Title:
A Virtual Design Approach to Simulate the Hob Energy Performance

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Introduction:
Eco-design strategies aim to integrate environmental considerations into product design and development, ISO, 2011[6], and several regulations, directives and standards have been issued on this topic during last years. European Directive 2009/125/EC [3] establishes the eco-design requirements related to domestic and commercial kitchen appliances (e.g. cookers, hobs, grills). The present paper focuses on domestic induction heating cookers, which are becoming one of the leading cooking systems due to their advantages, e.g. energy efficiency, rapid heating, cleanliness, and user safety.

Among the eco-design framework, the European Standard EN 60350-2 [7] regulates the measurement of energy performances for induction hobs. Product energy performance is a crucial parameter both for manufacturers and end-users. Indeed, it represents a powerful marketing mainstream due to the fact that efficient energy consuming products could lead to a reduction in the total amount of the consumed energy. The assessment of energy performances represents a fundamental action for producers. During the last years, many researchers have focused on the induction heating with different studies concerning: (i) the development of high efficiency power electronic systems, (ii) the design of the inductor, and (iii) the efficiency improvement of the cooking processes by means of the pot optimization. [1], [13]. In particular, some authors have studied the behavior of cooking stoves and pots with theoretical models and experiments, focusing to the thermal efficiency of pots [12]. Other researchers have analyzed the efficiency improvement of the cooking processes by means of the pot optimization, on the study of the efficiency of pots through experimental and neural network methods [11], [14]. Other works have focused on models that consider a uniform heat distribution in the bottom of the pot [2], [5]. However, these works lack in two main aspects: (i) they started from physical prototypes, and (ii) eco-design consideration are not included in the analysis. Numerical tools for the simulation of cooktops use phase, based on thermodynamic modelling, are able to provide additional information regarding the performance of cooking system. In the literature review only few works have been developed considering thermodynamic models for induction hob simulation [9].]In particular, these tools are conceived as tools for the design and simulation of the technology, rather than for the simulation of product performances. As an example, McCarthy and Bryden [10] proposed a steady-state heat transfer model for the improvement of the cooking stoves, investigating fluids around the pot. The limit of this work is that the discussion is not extended to the thermodynamic phenomena within the pot and assumes that the water in pot is already at the boiling temperature. Similarly, other works [4], [8] developed

detailed thermodynamic model including also losses from the pot sides and heat transferred to water volume, but in both cases the water was assumed to be already at the boiling point. From the literature emerges that existing models do not consider all the parameters that are needed to allow the simulation of system operative principle under different conditions. A virtual model focused on the induction hob-pot system and on its different configurations, would be needed.

The objective of the present paper is therefore to propose a methodology able to support designers in evaluating heating performances of induction cooking appliances, yet in the early design phases, through a virtual and multi-physical product model. These performances are determined by measuring several parameters and reproducing the energy consumption test by the mean of a virtual prototyping tool.

The paper is organized as follow: the next paragraph presents the methodological approach that leads to the evaluation of the energy efficiency of the product from the virtual model. Then the test case used to validate the virtual model through the comparison with experimental tests is described. Finally, the conclusion section, with a discussion on the main advantages of the proposed methods and future works are presented.

Methodological Approach:

Fig. 1., represents the framework of the proposed approach including the adopted software tools. The virtual design approach requires the definition of three main items (i) a parametric CAD model, (ii) a multi-physical virtual model, and (iii) a real test experimental set.

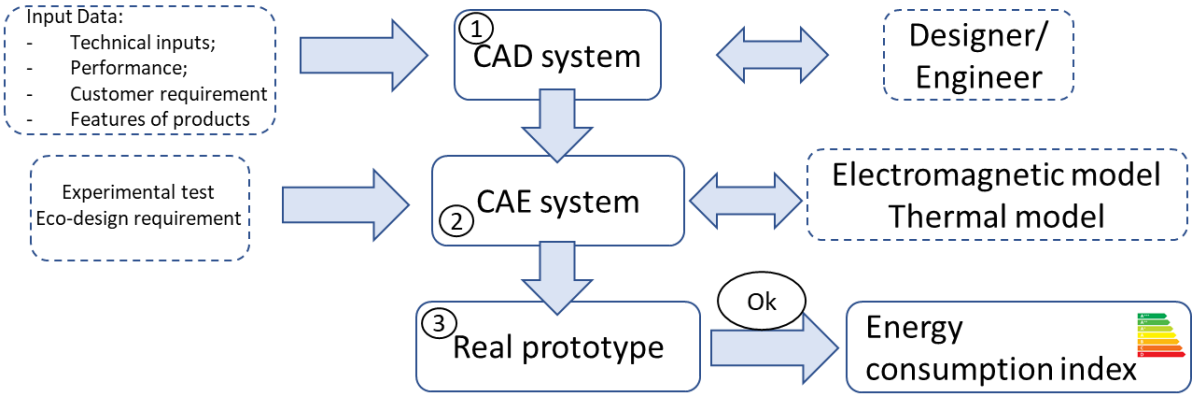

Fig. 1: Methodological approach.

The approach starting with the definition of input data, such as technical inputs, performance, customer requirements, features of the product. The first phase regards the definition and the generation of a 3D CAD model. During this phase, designer and engineers develop the product virtual model of the system under analysis avoiding detailed geometrical entities with the aim to simplify the geometrical complexity of the product (as shown in Fig. 2.). The resulting geometry is a model which excludes all those elements with a low influence on mechanical behavior, e.g. through holes, threads, small fillets and chambers, electrical components, etc. At this level, the main geometrical and non-geometrical parameters have to be identified and a parametric simplified CAD geometry is created.

The second step is characterized by multi-physical model setting definition which allows to simulate the electromagnetic and thermos fluid dynamics behavior of induction hob using FEM and CFD tools. The electromagnetic model solves the Maxwell's equations (FEM tools), while the thermal model solves the thermodynamics equations (CFD tools). In the multi-physical model, the output obtained by the electromagnetic model is the input to the thermal one. Depending on the current and frequency that passes in the copper coil, it is possible to evaluate the eddy currents generated on the

bottom of the pot and the relative heat generated by the Joule effect. The heat which is obtained through the electromagnetic model is an input to the thermal module and is able to simulate the fluid-dynamic behavior of the product. The simulation process is carried-out in three steps: pre-processing, processing and post-processing. During the pre-processing phase the finite element model is built: the CAD geometry is discretized and the set up and boundary conditions are defined. At the end of the numerical model processing, results are assessed (post-processing) and analyzed.

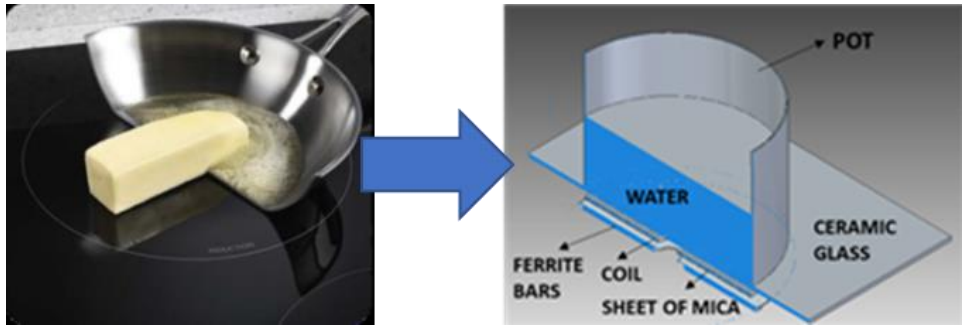

Fig. 2: Parametric CAD model of induction hobs.

The last step of the methodology is the comparison between the results gained with the numerical model and the results of experimental tests with the aim to evaluate the gap between the virtual and the real models. The final result is the evaluation of the energy consumption of the product from the virtual model, since the first design phases and overcoming the need of experimental tests.

Test Case:
In order to validate results obtained through virtual tests, several physical tests have been conducted. The first step of the proposed approach is to define the characteristic of the hobs. In this case, a standard induction hob, which is described in Fig. 3a., has been chosen.

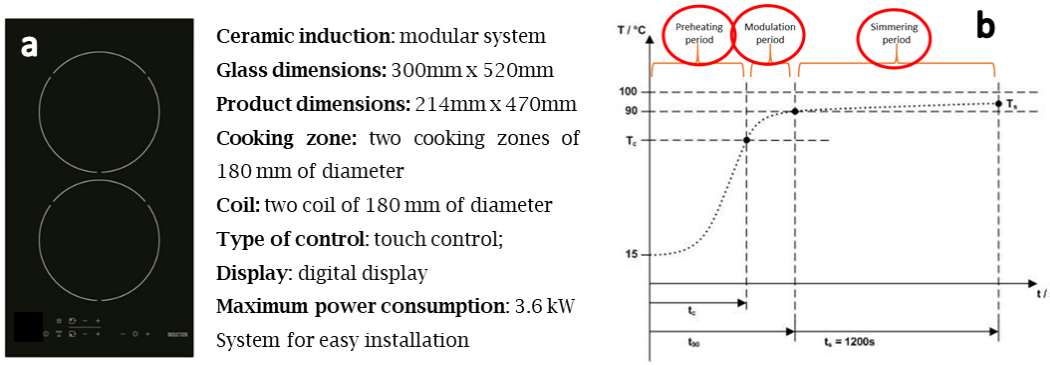

Fig. 3: Induction hob data sheet (a) and eco-design test (EN 60350-2:2013) (b).

The European Standard (EN 60350-2:2013) defines the features to control (time and Temperatures) during the execution of the test: the preheating period is the period of the test in which the induction plan is set to the maximum power until the water reaches a temperature of 70 [°C]. At this point, power is reduced to 25% ±5% of maximum and the water temperature still continues to rise until it reaches the temperature of 90 [°C] (modulation period). The simmering period starts when water reaches for the first time the temperature of 90 [°C] and lasts 20 [min] in order to obtain a temperature

≥ 90 [°C]. Heating up and keeping the temperature for a defined period represent a typical household cooking process. The simmering time of 20 [min] represents an average household cooking duration (Fig. 3 (b).).

Starting from the physical characteristics of the product and the test conditions, a CAD model has been made. It is composed by: (i) a pot (of different diameters), (ii) a cooking surface realized in glass ceramic material, (iii) a layer of electric insulation material consisting in a sheet of mica (Potassium Aluminum Silicate), (iv) an inductor coil (180 [mm] of diameter) to generate the magnetic field, (v) a flux conveyor consisting in several ferrite bars (these latter are disposed radially and equidistant with the aim to reduce the dispersion of the magnetic field), and (vi) the water inside the pot.

The Multiphysics virtual model is composed by a virtual analysis of the electromagnetic phenomenal and of the thermal aspects. The electromagnetic simulation allows to estimate the value of the power produced on the bottom of the pot, while the thermal fluid dynamic simulations investigate the heat exchange and distribution. FEM and CFD tools (Ansys Workbench) are coupled to solve simultaneously the electromagnetic and the thermal fluid dynamic behavior of the product analyzed. For accurate FEM and CFD analysis, the system is discretized in a grid made up of finite element in coded form. The quality of the mesh has a significant impact on the accuracy of the numerical solution.

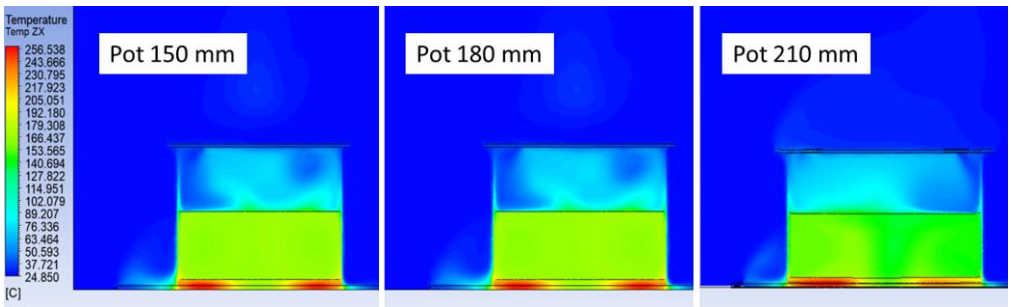

Fig. 4: Trend temperature for different type of pot at the end of preheating phase.

To determine the validity of the virtual model, the comparison with experimental tests are provided. Tab. 1., shows the result obtain with virtual and physical test. The result refers to the energy consumption tests of the real product under analysis. A good correspondence, both in terms of the maximum power values and the energy consumed during the test is noticed (max error = 3% for the 180 [mm] pot).

	Pot 150 [mm]			Pot 180 [mm]			Pot 210 [mm]		
	Virtual test	Real test	Err %	Virtual test	Real test	Err %	Virtual test	Real test	Err %
Max Power [W]	2640	2674	1.29	2500	2580	3.2	2353	2384	1.31
Energy consumption [Wh]	117.33	119.21	1.60	145.65	148.57	2.01	196.13	198.32	1.11

Tab. 1: Comparison between virtual and real test for 180 mm of coil and different type of pot.

Conclusions and Future Development:

This paper presented describes an approach to support designers during the design phase of household appliances. In particular, the aim of this paper is the definition of a methodological

approach able to replicate, through virtual prototyping tools, the real energy consumption test in accordance with the reference European normative.

A Multiphysics approach has been applied for the virtual analysis of both the electromagnetic behavior and the thermal fluid dynamic one. Virtual analyses (FEM and CFD) have been compared with real experiments and a gap of 3% has been noticed. By measuring the energy absorbed during the test of energy consumption it has been possible to quantify the energy class of the analyzed product. Through the analysis of the results, the designers can identify which are the most influential parameters on product performance and consequently make the necessary adjustments and technical considerations (design actions).

The methodology proposed in the paper has been developed for induction hobs, but its structure is flexible, and it could be applied to different types of products whose operational phase is Multiphysics. Further works will consist in applying the general architecture of the proposed approach to other products, by the definition of specific models on the basis of the physical behavior to simulate.

References:

[1] Acero, C.; Carretero, I.; Lope, R.; Alonso, O. -L.; Burdio, J.-M.: Analysis of the mutual inductance of planar-lumped inductive power transfer systems, IEEE Transactions on Industrial Electronics, vol. 60(1), 2013, 410-420.

[2] Cadavid, F. F. J.; Cadavid, Y.; Amell, A.-A.; Arrieta, A.-E.; Echavarría, J.-D.: Numerical and experimental methodology to measure the thermal efficiency of pots on electrical stoves, Energy 73, pp 258–263, 2014.

[3] European Commission: Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products.

[4] Gogoi, B.; Baruah, D.-C.: Steady state heat transfer modeling of solid fuel biomass stove: part 1. Energy, 97:283e95, 2016. https://doi.org/10.1016/j.energy.2015.12.130.

[5] Hannani, S.K.; Fardadi, M.; Jeddi, M.-K.: Mathematical modelling of cooking pots thermal efficiency using a combined experimental and neural network method, Energy 31, 2006, 2969–2985.

[6] International Organization for Standardization (ISO), 2002. Environmental Management e Integrating Environmental Aspects into Product Design and Development. ISO 14062

[7] International Standard IEC 60350-2:2011, Household electric cooking appliances - Part 2: Hobs - Methods for measuring performance, Publication date 2011-12-16.

[8] Kshirsagar, M.-P.; Kalamkar, V.-R.: A mathematical tool for predicting thermal performance of natural draft biomass cookstoves and identification of a new operational parameter, Energy; 93:188e201, 2015. https://doi.org/10.1016/j.energy.2015.09.015.

[9] Landi, D.; Cicconi, P.; Germani, M.; Russo, A.-C.: A methodological approach to support the design of induction hobs, systems, design, and complexity, ASME International Vol 11, 2016.

[10] MacCarty, N-A.; Bryden, K-M.: A generalized heat-transfer model for shielded-fire household cookstoves. Energy for Sustainable Development 33:96-107, 2016. https://doi.org/10.1016/j.esd.2016.03.003.

[11] Sanz-Serrano, F.; Sagues, C.; Llorente, S.: "Inverse modeling of pan heating in domestic cookers, Applied Thermal Engineering, vol. 92, 2016, 137–148.

[12] Shi, M.-M.: An analysis of the realization of induction cooker power control, Journal Changshu Institute Technology 2, 2008, 76–78.

[13] Zhang, C.; Zheng, Y.-J.; Sun, Z.-F.: A fuzzy control method to obtain the steady output power in induction cooker power control, Advanced Materials Research vol. 732-733. https://doi.org/10.4028/www.scientific.net/AMR.732-733.965

[14] Zorrilla, S.-E.; Singh, R.-P.: Heat transfer in double-sided cooking of meat patties considering two-dimensional geometry and radial shrinkage, Journal Food Engineering, 57, 2003, 57–65.