

International forum on Digital Twins Design & Operation (DTD&O)

A digital twin methodology for predictive maintenance of reciprocating compressor for gas transport

Chetra MANG, Florent BRISSAUD-DELORD, Gregory JARDON, Selma KHEBBACHE

- Overview of digital twin projects
- Industrial background
- Description of the reciprocating compressor for gas transport
- A proposed digital twin methodology for the predictive maintenance
- Data acquisition methodology
- Physical modeling methodology for the reciprocating compressor
- Results on physical modeling
- Conclusions and perspectives



Jumeaux
Numériques
des systèmes
Industriels

JNI3 project is part of JNI program, one of the most important flagship program on digital twin at IRT SystemX

Launch: September 2022

Duration: 4 years

Site: Moulon

JNI3 aims to develop and establish digital twins capable of monitoring how the state of health of industrial systems evolves. It focuses on the definition of digital twins capable of acquiring data in real time/delayed time, and processing it in order to assess the state of health of the industrial system. Furthermore, the digital twin must be able to predict and optimize how the lifetime of the physical system evolves, based on the different health indicators identified.

Objectives:

- Define relevant health indicators from data flows collected in real time/delayed time on the industrial asset
- Develop data selection methods to establish a health model
- Develop a digital twin capable of predicting early signs of equipment deterioration and offer preventive measures
- Based on the prognosis of the industrial system on the availability of maintenance teams and production needs, develop a data-based digital twin to optimize under uncertainty the maintenance of intelligent industrial systems

Industrial partner



Academic partners



TBD

Missions of GRTgaz

- Assure the gas transport continuity
- Involve in renewable gas development and energy transition

Main industrial assets

- >32.500 km high pressure pipelines
- 26 compression stations
- >5.000 expansion and delivery posts
- ~4.800 sectioning and cutting posts
- >50 biomethane injection posts
- >10 reciprocating compressor posts



Characteristics

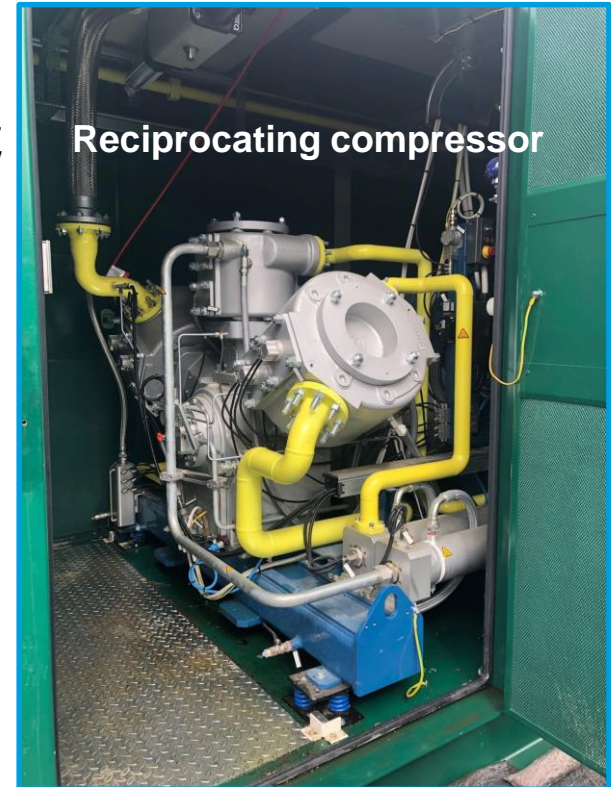
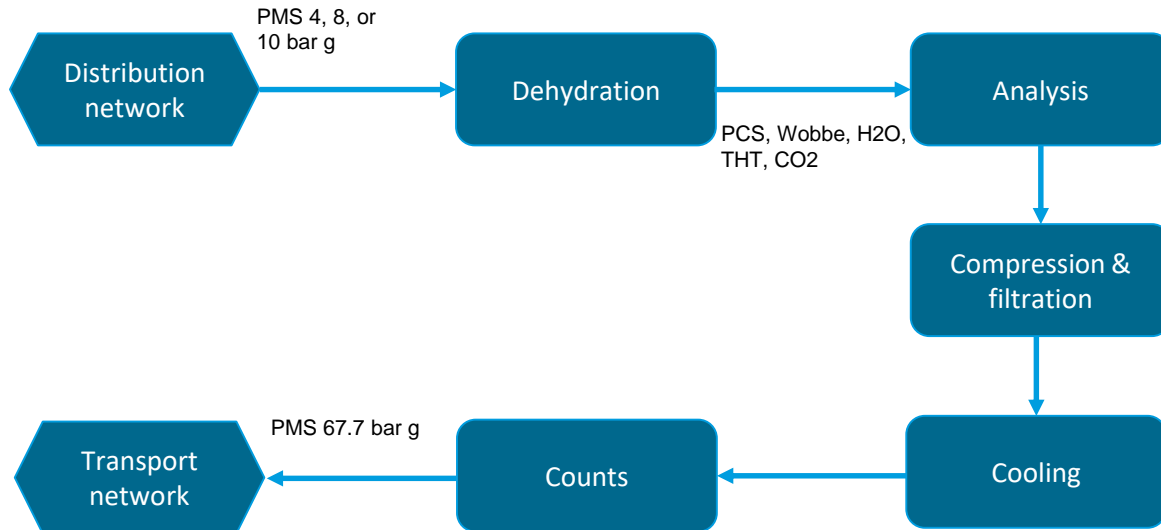
- Functionality : compress the gas (biomethane) of the distribution network to the transport network
- Three stage electro-compressing

→ ~10 machines in operation

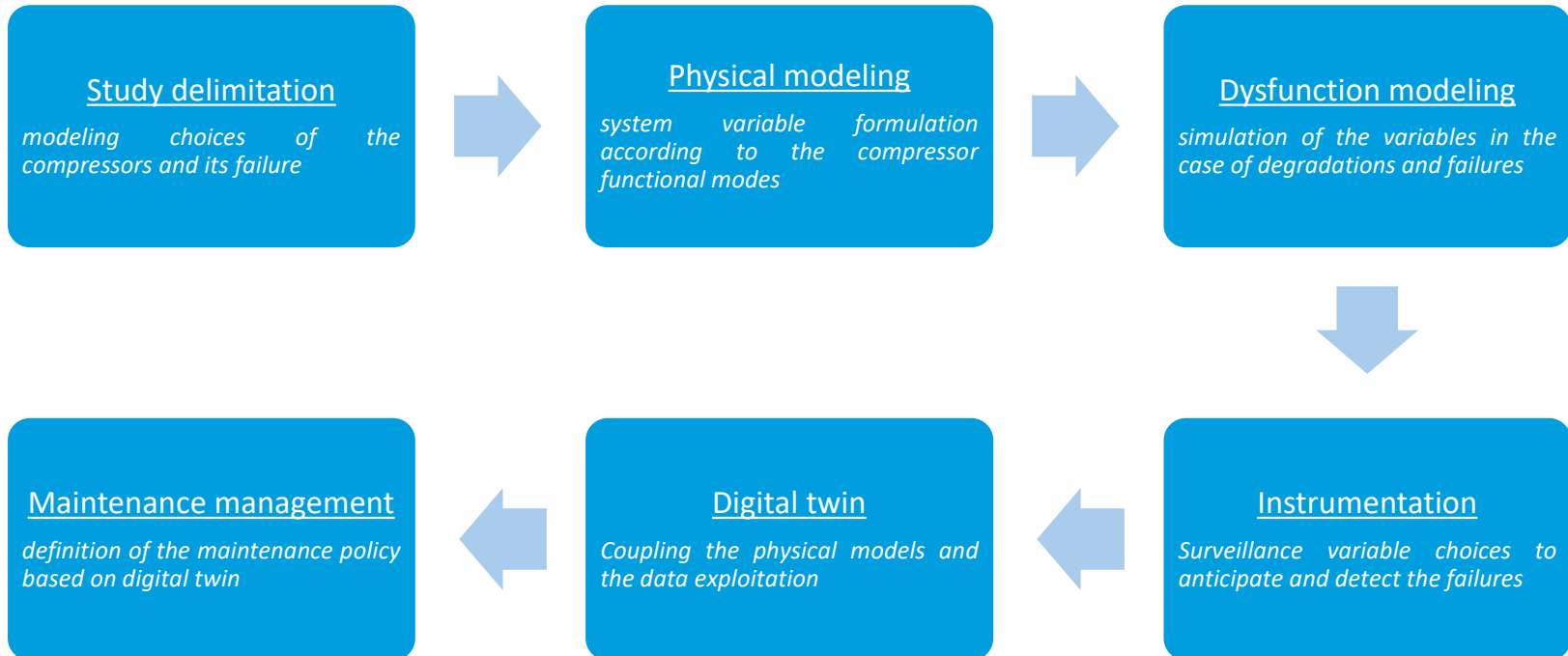
→ Seasonal request

Available data

- Corrective maintenance date
- Predictive maintenance date
- Surveillance measure (vibrations, velocity, temperatures, pressions, flow rate...)



Methodology



Data acquisition methodology

Human-machine interface control command

- Weak data retention
- Uniquely useful data for supervision



Data storage policy

- Data routing corresponding to its uses
- Retention duration and sampling period definition
- Cybersecurity rule application

IOT Laboratory

- Prototyping orientation
- Limited services and supports

SCADA

- Important data retention
- Data oriented network management and supervision



IOT Prod

- Data analysis orientation
- Implementation simplification & cost reduction

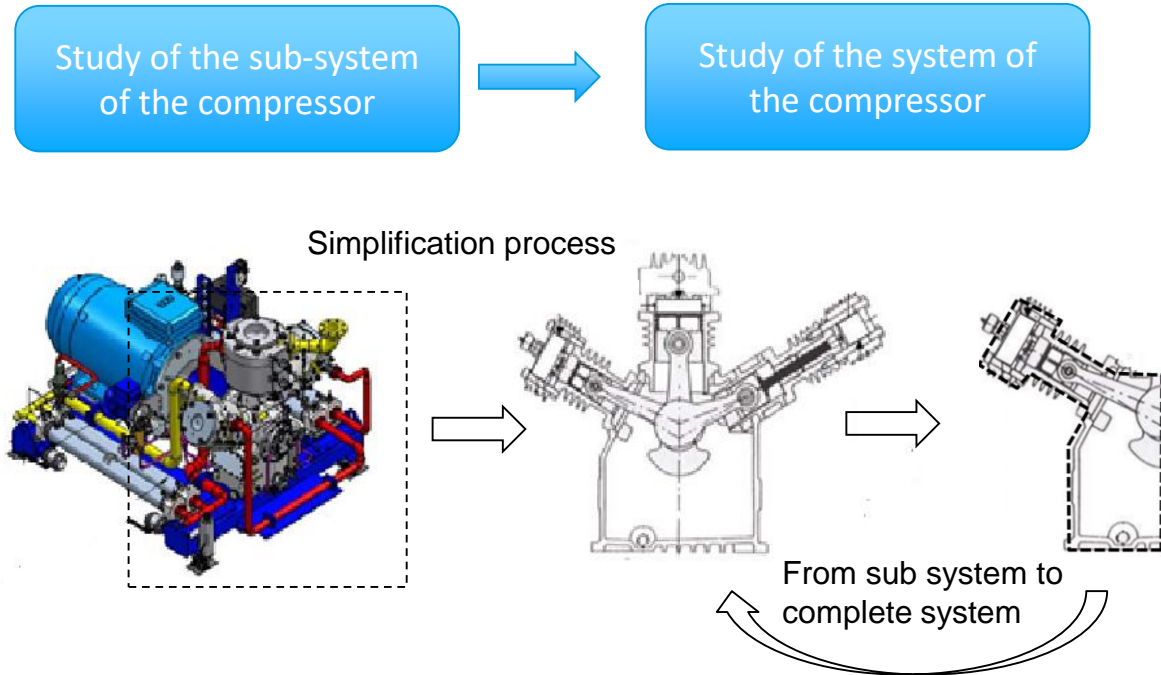
Digital Twin

IA Platform

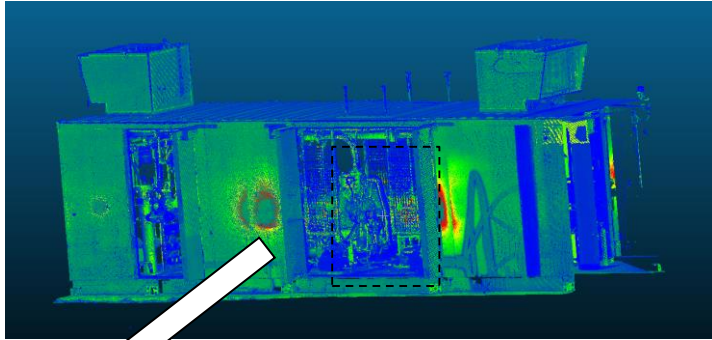
- Data preparation
- Machine learning
- Analysis

Modeling of the sub-system

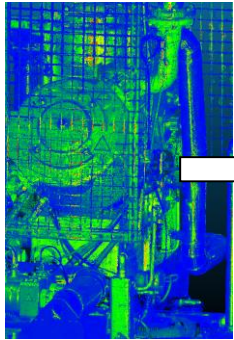
- Geometry and mesh
 - Scan of the compressor sub system by a digital camera
 - Cloud point image processing and compressor dimension computation
 - Build of a simplify geometry
 - Computational mesh
- Physical models
 - Dynamic modeling
 - Thermal modeling
- Physical model inputs
 - Material parameters
 - Physical parameters
 - Boundary conditions
- Verification and validation
 - Sensors (accelerometer, thermocouple)
 - Physical model calibration
 - Physical model validation



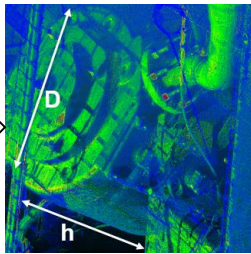
Physical modeling methodology : scan, geometry and mesh



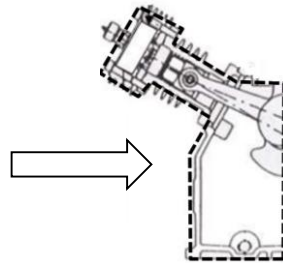
Scan and cloud point of the compressor



Zoom on a sub system

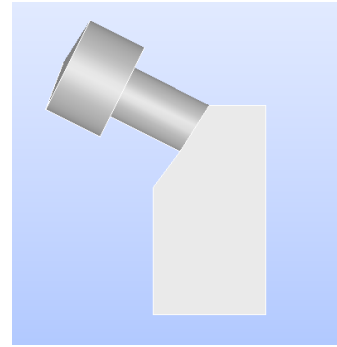


Measure of its dimension

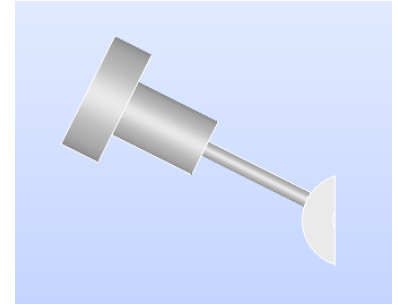


Reconstruction of the compressor dimension

Simplified geometry

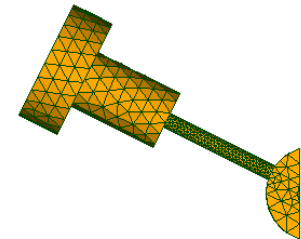
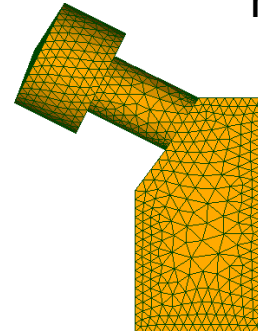


Compressor envelop



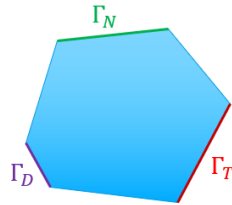
Piston system

Mesh



Physical modeling methodology : boundary conditions & input parameters (physical models and their inputs)

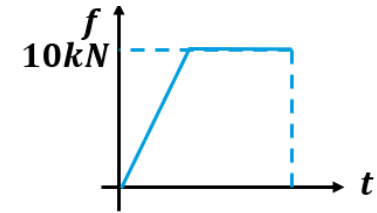
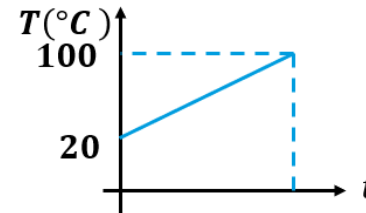
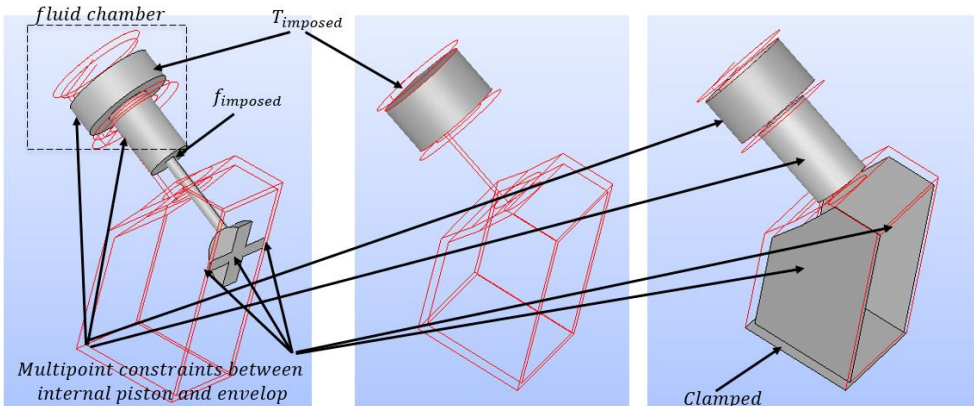
$$\left\{ \begin{array}{l} \rho \frac{\partial^2 \mathbf{u}}{\partial t^2} - \text{div}(\boldsymbol{\sigma}(\mathbf{u})) = \mathbf{f} \text{ dans } \Omega \\ \mathbf{u} = \mathbf{u}_0 \text{ sur } \Gamma_D \\ \boldsymbol{\sigma} \cdot \mathbf{n} = \mathbf{g} \text{ sur } \Gamma_N \\ \rho C \frac{\partial T}{\partial t} - \lambda \Delta T = s \text{ dans } \Omega \\ T = T_0 \text{ sur } \Gamma_T \\ \boldsymbol{\sigma}(\mathbf{u}) = C \boldsymbol{\varepsilon}(\mathbf{u}) \\ \boldsymbol{\varepsilon}(\mathbf{u}) = \boldsymbol{\varepsilon}^e(\mathbf{u}) + \boldsymbol{\varepsilon}^T(\mathbf{u}) \end{array} \right.$$



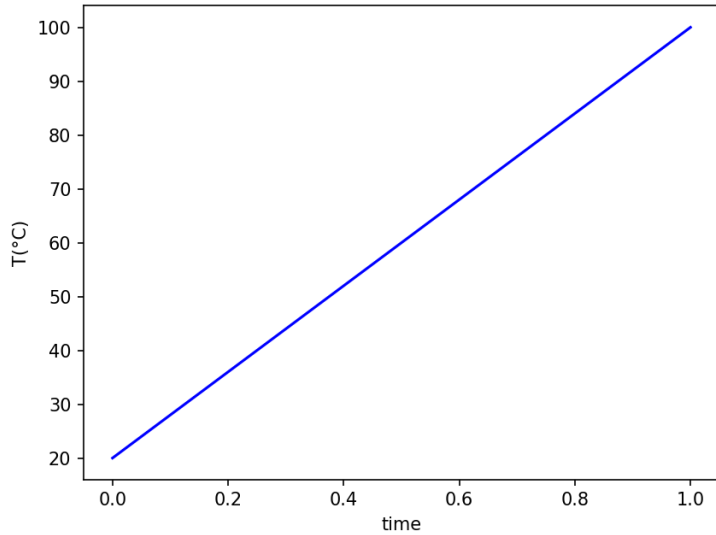
Steel	$E(MPa)$	ν	$\rho(g/mm^3)$
Parameters	200000	0.3	$7.85e^{-3}$
Steel	ρC_p	α	λ
Parameters	$0.1e^{-3}$	$10e^{-6}$	$1e^{-3}$

Physical hypothesis:

- Linear elastic problem
- Small strain hypothesis
- Multipoint constraints between the envelop and piston system

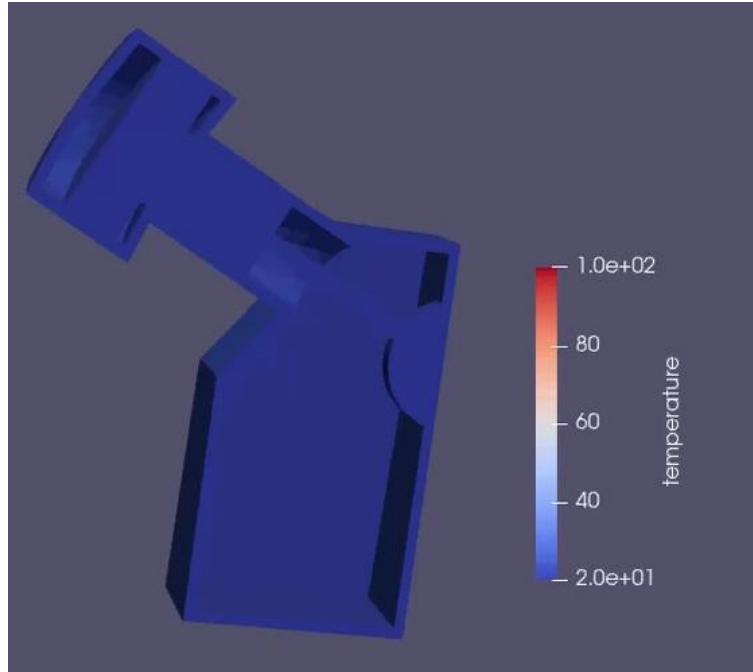


Temperature

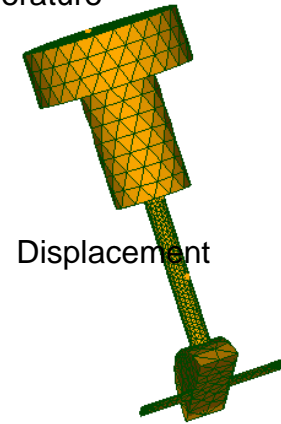


Temperature linearly evolves because of the linearly imposed temperature on the piston.

Video of temperature propagation

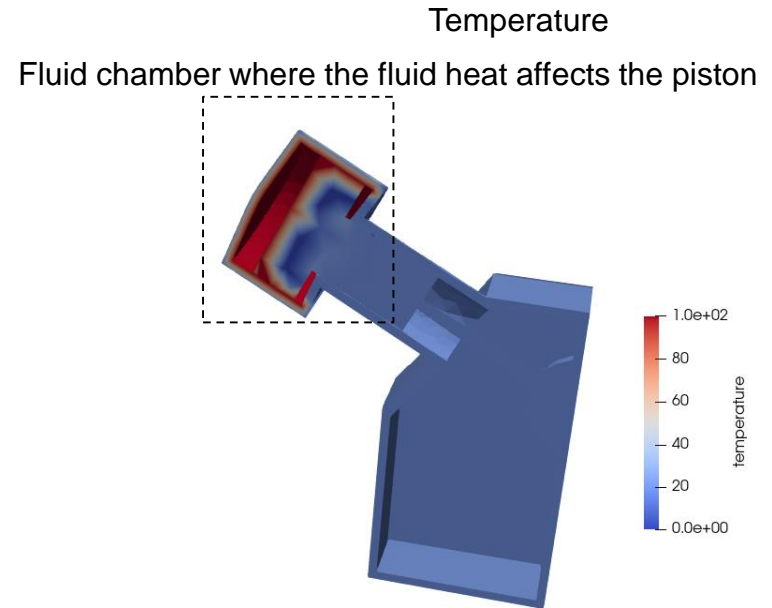


Temperature

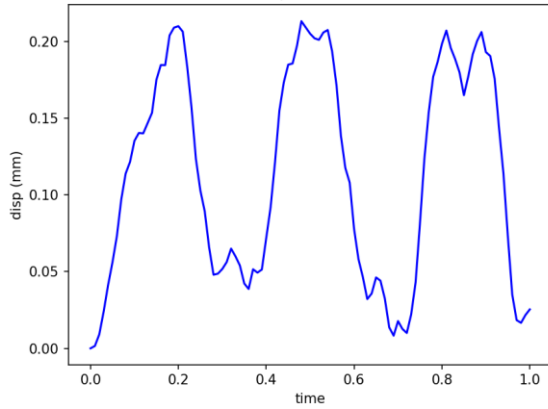


Displacement

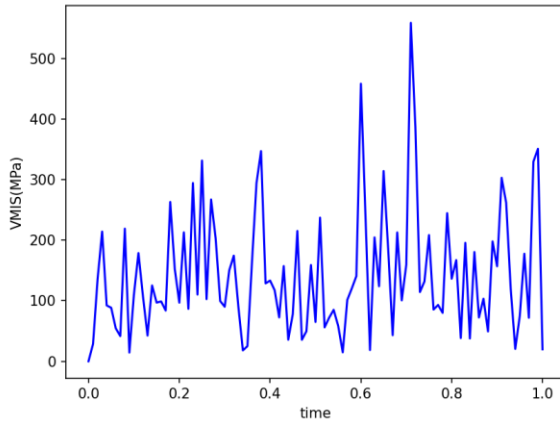
- Temperature increasingly propagates around the piston's head;
- Temperature propagation can be captured at any points on the piston as well as on its envelop;
- Temperature impacts on the structural deformation of the piston;
- Simulated temperature can be used as a complement to the temperature sensor (thermo-couple).



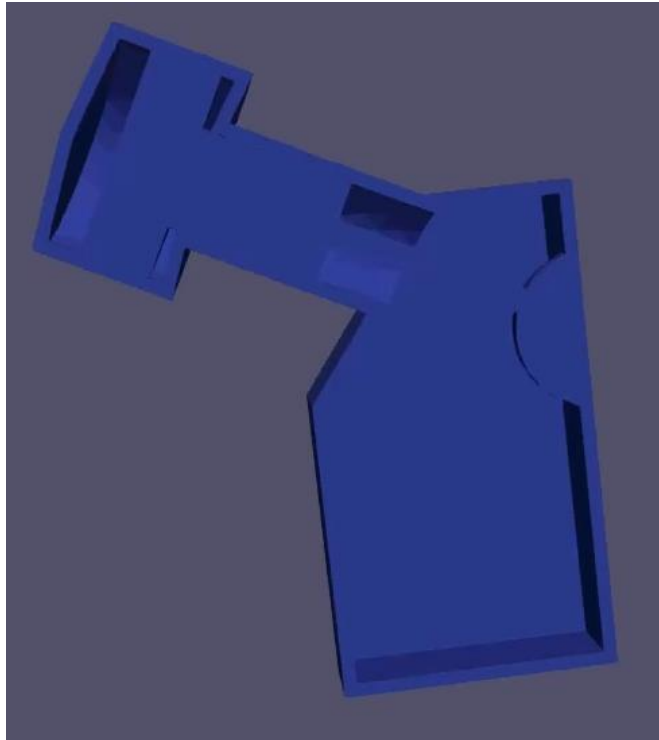
Displacement



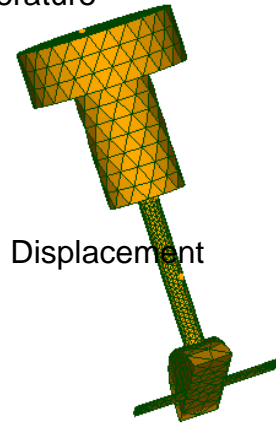
von Mises Stress



Video of structural deformation and stress evolution



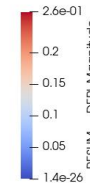
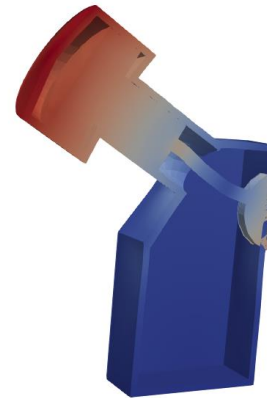
Temperature



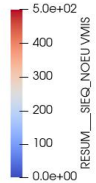
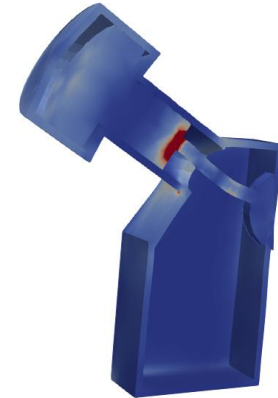
Displacement

- Displacement and stress can be captured anywhere in the piston system as well as its envelop;
- Structural deformation is large on the piston's bar;
- Highly concentrated stress can be observed at the connection between the piston and the bar;
- With dynamic modeling, the vibration of the piston system can be observed at a point on the piston's bar.

Displacement



Stress



Conclusions

- Reciprocating compressor for gas transport;
- proposed digital twin methodology for the predictive maintenance;
- Data acquisition strategy;
- Physical modeling methodology;
- Physical simulation results.

Perspectives

- Sensor implementation in the reciprocating compressor system;
- Physical model parameter calibration;
- Physical model validation;
- Coupling between physical simulation and sensor data;
- Digital twin implementation for predictive maintenance.