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INVESTIGATION ON THE NOISE EMISSION MECHANISM OF PC KEYBOARDS

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ABSTRACT

The noise emitted from information technology (IT) machines is one of the main annoying sound sources in office environments. Although recent research has aimed at reducing the noise emitted by personal computers (PCs) no major effort has been invested with the study of the characteristic and reduction of the noise emitted by PC keyboards.

This paper studies the noise emitted by PC keyboards in order to give indications and provide strategies in order to reduce such noise. The main objectives of the research are: 1) suggesting an experimental repeatable way to measure the noise emitted from a keyboard; 2) characterising keyboard noise; 3) identifying possible sources of noise in order to understand the ways of possible intervention.

A test rig has been built in order to generate repeatable tapping of the keys which resembles human tapping. Force, acceleration of the key and noise have been recorded and analysed. Noise emitted by different keys and different keyboards have been also compared.

The designed test rig has proved to be a reliable tool to measure and study the noise emitted by IT keyboards. The spectral investigation showed that the maximum noise contribution is due to the impact of the key with the base of the keyboard, and to the free oscillation when the key is released. It is also shown that the keyboard structure contributes to the noise radiation.

1. INTRODUCTION

Although background speech is the major contribution to the noise of office environments, it has been proved that the prolonged exposure to keyboard noise may causes annoyance [1]. Despite this, previous studies into the noise from personal computers and office equipment noise have mainly focused on the noise emitted from hard drives and cooling fans. Only a few studies can be found specifically targeted at the noise emitted by keyboards. Arendt [2] has recently presented an investigation into keyboard noise emissions. One of the main objectives of this study was to demonstrate which effect has the typist on the actual measured sound pressure. Different keyboards were tested by a number of different typists. Results showed a low level of reproducibility because of the typist influence. In order to reduce this influence it is suggested to average the measurements from several typists. Such way of measuring keyboard sound pressure, although it tries to reproduce the actual working conditions, does not provide an objective measure of keyboard noise. Moreover this testing is expensive and time consuming.

The noise emission test code for IT equipment ECMA 74 [3] gives vague indications on how to realise a typing robot and on how to carry out tests on keyboards, but these indications do not seem supported by scientific evidence. Also no attempt to identify the causes of noise emission has been presented before. We feel then there is still the necessity of defining an objective and repetitive way for keyboard testing.

Interest in keyboard noise emission has also been expressed in the security sector [4], in which a quiet or homophonic (i.e. each key produces the same sound profile) keyboard would be welcomed. However, no previous study has yet been undertaken on the description of the noise emission mechanism of IT equipment. On the contrary, the ergonomic and biomechanics of typing on a keyboard has seen a great amount of literature in the last fifty years [5-6].

The aim of this research is to understand in detail the mechanism of sound generation when the key of a keyboard is depressed by a finger in the manner of a typical person typing. Furthermore, to use this information in order to reduce or modify its sound radiation. We will show that the dynamic response of a key as it forced by the typical force profile of a finger is complex. Its subsequent sound radiation is correspondingly complex comprising different transient events during a typical key cycle. An experimental measurement method is proposed for testing keyboard noise that uses standard laboratory equipment, is objective and repeatable. The characteristics of the keyboard noise are reported.

2. DESIGN OF THE TEST RIG

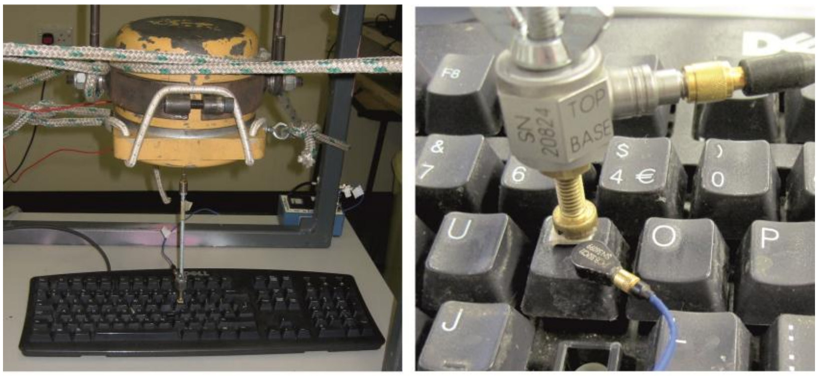
This section shows the test rig designed to generate repeatable keystrokes which resemble human tapping. Together with the equipment and settings, the characteristics of a common keystroke will be described.

2.1 Experimental Setup

Figure 1 shows the test rig designed and constructed to investigate the noise from PC keyboards. In order to strike a key of the keyboard in a repeatable manner a shaker was used with a maximum vertical stroke of 1 cm. The shaker was suspended from a metal frame by bungee chords and carefully placed with its axis perpendicular to the plane of the keyboard. In order to approximately simulate the compliance of a typical finger the tapping element that strikes the key was covered with a thin layer of rubber. The tapping element is driven by the shaker through a stinger, a steel threaded bar (M5). The threaded bar has been used to extend the excitation axis. A force gauge (PCB 208C01 SN 19040 sensitivity 1114mV/N) was used between the threaded bar and the tip (see Figure 1(b)) to monitor the time variation of force applied to the key. The excited key was also instrumented with an accelerometer (PCB 352C22 SN 47030 sensitivity 954 mV/g) in order to record the time varying acceleration of the key as it is struck repetitively by the tapper. A standard inexpensive commercial keyboard, DELL RT7D20, was used for the test, as shown in Figure 1. Finally, a microphone (PCB 377B11 SN 305663) was placed at a distance of 5cm from the key to record the noise emissions from the keyboard.

The signals from the force gauge, accelerometer and the microphone were simultaneously recorded for a duration of 6s at sampling frequency of 24 kHz. The microphone was inclined of 45 degrees with respect to the axis of the shaker. The shaker was driven with a sinusoidal signal with frequency of 6.4 Hz with an amplitude that produced a vertical stroke of approximately 4 mm.

Before each recording, the vertical position of the shaker and the amplification of the shaker driving signal were adjusted so that the force history applied by the tapper to the key resembled as close as possible that reported in Figure 2, which has been shown to be characteristic of that during typing [5].



(a) (b)

Figure 1. Apparatus setup (a) a shaker is used to tap the keyboard (b) key “I” and tip are instrumented

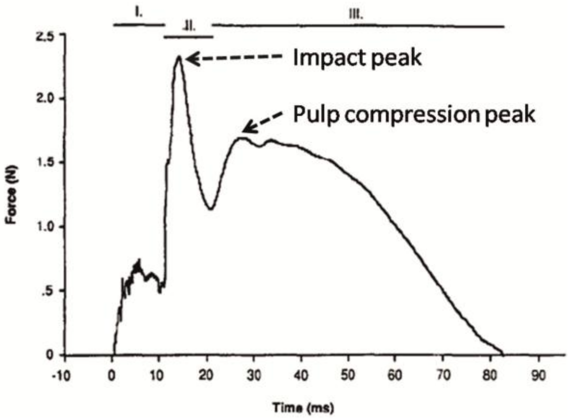


Figure 2. Typical fingertip force time history; taken from [5].

2.2 Fingertip force time history

Figure 2 shows the force applied to a key during a typical keystroke taken from the paper by Rempel *et al* [5].

Three separate phases can be distinguished during a single keystroke:

I. Keyswitch compression

During phase I the finger comes in contact with the key. The key does not move until the force reaches the key resisting force. During the phase I the key moves from the resting position down to the fully pressed position. During the motion, the recorded force is constant and equal to the resisting force of the key (about 0.6 N).

II. Impact

During the second phase the key has reached the end of stroke and the force peaks (impact peak in the Figure).

III. Fingertip pulp compression and key release

After the peak the key starts moving backward and it bounces back against the finger and the force reaches a second peak, called pulp compression peak in Figure 2.

Rempel *et al* [5] showed that the mean peak forces ranges from 1.6 to 5.3 N with mean peak velocities between 0.3 and 0.7 m/s. The full key stroke is about 3.5 mm. The duration of the keyswitch compression (phase I) averages to 9.1 ms. The second phase (impact) averages to 8.8ms. The total average duration of a keystroke is 77.2 ms which correspond to half period of the sinusoidal displacement of the tip which has consequently a frequency of about 6.4 Hz.

The main requirement of our rig is that it can reproduce Figure 2 consistently and repetitively.

2.3 Design of the mechanical fingertip

The critical element of the rig for the close reproduction of a human finger tap is the tip used to mimic the stiffness of the finger pulp (the name given to the elastic material surrounding the finger bone). The force history recorded with three different foam tips and a rubber tip with the same cross section (8x8 mm^2) and different thicknesses were tested in their ability to reproduce Figure 2. Figure 3 shows the force time histories over three cycles for 1mm, 2mm and 3mm thick soft foam and a 2mm thick rubber tips. The excitation frequency was a 6.4 Hz sine wave.

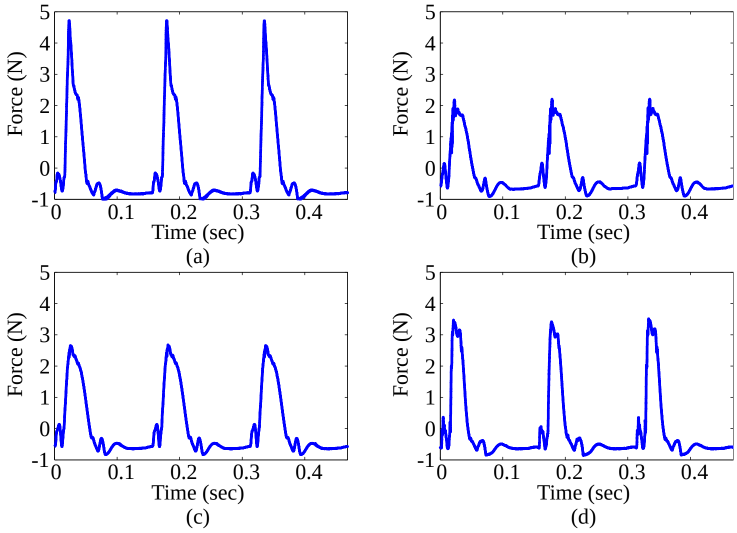


Figure 3. Tapping force histories for different tips while pressing a keyswitch with a 6.4 Hz sinusoid signal: 1mm foam (a) 2mm foam (b) 3mm foam (c) 2mm rubber (d).

All four tips allow the reproduction of the three phases reported by Rempel *et al* [5] and listed above. The 1 mm thick foam tip shown in Figure 3(a) produces an impact peak that is much higher than the pulp compression peak because the tip has very little damping. The 2mm and 3mm thick foam tips exhibit similar force time histories whereby both impact and pulp compression peaks have been reduced compared to Figure 3(a). However the distinction between the two peaks is not as evident anymore. The 3mm thick rubber tip seems to provide the force tip history that most resembles a typical finger in as much as the impact and pulp compression peaks have a limited value but they are still not very distinguishable. This tip will therefore be used in the remaining work.

2.4 Data collection and signal processing

The data recorded from the accelerometer, force gage and microphone were then elaborated to obtain frequency domain results such as spectral densities and coherences. Figure 4 shows some exemplary results were a sampling frequency of 24 kHz was used. Time domain signals were initially divided in individual pulses. The signals of the example of Figure 4 included 33 periods, each composed of 3836 samples. The power spectral densities of each pulse limited signal were obtained by their discrete Fourier transforms. In fact, the cross spectral density S_{xy} between two general signals $x(t)$ and $y(t)$, can be obtained as [7]

$$S_{xy} = X^{*}Y \tag{1}$$

In some case it may be interesting to look at the coherence between signals. The coherence between two signals has been evaluated as [7]

$$\gamma_{xy}^{2} = \frac{S_{xy}S_{yx}}{S_{xx}S_{yy}} \tag{2}$$

Figure 4(b) shows the coherence γ_{pf}^{2} between the sound pressure and the tip force while Figure 4(c) shows the coherence γ_{pa}^{2} between the sound pressure and the acceleration of the key.

The power spectral density shows a general down slope with frequency superimposed to some resonant behaviour. The most evident resonant peaks are at lower frequencies. Two peaks at about 60 and 125 Hz stick out. The coherences with acceleration and force at low frequency are also very high. The sound pressure spectrum at high frequency is very low (60dB below the main peak) and the coherence are poor because of the signal falling in the background noise.

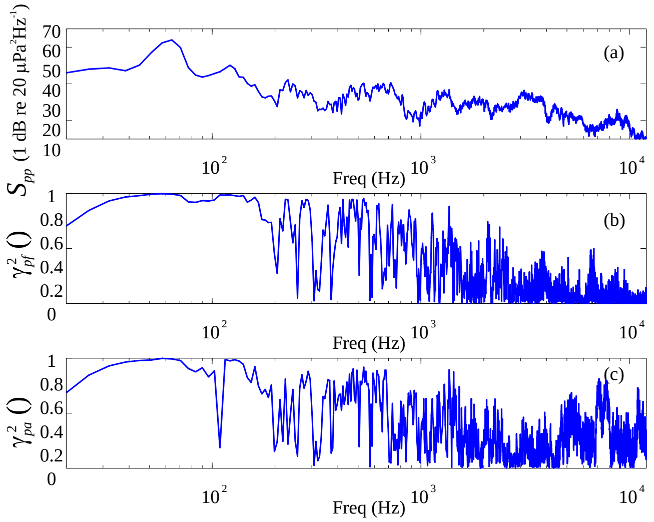


Figure 4. Noise emission 'I' key on Dell keyboard: (a) sound pressure PSD: (b) coherence between sound pressure and impact force: (c) coherence between sound pressure and key acceleration.

3. KEYBOARD NOISE

3.1 Noise emissions of a keystroke

The noise emission from a single keystroke is now examined. For illustrative purposes, only the key "I" is considered in this section. Experiments have been carried out on several keys all showing similar results. Figure 5 shows the force content, the acceleration and the sound pressure recorded during 33 repeated keystrokes. The individual keystrokes have been overlapped to show the repeatability in time and magnitude of the experiment. Thanks to the force recording it is possible to identify the different phases described above. The first phase lasts about 11 ms while the second and third phases together last about 46 ms. The remaining part of the recording does not see any excitation but shows anyways some oscillation in the acceleration and some significant contribution in the sound power (see Figure 5(b) and (c)).

The average power spectral density of the sound power PSD of the 33 repetitions is represented in Figure 6. In this Figure the thick line represents the PSD obtained by using the full data set. If a shorter data set is used, corresponding to phases I, II+III and free oscillation as in Figure 5, the other three lines are obtained. Since this PSD have been obtained from non-stationary signals their value has been normalised to the full spectrum by the length of the signal used to compute the PSD. Phase I contributes less than the other phases to the overall tapping noise. This is not surprising since only the key and finger are moving during this phase. Phase II and III seem to be responsible of the majority of the sound produced. However, more interestingly and surprisingly, the free oscillation seems to contribute considerably to the noise generation. Although during this phase there is no active excitation, the key and the full keyboard are still moving and generating noise.

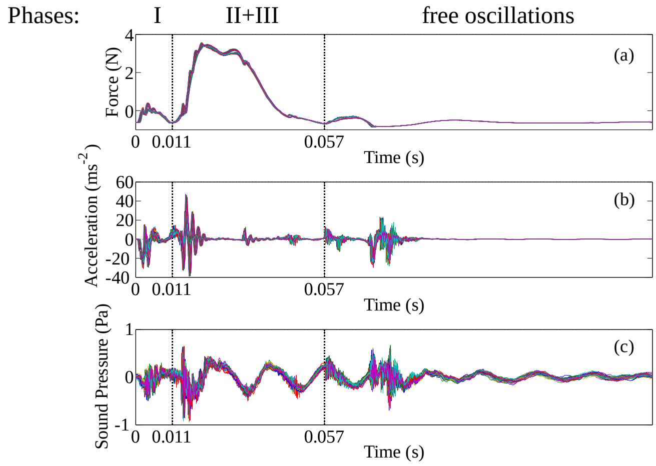


Figure 5. Force (a), acceleration (b) and sound pressure (c) recorded during 33 different keystrokes.

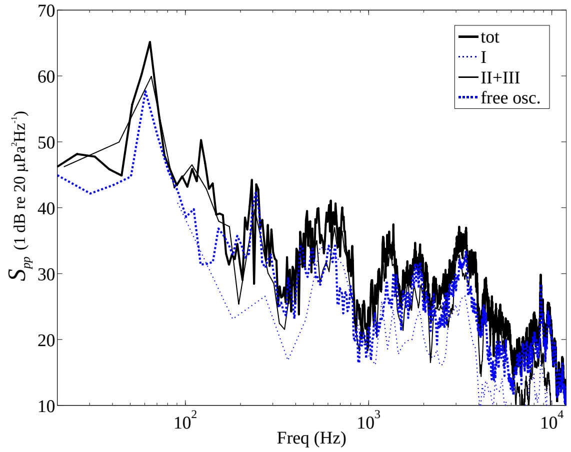


Figure 6. Sound pressure PSD for the full keystroke (thick solid black line) and for the periods I (thin dotted blue line), II+III (thin solid black line) and free oscillation (thick dotted blue line).

3.2 Investigation on the noise emission mechanism

In the previous section, it has been observed a considerable contribution to the sound pressure also when the excitation (tapping) is terminated. Also, at low frequencies the noise generated is essentially tonal, with two main harmonics at about 60 and 125 Hz (see Figures 4 and 6). This suggests that the structural dynamic behaviour of the keyboard is important for the noise propagation mechanism. In order to study the modal behaviour of the keyboard a vibration analysis of the keyboard has been carried out using a Polytec laser scanning vibrometer. The "I" has been excited using the same shaker. Instead of a sinusoidal excitation a white noise excitation signal has been used. During these tests the key was pressed down by the tap and care was taken that it was not released during the excitation. Figure 7 shows the results of this investigation, showing in particular two mode shapes of the keyboard, one at 61.27 Hz and the other at 126.9 Hz. This seems to indicate that the main mechanism of noise generation at low frequency is structure born and is generated by the full keyboard surface vibrating as shown in Figure 7.

As a further proof of this result a cut-out of the keyboard (Figure 8) has been tested. The noise emitted by this cut-out is compared with the noise emitted by the full keyboard. When the cut-out is excited the low frequency tonal behaviour disappears from the sound pressure PSD (see Figure 9). In particular all the tonal behaviour up to 1 kHz is particularly reduced. This suggests that not only the design of the key is important, but the design of the full keyboard is important if the emitted noise has to be reduced.

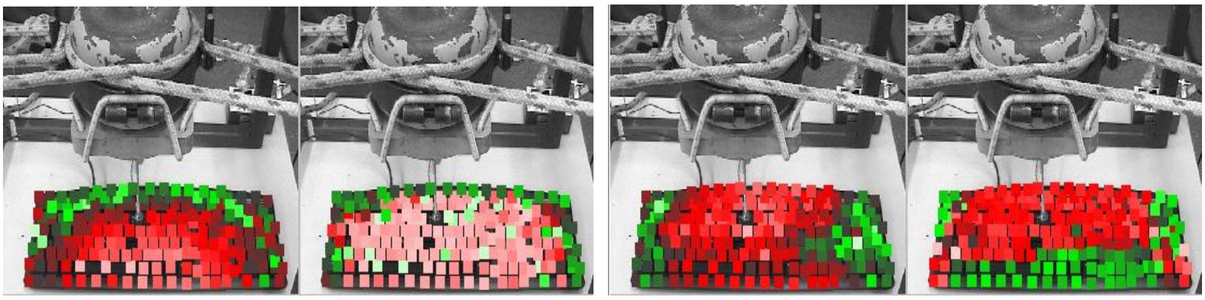


Figure 7. Mode of vibration at 61.25 Hz (a-b) and at 126.9 Hz (c-d) recorded by the Polytec laser scanning vibrometer. Velocity magnitude (a,c) and phase (b,d).

Figure 8. A keyboard cut-out around the "I" key.

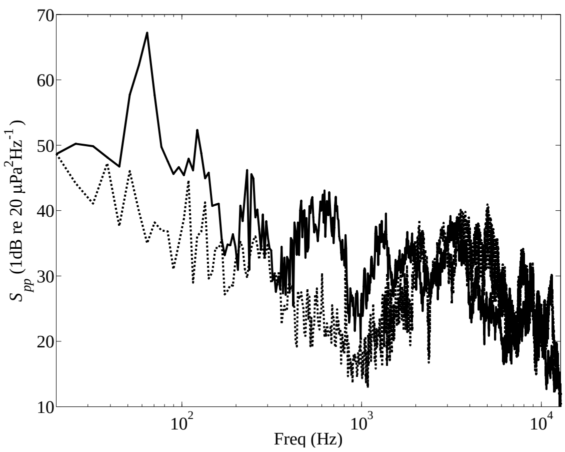


Figure 9. Sound pressure of the full keyboard (continuous line) and of the cut-out of Figure 8 (dotted line).

4. CONCLUSIONS

A quick, economic, repeatable and objective way of measuring the noise emitted from a keyboard has been proposed. Only general lab equipment has been used. The keyboard noise of the DELL RT7D20 has been characterised and possible mechanisms for the generation of noise have been identified. In particular it has been observed a mainly tonal behaviour at low frequencies (below 250 Hz) which has been proved to be due to the modal characteristics of the full keyboard radiating as a vibrating plate. It has been shown that the keyboard as a whole influence the noise radiation up to 1kHz. In the light of this conclusion appear evident the necessity of intervening on the full keyboard structure in order to reduce the emitted noise. Future work will look at the noise emission of other keyboards and at modelling the noise emission. The availability of a model is necessary to run parametric studies which would permit to identify ways to reduce keyboard emissions.

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