MECSPE

TECNOLOGIE PER L'INNOVAZIONE - INDUSTRIE 4.0

23-25 NOVEMBRE 2021

BOLOGNA FIERE

Additive manufacturing e tecnologie Cyber-physical per la MECcatronica del futuro

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA
CENTRO INTERDIPARTIMENTALE DI RICERCA INDUSTRIALE MECCANICA AVANZATA E MATERIALI

UNIMORE UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA
Centro Interdipartimentale per la Ricerca Applicata e i Servizi nel Settore della Meccanica Avanzata e della Motoristica INTERMECH

romagnatech INNOVATION VALUE

Progetto cofinanziato dalla Regione Emilia-Romagna (POR - FESR 2014 - 2020)

POR FESR EMILIA-ROMAGNA 2014/2020

UNIONE EUROPEA Fondo europeo di sviluppo regionale

RegioneEmilia-Romagna

Laboratories and innovation centers:

Project leader:

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CENTRO INTERDIPARTIMENTALE
DI RICERCA INDUSTRIALE MECCANICA AVANZATA
E MATERIALI

Partners:

UNIMORE
UNIVERSITÀ DEGLI STUDI DI
MODENA E REGGIO EMILIA

Centro Interdipartimentale per
la Ricerca Applicata e i Servizi nel Settore
della Meccanica Avanzata
e della Motoristica INTERMECH

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INNOVATION VALUE

Industrial partners:

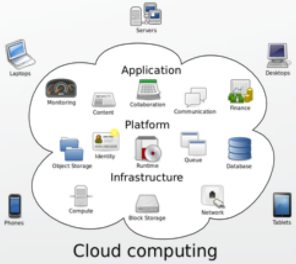
G.D
a coesia company

MARCHESINI
GROUP

Premise

Industry 4.0 leads to innovation:

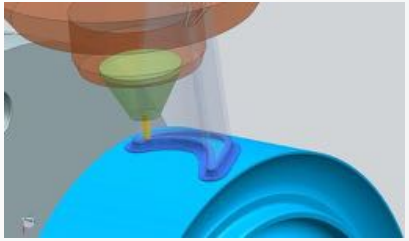
- ***above* mechatronics**
  - High levels of the industrial automation pyramid
  - IoT / Big data / Cloud / AI for the optimized process management
- ***beside* mechatronics**
  - Digital Twin
    - Functional design
    - Virtual Training
  - Predictive Maintenance



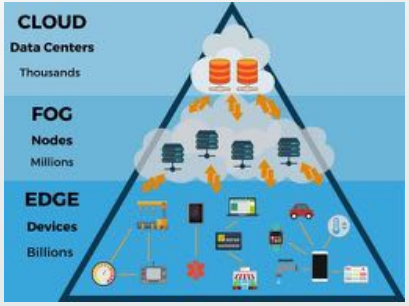
Project Goal

To develop innovative solutions for mechatronics:

- **Additive manufacturing** for innovative and customized mechanisms and actuators, leading to:
  - minimal material and energy consumption
  - sustainable production of small batches



- **Edge-computing-based Cyber-physical technologies** to enable the control algorithms for the proposed innovative structures



High-performance nonlinear mechanisms for automatic machines

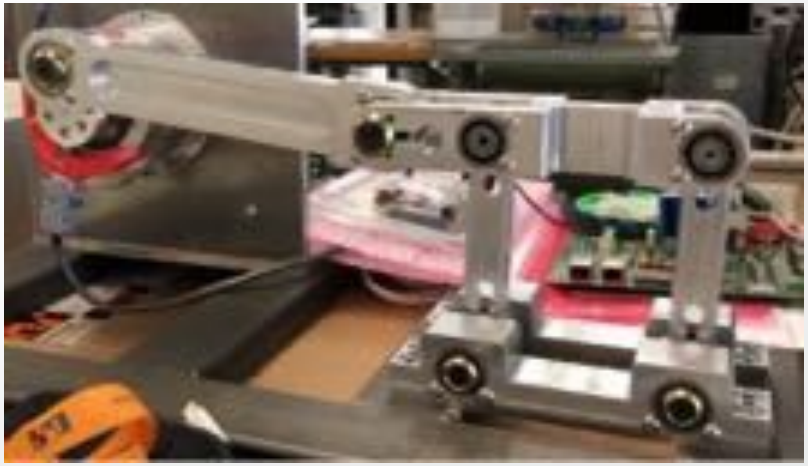
Involved research teams:

- Structural design: team of Prof. Rocco Vertechy (UNIBO - DIN)
- Control design: team of Prof. Andrea Tilli, ACTEMA (UNIBO - DEI)

Progetto cofinanziato dalla Regione Emilia-Romagna (POR - FESR 2014 - 2020)

Servomechanisms for automatic machines

- **Repetitive tasks**
- Mechanisms subject to predominantly **inertial loads**

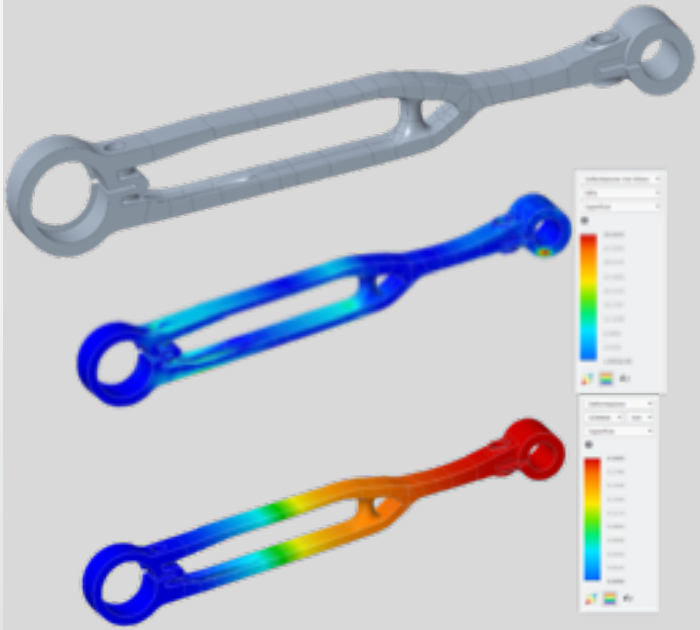


ACMEC Objectives:

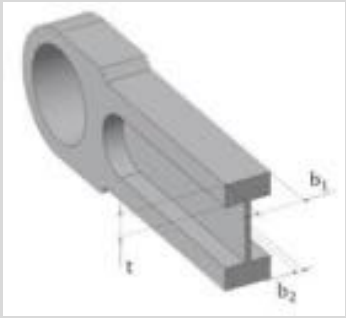
- Optimization of the mechanical structure for **motor torque and vibration reduction**
- **Accurate tracking** through internal model and repetitive control.

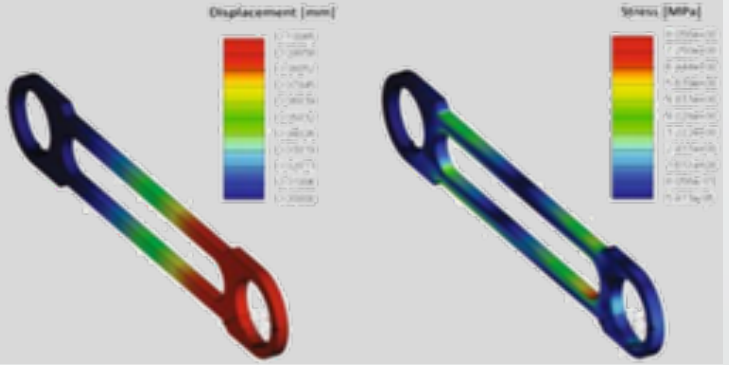
Structural optimization for motor torque reduction

Topology optimization (TO) + **Additive** Manufacturing Technologies (**AMT**) **CFRT-FDM**



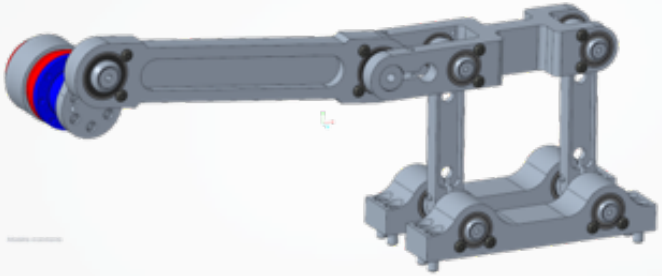
Size optimization + Material **Subtractive** Technologies (**MST**)

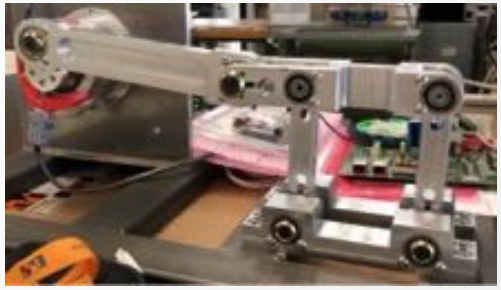




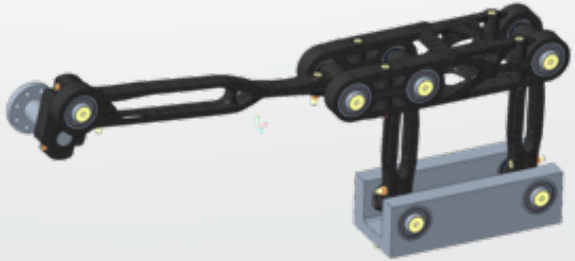
Topology optimization

Initial aluminum structure:





Optimized 3-D printed structure:

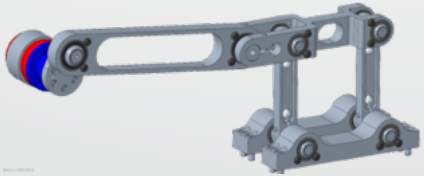


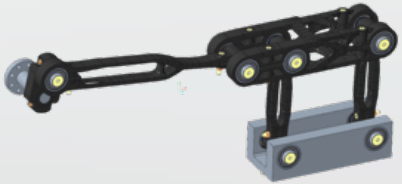
New approach for structural design

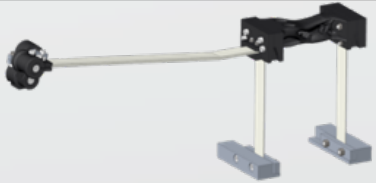
- FDM printing of **CFRT**
- **Replacement** of the majority of rigid links and traditional kinematic pairs with **compliant joints** (**flexible laminas**)
- **Mass reduction** for the bulky and stiff parts of the mechanism via **topology optimization**
- **Dimensioning** the **compliant joints** to make the mechanism operate in a "resonating" condition

Torque comparison:

	SO	TO	Lamina
MT Peak Value [Nm]	2.5	2.1	0.3
Reduction	13%	27%	**89%**

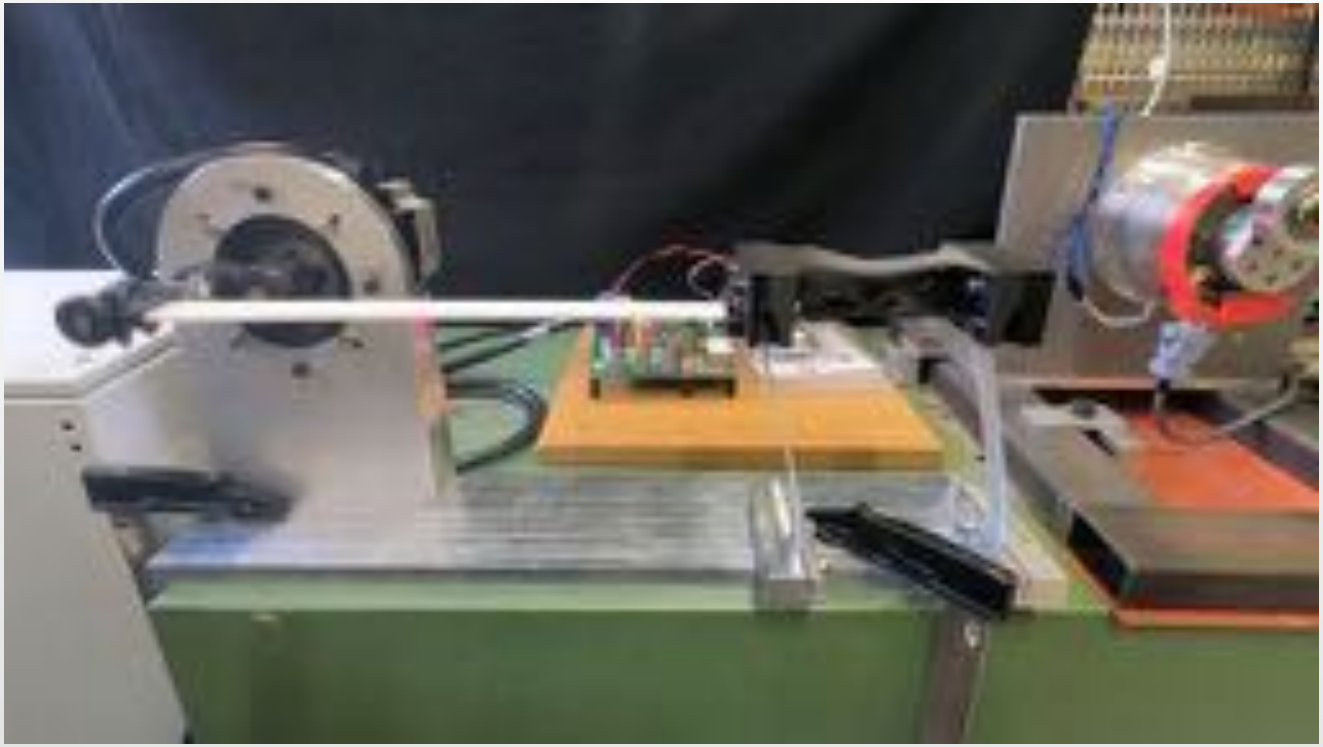






Advanced control for accurate periodic motion

Repetitive, internal model, adaptive, and constrained techniques



Shape Memory Alloy Modeling and Actuators

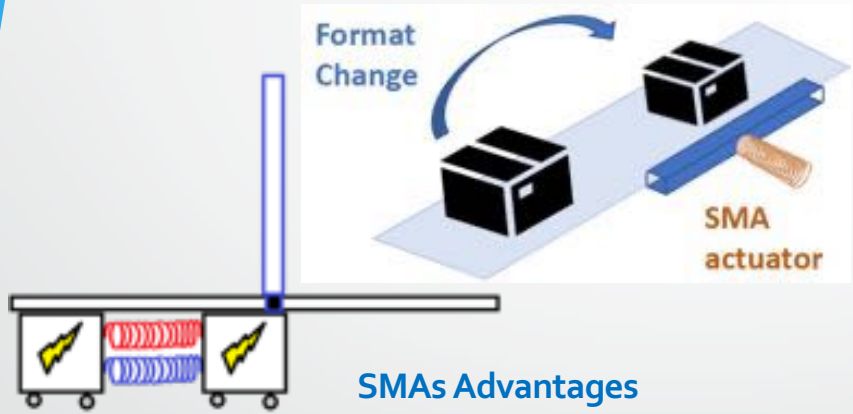
Involved research teams:

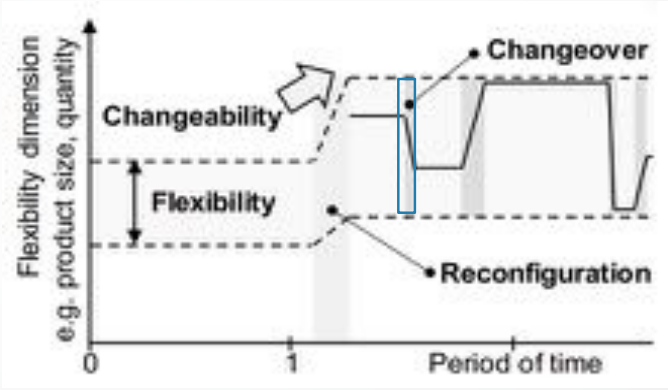
- Structural design: team of Prof. Andrea Zucchelli (UNIBO - DIN)
- Control design: team of Prof. Andrea Tilli, ACTEMA (UNIBO - DEI)

Progetto cofinanziato dalla Regione Emilia-Romagna (POR - FESR 2014 - 2020)

SMA in Automatic Machines

A new actuation system
for an Automatic and Smart
Format Changeover





SMAs Advantages

- Simple mechanical design
- High force to mass ratio

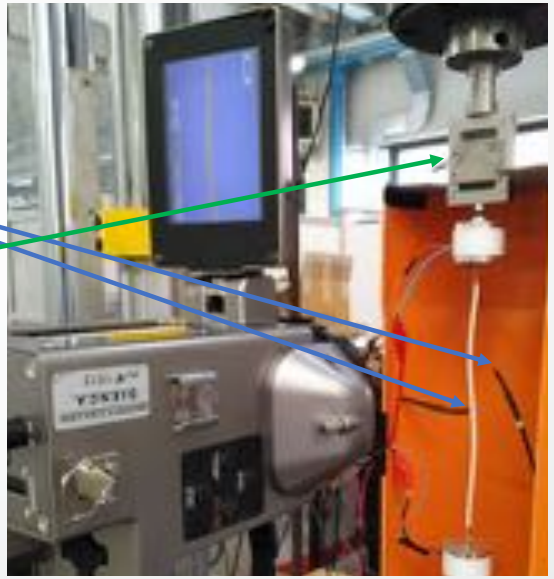
ACMEC Objectives

- Development of control strategies based on a **novel Constitutive Model designed** for the application
- Design of smart structural elements of automatic machines using **SMA integrated actuators and sensors**

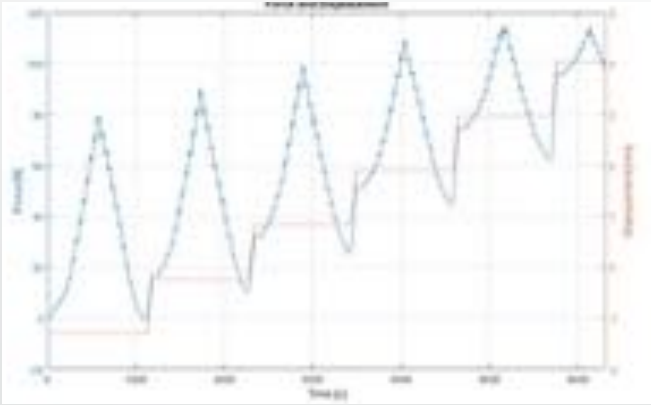
SMA - How it works

Modeling for control

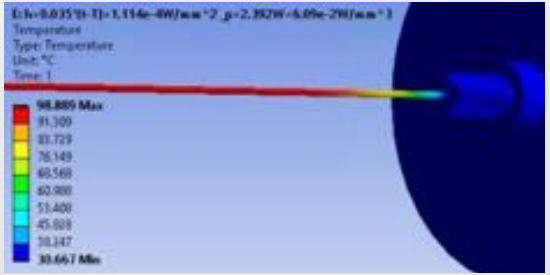
- **LARDRIVE** *Custom Made Drive*
  - Temperature - Pt 100
  - Current (I,V)
  - MTS I/O
- **MTS** *Testing Machine*
  - Force LoadCell - S-type
  - Displacement
- **External**
  - Temp. distribution Thermocamera



Results

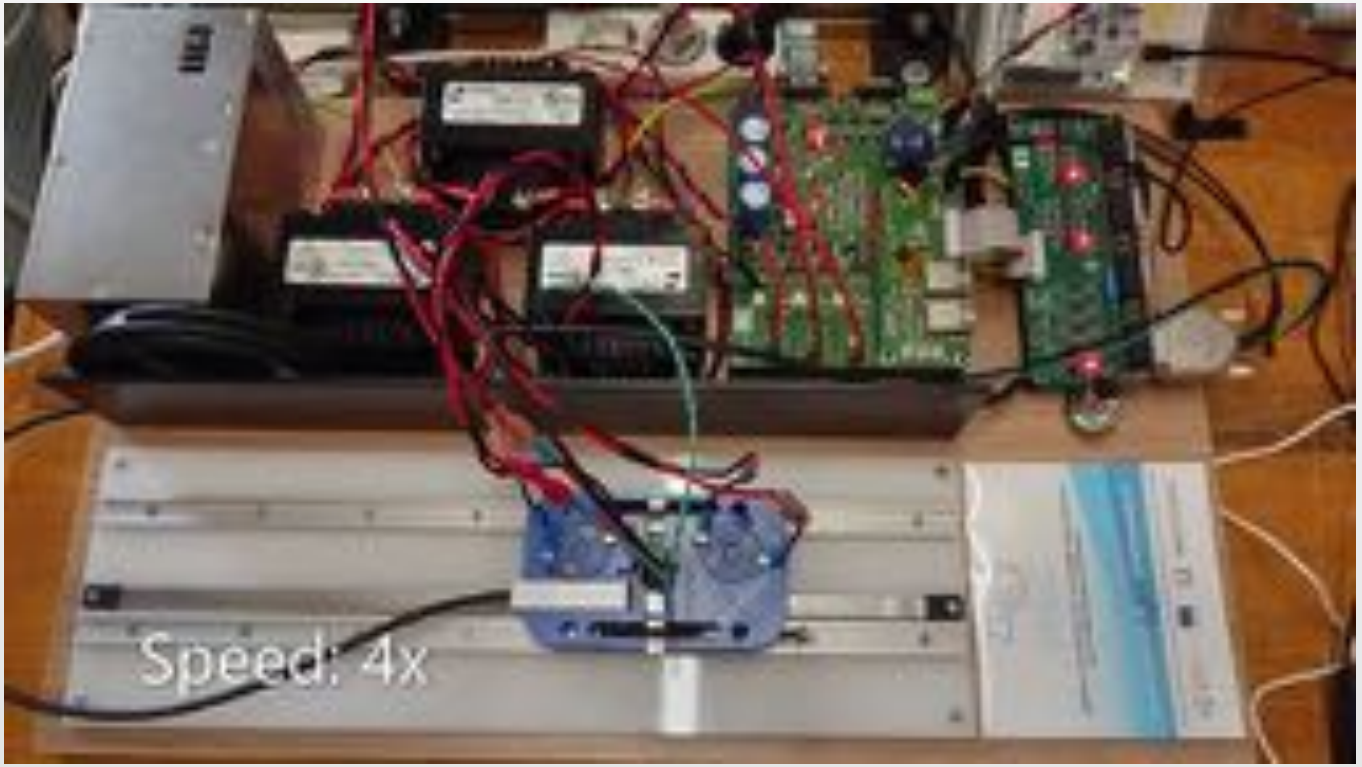


FEM



SMA - Prototype

Large Displacements Actuator Alternating Locomotion System



Optimized design of a synchronous reluctance machine rotor

Activities of the electric machines research group (UNIBO - DEI)

- Ing. Giacomo Sala
- Ing. Gabriele Rizzoli
- Prof. Michele Mengoni
- Prof. Luca Zarri
- Prof. Angelo Tani

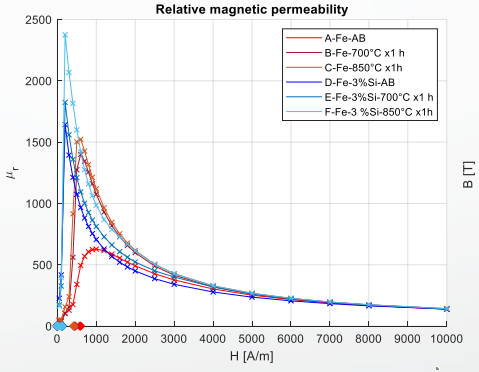
Progetto cofinanziato dalla Regione Emilia-Romagna (POR - FESR 2014 - 2020)

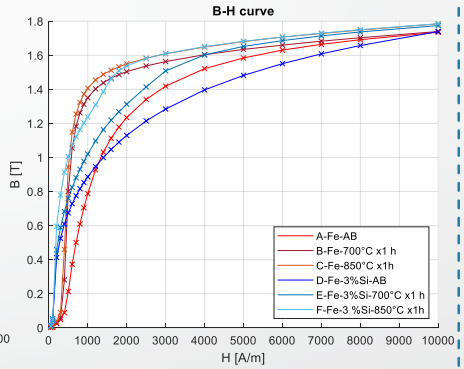
Electromagnetic characterization

Magnetic samples with primary and secondary coils for measurements.

IEC 60404-4: Magnetic materials - Part 4: Methods of measurement of d.c. magnetic properties of iron and steel.

d.c. magnetic properties





a.c. magnetic properties

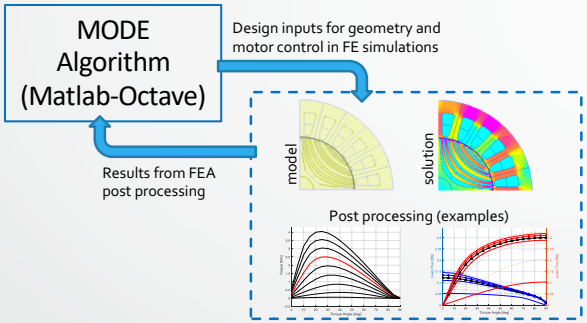
Fe	Res (Ωm)	FeSi - 3%	Res (Ωm)
A	7.65E-08	D	2.83E-07
C	7.02E-08	F	2.70E-07

Indirect evaluation of material resistivity.

Credits: Spin Applicazioni Magnetiche

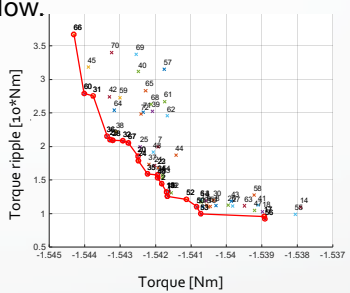
Electromagnetic design

Design mainly based on the use of the open source software Syr-e and Femm4.2.



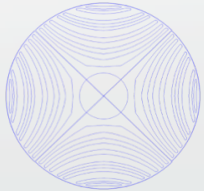
MODE (Multi-Objective Differential Evolution) optimization algorithm. Optimization based on Finite Element non-linear simulations.

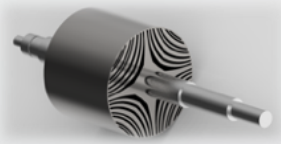
Optimization results: example of selected motors in one step of the design workflow.

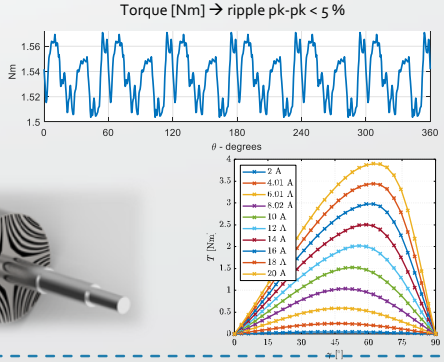


Local search of the optimum motor layout is obtained with a reduced range of parameter values around the optimal of the global search.

Prototype layout







Study of materials for additive manufacturing of mechatronic systems

Activities of the metallurgy research group (UNIBO - DIN)

- Prof. Lorella Ceschini
- Ing. Lavinia Tonelli
- Ing. Mattia Zanni

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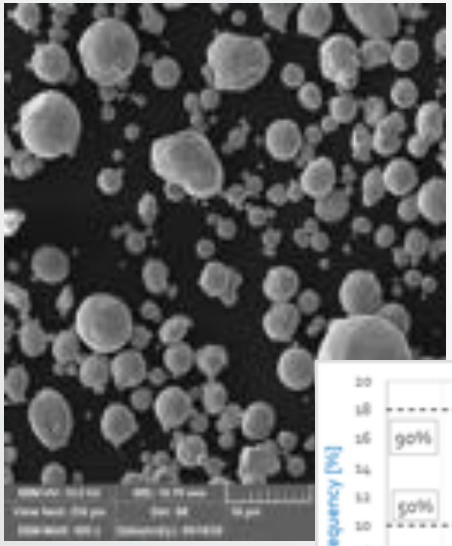
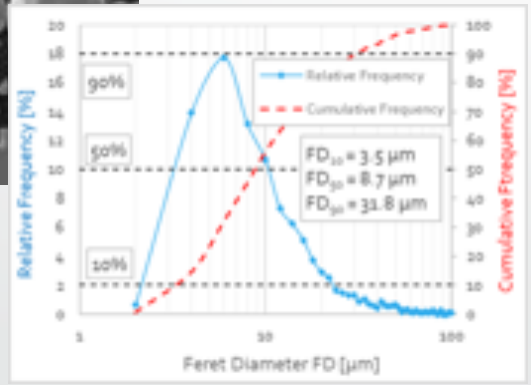
Characterization of dusts for SLM:

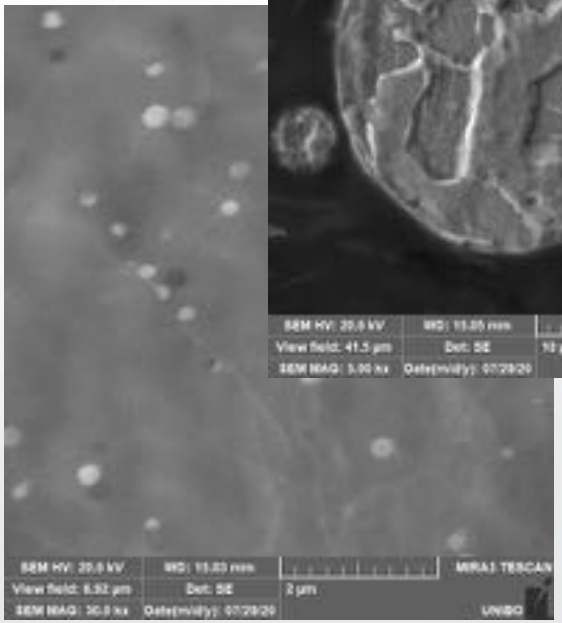
- Pure iron
- Fe- 3wt.%Si

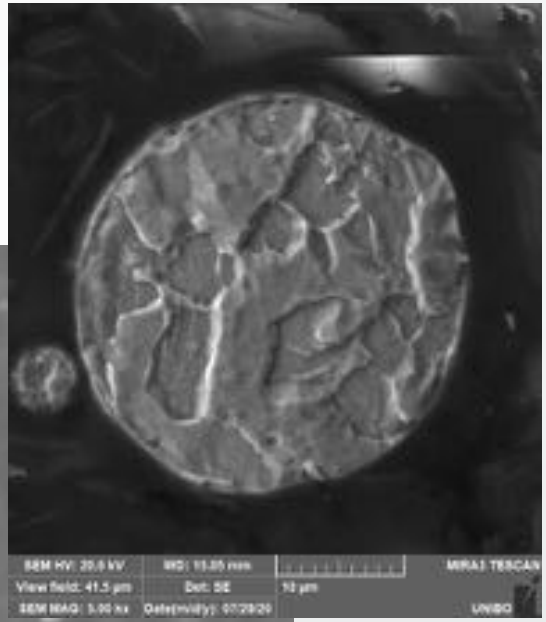


Morphology and size

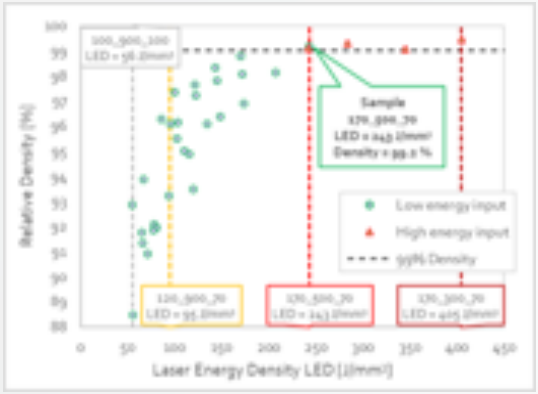


Microstructural analysis

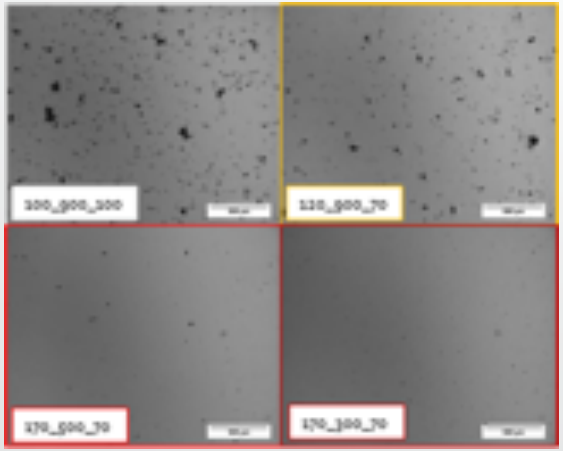




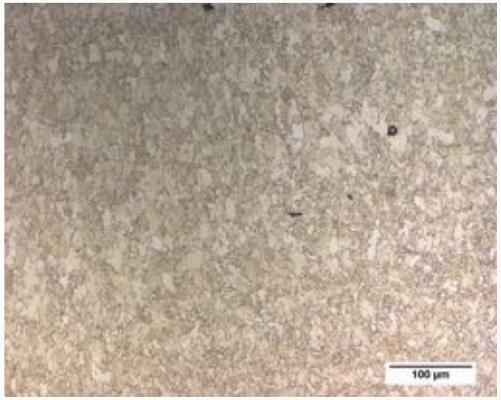
Effects of SLM process parameters on density



Size and morphology of defects:

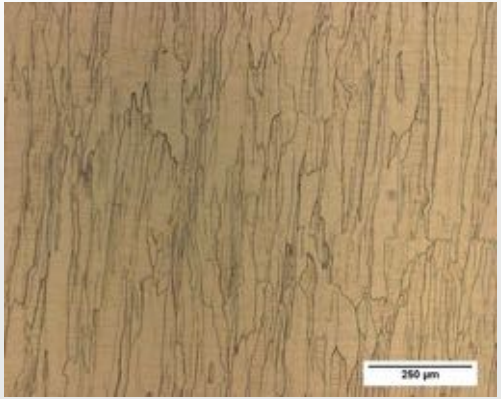


Microstructures in the as-built state



Pure iron

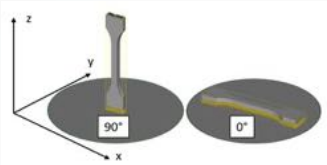
- Fine and equiaxed Fe-α grains
- Average size: ≈ 5 µm
- Isotropic structure

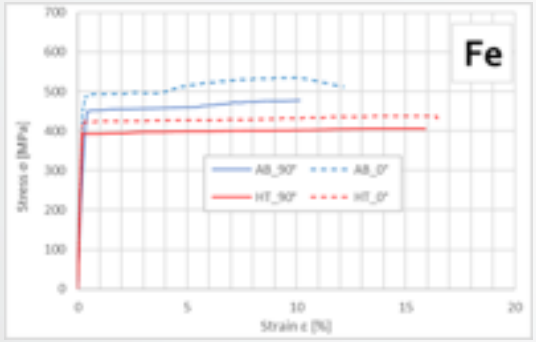


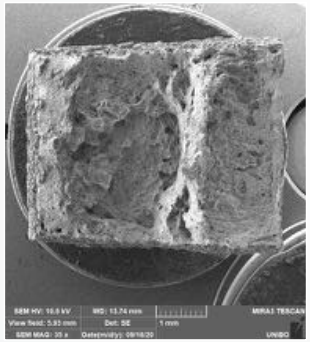
Fe- 3wt.%Si

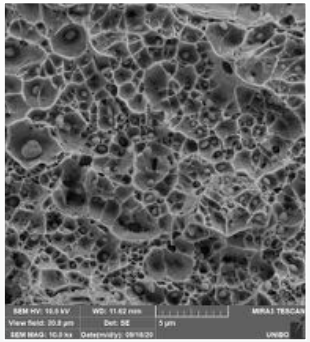
- Coarse columnar Fe-α grains
- Grain length >> 100 µm
- Anisotropic structure

Traction behavior of the of as-built (AB) state and after the heat treatment (850 °C for 1 h, HT), along different growth directions



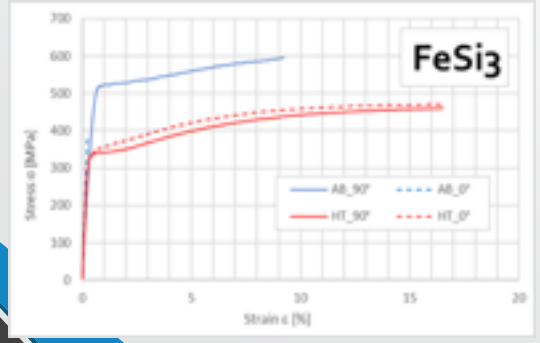


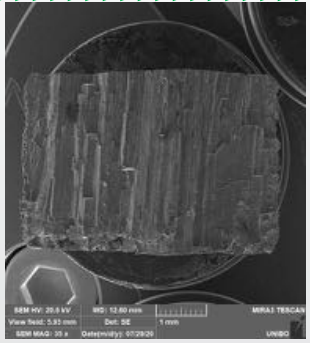


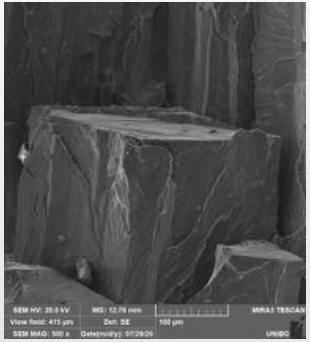


Pure iron

- High resistance
- Ductile fracture
- Slight anisotropy
- Small resistance reduction and ductility increase after the heat treatment







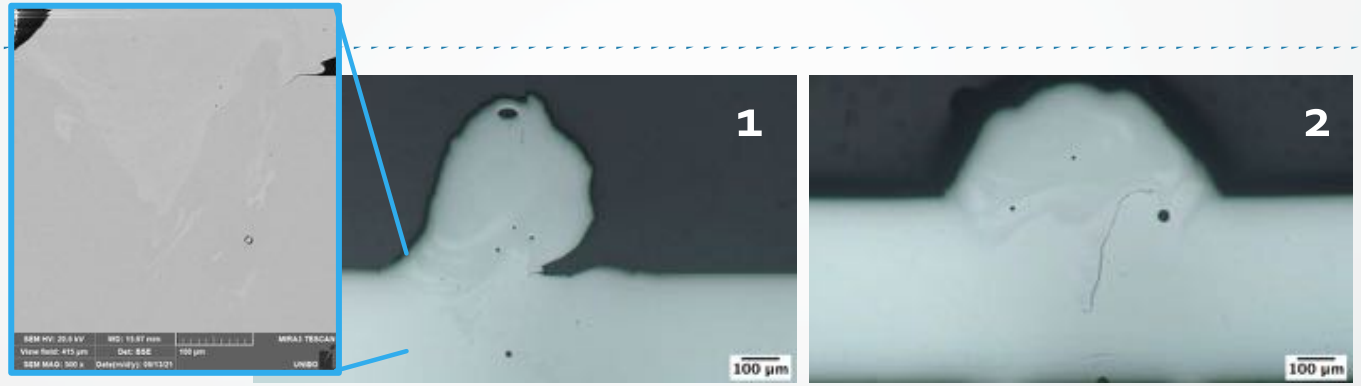
Fe- 3wt.%Si

- High resistance but brittle fracture in the as-built state
- Significant resistance reduction after the heat treatment, but ductile behavior
- High anisotropy of mechanical properties

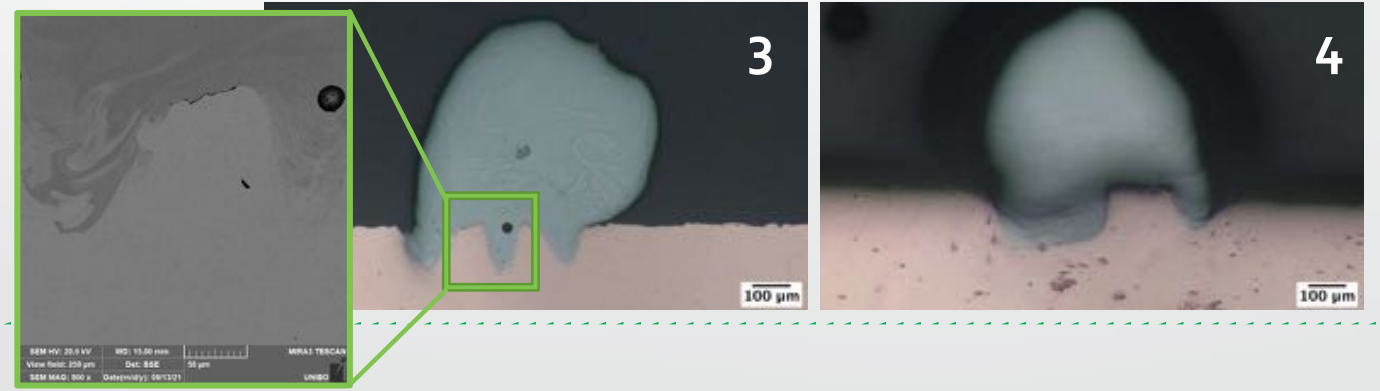
Microstructural characterization of laser welding of Shape Memory Alloys (SMA) NiTi with substrates:

- Austenitic stainless steel 304L
- Pure copper

SMA + 304L



SMA + Cu



Additive manufacturing technologies for synchronous reluctance machine rotors

Activities of the technology research group (UNIBO - DIN)

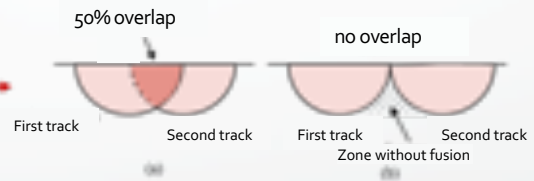
- Prof. Alessandro Fortunato
- Ing. Giuseppe Valli

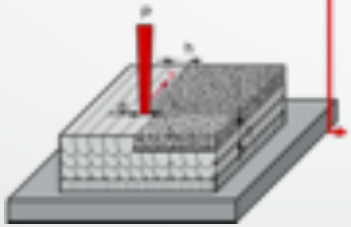
Progetto cofinanziato dalla Regione Emilia-Romagna (POR - FESR 2014 - 2020)

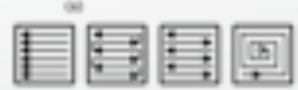
Study and optimization of LPBF process parameters

- Power [W]
- Speed of laser beam [mm/s]
- Distance between traces [mm]
- Layer width [mm]
- Scan strategy
- Alignment and supports

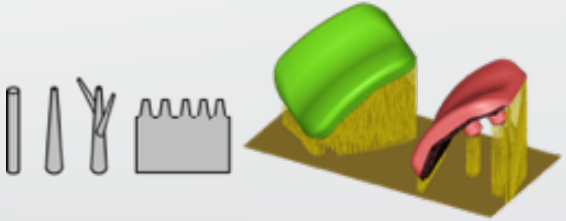
$$E_v = \frac{P}{v \cdot h \cdot t} \left[\frac{J}{mm^3}\right]$$





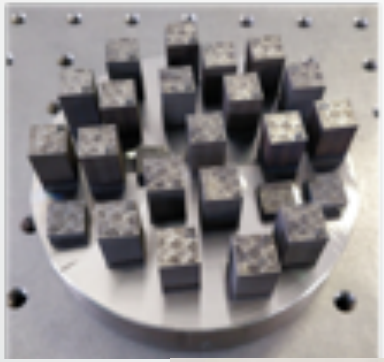


Alignment and supports



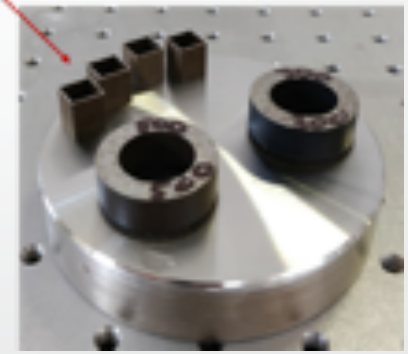
Sample realization for the mechanic and magnetic characterization

Parallelepipeds for density, hardness, and roughness analysis



Toroids for magnetic characterization

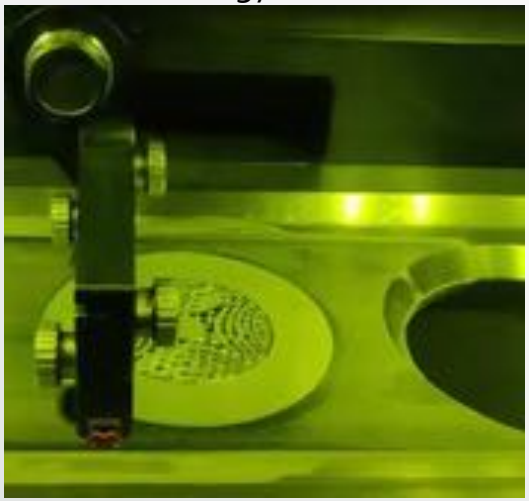
Thin surfaces



Dog bone samples for static traction tests

Rotor production and treatment

Production through LPBF technology



Finite product assembly

Heat treatment*

*Using furnaces of SACMI

High-performance edge-computing platform for next-generation mechatronics

Activities of the ACTEMA research group (UNIBO - DEI)

- Coordinated by Prof. Andrea Tilli

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA
CENTRO INTERDIPARTIMENTALE DI RICERCA INDUSTRIALE MECCANICA AVANZATA E MATERIALI
UNIMORE UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA
Centro Interdipartimentale per la Ricerca Applicata e i Servizi nel Settore della Meccanica Avanzata e della Motoristica INTERMECH
romagnatech INNOVATION VALUE
Progetto cofinanziato dalla Regione Emilia-Romagna (POR - FESR 2014 - 2020)
POR FESR EMILIA-ROMAGNA 2014/2020
UNIONE EUROPEA Fondo europeo di sviluppo regionale
RegioneEmilia-Romagna

ACMEC-Drive, 48V Multi-Axes Edge-Computing-Enabled Electric Drive

Idea:

- To exploit innovative edge-computing processors
  - Pros: high computational power and flexibility
  - Cons: no-RT or soft-RT
- To move toward high-freq MOSFET: GaN

Main features:

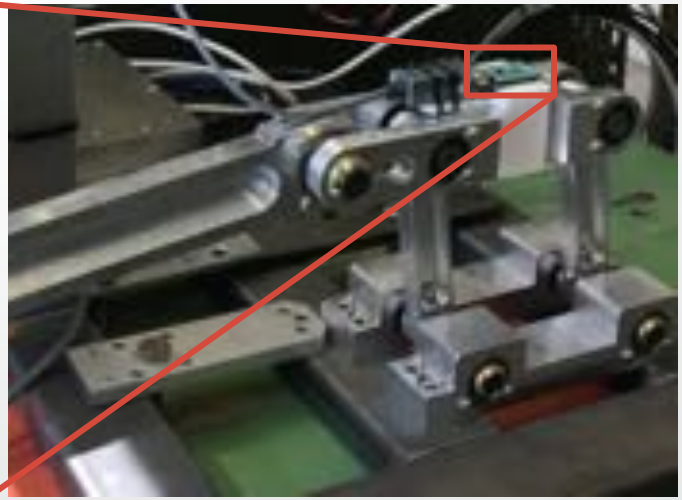
- Computation & Communication Unit (CCU):
  - Dual-Core ARM Cortex-A7 @ 800MHz
  - Single-Core ARM Cortex-M4 @ 209MHz
  - EtherCAT Slave + GbEthernet (EtherCAT Master)
  - XMI (External) Interface
  - 4xUSB Hub, 1xUSB Host, 1x HDMI, 1x CAN
- Up to 6 Actuation Units (AU) - three-phase + brake:
  - Operating DC-Link voltage: 24 … 48 V
  - Nominal Single-Phase current: 20 Arms
  - Peak Single-Phase current: 100 Apeak
- Backplane for power distribution and high-speed hard-RT interfacing

The ACMEC-Drive CCU is the Master of the ACMEC-Drive:

- Taking advantage of SOMs for IoT / HMI devices
- STM32MP157F/A Dual-Core MPU + Single-Core MCU:
  - 1xCortex-M4 @ 209 MHz
    - Rich set of Connectivity Peripherals
  - 2xCortex-A7 @ 800 MHz (650MHz A-Variant)
    - Non Real-Time OpenST Linux
    - Rich set of High-Level features
  - 1xVivante-GPU @ 533 MHz
    - Linux drivers to power HMI features
- CHANGE ITS ORGANIZATION PARADIGM:
  - Cortex-M4
    - Board and Real Time master by our RTOS AEON-RT
  - 1 Cortex A7 Linux
    - Non-RT services
  - 1 Cortex A7 bare-metal
    - Computation-slave for high performance control
    - Jailhouse hypervisor and other elements to avoid L2-cache interference

XMI Expansion Interface, connecting the ACMEC-Drive CCU to **multiple external devices** through a **10Mbps Hard Real-Time** ACTEMA Proprietary Bus with **Power Delivery** (12V, 36W)

- **Deployment of distributed 5KHz Sample Rate 6DoF IMUs (XMI boards in photo)**



Inertial Measurement Unit developed by Romagna Tech

ACMEC-Drive AU, **GaN Based Electric Drive** for three-phase motors with brake configurable to **four independent half-bridges:**

- **Single-Core ARM Cortex-M4 @ 180MHz with CORDIC DSP**
- **Operating DC-Link voltage: 24 … 48 V**
- **GaN Nominal Half-Bridge current: 20 Arms**
- **GaN Peak Single-Phase current: 100 Apeak**
- **GaN Power Stage Switching (PWM): > 200 KHz**
- **2 Encoder Slots supporting BISS-C, SSI, ABZ Incremental**
- **XMI, USB-Serial, USB-FS Device/Host and CAN Bus Intf.s EtherCAT Slave Stack DSP402 (AoE, MDP, CoE)**
  - **For STAND-ALONE applications**