Robotic Grinding

Speaker 1 : François Léonard

Speaker 2 : Vianney Papot

Main results from PhD student Mohamed Didi Chaoui

Mohamed Didi Chaoui « Contribution to the robust control of a manipulator robot used in grinding ».
PhD thesis of Université de Lorraine, funded by the interreg project ''Robotix Academy'', 2020.

Summary

Introduction

- Robotization of the process is more profitable (lower costs, less time, better quality)

- Minimize the number of dangerous and tedious tasks assigned to operators :

  - Emission of dust
  - Generation of vibrations and noise
  - Biomechanical stresses

Introduction

Grinding issues

- Grinding a workpiece with an irregular surface
- Variation in grinding force
- Presence of vibration
- Deterioration of the surface quality
- Disproportionate damage to grinding tools

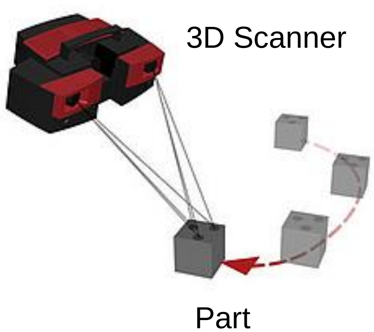
What is the right solution to grind a part efficiently and with the best surface results?

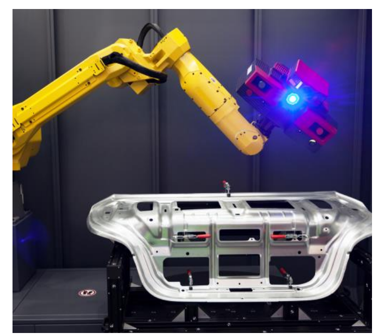
Introduction

Objectives

- Develop a robotic grinding system capable of grinding a part with a controlled depth of cut

Location and measurement → Grinding → Quality control





3D Scanner

Klingspor Fiberscheibe and Dreamstime Photo

Grinding effector

- Use of an angle grinder for :

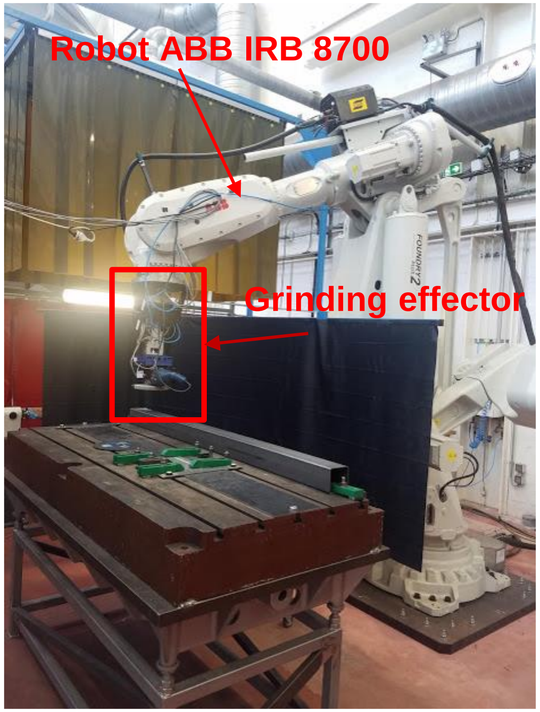
Polishing

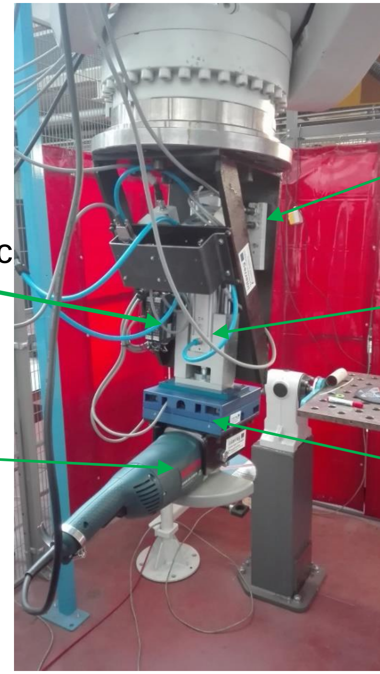
Cutting

Surfacing

Main application of proposed grinding effector : Surfacing

Grinding effector





Grinding effector

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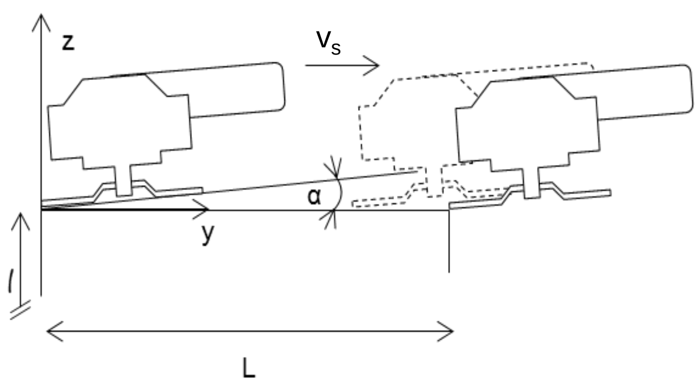
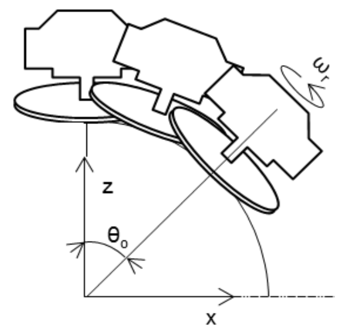
Grinding effector

- The pneumatic actuator is placed between the robot and the grinder.
- The functions of the damper are:
  - Maintain a constant grinding force
  - Reduce vibrations
  - Follow the shape of the workpiece



Grinding configuration in the plane YZ



Grinding configuration in the plane XZ

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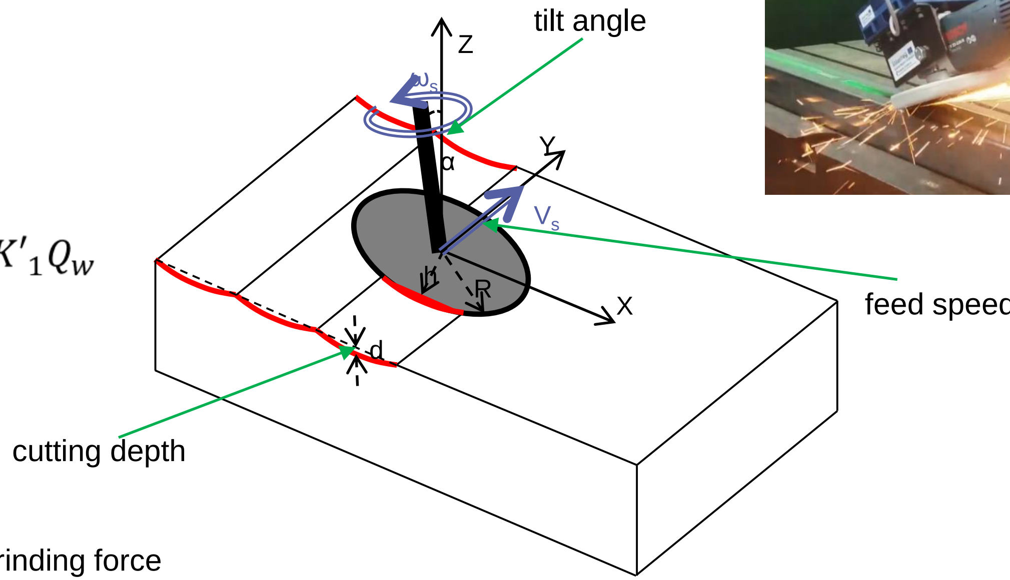
Grinding model

- Grinding model used (see Persoons et Vanherck)

$$F_p = K'_0 + K'_1 Q_w$$



With
F_p : normal grinding force
K'_0, K'_1 : constants
Q_w : material removal rate

W. Persoons, P. Vanherck, A Process Model for Robotic Cup Grinding, CIRP Annals, Volume 45, Issue 1, 1996, Pages 319-325

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New grinding model

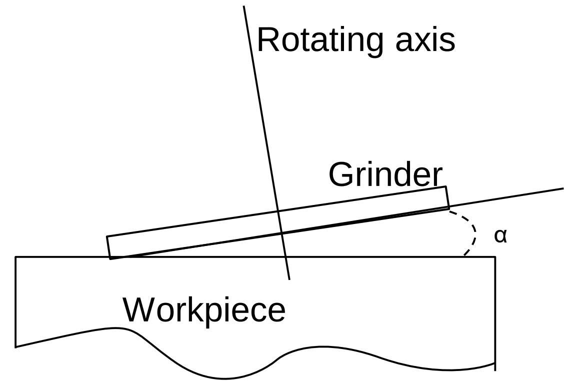
Material removal rate:

$$Q_w = V_s S$$

$$S = \left(\frac{d}{cos\alpha}\right)^{\frac{3}{2}} \sqrt{2R}$$

Force model

$$F_p = K_1 + K_2 S V_s$$



If R, α and V_s are constant, the simplified model becomes:

$$\boxed{F_p = K d^{\frac{3}{2}} + K_1}$$

With K1 and K are constants to be identified, $K = \frac{K_2 V_s \sqrt{2R}}{(cos\alpha)^{\frac{3}{2}}}$

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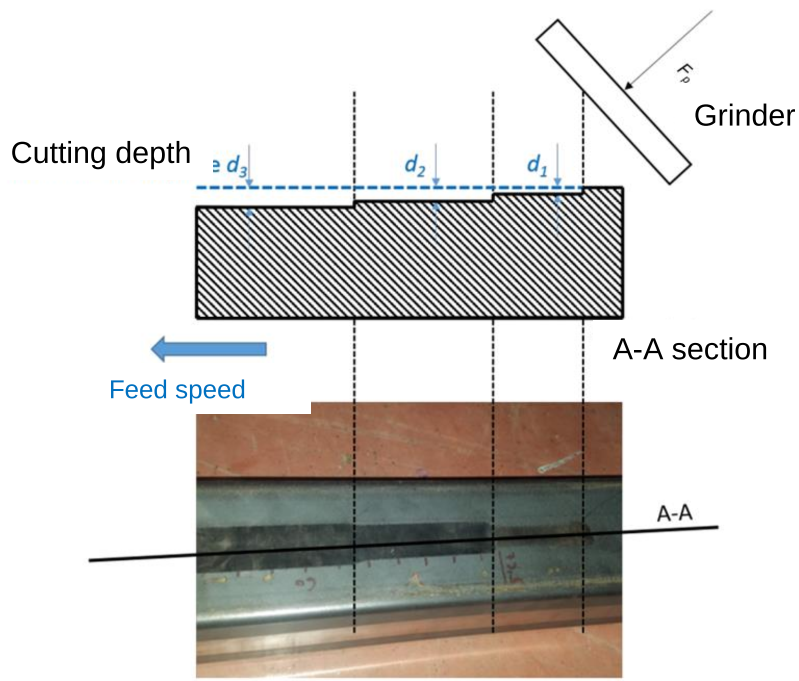
Grinding effector

Identification of grinding force model parameters F_p



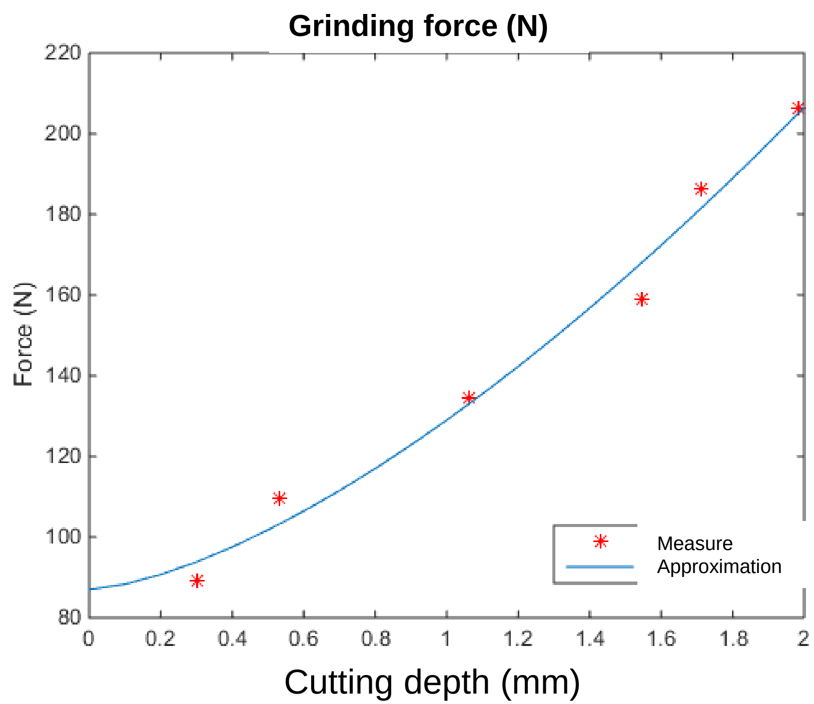
Grinding effector

Identification of grinding force model parameters F_p

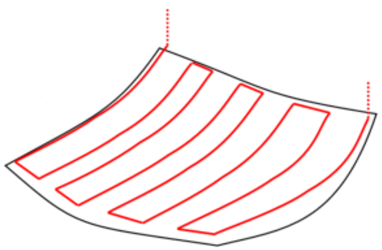
Vanherck modified model :

$$\boxed{F_p = K\,d^{\alpha} + K_1}$$

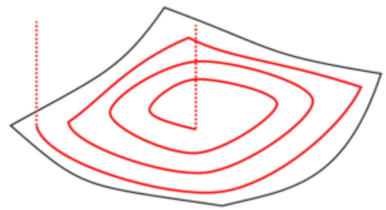
K=42,5 ($m^{3/2}s^{-1}$)
α= 1,5
K_1=87 (in N)



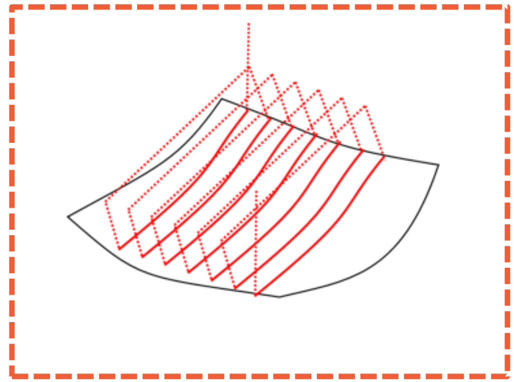
Path Planning



Zigzag

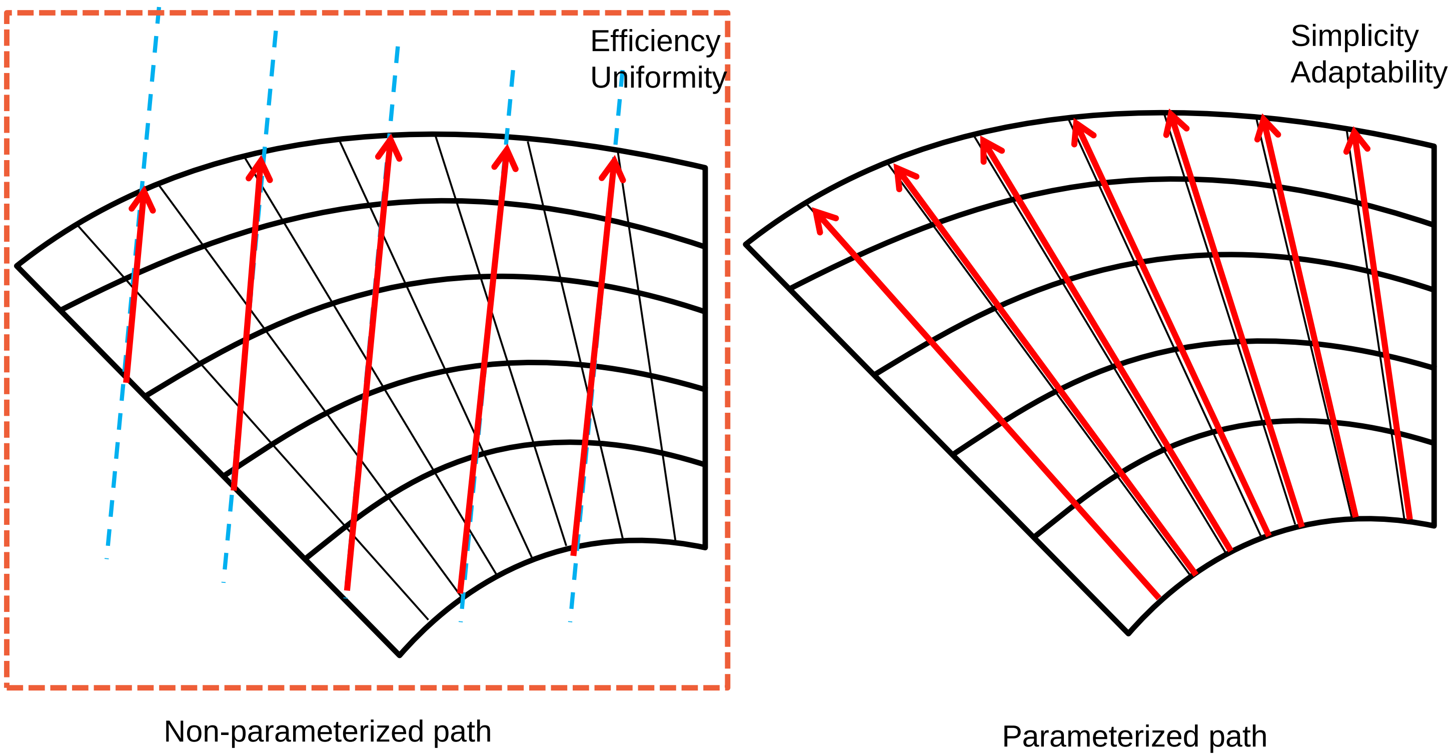


Circular

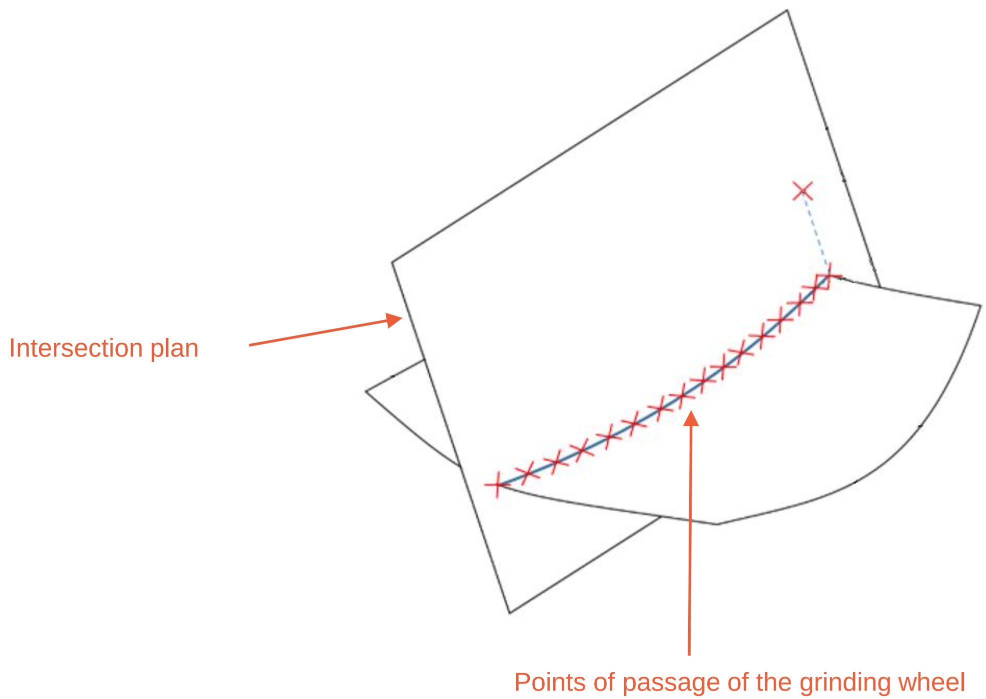


One way

Choice of feed direction



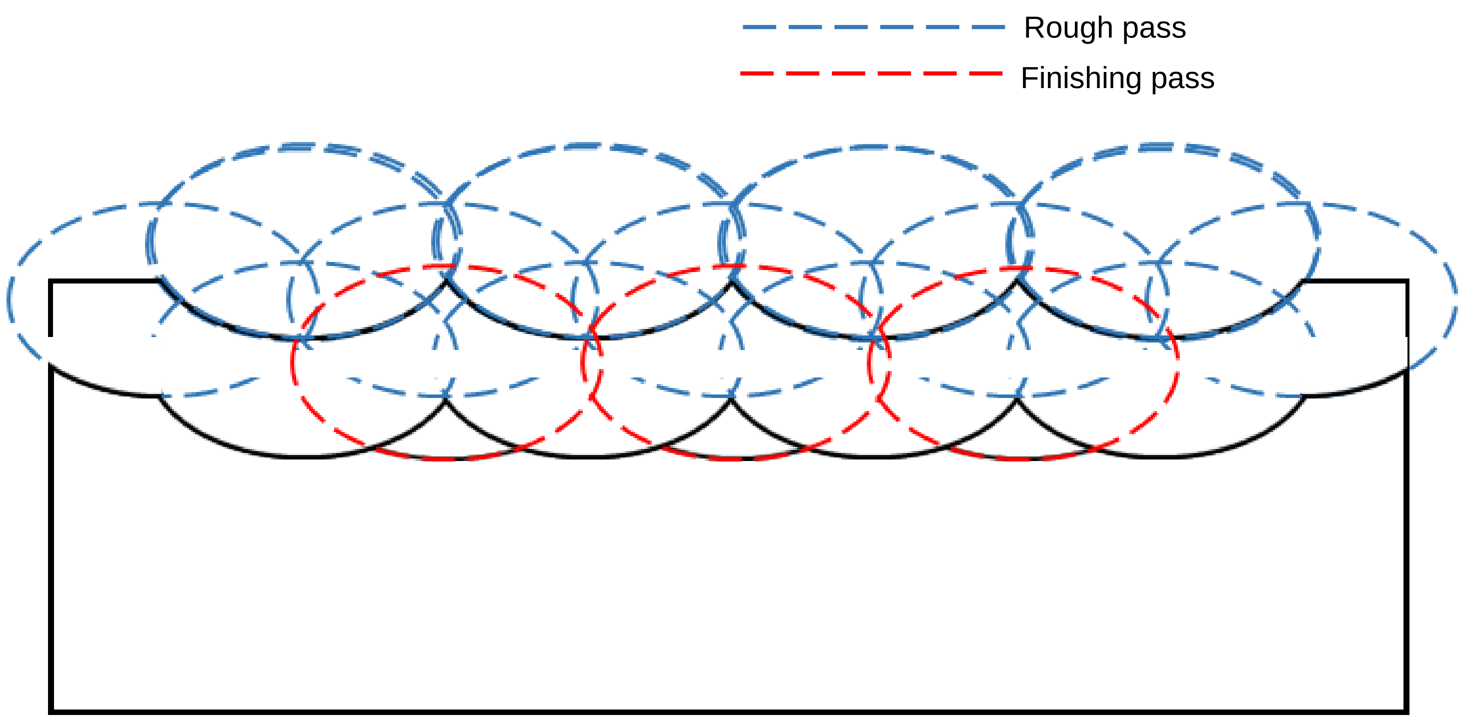
Definition of the trajectory points



Non-parameterized path

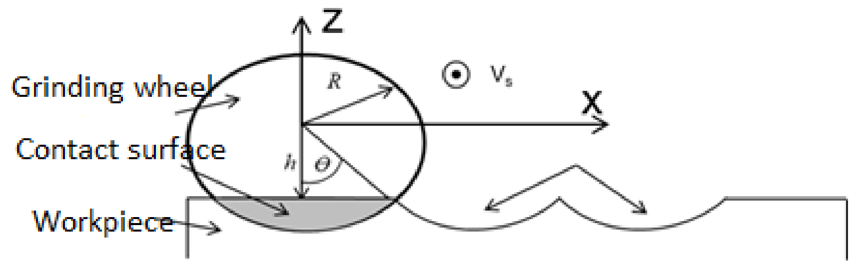
Path Planning

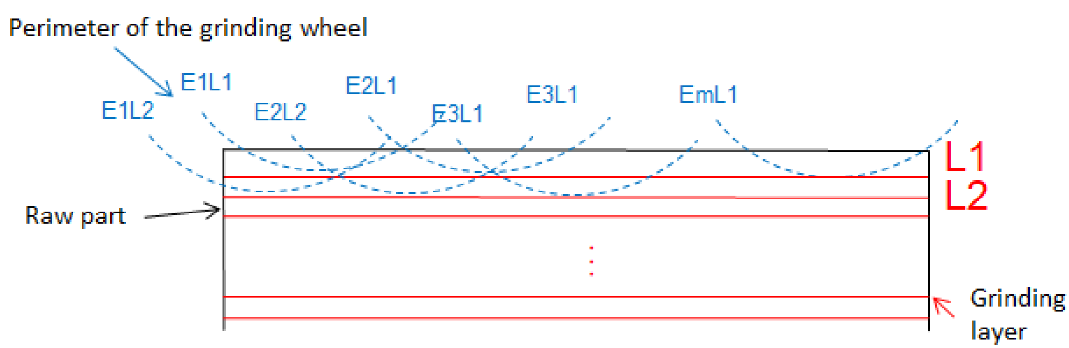
Off-line planning methodology



Off-line planning methodology

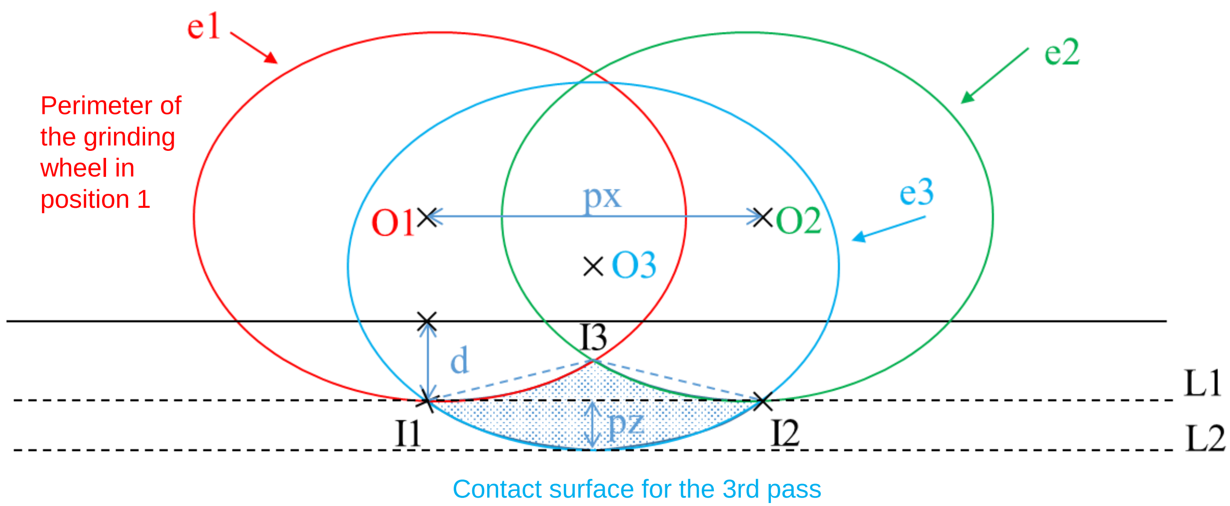
- The grinding is done in several layers
- The last layer is the finishing layer





Path Planning

Off-line planning methodology



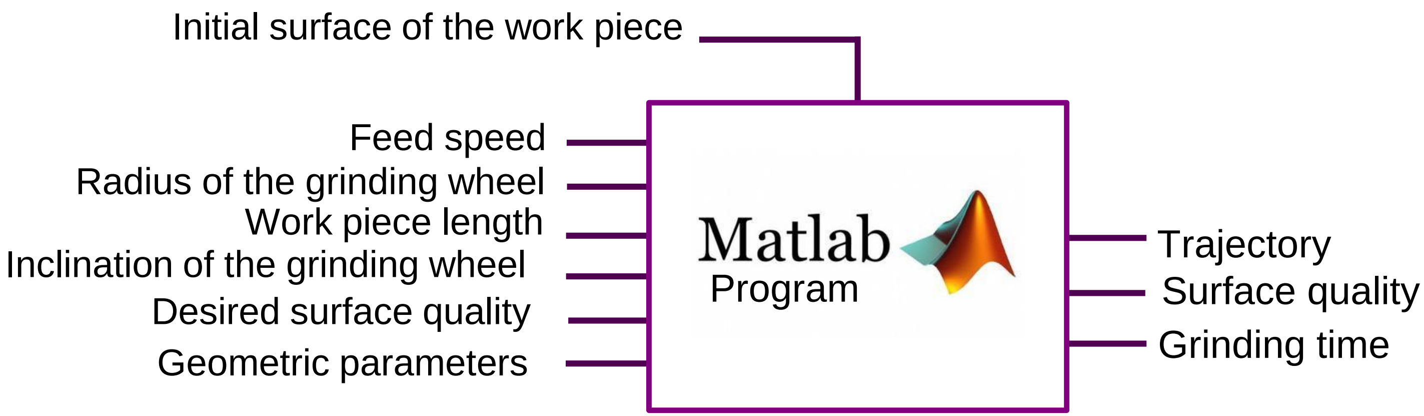
Path Planning

Off-line planning methodology

Generation of the pass points from the work piece geometry.

- Calculation of number of passes N_p and the number of grinding layers N_c
- The intersection planes j_i are constructed
- Calculation of number of points N for each pass (depends on the precision)
- Interpolation of the points located in the intersection between the planes and the surface of the part

Matlab program



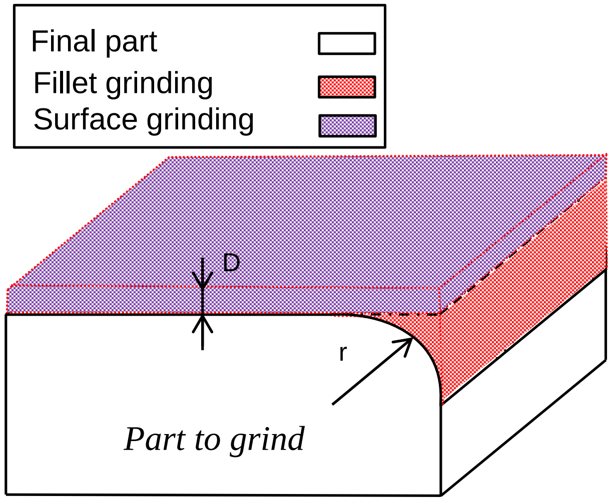
Inputs and outputs of the Matlab program

Path Planning

Case study

- Surface grinding
  grinding depth : D

- Fillet grinding
  radius of the fillet : *r*



1st grinding step

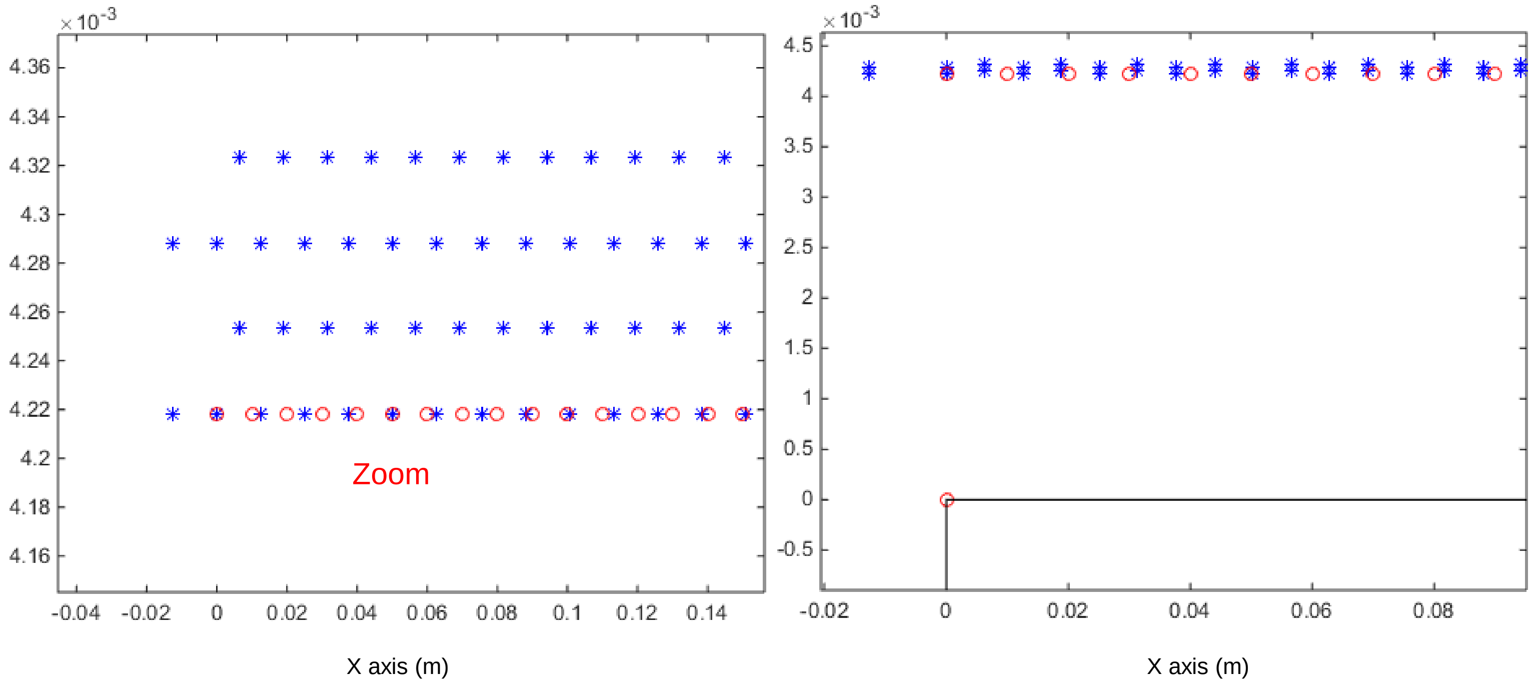
- Maximum grinding force
- Feed speed: V_s=cst
- Maximum material removal rate

2nd grinding step

- Variable grinding force
- Feed speed : V_s= variable
- Lower material removal rate

Path Planning

Path planning results

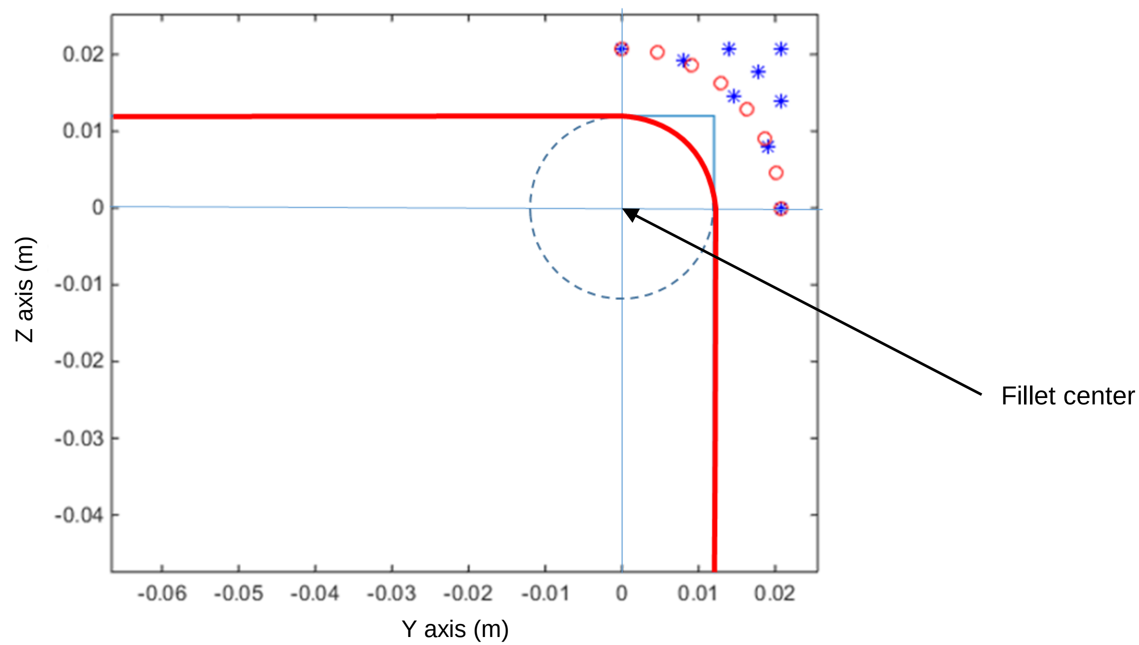


Perimeter of the disc in the both grinding steps

Depending the choosen parameters, we can estimate the grinding time.

Path Planning

Path planning results



Perimeter of the grinder disc in both steps

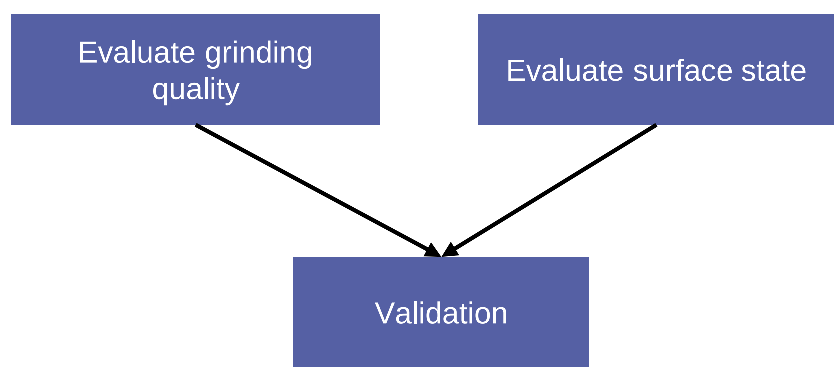
1) Fist step (in blue)
Material removal rate is maximum.

2) Second step (in red)
- Improve the surface quality
- Reduce geometry fault

Experimental validation

Approach

- A grinding test is composed by the following steps :
  - Scanning of the blank part
  - Path planning and force profile
  - Robotic grinding
  - Scanning of the machined part



Experimental validation

Blank parts for tests

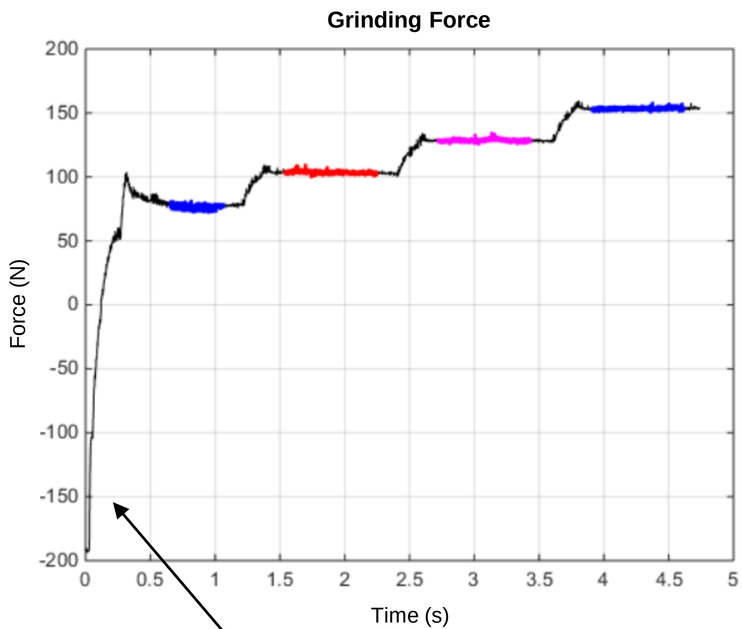
- Surface grinding tests on a metal sheet
- Fillet grinding tests on a metal prism

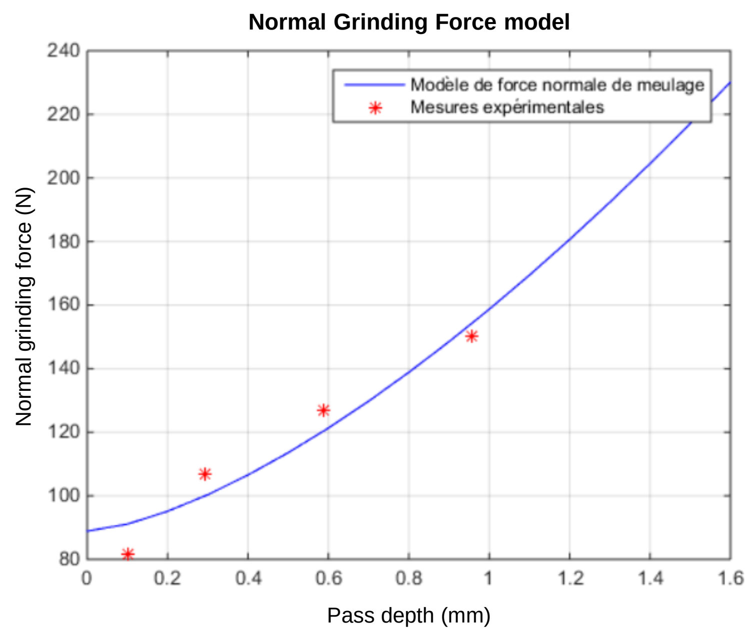
Material: steel S235

Experimental validation

Identification test

- To identify the force model.



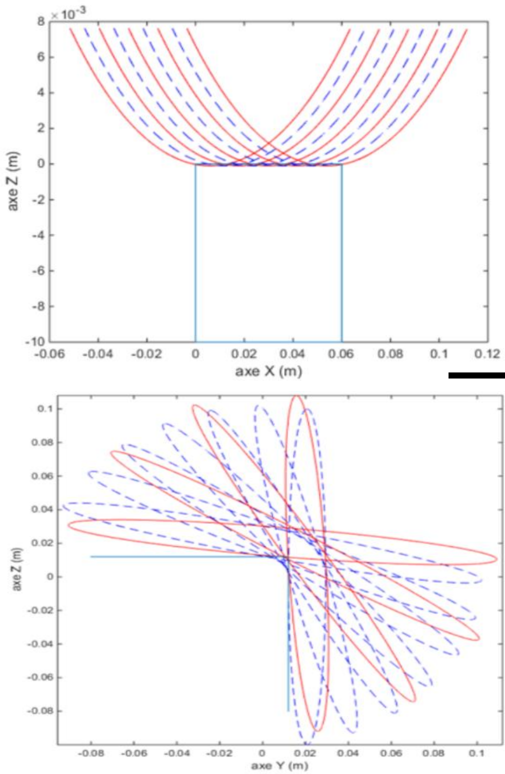


Starting force is negative because the actuator is kept retracted.

Experimental validation

Case study trajectory

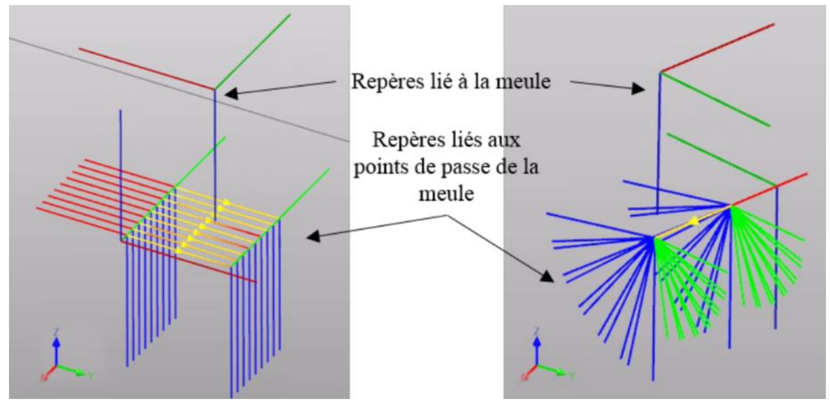
Matlab trajectory



Surface

Fillet

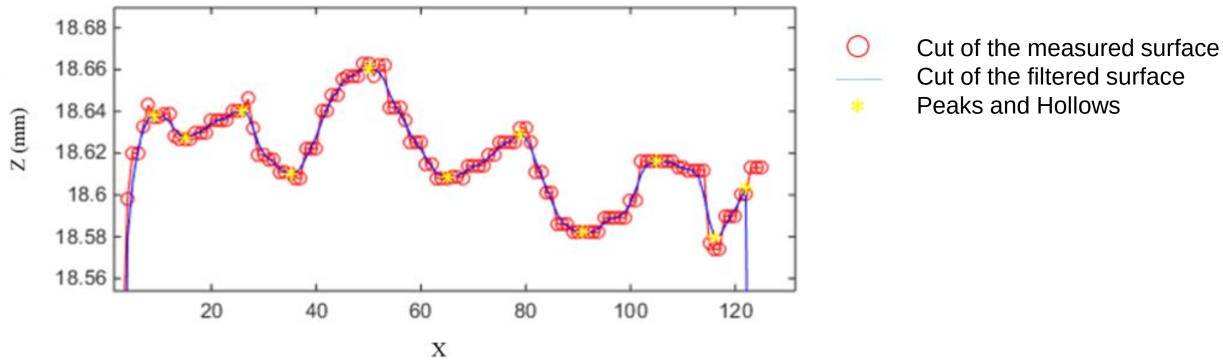
Trajectory exported to RobotStudio



Perimeter of the disc for draft passes
Perimeter of the disc for finishing passes
X axis
Y axis
Z axis

Experimental validation

Filtering and approximation



$$data.zf = data.z \circledast g$$

Gaussian convolution filter → Separation of component profiles

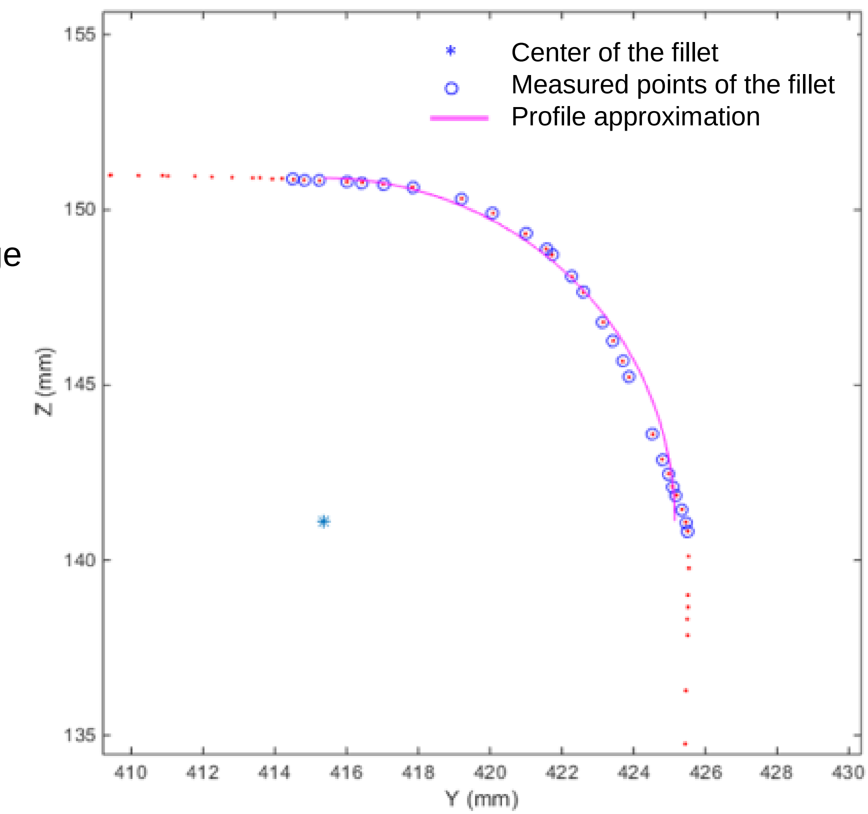
shortwave component profiles
→ Roughness

long-wave component profiles
→ Corrugation

Experimental validation

Filtering and approximation

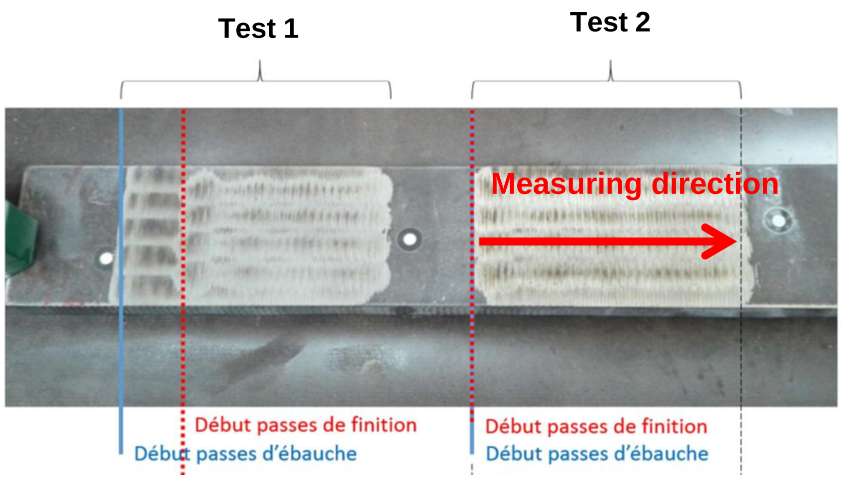
The conjugate gradient method used determines the radius and center of the edge from the mesh.

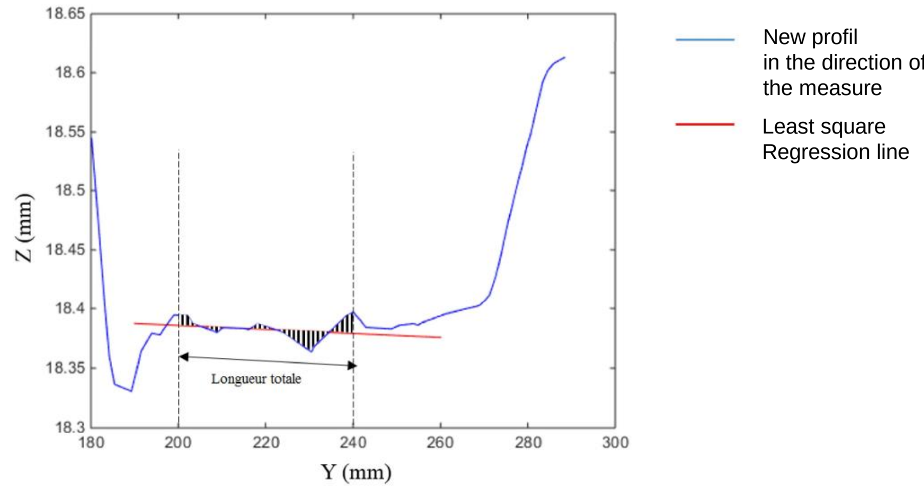


Section along the x-axis at the edge

Experimental validation

Calculation of the roughness : R_a





$$R_a = \frac{1}{l}\int_0^l |Z|dY = \frac{\sum(Aire+) + \sum(Aire-)}{l}$$

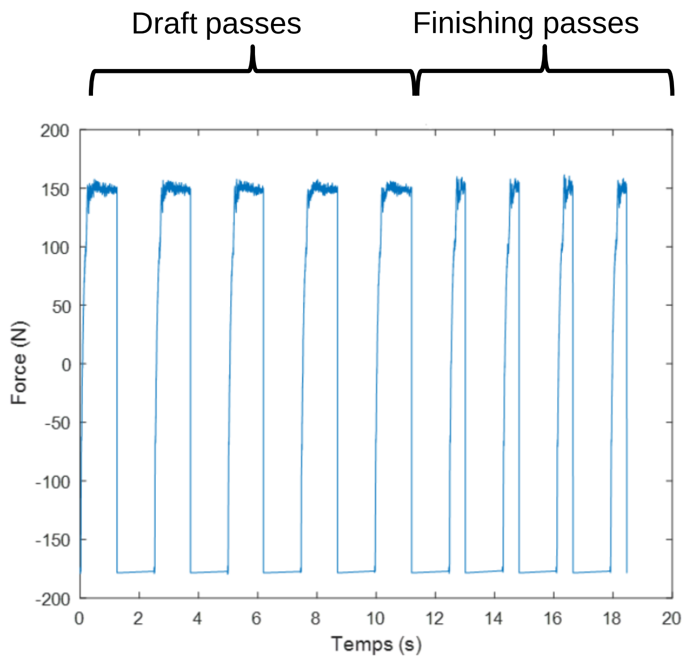
l : Base length (= 8mm on 40mm)
Z: Position of the surface in relation to the Z axis
Y: Measuring direction

Experimental validation

Grinding parameters

Grinding parameters for draft and finishing steps.

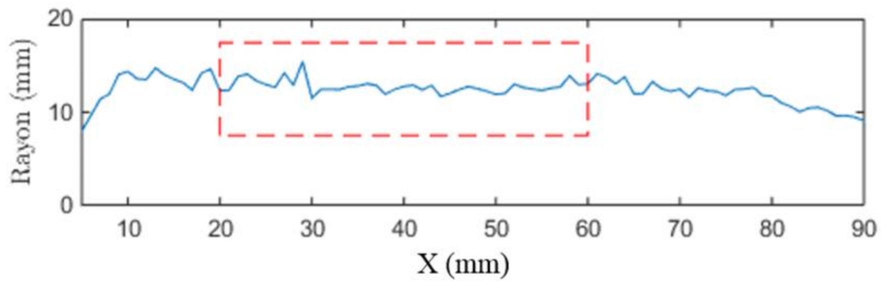
Grinding parameters	Draft step	Finishing step
Feed speed, V_s	75 mm/s	225 mm/s
Tilt angle, α	30°	30°
Grinding force, F	150 N	150 N



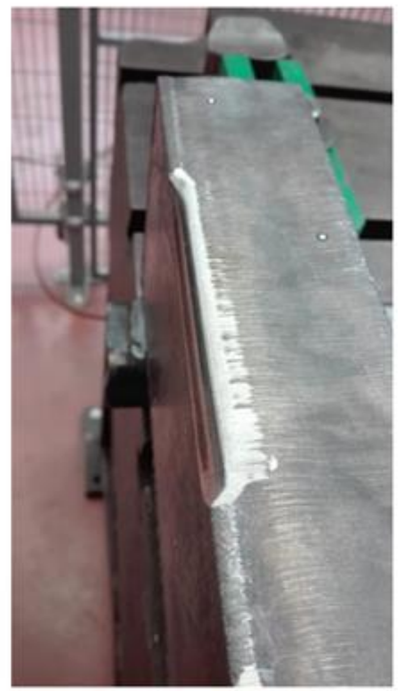
Grinding force profil for surface grinding

Experimental validation

Robotic grinding results



Quality parameters		Values
Average perimeter (mm)	l_a	**16,48**
Average surface (mm²)	A	**79,12**
Circularity (S.U.)	$C_{average}$	**1,09**
	C_{max}	**1,16**
Radius (mm)	r_{ave}	**12,78**
	r_{max}	**15,4**
	r_{min}	**11,54**
Surface roughness (S.U.)	R_s	**1,02**



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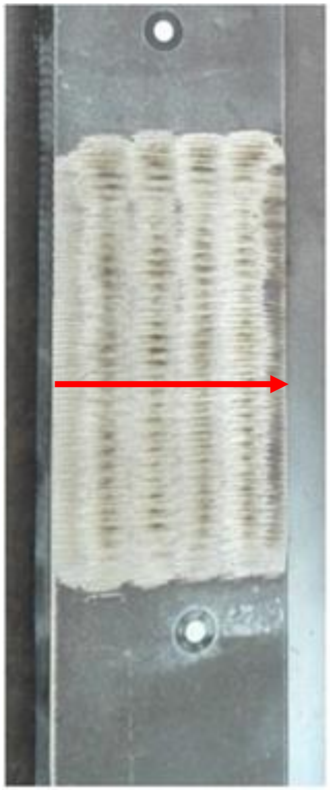
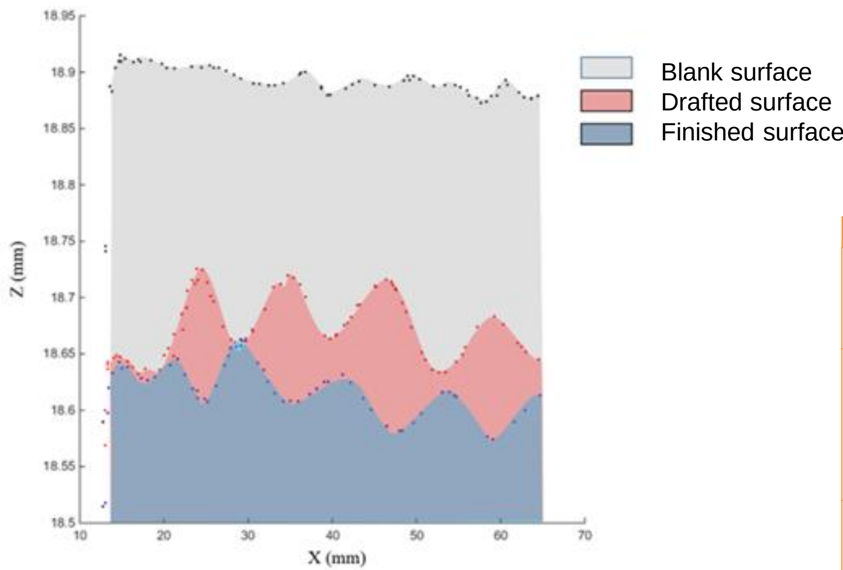
Robotic grinding results



Second measure direction



Measure width : 40 mm
Base lenght (filtering) : 8 mm

Quality parameters		Values
Roughness (µm)	R_a	3,78
	R_q	4,57
	R_z	8,72
Surface Roughness	A_t (mm²)	2032,31
	A_n (mm²)	2000
	R_s	1,02
Corrugation (mm)	h_{max}	0,05
	h_{moy}	0,03
	Step	12

Experimental validation

Synthesis

- Tests results
  - Robotic grinding is stable
  - No big grinding defect.

- Analysis
  - Surface state is acceptable
  - Process efficency is around 45 %

Conclusion

- Description of the grinding process
- Digital validation
- Path planning
- Experimental validation

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Conclusion

- Consideration of the effect of the robot joint deformation and the gyroscopic effect of the grinding disc
- Consideration of disc wear on the path planning
- Modeling the variation of the grinding wheel profile
- Improved grinding at contact and shrinkage points
- Exploration of different path planning methods.

Robotic Grinding

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