Thermomagnetic energy harvesting from low-grade waste heat using tunable Heusler alloys

F. Cugini[1,2*], G. Garulli[1], L. Gallo[2], S. Gabbi[1], E. Milani[1], S. Fabbrici[2], F. Albertini[2], M. Solzi[1,2]

[1] University of Parma, [2] IMEM-CNR Institute
*francesco.cugini@unipr.it

Thermomagnetic power-generation (TMG), based on magnetic materials, has emerged as a promising technology for harvesting and converting the vast amount of low-grade waste from sources operating below 100°C [1]. Although the principle of TMG has been known for over a century significant research efforts in the past decade have focused on materials development and prototypes design, the full potential of this technology has yet not been realized.

In this contribution, we present a laboratory-scale prototype of a thermomagnetic generator, designed as a versatile test bench for the in-operando evaluation of thermomagnetic materials and the enhancement of thermomagnetic devices [2]. The core of the generator is a thermomagnetic motor, based on the "Curie wheel" principle, which converts thermal energy into mechanical energy. It operates between two controllable thermal reservoirs, enabling the evaluation of materials performance over an adjustable temperature range. The motor shaft is coupled to a custom-built, two-phase, electric generator specifically optimized for low-speed operation. This setup generates electric power while simultaneously allowing the measurement of torque, rotation speed and mechanical power output. The active rotors were fabricated using a simple method that combines composite materials with 3D-printed soluble moulds, starting from coarse powders of thermomagnetic materials. [3].

The generator was tested with various Ni-Mn-based Heusler alloys exhibiting Curie transitions in the 20–60 °C range [2]. The magnetic properties of these alloys were tailored using three approaches: (1) substituting the nonmagnetic element (In, Sn, Ga), (2) adjusting the Ni/Mn ratio, and (3) introducing additional elements (e.g., Fe, Cu). The mechanical output of the thermomagnetic motor was correlated with the magnetic work of thermomagnetic cycles, derived from magnetization data. The results highlighted the crucial influence of transition temperature and saturation magnetization in determining the maximum power output of the thermomagnetic generator. Notably, the generator operating with the $Ni_{48}Mn_{36}In_{16}$ alloy achieved the highest power density and efficiency in the 45–65 °C range, outperforming other thermomagnetic generators reported in the literature.

This work received financial support from European Union -NextGenerationEU (PRIN 2022 PNRR Project "STEve" P2022KMXBL, CUP: D53D23019360001).

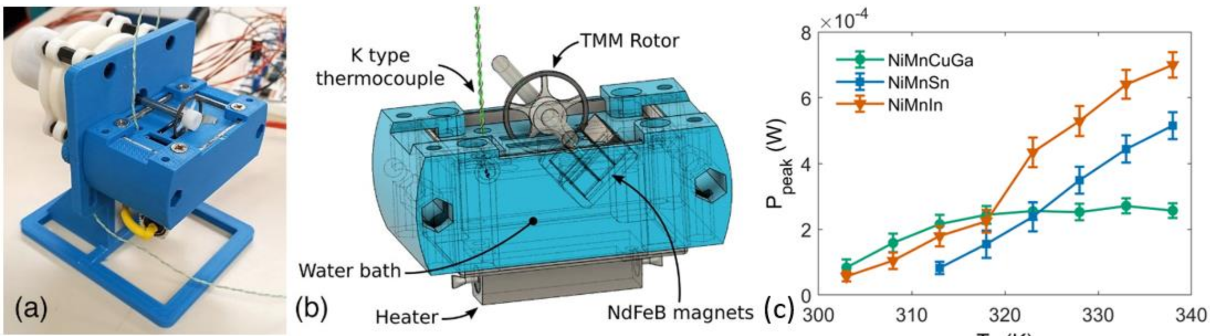

Figure 1. On the left: photograph and sketch of the TMG prototype. On the right: maximum mechanical power of the generator as a function of temperature of the hot reservoir obtained exploiting NiMnIn, NiMnSn and NiMnCuGa Heusler alloys as active material.

References

[1] D. Zabek, F. Morini, Therm. Sci. Eng. Prog., **2019**, 9, 235–247.
[2] F. Cugini et al., Acta Mater., **2025**, 288, 120847.
[3] C. Coppi et al., Adv. Eng. Mater., **2023**, 25, 2200811.