Deriving Position of Bending Roll by Experiment and Analysis (High Precision Roll Bending of Titanium Alloy Wire for Glasses Frame)

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Deriving position of bending roll in roll bending of titanium alloy wire for glasses frame

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Abstract

Titanium alloy is used for a wire for glasses frame due to having high corrosion resistance and human body compatibility. The wire is formed into a three-dimensional design shape by an NC exclusive bending machine. In present, craftsmen adjust the bending roll position by trial and error at every design change. The purpose of this study is suggesting a feedback control method to revise a formed shape into a design shape with a smaller number of trials. It is desirable to introduce a feedforward compensator into a feedback control loop to reduce the trial number. About one of the two-dimensional curves to constitute the three-dimensional curve of the glasses frame, this paper proposes a derivation method of a bending roll position that getting first formed shape near the design shape. This method is based on geometric relations in a steady bending, and equivalent to a feedforward compensator in the control loop. Design shapes are real glasses and squares that have fileted corners, the curvature becomes more than 300 m^{-1}. It is particularly paid attention to the availability of "indentation" as the governing quantity of moment, every moment arm at no load. By the absolute total of the curvature deviation, it is confirmed that the shape formed by the suggested method is closer than that by a conventional method.

Keywords: Titanium alloy; Bending; Positioning; Numerical Control; Accuracy

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1. Introduction

The production of glass frame in Fukui accounts for more than 90 % of the domestic share in Japan, and is considered to be one of the main industries Statistics Section of Fukui Prefecture ed. (2012). In recent years titanium or titanium alloys are used as major materials for glasses frames (Yamauchi, 2004). It is difficult to form titanium accurately because of the large amount of spring back (Japan Titanium Society ed., 1996).

In the real working scene, when the makers get reorder of previously formed design, the design shape are not available even if they form with the previous working data and the same machines. Thus, skilled glasses frame makers adjust the working conditions and machine settings by trial and error in every change of ordered products. To finish adjusting with smaller number of trials, it is desirable that the first formed shape is closer to the design shape. Thus, a simple derivation method of roll position is required, which is available for the change of bending condition which includes clearance, precision of reassembly and change of production lot of wire.

Although real glasses frames have three-dimensional shape, as a first approach of solving problems which mentioned above, a derivation method of a bending roll position for getting closer first formed shape to the design shape is proposed in this study. The validity of the proposed method is confirmed in the roll bending of two-dimensional shape (in a plane) which needs large curvature "rim holding curve".

Nomenclature

E	Young's modulus
G	x direction distance between Roll 7 and Roll 8
h	total indentation of steady bending
h_C	indentation for contact in steady bending
h_M	indentation for moment in steady bending
$H(n)$	total indentation of non-steady bending at point n
$H_C(n)$	indentation for contact in non-steady bending at point n
$H_M(n)$	indentation for moment in non-steady bending at point n
$H(n)$	total indentation of non-steady bending at point n
$H_C(n)$	indentation for contact in non-steady bending at point n
$H_M(n)$	indentation for moment in non-steady bending at point n
I	moment of inertia.
$L'_x(\mathrm{n})$	x direction length of moment arm at point n in contact state.
t	thickness of wire
r_7	radius of roll 7
r_8	radius of roll 8

2. Fractures of glasses frames and bending machine

Fig. 1 shows the names of glasses frames defined by Japanese Standards Association ed, (2006), and cross-sectional shape of wire. Fig. 2 shows rim holding and lens curvatures. In this report, the forming of rim holding curve is targeted.

Fig. 3(a) shows the entire equipment for bending glasses frames. Fig. 3(b) shows all roller positions of production part, Fig. 3(c) shows the part of forming rim holding curve. The directions of feeding wire without moment, thickness of wire, width of wire are x-, y- and z-directions, respectively. In order from the upstream side, the rolls contact with wire in y direction were numbered and those contact with wire in z direction named alphabetically. Roll 8 slides in y direction. In this paper, only controlling the curvature of rim holding curve is targeted. As shown in Fig. 3(c), the contact position of straight wire and Roll 8 is the origin of indentation. The displacement from the original position is defined to indentation value, *h*.

3Al-2.5V titanium alloy which corresponds to type 61 in JIS4650, commonly used as metal glasses frame material, is used for specimen. Width of wire is 2.0 mm and thickness is 1.0 mm for both rectangular and rim wires. Table 1 shows chemical composition of used titanium alloy (Japanese Standards Association ed. (2012)).

Fig. 1. Names of glasses frame parts and sectional shape of wire.

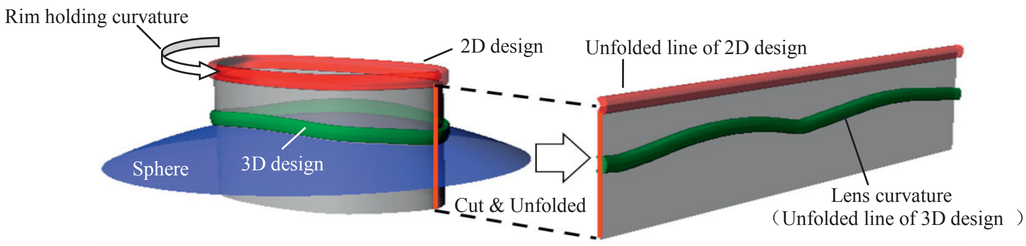
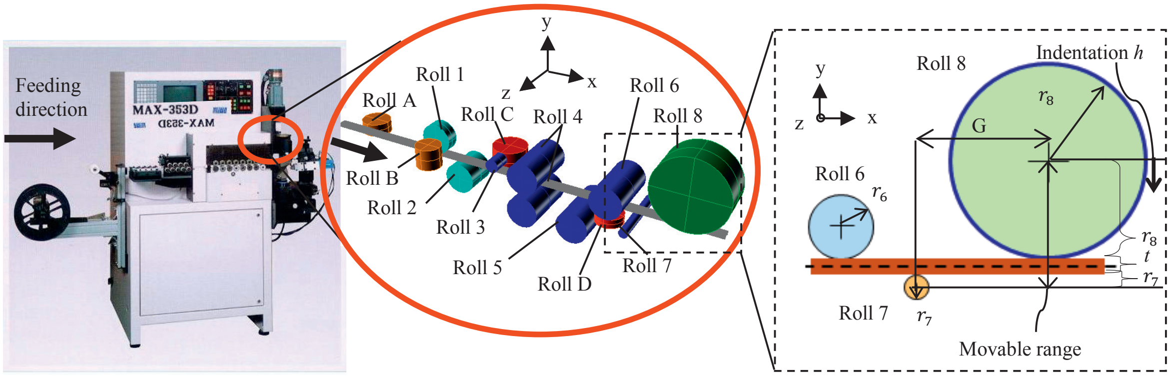


Fig. 2. Definition of curvatures.



(a) Appearance of bending machine (b) Layout of rolls (c) Indentation and positions of bending rolls

Fig. 3. Bending machine.

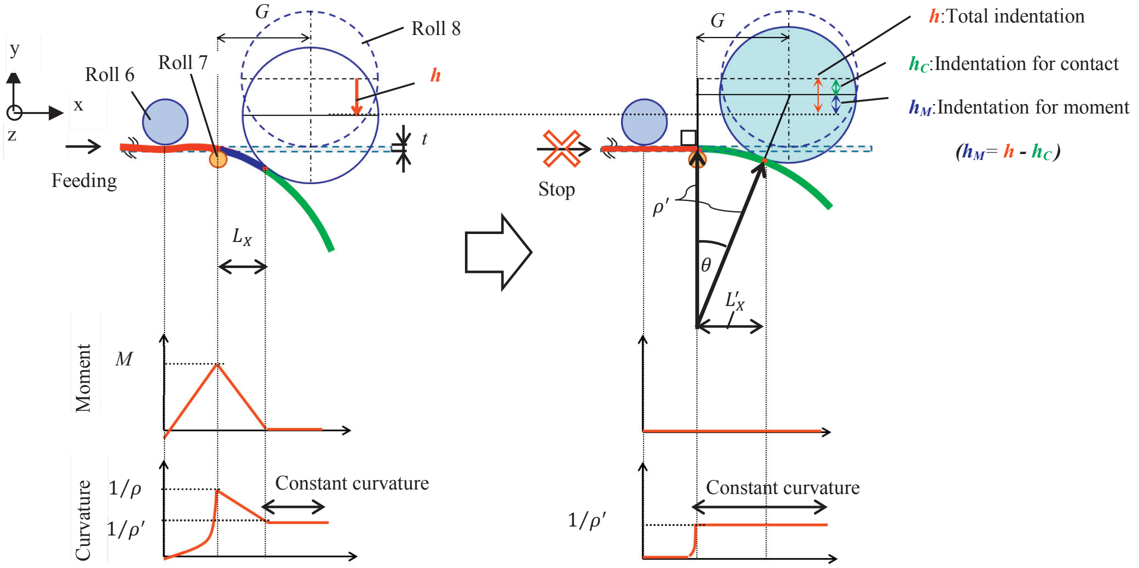
Table 1. Chemical composition of used titanium alloy. [mass %]

N	C	H	Fe	O	Al	V	Ti
≤0.03	≤0.08	≤0.015	≤0.25	≤0.15	2.50 - 3.50	2.00 - 3.00	Bal.

3. Basic experiment and decomposition of indentation

Fig. 4 shows experiment outline of the steady bending. Fig. 4(a) is illustrates of “steady state”, the Roll 8 is fixed to the position of the indentation h and the wire is fed enough to obtain constant curvature. Hereafter, variables after springback are described with $'$. Fig. 5 shows the relationship between the indentation h and curvature radius of the neutral line, ρ'. From curvature radius ρ' of every arc measured in experiment of steady bending, moment M applying at the deformation point around Roll 7 in the steady state is calculated.

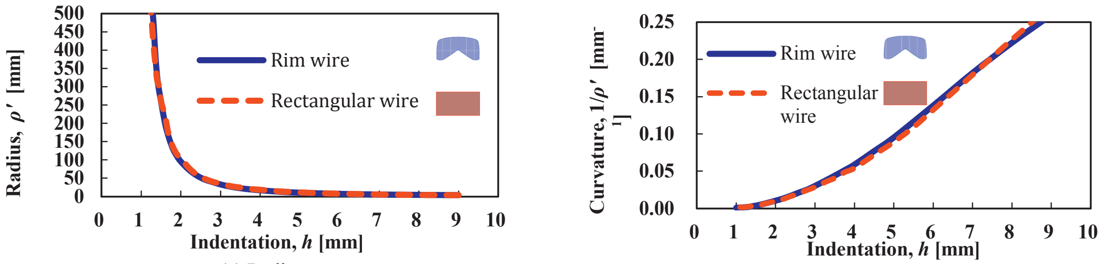
From the geometrical relation, length of the moment arms without load L'_X (shown in Fig. 4(b)) is calculated. Thus assuming no load, the relationship between induced moment per unit indentation in each moment arm is obtained.



(a) Moment and curvature distribution at steady state

(b) Decreasing indentation to zero moment after stopping wire forwarding

Fig. 4. Illustration of steady bending process.



(a) Radius

(b) Curvature

Fig. 5. Relationship between radius $\boldsymbol{\rho'}$ and indentation $\boldsymbol{h}$.

4. Deriving position of Roll 8 when producing rim holding curve

Fig. 6 shows the positions of Roll 7 and 8 corresponding to design shape of rim. A solid line is design shape of neutral line. A dotted one is defined as Track 7 that design shape is offset one of the inward by r_7+0.5t. A dashed-dotted one is defined as Track 8 that design shape is offset outward by r_8+0.5t. A certain Point n of design shape is focused on. Distance between centers of Roll 7 and Roll 8 is constant and defined as G.

Curvature radius at Point n, distance in x-direction between point C_7 and C_8 in contact state, and displacement to contact state are defined as $\rho'(n)$, $L'_X(n)$, $H_C(n)$, respectively. The center of Roll 8 at zero indentation is distance G far from the intersection of normal at Point n and Track 8 in the downstream side. In contact state, the center of Roll 7 passes on Track 7 and the center of Roll 8 passes on Track 8. The center of Roll 8 in contact state locates at a intersection of the normal at Point n and Track 8. Therefore, Point C_8 is identified. As mentioned above, displacement $H_C(n)$ and $L'_X(n)$ are obtained. Next, a method of deriving displacement $H_M(n)$ which contributes to moment is explained. Required moment for bending is defined as $M(n)$. $M(n)$ is calculated by substituting $\rho'(n)$ into Eqs. (4) and (5). $H_M(n)$ is obtained by calculating with dividing $M(n)$ by moment per unit indentation in each moment arm mentioned in chapter 3. Then, total indentation $H(n)$ is obtained by adding $H_C(n)$ and $H_M(n)$.

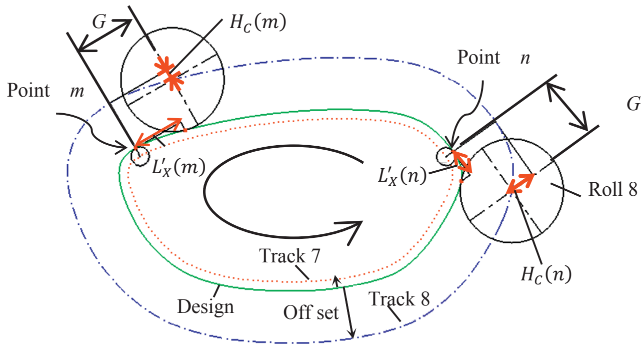


Fig. 6. Position relations among design shape and rolls.

5. Demonstration experiment and evaluation

Experiment of forming rim wire into 3 design shapes as shown in Fig. 7 with 2 forming methods was carried out. Design shape 1 is actual glasses shape. Design shape 2 and 3 are squares having different round corner and the radii were 5.0 mm and 7.5 mm. Method 1 is proposed one in this study and the motion of Roll 8 is derived in chapter 3 and 4. Method 2 is the conventional one and the relation between displacement of Roll 8 and curvature in experiment of steady bending is used.

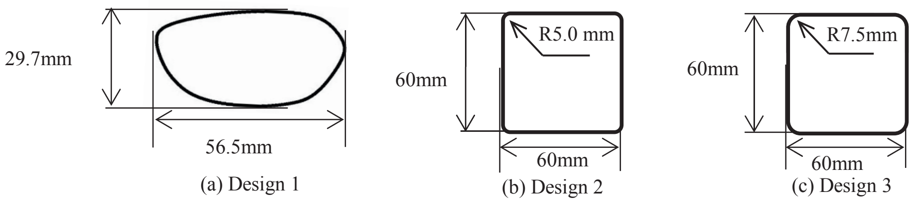


Fig. 7. Design shapes.

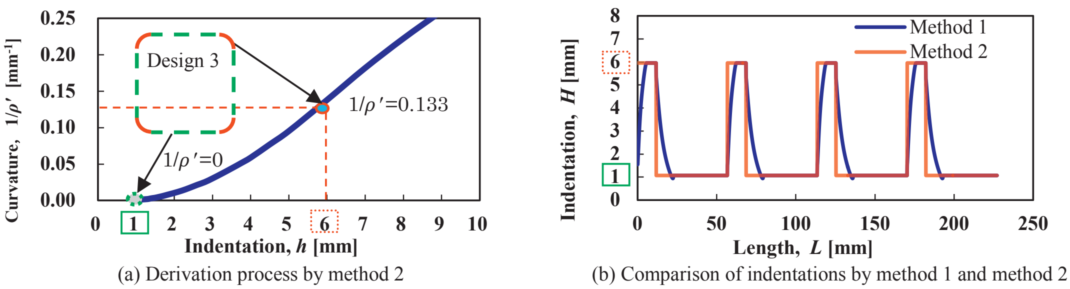
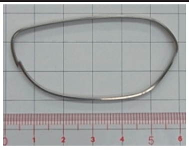
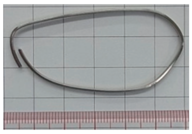


Fig. 8. Experimental results for design 3 by method 1 and method 2.

Photos of formed wire and accuracy are listed in Table 2. Comparing with Method 1 and 2, no large difference of formed shape for Design 1 was observed. Similar shape to the Design 2 and 3 were obtained by Method 1, however, over bending at the corner was observed by Method 2. This reason is considerable that curvature and indentation are correspondent and constant indentation at the corners and excessive moment was generated due to assuming that the wire is straight line during forming between Roll 7 and 8 whereas the wire is arc shape.

Table 2. Results of bending rim shape by proposed method 1 and reference method 2.

	Design 1	Design 2	Design 3
Method 1			
Method 2			

6. Conclusions

In the forming of two-dimensional rim holding curvature (closed curve on a plane) of glasses frames, first in the experiment of steady bending, practical equations which derive displacement of bending roll to contact and moment arm with total indentation of roll and radius of curvature was calculated. Geometrical decision making method of roll displacement to contact and method of deriving roll displacement contributing to moment on the basis of moment arm in contact state was proposed about design shape having curvature change. Experiment of forming glasses design and rectangle shape was conducted to evaluate the effectiveness of proposed method for deriving roll displacement. Formed shape by proposed method was closer to the design shape than that by previous method particularly in the case of forming into shape having large curvature changes.

In this research, it is highly practical that strategy of bending roll indentation can be determined with Young's modulus, proof stress, cross-sectional shape of wire and experiment data of steady bending by actual machine. Following further researches are required.

(1) Process of two-dimensional design bending and unbending (curve in a plane) corresponds to two-dimensional glasses curve bending.

(2) Three-dimensional bending combined two-dimensional rim holding curve and two-dimensional lens curve, and modification method with feedback control.

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