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Feedback Control of Robotic Friction Stir Welding

Research Projects

- *ARoStir*: Increased Automation of Robotic FSW
  - » KK-foundation
  - » 2 years – total budget € 800’000

- Partners for FSW continuation project
  - » Robotic, control, optimisation
  - » New process variants (Stationary shoulder,…)

Friction Stir Welding

- Joint type
- Material type(s)

Joint

- Welding path
- Tilt angle
- Axial force
- Welding speed
- Rotational speed

Actuator (robot)

- Dimensions
- Features
- Material

Tool

- Clamping force
- Backing bar material
- …

Fixture

In-process parameters

CONTROLLABLE

- Forces = RQ 1
- Temperature = RQ 2
- Spindle torque

Mechanical properties

- Tensile
- Fatigue
- Corrosion
- …

Visual properties

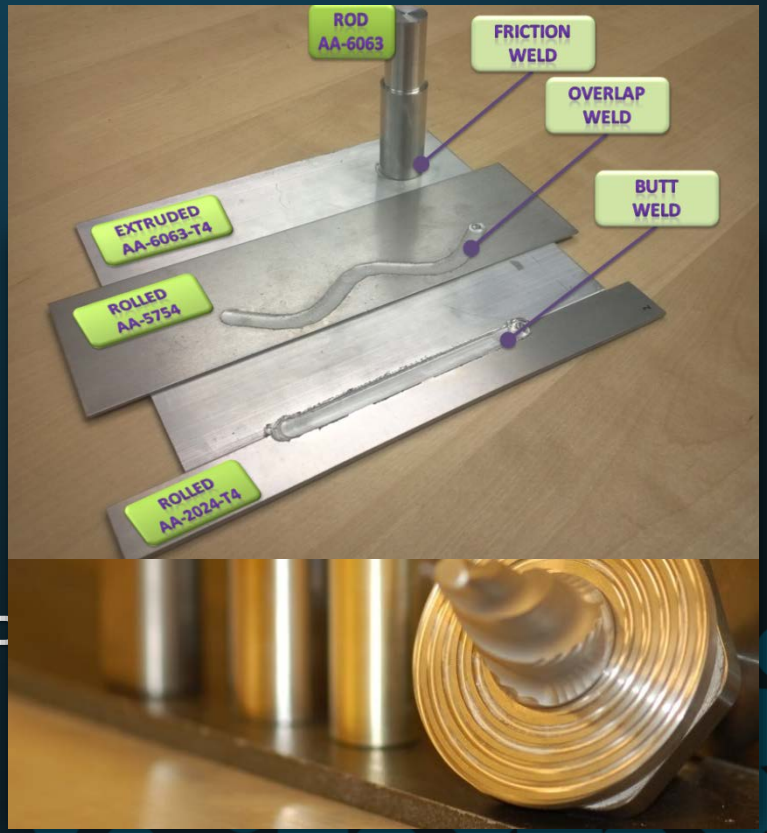
- Flash
- Keyhole
- Surface roughness

Experimental Platform

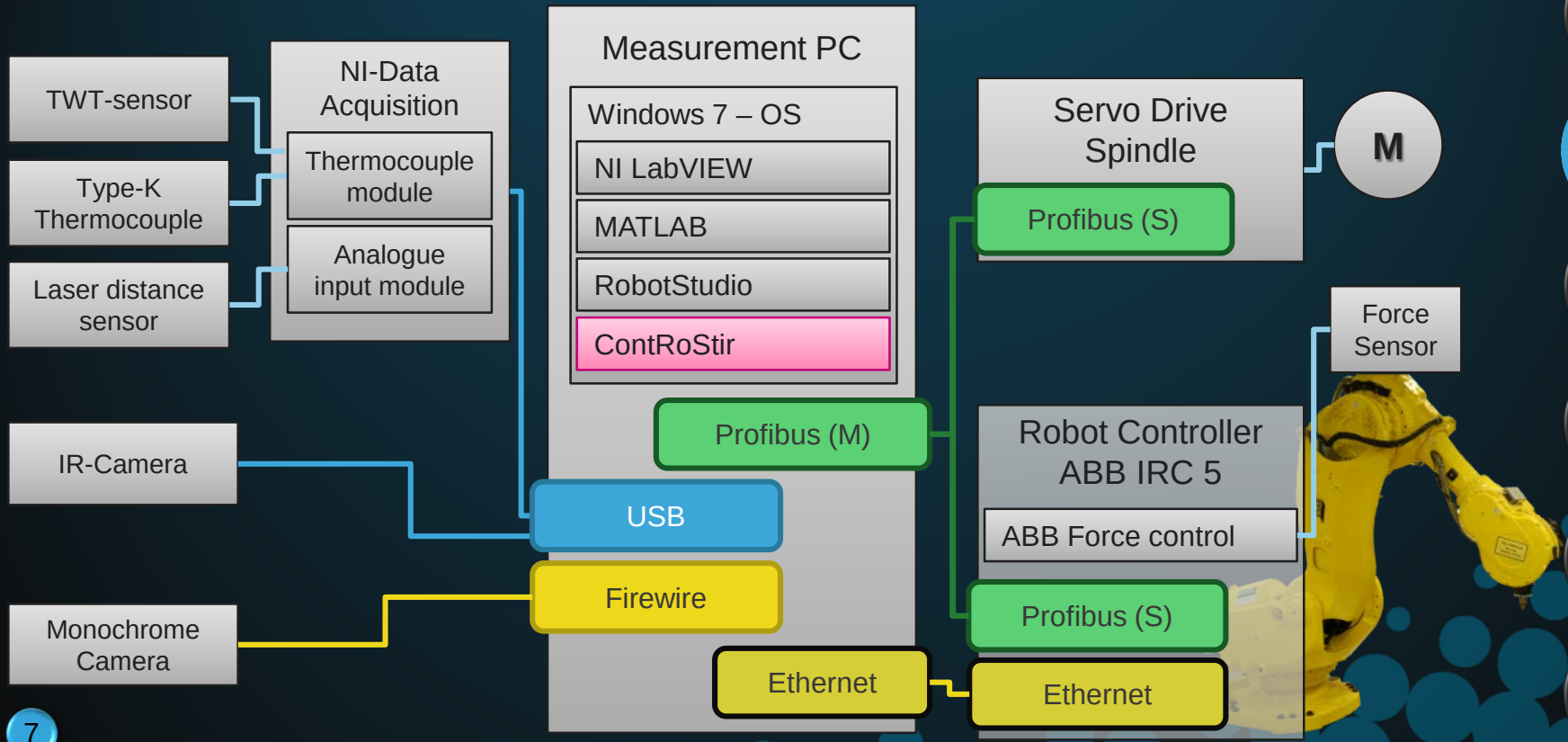
- ESAB Rosio FSW Robot
  - » 500 kg payload – Max 15 kN axial force
  - » Spindle motor: 4500 rpm – 30 Nm
  - » ABB force control
  - » ATI force sensor

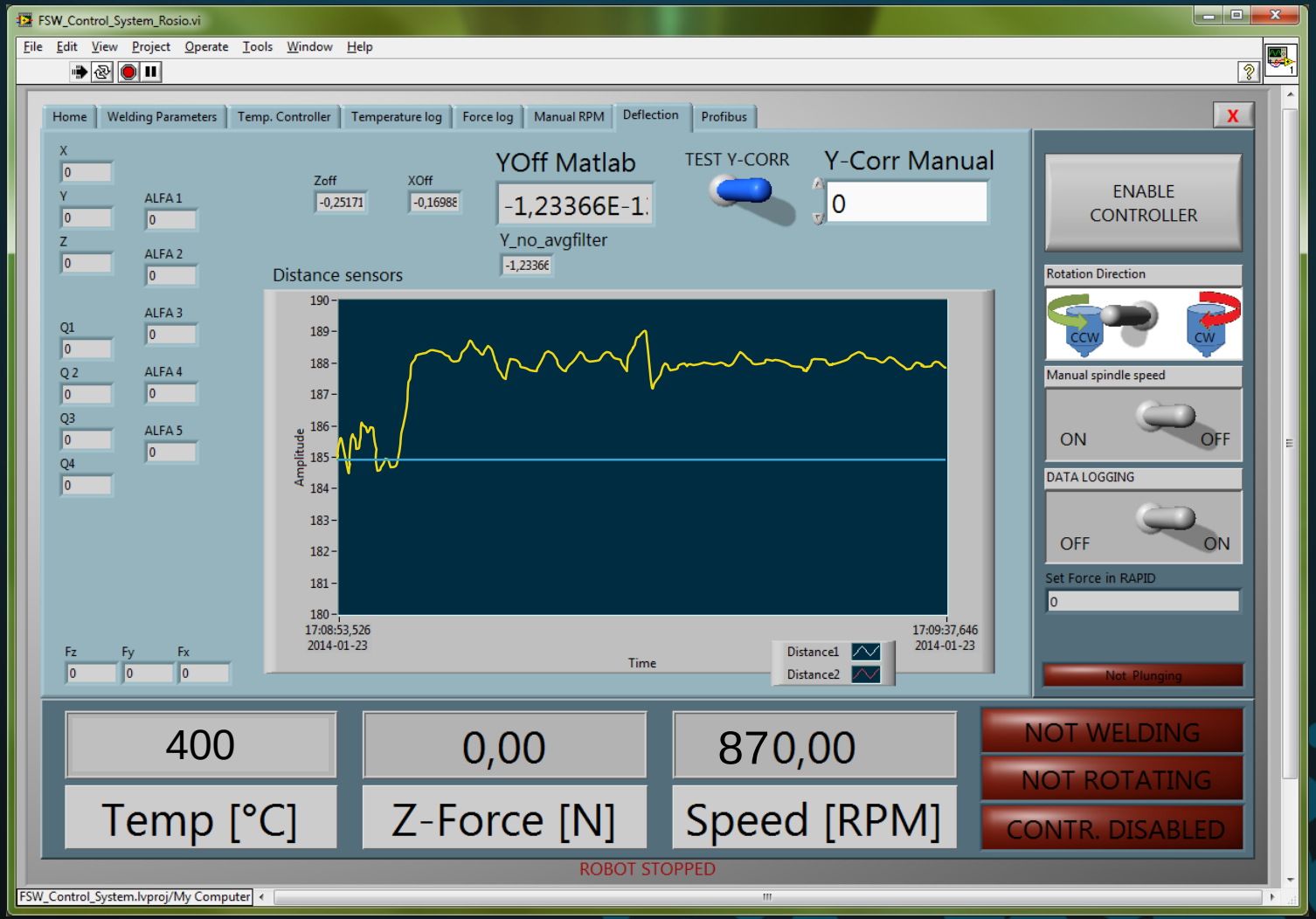
Experimental Platform

- Used FSW-tools:
  - » Ø 10 mm shoulder
  - » 1 – 4 mm pin length
  - » Tool steel
- Used materials
  - » Aluminium alloys only
  - » Strength 100 – 600 MP
  - » Lap & butt-joints



Experimental Platform




FSW_Control_System_Rosio.vi
File Edit View Project Operate Tools Window Help
Home
Welding Parameters
Temp. Controller
Temperature log
Force log
Manual RPM
Deflection
Profibus
X
Y
Z
Q1
Q 2
Q3
Q4
ALFA 1
ALFA 2
ALFA 3
ALFA 4
ALFA 5
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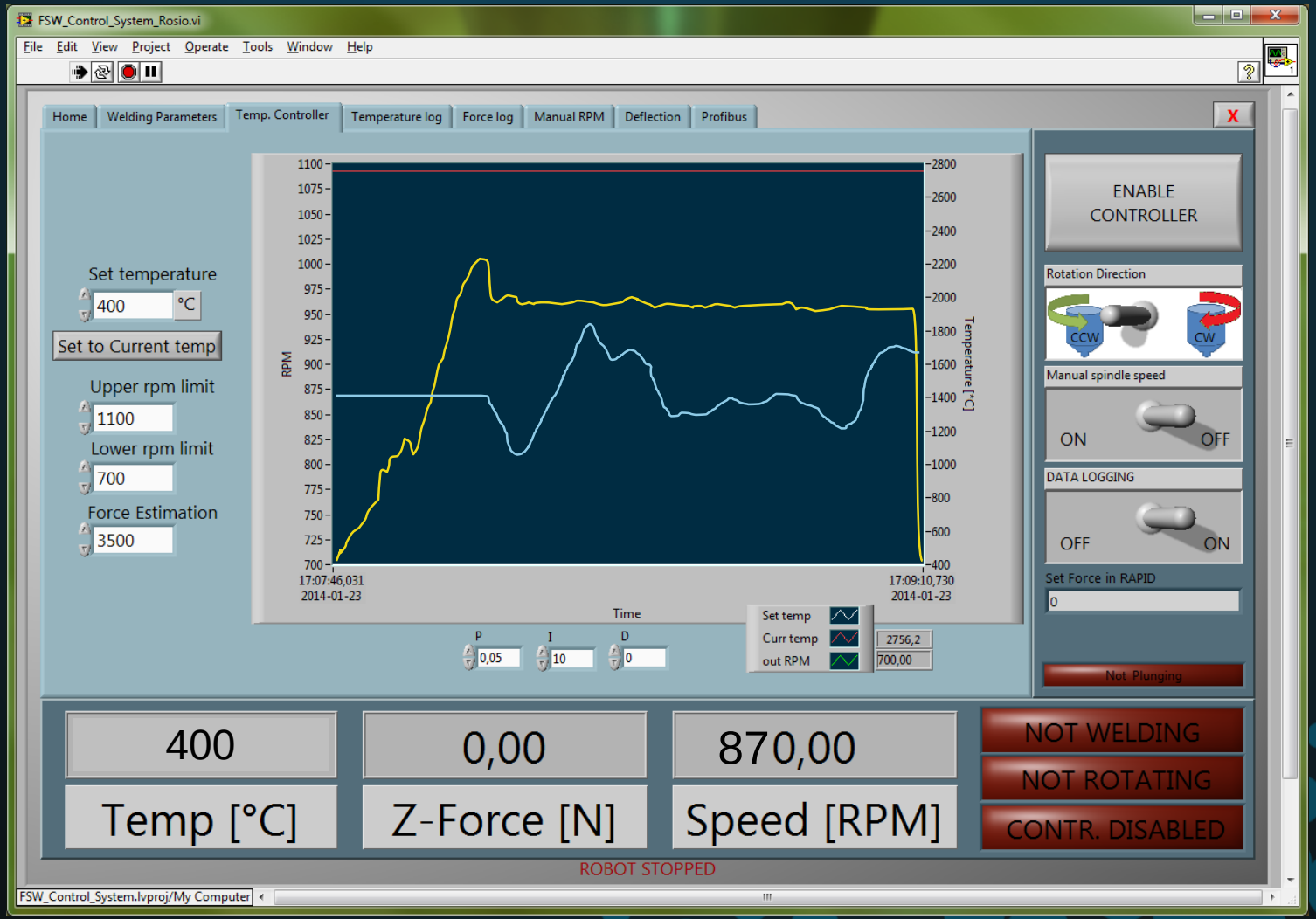
XOff
-0,16988
YOff Matlab
-1,23366E-1
Y_no_avgfilter
-1,23366
TEST Y-CORR
Y-Corr Manual
0
Distance sensors
Amplitude
Time
17:08:53,526
2014-01-23
17:09:37,646
2014-01-23
Distance1
Distance2
Fz
Fy
Fx
ENABLE CONTROLLER
Rotation Direction
CCW
CW
Manual spindle speed
ON
OFF
DATA LOGGING
OFF
ON
Set Force in RAPID
Not Plunging
400
Temp [°C]
0,00
Z-Force [N]
870,00
Speed [RPM]
NOT WELDING
NOT ROTATING
CONTR. DISABLED
ROBOT STOPPED
FSW_Control_System.lvproj/My Computer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Home
Welding Parameters
Temp. Controller
Temperature log
Force log
Manual RPM
Deflection
Profibus
X
Set temperature
400
°C
Set to Current temp
Upper rpm limit
1100
Lower rpm limit
700
Force Estimation
3500
RPM
Temperature [°C]
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17:09:10,730
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Rotation Direction
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Manual spindle speed
ON
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DATA LOGGING
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Set Force in RAPID
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Not Plunging
400
Temp [°C]
0,00
Z-Force [N]
870,00
Speed [RPM]
NOT WELDING
NOT ROTATING
CONTR. DISABLED
ROBOT STOPPED
FSW_Control_System.lvproj/My Computer

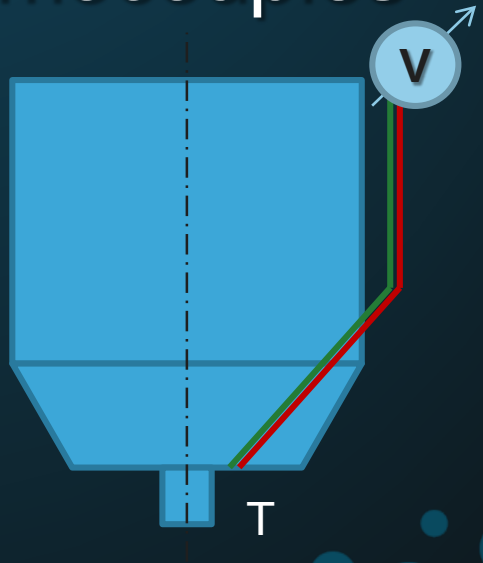
Temperature Control

- “Can a temperature controller prevent overheating of the material during FSW and thereby improve process robustness and weld quality?” (Thesis RQ1)

  - » Temperature measurement method
  - » Controller development
  - » Experimental verification
  - » Aim: Improveme Weld quality

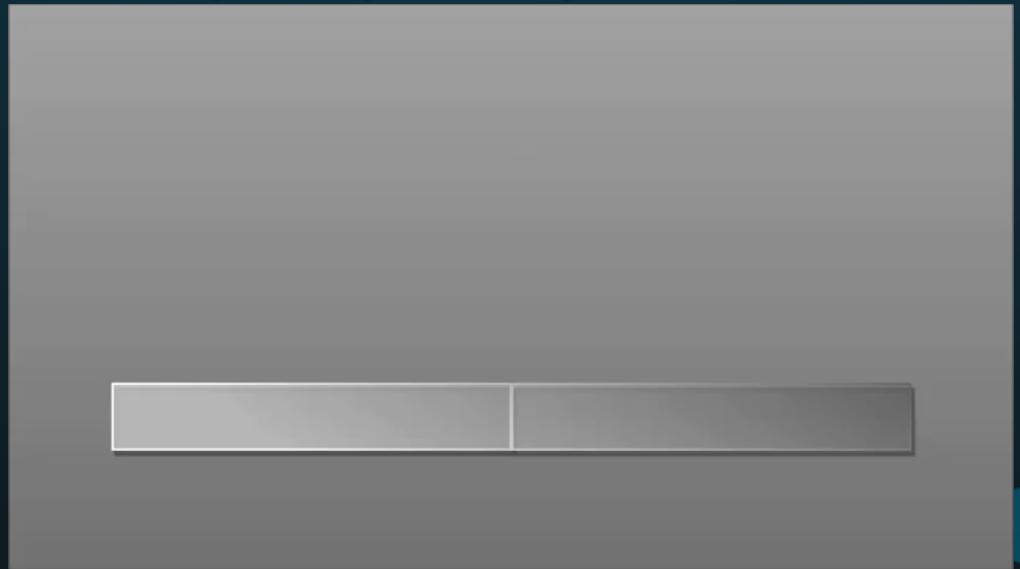
Temperature Measurement

- Classical approach: Thermocouples
  - » Two thin wires
  - » Inserted into the tool
  - » Voltage ~ Temperature

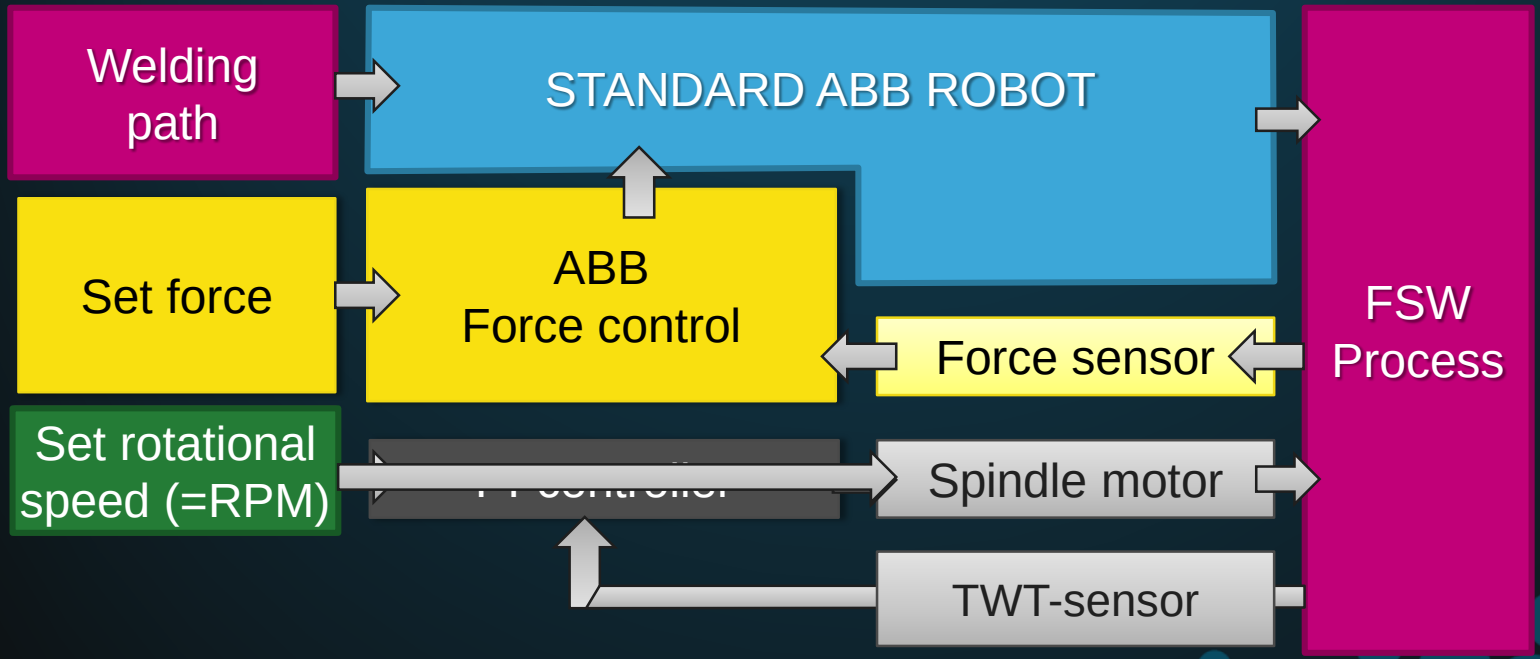


Temperature Measurement

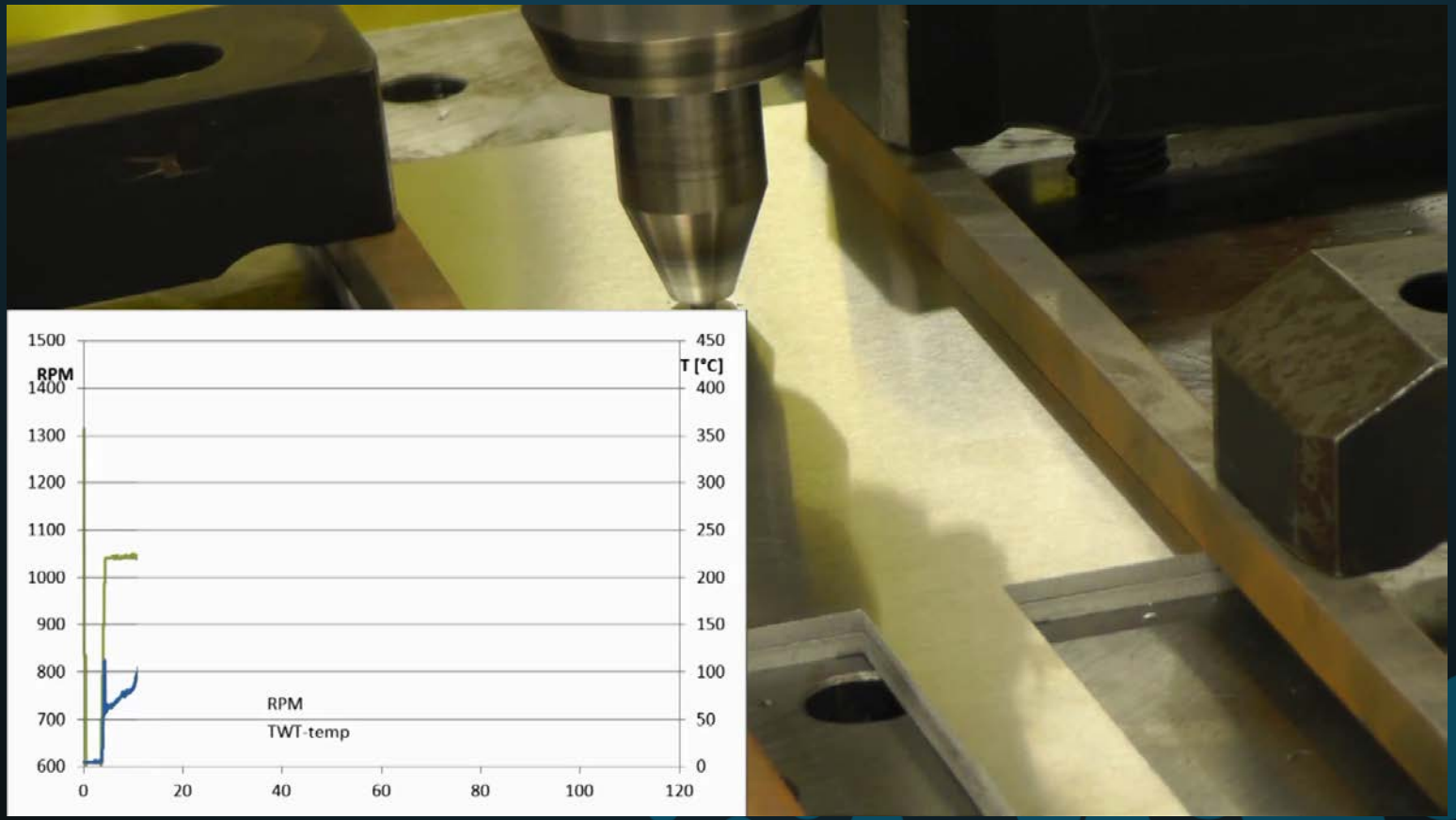
- New approach: Tool-Workpiece Thermocouple (TWT)



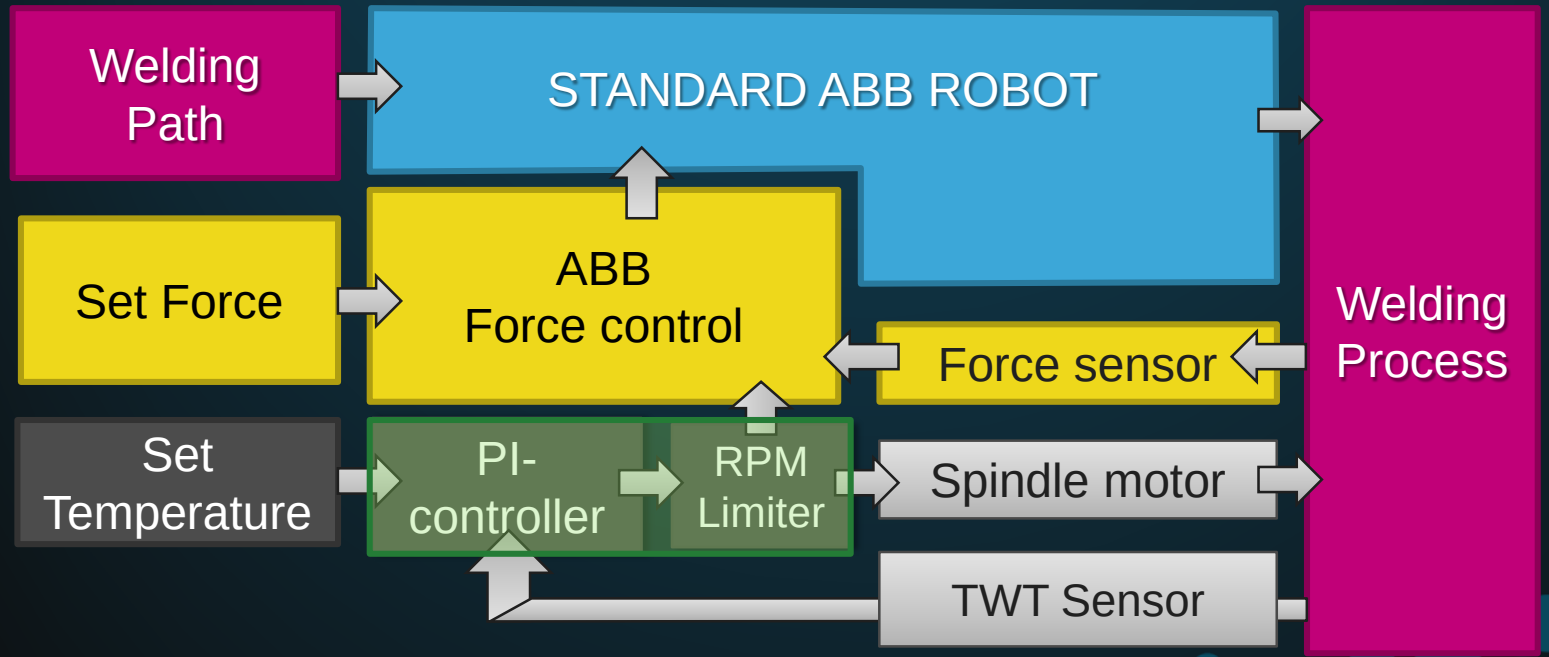
Temperature Control of RPM



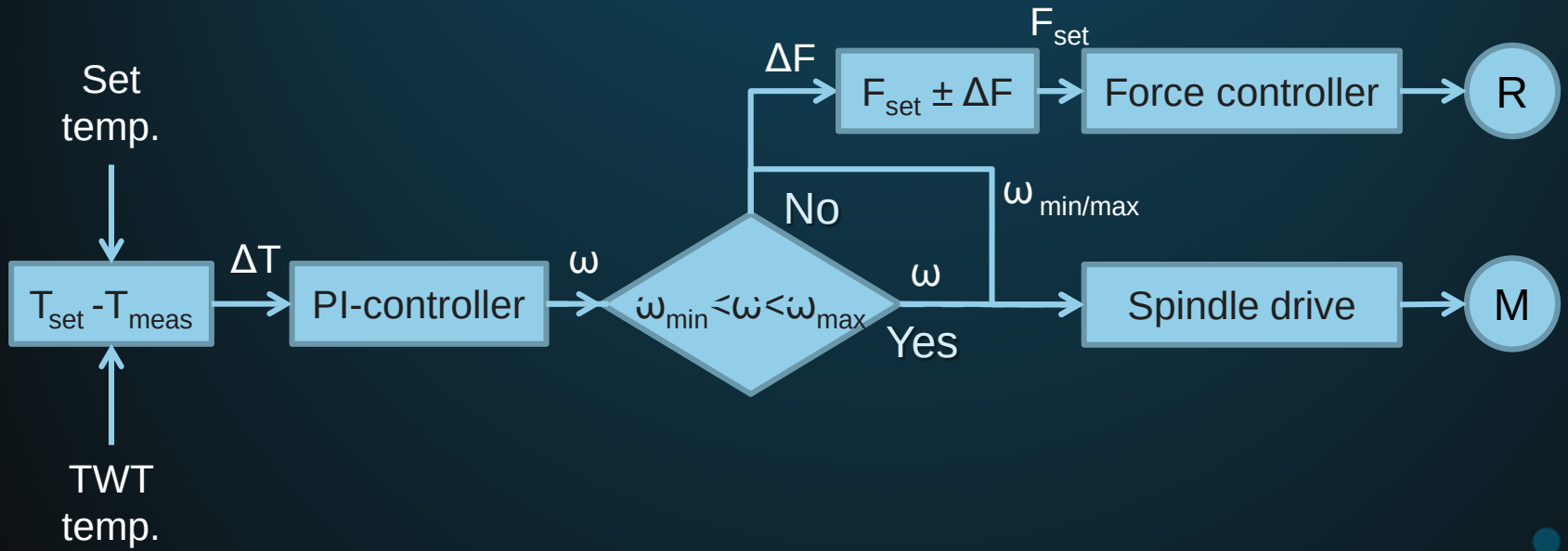
Temperature Control of RPM



Temperature Control of RPM+F

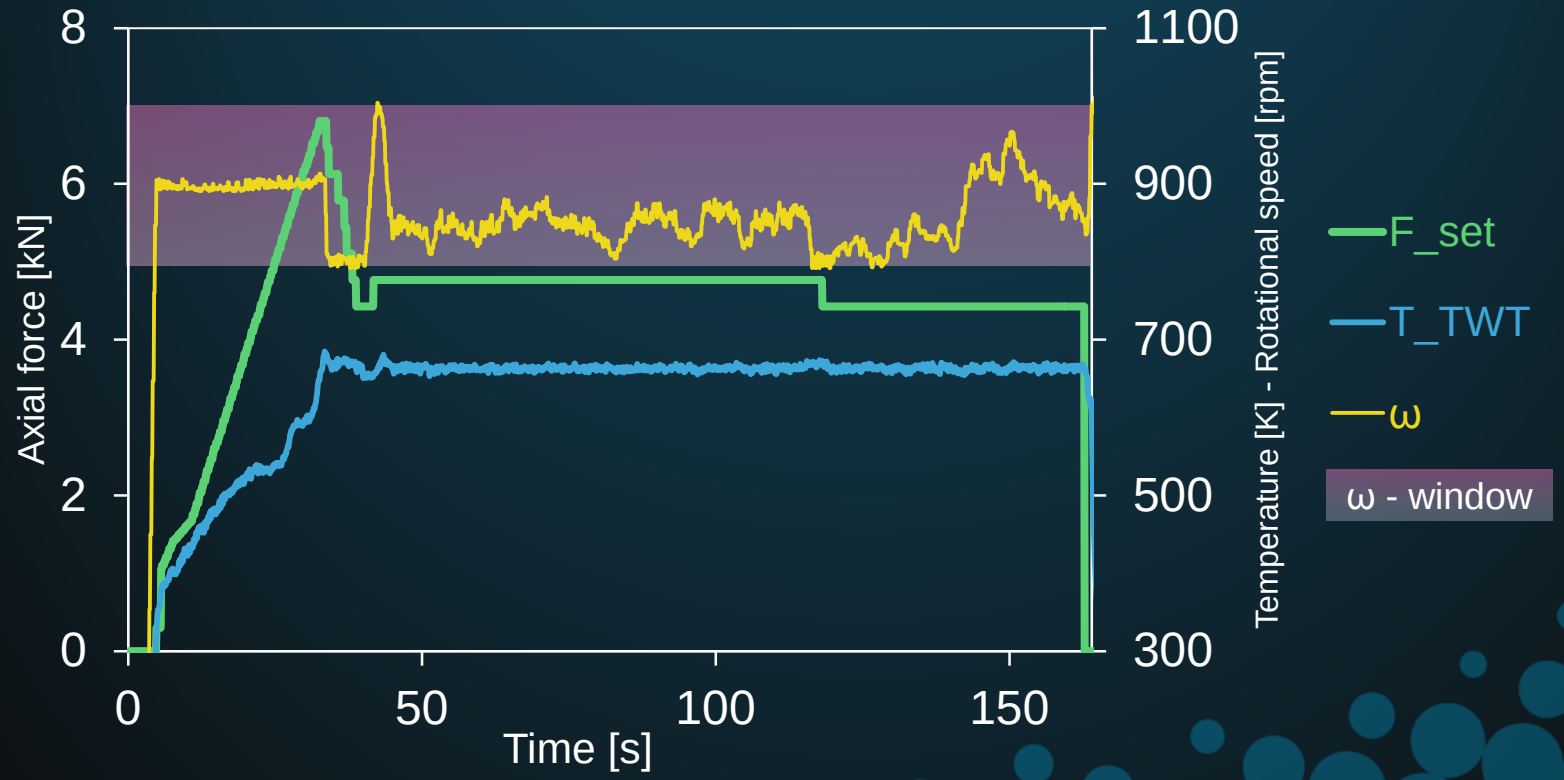


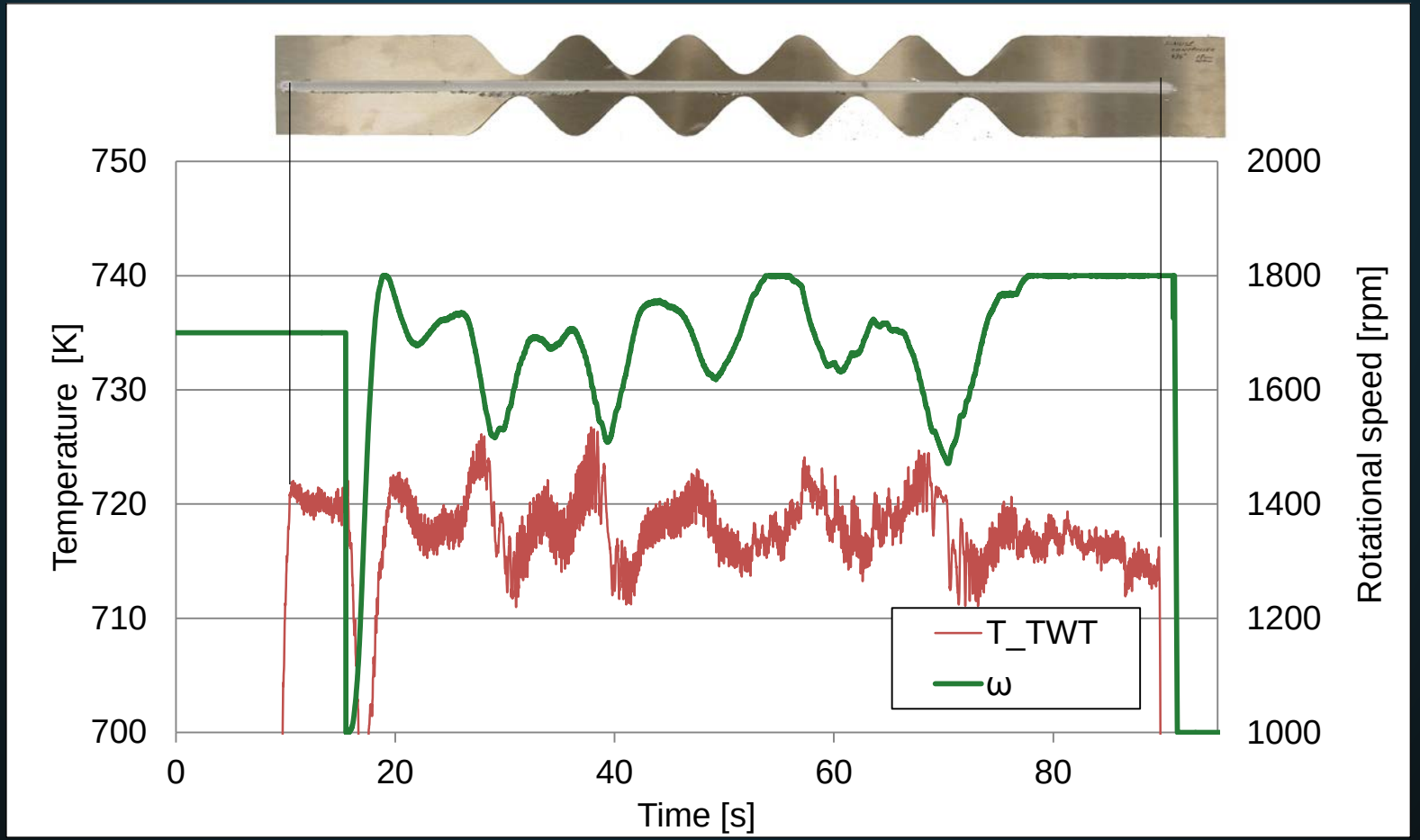
PI-controller + RPM-limiter

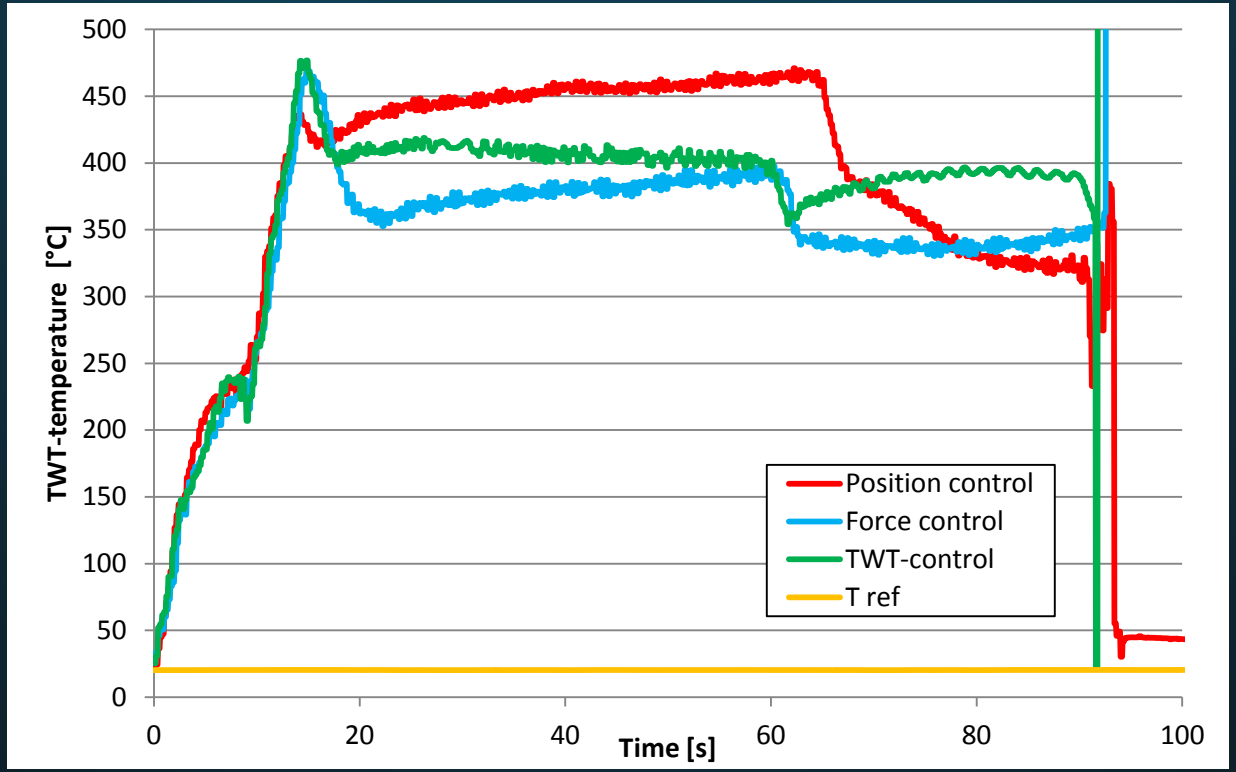


Automatic parameter tuning

AA 6082-T6, 2 mm




750
740
730
720
710
700
Temperature [K]
2000
1800
1600
1400
1200
1000
Rotational speed [rpm]
0
20
40
60
80
Time [s]
T_TWT
ω



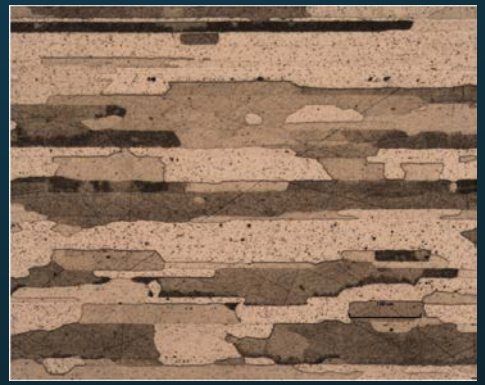
6xxx aluminium

Nickel 718

Copper

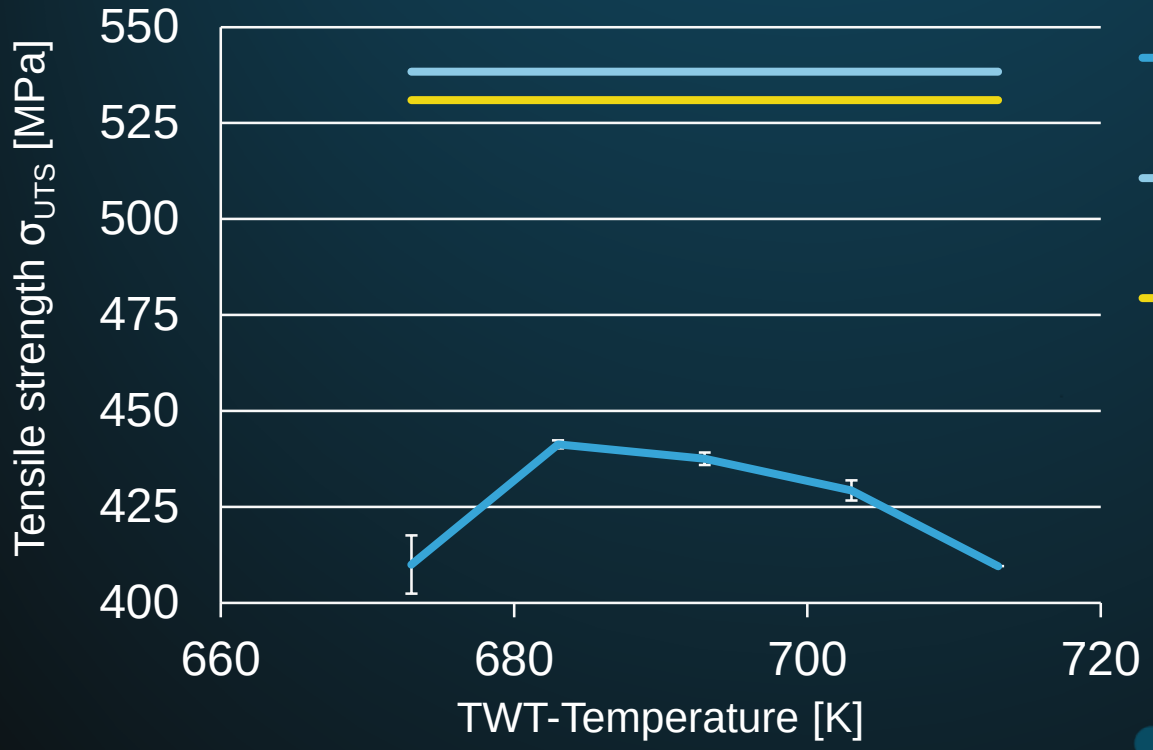
Study of AA-2060 using TWT

- New 2xxx series alloy, lithium based
- Main properties:
  - » High strength
  - » High E-modulus
  - » Low density



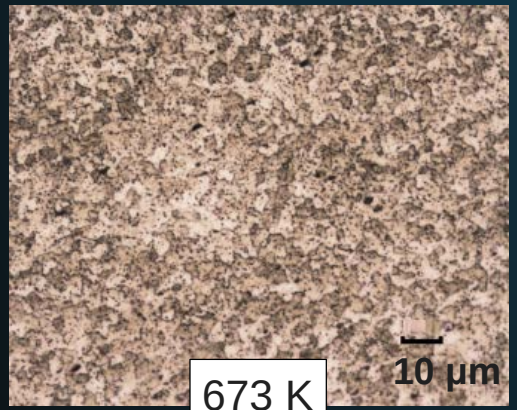
- Improved ductility, toughness, corrosion properties compared to previous Al-Li alloys

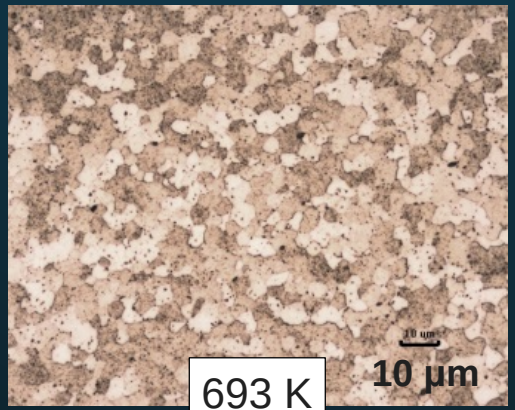
Quality improvement – AA 2060-T6

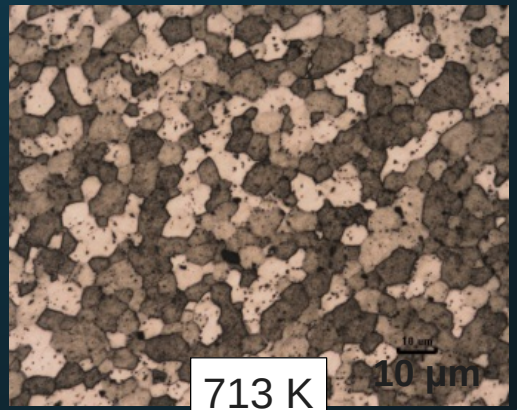


Microstructure – AA 2060-T6

- TWT-Temperature ~ Grain size

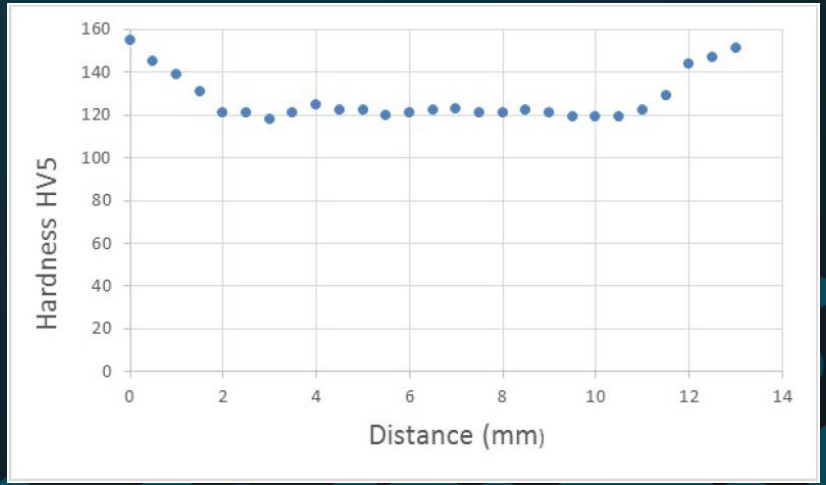






Hardness – AA 2060-T6

- Absence of the typical drop in HAZ
- No effect of temperature on hardness
  - » Cooling rate?



Conclusions

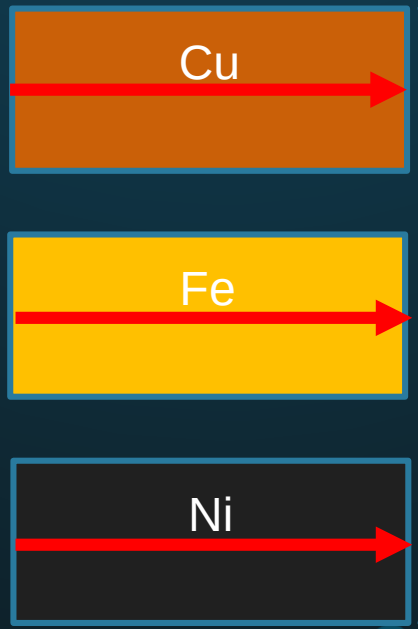
- *RQ2: Can a temperature controller prevent over-heating of the material during FSW and thereby improve process robustness and weld quality?*
  - » TWT method
  - » Implementation of PI-controller for RPM
  - » Adaptation of axial force
  - » Previously unweldable geometries are now possible to FSW
  - » Reduction of programming time & cost

Future perspectives

- TWT controller
  - » New FSW variants (stationary shoulder)
  - » Dissimilar materials (variable TWT coefficient)

Cooling rate

- Effect of backing plate in:
  - Mechanical properties
  - Microstructural
  - Optimal parameters

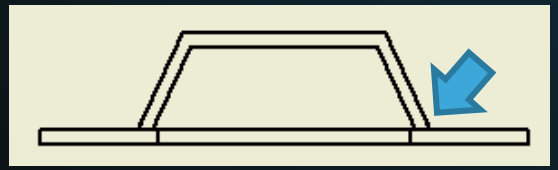


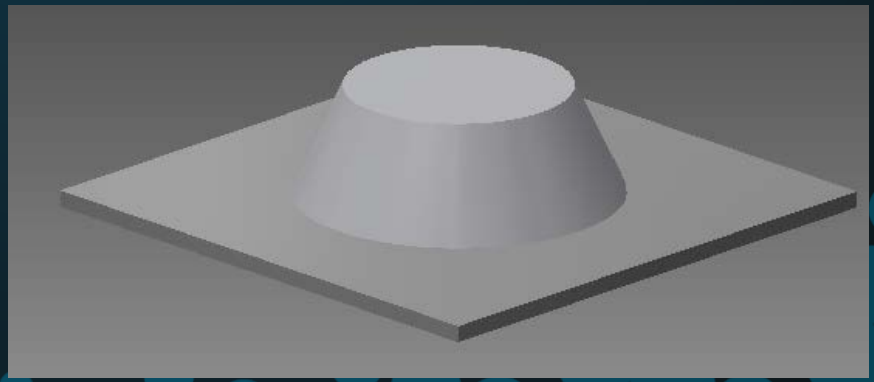
How lower can the forces be?

- Temperature
- Rpm
- Force
- welding speed

Stationary shoulder

- Corner welding
- Limitation of 5-axis machines





Off-topic (but still FSW)

Type of examination and testing	Extent of examination and testing
Visual testing [a]	100 %
Transverse tensile test [b]	2 test specimens
Transverse bend test for wrought materials [c]	2 root test specimens
Fracture test for cast materials or wrought/cast combinations [d]	2 face test specimens
Macroscopic examination	1 test specimen
Additional tests (e.g. non-destructive)	If required [e]

[a] Testing shall be carried out to avoid discarded areas, as shown in

[b] For a butt joint in tube, at least one transverse tensile test should b

[c] For material over 12 mm in thickness, four transverse side-bend root and two face-bend test specimens. One longitudinal face-bend test specimen may be substituted for the four transverse-bend test spe

[d] See ISO 9017.

[e] Additional tests shall be carried out in accordance with the relevan

ISO 25239-4

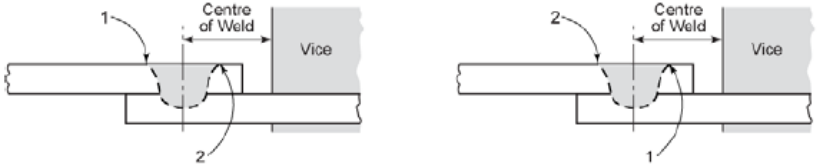
Type of examination and testing	Extent of examination and testing
Visual testing [a]	100 %
Macroscopic examination	2 test specimens
Additional tests (e.g. peel test, shear test, hammer "S" bend test, non-destructive test)	if required [b]

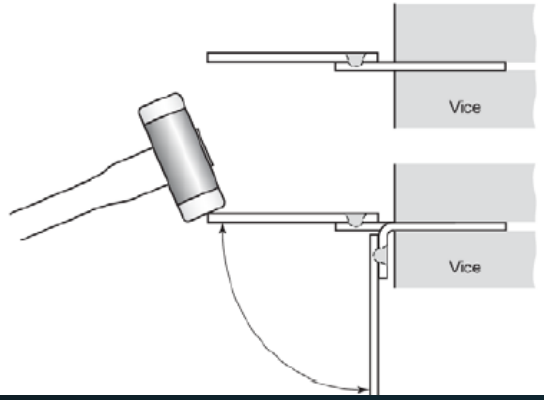
[a] Testing shall be carried out to avoid discarded areas, as shown in Figure 6.

[b] Additional tests shall be carried out in accordance with the relevant requirements or the design specification. Information on the hammer "S" bend test is given in Annex C.

Off-topic (but still FSW)

This test does not replace any other quantitative tests.





ISO 25239-4

Thus: No quantitative testing method for lap joints?

Tack!