Computational Geometric Techniques for Sculptured Surface Manufacturing and CAD/CAM

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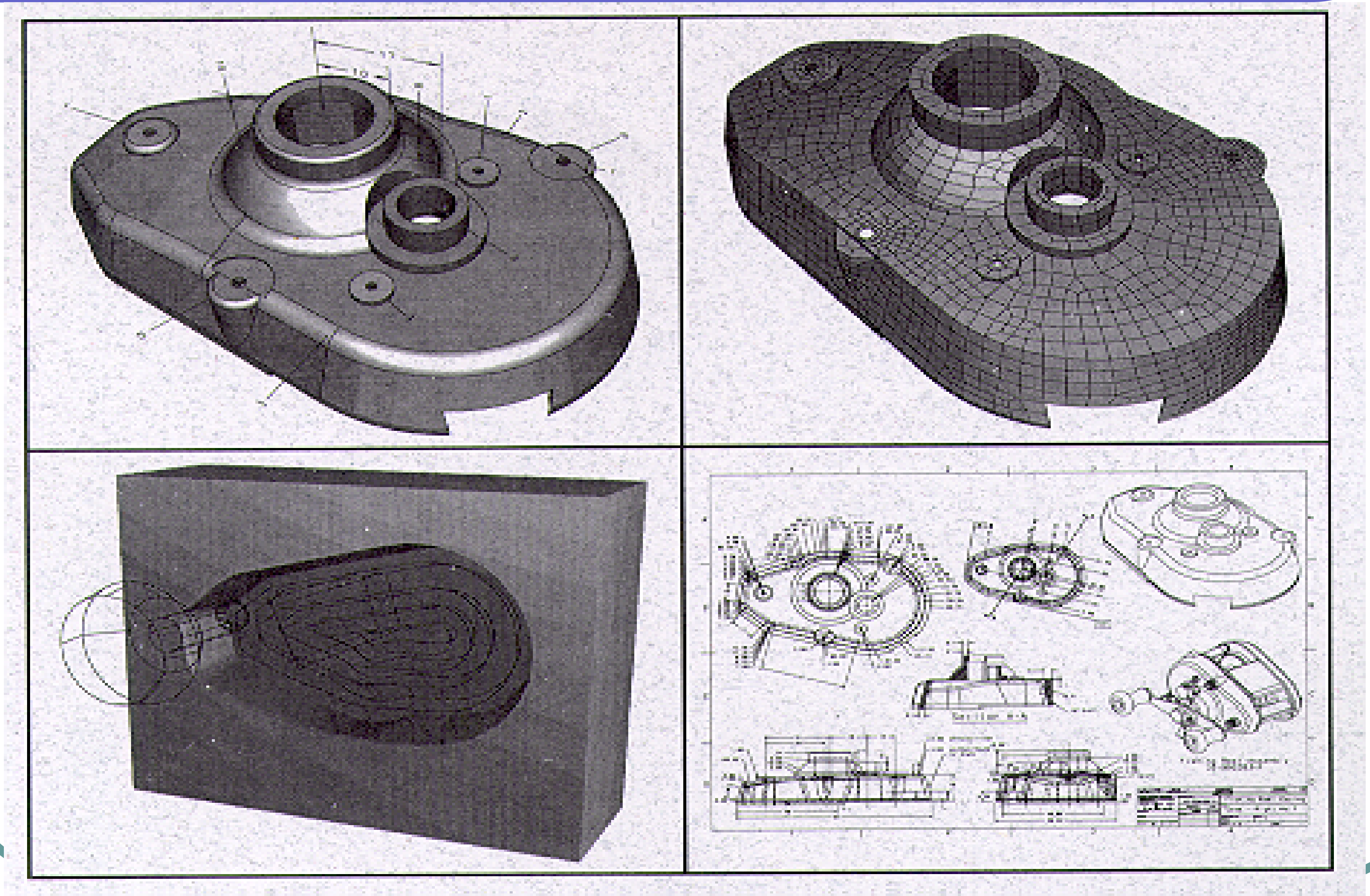
October 7, 2003

Outlines

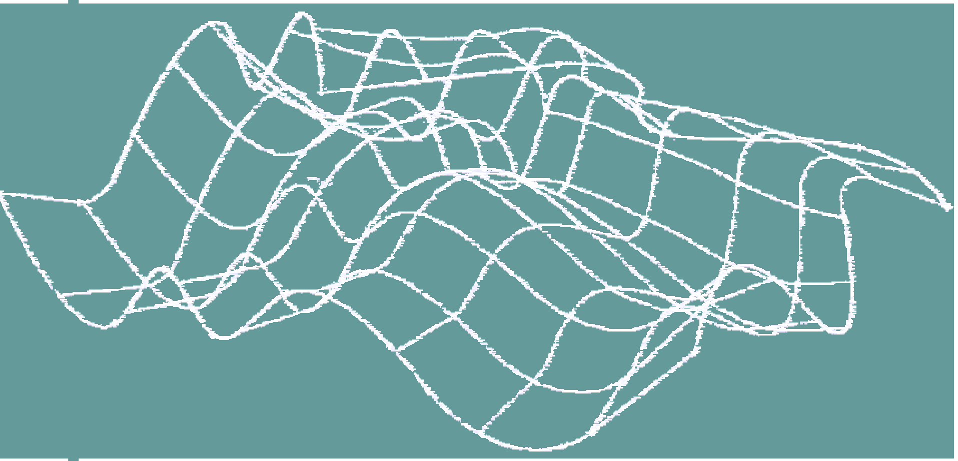
- Introduction of Sculptured Surface Machining (SSM)
- CAD/CAM for Polyhedral Model Machining
- 5-Axis Tool Path Generation in CAD/CAM
- Machining Potential Field (MPF) for Complex Surface Manufacturing
- High Speed Machining (HSM) of Sculptured Surfaces
- Constant Material Removal Rate for HSM
- Adaptive Feedrate Scheduling for HSM
- Conclusions

1. Introduction of Sculptured Surface Machining (SSM)

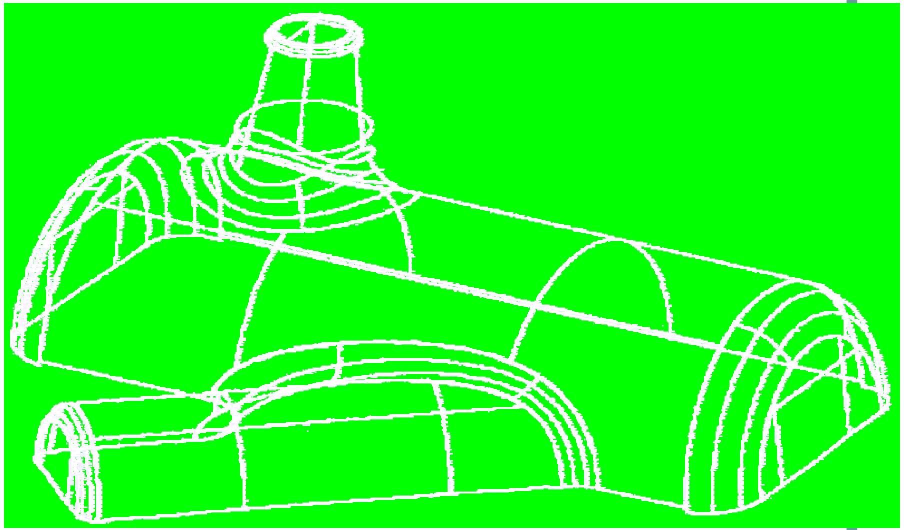
Product Design with Sculptured Surfaces



NURBS Surface and Applications



The NURBS surface interpolating four boundary curves.



NURBS surface of the core pattern

Product Geometric Modeling and Manufacturing

- Conceptual model:

- Physical model: clay model

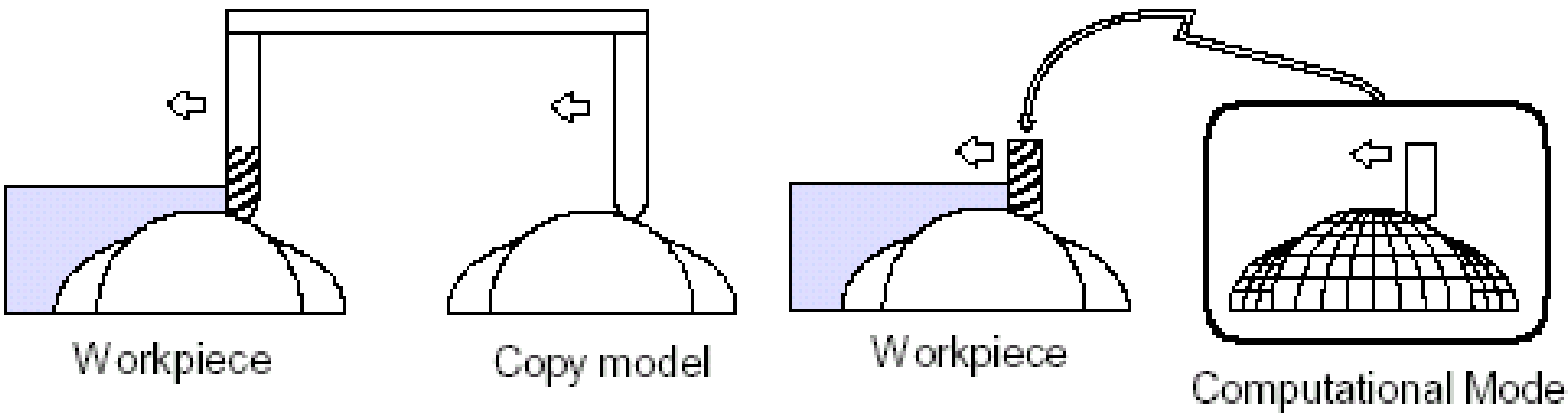
- Descriptive model : engineering drawing

- Mathematical model:

- Computational model:

Wireframe model
Surface model
Solid mode
Non-manifold model

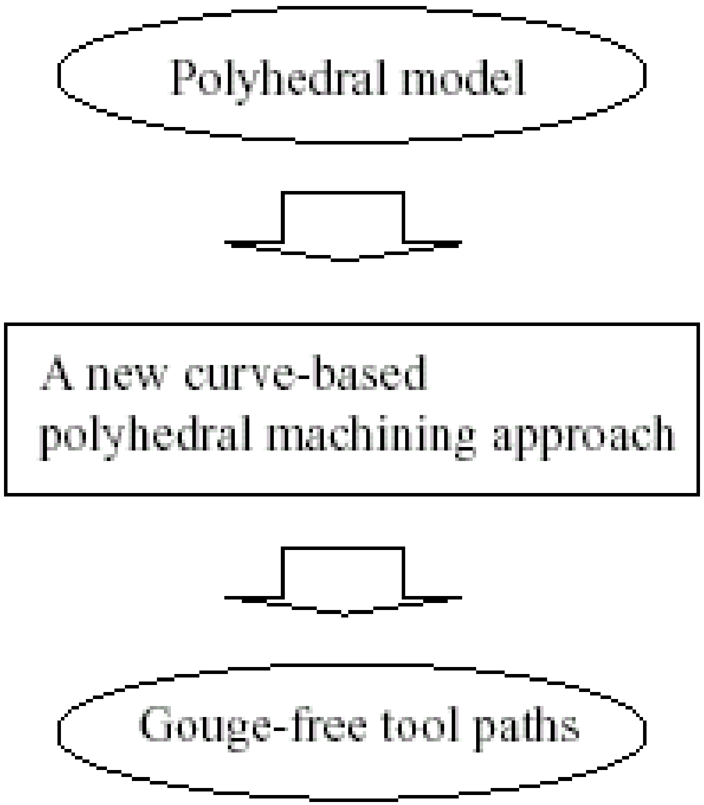
Introduction to Sculptured Surface Machining (SMM)

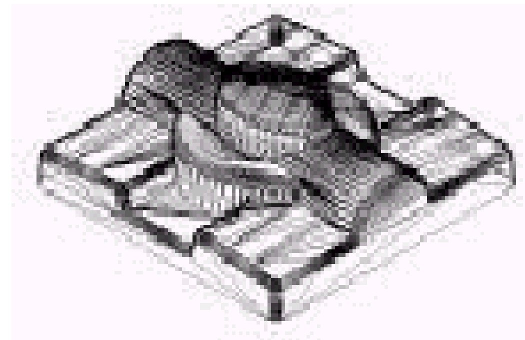


Copy milling NC milling

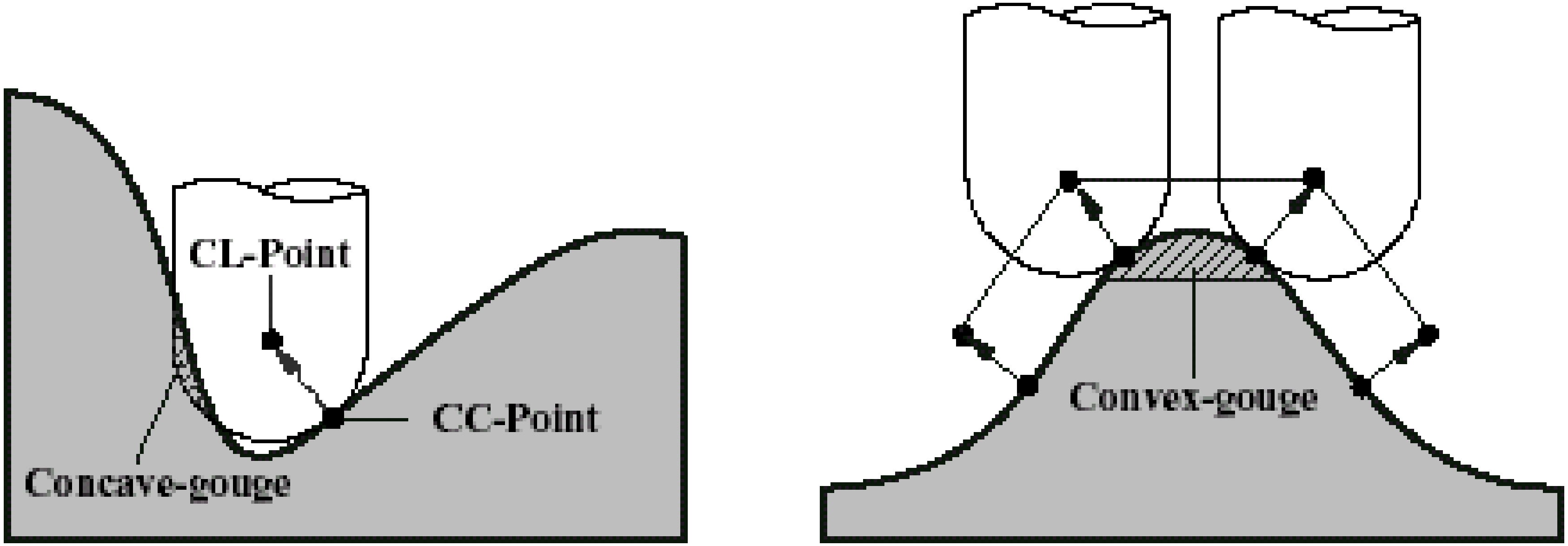
2. CAD/CAM for Polyhedral Model Machining

Polyhedral Models and NC Machining

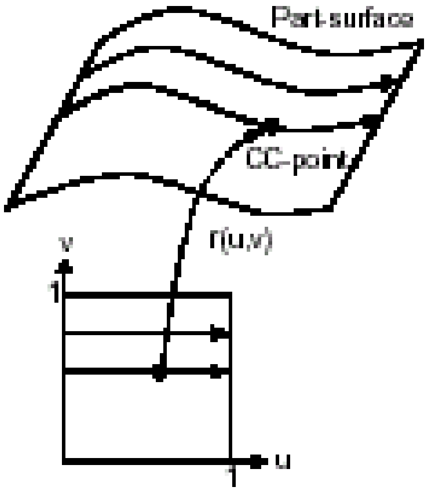




Cutter Gouging Problems in Sculptured Surface Machining

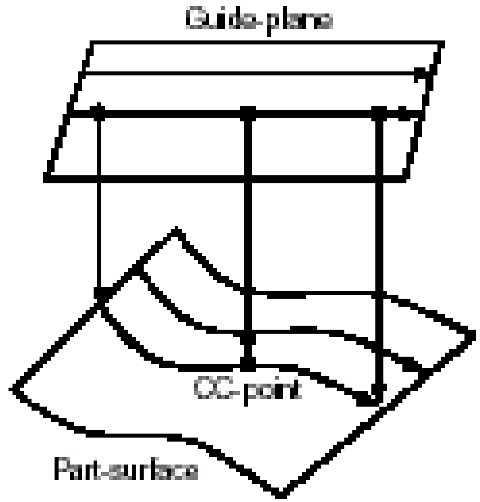


NC Cutter Path Generation Methods

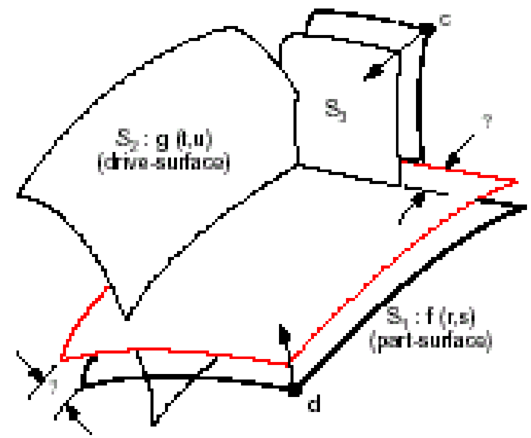


1. CC-based path

(Iso-parametric)

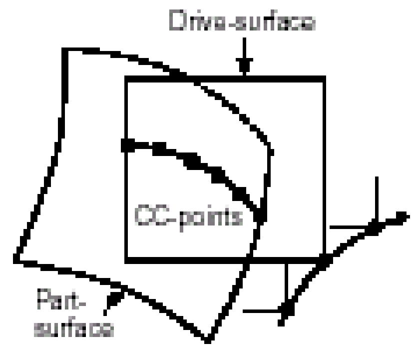


2. CC-Cartesian path



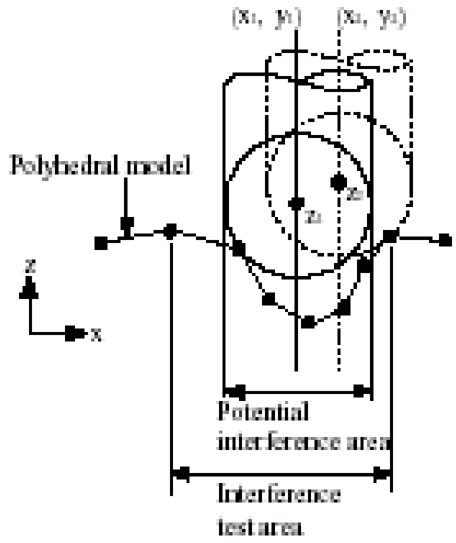
3. CL-based path (offset)

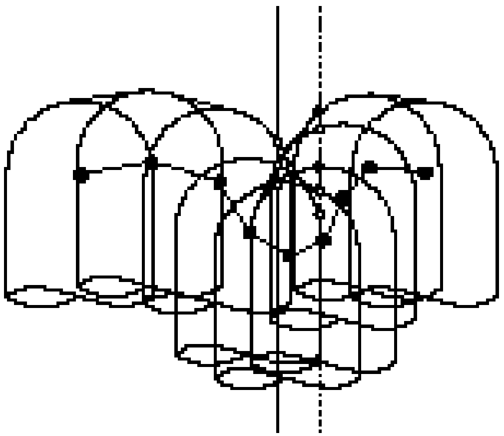
4. APT-type path



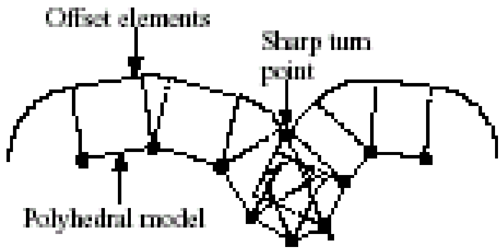
Offset of Polygon for Cutter Location (CL)

Point-based approach



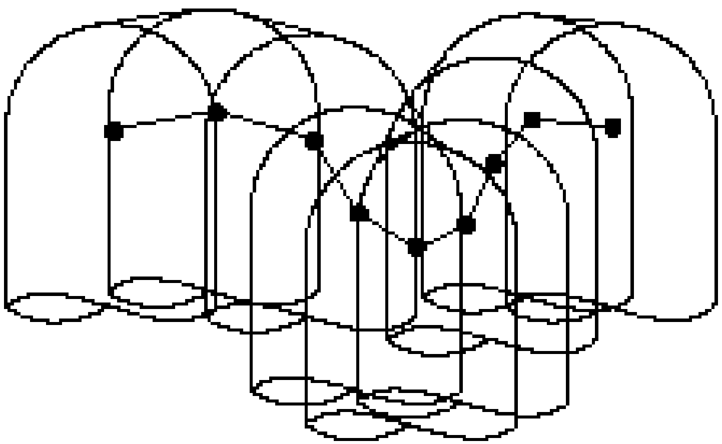


Curve-based approach



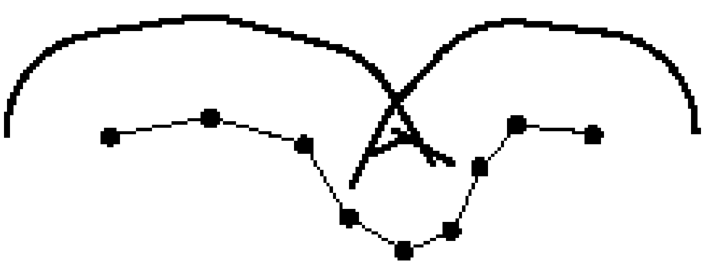
Three Schemes of Polyhedral Offsetting

? Individual offsetting scheme

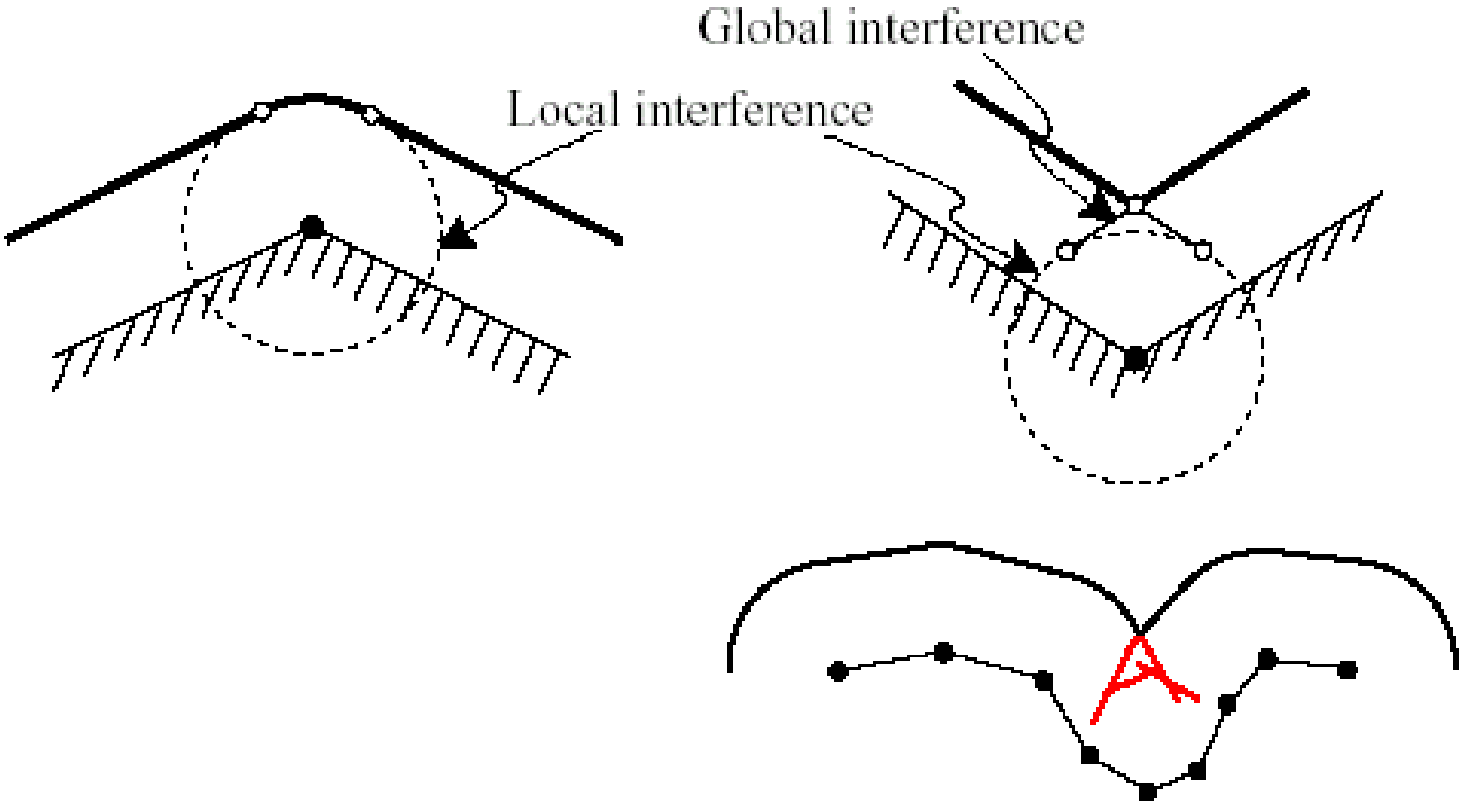


? Global-offsetting scheme

? Local-offsetting scheme

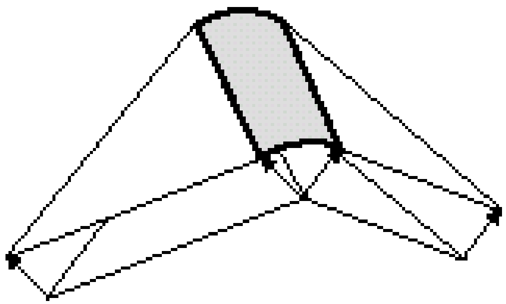


Deleting Interference to Avoid Gouging

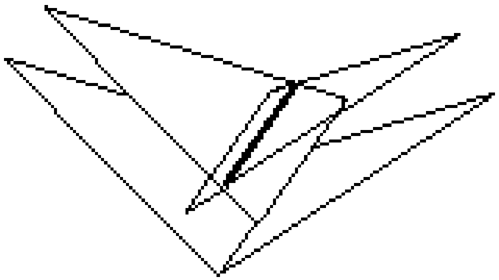


Offset of Triangles and Edges of Polyhedral Models

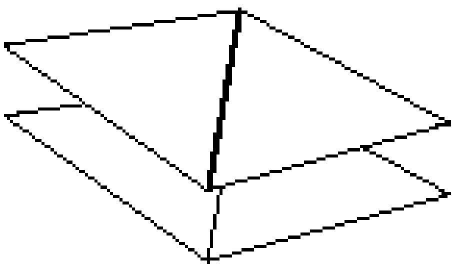
? Convex edge



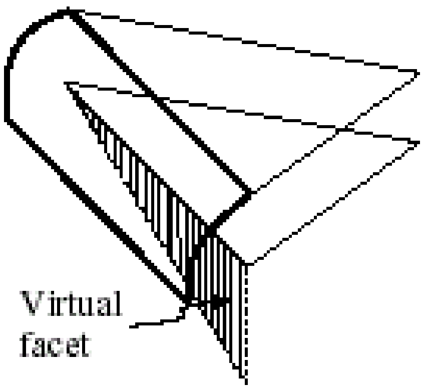
? Concave edge



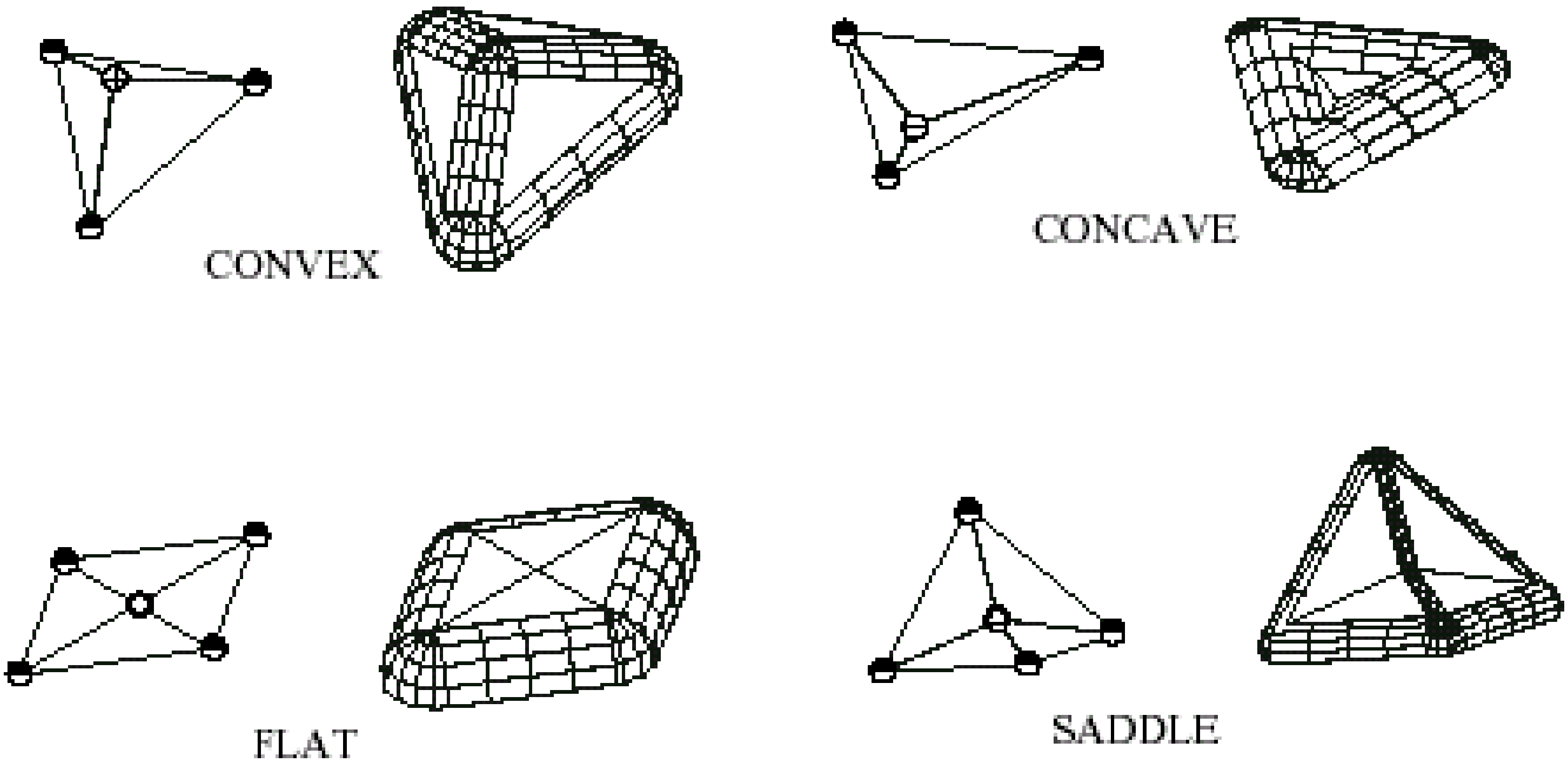
? Flat edge



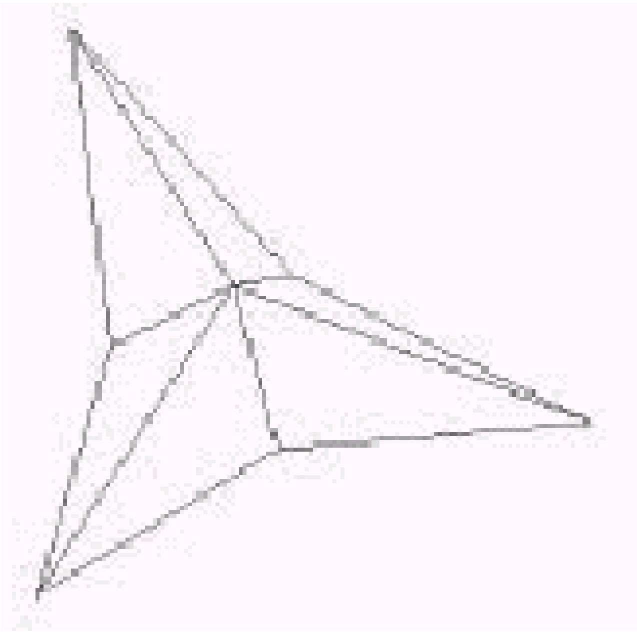
? For a boundary edge

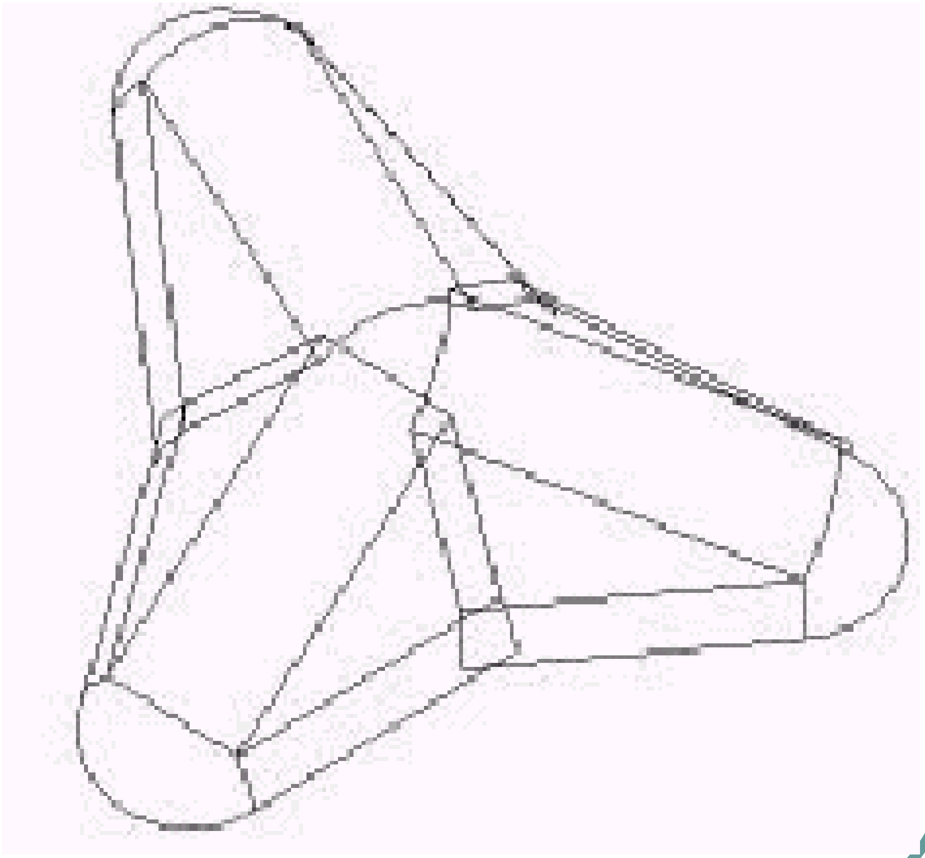


Offset of Vertex in Polyhedral Models

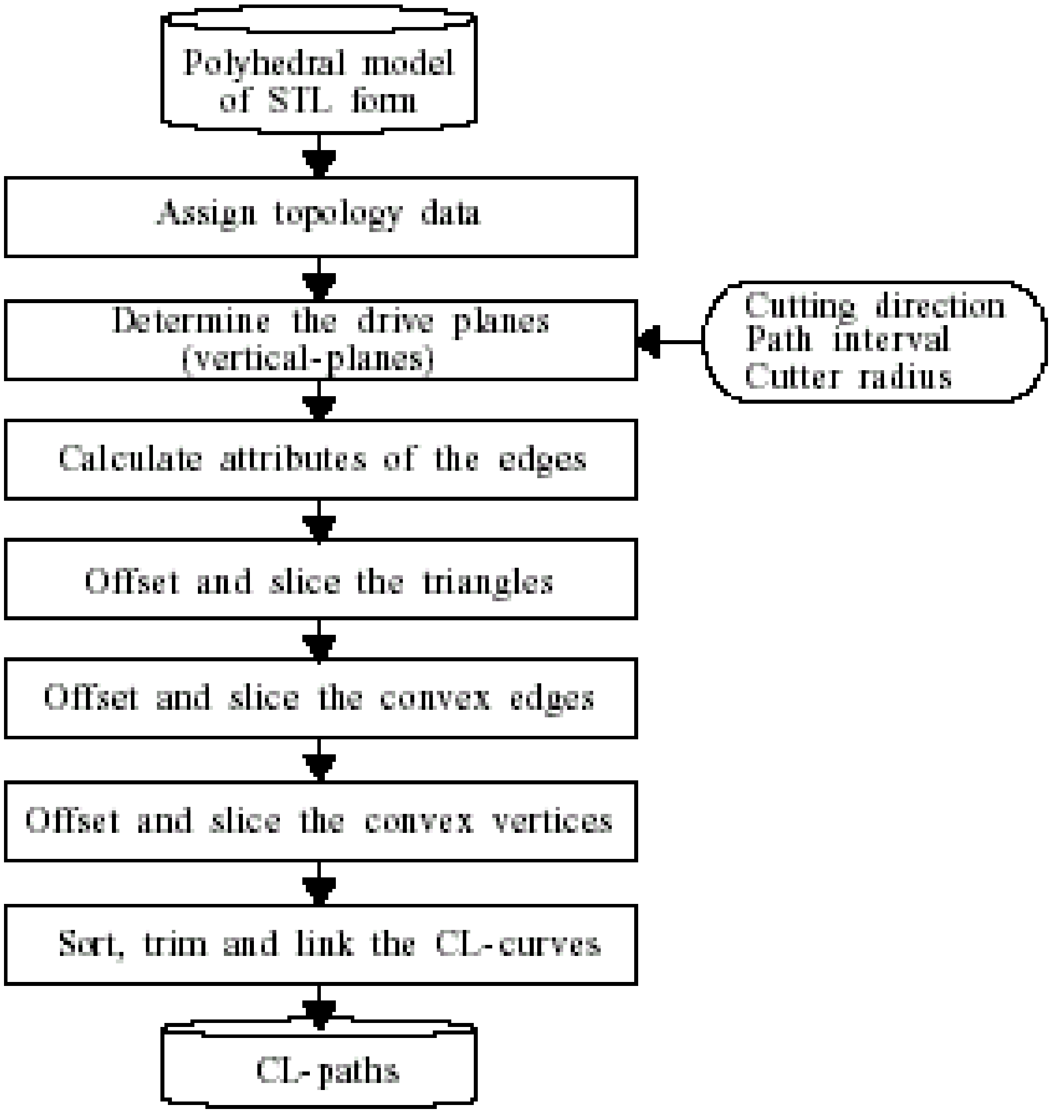


Local Offset Example





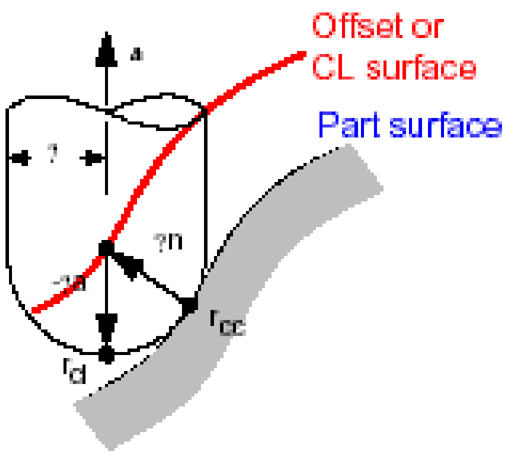
Tool Path Generation for Polyhedral Machining



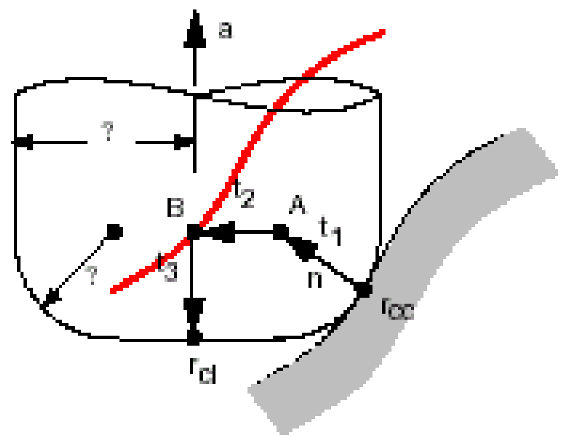
Cutter Path Generation for NC Machining

CC Point: Cutter contact point

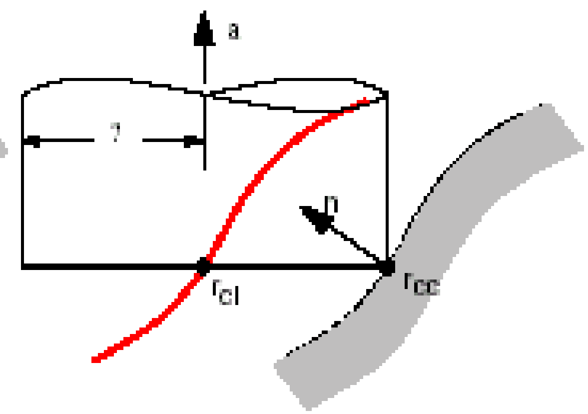
CL Point: Cutter location point



Ball-endmill

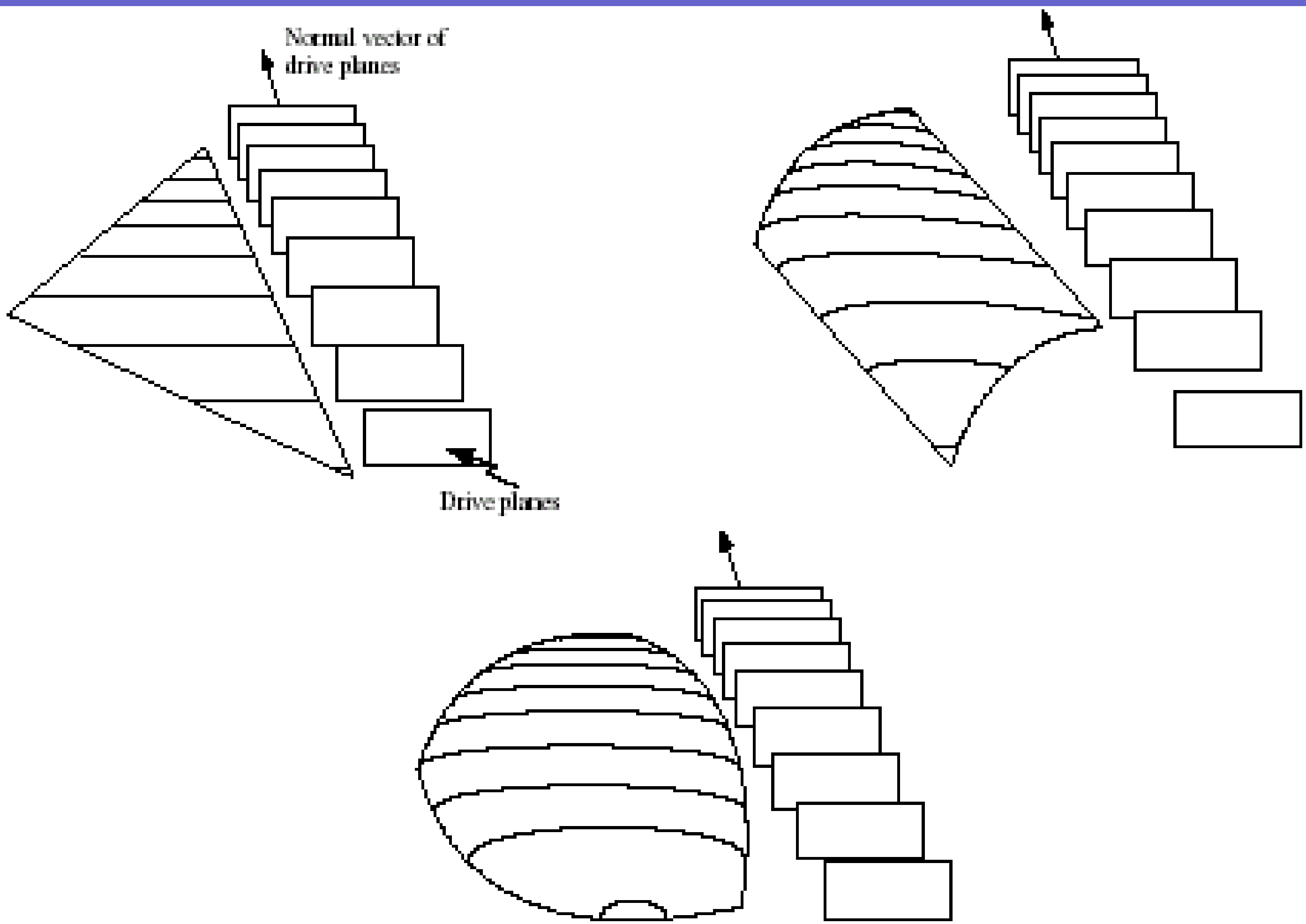


Filleted-endmill

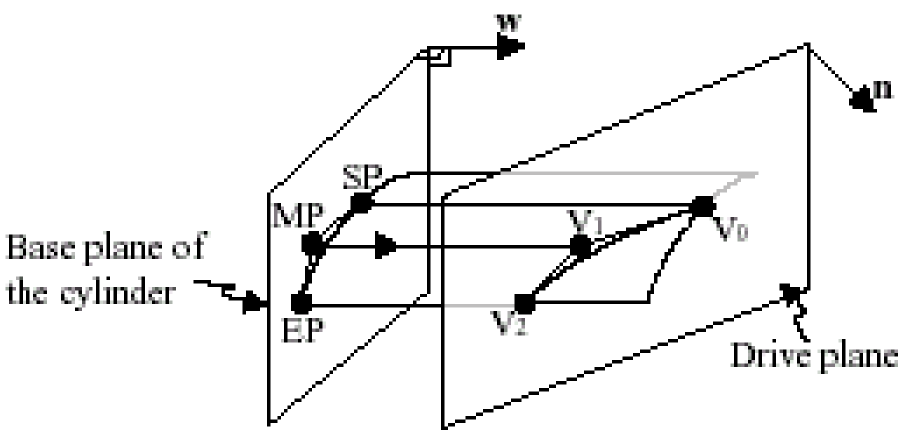


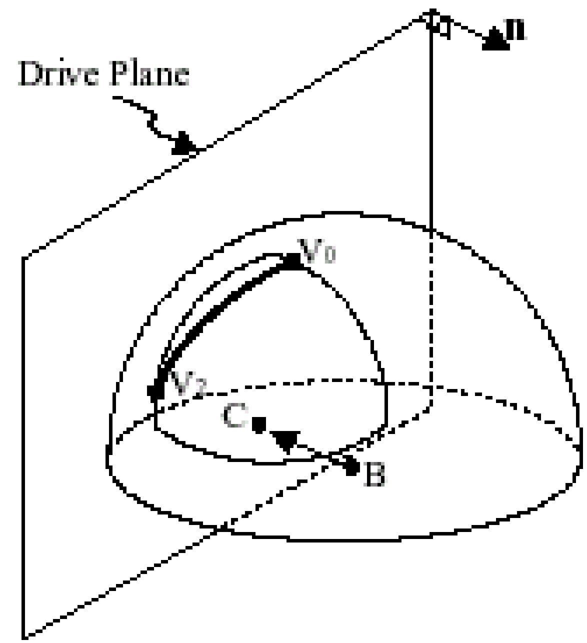
Flat-endmill

Slicing of Offset Elements for Tool Path Generation

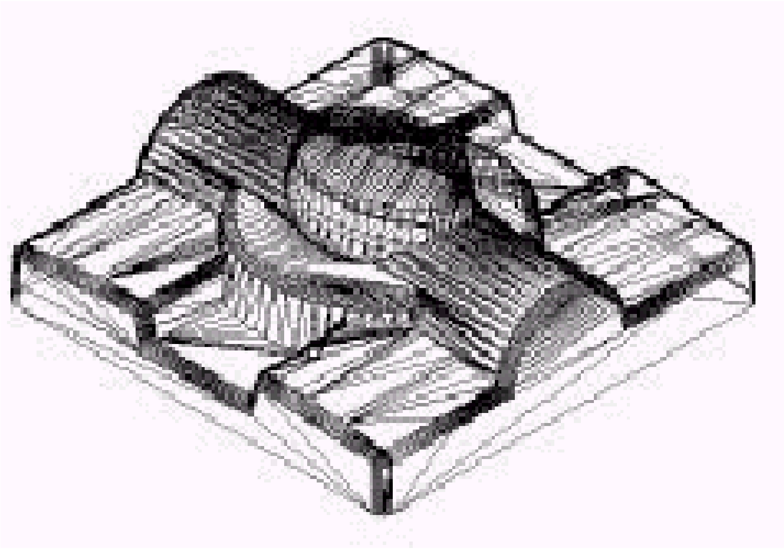


Slicing the Spherical and Cylindrical Surfaces for Polyhedral Machining

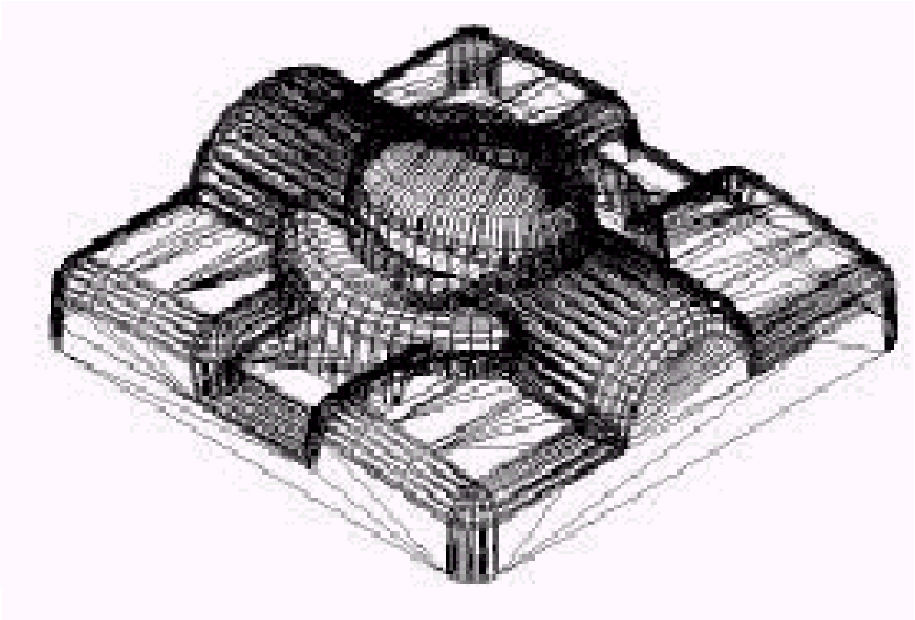




Example of Polyhedral Model Machining

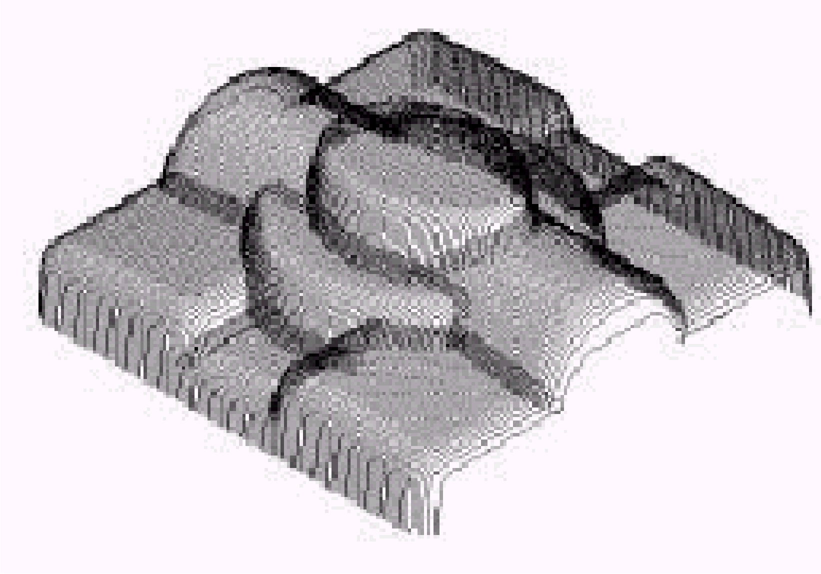


Polyhedral model

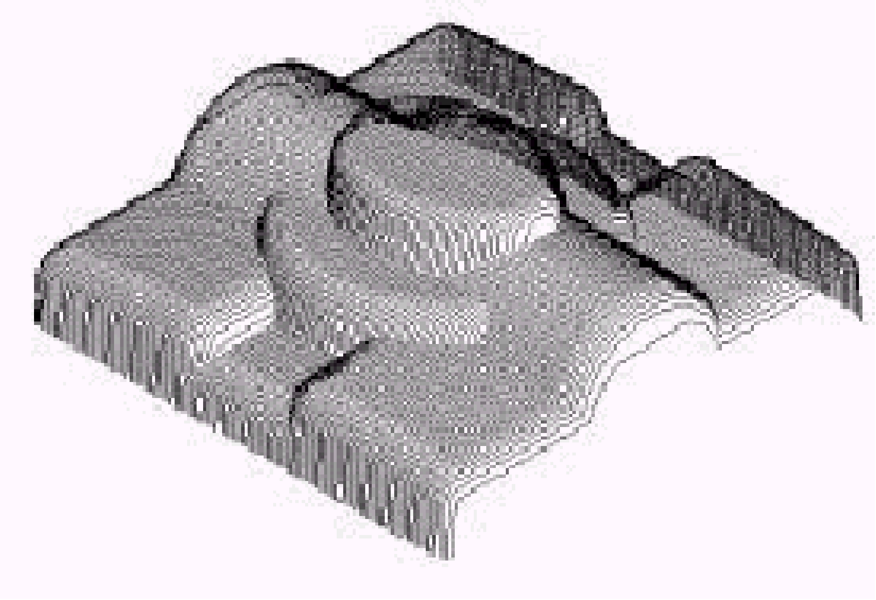


Offset model

Tool Path Generation for Machining of Example 1



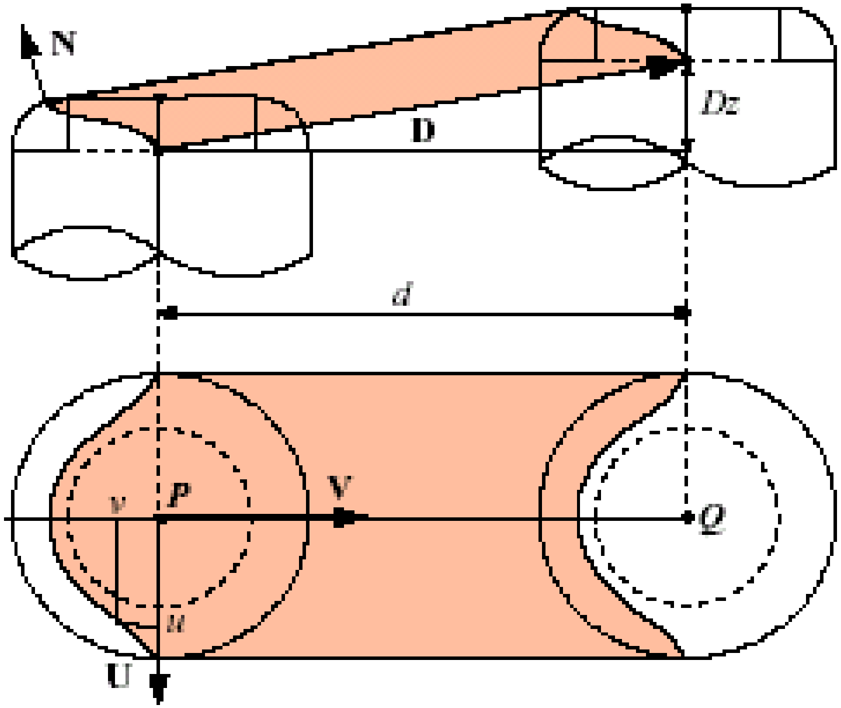
CL-curves



CL-paths

Polyhedral Machining with Fillet-Endmills

Offset and Slicing of Convex Edges with Fillet Endmills



ITSS: Inverse Tool Swept Surface

Silhouette curve: $\mathbf{N} \cdot \mathbf{D} = 0$

D : tool movement vector

d = Dxy

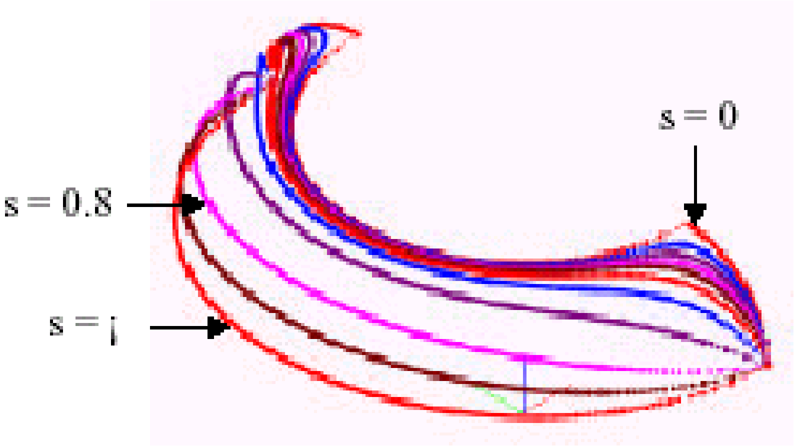
s : slope of tool movement (D_z / d)

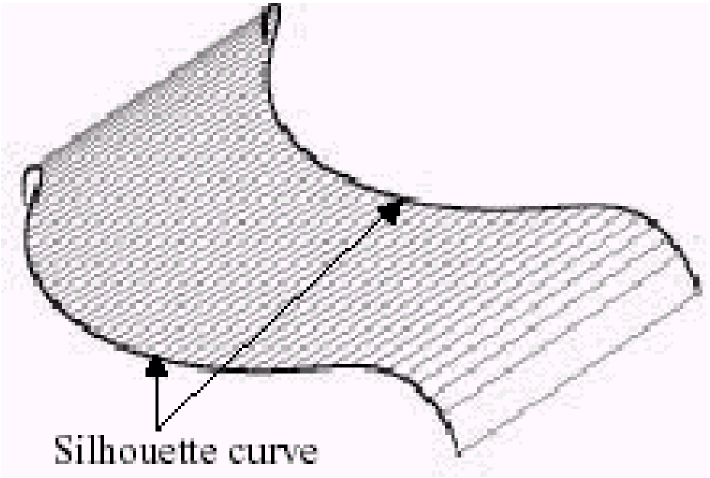
$\mathbf{V} = (D_x, D_y, 0) / d$

$\mathbf{U} = (V_y, -V_x, 0)$

$\mathbf{N}(u,v)$: normal vector of the ITSS

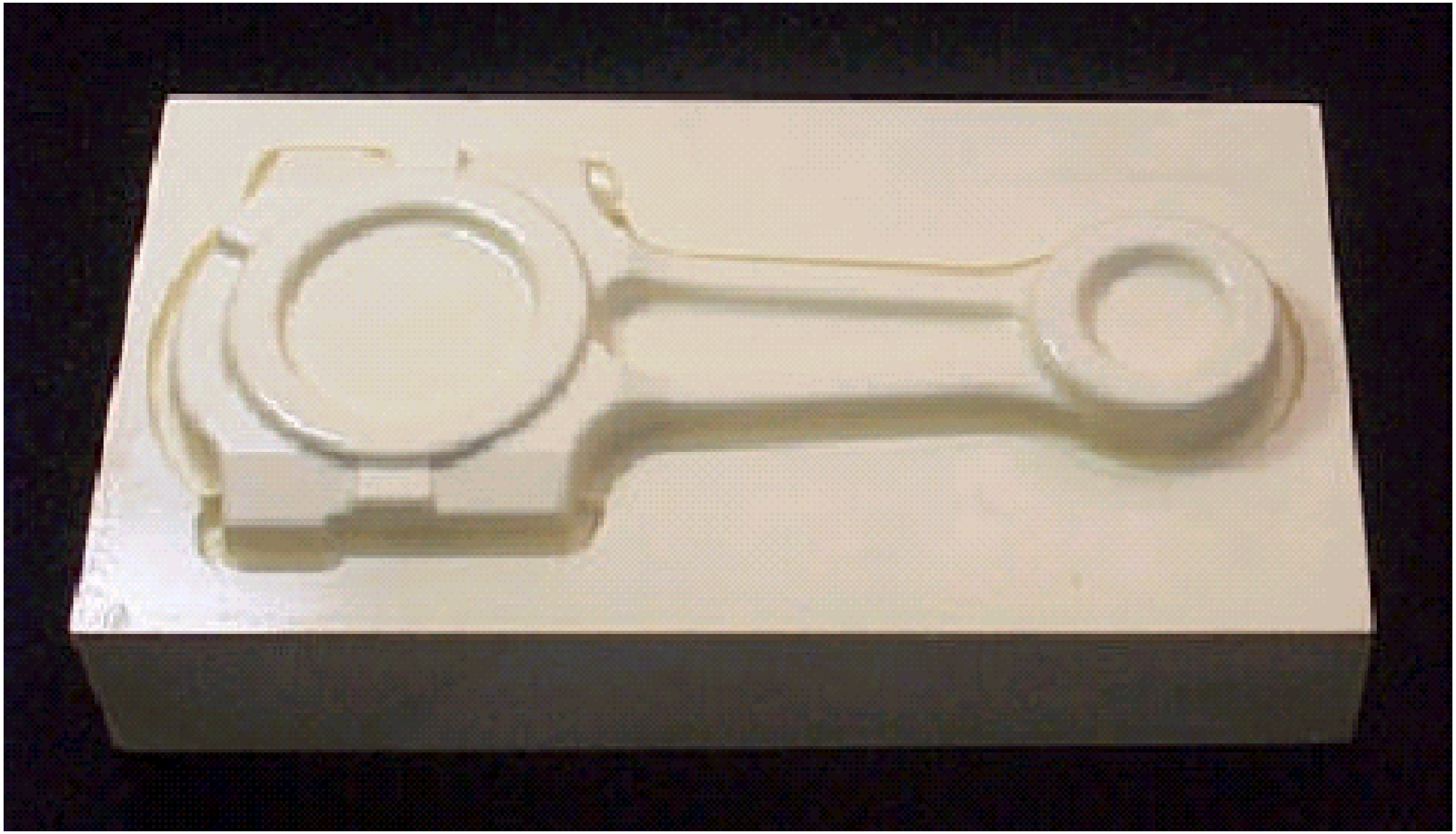
Effective Cutting Shapes of Fillet-Endmills





Example 2 of Polyhedral Machining

Example 2 of Polyhedral Machining

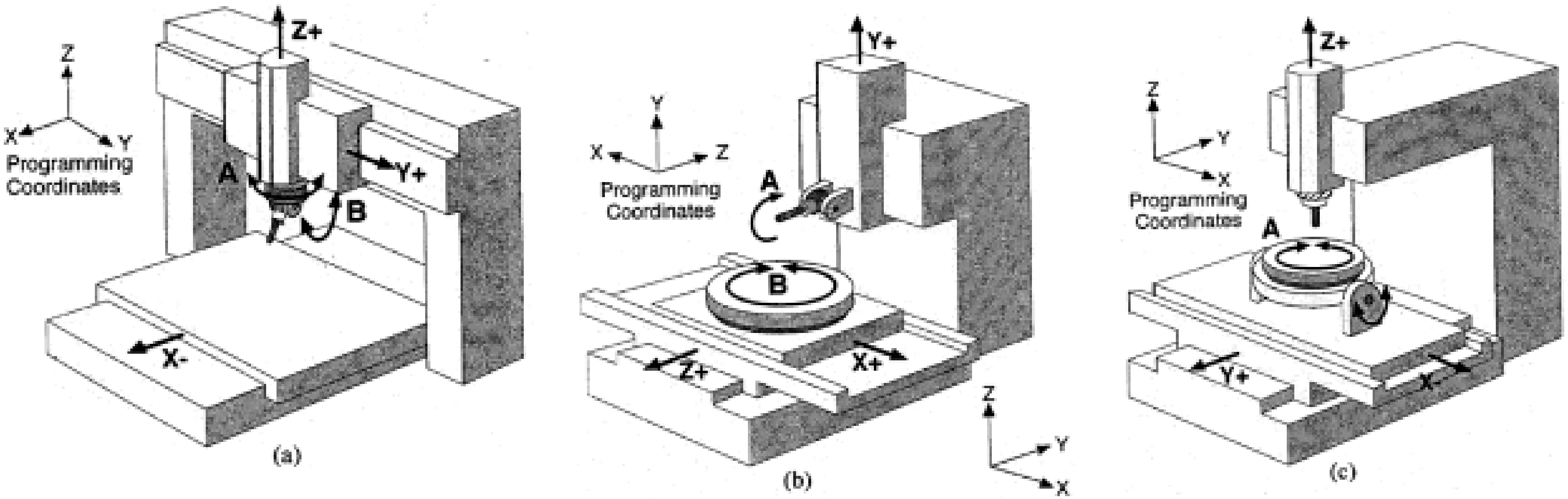


Computation Time for Machining Examples

Mode	Tool diameter (mm)	Path interval (mm)	Computational time (seconds)	
			A curve based	A point based
Connecting rod (850 facets)	10	0.5	2.73	20.74
	20	0.5	4.36	50.94
	50	0.5	10.95	325.69
	100	0.5	19.63	1413.03
	10	1.0	1.47	10.23
	10	2.0	0.89	5.13
Face 226,440 facets)	3	0.5	233.08	1596.68

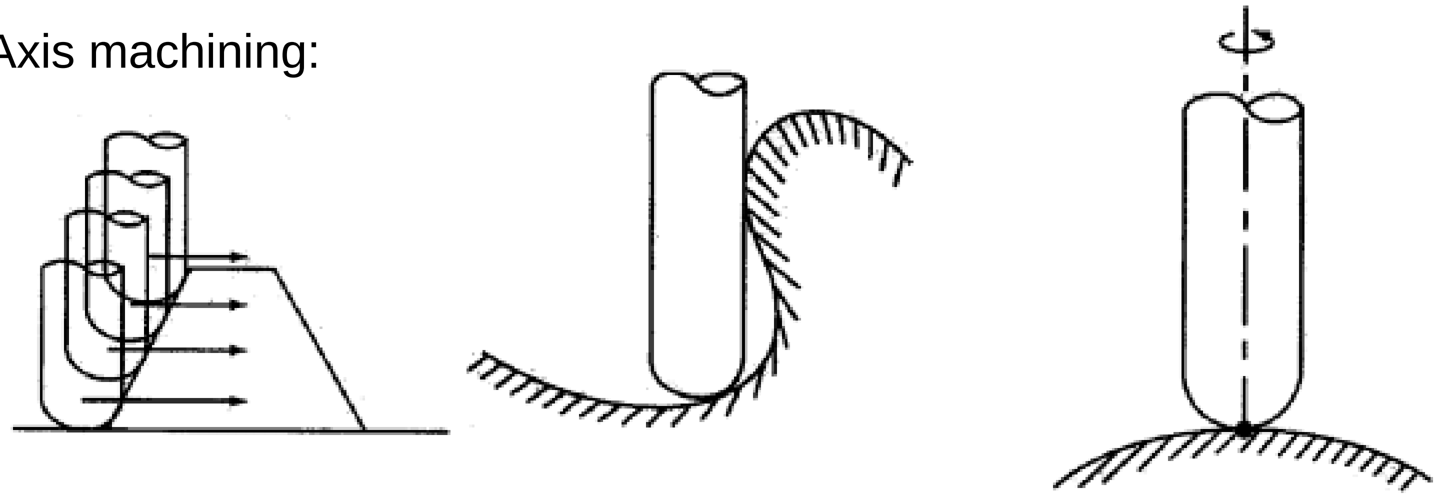
3. 5-Axis Tool Path Generation for Sculptured Surface Machining (SSM)

5-Axis NC Machine Tools

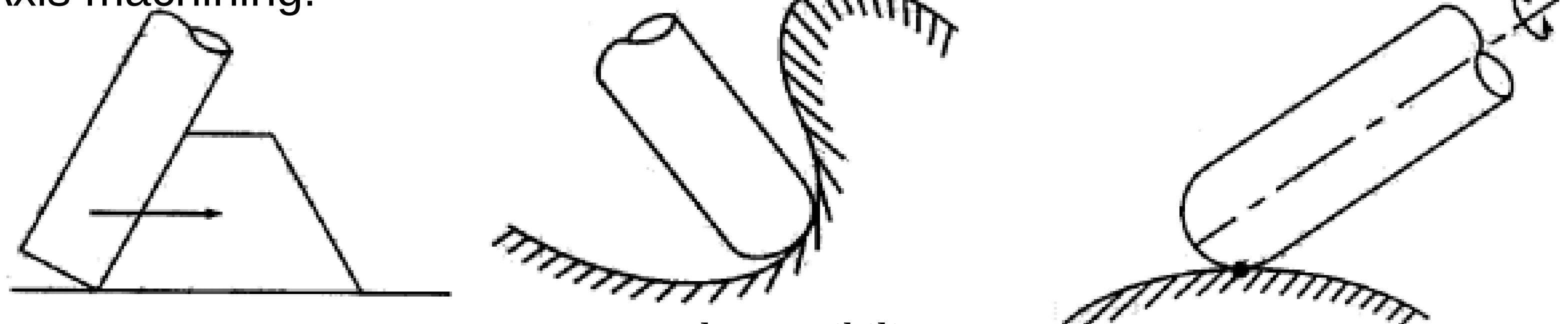


5-Axis Machining v.s. 3-Axis Machining (1)

3-Axis machining:



5-Axis machining:

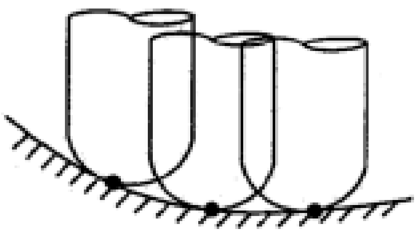


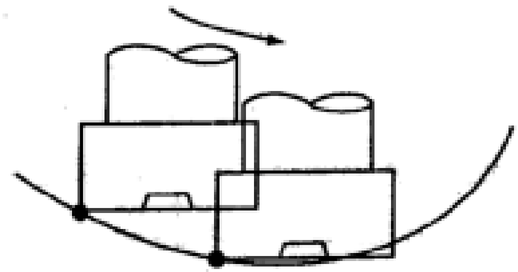
Efficient in machining

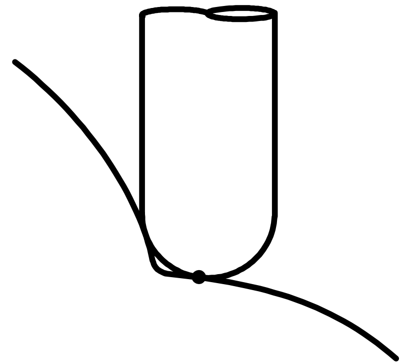
Tool accessibility

5-Axis Machining v.s. 3-Axis Machining (2)

3-Axis machining:

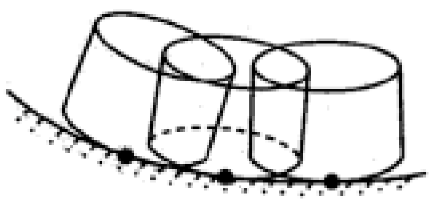


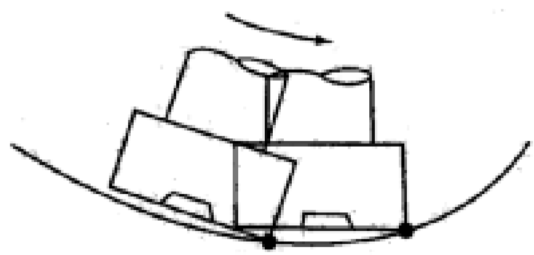


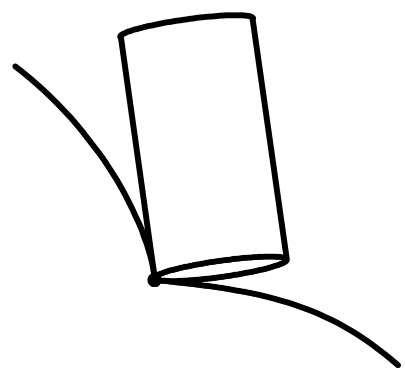


Cutter gouge

5-Axis machining:



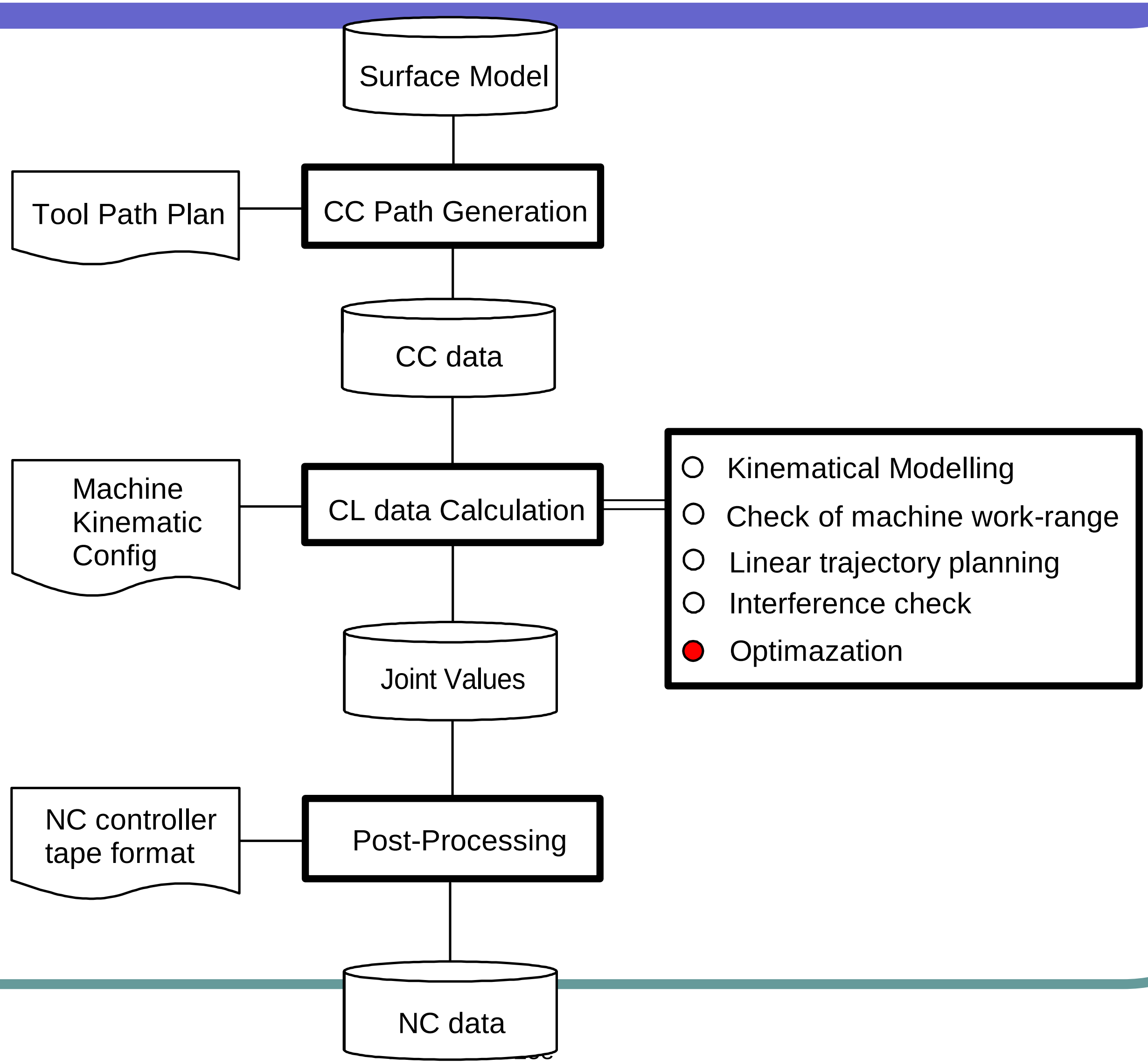




Improved surface finish

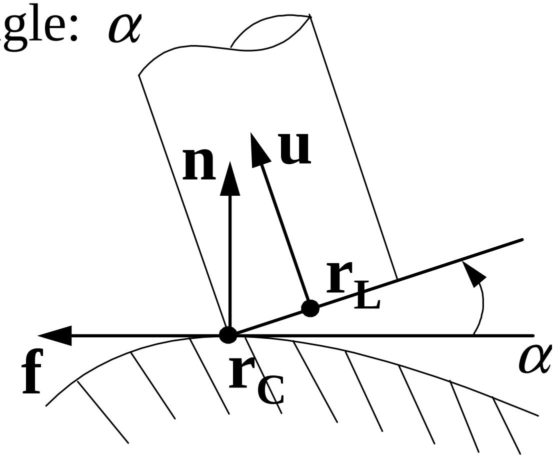
Clean-cut

Procedure of 5-Axis Tool Path Generation



Definition of Tool Orientation in 5-Axis Machining

- Tilt angle: α



where,

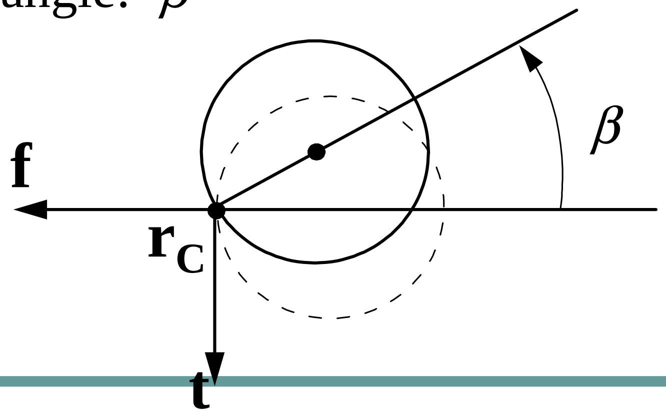
$\mathbf{r}_L$: cutter location point
u : cutter axis vector
} CL data

$\mathbf{r}_C$: cutter contact point
n : normal vector of surface
} CC data

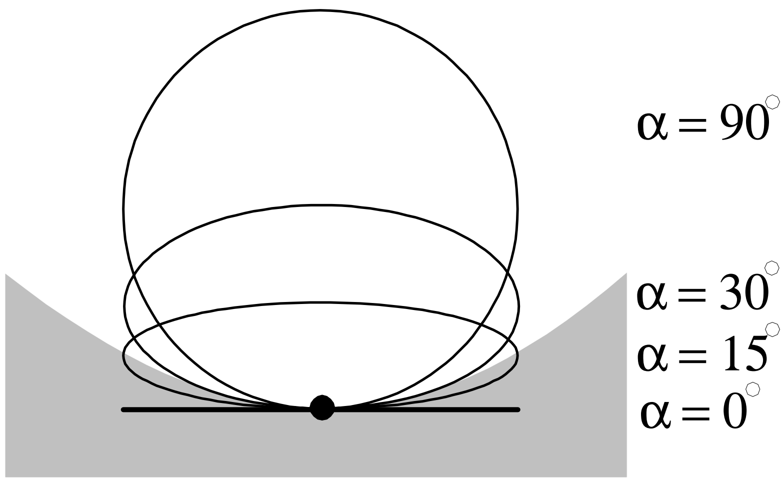
f : a cutter feed vector

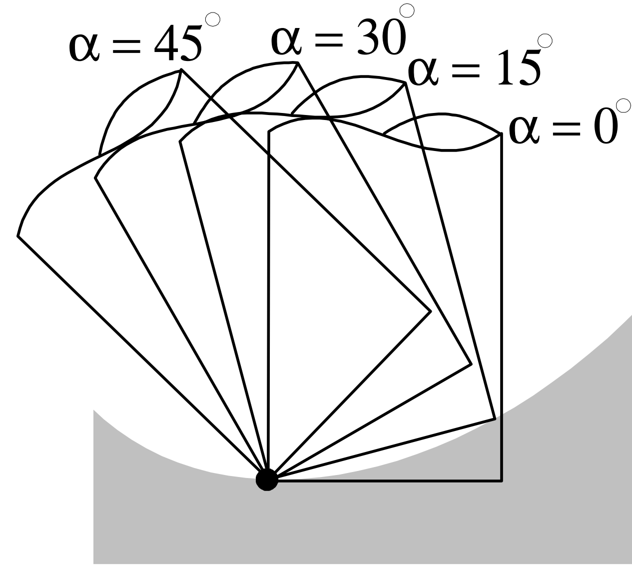
t : **n** x **f**

- Yaw angle: β

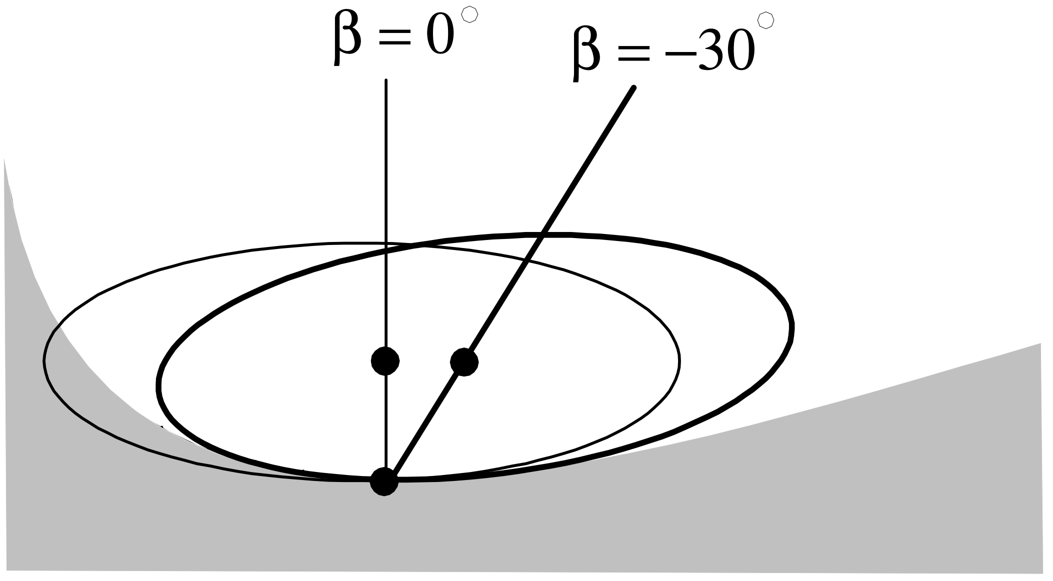


Effect of Tool Inclination Angle in 5-Axis Machining



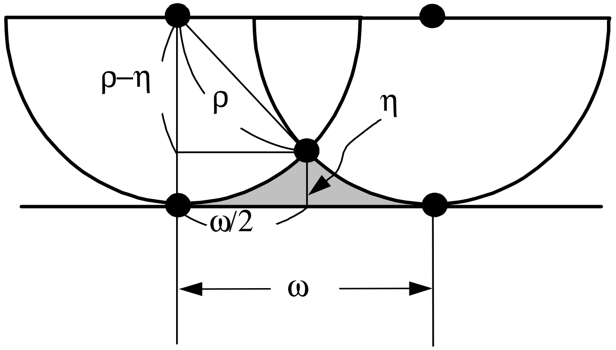


Effect of Tool Yaw Angle in 5-Axis Machining

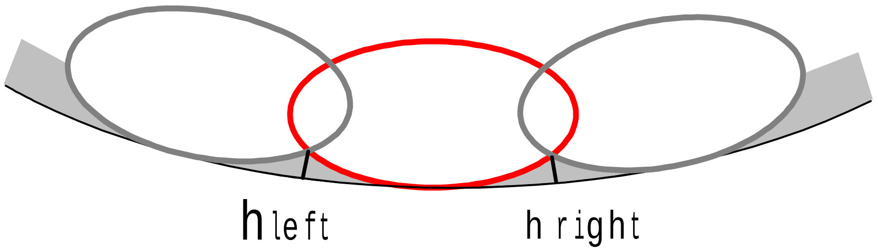


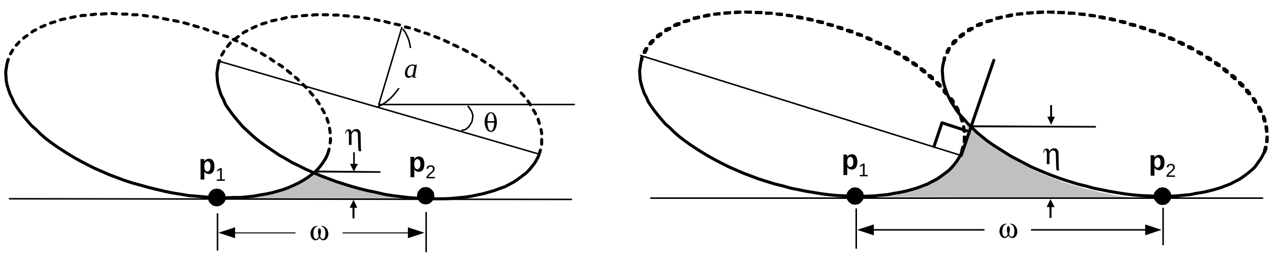
Cusp Height Errors in Sculptured Surface Machining

3-axis machining:



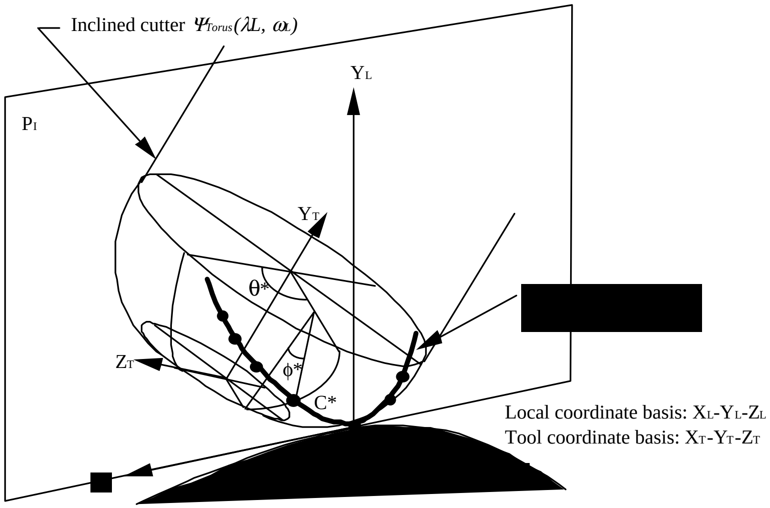
5-axis machining:

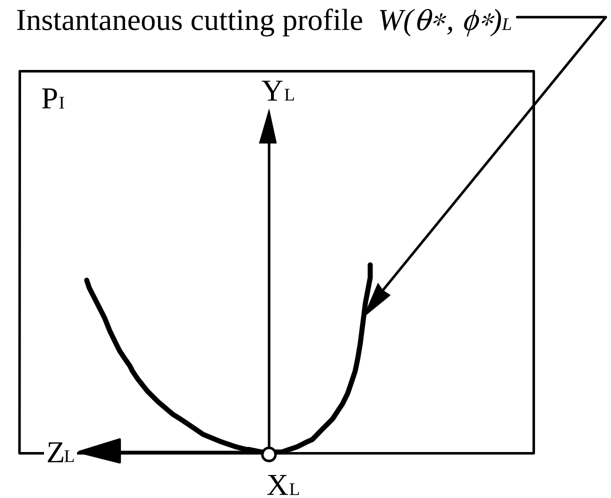




(a) (b)

Finding Effective Cutting Shape in 5-Axis Machining





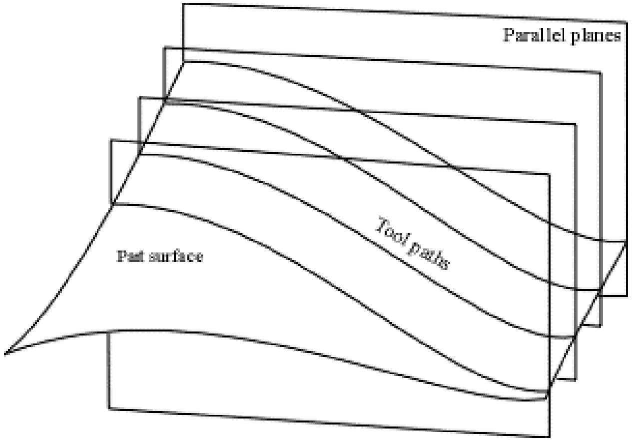
Effective cutting shape can be found as follows:

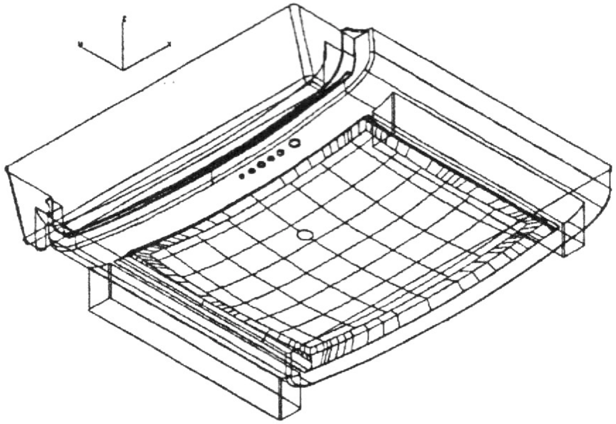
$$W(\theta,\ \phi)_L = \begin{pmatrix} x_L = 0 \\ y_L \\ z_L \end{pmatrix}^G_{\Psi,\ L} = \Psi(\theta,\ \phi,\ \lambda_L,\ \omega_L)^{G}_{L, x_L = 0}$$

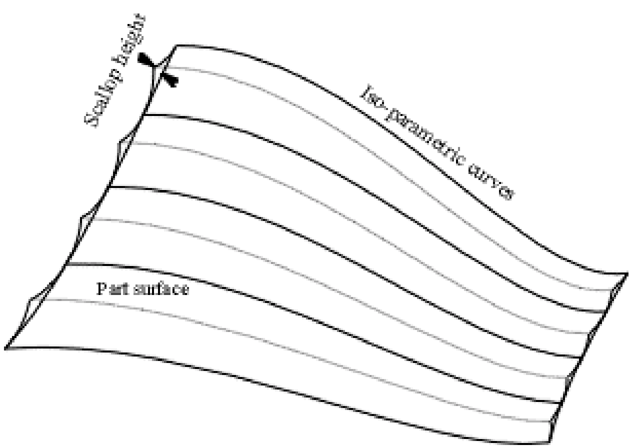
$$W(\theta^*,\ \phi^*)_L = \begin{pmatrix} x^*_L \\ y^*_L \\ z^*_L \end{pmatrix}^G_{\Psi, L} = \begin{pmatrix} 0 \\ m_7 \sin\theta^* \sin\phi^* + m_8 \sin\theta^* + m_9 \cos\phi^* + m_{10} \\ m_{11} \sin\phi^* \sin\theta^* + m_{12} \sin\phi^* \cos\theta^* + m_{13} \sin\theta^* + m_{14} \cos\theta^* + m_{15} \cos\phi^* + m_{16} \end{pmatrix}_L$$

3. Optimizing Tool Path Generation for CAD/CAM Systems

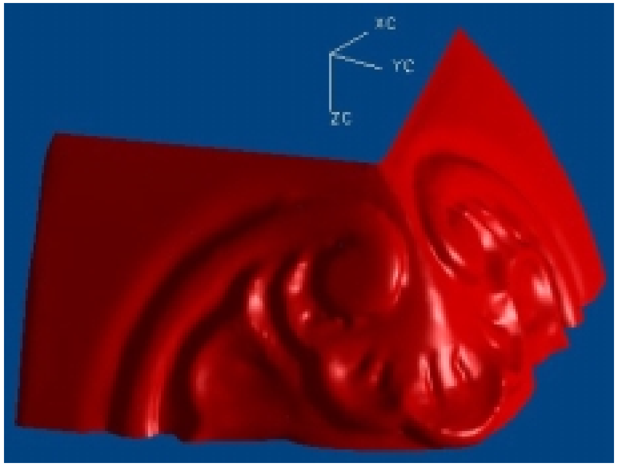
Machining of Sculptured Surfaces





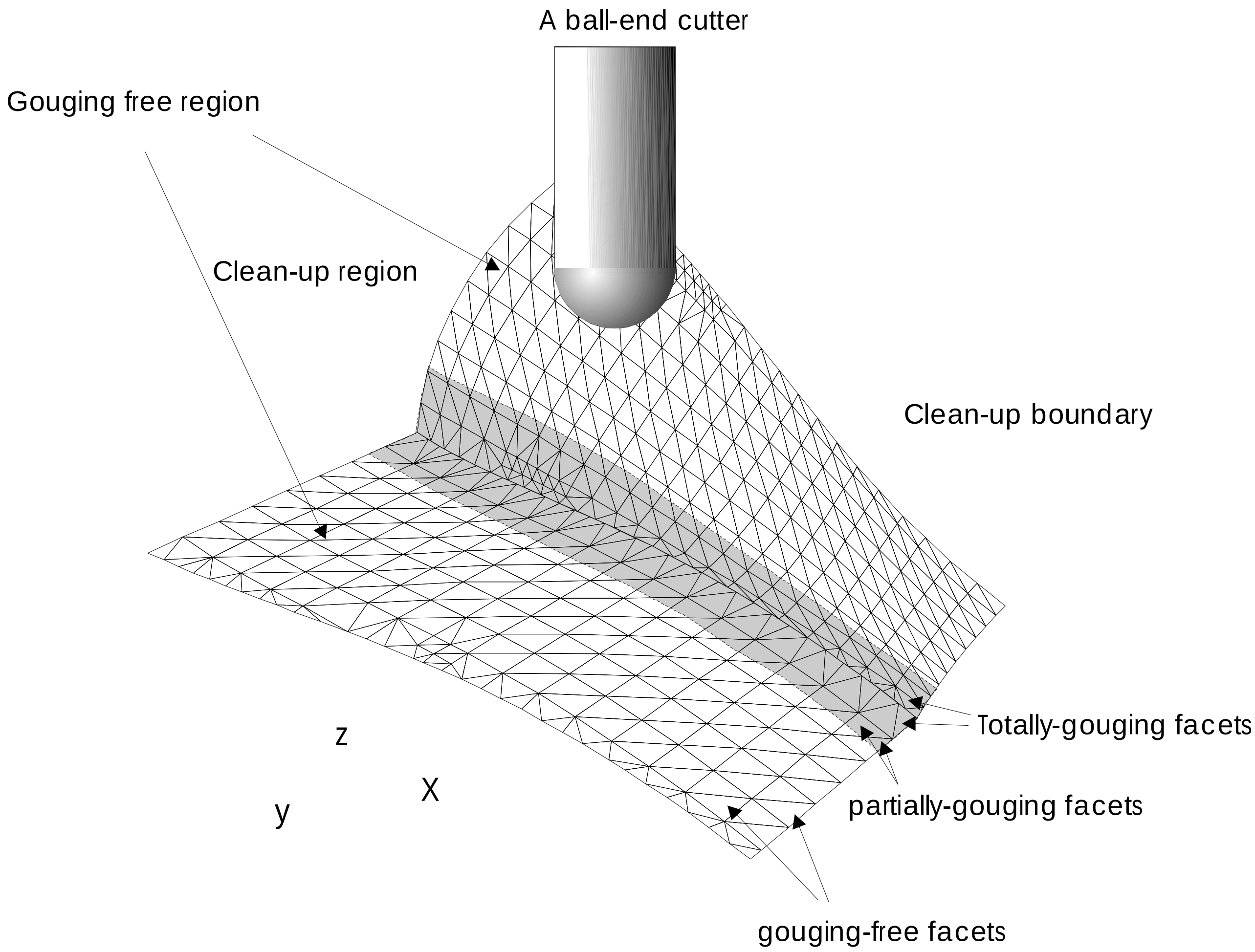


Traditional machining planning



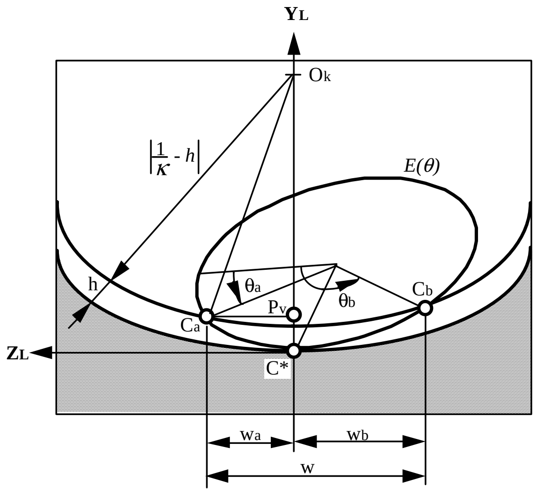
3D path planning

Rolling-Ball Method for Extracting Clear-Cut Regions

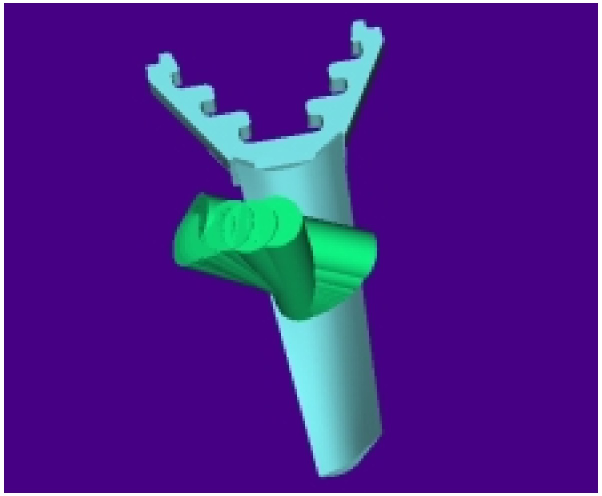


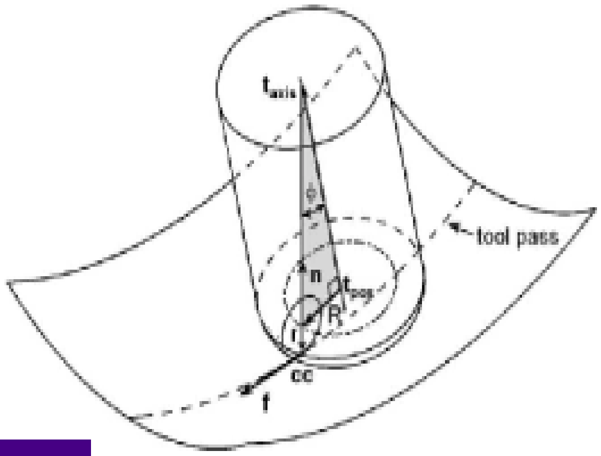
Finding the Optimal Tool Orientation for 5-Axis Surface Machining

Fitting cutting shape on local part surface



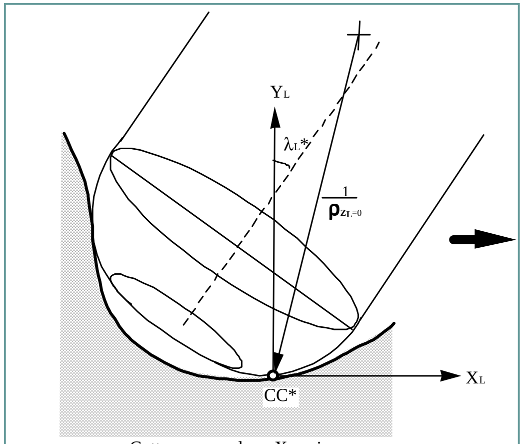
Cutting direction (XL) out from the paper



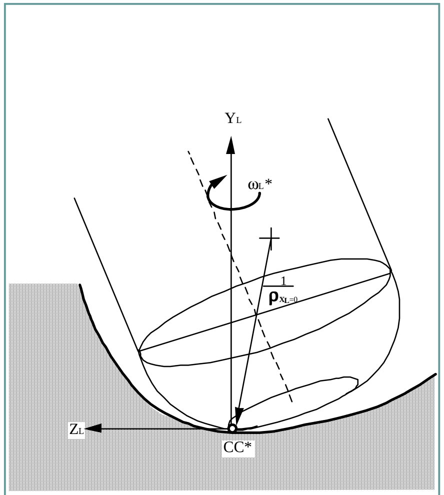


Using surface curvatures for optimal tool orientation

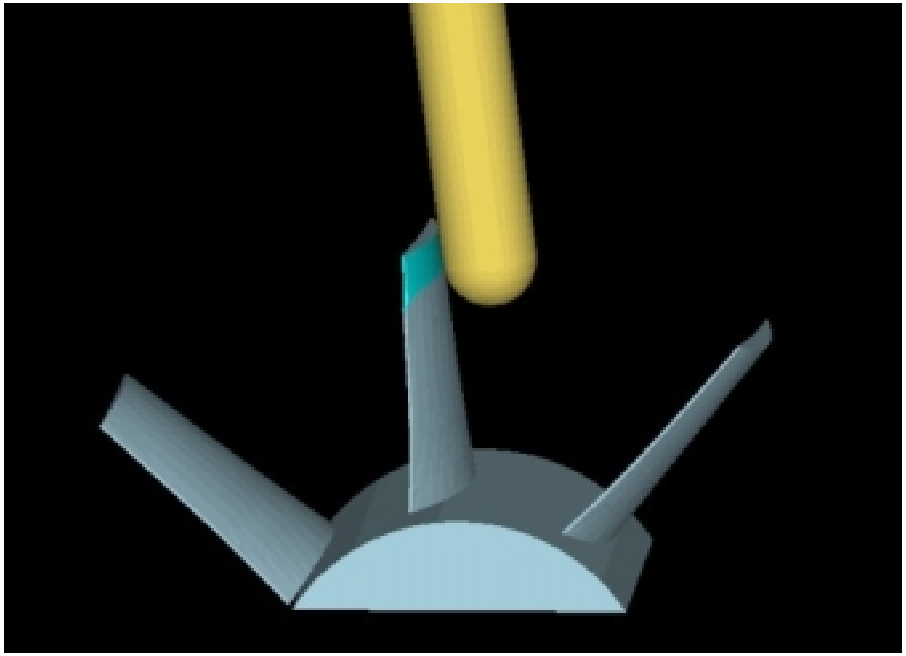
Tool Collision and Gouging Avoidance in 5-Axis Machining



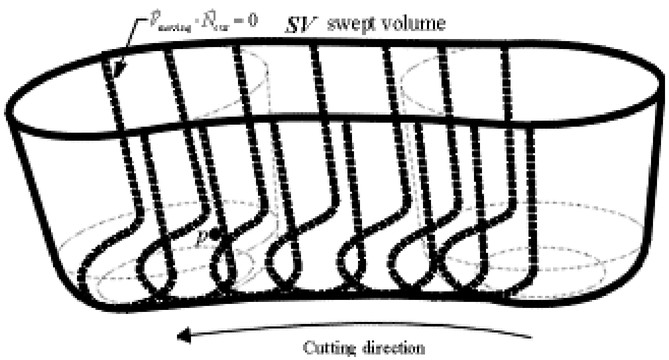
Cutter moves along XL-axis

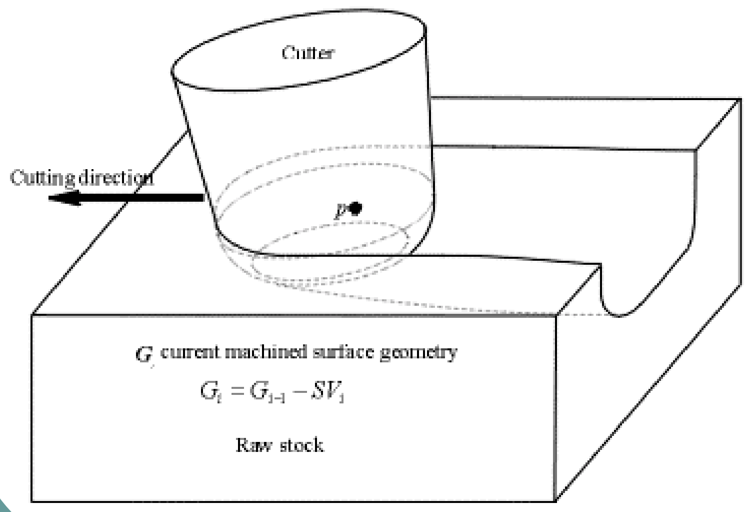


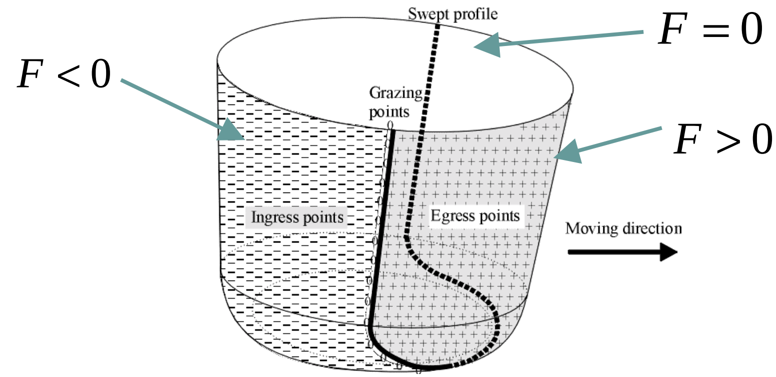
Cutter moves out from the paper



Material Removal Rate (MRR) Analysis for 5-Axis High Speed Machining

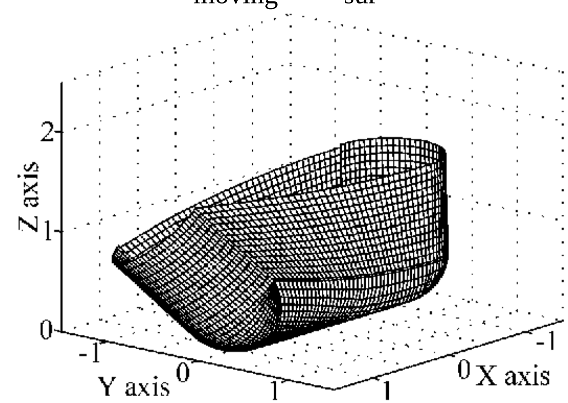






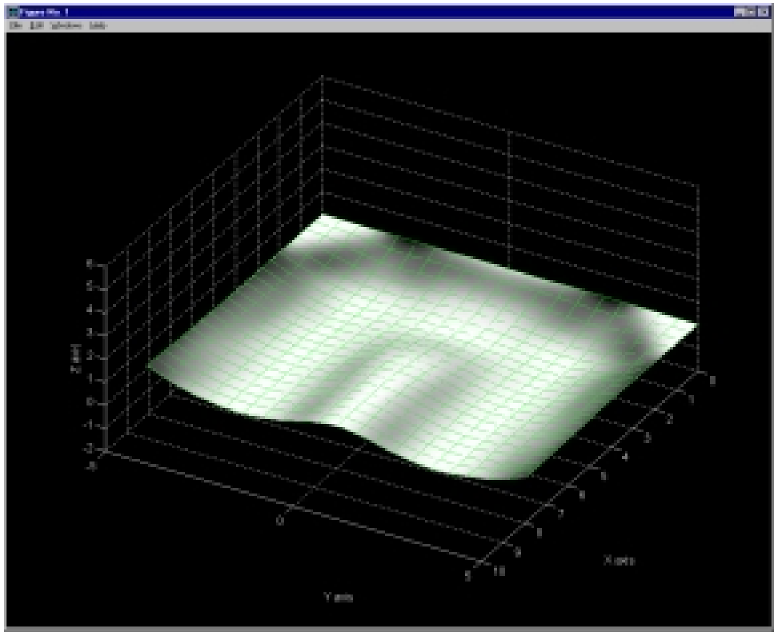
$$\vec{V}_{\text{moving}} = \vec{V}_{\text{translation}} + \vec{\Theta}_{\text{rot}} \cdot \vec{D}_{\text{dis}}$$

$$F = \vec{V}_{\text{moving}} \cdot \vec{N}_{\text{sur}} = 0$$

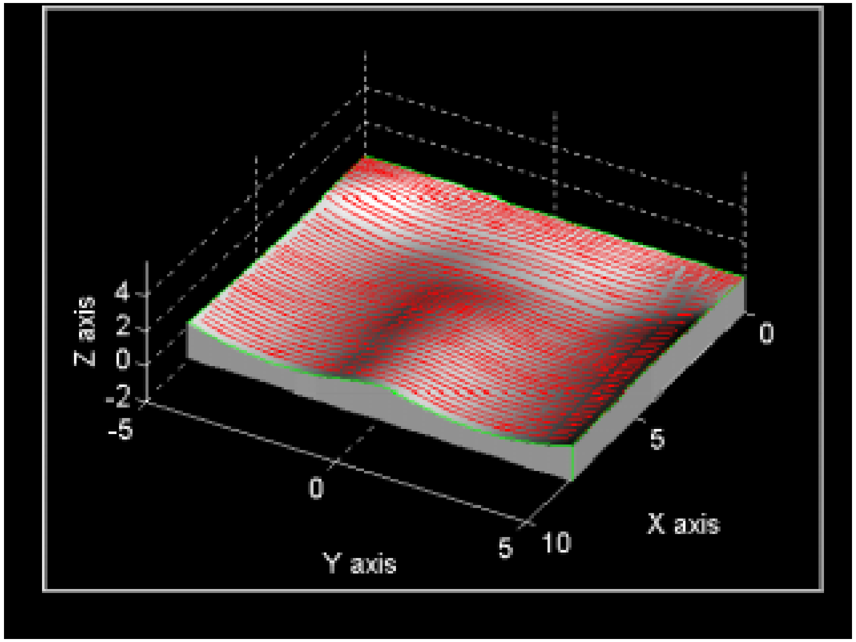


Optimizing 5-Axis Tool Path Generation in CAD/CAM

Q: **Is it possible to find the best path distribution for SSM?**



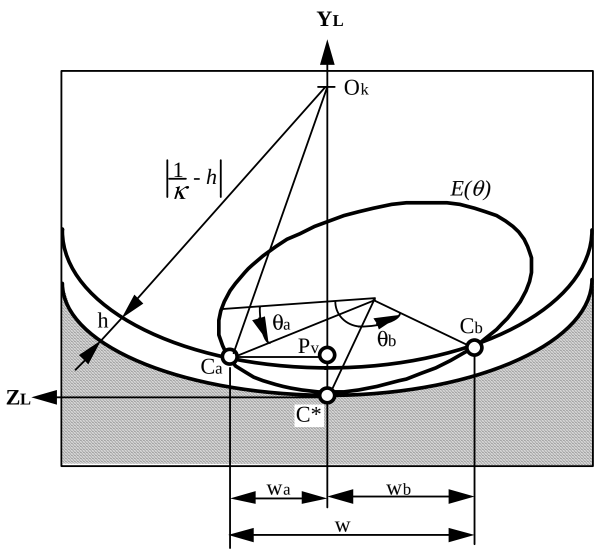
Sculptured surface design



Traditional tool path planning

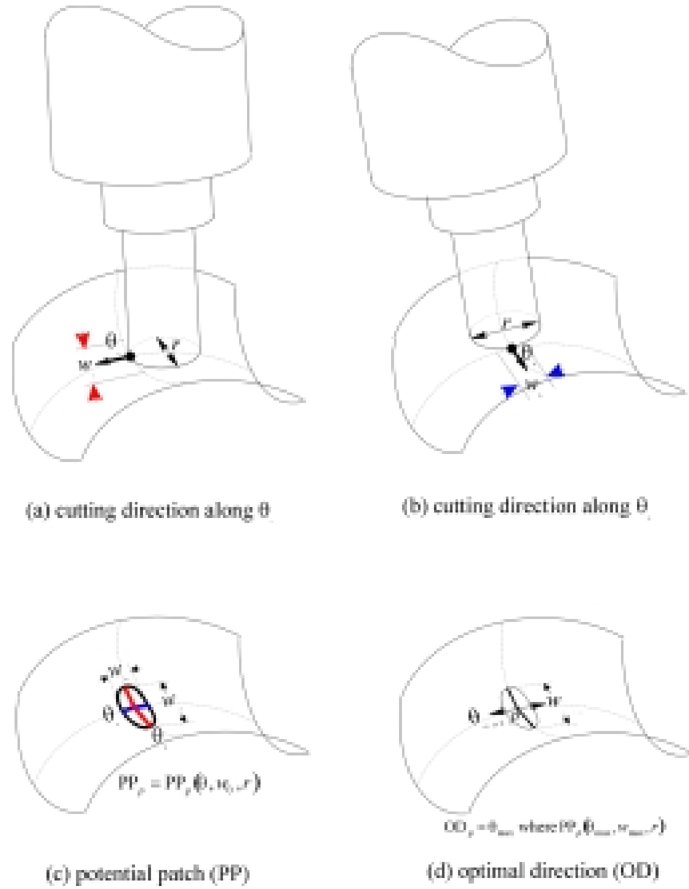
Optimizing 5-Axis Tool Path Generation

- What is the best cutting direction?



Cutting direction (**X**L) out from the paper

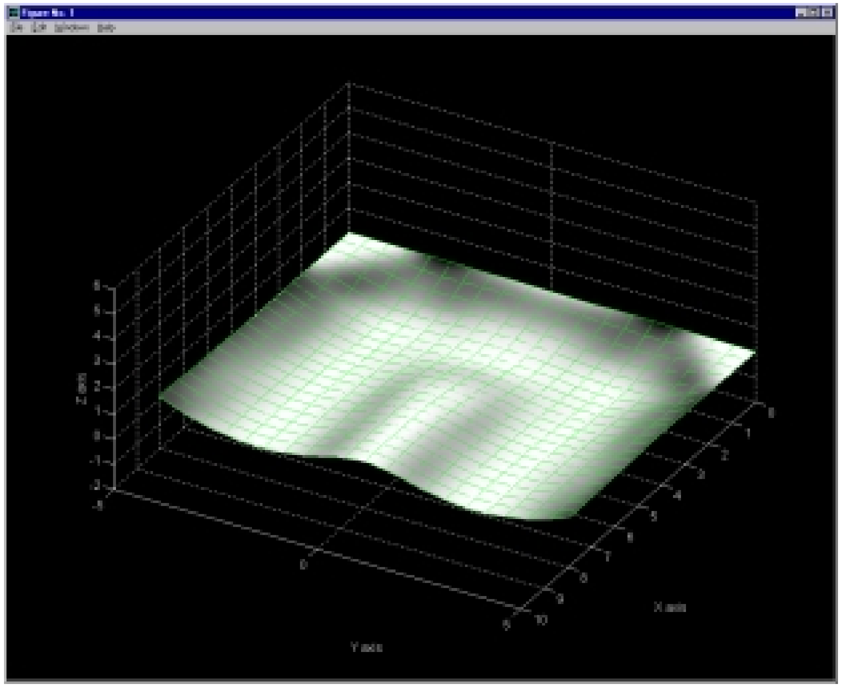
Machining strip width
(dependent of λ, ω)



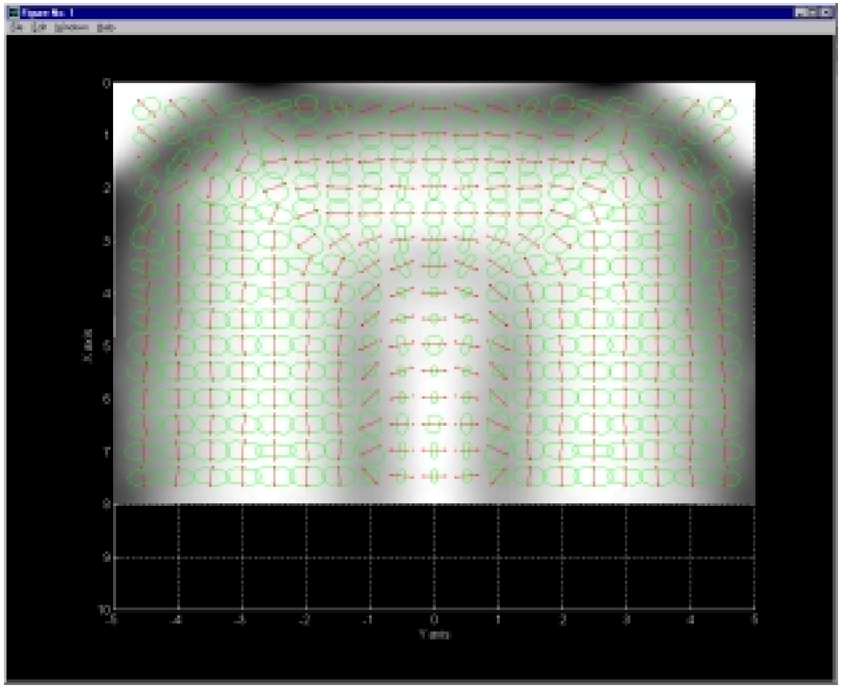
Optimal cutting direction

Machining Potential Field (MPF) for Sculptured Surface Machining

Q: Is it possible to find the best path distribution for SSM?



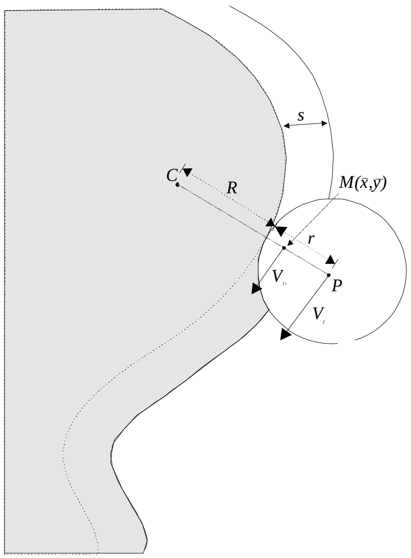
Sculptured surface design



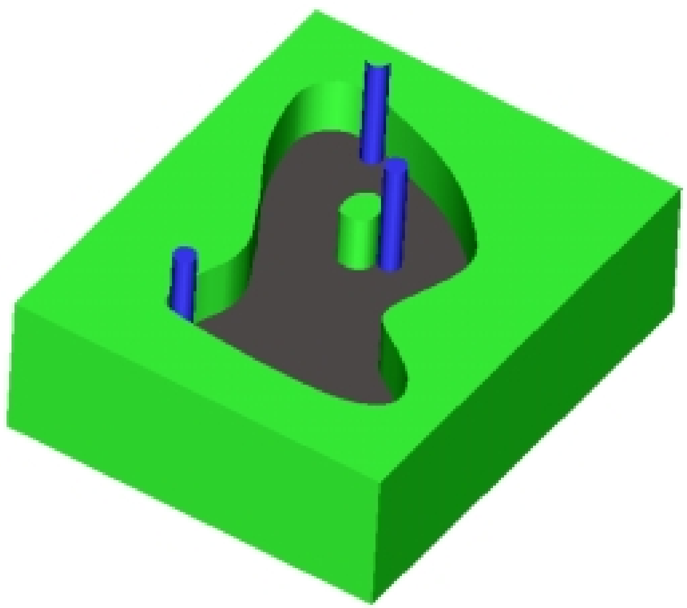
Machining potential patches

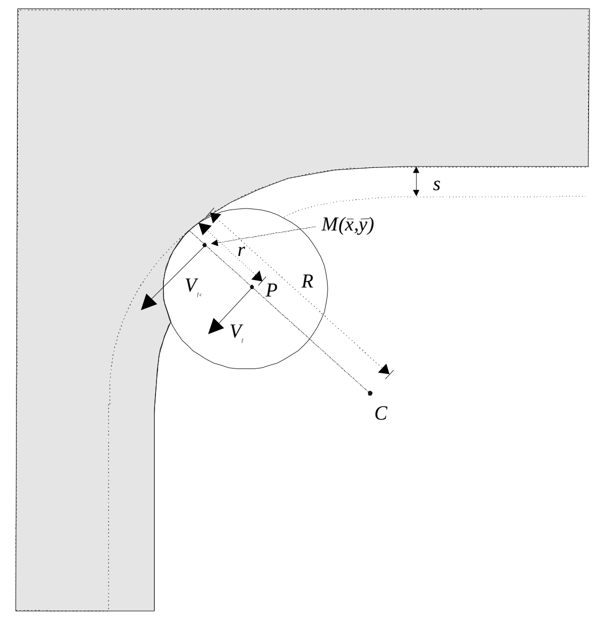
4. Adaptive Feed Scheduling for High Speed Machining (HSM) of Complex Surfaces

Change of Material Engagement for High Speed Machining (HSM)

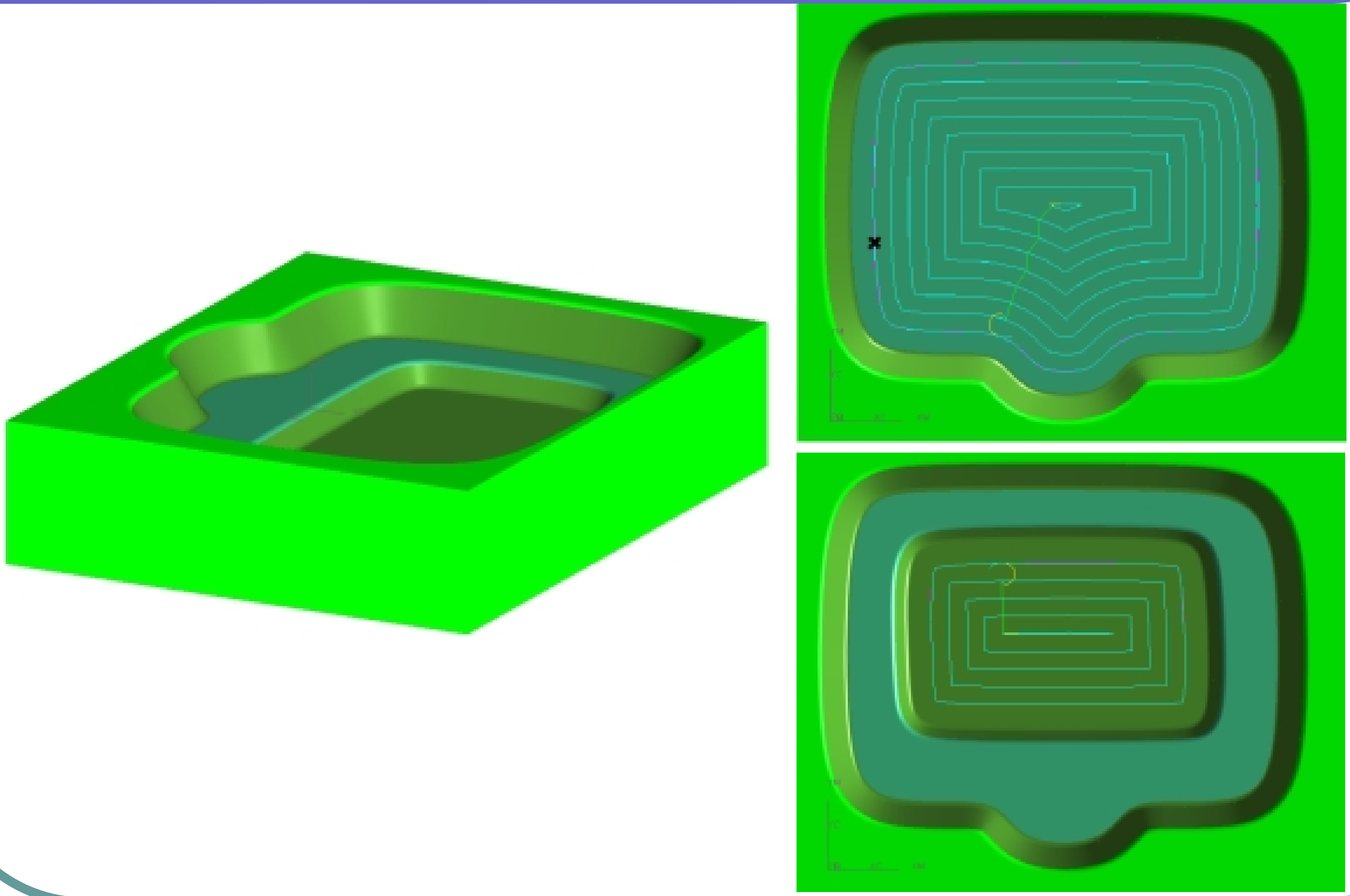


C : center of circular arc
R: radius of circular arc
P: cutter tip.

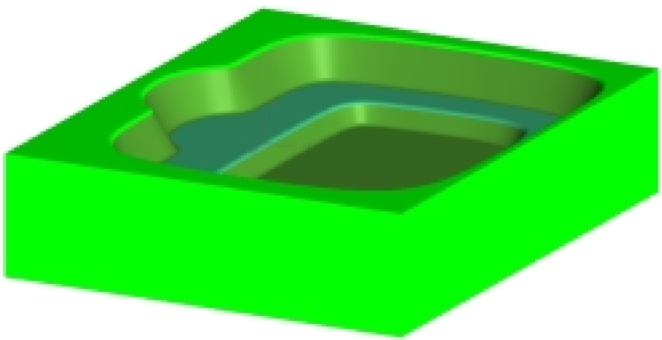


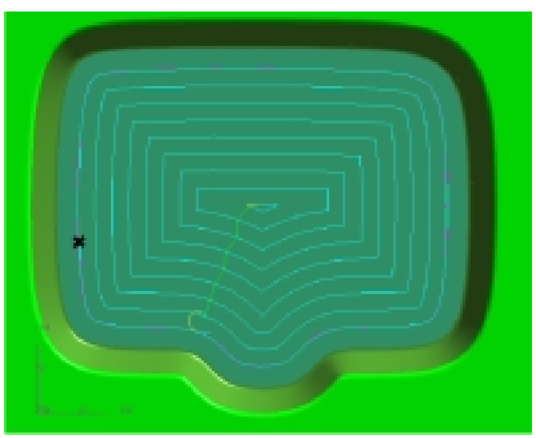


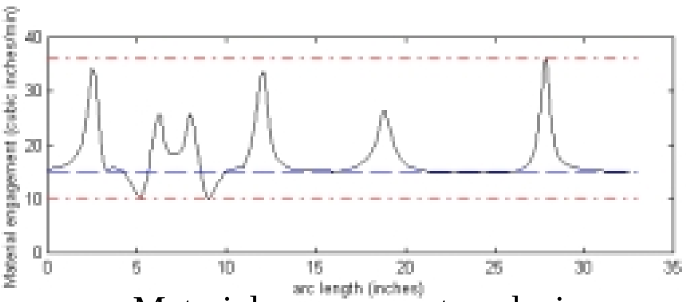
Adaptive Feed Scheduling For High Speed Machining (HSM)



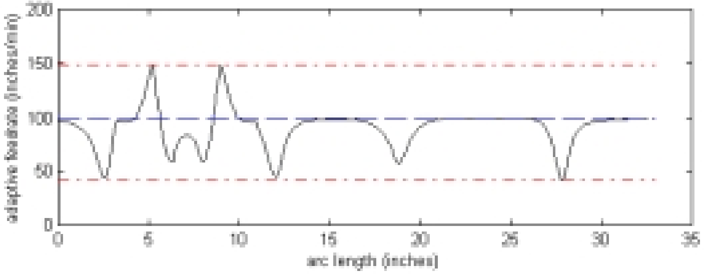
Adaptive Feed Scheduling for High Speed Machining (HSM)



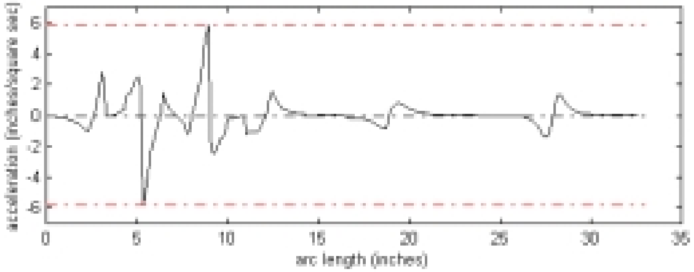




Material engagement analysis



Adaptive feedrate scheduling



Machine acceleration analysis

Conclusions

- Modeling of complex surfaces for product development
- CAD/CAM for polyhedral model machining
- 5-Axis machining of sculptured surfaces
- High Speed Machining (HSM) can greatly benefit manufacturing process by shortening the machining time and reducing the manufacturing cost.
- HSM CAD/CAM shares an increasing market in recent years and the trend will continue.

Thank you !!

Any Question ?