Structural Integration of Sensors / Actuators by Laser Beam Melting for Tailored Smart Components

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OUTLINE

- Introduction
- Material and methods
- Results
- Discussion and outlook

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Introduction

- Several applications seeking for tailored smart components through the integration of sensors and/or actuators, e.g.:
  - medical implants (detect loosening, improve long term stability,…)
  - lightweight structures (aerospace, automobile, railway, shipbuilding)
  - turbine machinery (improved process understanding & control)
  - machine tools (predictive maintenance, cyber physical systems)

→ DEMANDS: materially bonded integration of sensors/actuators within metallic mechanical structures for high sensitivity and conversion efficiency, min. consumption of energy, application in harsh environments

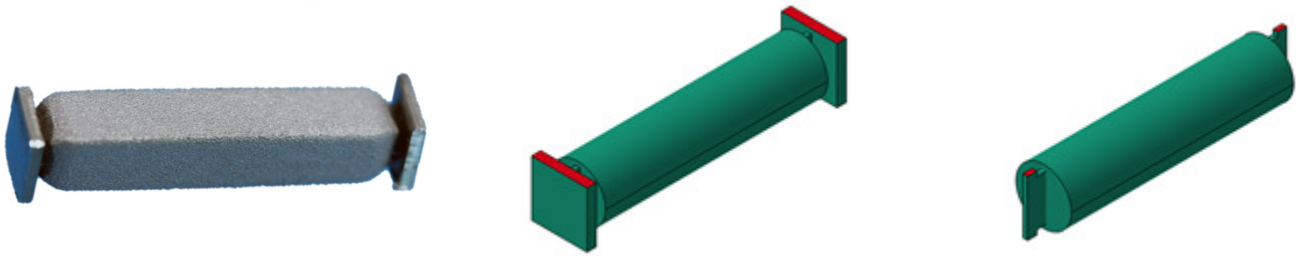
→ CHALLENGES: low temperature resistance of most smart materials (e.g. Curie and melting temperature, magnetic remanence)

sensor/actuator design & additive manufacturing

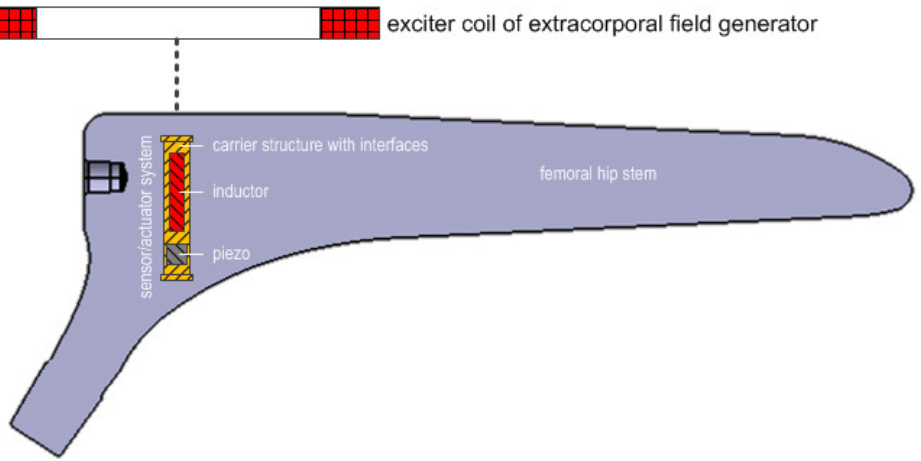
Material and methods

Actuator/sensor system design & energy transfer and control

- Self-developed sensor/actuator system with metallic carrier structure for piezo ceramic, inductor, connection and fixing technology and multi-material/multi-layer thermal protection system



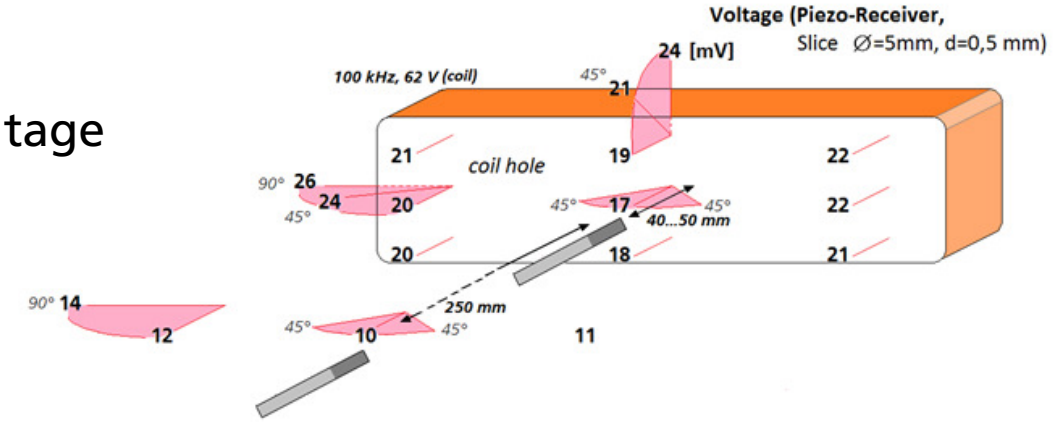
- Wireless far-field inductive energy transmission with a coil array
  - alternating and rotating magnetic fields
  - large aperture angle and range
  - transmitters and receivers can change their position and distance during operation



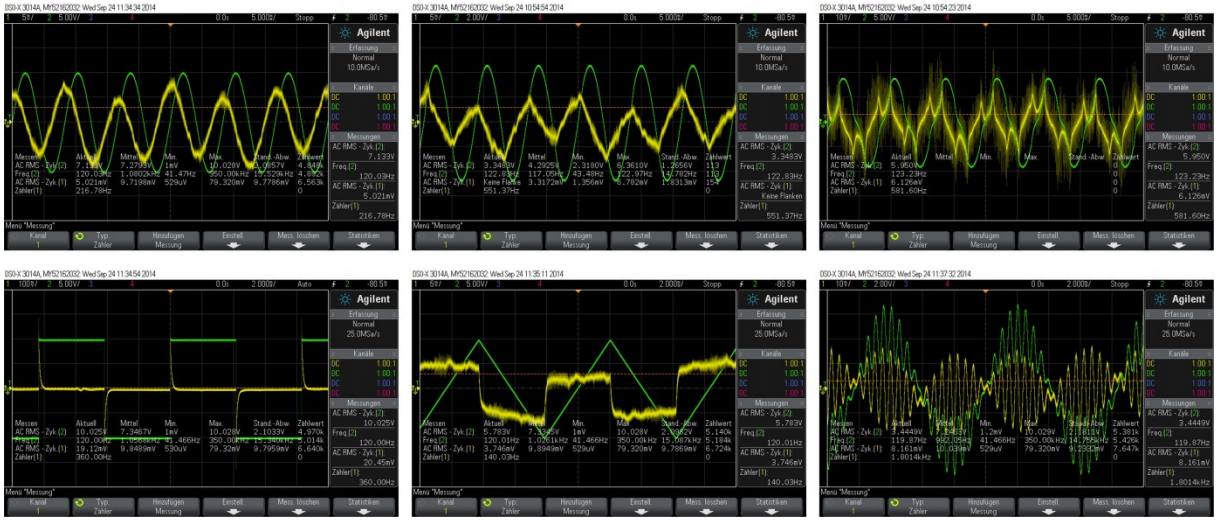
Material and methods

Characteristics of the energy & signal transfer and control

- Output voltage



- Tailorable input and output signals in actuator mode

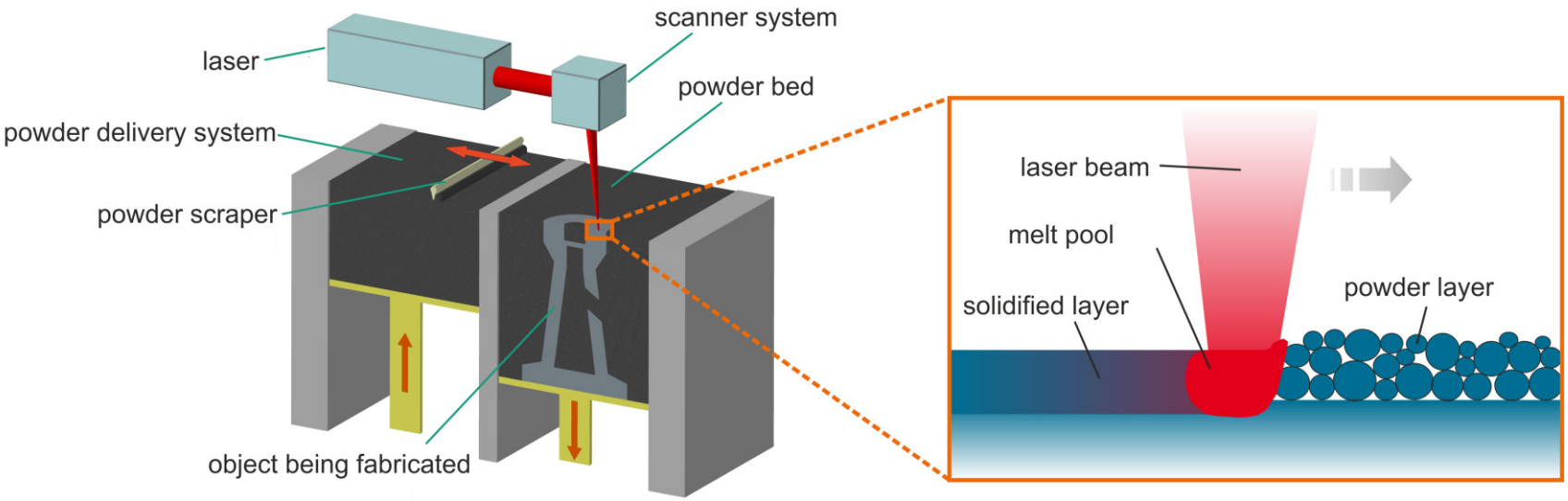


Green: input

Yellow: output

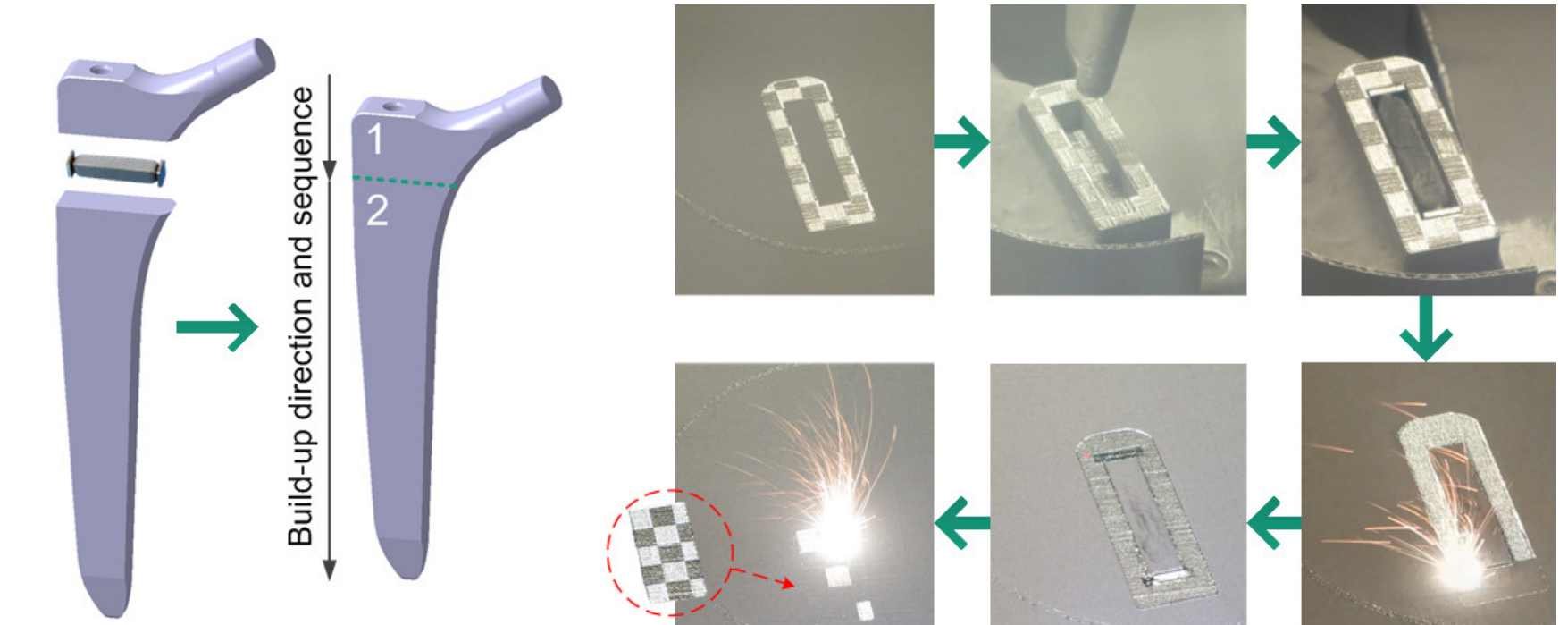
Material and methods
LBM embedding process

- Globally low and only selectively high heat input during laser beam melting (LBM) process



Material and methods
LBM embedding process

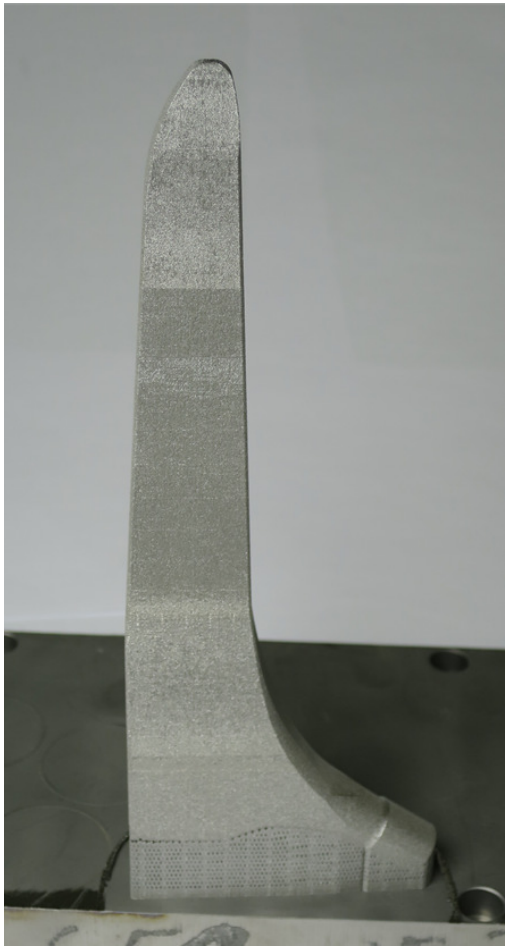
- LBM machine and material: Concept Laser M2 cusing, Ti-6Al-4V ELI
- Manufacturing sequence:

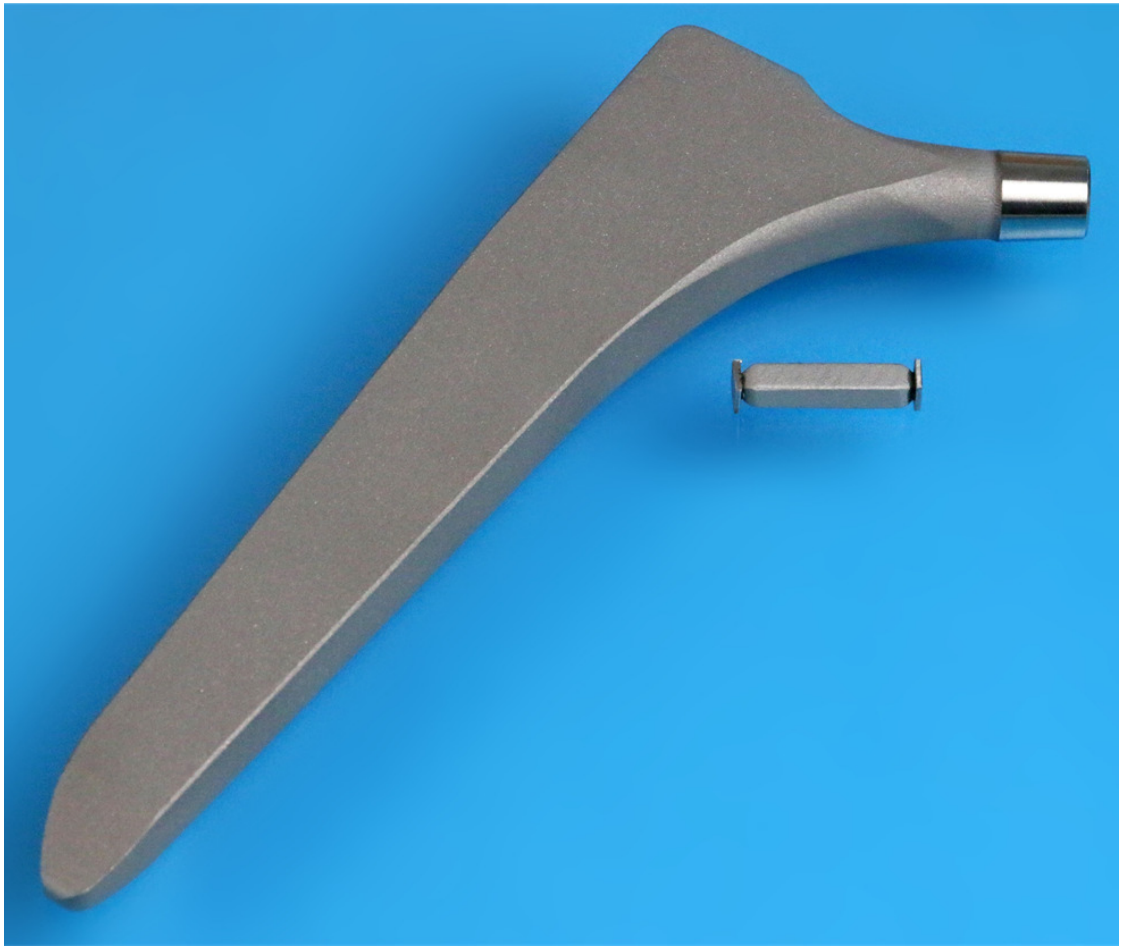


Hip stem design TRJ® by Aesculap AG (Germany)

Results

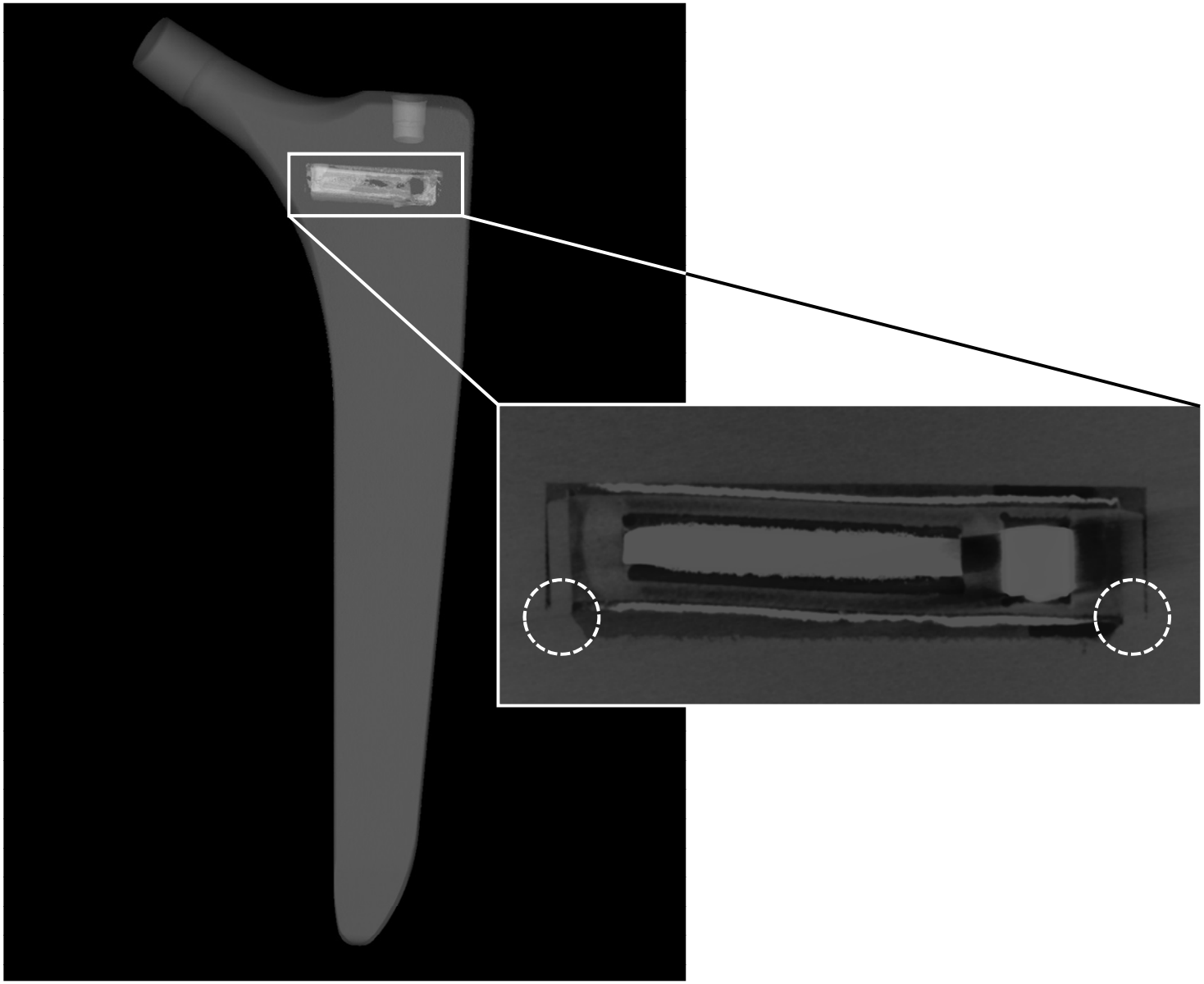
Hip stem as-built and machined





Results

CT scan

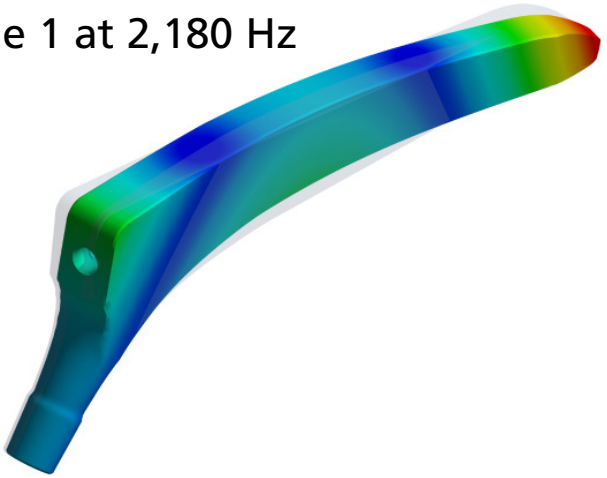


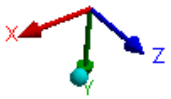
Results

Numerical modal analysis vs. 3D laser scanning measurements

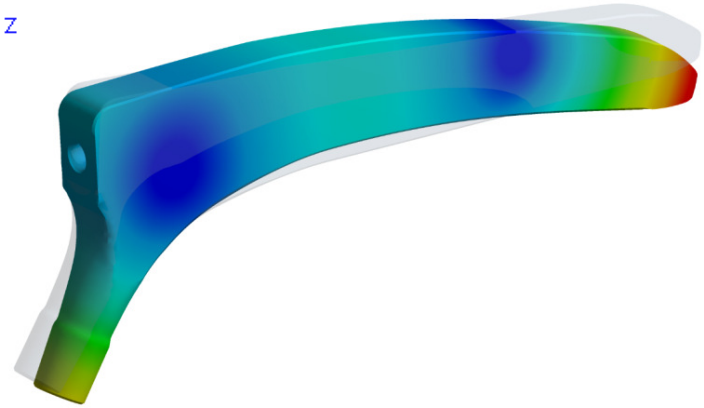
NUMERICAL

mode 1 at 2,180 Hz



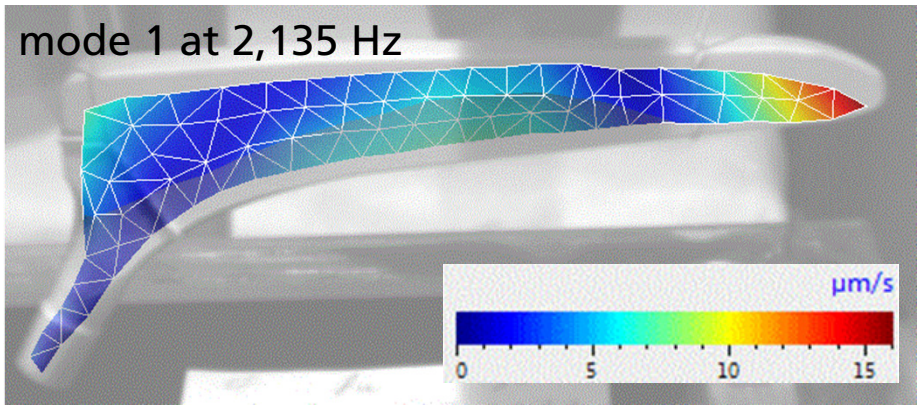


mode 2 at 3,488 Hz

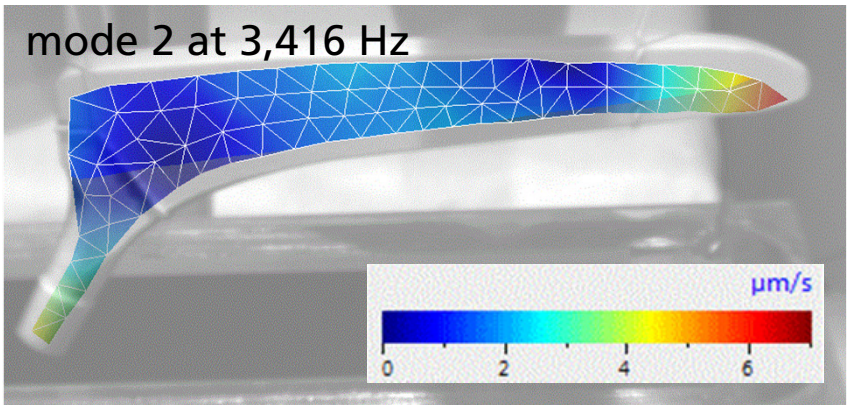


EXPERIMENTAL

mode 1 at 2,135 Hz



mode 2 at 3,416 Hz



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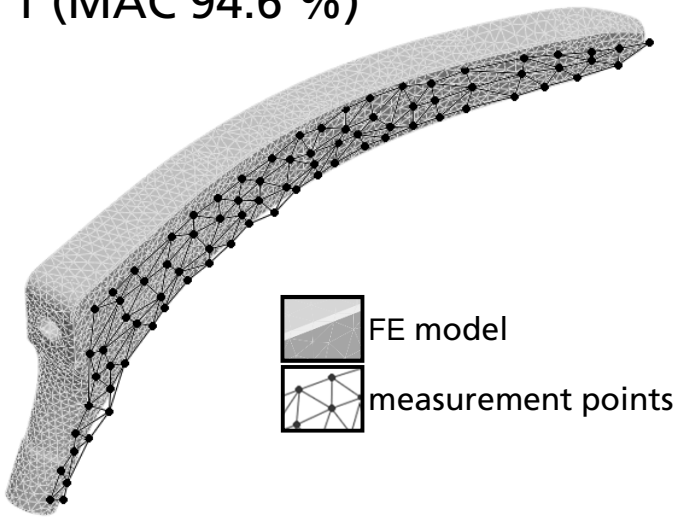
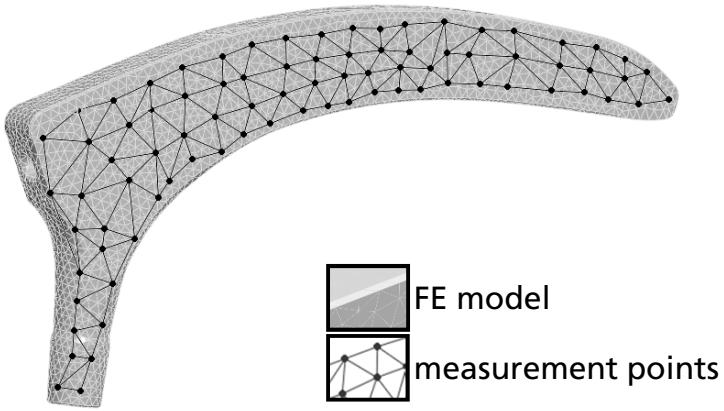
Results

Numerical modal analysis vs. 3D laser scanning measurements

mode 1 (MAC 94.6 %)



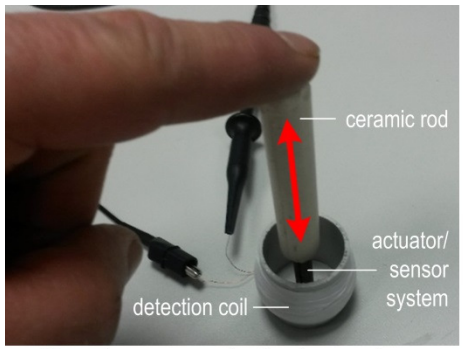
mode 2 (MAC 92.4 %)



- Quantitative comparison of simulation and experimental data with modal assurance criterion (MAC):
  - ➢ very good correlation between numerical and experimental obtained mode respectively bending shapes
  - ➢ embedding method and actuating function are working as designed and predicted

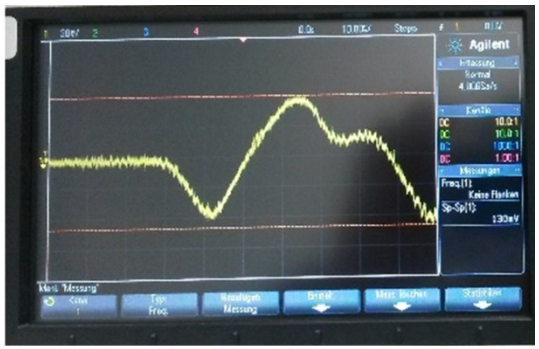
Results

Inverse sensory mode of the sensor/actuator system

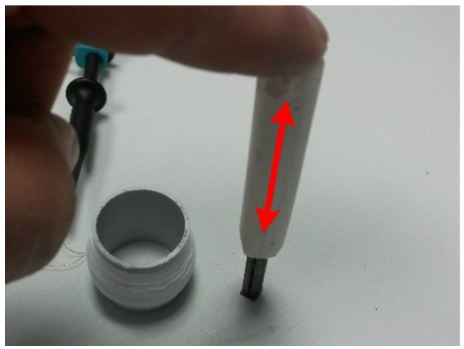


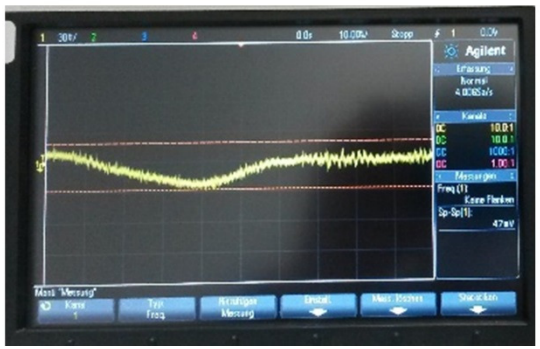
Tapping sensor/actuator system inside (top) and outside (bottom) a detection coil

306 mV
Response voltage with low resolution x-axis
47 mV



130 mV
Response voltage with high resolution x-axis
168 mV





→ Energy self-sufficient sensor system

→ Combining two ore more systems in one component

➢ system changes are measurable (e.g. for structural health monitoring)

Discussion and outlook

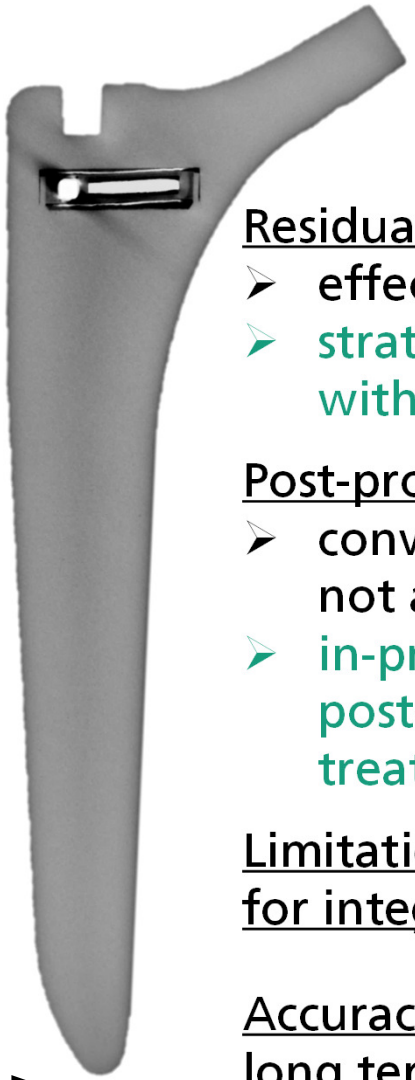
Key parameters and inter-dependencies for tailoring functionality:

Component:
- functional requirements
- suitable s/a principle
- design, dimension, material

installation site & positioning

Sensor/actuator system:
- design, performance, type
- protective layers, materials
- mechanical interfaces

External parameters:
- LBM parameters
- Energy & signal transmission



Challenges and tasks for future works:

Residual Powder:
- effect of loose powder
- strategies for embedding without powder residues

Post-process treatments:
- conventional heat treatment not applicable
- in-process heat or selective post-process mechanical treatment

Limitations in freedom of design for integration of sensor/actuat.

Accuracy, reproducibility and long term stability

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THERANOSTIC IMPLANTS

Parts of this work were supported within the Fraunhofer Lighthouse Project “Theranostic Implants”.

Patents are pending on the sensor/actuator system and the embedding process. [WO17054799; WO17036454]

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