A Highly-Flexible Electromechanical Drive Integrating Electronic Poles Variation and HTS Coated Conductors Based Motors

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Abstract

Developing new technology is one of the four-pillar strategies for mitigating CO_2 emissions in the aviation sector, according to the Carbon Offsetting and Reduction Scheme for International Aviation. Although this is usually associated with more efficient combustion engines, the all-electric aircraft (e-aircraft) vision is being pursued even by major companies, as a means to reduce emissions and comply with the targets set in the Paris Agreement. To turn this vision into reality, it is not only required to advance the technological development of batteries and other storage means but also of the distribution and use of electrical energy inside the aircraft. High-Temperature Superconductivity (HTS) may play a role in the field, as it allows for more compact and lighter devices, even when considering cryogenics, which is of utmost importance for aircraft applications.

This work is focused on the development of new, highly-flexible electromechanical drives that can potentially be integrated into e-aircraft, as well as in other transportation and industrial applications. The drive comprises two distinctive features, namely

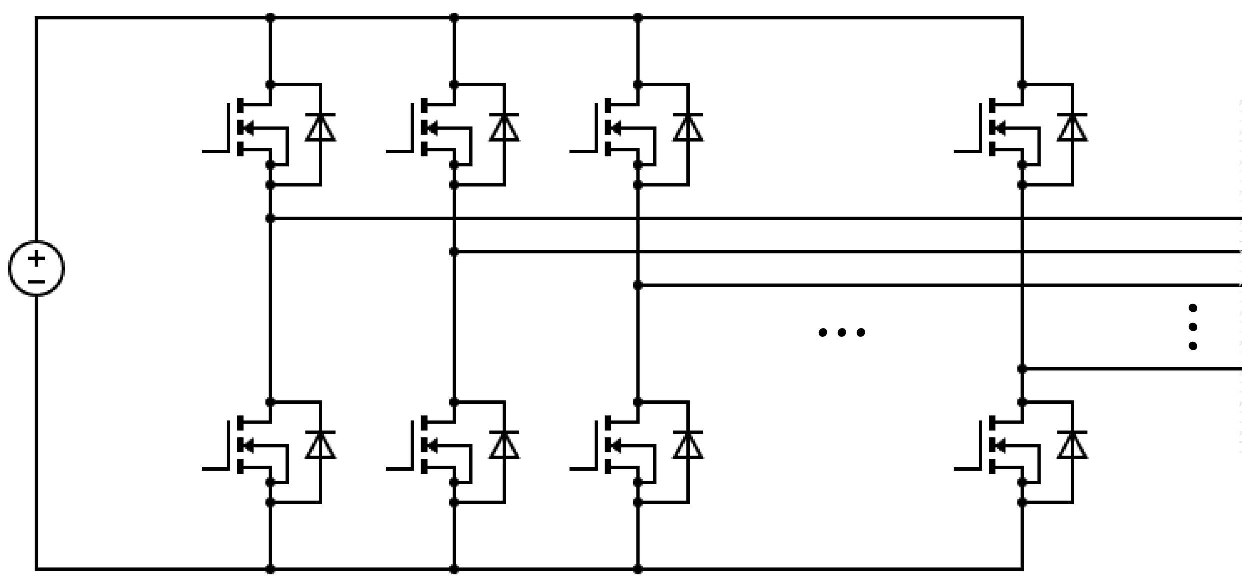
i. an electronics pole variation operation system that allows changing the speed/torque characteristics of the electrical machine by changing the number of magnetic poles of its armature, and
ii. motors with rotors built by HTS coated conductors in different configurations.

The power electronics converter required in i. is also distinct from conventional industrial converters, showing an increased complexity when compared to the latter.

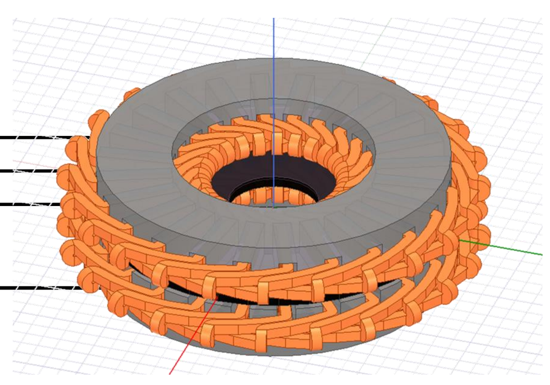
A preliminary validation of the drive is performed by simulations and experimental results. The motor is of trapped-flux rotor type, and the reconfiguration of flux distribution, when poles are changed, is assessed. Prospects for the application of this drive are discussed.

Architecture of the electromechanical drive

PWM converter with N arms



N slots/phases motor



Operation concept

Number of slots in the stator: N
Number of phases: N
Phases generated by the PWM converter:

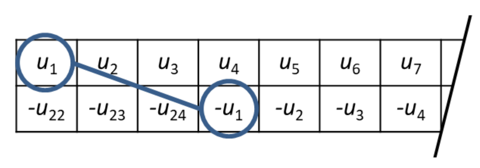
$$u_1(t) = \sqrt{2}U\cos(\omega t + \varphi_1)$$
$$u_2(t) = \sqrt{2}U\cos(\omega t + \varphi_2)$$
$$\vdots$$
$$u_N(t) = \sqrt{2}U\cos(\omega t + \varphi_N)$$

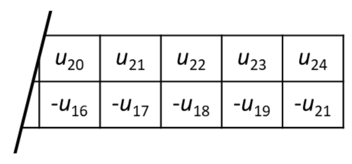
Each phase angle is given by:

$$\varphi_k = \varphi_{k-1} + \Delta\Phi, \text{ where } \Delta\Phi = 360° \frac{p}{N}$$

where p is the desired number of pairs of poles.

Upper layer



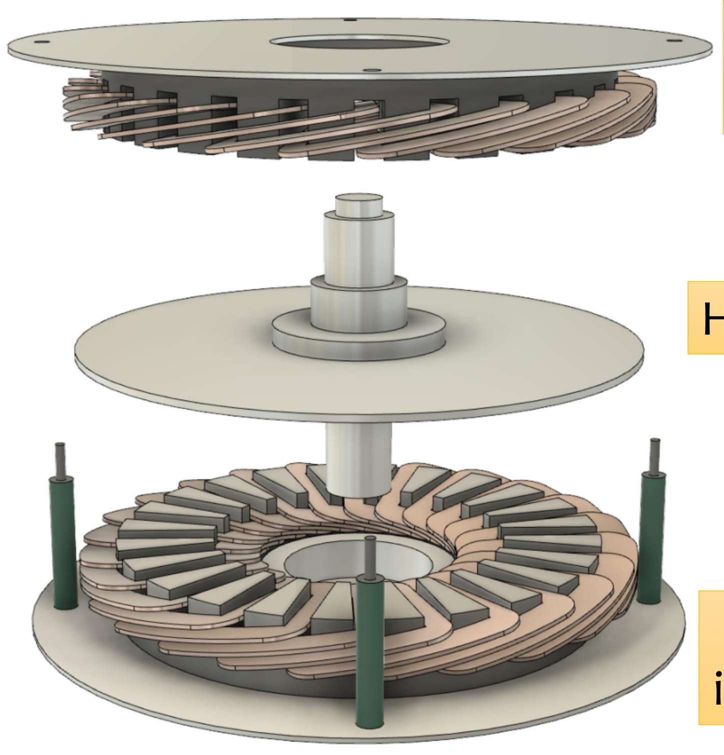


Lower layer

Synchronous speed (rpm): $N_S = \frac{60f}{p}$
Phase frequency: f

The double layer and the winding configuration leads to a modulation of the magnetomotive force (MMF) that generates the desired number of magnetic poles in the airgap. Distinct frequencies are also easily generated by the electronic converter. This allows a full and flexible control of **speed** and **torque**.

Motor configuration



Double stator (conventional)

HTS rotor

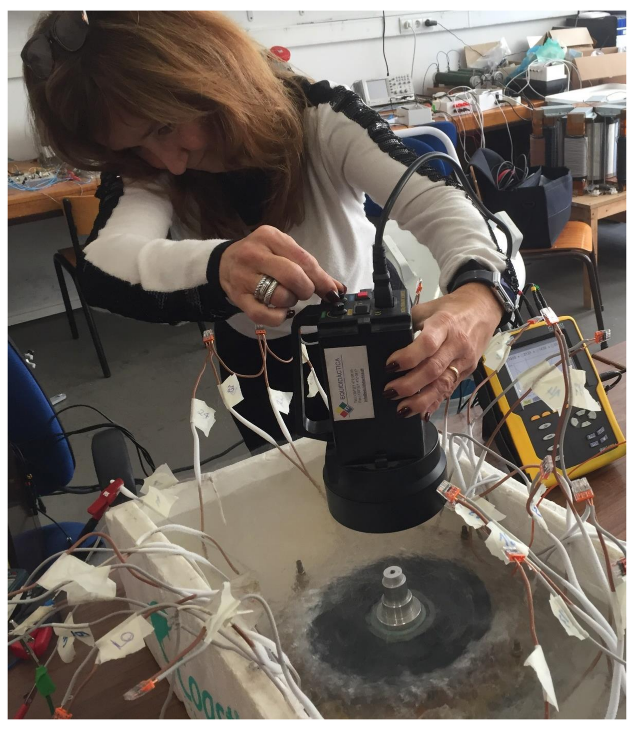
Stator phases independently controlled

Previous work – Proof of concept

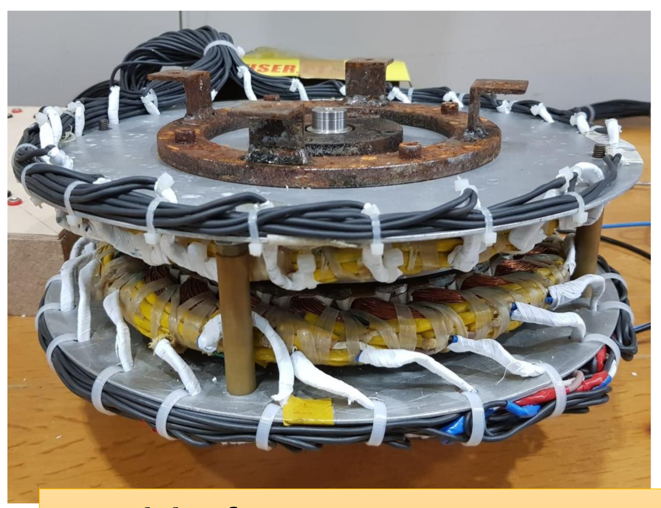
HTS bulk rotor

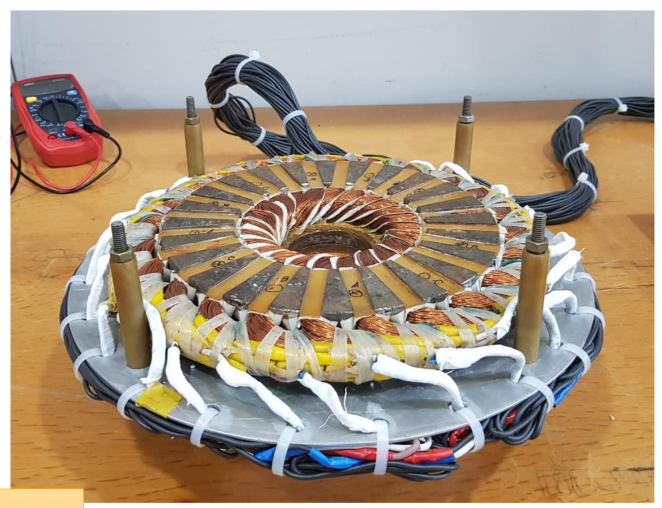
	Stator	Rotor
Ø (mm)	200	200
Material	Steel	Bulk YBCO (ATZ)
Height (mm)	30.9	10
Coils / Slots	24	-
Slot height (mm)	20.6	-
Slot length	10.3	-

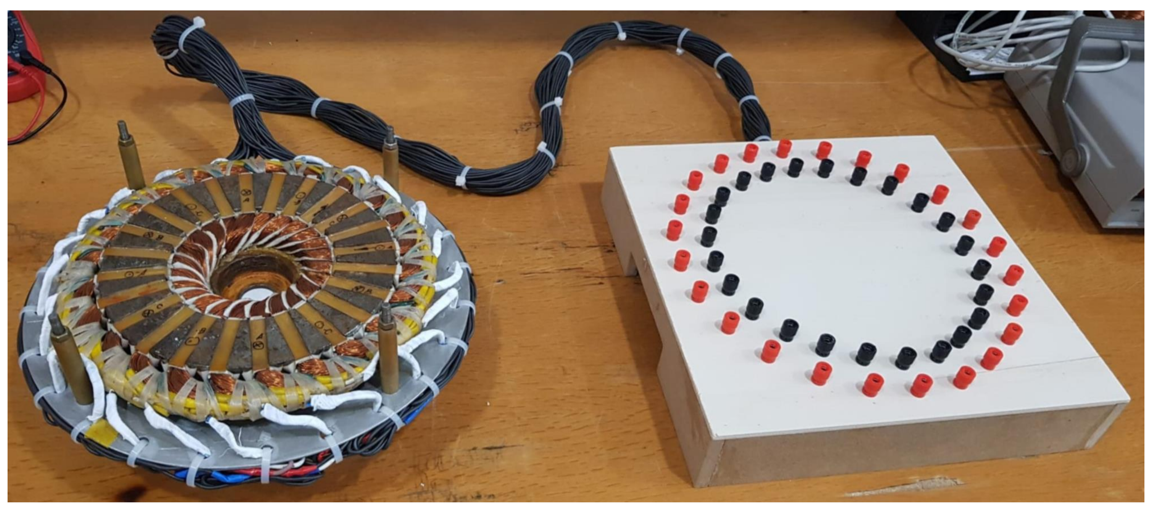
	6 phases	12 phases
Poles	8	4
Synch. Speed (rpm)	750	1500
Coils per phase	4	2
ΔΦ	60°	30°



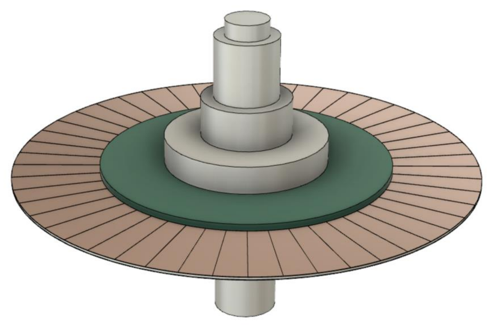
Current configuration

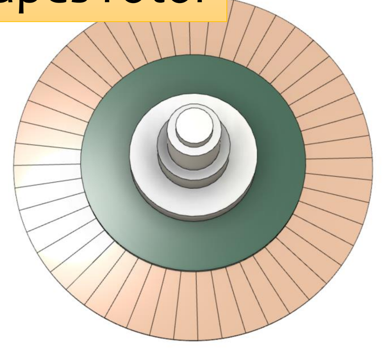


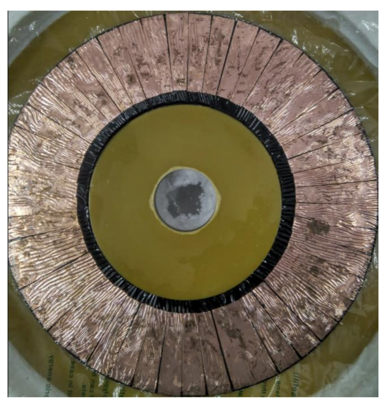




Double-face REBCO tapes rotor



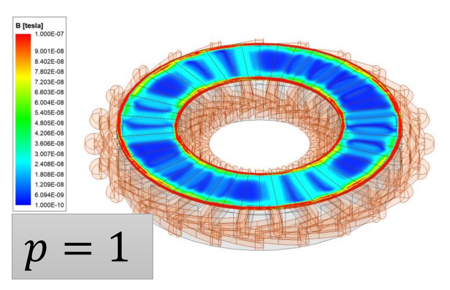


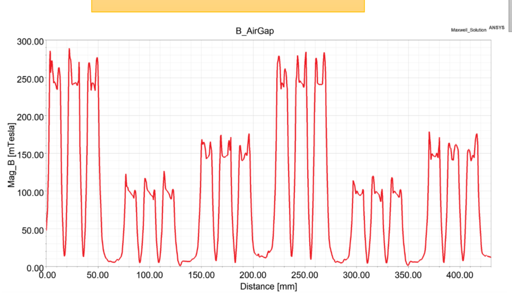


REBCO Tape	
Manufacturer	SuperOx
Thickness (μm)	60
Width (mm)	12
I_C (A)	620
Copper layers (μm)	20

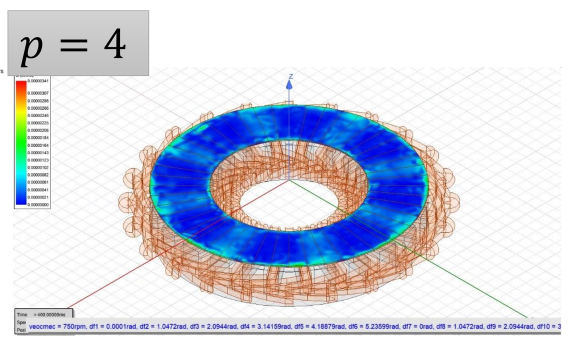
Simulations

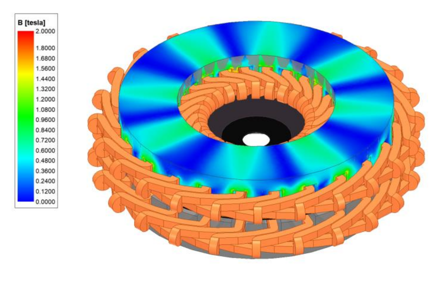
$p = 1$

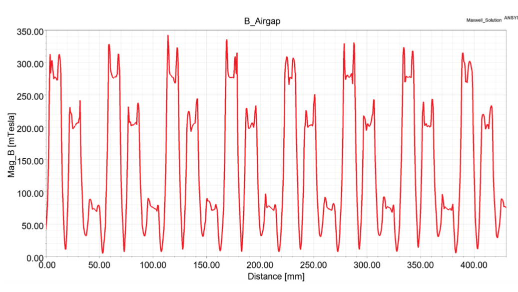




$p = 4$







Conclusion, on-going and future work

- A highly-flexible HTS-based electromechanical drive is presented in this work.
- Preliminary experimental results validated the concept. Yet, a careful design is required, as the characteristics of the tapes (rotor) must be suited for the generated MMF (stator).
- A variable frequency drive, together with the pole changing concept, allow a large span in the torque-speed plan.
- The viability of the drive for energy regeneration is currently being assessed, as well as its electromechanical characteristics.
- HTS AC losses and iron losses are being characterized.
- The control of the drive is extremely challenging, for which artificial intelligence-based controllers are foreseen.
- Envisaged applications are:
  - High-torque drives that require step changes in speed (e.g., cranes, hoists).
  - Distinct drives in systems where cryogenics is already available (e.g., HTS-based electric aircraft).

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