TOOL PATH GENERATION FOR 5-AXIS LASER CLADDING

Author: M. Kerschbaumer *, G. Ernst *
P. O´Leary **

Date: September 24, 2004

* JOANNEUM RESEARCH
Forschungsgesellschaft mbH
Laser Center Leoben, Leobner Strasse 94, A-8712 Niklasdorf, Austria
Phone: +43 3842 81260 2304, Fax: +43 3842 81260 30
lzl@joanneum.at, http://www.joanneum.at/lzl

** Christian Doppler Labor für Sensorische Messtechnik, A-8700 Leoben, Austria

JOANNEUM RESEARCH

Presentation contents

1. Introduction

Many similar methods with the same basic process of fabricating a component have been developed:

- Laser Engineered Net Shaping (LENS)
- Laser Cladding (LC)
- Laser Metal Forming (LMF)
- Direct Metal Deposition (DMD)

JOANNEUM RESEARCH

1. Introduction

- Powder is injected into the melt pool through a coaxial nozzle.
- Well-bonded coating of various materials can be deposited on the substrate.
- Complex parts can be built up layer by layer for rapid prototyping or repair engineering.
- In all RP processes a CAD solid model is sliced into thin layers of uniform thickness.
- The tool path data include data such as positional coordinates (X,Y,Z) and rotation angles (A,C) of the turning tables.
- The tool path data are created by a software prototype, which is a special CAM software with automatic generation of 3D tool paths.

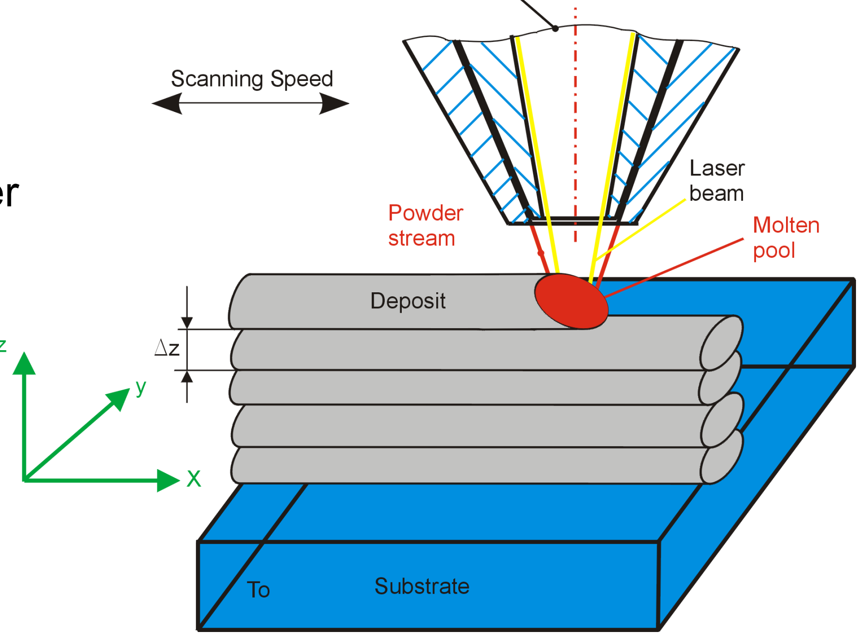


Fig. 1: *Schematic representation of the laser metal forming process*

2. 5-axis machining and inverse kinematics transformation

2.1 5-axis machining

- The CAD/CAM system calculates a tool path defined by a set of successive tool positions expressed in the P-system.

- A laser beam position is given by the position vector $\vec{x}(xp, yp, zp)$, and by the unit vector associated to the laser axis direction, $\vec{q}(i, j, k)$.

- The laser tool center (LTC) point follows the tool path, which is calculated so that the contact point between the clad and the part surface contour (clad contact point) approximate the surface within a given tolerance.

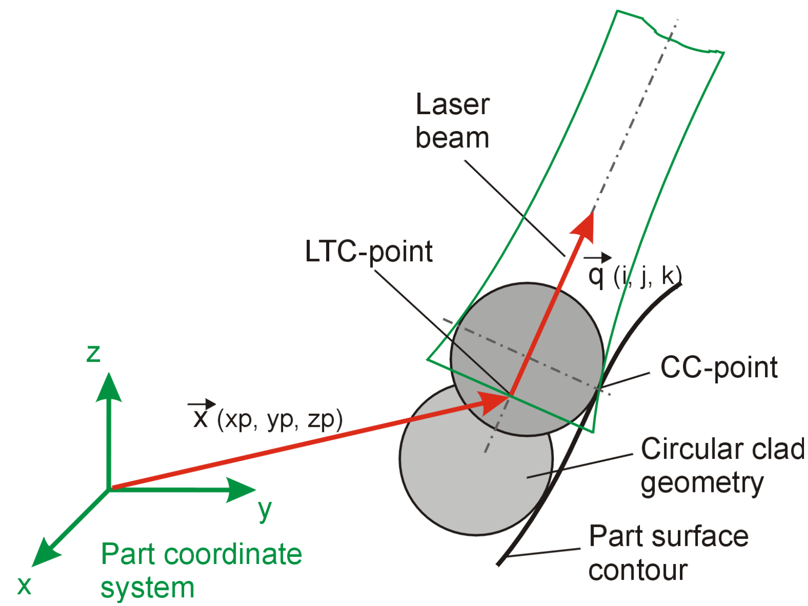


Fig. 2: *Laser beam positioning in the part system*

2. 5-axis machining and inverse kinematics transformation

- Basically, the configuration of a serial structure 5-axis machine is characterized by three translation movements and two rotations (A and C for example).

- Therefore, it is necessary to transform the variables x_p, y_p, z_p, i, j and k associated to one tool position into five position instructions x_m, y_m, z_m, A and C, that means 5 orders of axis movement.

- This transformation is denoted the inverse kinematics transformation, and strongly depends on the structure of the studied machine.

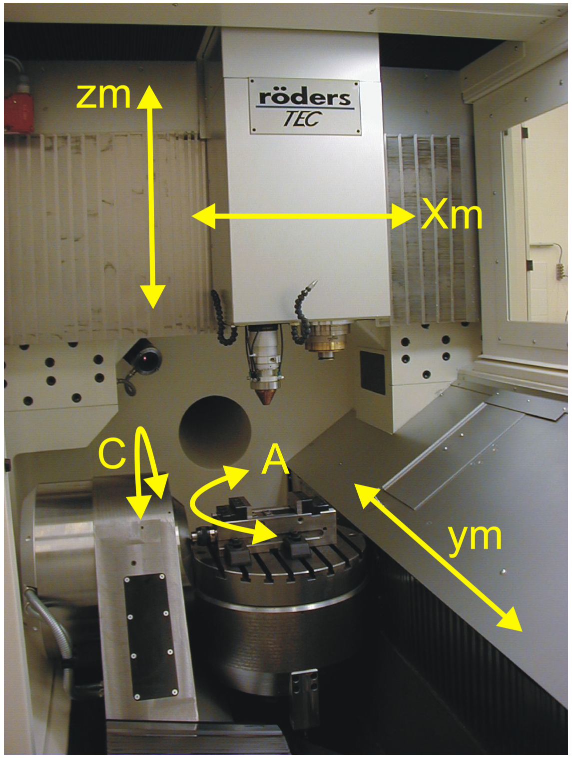


Fig. 2b: Configuration of a serial structure 5-axis machine

2. 5-axis machining and inverse kinematics transformation

2.2 The inverse kinematics transformation

- Calculation mode 1:
  The post-processor carries out the whole inverse kinematics transformation.

- Calculation mode 2:
  The NC unit carries out the inverse kinematics transformation in real-time.

- Calculation mode 3:
  The post-processor carries out the calculation of the rotation angles, but the NC unit carries out the position correction.

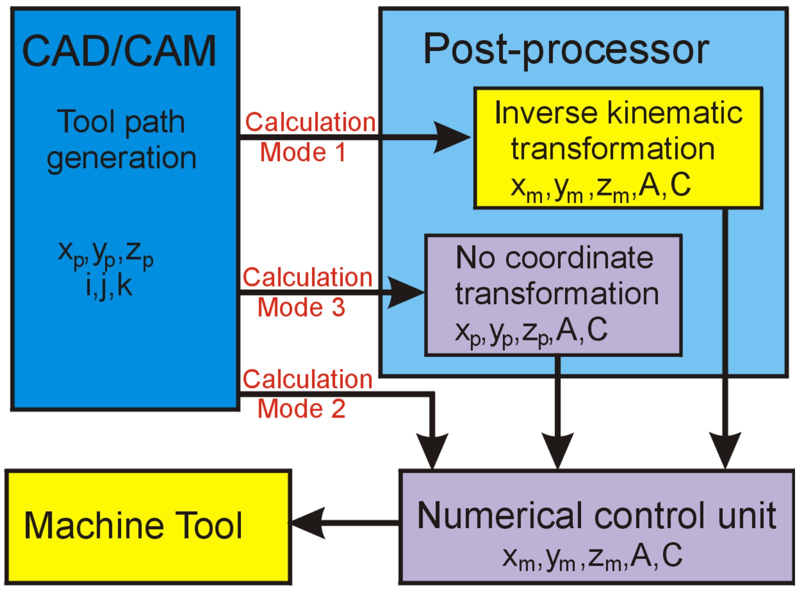


***Fig. 3:** Data transmission between CAD/CAM system and NC machine tool*

3. Process planning for laser cladding

3.1 Process planning model

- Process planning phase: contouring and filling
- Tool path generation phase: tool path planning and LTC-point computation
- Validation phase: NC verification

3.2 The contouring process

- Fabrication of a frame structure.
- Overhanging walls up to 30° with only three axes (x,y,z) systems.
- $\Delta x = \Delta z / \tan \alpha$
- The process becomes instable if the distance Δx is greater then the half of the laser beam interaction zone.
- The melt pool is effected by the gravity and so the melt flows down the side.

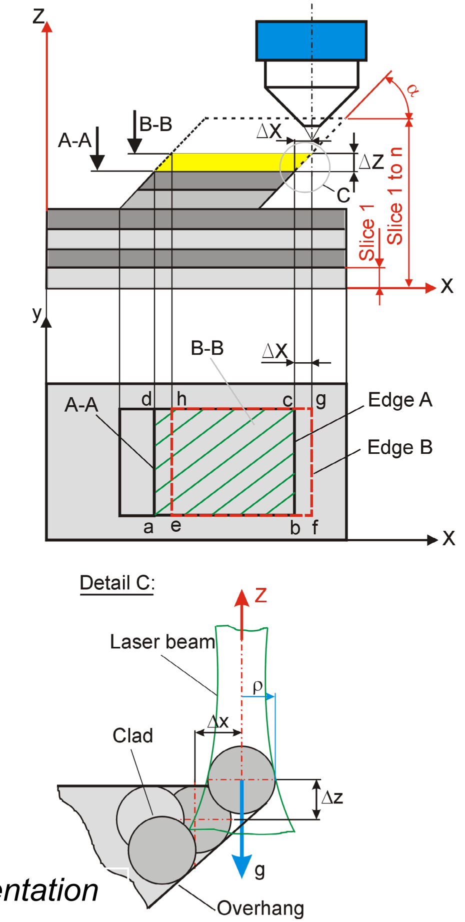


Fig. 4: Constant substrate orientation

3. Process planning for laser cladding

- Build problems can be avoided by 5-axis machining.
- Down hand strategy.
- The gravity has no significant effect on the remelted layer.
- With the 'down hand strategy' it is possible to realize arbitrary overhangs.
- Local collisions between the nozzle and the part being machined have to be considered.

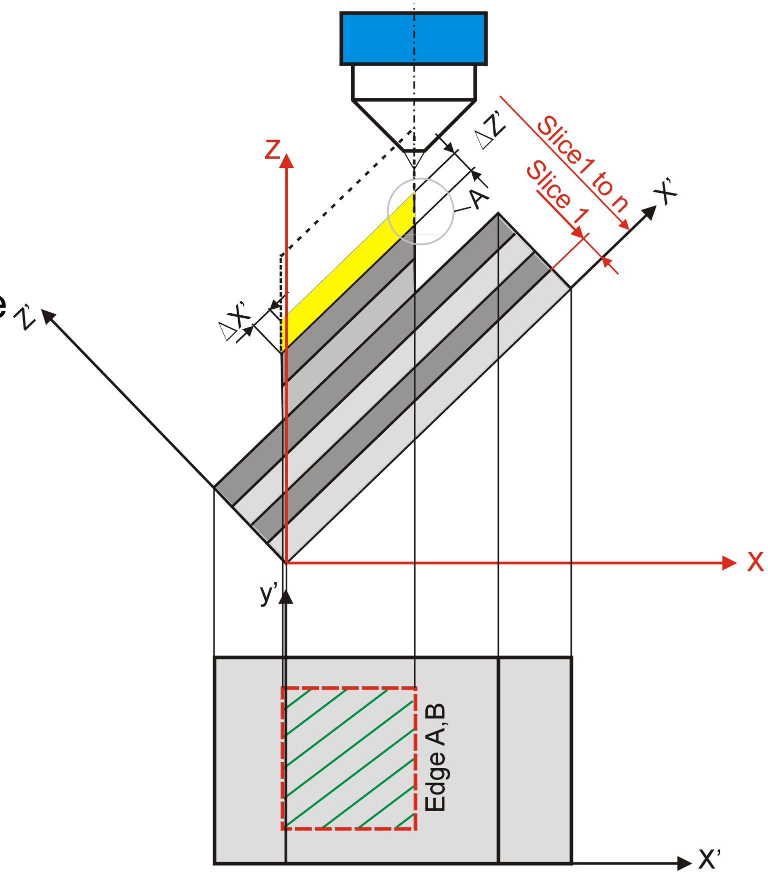


Fig. 5a: Down hand strategy

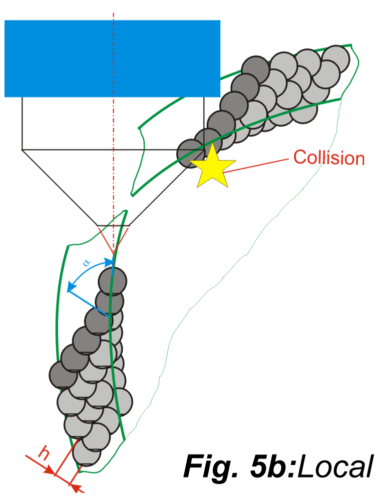
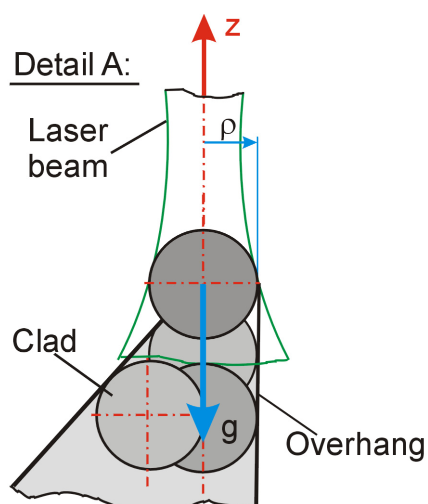


*Fig. 5b:*Local collisions



4. Tool path generation for contouring

4.1 STL slicing software for 5-axis machining

- The cladding regions can be generated via a query of the solid model.
- The part surface is represented in the STL format.
- For 5-axis LC additional part informations, e.g. the normal vector $\vec{N}(Nx, Ny, Nz)$ of the triangular facet belonging to each CC-point is necessary.

Slicing algorithm:

Step 1: Convert a 3D CAD model into a triangular facet file format, the STL file.

Step 2: Read the STL file of the model and store the data for all facets in a convenient and systematic way.

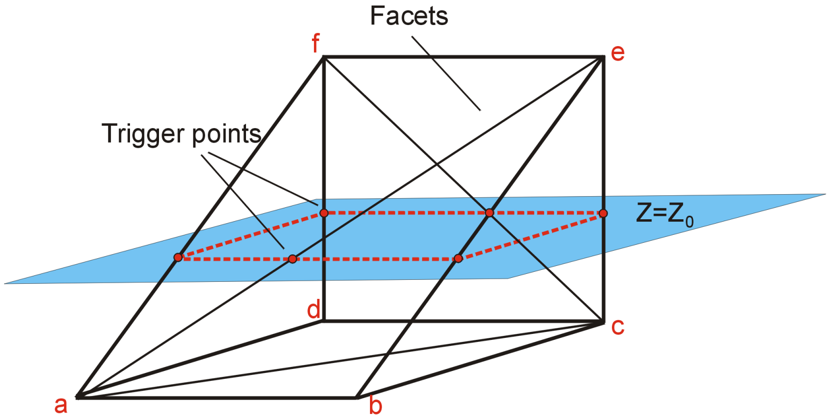


Fig. 8: *Slicing STL data*

4. Tool path generation for contouring

Step 3: Set the height value $z=z_0$ and look for all triangular patches which cross the plane at a specific z-height. Calculate the crossing segments with each triangle and sort and connect the segments to form a loop of single contour. The slice data include the point data (X,Y,Z) of each contour and the normal vector $\vec{N}(Nx, Ny, Nz)$ of the triangular facet. The intersection points (trigger points) correspond to the CC-points.

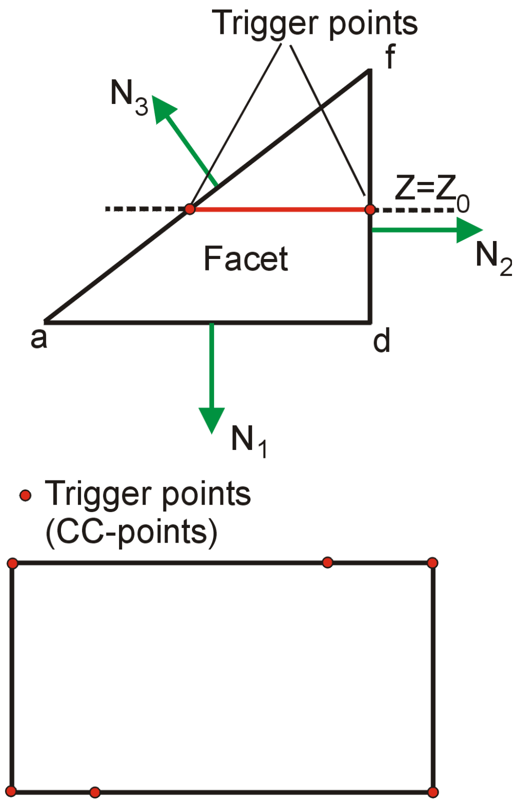


Fig. 9: *Slicing triangular patch*

4. Tool path generation for contouring

Step 4: Sequencing all these CC-points in a given loop to create a CC-path and calculate the LTC-path with a 2D-offset algorithm.

Step 5: Repeat this procedure until $z=z_n$

Step 6: Use geometric relations to generate 5-axis CNC-Code for tool movement from one tool position to another.

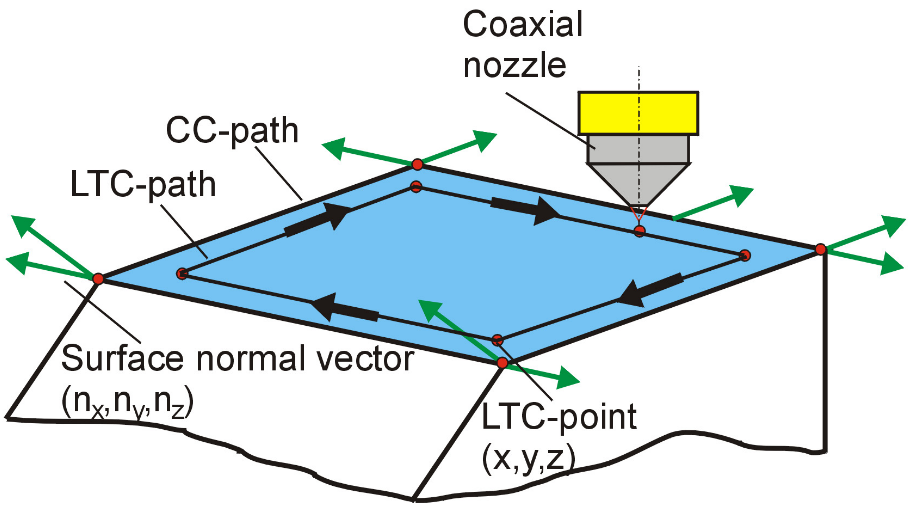
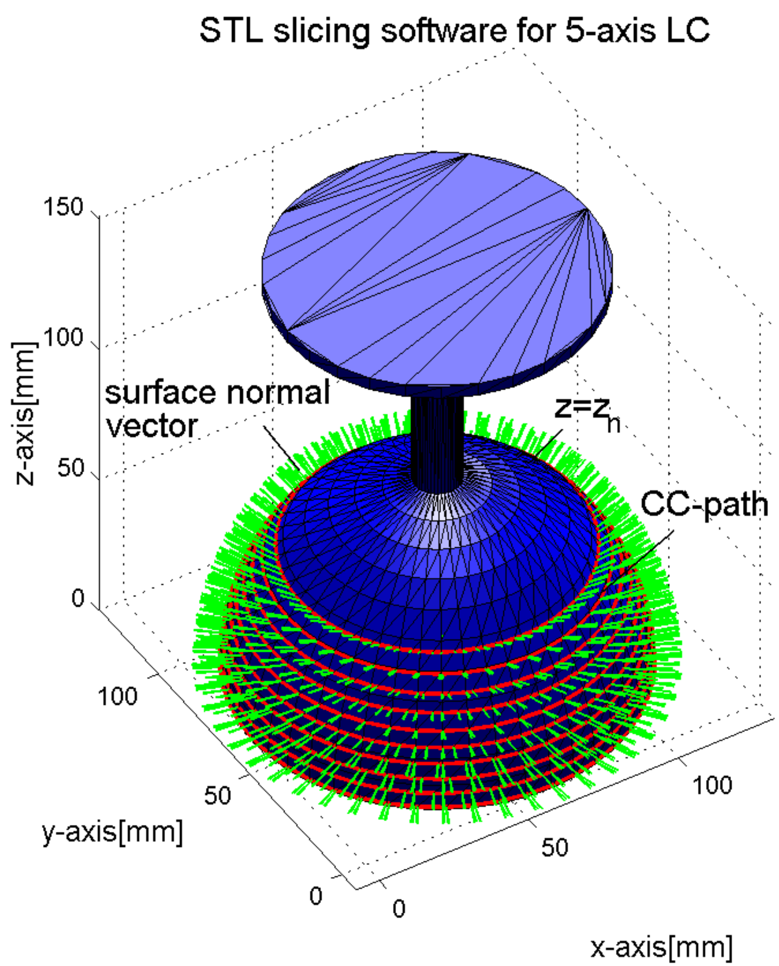


Fig. 10: *Generated tool path for LC*

4. Tool path generation for contouring



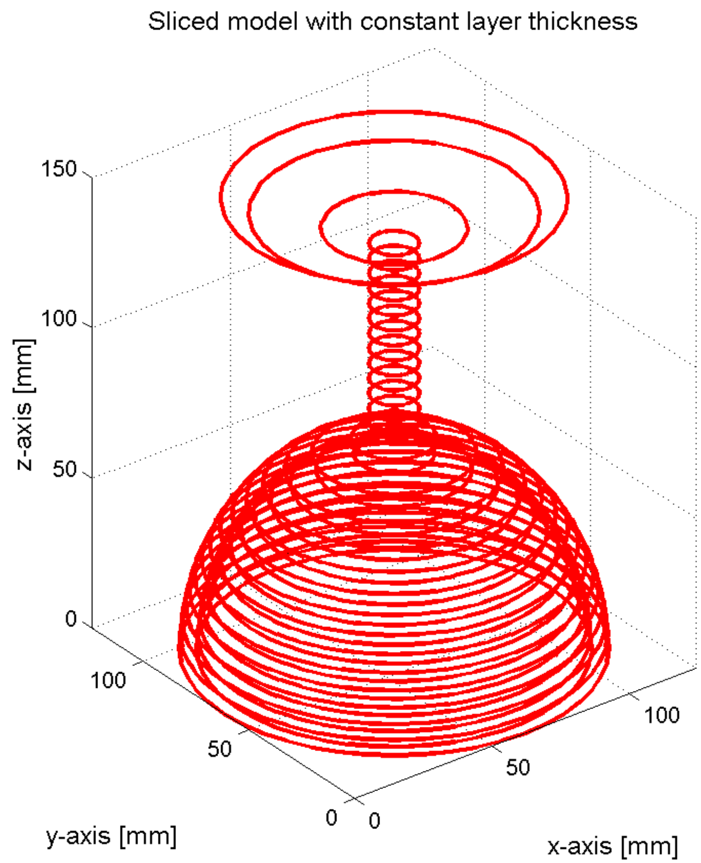


Fig. 11: *STL slicing software for 5-axis LC*

5. Tool path generation for filling

The path linking problem:

- Input: a tool path file; an area loop; island loops; filling strategy (oneway/zigzag)
- Output: a linked sequence of path segments

5.1 Path curve segmentation

- tool path file $=\{C_1,C_2,C_3,C_4\}$
- $C_1=\{S_{11}\}$; $C_2=\{S_{21}, S_{22}, S_{23}\}$; $C_3=\{S_{31}, S_{32}, S_{33}, S_{34}, S_{35}\}$; $C_4=\{S_{41}\}$

Segment node entities:

- input ports: LeftIN-port and RightIN-port;
- output ports:LeftOUT-port and RightOUT-port;
- internal links:LR-link (LeftIN to RightOUT link) and RL-link.

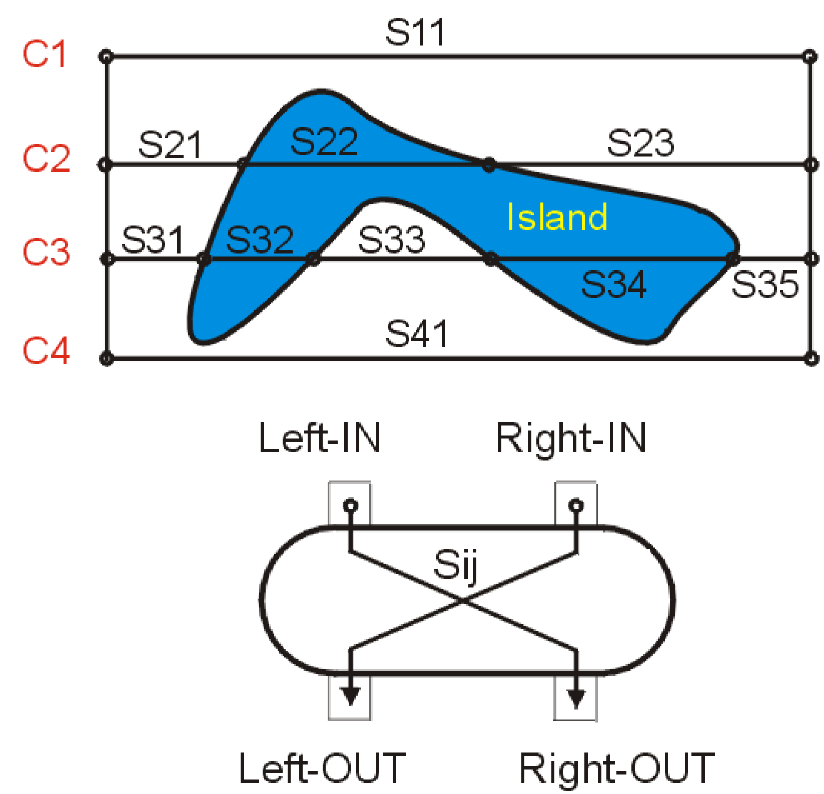


Fig. 12: Path curve segmentation

5. Tool path generation for filling

5.2 Segment net construction

- The segment net is constructed by defining external links between adjacent segment nodes.

There are four types of external links:

1. Left-link: to join the LeftOut-port of a node to the LeftIn-port of the next node.
2. Right-link: to join the RightOUT-port to the RightIN-port of the next node.
3. Left-Right-link: to join the LeftOut-port to the RightIn-port of the next node.
4. Right-Left-link: to join the RightOut-port to the LeftIn-port of the next node.

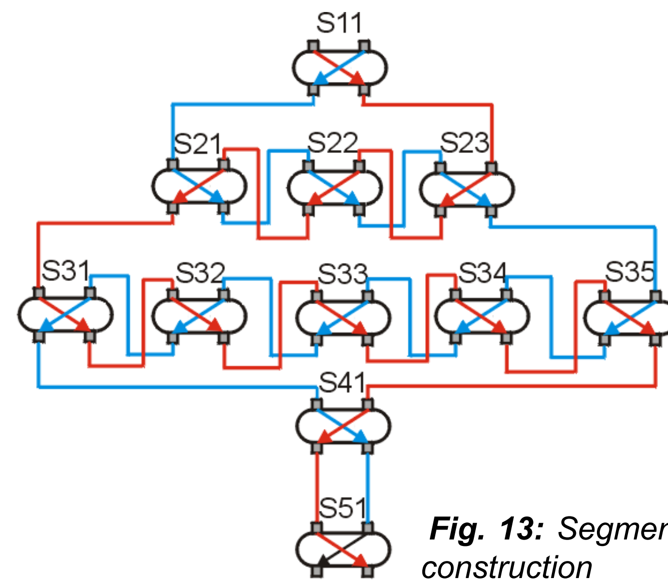
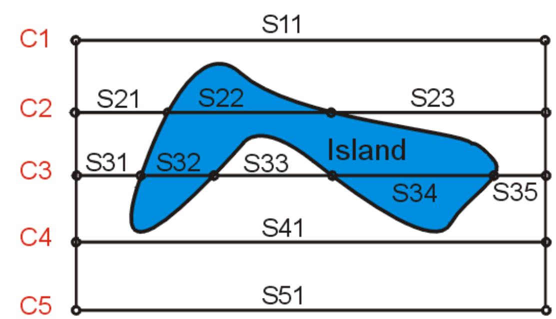


Fig. 13: *Segment net construction*



5. Tool path generation for filling

5.3 Local path linking

• The operation of linking directly connected path segments is called local path linking.

Procedure for linking zigzag tool paths :

1. Select an input-port (LeftIN-port or RightIN-port) and an internal link (LR-link or RL-link)
2. Set LR-links and RL-links, respectively in each row in the segment net.
3. Traverse the segment net following a ‘zigzag pattern’ while marking the visited nodes until nowhere to go.
4. Construct the LTC-path and go to the next layer

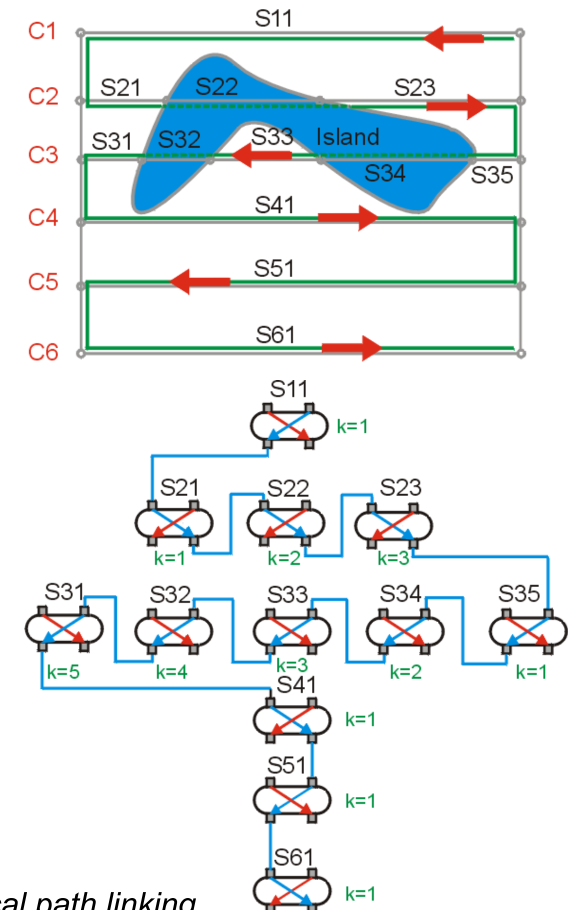
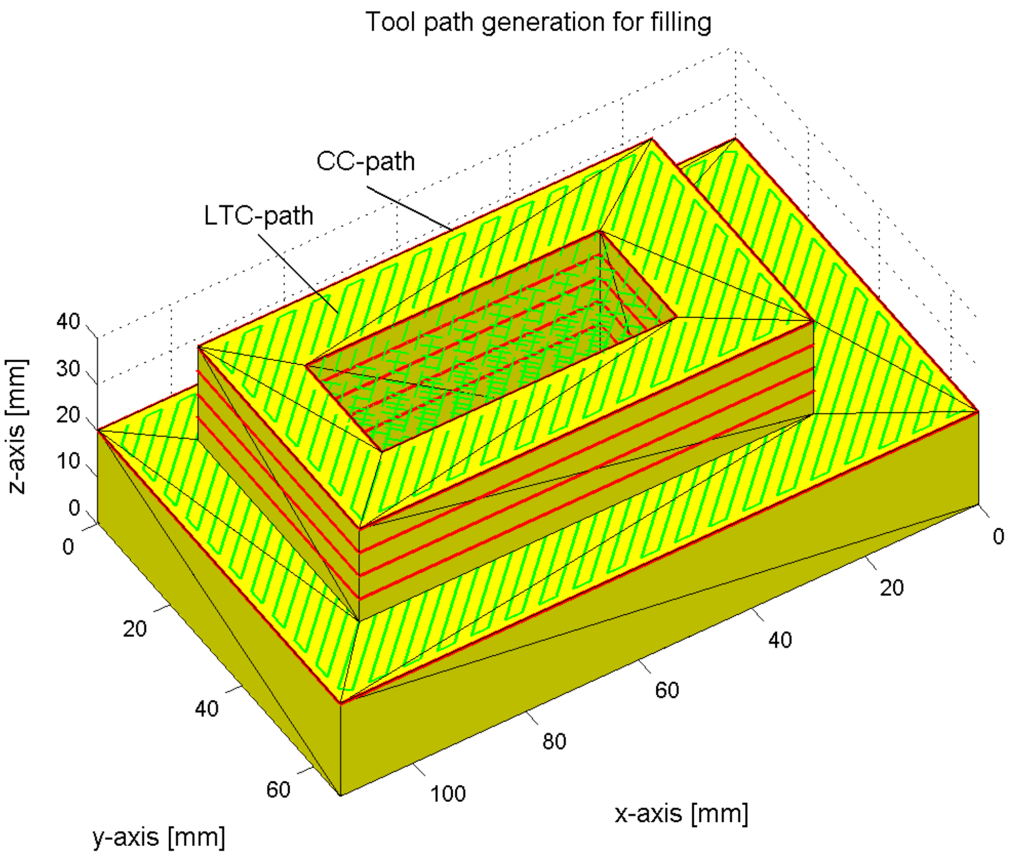


Fig. 14: Local path linking

5. Tool path generation for filling



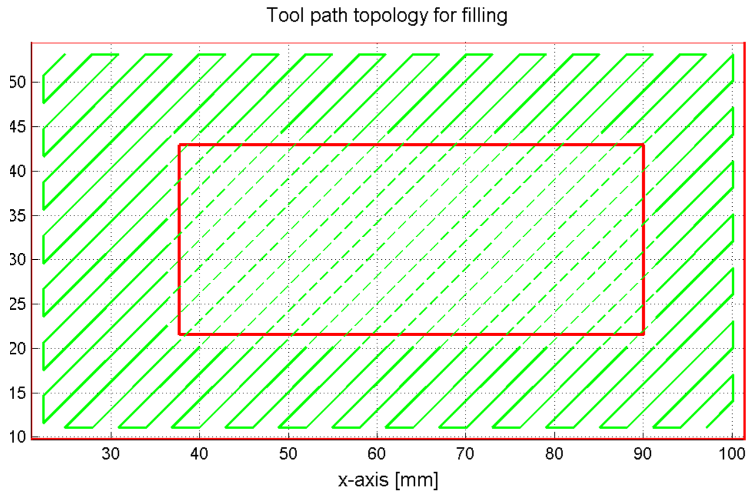
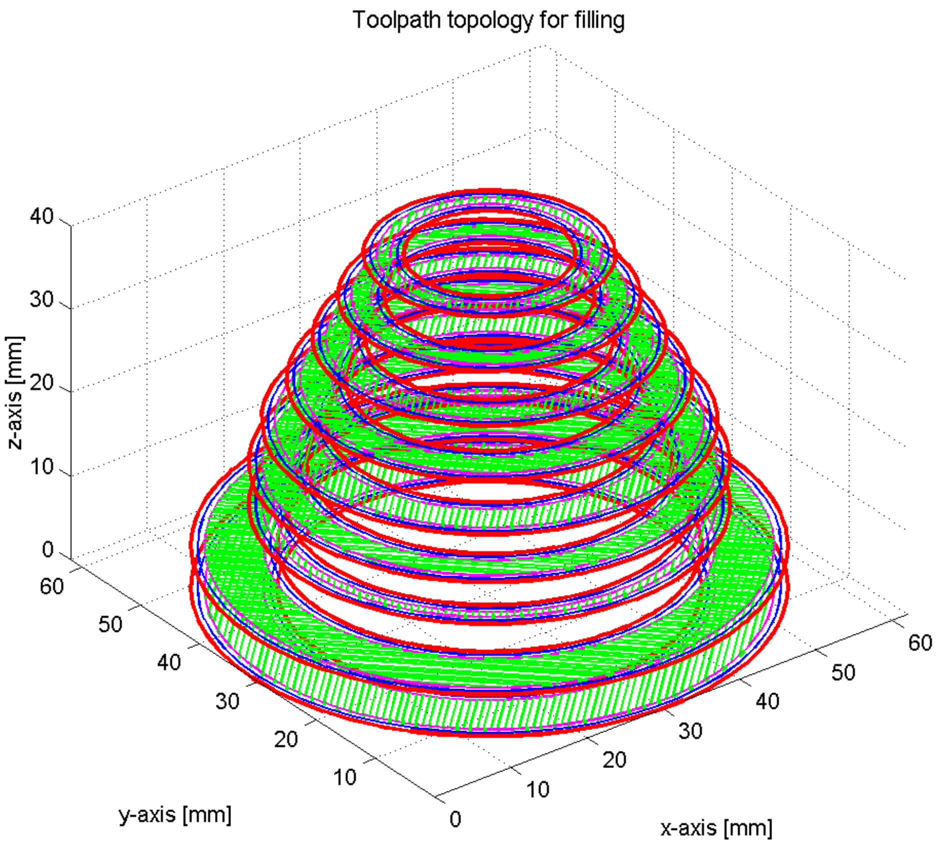


Fig. 15 a: *Planned tool paths for filling*

5. Tool path generation for filling



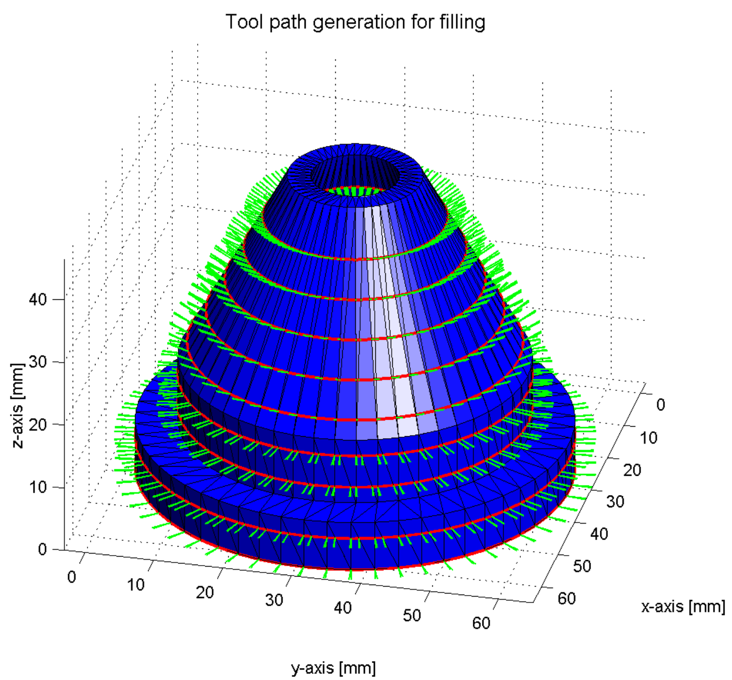


Fig. 15 b: *Planned tool paths for filling*

JOANNEUM RESEARCH

6. Results and conclusions

- We have developed a procedure and a software prototype through which NC tool paths for laser cladding of complex parts on 5-axis machines can be directly generated from a STL-CAD model.

- Tool path topologies and path linking algorithm are developed and implemented in the software.

- Some metal components were fabricated with the software.

- It was possible to produce overhanging walls of up to 30° with only 3-axis machining.

Fig. 16: *Nickel-base alloy parts fabricated by 3-axis LC*

6. Results and conclusions

• Initial trials proved that it was possible to produce the most complex parts with laser cladding by using 5-axis machines.

• For tool path generation we employ a boundary extraction algorithm to compute the contour curves and the normal vector of the triangular facet belonging to each point.

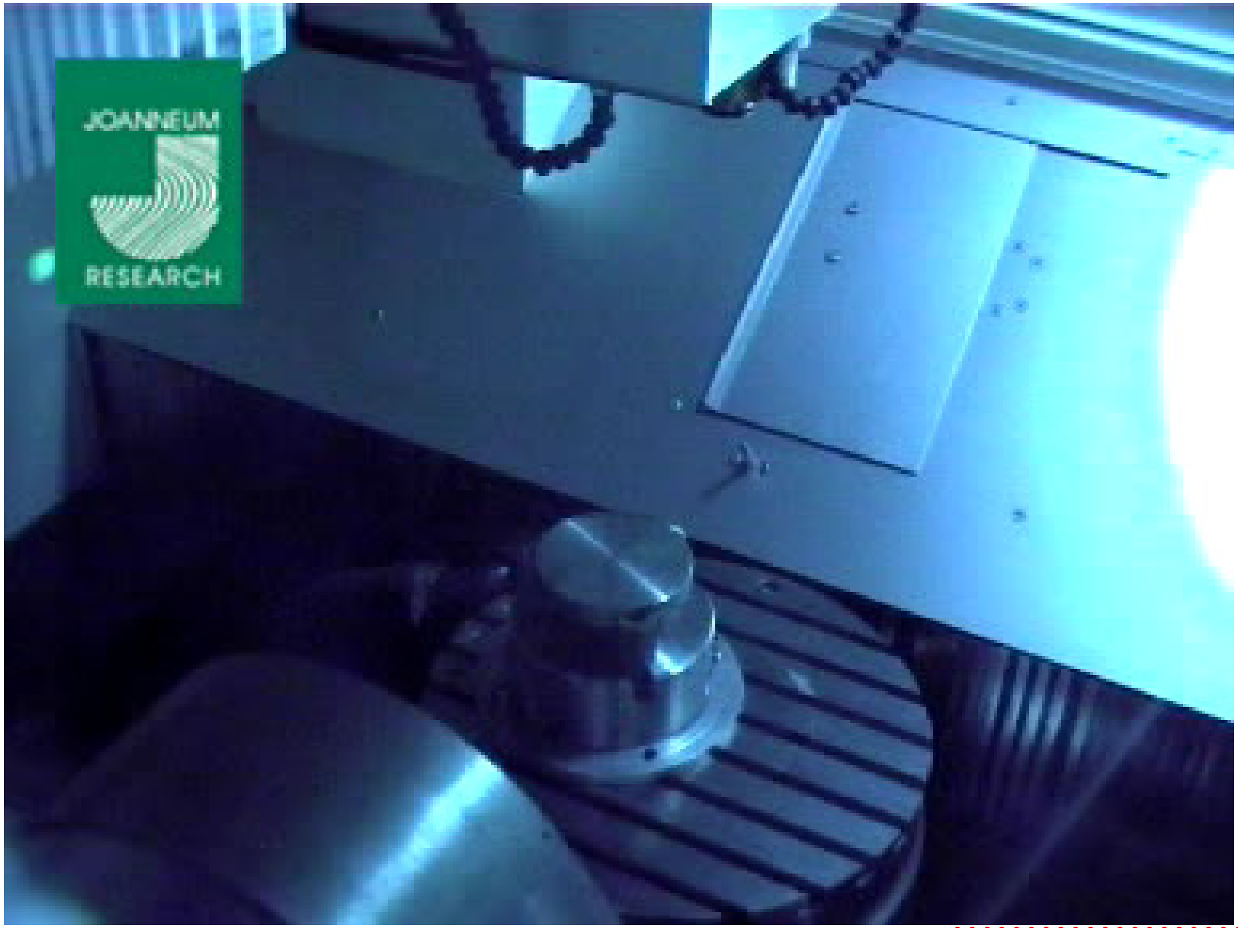
• The normal vector is used for substrate orientation.

•A zigzag algorithm was implemented in the software to compute the tool paths between the outer and inner boundary.

Fig. 17: *Wineglass fabricated by 5-axis LC*

JOANNEUM RESEARCH

6. Results and conclusions



ISO 9001 certified

a TRADITION of INNOVATION

TOOL PATH GENERATION FOR 5-AXIS LASER CLADDING

M. Kerschbaumer

JOANNEUM RESEARCH
Forschungsgesellschaft mbH
Laser Center Leoben, Leobner Strasse 94, A-8712 Niklasdorf, Austria
Phone: +43 3842 81260 2319, Fax: +43 3842 81260 30
michael.kerschbaumer@joanneum.at, http://www.joanneum.at/lzl