Vibro-Acoustical Analyses of a Dishwasher

Serkan Atamer, M. Ercan Altinsoy, Johannes Hirschfeld
Chair of Acoustic and Haptic Engineering, TU Dresden, 01062, Dresden
E-Mail: serkan.atamer@tu-dresden.de

Introduction

Quiet products are increasing their market share due to the limiting regulations, lawsuits and increased sensitiveness on noise emission from household appliances. Especially with the changing home layouts in recent years by imposing modern kitchens with open spaces directly connected to the living rooms, noise exposure from the kitchen white goods such as dishwashers are increasing. A recent study from Olvera et al. [1] gives an overview of the increased market share of the quiet products and possible reasoning behind. Recent years with the introduction of Energy Labels [2] consumer behavior changed drastically since the labelling gives easy-to-reach information for the buyers related to the efficiency of the device. Energy Label also includes the overall sound power level of the equipment, which is an important but not sufficient tool for characterization the human perception of appliance noise. Sound power level estimations brought the market to the point that the awareness is increased, however, there is still room to be investigated especially from the psychoacoustical perspective which is focusing on the perceptual dimensions of the appliance noise rather than describing it in overall levels by considering the temporal and frequency dependent aspects of noise. Altinsoy and Atamer's recent work [3] gives insights on developed Sound Labels for household appliances based on psychoacoustic properties of noise and characterization of household appliance noise with listening tests. Though, it is quite important to understand the noise generation mechanism of a dishwasher more in detail in order to have more reasonable generalizations on perceived noise and possible future improvements of dishwasher noise.

Dishwasher Noise

Although publicly available literature on dishwasher acoustics is limited since most of the research done is confidential company information, there are still some important studies focusing on the dishwasher noise. Study of Sanchez and Llado [4] mainly focuses on the intensity mapping of an example dishwasher with bituminous plates and acoustic blankets and focusing on the lower kick plate region where acoustically critical. The M.Sc. thesis of Haglund [5] is focusing on the noise reduction solutions for a compact dishwasher, giving insights on basic hydraulics and vibration isolation improvements on pump vibrations. Also, the study of Lee and Park [6] aims at decreasing the noise levels of a dishwasher in a defined cost space by using active noise control method.

Dishwasher noise can be better understood by examining the main mechanical components. A dishwasher can be investigated in three main parts. The first one is a tub, metal structure where the rotating arms and baskets are placed and where the washing takes place. The tub is covered with an enclosure, which is the second main structural component of a dishwasher. Enclosure hides the mechanical elements and sound insulation materials and giving the dishwasher the final look. Lastly, usually underneath the tub in a volume, covered by the enclosure, all the mechanical elements required for the washing are standing. This is the third important part of a dishwasher.

Washing takes place in the tub, where the water is hitting the tub surface generating structure-borne noise. Vibrations can be transferred to the enclosure since tub and enclosure are mechanically coupled with each other. Lastly, all the mechanical elements are fixed to the tub structure generating a secondary structure-borne noise path. Besides these structure-borne noise paths, there are also direct airborne noise paths to be considered.

Recordings of an example dishwasher are done in a semi-anechoic room with a reflective floor surface by a defined "user-position" being at 1.6 m height and 1 m away from the dishwasher. Water pressure is controlled with a pressure regulator to be kept as 3 bars. For this particular study, devices are recorded in the unloaded case. During the recording, MDF (medium-density fibreboard) housing is used to represent kitchen structure as defined in international standard EN 60704-2 [7] (Figure 1). A 50°C ECO program, usually adopted for any kind of technical studies related to dishwashers, is taken into account. Figure 2 shows an example spectrogram of an overall washing cycle. For this particular dishwasher, noise lies between 50 Hz – 3 kHz region. For the "acoustically treated" dishwashers, it is usually the case that more than 3 kHz range is already quite low that it is below the hearing threshold.
Although it might be different for different brands/units, usually, modern dishwashers start the washing cycle with water drainage. That is to make sure that any excess water stayed in the machine from the last washing cycle is pumped out. For cases where there is no excess water from the last washing, the drainage pump has to work in "dry" conditions, making a distinctive tonal noise. Figure 3 shows the example of water drainage spectrogram. It can be seen in the highlighted portion that the pump is working almost 30 seconds in "dry" conditions, yielding in higher levels with tonal characteristics. Afterwards, the washing starts with water intake. The washing noise of a dishwasher shows distinctive patterns (Figure 4). It has a quasi-stationary characteristic, as can be described in repetitive impulses with equal time distances in between. The overall level and the frequency content of a washing noise mainly dominated by two factors: the functioning spray arm and the rotational speed of the spray arm. Different spray arms yields in different noise emissions in different rotational speeds. At the end of the washing, drying takes place. The drying portion is relatively quieter than the washing portion, however, due to the characteristics of the fan being used for drying, it might have distinctive tonal components (Figure 5).

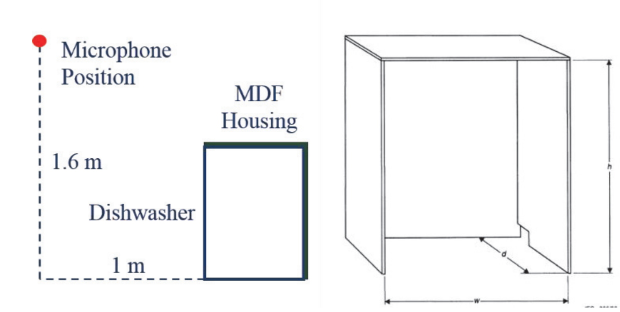

Figure 1: Measurement position and MDF housing defined in [7]

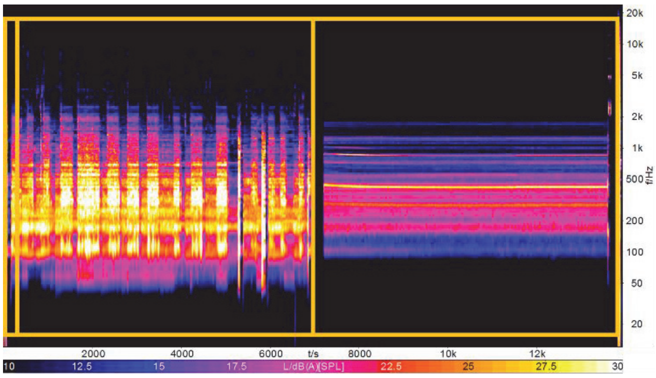

Figure 2: Spectrogram of overall washing cycle of an example dishwasher, ECO program. Three distinctive portions: water drainage, washing and drying. (A-weighted, Spectrum size: 4096)

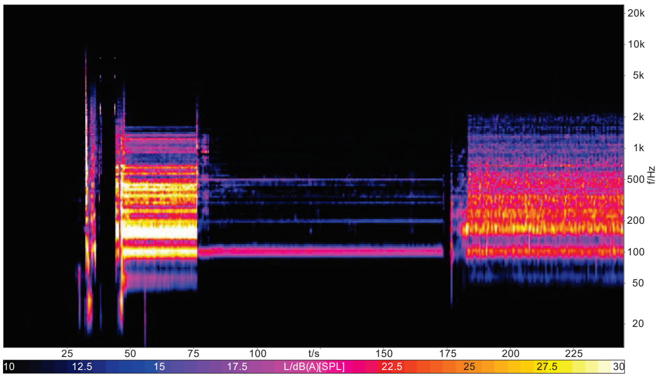

Figure 3: Drainage noise. (A-weighted, Spectrum size: 4096)

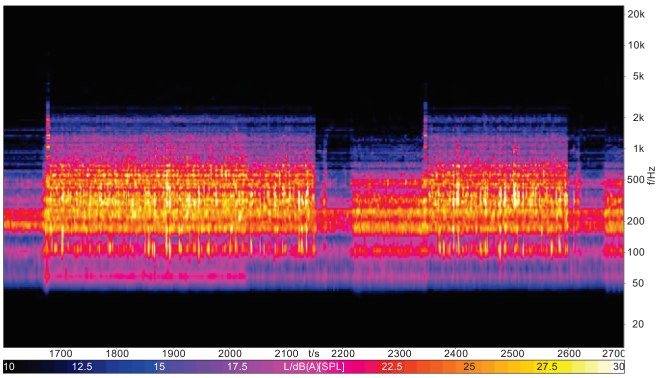

Figure 4: Washing Noise. (A-weighted, Spectrum size: 4096)

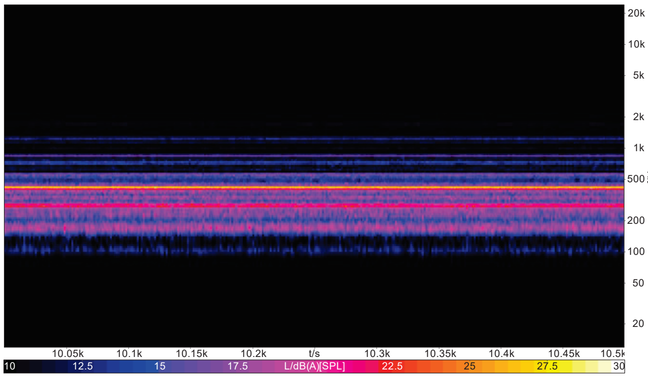

Figure 5: Drying noise. (A-weighted, Spectrum size: 4096)

Operational features and noise characteristics of dishwashers are intensively described in [8], especially focusing on the effect of different noise treatments in overall levels. Frequency components and overall sound levels of dishwashers are based on rotational speed of the spray arms, type and design of spray arms, amount of water usage, amount of dishes loaded in device, resonance frequencies of the tub, amount of isolation material used, type of pump used, mounting of the pumps and so on.

Noise Paths of a Dishwasher

There are three main working machinery in a dishwasher which vibrates during working. They are drainage pump, inlet pump and fan. For European-type devices, drainage and inlet circulation pumps are separated while most of the American manufacturers use the same motor for both tasks by changing the direction of rotation.

Eventually, vibrations generating from these machinery is transmitted through mechanical coupling to the tub, which is eventually connected to the enclosure. That generates a structure-borne noise path and described with the red arrow in Figure 6.

Moreover to that, as the inlet pump circulates the water to the piping, that flow might be in the turbulent phase, generating vibrations through piping, eventually connected with the tub. Afterwards, the circulated water is sprayed out through the nozzles of spray arms and hitting the tub surface and making it vibrate. This generates another structure-borne path and also shown with red arrows in Figure 6.

For all of the structure-borne noise paths, tub and enclosure modal characteristics are important. The amount of bitumen material applied to the tub structure contributes a significant effect on overall noise characteristics. Moreover, the cavity between the tub and the enclosure and the amount of absorbing material used within the cavity can also show a significant effect on the noise levels.

Lastly, all of the mechanical elements can also have direct airborne noise paths which are shown in green arrows in Figure 6.

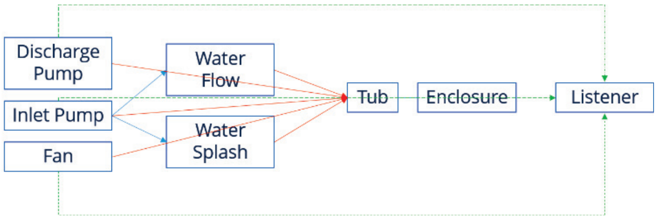

Figure 6: Possible noise paths in a dishwasher, green showing the airborne, red showing the structure-borne noise paths.

Noise Contribution Analyses

Spray Arms

Different spray arms yields in different noise characteristics. Figure 7 shows the acceleration levels of the middle point of the front enclosure surface for the first 530 seconds. Within this first portion, it is possible to observe the main characteristics of dishwasher noise: the upper spray arm, the nozzle at the top (might not be available for every brand/unit), and the lower spray arm. Usually, the lower spray arm generates more noise due to the impact angle of sprayed water and the higher water pressures in lower spray arms. For the acceleration values, it can be clearly observed that the lower spray arm values are higher. Moreover, it is shown in Figure 8 that the lower spray arm generates more noise, as the noise of each spray arm evaluated separately.

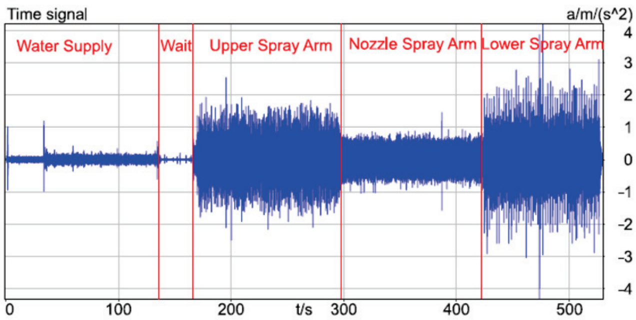

Figure 7: Acceleration values of the first 530 seconds, measured on the mid-point of the front enclosure.

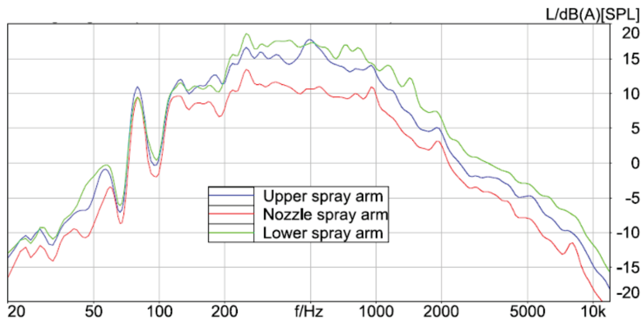

Figure 8: Comparison of the measured A-weighted sound levels for different spray arms. (Spectrum size: 4096)

Pump Vibrations

Roughly speaking, although there are other components yielding in the overall noise of dishwashers, perceived noise of a dishwasher can be described in two main parts, namely, the vibrations transferred from the pump to the body and the eventual water splash to the tub surface. It is aimed within this study to understand the effect of these two components more in detail by separating their effect mechanically from each other. For the first try, the pump is disconnected from the tub and moved to the outside of the dishwasher and connected to the dishwasher with extra piping. Figure 9 shows schematically the methodology. The rotational speed of the spray arms are measured for the original and modified case and no significant changes are observed. The fact that spray arms rotate passively due to the water pressure generating momentum at the nozzle, it can be referred that there is negligible head loss to the system due to the added piping. (Figure 10)

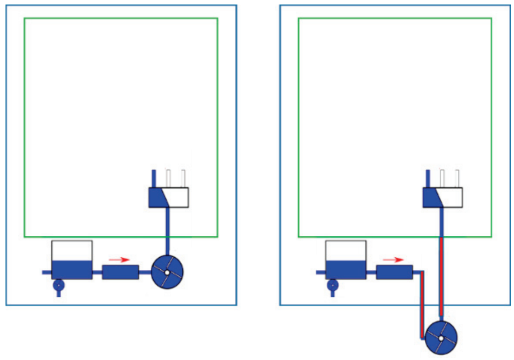

Figure 9: Pump noise vs. splash noise: Decoupling the pump from the system.

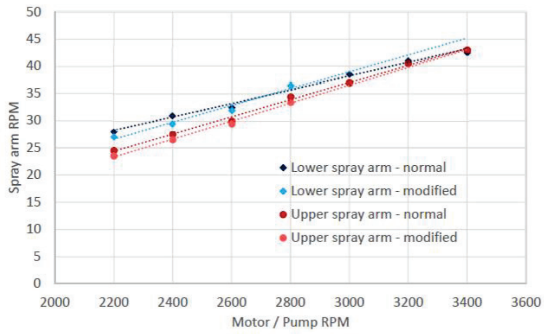

Figure 10: Rotational speeds of spray arms for original and modified machine.

After the modification, for this particular example device, no change in overall levels observed. Overall levels for lower spray arm rotation for the original and modified machine is given in Figure 11. The pump isolation hangers are well designed in this particular device, such that the pump was already decoupled from the system in original form.

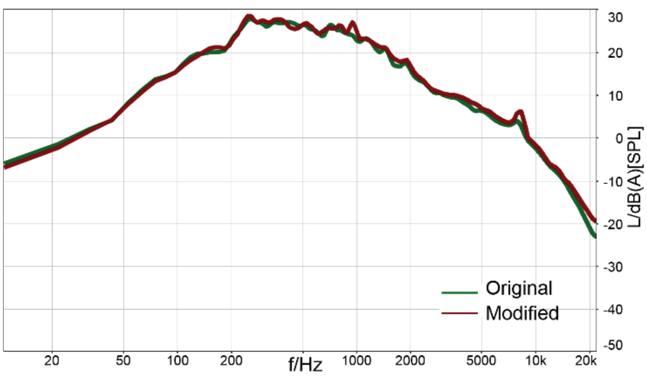

Figure 11: Results after the first modification, where the pump is decoupled from the system

Water Splash Noise.

After the first modification, it is aimed within this study to observe the effect of the water splash noise separately. For this reason, as described in Figure 12, lower spray arm is taken out and extra piping is introduced to the system to shortcut the lower spray arm opening and the water tank, such that the water recirculation is kept without any water splash to tub during the rotation of the lower spray arm.

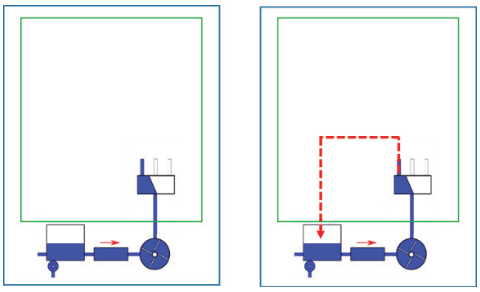

Figure 12: Pump noise vs. splash noise: Decoupling the water splash from the system

Figures 13 and 14 show the results obtained from the second modification. It is obvious that, after 100 Hz, most of the components are disappeared, only around 100 Hz component stayed the same. These results show the importance of water splash noise and its dominance in the overall noise of dishwashers.

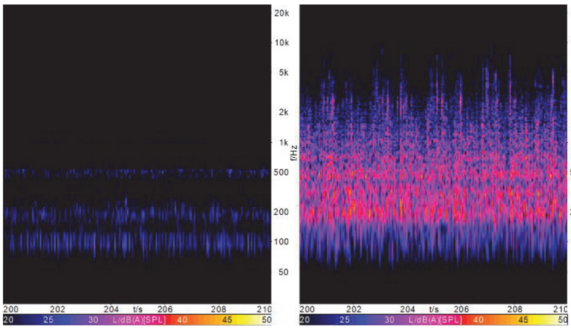

Figure 13: Results after the second modification, where the water splash is decoupled from the system.

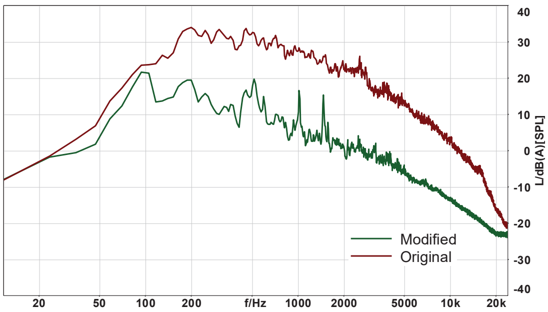

Figure 14: Results after the second modification, where the water splash is decoupled from the system.

On Water Splash Noise

It is found out that the water splash noise is the most important noise component in a dishwasher when the proper isolation and damping measures are taken. At this point, it is important to understand the mechanism of water splash noise. One study is carried by using the increased rotational speed of the inlet pump used in the device, which has 6 different rates, being increased in each segment. Figure 15 shows the calculated loudness values of different RPM values. The overall loudness of the device increases drastically with increased RPM values.

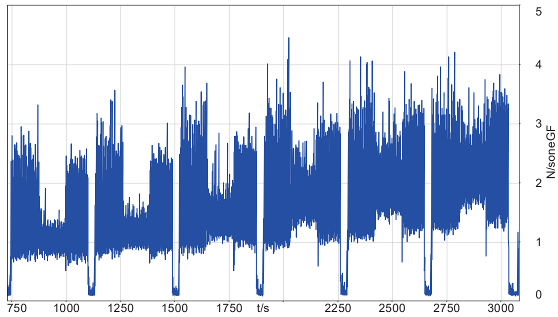

Figure 15: Results after the second modification, where the water splash is decoupled from the system.

Conclusions

The main noise components of a dishwasher are discussed in this study and the separate effect of pump vibrations and water splash is investigated separately. It is found out that, when the pump isolation design is successful, the only remaining component in a dishwasher noise is the water splash noise. Water splash noise is increased with the increased rotational speed of the pump, hence increasing the flow rate of the water coming from each nozzle of spray arms. Importance of the water splash is emphasized and detailed work on water splash noise mechanism is planned as future work.

References

[1] Olvera, E., Bruce, R. D., Young, A., Bommer, A., & Harwell, I. (2016). “What Causes Quiet Products to Come to Market?” Sound & Vibration.

[2] EU Regulation No: 1059/2010 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of household dishwashers

[3] Altinsoy, M. E., & Atamer, S. (2018). “Sound Label for Household Appliances”. ASME 2018 Noise Control and Acoustics Division Session presented at Internoise 2018

[4] Sanchez, B., & Llado, J. (2000). “Determination of sound sources in a dishwasher”. Internoise & Noise-Con Congress and Conference Proceedings (Vol. 2000, No. 3, pp. 4172-4177).

[5] Haglund, P. (2013). “Noise reduction solutions for compact dishwasher”. M.Sc. Thesis.

[6] Lee, N., & Park, Y. (2016). “Active Noise Control for Dishwasher Noise”. Journal of Physics: Conference Series (Vol. 744, No. 1, p. 012189).

[7] DIN EN 60704-2-3: “Elektrische Geräte für den Hausgebrauch und ähnliche Zwecke – Prüfvorschrift für die Bestimmung der Luftschallemission – Teil 23: Besondere Anforderungen für Geschirrspülmaschinen”

[8] Oztürk, C. (1996) “Development of efficient treatment methods to reduce the noise level of dishwashers.” The Journal of the Acoustical Society of America (100.6: 3986-3989)