# Kickoff Meeting "FairMillData2"

# Basis for Open Milling Process Improvement by Analysing FAIR Milling Dataset

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# Agenda

- Motivation & project goal
- Milling experiments
- Dataset
- Outlook

# Motivation & project goal

*Use sensor data from milling machine tools to make milling more efficient*

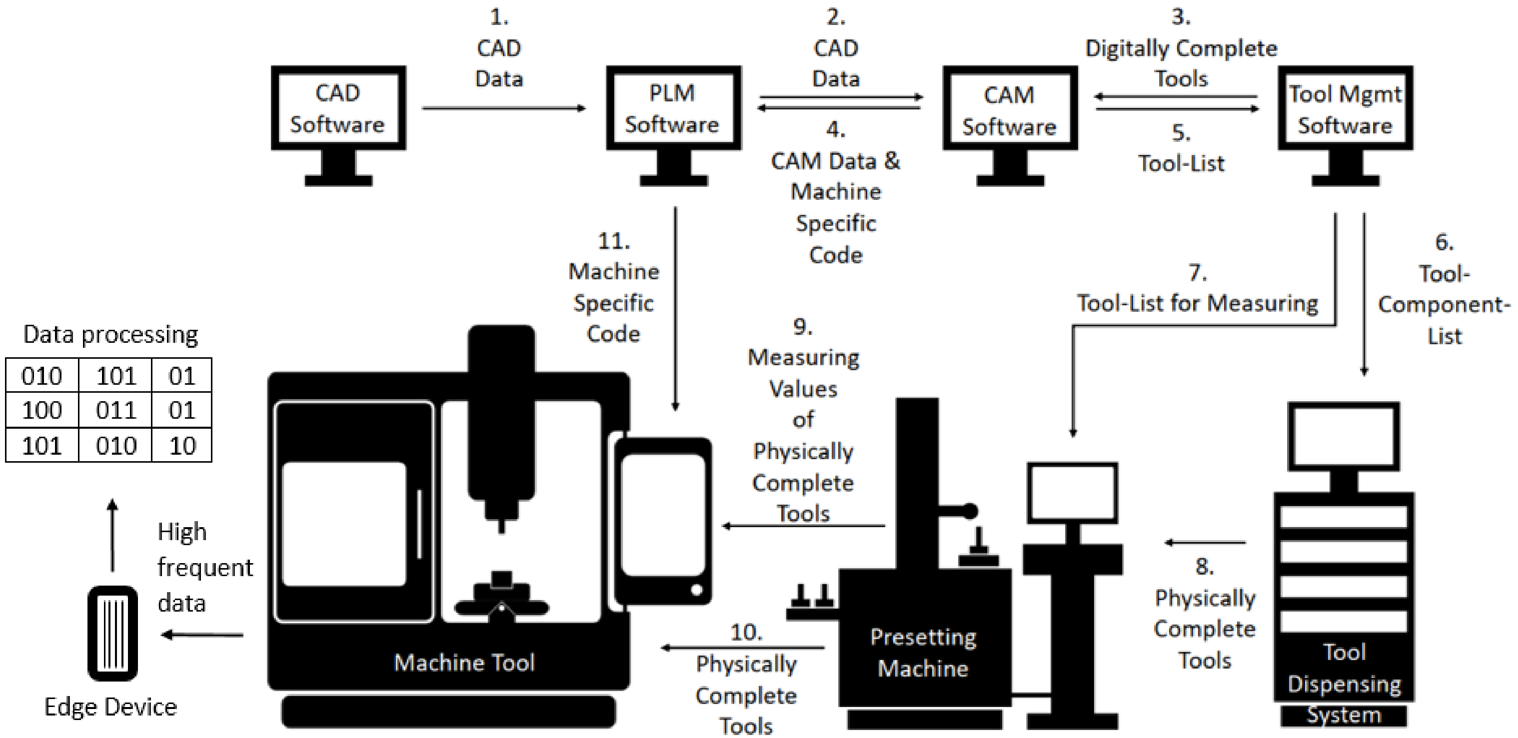

- Data-analysis-based optimization of milling operations
- Use “FairMillData” dataset composed of machine tool-internal sensor data labeled with “metadata” that describe their collection conditions.

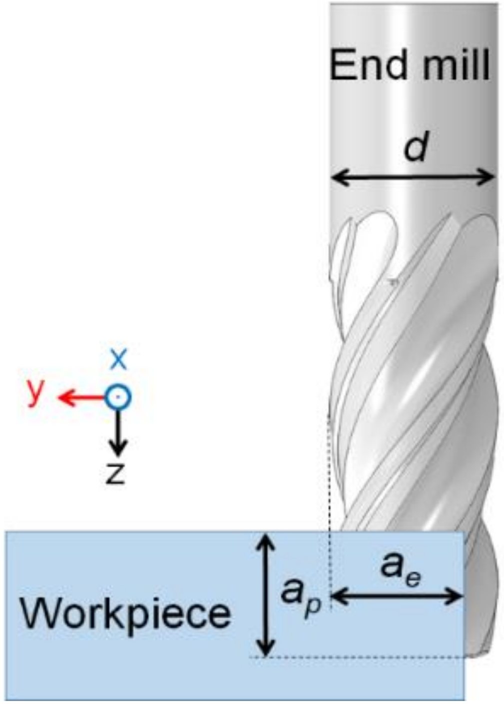
# Motivation & project goal

*Optimization goals*

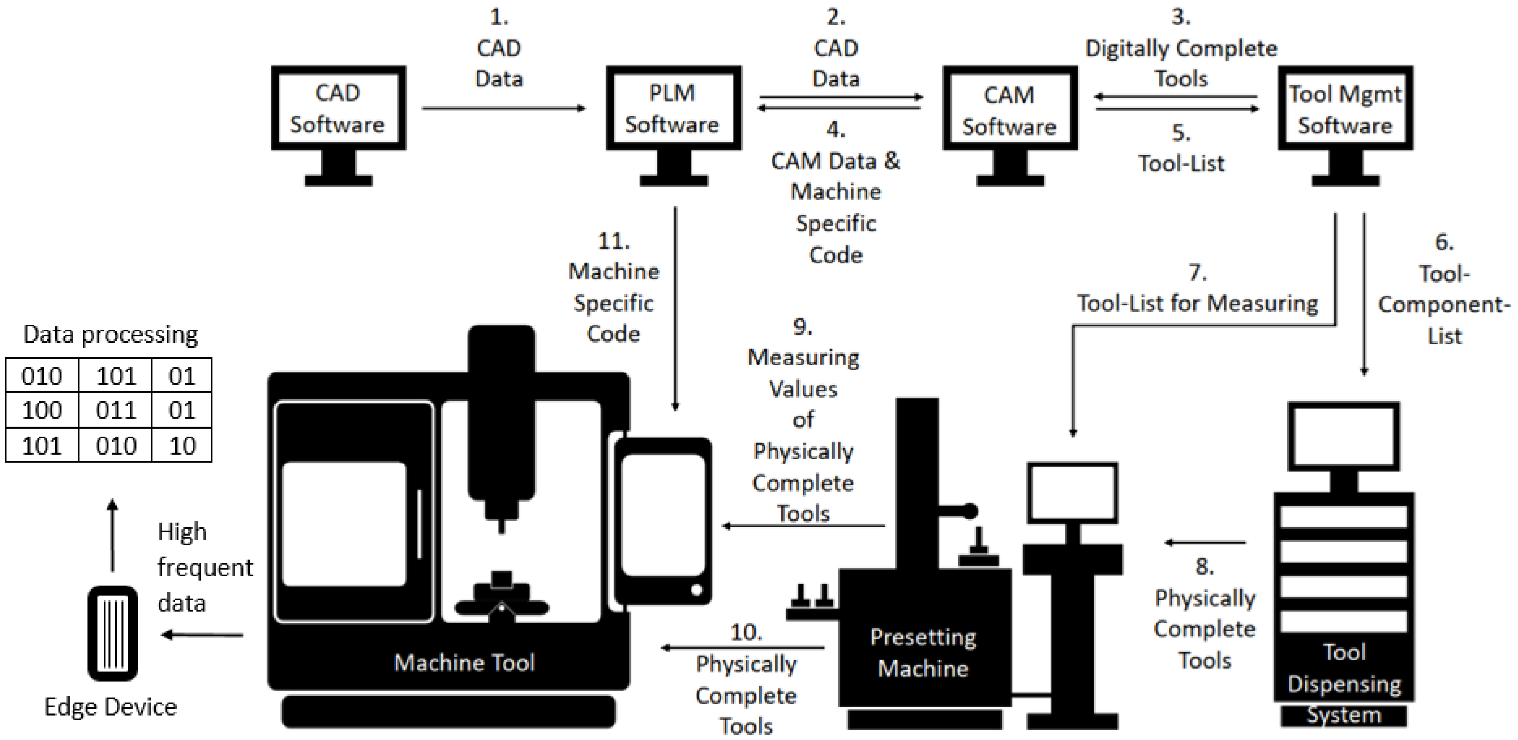
Sensor-data-based analysis of impact of variations in milling parameters on quantities such as:

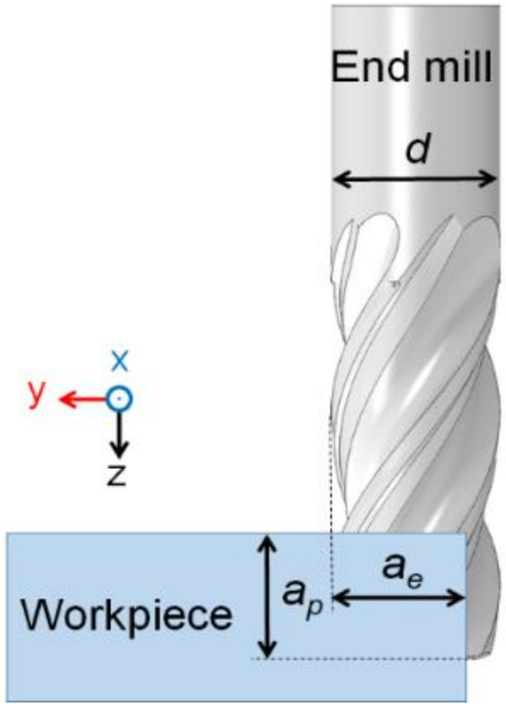
- Energy consumption
- Positional accuracy
- Actual tool acceleration patterns
- Tool cutting edge loads as f(tool path)
- Machine tool motor loads




- Well-structured “metadata” prerequisite for data analysis
- Metadata describe the boundary conditions of (ideally) the complete milling process chain

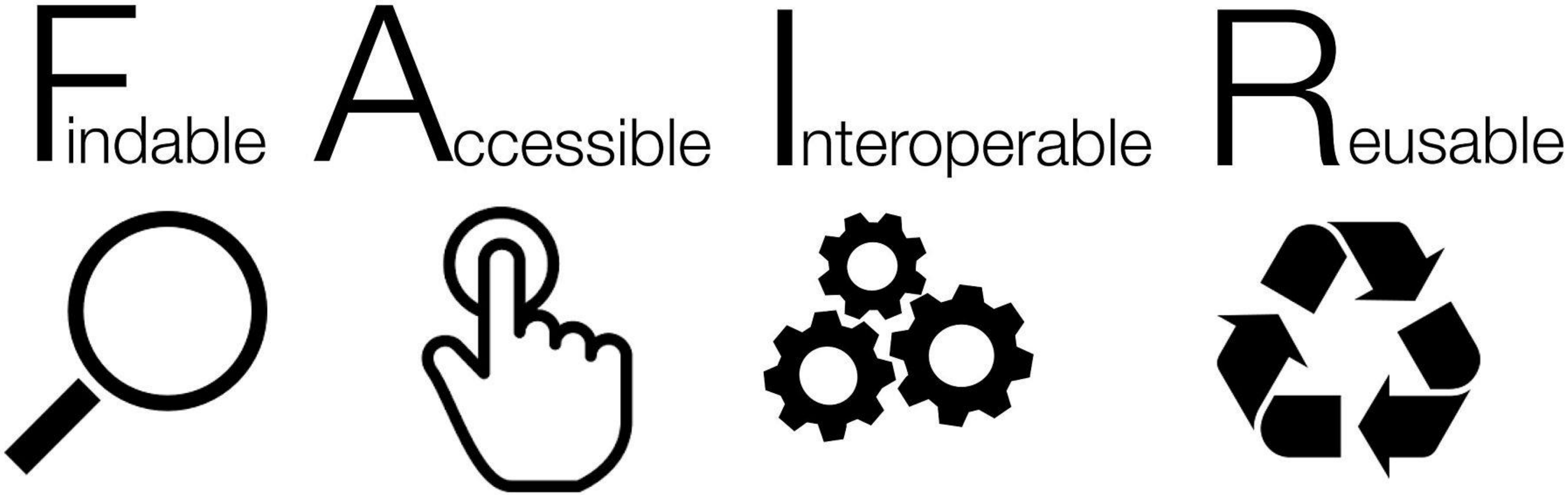



"FairMillData" dataset contains description of code versions necessary for milling process execution, variation in milling parameters, workpiece material, milling tool geometry, etc.

# Motivation & project goal

## *FAIR principles*




- FAIR principles aim at maximizing effective (re)use of acquired datasets

  → [Wilkinson2016], https://www.go-fair.org/fair-principles/

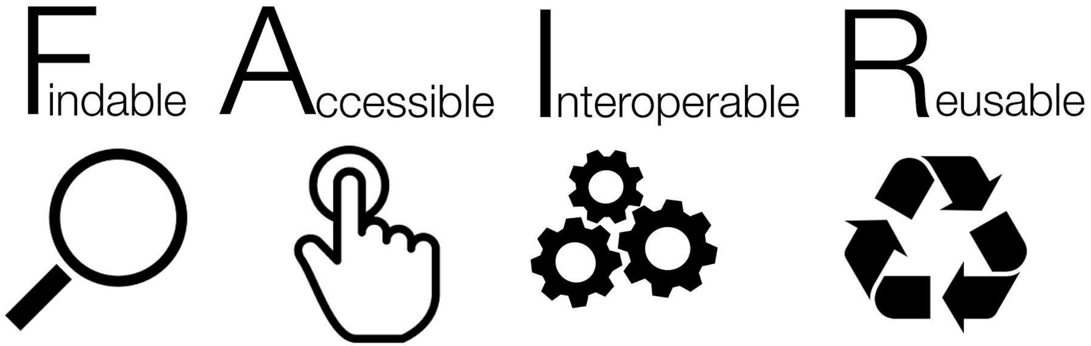
- We believe milling needs many datasets, used by many!



M. Wilkinson, *et al. Sci Data* **3** (2016) 160018.

# Motivation & project goal

*FAIR principles*




Publish dataset on Zenodo.org

- ❖ Receives DOI (digital object identifier) → Findable
- ❖ Funded by European Commission → Accessible

Metadata:

- ❖ use precise & understandable language → Interoperable
- ❖ are richly described with a plurality of accurate and relevant attributes → Reusable

# Agenda

- Motivationv & project goal
- **Milling experiments**
- Dataset
- Outlook

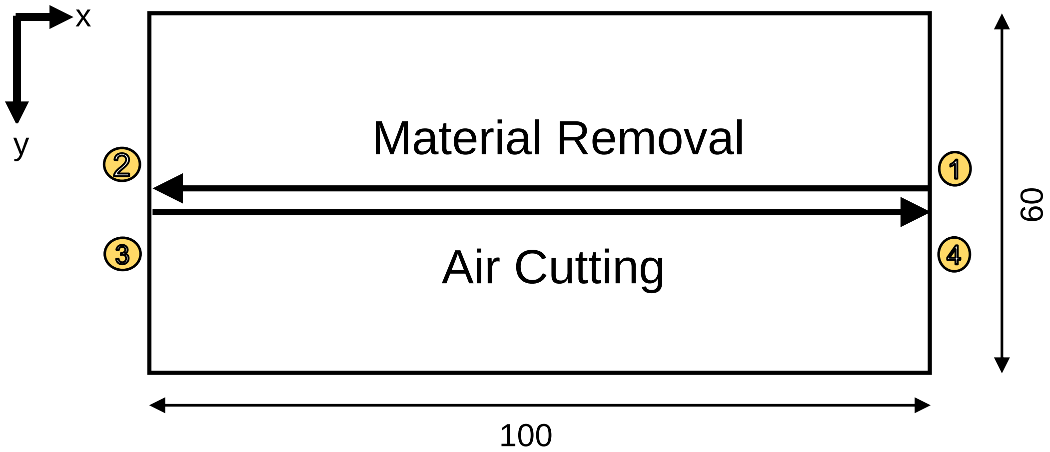
*Overview*

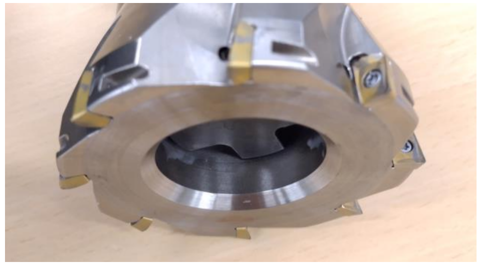
| | Face Milling | End Milling | Plunge Milling | Slot milling |
|---|---|---|---|---|
| Varied Parameters | Feed Rate $\mathbf{v_f}$<br>Cutting Speed $\mathbf{v_c}$ | Radial Depth $\mathbf{a_e}$<br>Axial Depth $\mathbf{a_p}$ | Plunging Strategy | Radial Depth $\mathbf{a_e}$<br>Axial Depth $\mathbf{a_p}$<br>Corner Velocity $\mathbf{v_{EP}}$ |
| Number of Experiments (Runs) | 48 | 10 | 12 | 20 |
| Tool | Indexable Cutter (d = 80 mm) | End mill (d = 10 mm) | End mill (d = 10 mm) | End mill (d = 10 mm) |
| Material | 1.2083 (X42Cr 13) Stainless Mold Steel | | | |

- Four milling operations were performed using a different set of parameters
- Dataset allows studying the effect of parameter variation on milling target quantities, e.g. energy consumption

## *Face milling*

| | Cutting Speed | Spindle Speed | Feed | Feed per Tooth | Feed Rate |
|---|---|---|---|---|---|
| Run Index | $v_c$ [m/min] | n [1/min] | f [mm] | $f_z$ [mm] | $v_f$ [mm/min] |
| 1-8 | 80,00 | 318,31 | 0,80 – 2,48 | 0,10 – 0,31 | 254,65 – 789,41 |
| 9-16 | 100,00 | 397,89 | 0,80 – 2,48 | 0,10 – 0,31 | 318,31 – 986,76 |
| 17-24 | 120,00 | 477,76 | 0,80 – 2,48 | 0,10 – 0,31 | 381,97 – 1184,11 |
| 25-32 | 80,00 – 108,00 | 318,31 – 429,72 | 0,80 | 0,10 | 254,65 – 343,77 |
| 33-40 | 80,00 – 108,00 | 318,31 – 429,72 | 2,00 | 0,25 | 636,62 – 859,44 |
| 41-48 | 80,00 – 108,00 | 318,31 – 429,72 | 2,96 | 0,37 | 942,20 – 1271,97 |



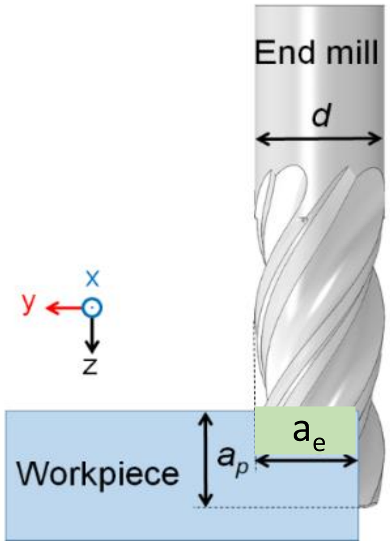



$n_{Inserts} = 8$
$d_{Tool} = 80$ mm

- For runs 1-24, feed parameters are varied with constant speed parameters
- For runs 25 – 48, speed parameters are varied with constant feed parameters

## *End milling*

| | | $v_c$ = constant = 100 m/min<br>$f_z$ = constant = 0,05 mm |
|---|---|---|
| Run 1 | $a_e$ = constant | 2 |
| | $a_p$ = variable | 10 |
| Run 2 | $a_e$ = constant | 2 |
| | $a_p$ = variable | 8 |
| Run 3 | $a_e$ = constant | 2 |
| | $a_p$ = variable | 6 |
| Run 4 | $a_e$ = constant | 2 |
| | $a_p$ = variable | 4 |
| Run 5 | $a_e$ = constant | 2 |
| | $a_p$ = variable | 2 |



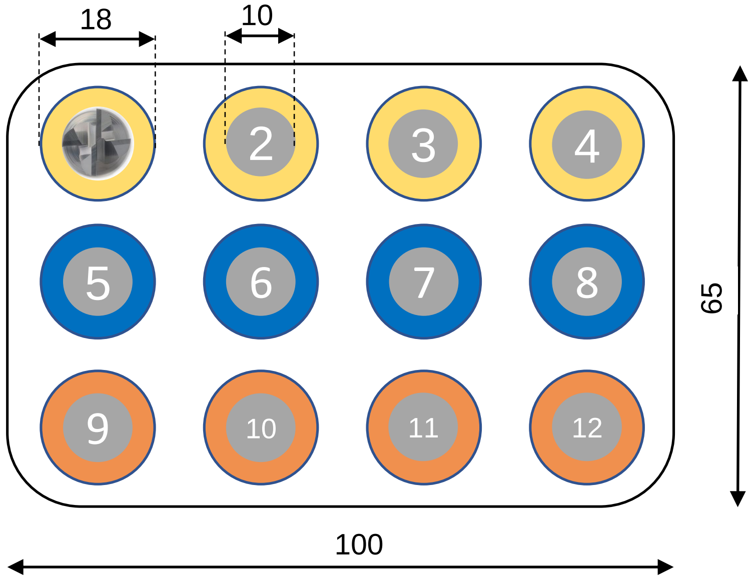

| | | $v_c$ = constant = 100 m/min<br>$f_z$ = constant = 0,05 mm |
|---|---|---|
| Run 6 | $a_e$ = variable | 10 |
| | $a_p$ = constant | 2 |
| Run 7 | $a_e$ = variable | 8 |
| | $a_p$ = constant | 2 |
| Run 8 | $a_e$ = variable | 6 |
| | $a_p$ = constant | 2 |
| Run 9 | $a_e$ = variable | 4 |
| | $a_p$ = constant | 2 |
| Run 10 | $a_e$ = variable | 2 |
| | $a_p$ = constant | 2 |

- 10 runs of end milling are performed
- For runs 1 to 5, $a_p$ is varied while $a_e$ is kept at a constant level
- For runs 6 to 10, $a_e$ is varied while $a_p$ is kept at a constant level

# Milling experiments

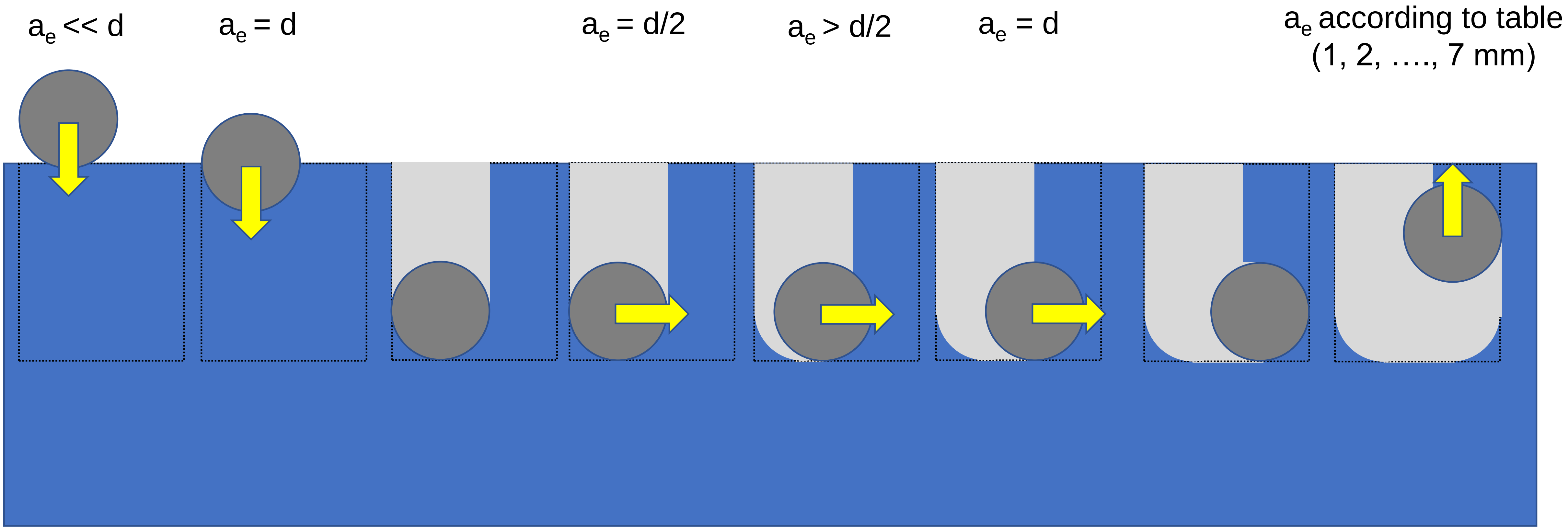
## *Plunge milling*

| Run | $a_p$ | Removal [mm] | Strategy | Immersion | Feed Rate $v_f$ [mm/min] | Roughing |
|---|---|---|---|---|---|---|
| 1 | $a_{p1}$ | 3 | Vertical Immersion | Vertical | 50 | Circular |
| 2 | $a_{p2}$ | 6 | | Vertical | 25 | Circular |
| 3 | $a_{p3}$ | 9 | | Vertical | 50 | Spiral & Circular Finish |
| 4 | $a_{p4}$ | 12 | | Vertical | 25 | Spiral & Circular Finish |
| 5 | $a_{p1}$ | 3 | Diagonal Immersion | Diagonal | 286,48 | Circular |
| 6 | $a_{p2}$ | 6 | | Diagonal | 286,48 | Circular |
| 7 | $a_{p3}$ | 9 | | Diagonal | 286,48 | Spiral & Circular Finish |
| 8 | $a_{p4}$ | 12 | | Diagonal | 286,48 | Spiral & Circular Finish |
| 9 | $a_{p1}$ | 3 | Helical Immersion | Helical | 286,48 | Circular |
| 10 | $a_{p2}$ | 6 | | Helical | 286,48 | Circular |
| 11 | $a_{p3}$ | 9 | | Helical | 286,48 | Spiral & Circular Finish |
| 12 | $a_{p4}$ | 12 | | Helical | 286,48 | Spiral & Circular Finish |




- 12 cylindrical pockets are milled into a workpiece with varying strategies
- Change in immersion (tool entering the workpiece) and roughing (extending the diameter from 10 to 18 mm)
  - Immersion is performed in a vertical, diagonal or helical manner
  - Roughing is performed circular or spiral with a circular finish
- Reasoning behind experiment: low tool wear, practical, interesting with respect to energy consumption

## *Slot milling - Operation principles*




- Draft shows tool path while performing one-sided extension of slot
- Curve radius of 6 mm with $d_{Tool}$ = 10 mm → simplification makes underlying phenomena easier understandable

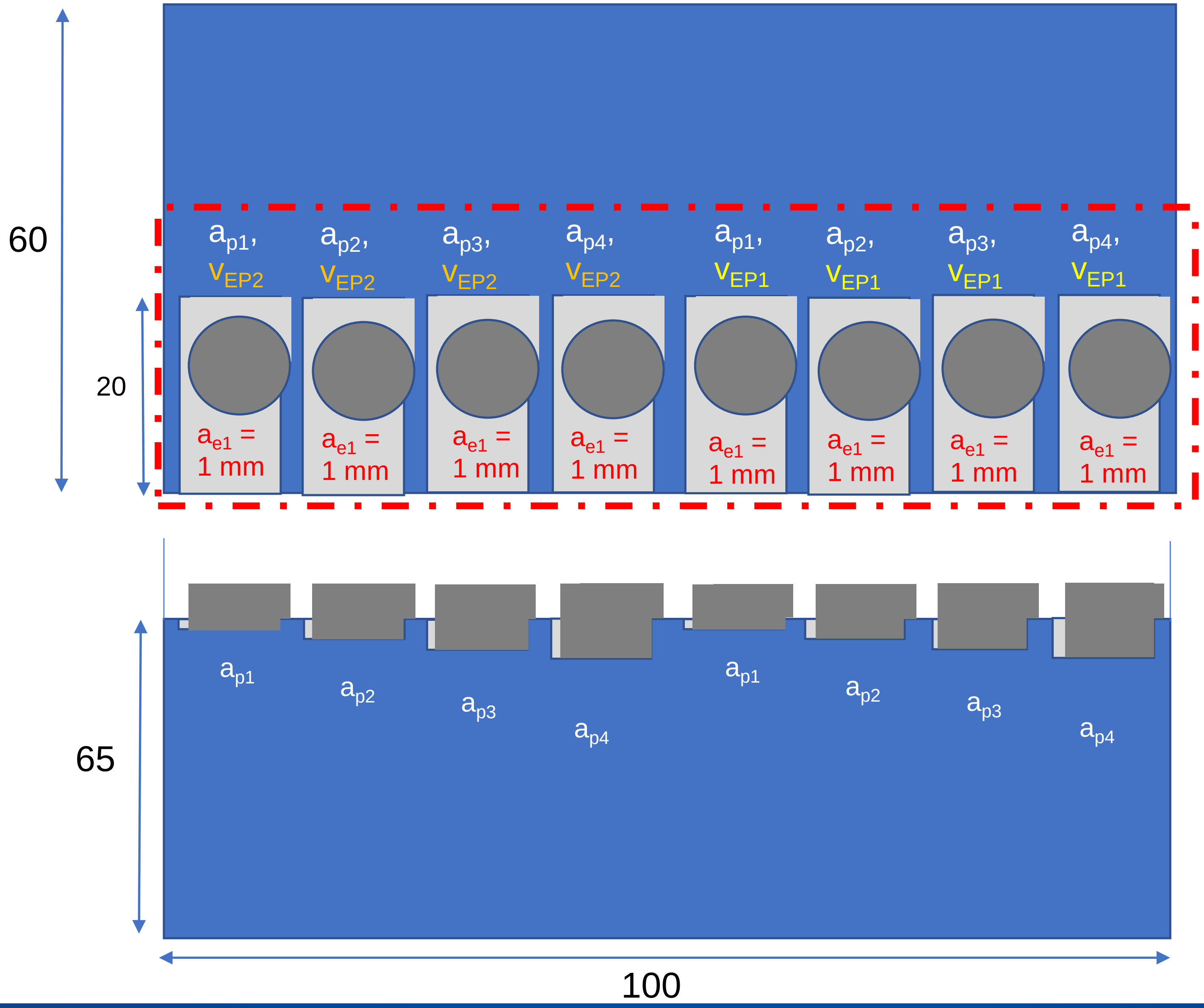
# Milling Experiments

## *Slot milling - Parameter overview*

| Run | | $a_p$ in mm | $v_{EP}$ in mm/min | | | $a_e$ in mm |
|---|---|---|---|---|---|---|
| 1 | $a_{p1}$ | 1 | $v_{EP1}$ | 80,21 | $ae_1$ | 1 |
| 2 | $a_{p2}$ | 2 | $v_{EP1}$ | 80,21 | $ae_1$ | 1 |
| 3 | $a_{p3}$ | 3 | $v_{EP1}$ | 80,21 | $ae_1$ | 1 |
| 4 | $a_{p4}$ | 4 | $v_{EP1}$ | 80,21 | $ae_1$ | 1 |
| 5 | $a_{p1}$ | 1 | $v_{EP2}$ | 187,17 | $ae_1$ | 1 |
| 6 | $a_{p2}$ | 2 | $v_{EP2}$ | 187,17 | $ae_1$ | 1 |
| 7 | $a_{p3}$ | 3 | $v_{EP2}$ | 187,17 | $ae_1$ | 1 |
| 8 | $a_{p4}$ | 4 | $v_{EP2}$ | 187,17 | $ae_1$ | 1 |
| 9 | $a_{p4}$ | 4 | $v_{EP1}$ | 80,21 | $ae_2$ | 2 |
| 10 | $a_{p4}$ | 4 | $v_{EP1}$ | 80,21 | $ae_3$ | 3 |
| 11 | $a_{p4}$ | 4 | $v_{EP1}$ | 80,21 | $ae_4$ | 4 |
| 12 | $a_{p4}$ | 4 | $v_{EP1}$ | 80,21 | $ae_5$ | 5 |
| 13 | $a_{p4}$ | 4 | $v_{EP1}$ | 80,21 | $ae_6$ | 6 |
| 14 | $a_{p4}$ | 4 | $v_{EP1}$ | 80,21 | $ae_7$ | 7 |
| 15 | $a_{p4}$ | 4 | $v_{EP2}$ | 187,17 | $ae_2$ | 2 |
| 16 | $a_{p4}$ | 4 | $v_{EP2}$ | 187,17 | $ae_3$ | 3 |
| 17 | $a_{p4}$ | 4 | $v_{EP2}$ | 187,17 | $ae_4$ | 4 |
| 18 | $a_{p4}$ | 4 | $v_{EP2}$ | 187,17 | $ae_5$ | 5 |
| 19 | $a_{p4}$ | 4 | $v_{EP2}$ | 187,17 | $ae_6$ | 6 |
| 20 | $a_{p4}$ | 4 | $v_{EP2}$ | 187,17 | $ae_7$ | 7 |

- 20 milling runs overall
- Two different corner velocities ($v_{EP}$) are tried:
  - Run 1 - 4: $v_{EP1}$ with varying $a_p$ and constant $a_e$
  - Run 5 - 8: $v_{EP2}$ with varying $a_p$ and constant $a_e$
  - Run 9 -14: $v_{EP1}$ with constant $a_p$ and varying $a_e$
  - Run 15 -20: $v_{EP2}$ with constant $a_p$ and varying $a_e$
- Slot milling consisting of
  - Immersion
  - Synchronous milling (Counterclockwise)

## *Slot milling - Operation details (1/3)*




Top view

Ground view

**Process parameters:**

$v_f$ = 3055 mm / min
f = 1,2 mm
$v_c$ = 80 mm/ min
d = 10 mm

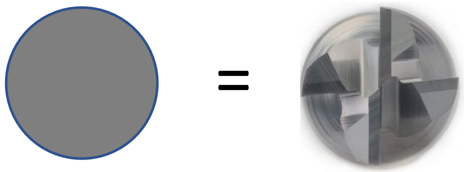
**Corner velocity:**

$v_{EP1} < v_{EP2}$
$v_{EP1} = 0.3 * v_f$
$v_{EP2} = 0.7 * v_f$

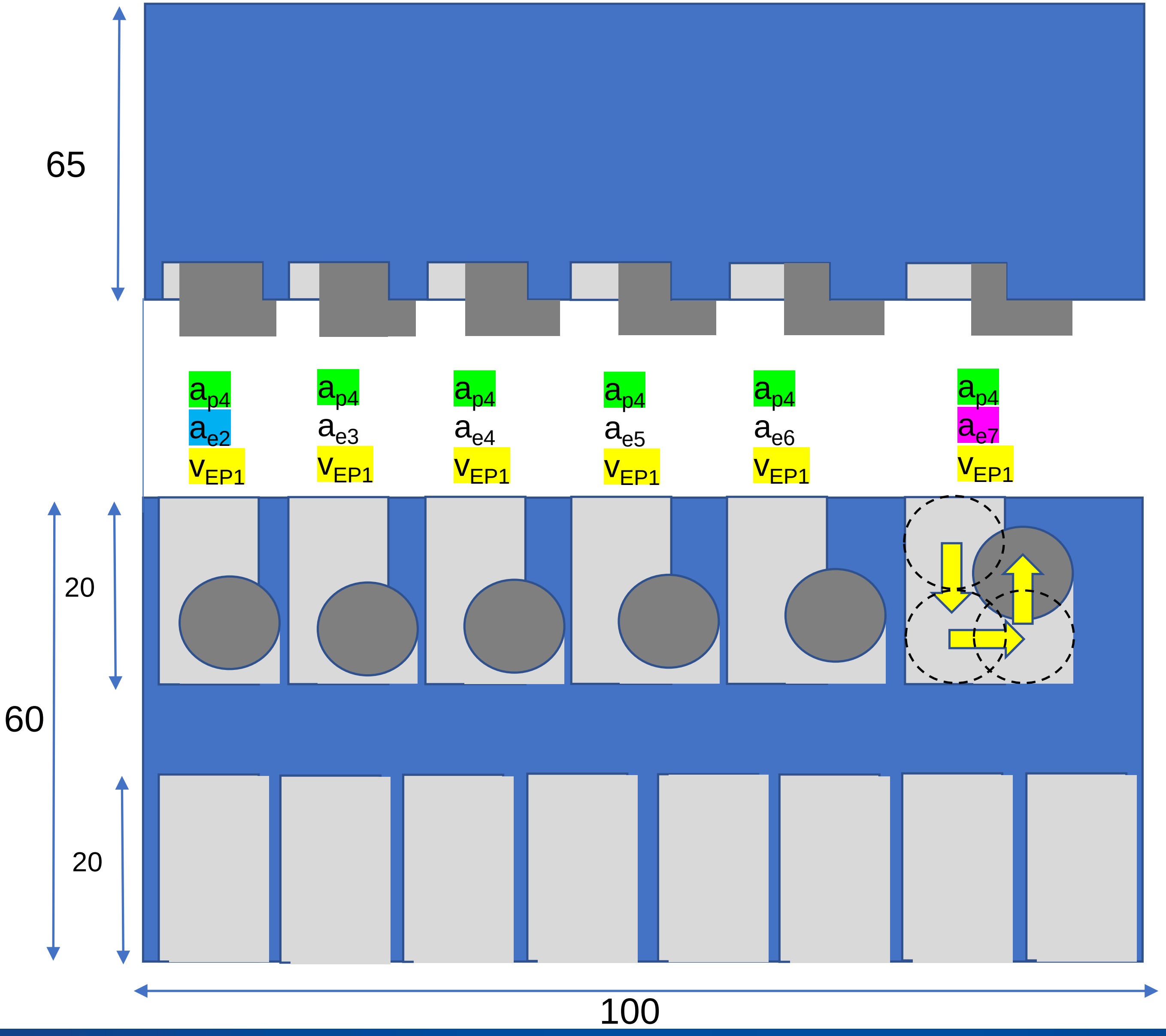
**$a_p$ & $a_e$**

$a_{p1}$ = 1 mm
$a_{p2}$ = 2 mm
$a_{p3}$ = 3 mm
$a_{p4}$ = 4 mm

$a_{e1}$ = 1 mm
$a_{e2}$ = 2 mm
$a_{e3}$ = 3 mm
$a_{e4}$ = 4 mm



*Slot milling - Operation details (2/3)*




Ground view

**Process parameters:**

$v_f$ = 3055 mm / min
f = 1,2 mm
$v_c$ = 80 mm/ min
d = 10 mm

**Corner velocity:**

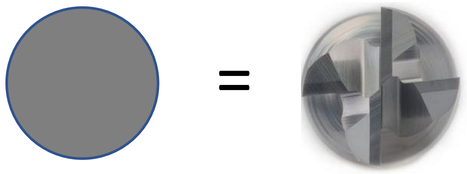
$v_{EP1} < v_{EP2}$
$v_{EP1} = 0.3 * v_f$
$v_{EP2} = 0.7 * v_f$

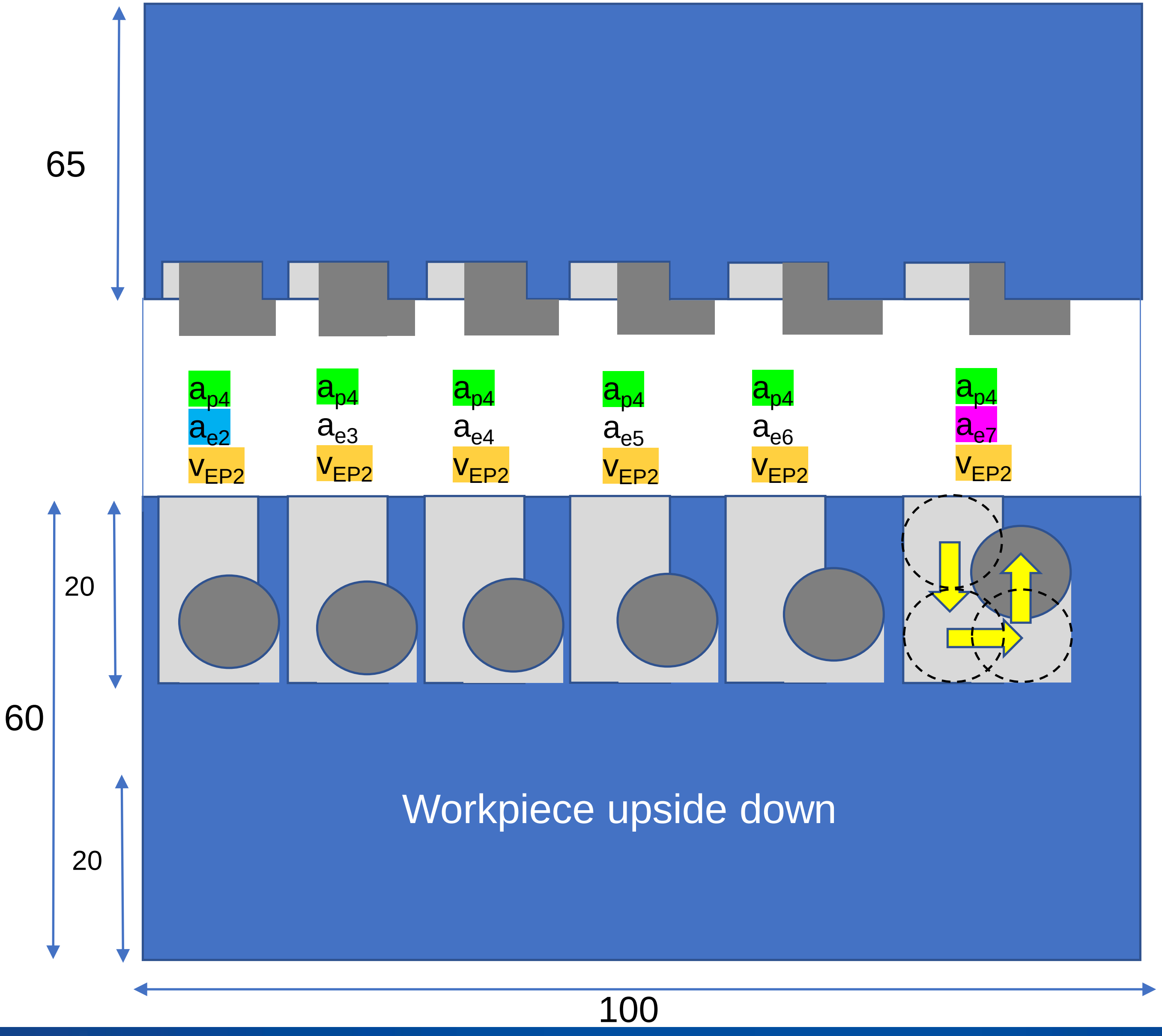
**$a_p$ & $a_e$**

$a_{p1}$ = 1 mm
$a_{p2}$ = 2 mm
$a_{p3}$ = 3 mm
$a_{p4}$ = 4 mm

$a_{e1}$ = 1 mm
$a_{e2}$ = 2 mm
$a_{e3}$ = 3 mm
$a_{e4}$ = 4 mm
$a_{e5}$ = 5 mm
$a_{e6}$ = 6 mm
$a_{e7}$ = 7 mm

Top view






Ground view

**Process parameters:**

$v_f$ = 3055 mm / min
f = 1,2 mm
$v_c$ = 80 mm/ min
d = 10 mm

**Corner velocity:**

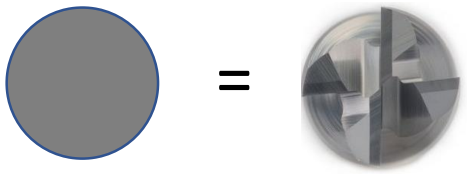
$v_{EP1} < v_{EP2}$
$v_{EP1} = 0.3 * v_f$
$v_{EP2} = 0.7 * v_f$

**$a_p$ & $a_e$**

$a_{p1}$ = 1 mm
$a_{p2}$ = 2 mm
$a_{p3}$ = 3 mm
$a_{p4}$ = 4 mm

$a_{e1}$ = 1 mm
$a_{e2}$ = 2 mm
$a_{e3}$ = 3 mm
$a_{e4}$ = 4 mm
$a_{e5}$ = 5 mm
$a_{e6}$ = 6 mm
$a_{e7}$ = 7 mm

Top view



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# Dataset

*Data structure*

Dataset overview:

- 1_Hardware-Fingerprint
- 2_Software-Fingerprint
- 3_Machine-tool_tool-information
- 4_FACEMILLING-MEOP247
- 5_EndMILLING_MEOP245
- 6_PlungeMILLING_MEOP246
- 7_SlotMILLING_MEOP248

4_FACEMILLING-MEOP247:

- 4.1_CAD-Files
- 4.2_CAM-Machining-Strategy
- 4.3_Toolpath-Simulation-before-Postprocessing
- 4.5_NC-Code-after-Postprocessing
- 4.6_NC-Code-after-check-at-machine-tool
- 5_High-frequent-machining-data
- 6_Photos_final-workpiece-REAL

| | |
|---|---|
| facemilling_2023_02_22_1_df_.h5 | HDF5 File |
| facemilling_2023_02_22_2_df_.h5 | HDF5 File |
| ⋮ | |
| facemilling_2023_02_22_47_df_.h5 | HDF5 File |
| facemilling_2023_02_22_48_df_.h5 | HDF5 File |

Face milling organized in 48 files. Each file is a hdf5 container with a python pandas DataFrame inside. Key is always „df".

⋮ 5_High-frequent-machining-data ⋮

| | |
|---|---|
| slotmilling_2023_02_21_1_df.h5 | HDF5 File |
| slotmilling_2023_02_21_2_df.h5 | HDF5 File |
| ⋮ | |
| slotmilling_2023_02_21_19_df.h5 | HDF5 File |
| slotmilling_2023_02_21_20_df.h5 | HDF5 File |

Slot milling organized in 20 files.

⋮ 5_High-frequent-machining-data ⋮

| | |
|---|---|
| plungemilling_2023_02_10_1_df.h5 | HDF5 File |
| plungemilling_2023_02_10_2_df.h5 | HDF5 File |
| ⋮ | |
| plungemilling_2023_02_13_11_df.h5 | HDF5 File |
| plungemilling_2023_02_13_12_df.h5 | HDF5 File |

Plunge milling organized in 12 files.

⋮ 5_High-frequent-machining-data ⋮

| | |
|---|---|
| endmilling_2023_02_09_01_df.h5 | HDF5 File |
| endmilling_2023_02_09_02_df.h5 | HDF5 File |
| ⋮ | |
| endmilling_2023_02_09_09_df.h5 | HDF5 File |
| endmilling_2023_02_09_10_df.h5 | HDF5 File |

End milling organized in 10 files.

Size: 2.4 GB
Zipped size: ~1 GB

## *Data structure – JSON to HDF - Signals*

Overview of all signals:

| | Name | Type | Axis | Address |
|---|---|---|---|---|
| 0 | Cycle | INTEGER | CYCLE | CYCLE |
| 1 | ControlDiff2 | DOUBLE | X1 | CTRL_DIFF2\|1 |
| 2 | ControlDiff2 | DOUBLE | Y1 | CTRL_DIFF2\|2 |
| 3 | ControlDiff2 | DOUBLE | Z1 | CTRL_DIFF2\|3 |
| 4 | ControlDiff2 | DOUBLE | B1 | CTRL_DIFF2\|4 |
| 5 | ControlDiff2 | DOUBLE | SP1 | CTRL_DIFF2\|5 |
| 6 | ControlDiff2 | DOUBLE | C1 | CTRL_DIFF2\|6 |
| 7 | Torque | DOUBLE | X1 | TORQUE\|1 |
| 8 | Torque | DOUBLE | Y1 | TORQUE\|2 |
| 9 | Torque | DOUBLE | Z1 | TORQUE\|3 |
| 10 | Torque | DOUBLE | B1 | TORQUE\|4 |
| 11 | Torque | DOUBLE | SP1 | TORQUE\|5 |
| 12 | Torque | DOUBLE | C1 | TORQUE\|6 |
| 13 | CommandedAxisPosition | DOUBLE | X1 | DES_POS\|1 |
| 14 | CommandedAxisPosition | DOUBLE | Y1 | DES_POS\|2 |
| 15 | CommandedAxisPosition | DOUBLE | Z1 | DES_POS\|3 |
| 16 | CommandedAxisPosition | DOUBLE | B1 | DES_POS\|4 |
| 17 | CommandedAxisPosition | DOUBLE | SP1 | DES_POS\|5 |
| 18 | CommandedAxisPosition | DOUBLE | C1 | DES_POS\|6 |
| 19 | Current | DOUBLE | X1 | CURRENT\|1 |
| 20 | Current | DOUBLE | Y1 | CURRENT\|2 |
| 21 | Current | DOUBLE | Z1 | CURRENT\|3 |
| 22 | Current | DOUBLE | B1 | CURRENT\|4 |
| 23 | Current | DOUBLE | SP1 | CURRENT\|5 |
| 24 | Current | DOUBLE | C1 | CURRENT\|6 |
| 25 | ControlDiff | DOUBLE | X1 | CTRL_DIFF\|1 |
| 26 | ControlDiff | DOUBLE | Y1 | CTRL_DIFF\|2 |
| 27 | ControlDiff | DOUBLE | Z1 | CTRL_DIFF\|3 |
| 28 | ControlDiff | DOUBLE | B1 | CTRL_DIFF\|4 |
| 29 | ControlDiff | DOUBLE | SP1 | CTRL_DIFF\|5 |
| 30 | ControlDiff | DOUBLE | C1 | CTRL_DIFF\|6 |

| | Name | Type | Axis | Address |
|---|---|---|---|---|
| 31 | ControlPos | DOUBLE | X1 | CTRL_POS\|1 |
| 32 | ControlPos | DOUBLE | Y1 | CTRL_POS\|2 |
| 33 | ControlPos | DOUBLE | Z1 | CTRL_POS\|3 |
| 34 | ControlPos | DOUBLE | B1 | CTRL_POS\|4 |
| 35 | ControlPos | DOUBLE | SP1 | CTRL_POS\|5 |
| 36 | ControlPos | DOUBLE | C1 | CTRL_POS\|6 |
| 37 | VelocityFeedForward | DOUBLE | X1 | VEL_FFW\|1 |
| 38 | VelocityFeedForward | DOUBLE | Y1 | VEL_FFW\|2 |
| 39 | VelocityFeedForward | DOUBLE | Z1 | VEL_FFW\|3 |
| 40 | VelocityFeedForward | DOUBLE | B1 | VEL_FFW\|4 |
| 41 | VelocityFeedForward | DOUBLE | SP1 | VEL_FFW\|5 |
| 42 | VelocityFeedForward | DOUBLE | C1 | VEL_FFW\|6 |
| 43 | Power | STRING | X1 | POWER\|1 |
| 44 | Power | STRING | Y1 | POWER\|2 |
| 45 | Power | STRING | Z1 | POWER\|3 |
| 46 | Power | STRING | B1 | POWER\|4 |
| 47 | Power | STRING | SP1 | POWER\|5 |
| 48 | Power | STRING | C1 | POWER\|6 |
| 49 | CountourDeviation | DOUBLE | X1 | CONT_DEV\|1 |
| 50 | CountourDeviation | DOUBLE | Y1 | CONT_DEV\|2 |
| 51 | CountourDeviation | DOUBLE | Z1 | CONT_DEV\|3 |
| 52 | CountourDeviation | DOUBLE | B1 | CONT_DEV\|4 |
| 53 | CountourDeviation | DOUBLE | SP1 | CONT_DEV\|5 |
| 54 | CountourDeviation | DOUBLE | C1 | CONT_DEV\|6 |
| 55 | Synchronuous Action variable | INTEGER | | A_DBD\|0 |
| 56 | CommandedSpeed | DOUBLE | X1 | CMD_SPEED\|1 |
| 57 | CommandedSpeed | DOUBLE | Y1 | CMD_SPEED\|2 |
| 58 | CommandedSpeed | DOUBLE | Z1 | CMD_SPEED\|3 |
| 59 | CommandedSpeed | DOUBLE | B1 | CMD_SPEED\|4 |
| 60 | CommandedSpeed | DOUBLE | SP1 | CMD_SPEED\|5 |

| | Name | Type | Axis | Address |
|---|---|---|---|---|
| 61 | CommandedSpeed | DOUBLE | C1 | CMD_SPEED\|6 |
| 62 | TorqueFeedForward | DOUBLE | X1 | TORQUE_FFW\|1 |
| 63 | TorqueFeedForward | DOUBLE | Y1 | TORQUE_FFW\|2 |
| 64 | TorqueFeedForward | DOUBLE | Z1 | TORQUE_FFW\|3 |
| 65 | TorqueFeedForward | DOUBLE | B1 | TORQUE_FFW\|4 |
| 66 | TorqueFeedForward | DOUBLE | SP1 | TORQUE_FFW\|5 |
| 67 | TorqueFeedForward | DOUBLE | C1 | TORQUE_FFW\|6 |
| 68 | Encoder1Position | DOUBLE | X1 | ENC1_POS\|1 |
| 69 | Encoder1Position | DOUBLE | Y1 | ENC1_POS\|2 |
| 70 | Encoder1Position | DOUBLE | Z1 | ENC1_POS\|3 |
| 71 | Encoder1Position | DOUBLE | B1 | ENC1_POS\|4 |
| 72 | Encoder1Position | DOUBLE | SP1 | ENC1_POS\|5 |
| 73 | Encoder1Position | DOUBLE | C1 | ENC1_POS\|6 |
| 74 | Encoder2Position | DOUBLE | X1 | ENC2_POS\|1 |
| 75 | Encoder2Position | DOUBLE | Y1 | ENC2_POS\|2 |
| 76 | Encoder2Position | DOUBLE | Z1 | ENC2_POS\|3 |
| 77 | Encoder2Position | DOUBLE | B1 | ENC2_POS\|4 |
| 78 | Encoder2Position | DOUBLE | SP1 | ENC2_POS\|5 |
| 79 | Encoder2Position | DOUBLE | C1 | ENC2_POS\|6 |
| 80 | Load | DOUBLE | X1 | LOAD\|1 |
| 81 | Load | DOUBLE | Y1 | LOAD\|2 |
| 82 | Load | DOUBLE | Z1 | LOAD\|3 |
| 83 | Load | DOUBLE | B1 | LOAD\|4 |
| 84 | Load | DOUBLE | SP1 | LOAD\|5 |
| 85 | Load | DOUBLE | C1 | LOAD\|6 |
| 86 | ActualAxisPosition | DOUBLE | X1 | ENC_POS\|1 |
| 87 | ActualAxisPosition | DOUBLE | Y1 | ENC_POS\|2 |
| 88 | ActualAxisPosition | DOUBLE | Z1 | ENC_POS\|3 |
| 89 | ActualAxisPosition | DOUBLE | B1 | ENC_POS\|4 |
| 90 | ActualAxisPosition | DOUBLE | SP1 | ENC_POS\|5 |
| 91 | ActualAxisPosition | DOUBLE | C1 | ENC_POS\|6 |

JSON data is converted to a Pandas (python library) DataFrame (tabular data structure):

The unit of the signal is appended at the end of each signal name.

Index in seconds:

| TIME_s | CYCLE_CYCLE_counter | DES_POS_1_X1_mm | DES_POS_2_Y1_mm | DES_POS_3_Z1_mm | DES_POS_4_B1_deg | DES_POS_5_SP1_deg | DES_POS_6_C1_deg |
|---|---|---|---|---|---|---|---|
| **0.000** | 2005766 | 89.651664 | -123.583230 | 315.951358 | 0.0 | 2857347.444 | 0.0 |
| **0.002** | 2005767 | 89.651664 | -123.583044 | 315.951358 | 0.0 | 2857352.592 | 0.0 |
| **0.004** | 2005768 | 89.651664 | -123.582537 | 315.951358 | 0.0 | 2857357.740 | 0.0 |
| **0.006** | 2005769 | 89.651664 | -123.581550 | 315.951358 | 0.0 | 2857362.888 | 0.0 |
| **0.008** | 2005770 | 89.651664 | -123.579924 | 315.951358 | 0.0 | 2857368.036 | 0.0 |

The JSON contains „BlockEvents“ which then contain G-code.
The G-code is extracted, matched with the HFProbeCounter & CYCLE_counter and then added to the DataFrame:

Example BlockEvent:


```
{'HFBlockEvent': {'HFProbeCounter': 1384042,
  'Channel': 1,
  'SeekOffset': 31,
  'SelectedTool': 40,
  'ActiveTool': 40,
  'GCode': 'G4 F1;START',
  'IpoGC': 'G0',
  'ipoReadError': None,
  'laBuf': 148}}
```


G-code added to DataFrame:

| TIME_s | CYCLE_CYCLE_counter | DES_POS_1_X1_mm | ... | TORQUE_6_C1_Nm | G-code |
|---|---|---|---|---|---|
| 0.000 | 1384042 | 89.651664 | | -0.522540 | G4 F1;START |
| 0.002 | 1384043 | 89.651664 | | -0.522540 | G4 F1;START |
| 0.004 | 1384044 | 89.651664 | ... | -0.522540 | G4 F1;START |
| 0.006 | 1384045 | 89.651664 | | -0.527291 | G4 F1;START |
| 0.008 | 1384046 | 89.651664 | | -0.522540 | G4 F1;START |
| ... | ... | ... | | ... | ... |

G-code stays active until another G-code line is activated.

# Dataset

## *Data structure – JSON to HDF – Reading Data*

Data can be easily loaded via python and pandas:

```python
import pandas as pd
path = r"...\facemilling_2023_02_22_1_df.h5"
df = pd.read_hdf(path, key = "df")
df
```

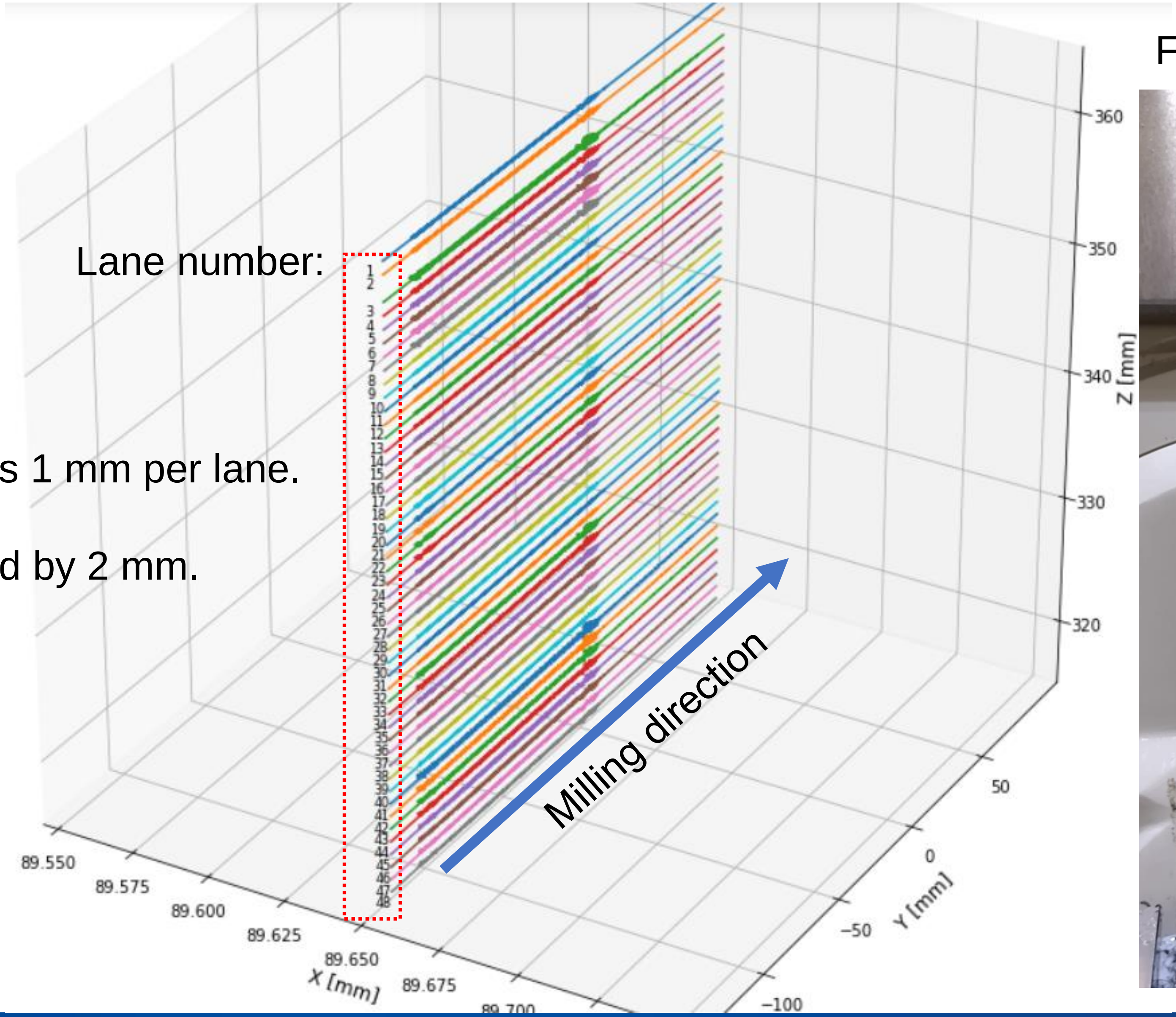
| TIME_s | CYCLE_CYCLE_counter | DES_POS_1_X1_mm | DES_POS_2_Y1_mm | DES_POS_3_Z1_mm | DES_POS_4_B1_deg | DES_POS_5_SP1_deg | DES_POS_6_C1_deg |
|---|---|---|---|---|---|---|---|
| **0.000** | 1384994 | 89.651664 | -123.582230 | 363.951358 | 0.0 | 36808.680 | 0.0 |
| **0.002** | 1384995 | 89.651664 | -123.582044 | 363.951358 | 0.0 | 36812.496 | 0.0 |
| **0.004** | 1384996 | 89.651664 | -123.581537 | 363.951358 | 0.0 | 36816.312 | 0.0 |
| **...** | ... | ... | ... | ... | ... | ... | ... |
| **50.258** | 1410123 | 89.651664 | 89.268743 | 363.951358 | 0.0 | 132700.944 | 0.0 |
| **50.260** | 1410124 | 89.651664 | 89.268743 | 363.951358 | 0.0 | 132704.760 | 0.0 |
| **50.262** | 1410125 | 89.651664 | 89.268743 | 363.951358 | 0.0 | 132708.576 | 0.0 |

25132 rows × 93 columns

## *Face milling – Path tool center point*

48 lanes.
Z level decreases 1 mm per lane.
Error for lane 3:
Z level decreased by 2 mm.

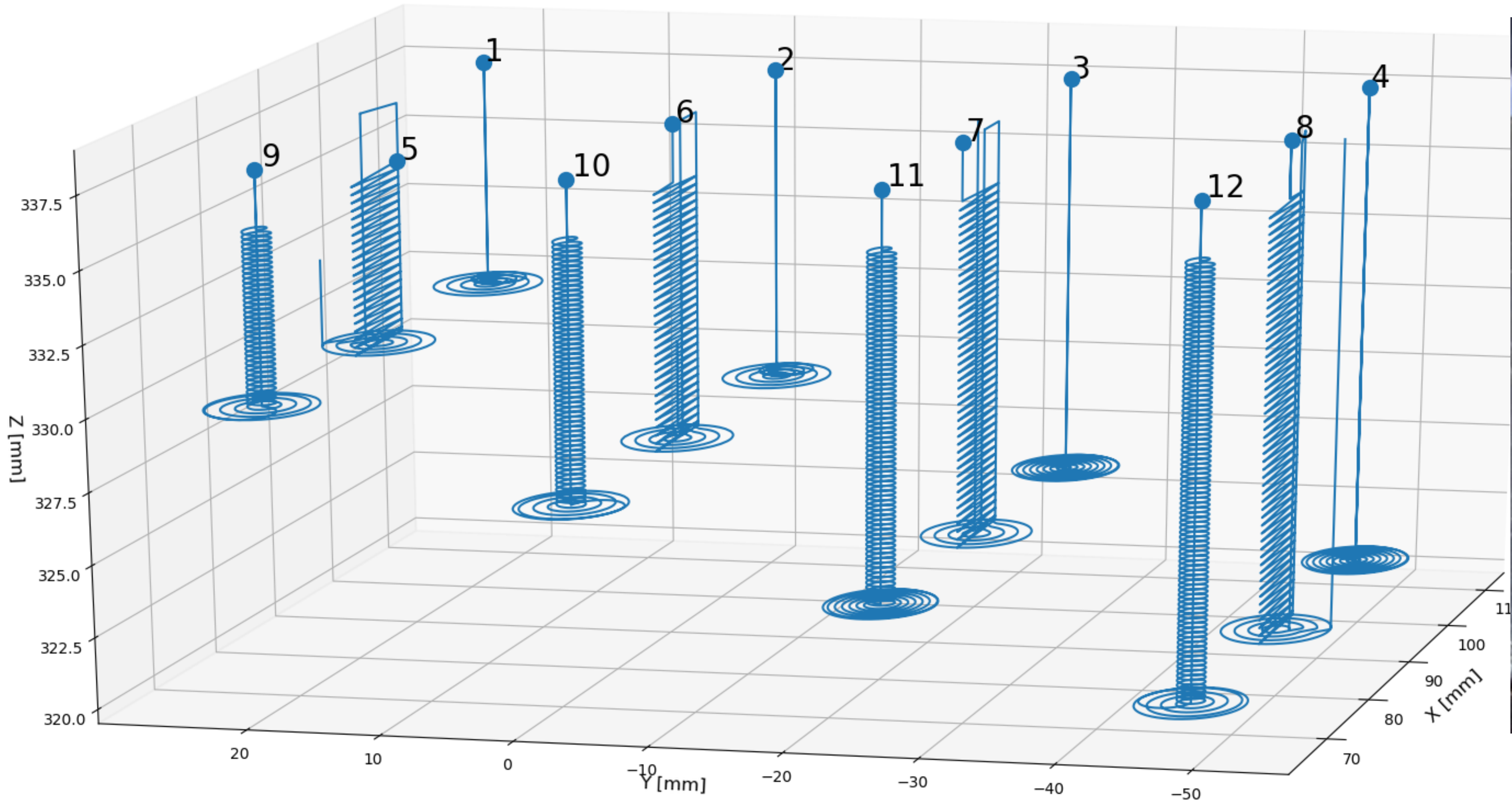
Lane number:




Final workpiece with tool:

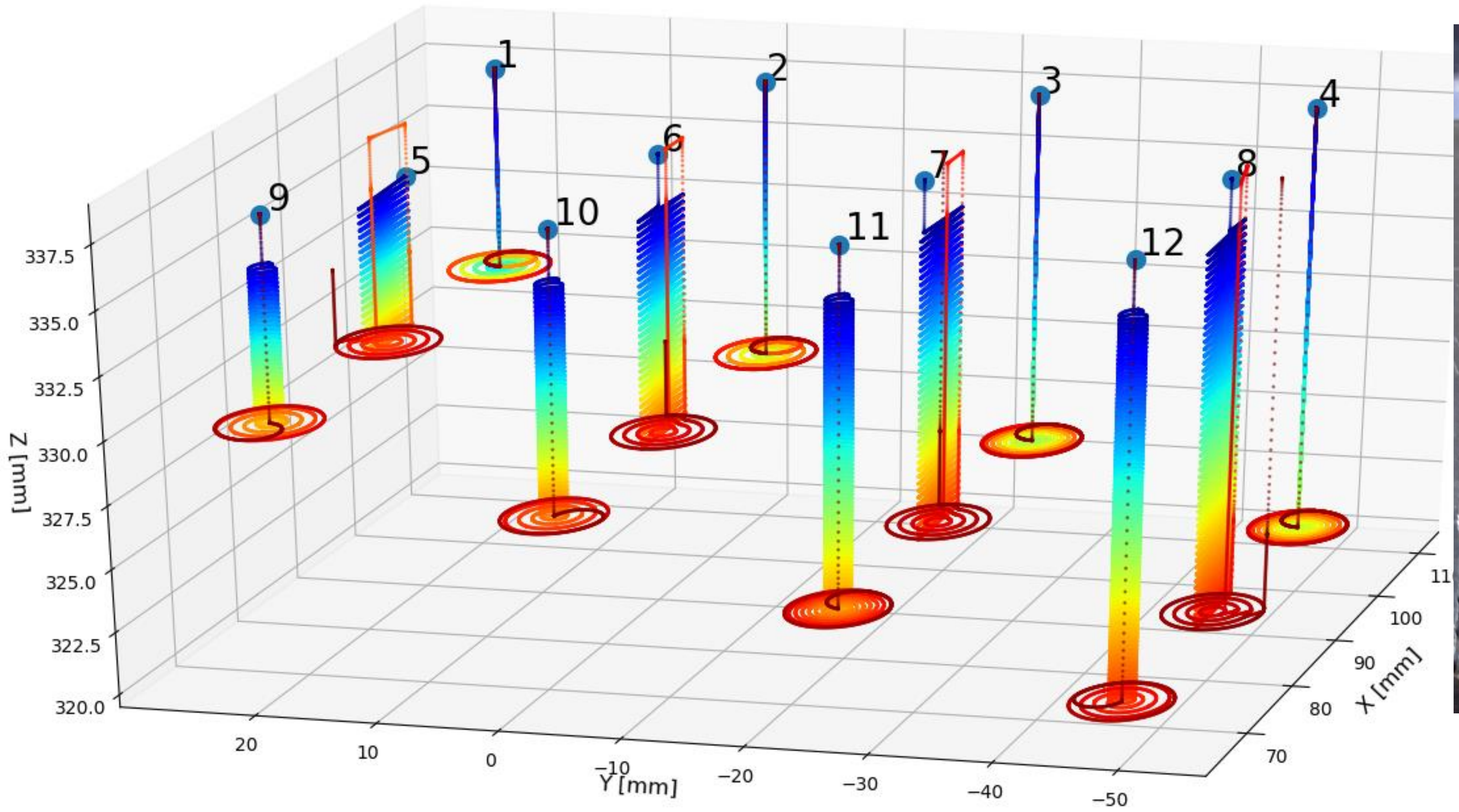
# Dataset

## *Plunge milling strategy – Path tool center point*



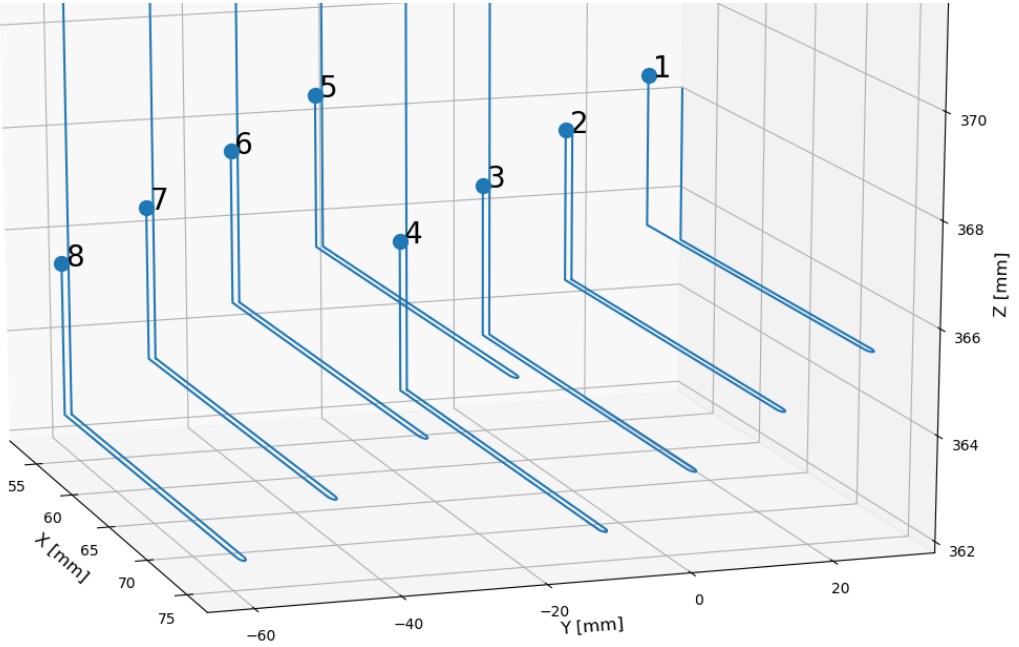

Different immersion strategies applied to holes 1 - 4, 5 - 8 & 9 - 12 use .

## *Plunge milling strategy – Path tool center point*



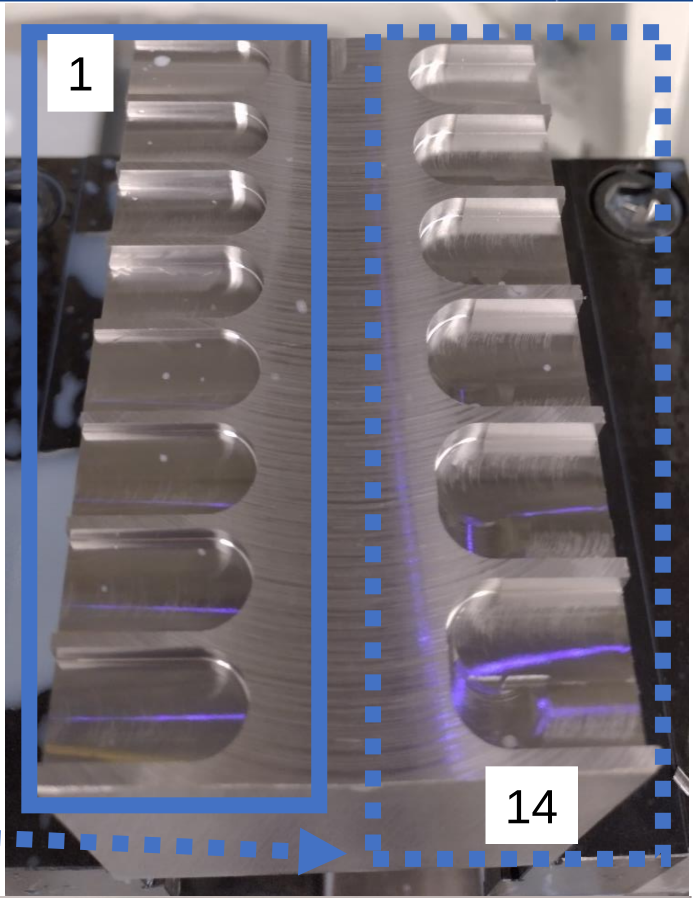

Tool center point position visualized from early plunge stage to late plunge stage.

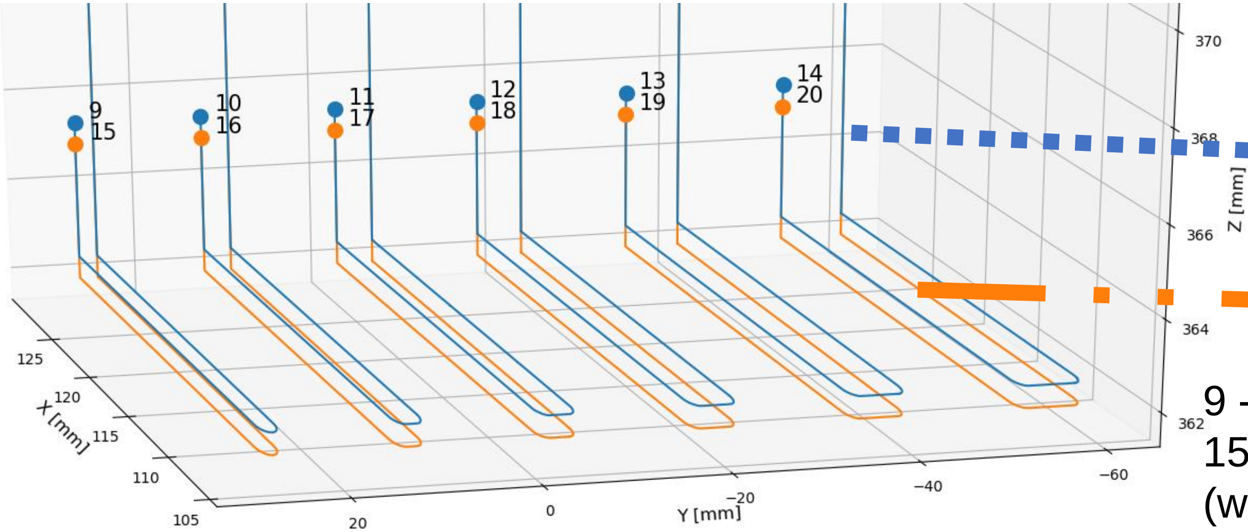
## *Slot milling strategy – Path tool center point*




Two different corner velocities ($v_{EP}$) :
1 - 4: $v_{EP1}$, varying $a_p$ & constant $a_e$
5 - 8: $v_{EP2}$, varying $a_p$ & constant $a_e$
9 - 14: $v_{EP1}$, constant $a_p$ 6 varying $a_e$
15 - 20: $v_{EP2}$, constant $a_p$ & varying $a_e$

1 - 8 are milled on the left side





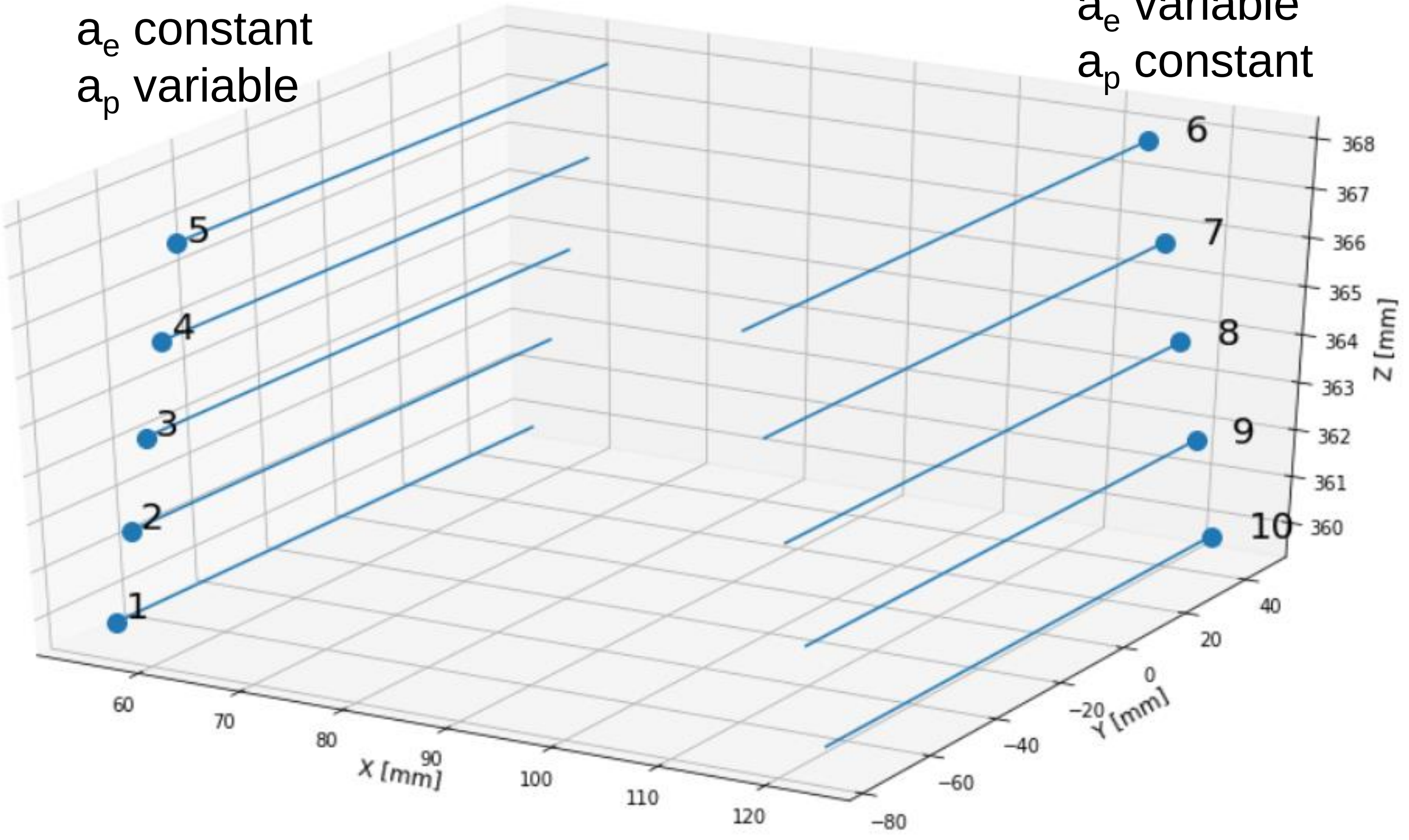
9 - 14 are milled on the right side
15 - 20 are milled on the bottom
(work piece flipped)

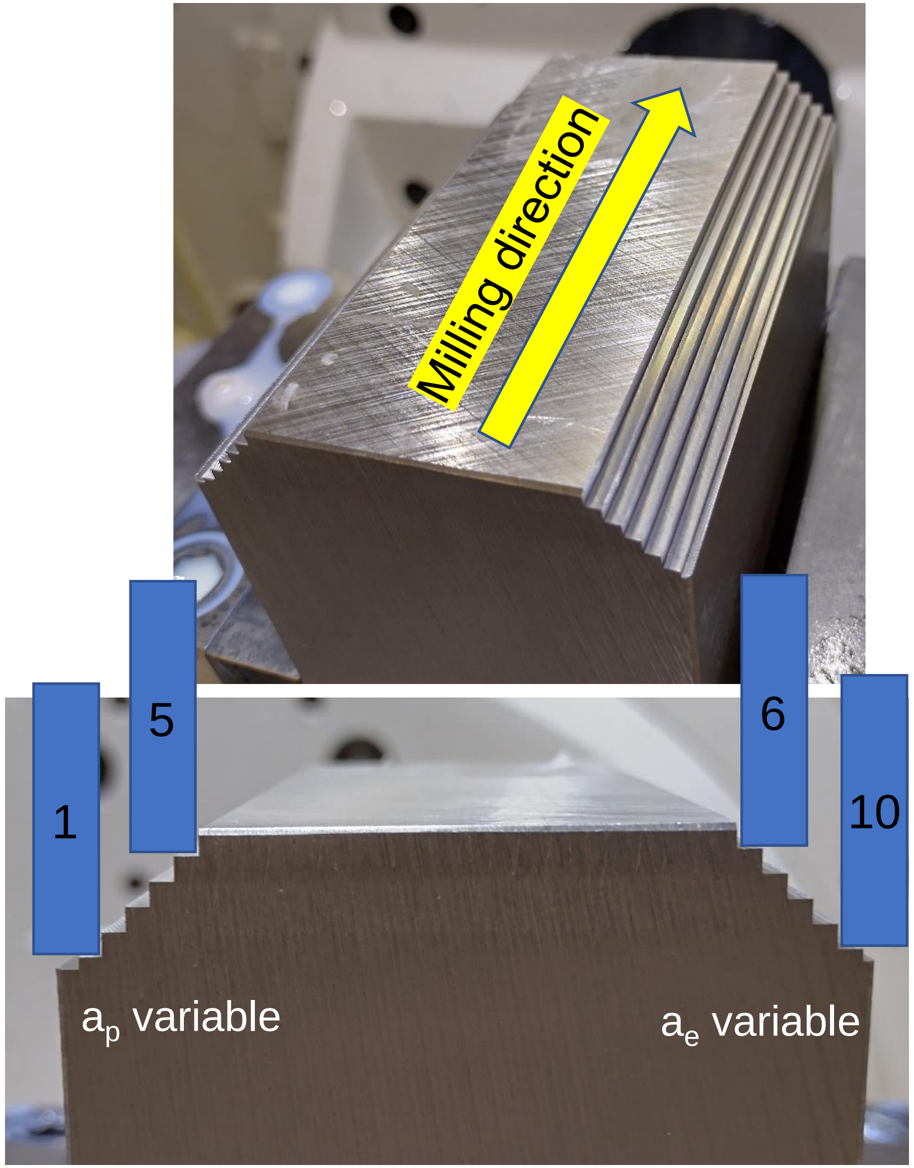
# Dataset

## *End milling strategy – Path tool center point*

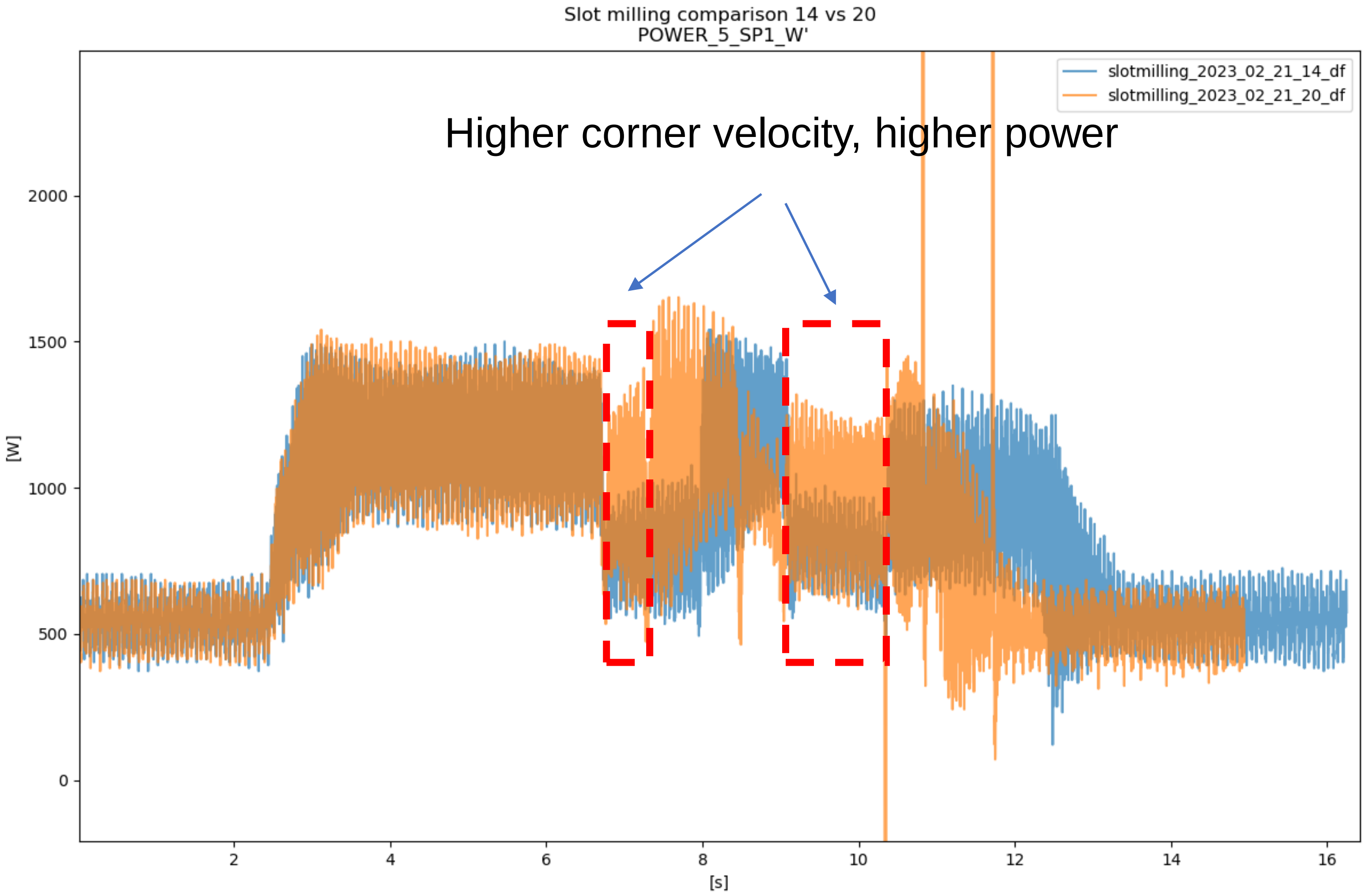
For 1 - 5:
$a_e$ constant
$a_p$ variable

For 6 - 10:
$a_e$ variable
$a_p$ constant



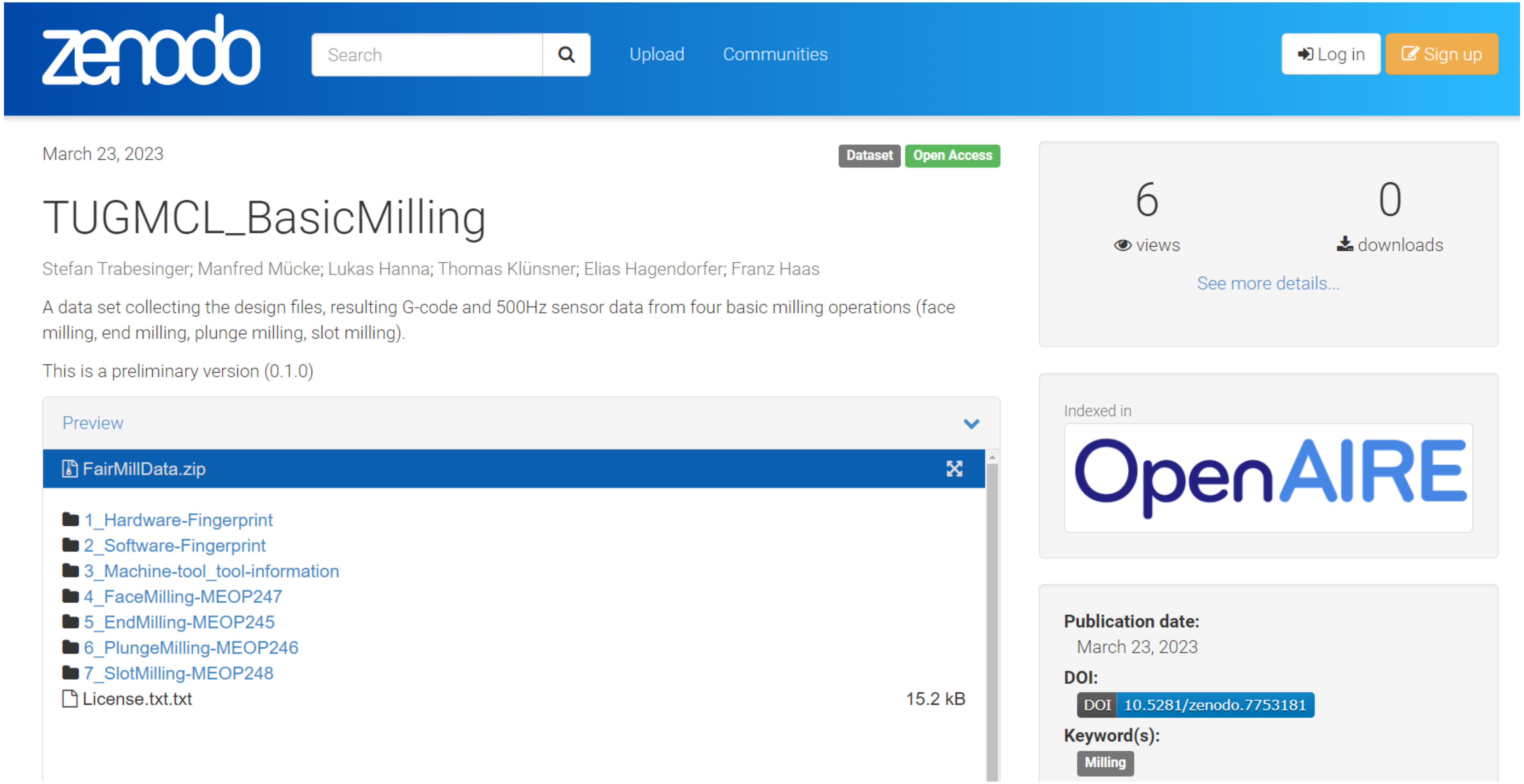
## *Energy / power as f(t) – Example slot milling*




Run 14 (blue): lower corner velocity
Run 20 (orange): higher corner velocity

Relations between milling parameters and e.g. consumed electric power can now be explored systematically.

# URL FairMillData dataset



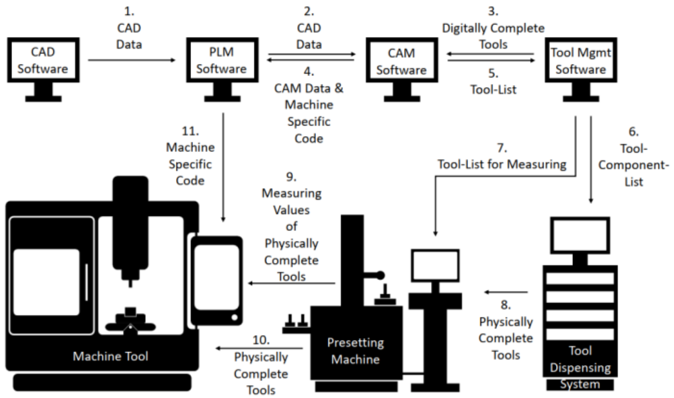

Dataset available on: https://doi.org/10.5281/zenodo.7753180

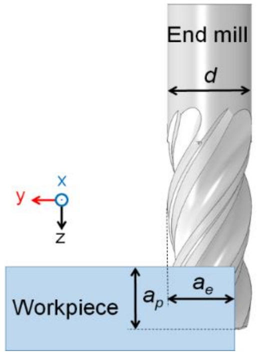
# Agenda

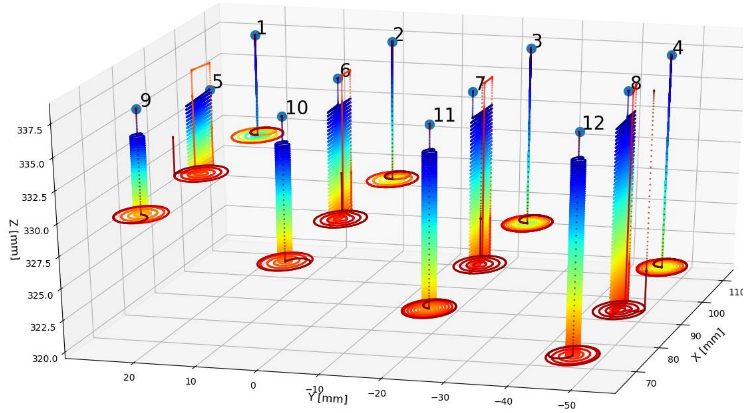
- Motivation & project goal
- Milling experiments
- Dataset
- Outlook

# Outlook

*Analysis goals for FairMillData dataset*



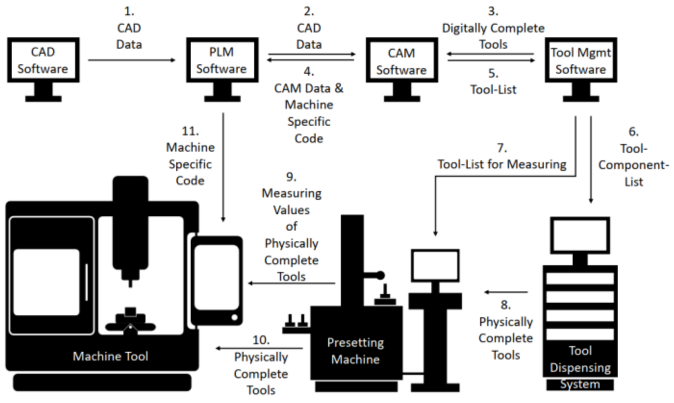



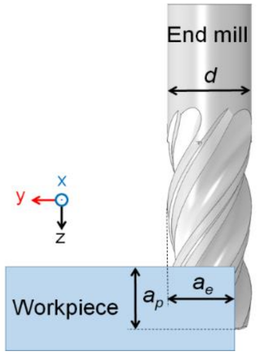

Study impact of performed variation in milling operations on quantities such as:

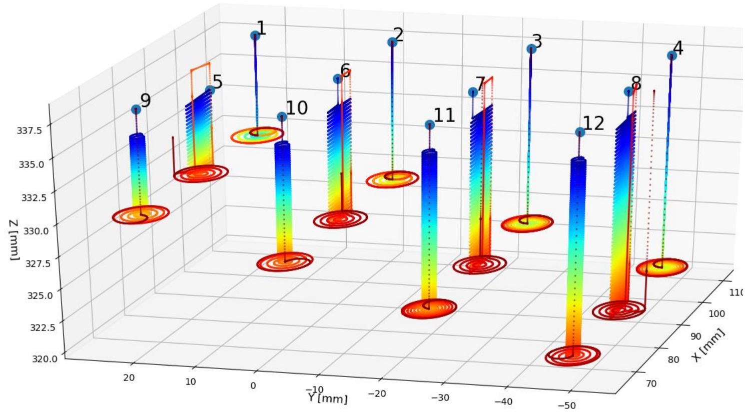
| | | |
|---|---|---|
| - Energy consumption | e.g. channels “Power” | (43 - 48) |
| - Positional accuracy | e.g. channels “ActualAxisPosition | (86 - 91) |
| - Actual tool acceleration patterns | e.g. channels “ActualAxisPosition | (86 - 91) |
| - Relative tool load | e.g. channels “Torque” | (7 - 12) |
| - Time efficiency | e.g. channels “VelocityFeedForward“ | (37 - 42) |

# Outlook

*Questions / discussion points?*




Any input for the to be done analysis?