DEVELOPMENT OF A QUIET, YET QUICK DRYING HAIR DRYER

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The hair dryer noise is dominated by the flow noise which is involved in various parts in the interior. In general, the flow speed and the amount of turbulence strength are the important points in the low-noise design, but the designer will meet a trade-off condition of the flow rate that is related to the drying speed. In this work, the state-of-the-art techniques for the quiet design strategies of major air-borne sources such as the fan, shroud, exhaust nozzle, and inlet grille are studied first and the characteristics of their major parameters are identified. Then, each noise source part is redesigned to produce the lowest noise, while obstructing the flow minimally. Instead of using a single fan, multiple smaller fans are used to reduce the broadband noise. Two types of quarter-wavelength tubes are installed within the shroud to reduce the blade passing frequency (BPF) tones. Additionally, a fan with unevenly-spaced blades is tested to eliminate the BPF. The jet noise at the exhaust nozzle is reduced by using the dual-tube: slow flow speed in the outer tube reduces the shear. The inner tube end is shaped with lobes. Spiral grille pattern is used for the lowest inlet turbulence and noise. Sound reduction through the shell is calculated. The acoustical and aerodynamic performance of the final prototype, which is an assembly of all low-noise design parts, is evaluated. Compared with the 4 competitive products in the market, the developed hair dryer reveals that the flow rate is higher by 20%, the overall sound level smaller by 6 dB, the loudness smaller by 30%, the sharpness by 15%, and the roughness by 9%.

Keywords: Hair dryer, Sound level, Sound quality, Flow rate, Quiet design, Flow noise

1. Introduction

Hair dryer is used nearly every day in the home, and the noise is often felt unacceptable because of the unpleasant tones and the masking of communication due to high sound level even though the usage time is short. In the hair shop, the hair designers should hear the hair dryer sound for a whole work day by direct or indirect use of it. The hair dryer noise contains many harmonic tonal peaks in the high frequency range and the wideband turbulence noise provides the basic loudness and annoyance. In the design viewpoint, the noise alone is not considered, but the drying speed is also essential, which has a trade-off relationship with noise, so it is not easy to improve them simultaneously. The purpose of this work is to design a quiet hair dryer with improved sound quality, while flow rate at the nozzle tip is set to be satisfactory in drying the hair quickly, which is comparable to or better than the best hair dryers in the current market. Besides, the price, weight, and size are also of concern in the design. The state-of-the-art knowledge for quietening the aerodynamic noise is applied with the empirical parametric tests, and the best methods and their optimal parameters are implemented in the prototype using the 3D printer. The acoustical performance and the other design
parameters are compared with the commercialized hair dryers having similar size and capacity in the current market.

2. General characteristics of noise sources in hair dryers

The air flow noise dominates the hair dryer noise, in particular, from fan and shroud, nozzle, and inlet grille. The body wall thickness, motor, and heat coil also affects the noise level.

2.1 Fan and shroud

Fan noise is consisted of tonal noise and broadband noise. Tonal noise occurs at motor rotation frequency, blade passage frequency (BPF), and its higher harmonics, mostly due to the flow cutting at the blade tip. The periodic interaction of rotating blade with surrounding structures as like shroud, heating coil, grille, etc. is also important [1]. Broadband noise is mainly generated through turbulence and vortices due to the separated flow at the blade tip and trailing edge. The noise characteristics of a ducted fan is totally different from the fan in a free stream and depends strongly on the geometry of covering duct and shroud [2].

2.2 Nozzle

Near the convergent nozzle, the jet noise or shear-layer noise occurs. The relationship of the overall sound power $W$ (watts) of the jet noise induced by the fluid flow with the jet upstream velocity $U$ in a free circular duct of diameter $D$ is as $W \sim \rho_0 U^5 D^2 / c_0^5$, where $\rho_0$ denotes the density of ambient air, $c_0$ the ambient speed of sound [3]. Because the overall sound power varies with $U^5$, it is the most important factor in controlling the jet noise.

2.3 Inlet grille

Tonal and broadband noise occurs from the air flow passing through the inlet grille depends on the sectional shape of grille, the flow velocity, the presence of porous screen, and the porosity of it. The Strouhal number can be used for describing the onset of the Aeolian tone due to vortex, and the noise is highest when the number becomes about 0.2 [1]. Broadband noise is also generated due to the turbulence of the flow passing through the grille and it can be a bit reduced by the porous screen.

2.4 Wall thickness

The airborne sound generated inside of the hair dryer can be transmitted through a solid casing wall to the ambient. In the mid- to high frequencies of concern, the sound transmission $TL$ (dB) will obey the mass law, which is given for the random incidence as $TL \sim \log(\rho hf)$. Here, $\rho$ denotes the wall density, $h$ the wall thickness, $f$ the frequency of incident sound. Therefore, high density material or thick wall will be beneficial for sound reduction, but the weight increase of the unit is inevitable.

3. Quiet design strategy

3.1 Fan and shroud

Decreasing the fan diameter and increasing the number of fans for a flow duct section, the total surface area of blades decreases, thus the broadband noise level decreases due to the reduction of vortex generated from the blades, as shown in Figure 2(a). To investigate the influence of the number of fans on noise spectrum, the same blade number is used as a control variable. However, to keep the flow rate above a required minimum value, the rotation speed of the triple fans should be increased. Accordingly, the BPF and its harmonics will shift to high frequencies, then the sound will be further sharp and unpleasant. The 3 fans with 5 blades are employed in the test varying the diameter and rotational speed: $\phi = 92$ and 7200 RPM, $\phi = 60$ and 10680 RPM, $\phi = 40$ and 18100 RPM. After the test, $\phi = 40$
mm fan is selected for the triple fan system. To suppress the BPF and its harmonic tones at high frequencies, two quarter-wavelength tubes, different in tuning frequency, are inserted in the cavity enclosed by the shroud and outer casing. The tuning frequencies are set to BPF and its first harmonic: 1510 Hz and 3020 Hz. Figure 2(b) shows the effect of these \( \lambda/4 \)-tubes, in which one can see a remarkable reduction of tuned tonal components. Additionally, a fan with unevenly-spaced blades is tested to mitigate the BPF peaks. Blade spacing is determined by the classical sinusoid equation [4]. However, small multiple fans made by the 3D printer has a problem in the rotating unbalance, so it is not applied to the final prototype.

![Image of triple fan configuration with \( \lambda/4 \)-tubes](image)

**Figure 1**: Configuration of the triple fan, of which the shroud and backing space is used for two \( \lambda/4 \)-tubes.

![Graphs showing effect of fans and \( \lambda/4 \)-tubes on sound](image)

**Figure 2**: (a) Effect of number of fans on sound: , single; , double; , triple. (b) Effect of \( \lambda/4 \)-tube on triple-fan noise: , without \( \lambda/4 \)-tube; , with a \( \lambda/4 \)-tube; , with double \( \lambda/4 \)-tubes.

### 3.2 Nozzle

If the convergent downstream nozzle is made of coaxial multiple tubes, of which the flow speeds are designed to become slow from inside to outside direction, the noise from the exhaust jet zone can be reduced due to the reduction of the strength of the shear layer [5]. In this work, a dual tube configuration is adopted for simplicity. The flow velocity ratio between inner tube (\( V_p \)) and outer tube (\( V_s \)) is varied as \( V_s/V_p = 0.55, 0.7, 0.85, 1 \), while maintaining the whole outer size of the nozzle. The test results reveal that the sound level is the lowest for \( V_s/V_p = 0.7 \).

Additional reduction of jet noise for this dual tube nozzle is obtained by shaping the downstream tip of the inner nozzle with lobes as can be seen in Figure 3(a). It is thought that the corrugated lobes around the nozzle edge cause the offset of the adjacent rotating vortices [6], and this is beneficial to the further reduction of sound level. In the design of lobe, the important parameters are known as the number, height, and penetration length. Because the gap between inner and outer tubes is narrow in this work, the effect of lobe height difference is not considered. In the present design, the parametric test is conducted with a fixed velocity ratio value of 0.7 although, exactly speaking, the whole performance will depend on the multi-variable change simultaneously. A full factorial experiment is
done varying the number and the penetration length. As the number of lobes increases and the penetration length of lobes becomes deeper, one can find in Figure 3(b) that the mixing effect of flow increases and the sound level decreases effectively. Based on this test result, the optimal parametric combination is determined as 15 mm in penetration depth for 28 lobes.

Figure 3: (a) Dual tube nozzle with 16 lobes at the end of inner nozzle. (b) Overall SPL varying the lobe number and penetration depth ($PL$ in mm): , $PL = 6$; , $PL = 9$; , $PL = 12$; , $PL = 15$; , single nozzle.

3.3 Inlet grille

In the previous work [7], it is known that the spirally-shaped grille pattern of inlet grille is the quietest of all possible patterns as well as having small loss in flow rate. By installing the porous PU filter in the downstream side of the spirally-shaped inlet grille, we can achieve about 0.5 dB reduction in the overall sound level by reducing turbulence size and strength.

4. Prototype and its performance

4.1 Prototype development and measurement setting

All the foregoing design methods are implemented in a prototype, of which parts are developed by using a 3D printer. Ready-made motors are used in the assembly. Measurement and analysis are conducted for sound levels and their qualities. The hair dryer prototype is installed at the centre of a semi-anechoic chamber. Microphones location and direction reflect the usual ear positions of the customer and hair designer as shown in Figure 4. One point represents the customer’s ear, which is 200 mm in distance, 20º to the left, and 30º to the bottom referenced to the nozzle tip; the other point represents the hair designer’s ear, which is 250 mm in distance, 30º to the right, and 30º to the top from the inlet grille. These locations are based on the preliminary measurement in the real situations, and these are the points exposed to the strongest noise during the drying process. The frequency range of interest is 100-4000 Hz, from which the contribution to the overall sound level is dominant.

Figure 4: (a) Assembled prototype. (b) Noise measurement points indicated with dots.
4.2 Results

Besides the measurement of the prototype performance, a comparison is made with 4 commercialized hair dryers having similar size and capacity in the current market. The flow rate at exhaust nozzle, overall sound level, and sound quality metrics of samples are measured and calculated based on ISO standards [8-10]. Figures 5 and 6 present the averaged sound spectrum and sound quality metrics of all 5 hair dryers. At the ear of a hair-designer, the present prototype is improved in the overall sound level by about 6 dB, loudness about 30%, sharpness about 15%, and roughness about 9%. Except the roughness, it is noted that the improved amounts are far larger than the usual just noticeable difference (JND). Similarly, the sound level and quality metrics at the ear of a customer are improved remarkably. In spite of such a big acoustic refinement, the flow rate is increased by about 20%.

![Sound level spectra of various hair dryers at the ear position of a hair designer](image5.png)

Figure 5: Sound level spectra of various hair dryers at the ear position of a hair designer: , Model P; , Model U; , Model B; , Model R; , prototype of the present study.

![Sound quality metrics evaluated at the ear position of a hair designer](image6.png)

Figure 6: Sound quality metrics evaluated at the ear position of a hair designer. (a) Specific loudness, (b) sharpness: , Model P; , Model U; , Model B; , Model R; , prototype of the present study.

5. Conclusions

In this work, almost all the state-of-the-art knowledge for quietening the aerodynamic noise are employed in the development of a quiet, yet quick-drying hair dryer, for which the design parameters are obtained from the test. The acoustical and mechanical performances are compared with the commercialized high-end products in the current market. The test results reveal that the broadband fan noise can be reduced by about 6 dB by replacing a single large fan by 3 small fans, and jet screech tones can be reduced by about 3 dB employing a dual nozzle with the lobed end of the inner nozzle. It is shown that the sound magnitude and quality are far enhanced with the developed prototype.
compared to the high-end commercial products, and also even the flow rate is improved. The overall size is limited as the constraint of the development to be similar to the current products, but it is noted that the weight and power consumption are also improved. Compared to the popular products in the market, the total weight is reduced by 35 g, and the motor power consumption is also reduced by 6 W on average. Further study on the application of the fan with unevenly-spaced blades, on the heat-coil noise reduction, and on the application of a thin absorbing or insulating liner in the inner wall.

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