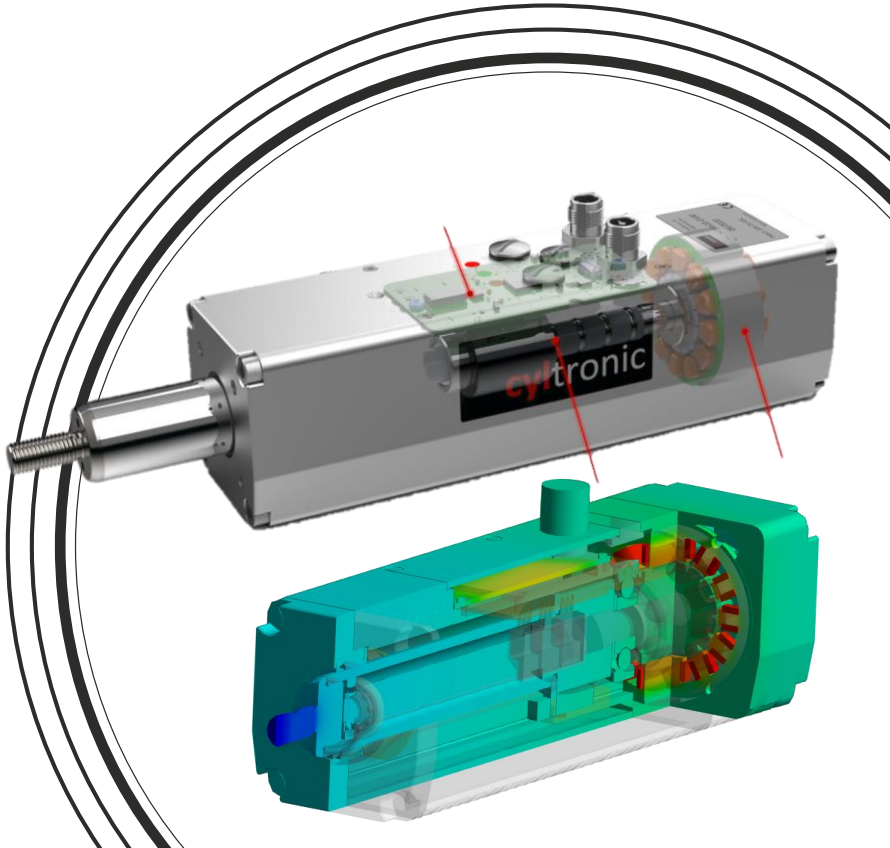
Thermal Uprating:
Jumeau numérique d´un actuateur mécatronique

Cyltronic AG
Daniel Baumann
CADFEM (Suisse) AG
Arno Douady
Joël Grognuz

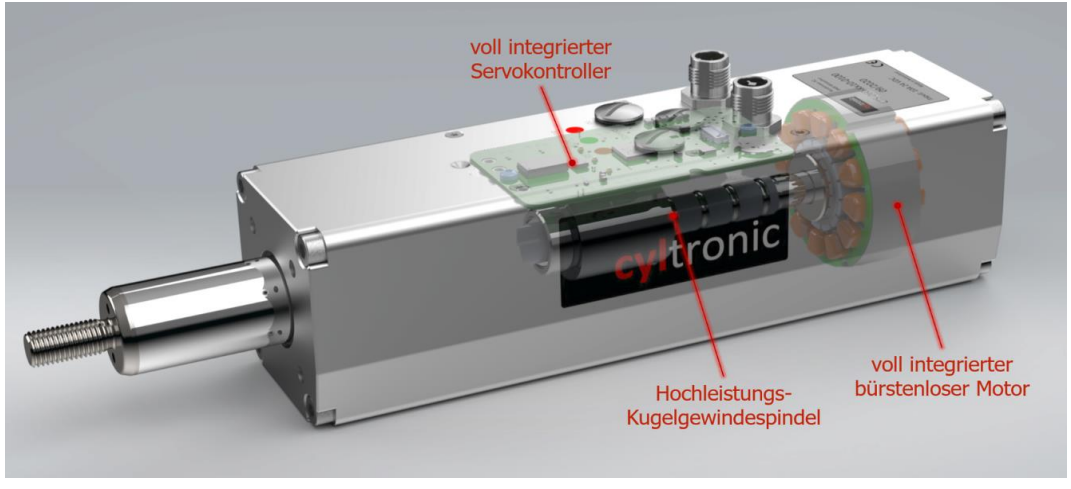


Cyltronic All-in-One

Business Case

"simple, compact and versatile IO-Link servo actuators!"

- **Proven in Service for many years**
- **Robust and reliable**
- **Easy to use All-in-One Solution**



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Cyltronic & CADFEM All-in-One; Business Case

Cyltronic actuators are:

50%
more compact
than the status quo

90%
reduction of implementation effort
compared to the status quo

92%
energy cost saving
compared to pneumatic actuators

How can we get even better?
How can we create more customer value?

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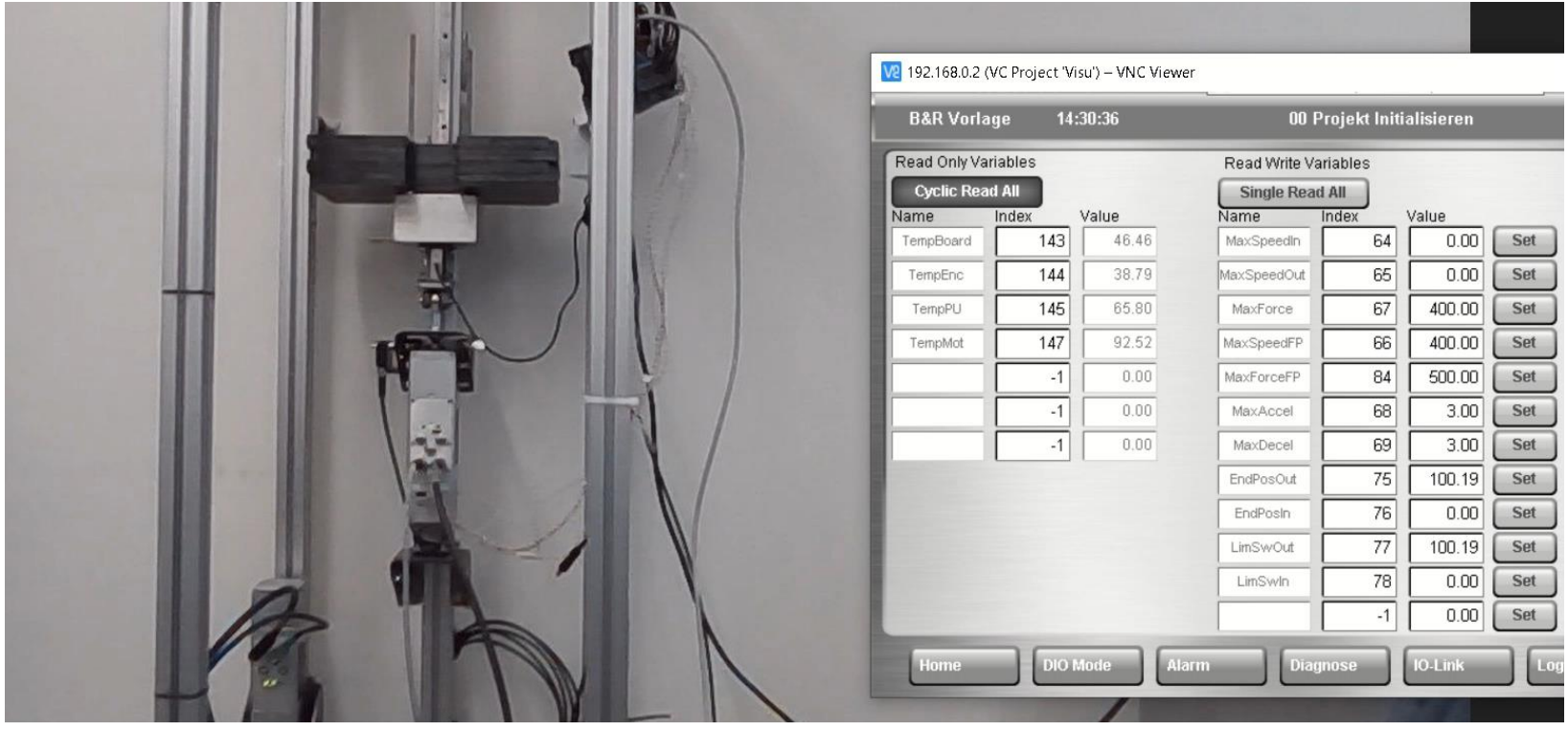
Cyltronic All-in-One

Initial status and improvements



Rising performance levels and testing specific load cases is very time consuming

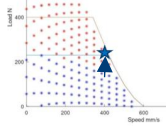
Cyltronic All-in-One
Business Values

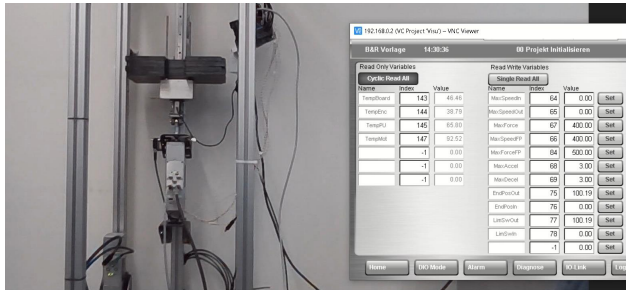
R&D

- Robust Design Optimization
- **Shorter Development time**
- **Better coverage of test cases**

Operator

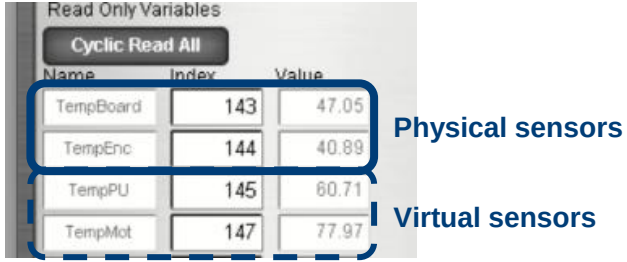
- **Customer Specific Planing**
- Duty cycle optimization / **Thermal Uprating**
- *Predictive Maintenance*





Product

- **Smart Monitoring** without extensive calibration



Cyltronic All-in-One

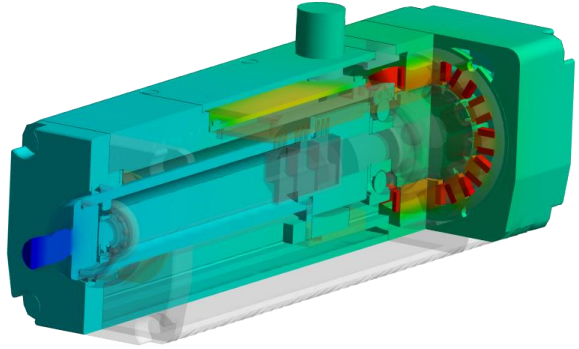
Twin Considerations

Business Value

“Track the past, provide deeper insights into the present, predict and influence future behavior”

Digital Twin

“Virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity”



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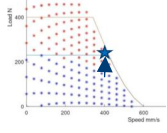
Cyltronic All-in-One
Business Values

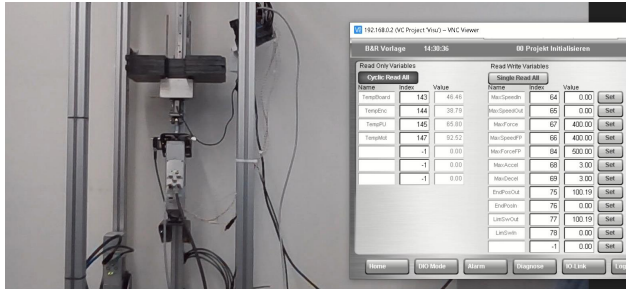
R&D

- Robust Design Optimization
- **Shorter Development time**
- **Better coverage of test cases**

Operator

- **Customer Specific Planing**
- Duty cycle optimization / **Thermal Uprating**
- *Predictive Maintenance*





Product

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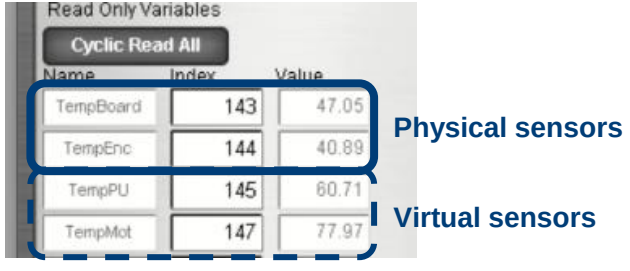
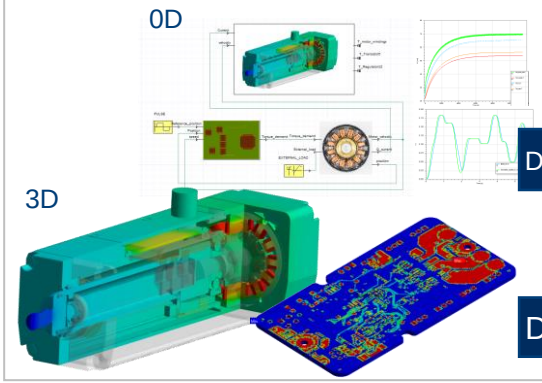


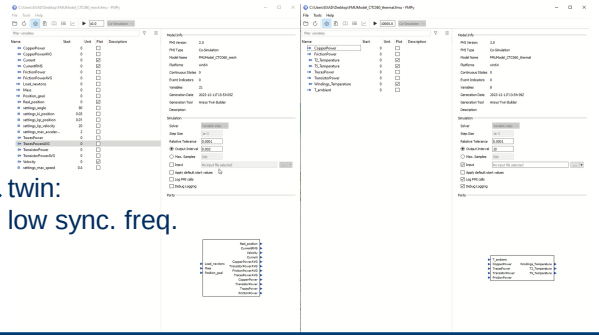
Cyltronic & CADFEM All-in-One

R&D / Virtual Prototyping



Deployment

Operator / Virtual Assistant



twin:
low sync. freq.

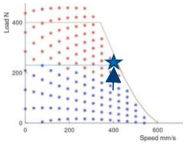
Deployment

Product / Virtual Sensors

twin:
high sync. freq.

- Robust Design Optimization
- **Shorter Development time**
- **Better coverage of test cases**

- **Customer Specific Planing**
- Duty cycle optimization / **Thermal Uprating**
- *Predictive Maintenance*



- **Smart Monitoring**
  without extensive calibration

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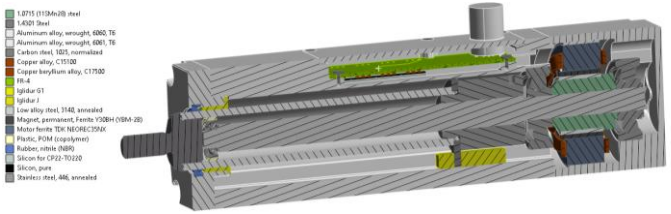
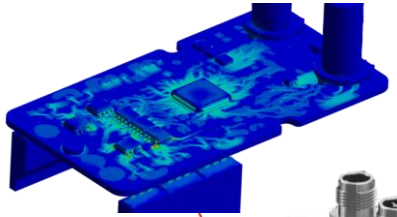
R&D / Virtual Prototyping

3D

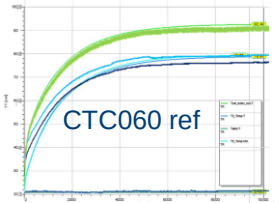
MCAD

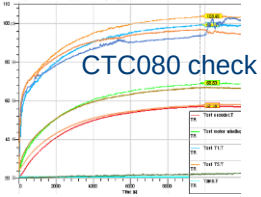


PCB Virtual Temp Sensors

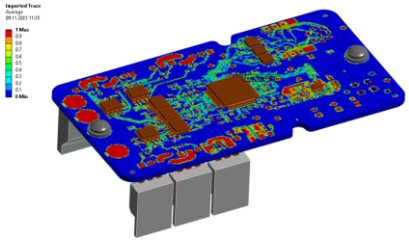


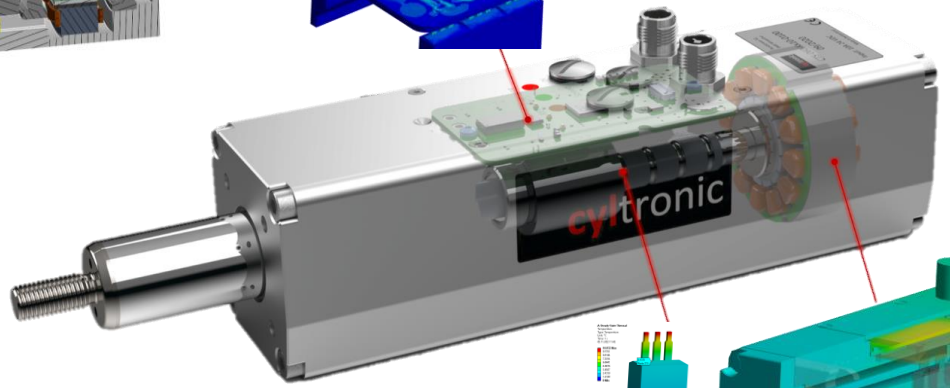
Validation with measurements:



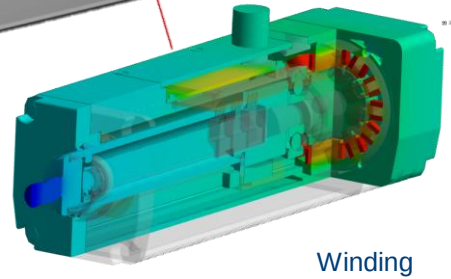


ECAD in Mechanical



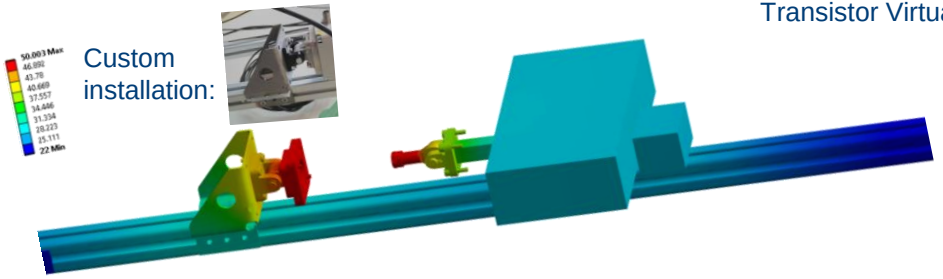


Transistor Virtual Temp Sensors



Winding
Virtual Temp Sensors

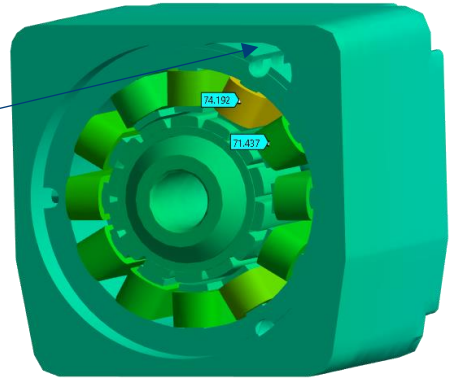
Custom
installation:



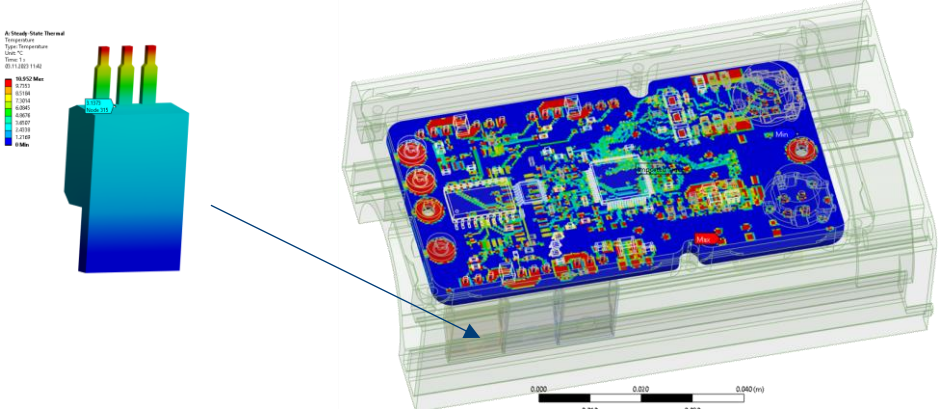
R&D / Virtual Prototyping

3D

- Design improvements
  - Local over-heating : An air gap „isolates“ one of the windings



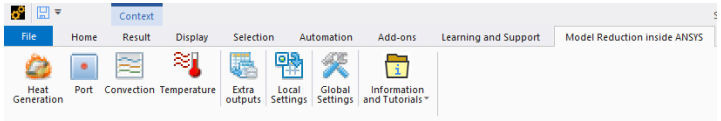
  - Transistors-to-environment frame thermal conduction : a stochastic parameter with large variance that can result in over-heating => improved quality control for more robust design.

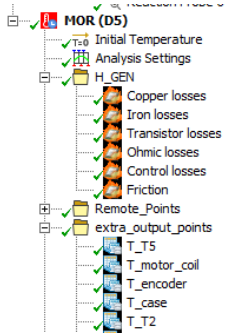


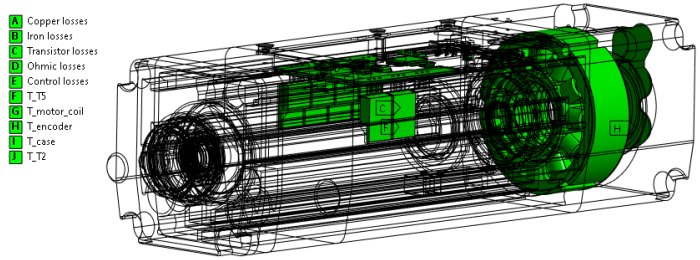
R&D / Virtual Prototyping

Model Order Reduction for 0D Prototyping (& Embedded Virtual Sensors)

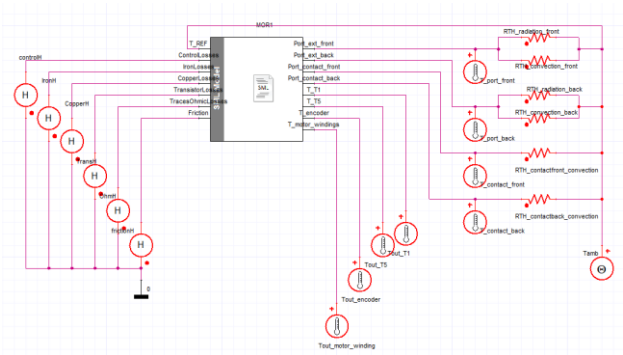
- MORiA Mechanical extension which allows quick and easy matrix reduction:



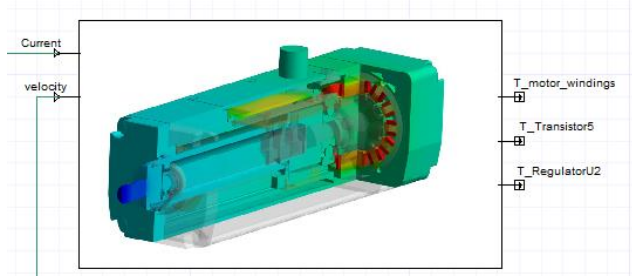




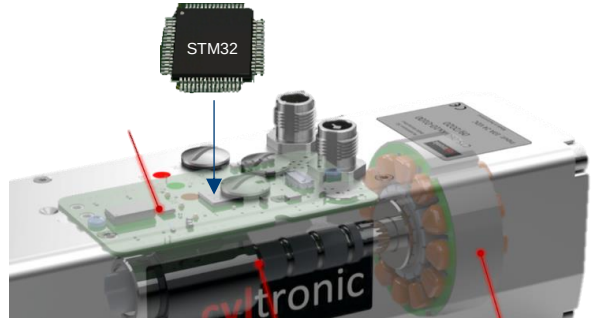
- Linear model for fast testing:



or

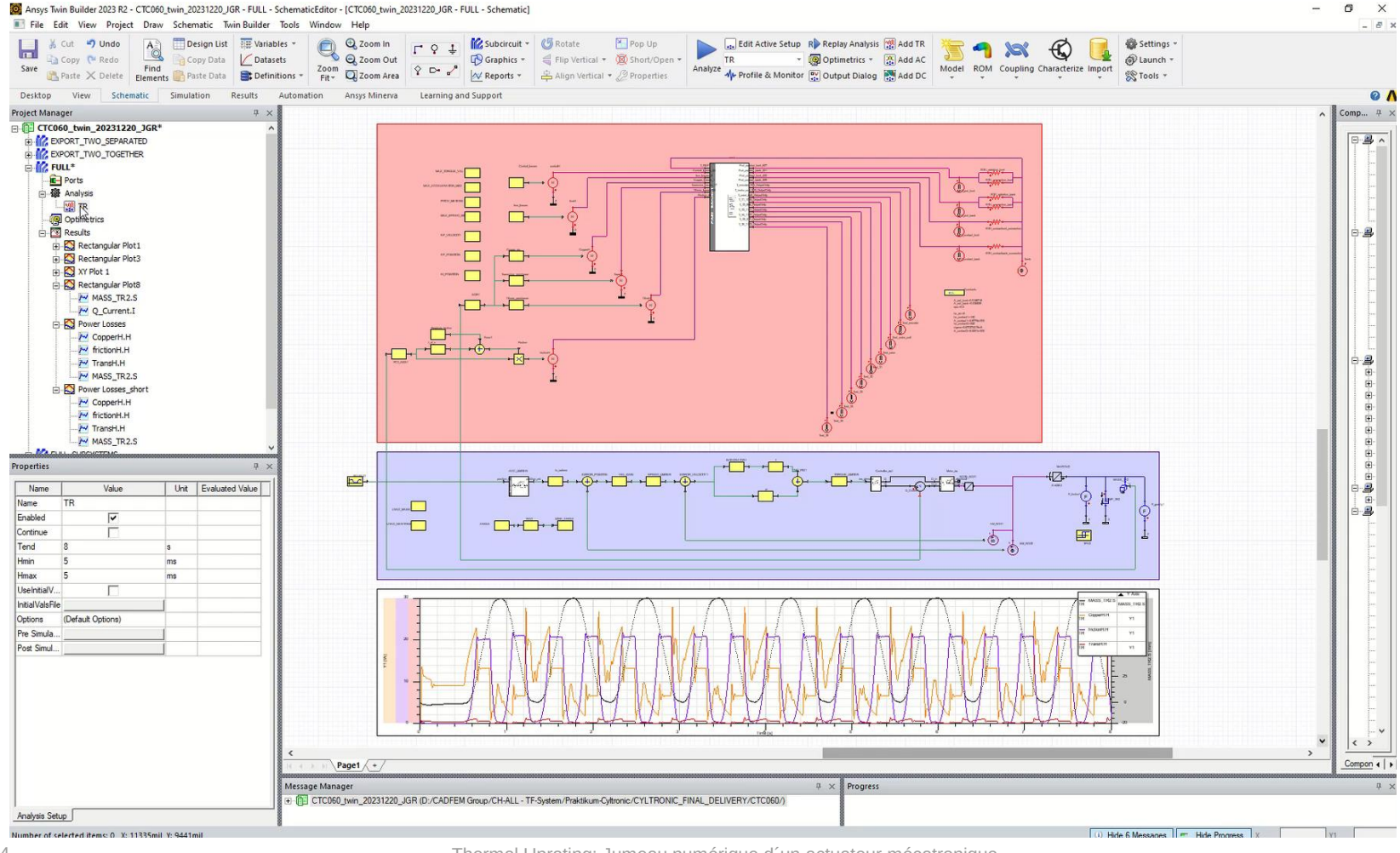


or



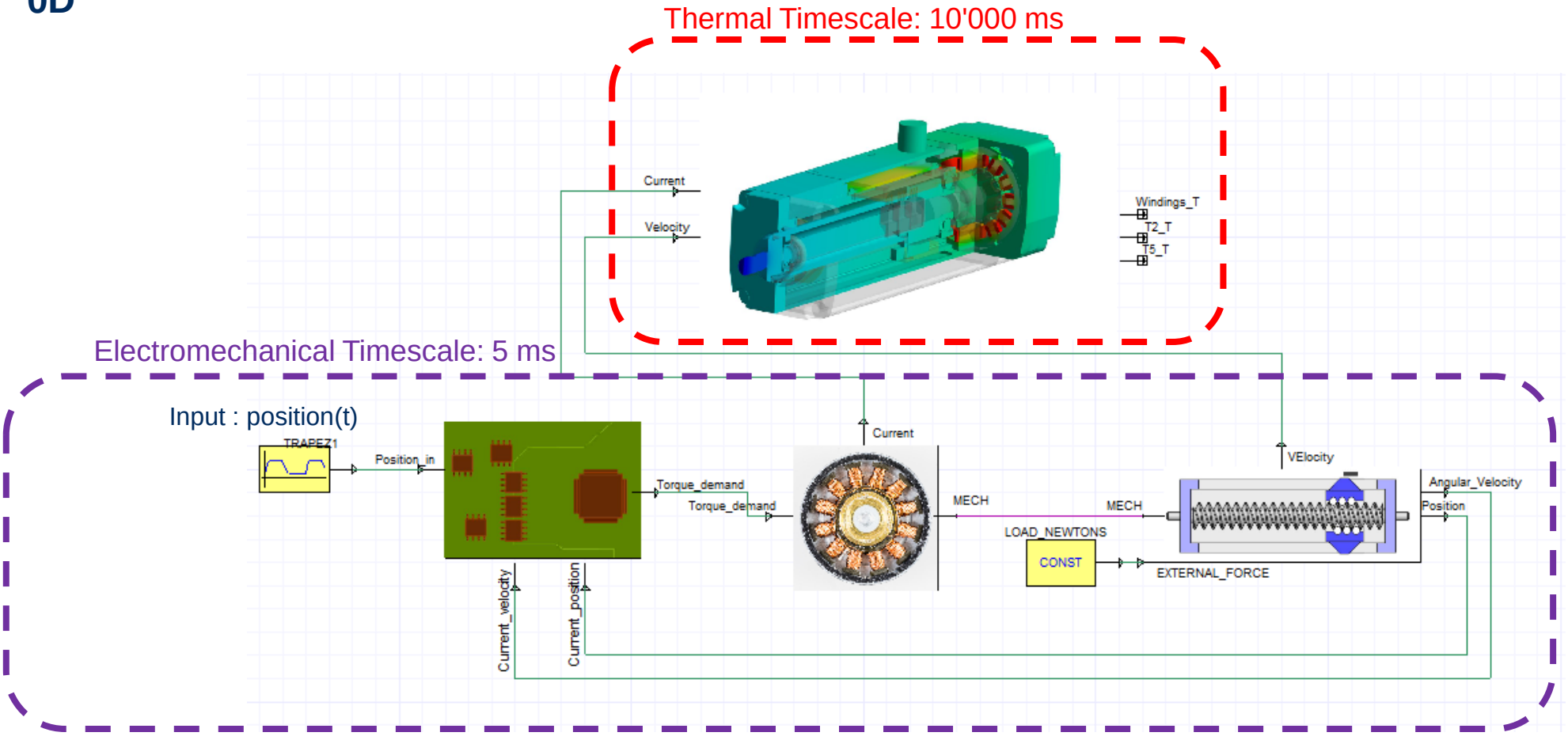
R&D / Virtual Prototyping

0D



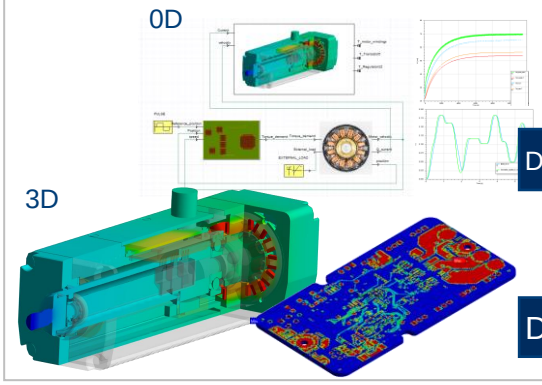
R&D / Virtual Prototyping

0D



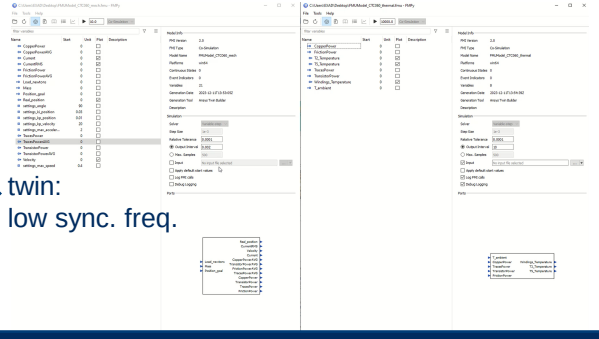
Cyltronic & CADFEM All-in-One

R&D / Virtual Prototyping



Deployment

Operator / Virtual Assistant



twin:
low sync. freq.

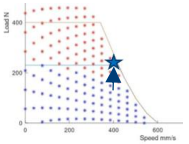
Deployment

Product / Virtual Sensors

twin:
high sync. freq.

- Robust Design Optimization
- **Shorter Development time**
- **Better coverage of test cases**

- **Customer Specific Planing**
- Duty cycle optimization / **Thermal Uprating**
- *Predictive Maintenance*



- **Smart Monitoring**
  without extensive calibration

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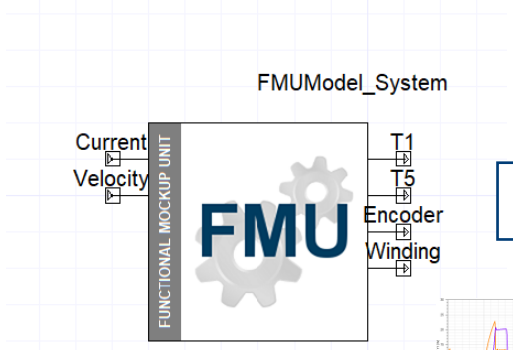
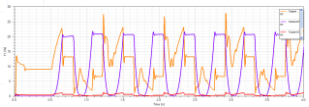
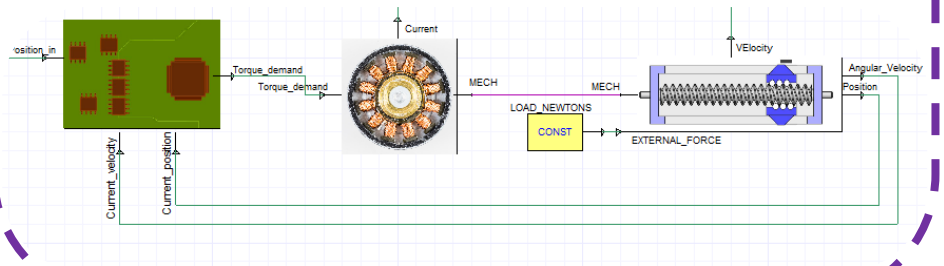
Operator / Virtual Assistant
Deployment

Electromechanical Timescale: 5 ms



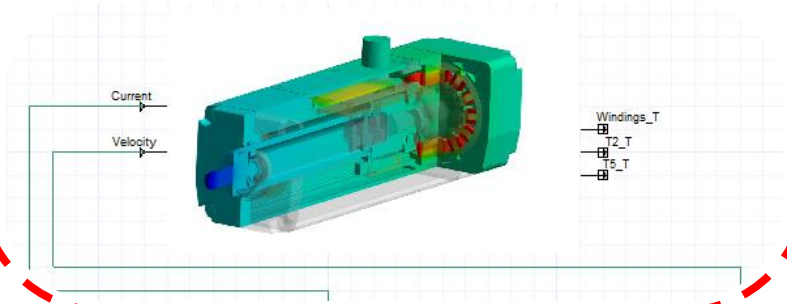




Avg(Periodic P(t))

Thermal Timescale: 10'000 ms

FUNCTIONAL MOCKUP UNIT FMU



C:\Users\EXAD\Desktop\FMUModel_CTC060_mech.fmu - FMPy

File Tools Help

10.0 Co-Simulation

filter variables

Name	Start	Unit	Plot	Description
CopperPower	0		☐	
CopperPowerAVG	0		☐	
Current	0		☑	
CurrentRMS	0		☑	
FrictionPower	0		☐	
FrictionPowerAVG	0		☐	
Load_newtons	0		☐	
Mass	0		☐	
Position_goal	0		☐	
Real_position	0		☑	
settings_angle	90		☐	
settings_ki_position	0.03		☐	
settings_kp_position	0.01		☐	
settings_kp_velocity	20		☐	
settings_max_acceler...	2		☐	
TracesPower	0		☐	
TracesPowerAVG	0		☐	
TransistorPower	0		☐	
TransistorPowerAVG	0		☐	
Velocity	0		☑	
settings_max_speed	0.4		☐	

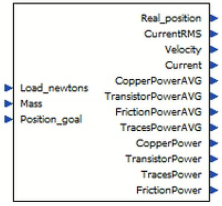
Model Info

FMI Version	2.0
FMI Type	Co-Simulation
Model Name	FMUModel_CTC060_mech
Platforms	win64
Continuous States	0
Event Indicators	0
Variables	21
Generation Date	2023-12-11T13:53:05Z
Generation Tool	Ansys Twin Builder
Description	

Simulation

Solver	Variable-step
Step Size	1e-3
Relative Tolerance	0.0001
◉ Output Interval	0.002
○ Max. Samples	500
☐ Input	No input file selected
☐ Apply default start values	
☐ Log FMI calls	
☐ Debug Logging	

Ports



C:\Users\EXAD\Desktop\FMUModel_CTC060_thermal.fmu - FMPy

File Tools Help

10000.0 Co-Simulation

filter variables

Name	Start	Unit	Plot	Description
CopperPower	0		☐	
FrictionPower	0		☐	
T2_Temperature	0		☑	
T5_Temperature	0		☑	
TracesPower	0		☐	
TransistorPower	0		☐	
Windings_Temperature	0		☑	
T_ambient	0		☐	

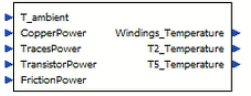
Model Info

FMI Version	2.0
FMI Type	Co-Simulation
Model Name	FMUModel_CTC060_thermal
Platforms	win64
Continuous States	0
Event Indicators	0
Variables	8
Generation Date	2023-12-11T13:54:39Z
Generation Tool	Ansys Twin Builder
Description	

Simulation

Solver	Variable-step
Step Size	1e-3
Relative Tolerance	0.0001
◉ Output Interval	10
○ Max. Samples	500
☑ Input	No input file selected
☐ Apply default start values	
☑ Log FMI calls	
☑ Debug Logging	

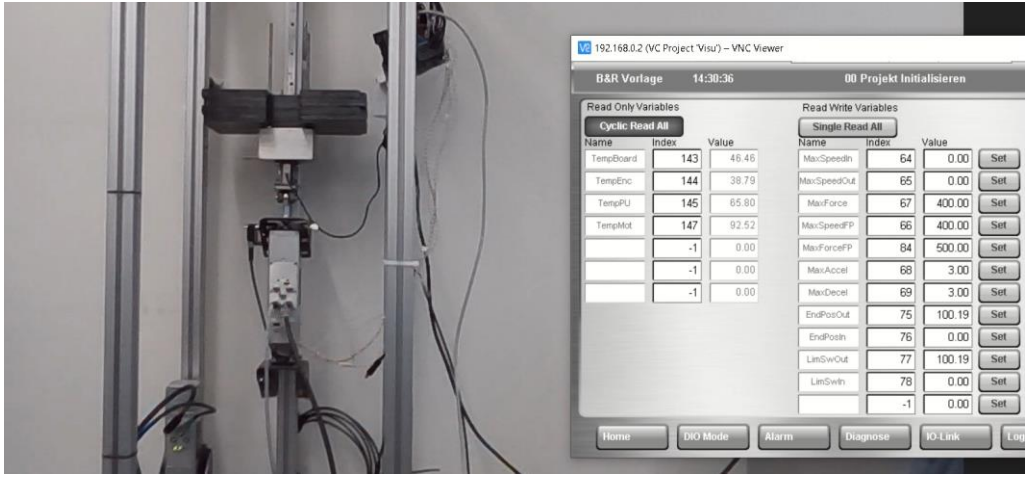
Ports



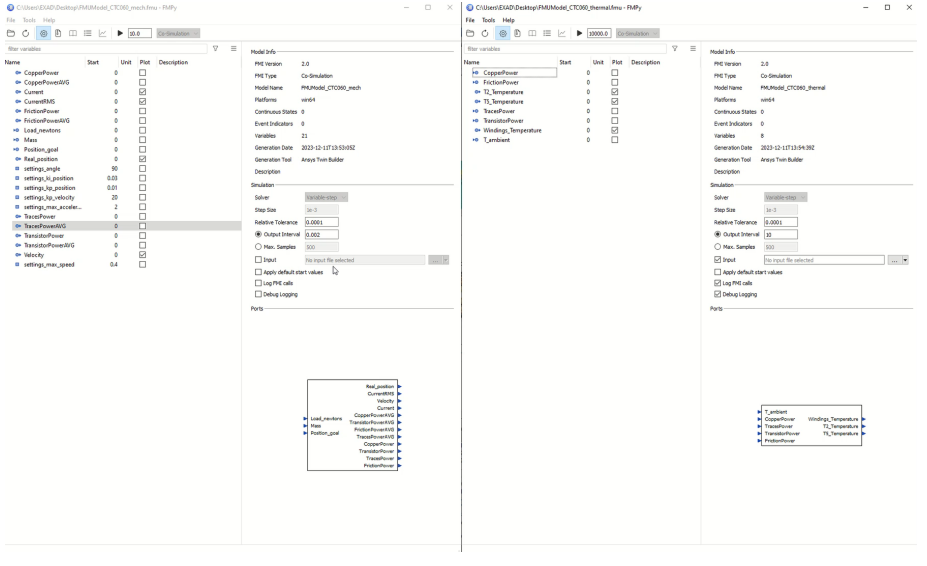
Operator / Virtual Assistant

1000 times quicker than experiment

2.8 hours (10’000 s)



in 10 s



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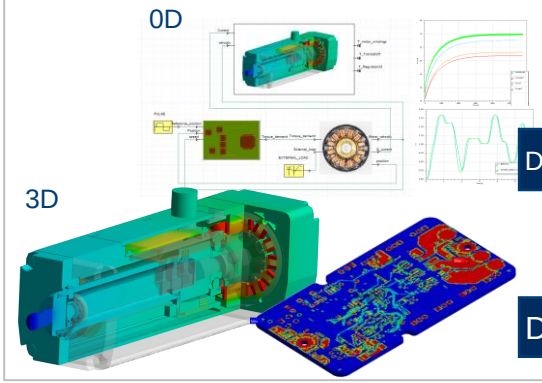
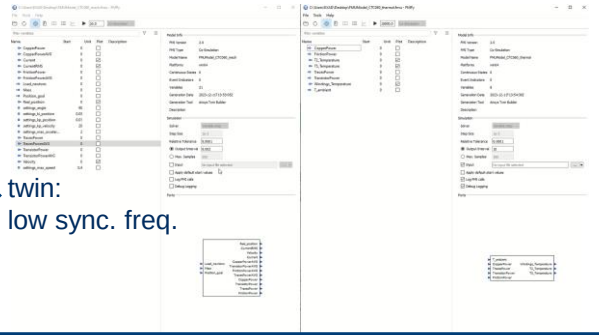
R&D / Virtual Prototyping



Deployment

Operator / Virtual Assistant



twin:
low sync. freq.

Deployment

Product / Virtual Sensors

twin:
high sync. freq.

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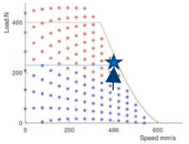
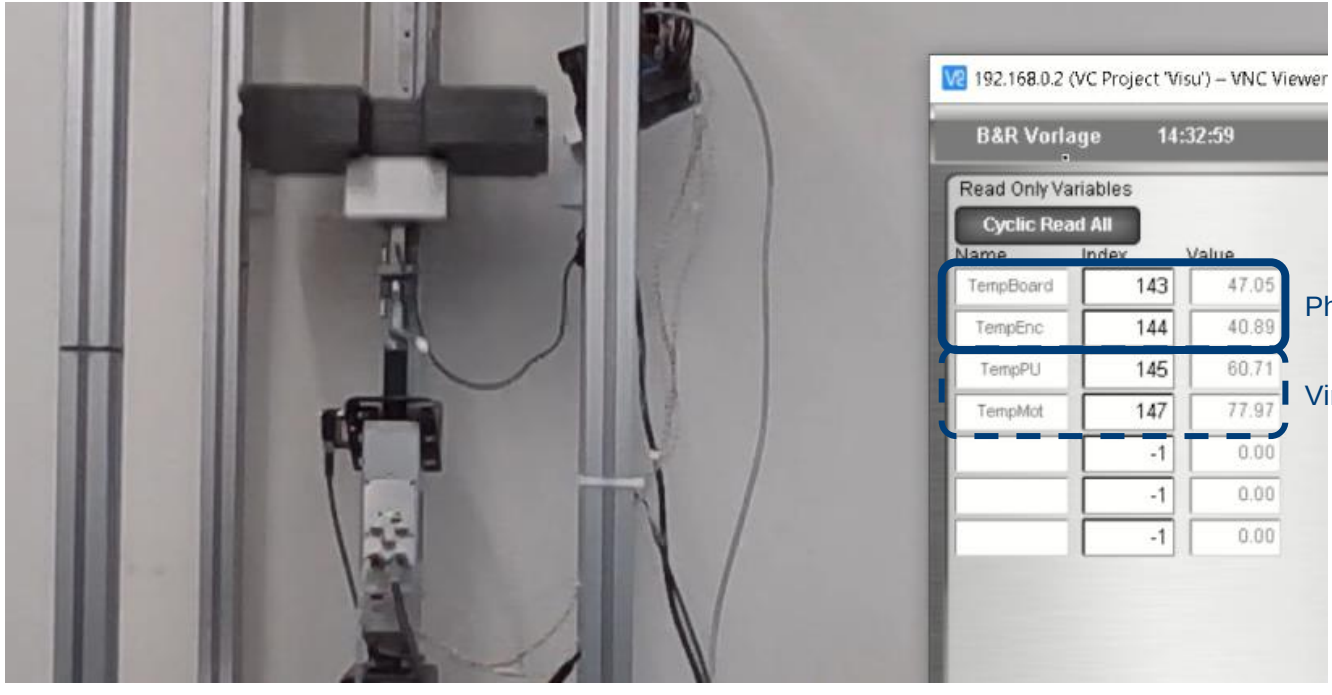


- **Smart Monitoring** without extensive calibration

Product / Virtual Sensors

Embedded model-based control

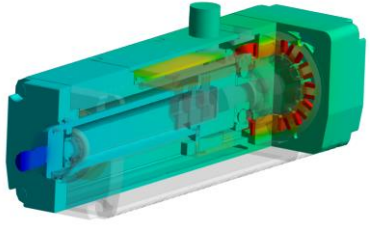
Virtual sensors temperatures based on current and speed (heat generation) readily available in the controler:



Product / Virtual Sensors

Embedded model-based control

MORiA State Space ABC matrices (reduced first order differential equations) :



$$\dot{x} = Ax + Bu$$
$$y = Cx$$

Heat Generation
Convection
Radiation
Conduction

Temperature outputs

Integration of Matrices and integration schemes to build virtual sensors directly within the embedded software:

```
//x = A*(pre(x)+Bu)

//x = pre(x)+Bu
for (unsigned int i = 0; i < THERMAL_ORDER; i++){
    for (unsigned int k = 0; k < THERMAL_INPUTS; k++){
        x[i] = x[i] + B_retrograde[i][k] * u[k];
    }
}

//x= Ax
for (unsigned int i = 0; i < THERMAL_ORDER; i++){
    x[i] = A_retrograde[i] * x[i];
}

//y = Cx + tamb
for(unsigned int i=0; i < THERMAL_OUTPUTS; i++){
    y[i] = t_amb;
    for(unsigned int j=0; j< THERMAL_ORDER; j++){
        y[i] += C[i][j] * x[j];
    }
}
```

```
const float A_retrograde[THERMAL_ORDER] = {0.340963,0.35085,0.356284,0.360858,0.414764,0.42748,0.469938,0.504959,0.537381,0.597567,0.649643,0.6735,0.735542,0.875536,0.919039,
0.929164,0.940543,0.957845,0.972243,0.976818,0.9809,0.987142,0.991446,0.99253,0.993942,0.994766,0.996727,0.997076,0.997602,0.997701,0.998065,0.998702,0.998915,0.999042,0.
999127,0.999281,0.999296,0.999495,0.999567,0.99961,0.999724,0.999749,0.999759,0.999791,0.999786,0.999832,0.999837,0.999849,0.999844,0.999864,0.999877,0.999889,0.999896,0.
999908,0.999912,0.999913,0.999919,0.999922,1,0.999927,0.99993,0.999935,0.999939,0.999943,0.999945,0.999947,0.999998,0.999951,0.999952,0.999995,0.999955,0.999994,0.999968,0.
999957,0.999962,0.999959,0.999956,0.99996,0.999963,0.999958,0.999991,0.999976,0.999989,0.999989,0.999978,0.999987,0.999981,0.999986,0.999985,0.999985,0.999983,0.999983,0.
999983,0.99985,0.999984,0.999984,0.999984,0.999984,0.999984};
const float B_retrograde[THERMAL_ORDER][THERMAL_INPUTS] = {{-0.00170427,-0.0696041,-0.00655533,-0.0127801,-0.00107458,3.92927e-05,-0.00553072,0.000532159,0.0332233,-0.
00919715},{0.0015286,-0.0128277,-0.000390447,-0.000455027,-0.000903777,6.87653e-05,-0.000859788,-0.000144094,0.00365968,-0.000243905},{-0.00632998,-0.20361,0.0217287,0.
00741227,0.00198461,-3.57021e-05,-0.00182886,0.0034606,-0.135145,-0.00261696},{-0.0050142,0.211799,-0.00664578,-0.0309799,-0.0355928,-0.000216886,-0.0228078,0.012113,0.
00521213,0.00749015},{0.0591645,-0.231082,0.196849,0.141393,0.17821,0.00179876,0.0256514,0.0968442,-0.110444,0.0617807},{-0.00427679,-0.000148306,0.00402042,-0.000681495,0.
0002403,-4.28695e-05,0.00200998,-0.00273225,-0.00473295,0.00165128},{0.00801128,-0.0355375,-0.0112855,0.0290433,-0.0348015,-0.000164158,0.00605357,-0.00383898,-0.0269264,0.
0247134},{0.0253071,0.038788,0.0487556,-0.0925361,0.0924698,0.000374301,0.00233872,0.00475895,0.0946562,-0.00581179},{-0.0422512,0.0403611,0.0137072,0.403617,0.0489468,-0.
0018811,0.0732132,-0.0319565,0.156773,0.127013},{0.110043,-2.45506,-0.132763,-0.0811271,2.90196,-0.00132523,0.0199658,-0.0788839,0.133879,0.089261},{0.0414886,-0.594057,-0.
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00484016,-0.42123,0.0324297,-0.233892,0.522285},{-1.20465,0.00551496,0.452037,0.150622,4.766,-0.00541264,0.751705,-0.325534,0.272007,-0.0790985},{-0.0798779,5.18966,-0.
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0502,-5.6668},{-5.21891,-60.4849,-0.251066,-0.933875,3.26402,0.0987866,0.937346,-1.18696,-2.98292,-1.39638},{-6.7367,-26.8229,0.521225,0.885444,6.02937,-0.0254389,0.343829,-0.
062972,-7.03645,-0.8781},{-0.00647516,1.8642,0.00752714,-0.00749486,0.109917,0.00166147,-0.0129732,-0.0162717,-0.035884,-0.0690104},{0.323766,-2.34636,0.0818464,-0.366994,-1.
13195,-0.0257084,0.226615,-0.347331,0.0525528,-0.204346},{0.00136702,-2.12811,0.0408818,0.0146556,0.0655874,-0.00239074,0.0317757,-0.00498314,0.103543,0.0358692},{0.296602,-4.
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866221},{0.230184,-1.42544,0.167195,-0.275822,0.772107,0.0133369,-0.378146,0.0206608,-0.295199,-1.44086},{0.216817,-0.164483,0.0282966,0.468958,-0.374137,0.0350787,-0.821865,
```
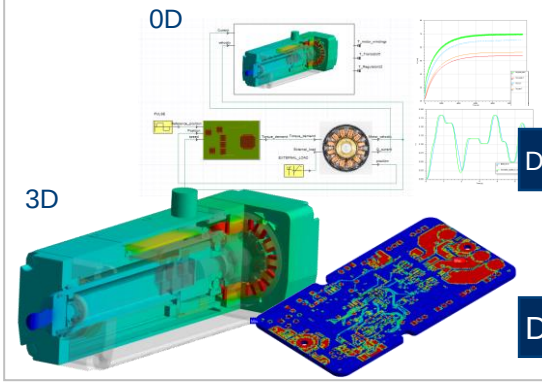
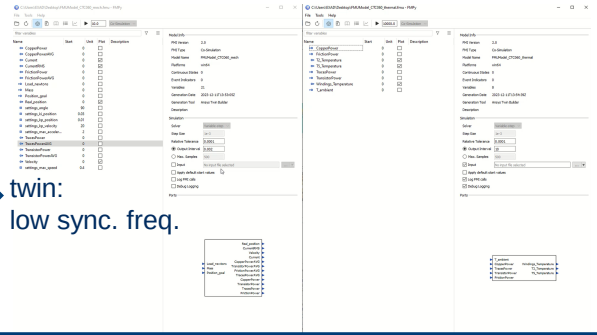

Cyltronic & CADFEM All-in-One

R&D / Virtual Prototyping



Deployment

Operator / Virtual Assistant



twin:
low sync. freq.

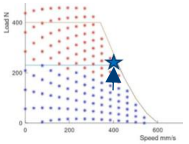
Deployment

Product / Virtual Sensors

twin:
high sync. freq.

- Robust Design Optimization
- **Shorter Development time**
- **Better coverage of test cases**

- **Customer Specific Planing**
- Duty cycle optimization / **Thermal Uprating**
- *Predictive Maintenance*



- **Smart Monitoring**
  without extensive calibration

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Conclusions

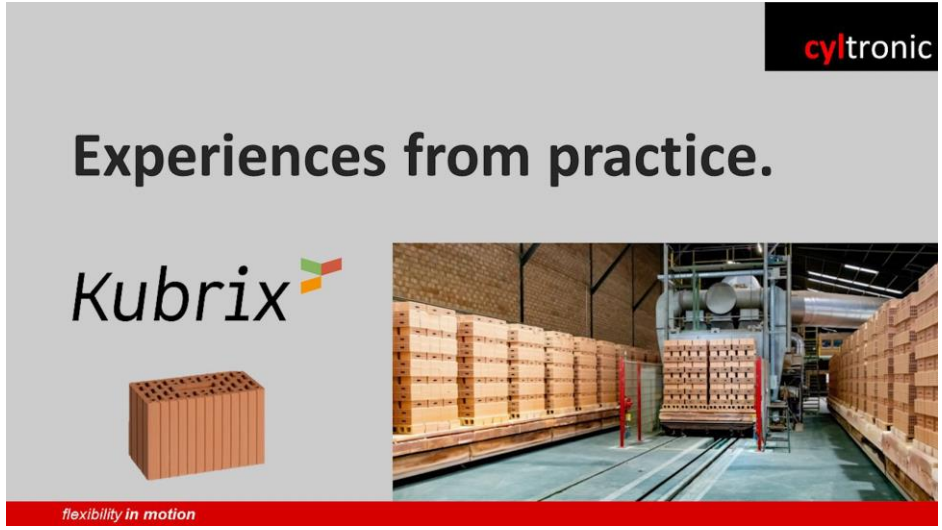
Results for Cyltronic

With our new simulation tools we can:

- **Expand the operational range of our products**
- **Make the dimensioning of the system easier for our customers**
- **Make precise forecasts for the performance at different ambient temperatures**

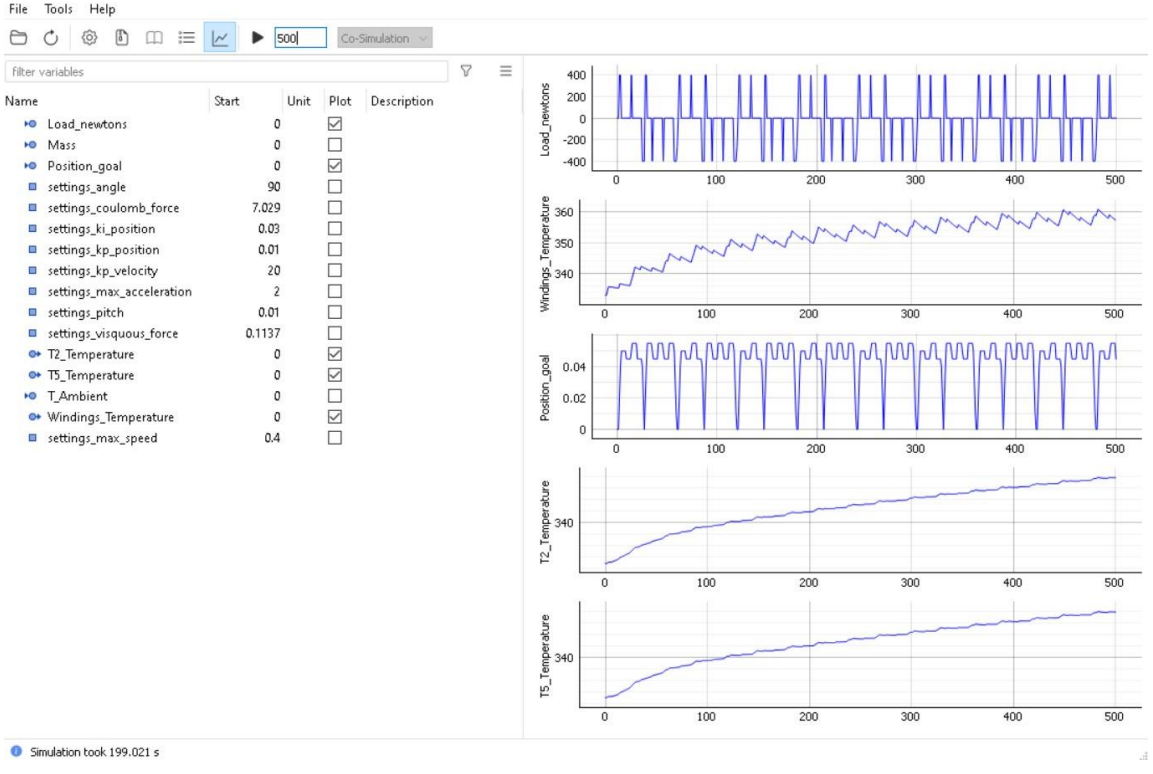
And in the future:

- **Offer digital twins for our customers**
- **Increase possibilities for predictive maintenance**



Conclusions

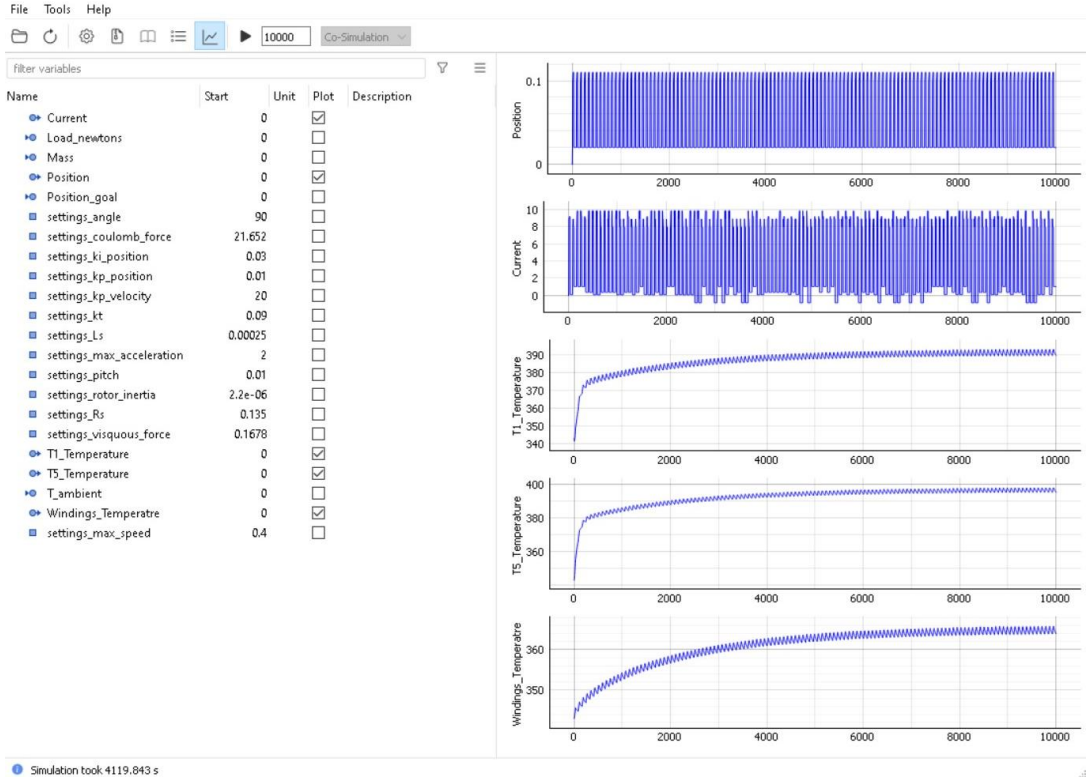
Cyltronic success stories using new simulation tools



Cyltronics CTC-060 proving its capability of running a complex customers profile at 60°C Ambient Temperature

Conclusions

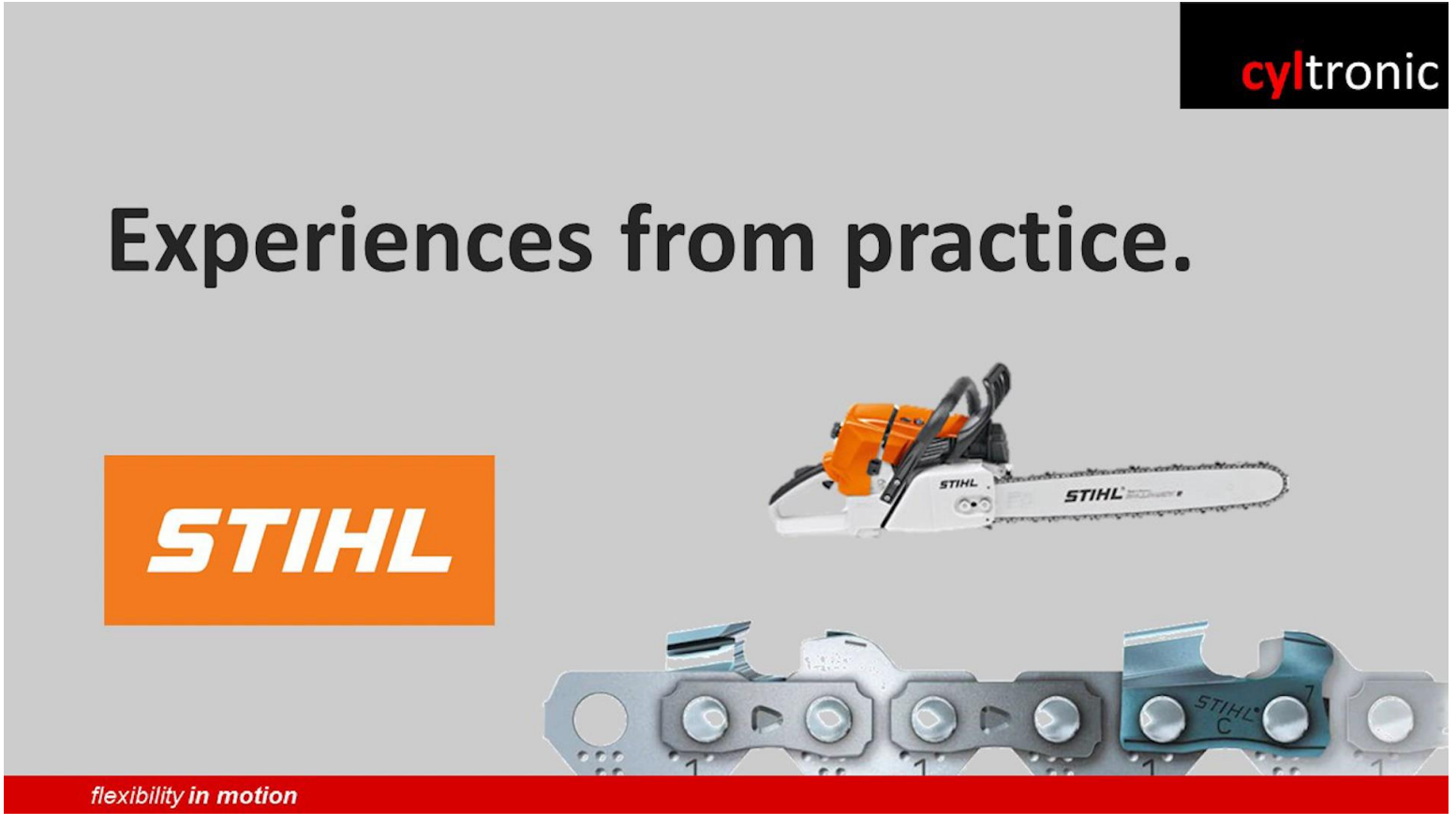
Cyltronic success stories using new simulation tools



Cyltronics new CTC-080 Press-Fitting with 500N at 70°C Ambient Temperature

Conclusions

Cyltronic Drives running in real lifes harsh conditions



Next Steps

Cyltronic is not a product – it's a product world

- **Faster development**
- **Reliable data for customers already in development stage**
- **Easy integration of Cyltronic products into your machines!**

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