Applied Acoustics 89 (2015) 234–243

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Identification of crack noises in household refrigerators

Hasan Koruk [a,b,*], Ahmet Arisoy [b,c]

[a] MEF University, Mechanical Engineering Department, 34396 Istanbul, Turkey
[b] EDA Enerji Dinamik Akustik Ltd., ITU Teknokent, 34469 Istanbul, Turkey
[c] Istanbul Technical University, Mechanical Engineering Department, 34437 Istanbul, Turkey

ARTICLE INFO

Article history:
Received 14 February 2014
Received in revised form 1 September 2014
Accepted 3 October 2014

Keywords:
Crack noise
Household refrigerator
Overall analysis
Frequency spectrum
Temperature change

ABSTRACT

The crack noises propagating from a refrigerator disturb residents in a household; however, the reasons behind the mechanisms of such noises have not been identified yet. In this study, the crack noises in modern household refrigerators are identified and their root causes are explored. The appropriate parameters for overall and Fourier analyses are first determined and the noise characteristics of typical household refrigerators under various conditions are presented. Then, a special test rig providing remote control of the subcomponents including the compressor, fan and heater is designed and structural acceleration and sound pressure measurements inside and outside the test rig in a quiet room are performed. The acoustic and vibration measurements are conducted under various conditions by separately controlling each subcomponent. The crack noises in typical household refrigerators are identified and their root causes are explored by using the results of the overall and Fourier analyses. Some solutions to minimize the crack noises in household refrigerators are also summarized.

1. Introduction

Vibration and acoustic behavior of domestic appliances are becoming increasingly more important as these commodities are linked with life quality and customer satisfaction [1–4]. Furthermore, noise and vibration levels perceived by consumers are frequently recognized as a measure of overall quality of domestic appliances [1,2,5]. Unlike other home appliances, refrigerators operate all day and users respond sensitively to the noise they generate. It is reported that more than half of the inhabitants are annoyed by refrigerator noise [5]. The inhabitants are more annoyed with the unsteady fluctuating noises as compared to the steady operating noise [1–3,5–6]. It should be noted that the impulsive type noises are common in modern refrigerator models [7,8] and such crack noises affect the sound quality of the product [8–11]. Especially, during sleeping hours due to natural decrease of the background noise, the noise emitted by a refrigerator could be very annoying.

There are many studies on the main noise sources of refrigerators such as compressor [12] and fans [13] and operating phases of a refrigerator such as start-up, steady state and ending [2]. Identification and quantification of the compressor and fan noises is relatively straightforward as the positions and the properties such as rotation speeds, and number of blades, of these components are known and the exact contributions of these components can be identified by using the frequency spectrums measured by operating each component separately. However, the crack noises, a serious problem of today's no-frost (modern) refrigerators, have not been identified and the root causes of such noises have not been explored in the literature [13–15]. This paper attempts to fill this void with a controlled experimental study and by analyzing a huge number of structural acceleration and sound pressure measurements conducted in a quiet room (representing a kitchen of a typical house) using a few refrigerators and a special test rig under various conditions. Based on the main findings, some solutions to minimize the crack noises in household refrigerators are also summarized.

2. Problem formulation

The exact components (or subcomponents) propagating the crack noises in household refrigerators are not known although the crack noises can be heard by ear and measured by a microphone outside a refrigerator in practical measurements. Furthermore, the reasons behind the mechanisms of such burst type noises are not well known. The noise characteristics including the crack noises in household refrigerators are first presented to reveal the existing state. Then, a special test rig providing remote

* Corresponding author at: MEF University, Mechanical Engineering Department, 34396 Istanbul, Turkey. Tel.: +90 2123953600.
E-mail addresses: korukh@mef.edu.tr (H. Koruk), arisoyah@itu.edu.tr (A. Arisoy).

http://dx.doi.org/10.1016/j.apacoust.2014.10.002
0003-682X/

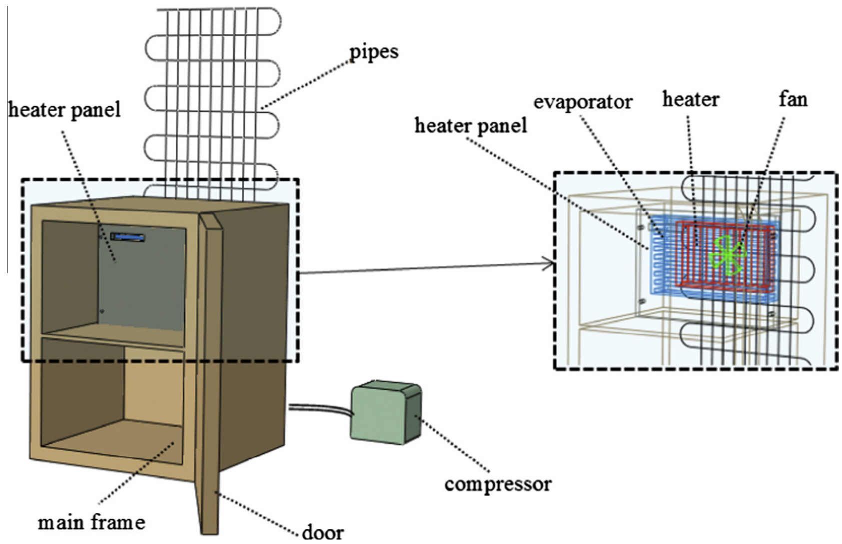

Fig. 1. The schematic of the test rig including the subcomponents.

and separate control of each subcomponent (i.e., the compressor, fan and heater) is designed to identify the crack noises in household refrigerators. The unnecessary components (or parts) creating difficulty to identify the crack noises with good reliability are excluded from the test rig designed here. The test rig includes mainly half of a refrigerator airframe, a compressor, a fan, a heater, an evaporator and cooling pipes. The schematic of the test rig including the subcomponents is shown in Fig. 1. Both structural acceleration and sound pressures are measured inside and outside the test rig in a quiet room representing a kitchen of a house. The temperature measurements on the surface of the heater are also conducted. The sensor positions where the measurements include structural acceleration (a), sound pressure (p) and temperature (T) are shown in Fig. 2 where a_1, a_2 and a_3 are the acceleration levels measured on the heater, inside and outside panels, respectively, and p_1, p_2 and p_3 are the sound pressures measured inside the cabinet and at some points close to the evaporator and compressor, respectively.

The time signals of both structural acceleration and sound pressure are first recorded with a high sampling rate ($f_s = 2^{15} = 32.8$ kHz) and the overall and Fourier analyses of the signals are performed as a post processing phase [16,17] later. The use of exponential averaging (i.e., the use of exponential time weighting) for continuous non-stationary signals is very common in acoustic measurements [18]. The overall value of a time domain sound pressure signal based on exponential averaging with time weighting τ at any time t is determined as follows:

$$p_\tau(t) = \sqrt{\frac{1}{\tau}\int_{-\infty}^{t} p^2(\xi)e^{-(t-\xi)/\tau}d\xi} \quad (1)$$

where $p(\xi)$ is the instantaneous time varying sound pressure and ξ is a dummy variable of integration. The overall value of the structural acceleration a (or displacement x and velocity v) is also calculated using Eq. (1) by interchanging p with a (or x and v). The value of the exponential time weighting τ should be small enough to capture the amplitudes of cracks with high accuracy. The overall sound pressure level for a given τ value as a function of time t is finally calculated as follows:

$$L_{p,\tau}(t) = 10\log[p_\tau^2(t)/p_0^2] \quad (2)$$

where $p_0 = 20$ μPa is the value of the reference sound pressure. The Fourier Transform (FT) of the time domain $p(t)$ signal is conducted as follows [17]:

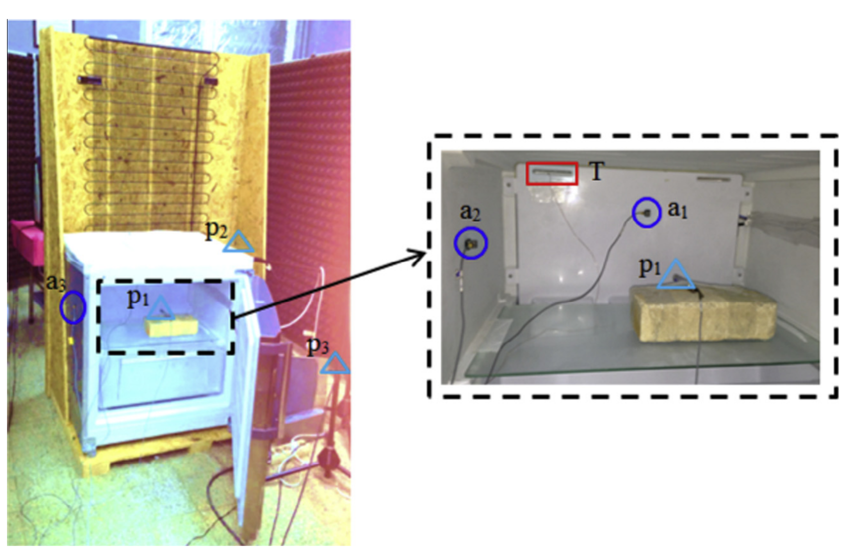

Fig. 2. Sensor positions where the measurements include structural acceleration (a), sound pressure (p) and temperature (T).