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# ACOUSTIC CHARACTERIZATION OF AN INDUCTION COOKER

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## Abstract

Induction hobs have many advantages over other cooking appliance methods, including efficiency, controllability, and safety, but as drawback their sound power level is the highest, and this reason could be a deciding factor in the purchase of other conventional cooktops. Nowadays, it does not exist a standard procedure to evaluate the sound power level of an induction hob. Therefore, this work has been focused on analyzing the time evolution of the sound pressure emitted by an induction hob. At a semi-anechoic room, the tests were performed with two types of pots filled with 2 litres of water, and placed on the bigger cooking zone. During the heating of the water at maximum power, it was found that the evolution of the sound pressure level does not depend on the type of cookware. Once the sound pressure level was characterized, the next step was to evaluate the sound power emitted by the induction hob and the pot. The sound intensity emitted by these two elements, was measured with an intensity probe according to ISO 9614, and it was determined that the sound power was similar for both of them. In base to these results, it is necessary to improve the design of both elements from an acoustical point of view. The future work proposed is the identification of the noise sources of the induction cooker in order to know which component is responsible for its sound emission, and the theoretical analysis of different pots by means of noise prediction software.

## INTRODUCTION

More silent household appliances are being demanded by the consumers more frequently, so acoustic premises must be considered in the design of an appliance. There are international standards that set the procedure to obtain the sound power of many appliances and moreover the European Community ecolabel [1] establishes noise limits for products such as dishwashers, refrigerators, washing machines, vacuum cleaners, etc. The cooking appliances are not considered because the sound power level of the traditional methods is very low in comparison with the appliances mentioned previously. However, one of the last cooking appliances developed, the induction hob, although is more efficient and safe has a drawback, sometimes its sound is perceptible by the consumer. This technique is based on the flux of electrical current in the bottom of a pot of ferromagnetic material, (See Figure 1). This current is generated by an electromagnetic field produced by the inductors placed under the crystal of the cooker.

This paper first describes a procedure based on the measurement of the sound pressure to characterize the acoustic behaviour of the induction cooking technique. Finally, due to the fact that the induction hob only works if a pot lies on it, the sound intensity method has been applied to know the relative importance and contribution of the induction hob and the pot to the total sound power.

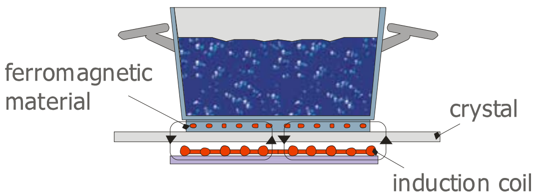


*Figure 1 – Induction cooking technique*

## CHARACTERIZATION OF THE SOUND PRESSURE LEVEL

As there are not standards to obtain the sound power emitted by an induction hob, first it is necessary to define the measurement requirements. An induction hob only works when a pot is placed on it, so the working conditions of the induction hob as well as the type of pot must be selected. In this case, it has been decided to heat at maximum power a pot placed on the bigger cooking zone. Two types of cookware of the same size, enamelled and stainless steel pots with sandwich bottom, have been analysed being each pot filled with two litres of water.

Under these conditions, at a semianechoic room the sound pressure level has been recorded with a microphone at position 1, according to ISO 3744 [2]. Initial measurements showed that the noise of the fan masked the rest, so during the tests the fan was switched off. The tests have been performed with three induction hobs, and three pots of each type. The induction hob is placed in a wooden cabinet to simulate its standard location in a kitchen.

Both pots behaved acoustically the same, as the pattern of the time evolution of the sound pressure level of Figure 2 shows. The lowest value is observed during the initial heating and the level is practically steady. Then, when the first bubbles appear, the sound pressure level rises sharply and reaches the maximum level that corresponds to the boiling phase. Finally, there is a slight drop.

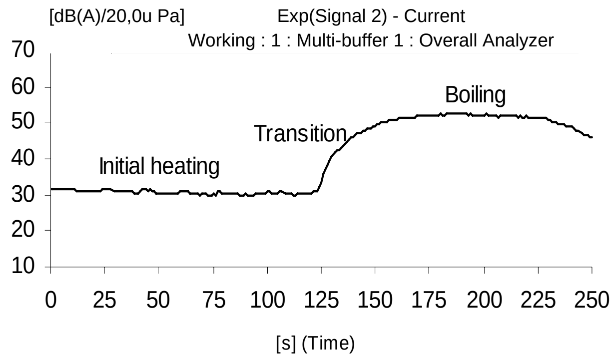


*Figure 2 – Sound pressure level pattern*

At initial heating the overall sound pressure level is about 20 dBA lower than the level at boiling stage, but consumer is used to hearing the noise due to the boiling and not the noise at initial heating, so this sound is also of concern in relation to the annoyance of consumers. In order to characterize the noise during both stages, one third octave band frequency analyses are performed.

Figure 3 compares the sound pressure spectra recorded from 80 to 100 s (initial heating) with the recorded one from 180 to 200 s (boiling). Preliminary analysis were made from 125 Hz to 20 KHz third octave bands, but the total sound pressure is very similar to the value obtained for the analysis carried out from 125 Hz to 8 KHz, as Table 1 shows. So the frequency range considered, as it is stated by the standards [3] about noise of household appliances, is from 125 Hz to 8 KHz.

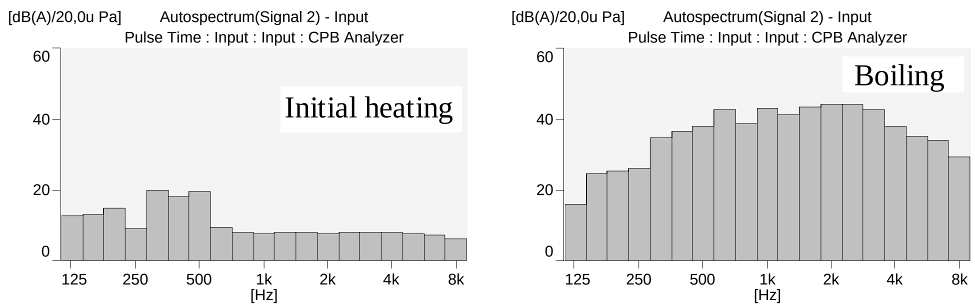


*Figure 3 – One third octave band sound pressure spectra*

At initial heating the values from 315 Hz to 500 Hz are the most noticeable, being the corresponding sound pressure 23,7 dBA. The values from 800 Hz to 8 KHz are irrelevant (See Table 1). When water boils, the maximum sound pressure levels are produced in the frequency range from 600 Hz to 4 KHz, where the level of all bands has increased more than 30 dBA. The values from 5 KHz onwards, are negligible as Table 1 shows.

*Table 1 – Total sound pressure (dBA)*

| Stage | 125 Hz÷8 KHz | 125 Hz÷20 KHz | 800 Hz÷8 KHz | 5 KHz÷8 KHz |
|---|---|---|---|---|
| Initial heating | 25,7 | 25,8 | 18,2 | - |
| Boiling | 52,3 | 52,3 | - | 38 |

A more detail FFT analysis, (bandwidth = 1 Hz) is depicted in Figure 4.

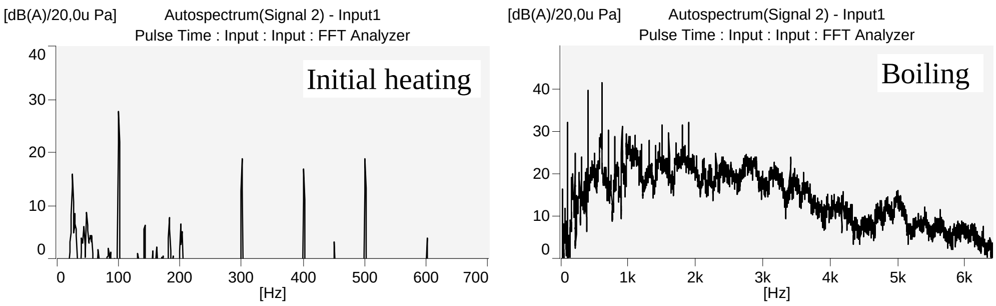


*Figure 4 – FFT sound pressure spectra*

During the initial heating, it can be observed harmonic components at 100, 300, 400 and 500 Hz, emitted mainly by the induction cooking itself, because the forces are modulated to a frequency equal to 100 Hz, twice the current frequency. When water boils emits broad band noise and in addition the interaction of water with the pot can also lead to the production of broad band noise as well as pure tones due to structure-borne noise produced by the vibration of the pot. The next step is the evaluation of the noise produced by each one of the elements that take part in the heating process.

## ANALYSIS OF THE SOUND POWER

In order to rank the sound power emitted by the pot and by the induction hob the sound intensity technique [4] has been applied. Sound pressure measurements allowed the definition of the significant frequency range from 125 Hz to 4 KHz, so an intensity probe with a spacer of 12 mm can be used. The surfaces considered are:

- the crystal of the induction cooker and the cabinet where it is placed
- the sides of the pot
- the top of the pot

The scanning of these areas let us obtain the sound intensity level, $L_I$, emitted by the induction cooker, the vibration of the pot and the water, respectively. Equation 1, let us work out the sound power level, $L_{wi}$, for each surface.

$$L_{wi} = L_I + 10 \log \frac{S}{S_o} \qquad (1)$$

, where S [$m^2$] is the area of each surface and $S_o$ equal to 1 $m^2$ is the reference area.

Sound intensity measurements have been performed during the two previous stages observed in the analysis of the sound pressure: initial heating, and boiling of the water. Table 2 shows the mean sound power emitted by each element.

It must be taken into account that the cabinet was empty and without door, so sound from the bottom of the induction cooking could freely travel outside it. For a standard working condition an oven or a closed cabinet is under the induction cooker, therefore the sound power level of the cabinet will be lower than the one obtained.

*Table 2 – Sound power (dBA)*

| Stage | Induction cooker | | | Pot | | |
|---|---|---|---|---|---|---|
| | crystal | cabinet | total | sides | top | total |
| Initial heating | 29,6 | 35,4 | 36,4 | 25,4 | 22,8 | 27,3 |
| Boiling | 54,9 | 55,7 | 58,2 | 51,3 | 49,8 | 53,6 |

At initial heating as well as at boiling, the sound power level obtained for the crystal is slightly higher than the level of the pot, so the contribution of both elements to the total sound power is relevant and any of them can be ignored in the task of reducing and improving the sound power level due to the induction cooking technique. Finally, the sound power level emitted by the sides of the pot points out that the structure-borne noise caused by the pot vibration is important.

## NOISE BLOCK DIAGRAM

Based on the components of the induction hob and on its working principles, Figure 5 shows the flow diagram developed to illustrate how noise and vibration can be generated within the induction hob and transmitted to the pot.

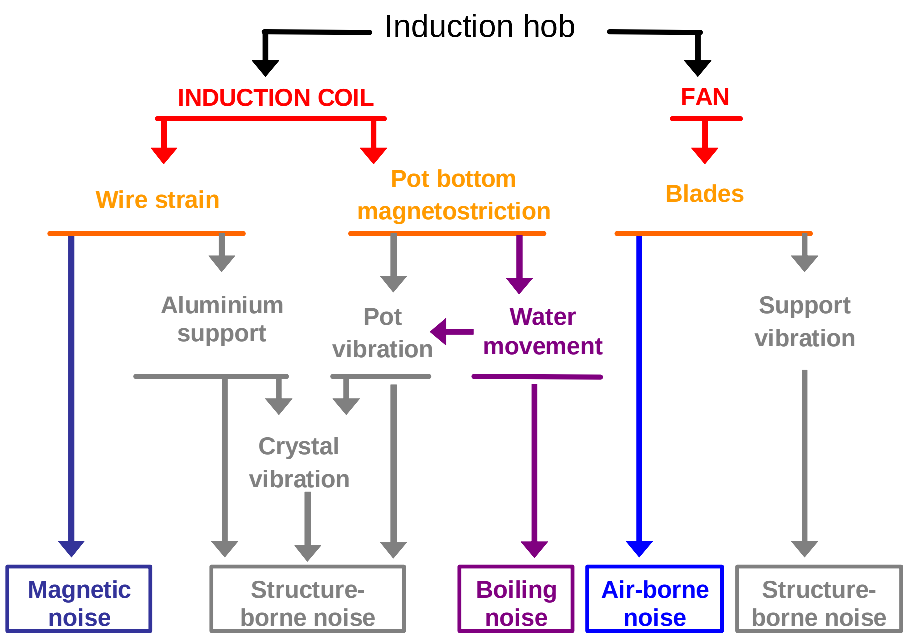


*Figure 5 – Noise generation. Transmission flow chart*

Two noise sources exist within the induction hob, the fan and the induction coil. This work has not taken into account the noise due to the fan because the target was the analysis of the noise due to the induction process, but it is an additional noise source that can be independently characterized. Preliminary tests showed that the fan sound pressure level was equal to 42 dBA, and this level can not be neglected if the fan works during initial heating. To reduce transmission of the fan noise outside the induction hob, shape and number of blades, air flow path and location of the fan must be studied and optimised. The induction coil generates electromagnetic noise due to the wire strain, and in addition it induces the vibration of the aluminium base that supports it. Moreover, structural noise can be produced by the vibration of the crystal and by the excitation of the bottom of the pot. The evaluation of the structure-borne noise requires the application of the selective intensity technique, to rank the contribution of the noise radiated by the vibration of each element to the total sound power.

Finally, boiling of the water tends to generate broad band noise, and the impact of the water against the pot generates vibrations which may be amplified by structural resonances causing noise from the pot. The pot structural dynamics depends on its natural frequencies, mode shapes, and damping coefficients. Noise prediction software will let us compare and rank different pots in terms of noise optimization, and design a pot whose natural frequencies are well away from the driving frequencies.

## CONCLUSIONS

As there are not standards to obtain the sound power emitted by an induction hob, the sound pressure level due to the heating of a pot filled with two litres of water has revealed two significant stages, initial heating and boiling.

Although at initial heating the noise emitted is not high in comparison with other appliances, consumers are not used to it so this sound is also of concern in relation to the annoyance of consumers.

The analysis of the sound power has shown that the noise emitted during the cooking process is caused by the induction cooker as well as by the pot, therefore both elements must be optimised from the point of view of noise emission.

Future work will be focused on the identification of the noise sources of the induction cooker in order to know which component is responsible for its sound emission, and in the theoretical analysis of different pots by means of noise prediction software. This work must be complemented with the development of a method that relates the objective characteristics to the psychoacoustic attributes of the sound.

## REFERENCES

[1] Regulation (EC) No 1980/2000 of the European Parliament and the Council of 17 July 2000 on a revised Community eco-label award scheme

[2] ISO 3744:1994, Acoustics- Determination of sound power levels of noise sources using

sound pressure- Engineering method in an essentially free field over a reflecting plane

[3] UNE-EN 60704-1:1998, Código de ensayo para la determinación del ruido aéreo emitido por los aparatos electrodomésticos y análogos

[4] ISO 9614-2:1996 Acoustics, Determination of sound power levels of noise sources using sound intensity -Part 2: Measurement by scanning