Estimation of the Closing Load of Precision Scissors for Haircutting or Medical Use

Takashi Iimura[1], Toshirou Iyama[2], Kenji Inoue[3]
[1]*Iwate Industrial Research Institute, Japan*
[2]*Iwate University, Japan*
[3]*Tokosha Co. Ltd., Japan*

t-iimu@pref.iwate.jp

Abstract

Precision scissors for haircutting or medical use are extremely important tools for fine cutting. A high-precision and complexly curved blade shape, an "Ogami" shape, is necessary for reliable cutting. In this paper, we propose a new analytical method, based on the "Ogami" shape, for estimating the closing load of precision scissors for haircutting or medical use, and verify the validity of the proposed method by comparing the analytically estimated loads with the experimentally obtained loads. Results show that the proposed method can estimate the closing load precisely.

1 Introduction

The performance of precision scissors for haircutting or medical use is evaluated from (a) the closing load necessary to push the grips of scissors with fingers to close them without cutting, and (b) the cutting load necessary to push the grips of scissors with fingers when cutting. The cutting load is a resultant load comprising of the closing load and a load that is necessary to cut an object with the blades, and is analysed using the closing load and the load to cut an object [1][2]. Therefore, the closing load is an important characteristic of precision scissors, and the relation between the closing load and the "Ogami" shape which denotes a high precision and complexly curved blade shape must be analysed for designing the new precision scissors. However, the analytical method of closing load is not proposed because of its complexity.

In this paper, we propose a new analytical method, based on the "Ogami" shape, for estimating the closing load of precision scissors for haircutting or medical use.

2 Outline of Precision Scissors

An outline of the Precision Scissors is presented in Figure 1. In Figure 1, the following variables are shown: L, distance from the blade tip to the screw; l, distance from the pushing point with finger to the screw; θ, opening angle; x_1, distance from the blade tip to the crossing point of the blades; l_i(i=1,2,3,4), distance from the screw to each point; $f(x_1)$, closing load at point x_1; μ_1, coefficient of friction of metal; μ_2, coefficient of friction of washer; $f_i(x_1)$ (i=1,2,4), friction force; $f_i'(x_1)$, vertical load; M, weight of the moving blade (gf); $f_3(x_1)$, force from weight of the moving blade; $b_j(x_1)$ (j=1,2), distance from the screw (transverse direction); $Z(x_1)$, value of "Ogami" at point x_1; λ_1, blade deflection caused by vertical force $f_1'(x_1)$; λ_2, blade tilt caused by the washer deformation caused by vertical force $f_1'(x_1)$; and E, Young's modulus of the blade.

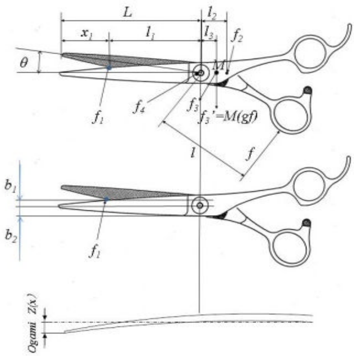

Figure 1: Symbols used in calculation

3 Estimation of the Closing Load

3.1 Estimation of the Closing Load with the Friction Force

The closing load is analysed using an equation of moment balance among the closing load, the friction forces $f_i(x_1)$ (i=1,2,4) and gravitation $f_3(x_1)$. The friction force is the product of the vertical force and the coefficient of friction, so the closing load is given by Eq.(1).

$$f(x_1)\times l = f_1'(x_1)\cdot\left[l_1\cdot\mu_1 + l_1/l_2\cdot\mu_1 + (1+l_1/l_2)\cdot l_4\cdot\mu_2\right] + M\cdot l_3\cdot cos\theta \quad (1)$$

As a result, the closing load is analysed using vertical force $f_1'(x_1)$.

3.2 Vertical Force Estimation

The vertical force $f_1'(x_1)$ results from the blade and washer deformation. The blade deformation $\lambda_1(f_1'(x_1))$ during the closing motion is given by Eq.(2) using the elasticity theory of a simple shape cantilever beam, where I_z=$2b_1h_x^3/12$.

$$\lambda_1(f_1'(x_1)) = \frac{f_1'(x_1)}{E}\iint\frac{x-x_1}{I_Z}dxdx \quad (2)$$

On the other hand, when the washer is approximated as shown in Figure 2, the washer deformation during the closing motion is given by Eq.(3) using the elliptical Hertzian contact theory [3].

$$\delta(f_1'(x_1)) = \frac{2F}{\pi m}\sqrt[3]{\frac{9}{4}\left(\frac{1}{E'}\right)^2 W^2 (A+B)} \quad (3)$$

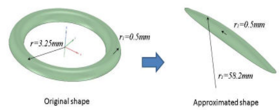

Figure 2: Approximation of washer

where $\frac{1}{E'} = \frac{1-\nu_1^2}{E_1}$, $A+B = \frac{1}{2}\left(\frac{1}{r_1}+\frac{1}{r_2}\right)$ and $W = f_1'(x_1)\left(\frac{\sqrt{l_1^2+b_1^2}+l_2}{l_2}\right)$

In Eq. (3), $2F/\pi m$ is a variable in the Hertzian contact theory, E_1 is the Young's modulus of the washer, ν_1 is Poisson's ratio of washer, and r_1 and r_2 are the curvatures of the approximated washer. As a result, the blade tilt $\lambda_2(f_1'(x_1))$ caused by the washer deformation $\delta(f_1'(x_1))$ is given by Eq.(4).

$$\lambda_2(f_1'(x)) = \delta(f_1'(x))\left(\frac{\sqrt{l_1^2+b_1^2}+l_2}{l_2}\right) \quad (4)$$

The sum of $\lambda_1(f_1'(x_1))$ and $\lambda_2(f_1'(x_1))$ is equivalent to the value of "Ogami" at point x_1, so Eq.(5) is true.

$$Z(x_1) = \lambda_1(f_1'(x_1)) + \lambda_2(f_1'(x_1)) \quad (5)$$

Consequently, the vertical force $f_1'(x_1)$ is analyzed using the known value of "Ogami" $Z(x_1)$, and the closing load $f(x_1)$ is finally analyzed by Eq. (1).

4 Verification of the Estimated Closing Load

We validated the closing load estimation method proposed in Section 3 for typical precision scissors (blade length is 98mm, L=86mm, $l2$=12mm). Figure 3 shows the measured values of "Ogami". The values are measured using a laser 3-D measuring machine.

The vertical force $f_1'(x_1)$ is estimated by Eq. (5) and the measured values of "Ogami" as shown in Figure 4. Therefore, the closing load is estimated by

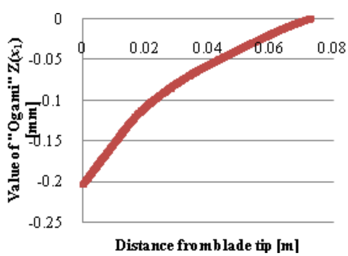

Figure 3: Measured value of "Ogami"

Eq. (1) and the estimated vertical force. Figure 5 shows the estimated closing load and the measured closing load. From Figure 5, it is presented that the estimated closing load and the measured closing load correspond, and the validity of the proposed method is verified.

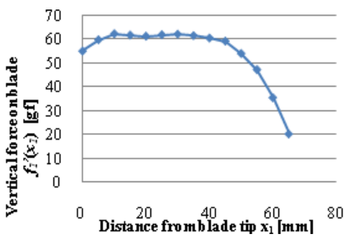

Figure 4: Vertical force

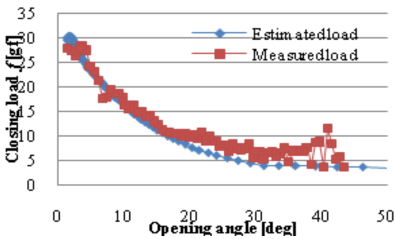

Figure 5: Comparison of the closing load

5 Conclusion

We propose a new analytical method based on the "Ogami" shape, for estimating the closing load of precision scissors for haircutting or medical use, and verified the validity of the proposed method by comparing the analytically estimated loads with the experimentally obtained loads. The estimation process is as follows: Step1: The blade deformation and tilt during the closing motion are analysed using the elasticity theory of a simple shape beam and the elliptical Hertzian contact theory, respectively. Step2: The friction forces occurring at the closing point, at the contact point, and at the washer are analysed using the vertical forces caused by the blade and washer deformations. Step3: The closing load is analysed using an equation of moment balance.

In future, we will design and fabricate scissors with a more ideal closing load using the proposed analytical method.

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