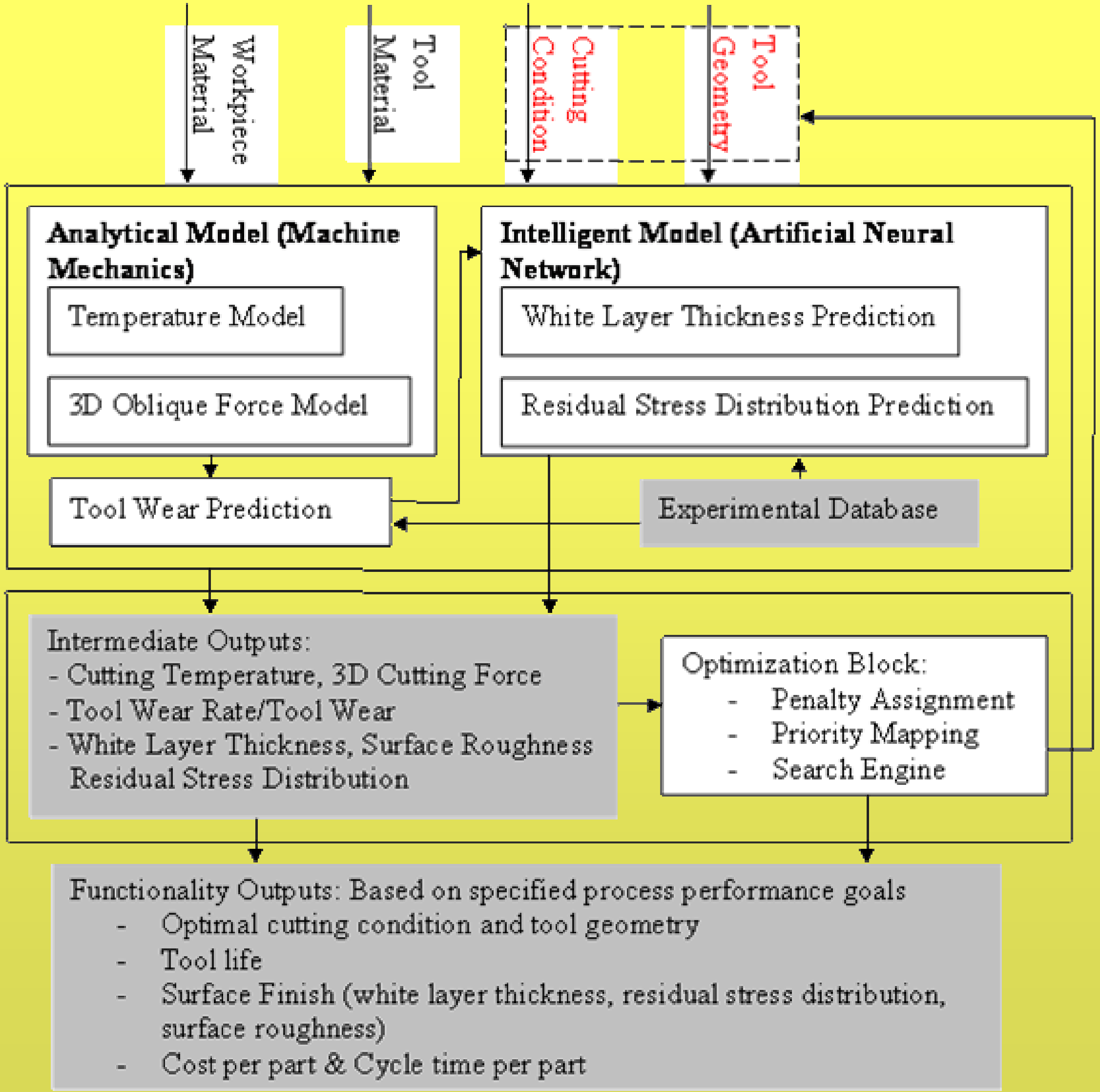
Objective

Design the optimal ***Tool Geometries*** (edge preparation, rake angle and tool nose radius…) and ***Cutting Conditions*** (cutting speed, feedrate and DOC) to achieve the specified process performance goals with satisfactory surface finish (surface roughness, white layer thickness, residual stress distribution) and any other practical constraints, such as tool life, power consumption and the vibration stability…

Process Optimization Flow Chart



Optimization Block (MIEA)

- The genetype space is the same as phenotype space
- One-gene-one-variable scheme
- Binary implementation for integer (discrete) variables
- Float point implementation for continuous variables
- Tournament selection (tournament size q=8)
- Local fine turning capabilities
- A new penalty constraint handling method
- α μ population initialization

Temperature Model 1

- <u>Average Temperature along Rake face and Flank face vs. VB</u>

$$T_{rake\_ave} = T_0 + \Delta T_{sz} + \psi \Delta T_M + \Delta T_{VB}$$

$$\Delta T_{sz} = \frac{(1-\beta) F_s V_s}{\rho C V_c a^* t^*} \qquad \Delta T_c = \frac{F V_{chip}}{\rho C V_c a^* t^*} \qquad \Delta T_{VB} = \frac{\Gamma q_{rubbing} VBw}{\rho C V_c a^* t^*}$$

$$\ln\left(\frac{\Delta T_M}{\Delta T_C}\right) = 0.06 - 0.195\delta\left(\frac{R_T t_2}{h}\right)^{1/2} + 0.5\ln\left(\frac{R_T t_2}{h}\right)$$

$$T_{rake\_ave} = T_{c\_ave}, \quad T_{flank\_ave} = \gamma T_{rake\_ave}, \quad T_{w\_ave} = T_{flank\_ave}$$

$$\beta = 0.5 - 0.35\log_{10}(R_T \tan\phi) \qquad \text{For } 0.04 \le R_T \le 10.0$$

$$\beta = 0.5 - 0.15\log_{10}(R_T \tan\phi) \qquad \text{For } R_T \ge 10.0$$

$\Gamma = 0.4, \ \gamma = 0.8$ **(Oxley, 1989; Boothroyd, 1963, 1967)**

Temperature Model 2

- Maximum Tool Temperature along Flank face vs. VB

$$\Psi = \frac{T_{\text{max\_flank}}}{T_{\text{ave\_flank}}} = k_1 V_c VB + k_2 doc / feed + k_3$$

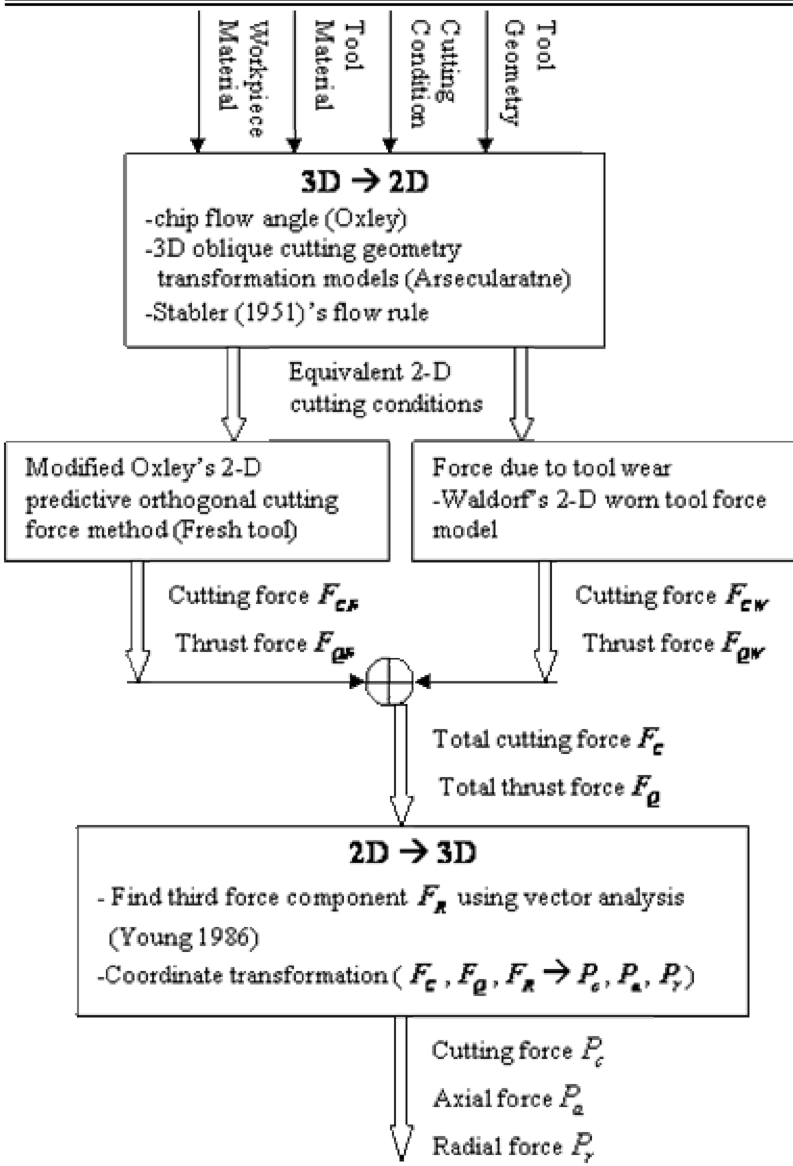
V_c: sfpm, VB:um, doc: inch, $feed$: ipr

$k_1 =$ 1.11219*1e-6,

$k_2 =$ 3.1906*1e-3,

$k_3 =$ 999.3387*1e-3

Force Model



Workpiece material property:

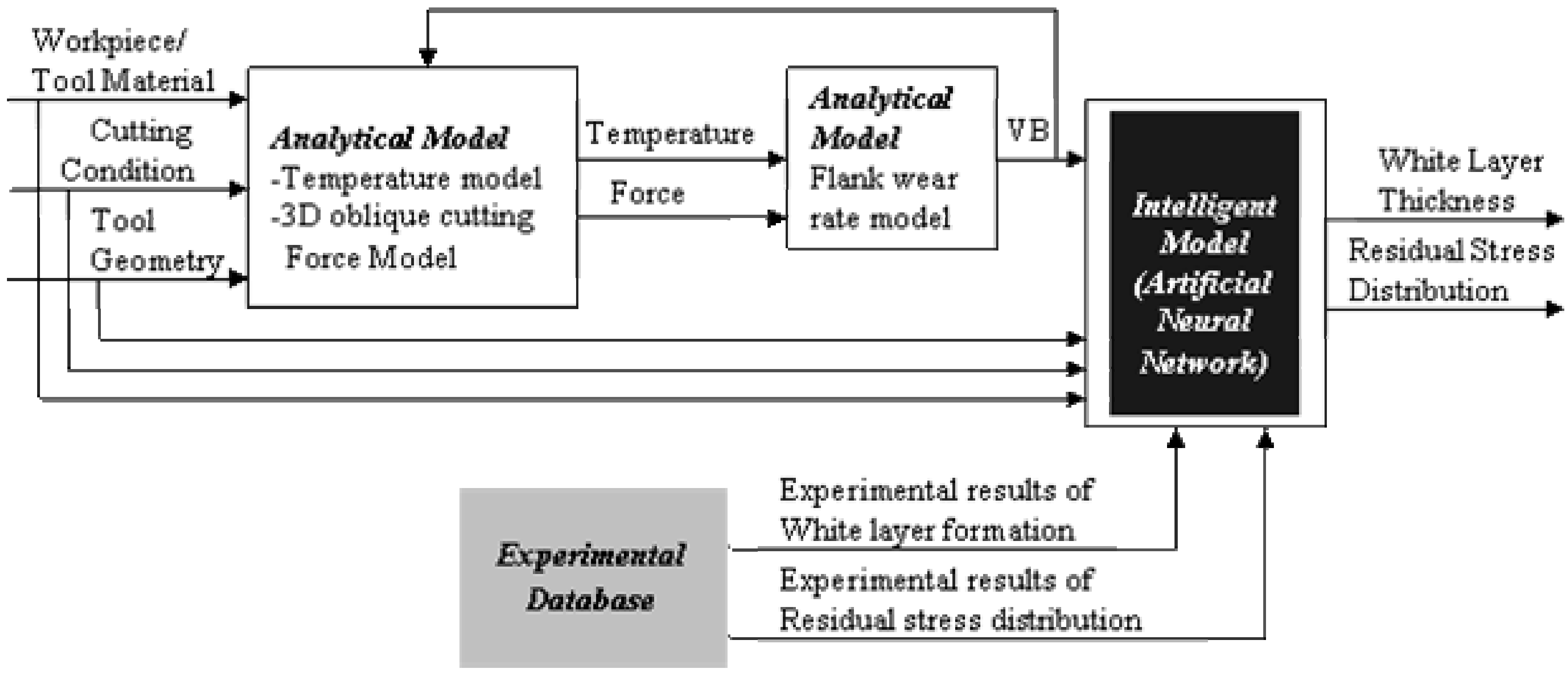
$$\sigma = \left(A + B\varepsilon^{n}\right)\left(1 + C\ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_{o}}\right)\left(1 - \left(\frac{T - T_r}{T_m - T_r}\right)^{m}\right)$$

- -Johnson-Cook equation coefficient: A, B, C, m, n
- -Specific heat capacity
- -Thermal conductivity
- -Density

Tool material property:

- -Specific heat capacity
- -Thermal conductivity
- -Density

Hierarchical Model Scheme



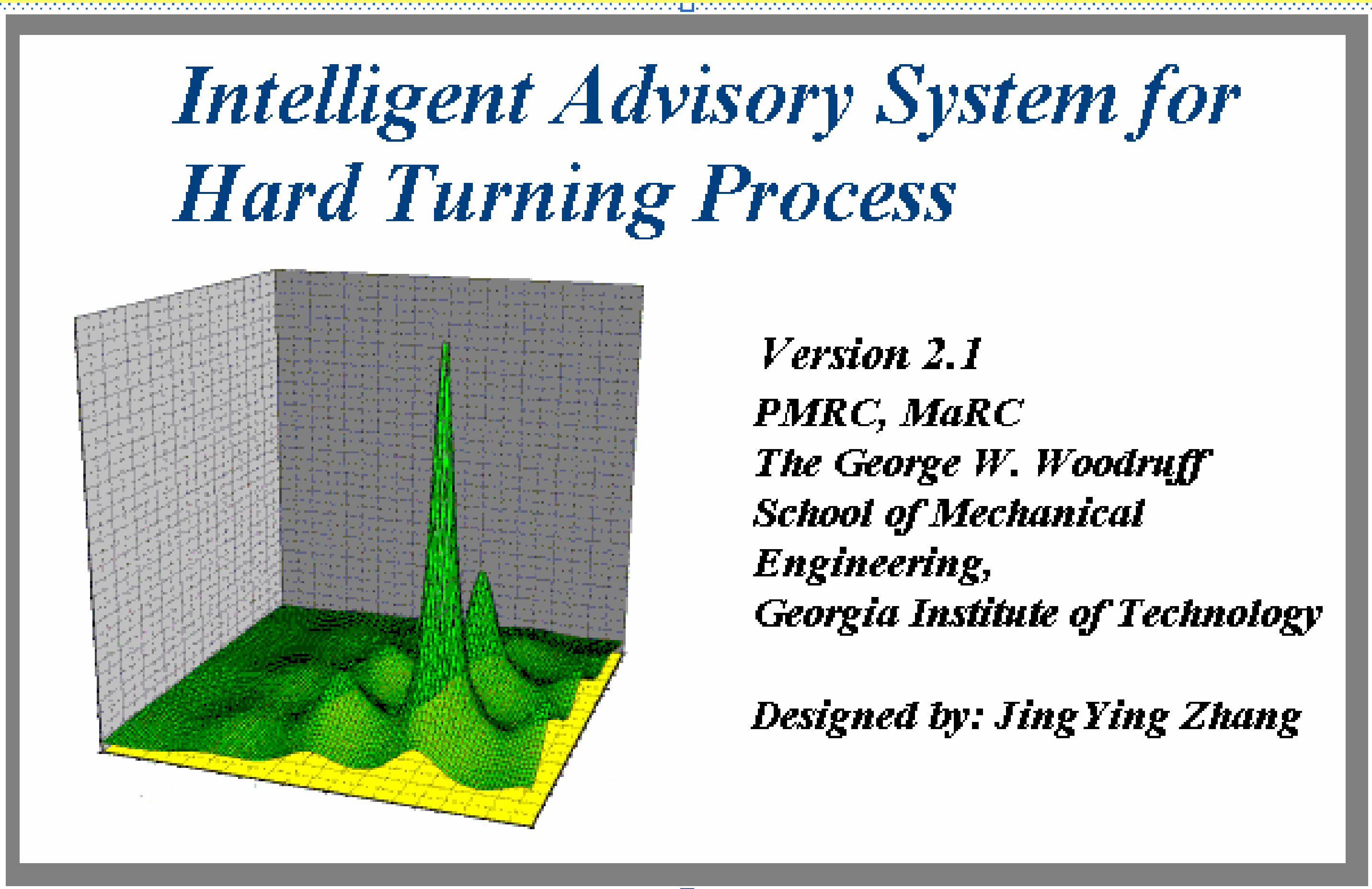
Flank Wear Prediction

$$\frac{dVB}{dt} = \frac{(\cot\gamma + \tan\alpha)R}{VB(R - \tan\gamma)} \left\{ \begin{array}{l} K_{abrasion} K \left(\dfrac{P_a^{n-1}}{P_t^{n}} \right) V_c VB \bar{\sigma} \\ + K_{adhesion} e^{aT} V_c \bar{\sigma} \\ + K_{diff} \sqrt{V_c VB} e^{-\frac{K_Q}{T+273}} \end{array} \right\}$$

(Huang & Liang, 2002)

Intelligent Advisory System

Intelligent Advisory System for Hard Turning Process



Process Optimization

Application:

- The inner ring OD hard turning
- Dry machining
- Material 52100(60~64HRC)
- Tool Insert KB5625
- Fixed Depth of Cut = 0.25 mm

Requirement

- Surface roughness is smaller than 0.5um
- No white Layer
- Compressive circumferential and longitudinal residual stress profiles
- Available power is smaller than 1.5HP

Design Variables

Tool Geometry:

Nose Radius: 2, 3, 4 nose *(Discrete Variable)*

Tool Orientation:

Back rake angle: -5 degree, 0 degree, +5 degree (Discrete Variable)

Clearance angle: 5, 8, 10, 12, 16, 20, 25, 30 degree (Discrete Variable)

Edge Preparation:

Chamfer angle: 0 degree, 15 degree, 20 degree (Discrete Variable)

Cutting Conditions:

- Cutting speed: V_c *(Continuous Variable)*
- Feedrate: f *(Continuous Variable)*
- The number of workpieces per insert: N *(Integer)*

Constraints

$300 \le v_c \le 600$ (sfpm)

$0.002 \le f \le 0.006$ (ipr)

Surface Roughness: $R_a(k) \le 0.5um$

White Layer Thickness: $WL(k) \le 0um$

Longitudinal residual Stress: $\sigma_L(k) \le 0$

Circumferential residual Stress: $\sigma_R(k) \le 0$

Power: $P(k) \le 1.5HP$

k=1,2,...N

Objective Function

- **Minimum Cost per Part**

$$C_p = (C_m^{'} + C_w^{'})t_t + \frac{C_t}{N}$$

- **Maximum Production Rate**

$$t_t = t_{load} + \frac{t_{mach}}{f_{mach}} + \frac{t_{ct}}{N}$$

- **Both**

$$Obj = w_p C_p + w_t t_t \qquad (w_p = 0.5, w_t = 0.5) \text{ is used}$$

Optimal Results

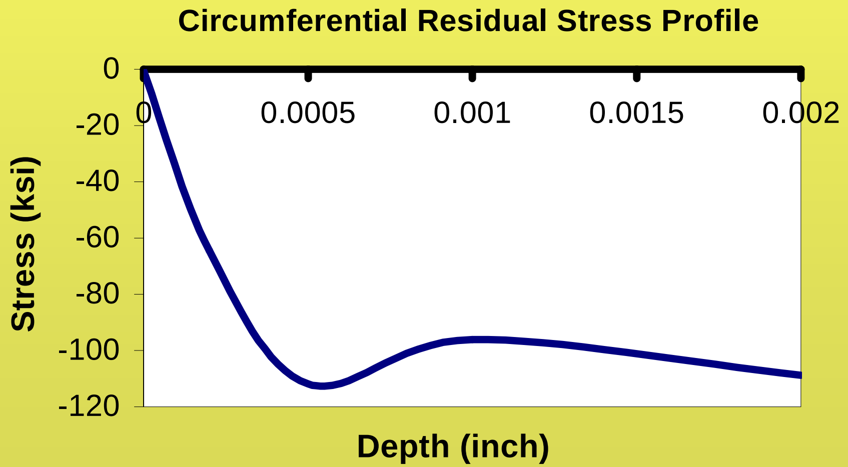
Minimum Cost per Part

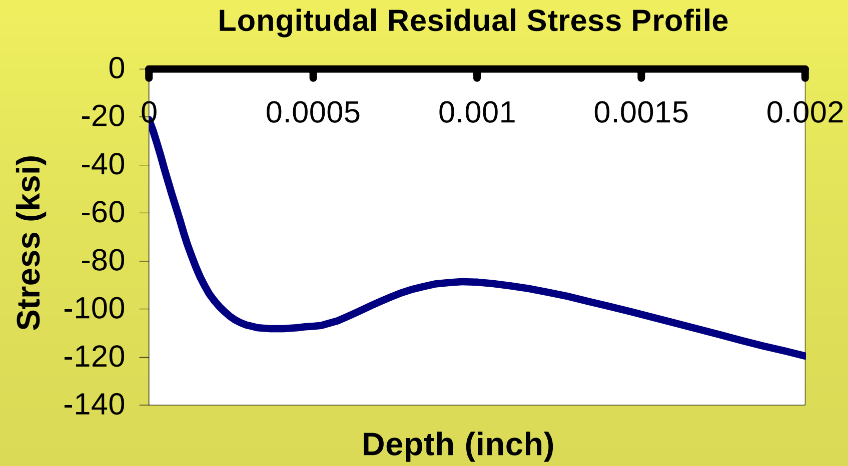
Design Variable	Value
Nose Radius	4 nose (1.588mm)
Back Rake Angle	-5
Chamfer Angle	-20
Clearance Angle	30
N	811
v_c (sfpm)/(m/s)	600/ 3.0488
f (ipr)/(mm)	0.006/0.1524

Optimal Results

Process Output	Constrain Value	Total Cost ($/pc)	Cycle Time
VB (um)	213.8		
Ra (um)	0.4571		
$WL(1)$ (um)	0	0.9116	0.8434
$WL(N)$ (um)	0		
$MRR(cm^3/s)$	11.6159		

Residual Stress Profile:





Thank You☺

Questions?