Application Of Vision-Based Fuzzy Control To Produce Variable Cross Sectional Profile Of Tubular Part

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Abstract

Dieless tube drawing offers flexibility to reduce the cross-sectional area of a tube only by adopting a drawing speed higher than the feeding speed without requiring dies or a mandrel. Dieless drawing proses able to produce variable cross-sectional profile of tubular part without using a die material, but only changing processing parameter. However, this promising technique faces the technological challenge of enhancing the drawn part accuracy. Therefore, a vision-based fuzzy control system is employed to control the deformation according to the desired geometries by adjusting the drawing speed. In this paper described implementation of vision-based fuzzy control to produce variable cross sectional profile of tubular part. The result shows that dimensional accuracy of the variable cross sectional profile improved after implementing the proposed control system. It can be concluded that vision-based fuzzy controller is appropriate to control deformation of dieless drawing process to produce variable cross-sectional profile of tubular part.

Keywords: Dieless drawing process, vision-based fuzzy control, variable sectional profile.

1. Introduction

The forming process of the tubular part can be classified according to the deformation purposes such as to make geometry variation in longitudinal axis, variation of the feature position relative to the longitudinal axis, and variation of the cross-section [1-3] .
Several application of variable sectional profile in axial direction is listed below: Kawaguchi successfully produces taper bar using dieless drawing for tapered spring coil. Taper angle 0.2° and 40 % reduction ratio[4]. The tapered spring coil performs advanced spring properties. Pulse Tube Cryocooler (PTC) is a refrigerator system that able to achieve cryogenic temperature by cycling a certain gases. In comparison with other cryocoolers, PTC has some distinct advantages: inherent simplicity, high reliability and low vibration at the cold end[5]. Taper tube structure has unique properties to absorb impact load from axial direction. The effect of taper tube in order to absorb the impact energy has been investigated. The result shows that taper tube able to absorb the impact from axial direction is much more effective compared with straight tube[6-8].
Variable cross section in axial direction of the tube or bar can be produced by using tube hydroforming, movable dies drawing[9-11], rotary swaging[2, 12] and spinning[13]. However those techniques require complex dies and advanced system control. Tapered profile fabrication using dieless drawing has been introduced [4, 14, 15]. Wang et al. (1995) introduce mathematical model to calculate drawing speed from variable sectional profile, then applied in the dieless drawing machine. The variable sectional profile is only a single side. Wengenroth perform double side tapered profile using dieless drawing process. The result shows that axial error is significant than radius error [16] with 30 % of maximum reduction ratio and 0.19° of taper angle. They claimed that the error is caused by improper fitting between target shape and the experiment result. In this paper observes fabrication of variable

sectional profile by applying fuzzy control and machine vision.

1.1. Dieless drawing process

Dieless drawing is heat-assisted forming to reduce the cross-sectional area of a tube or wire.. The main prerequisites of dieless drawing are localized heating and uniaxial tension by applying $v_1 > v_2$, (**Fig. 1**). Localized reduction in an area is caused in the tension state by low flow stress at the locally heated part. Reduction of cross sectional area obey volume constancy law as express in **Eqs. 1-3**. It can be seen that out put radius depends on speed ratio of v_1 and v_2.

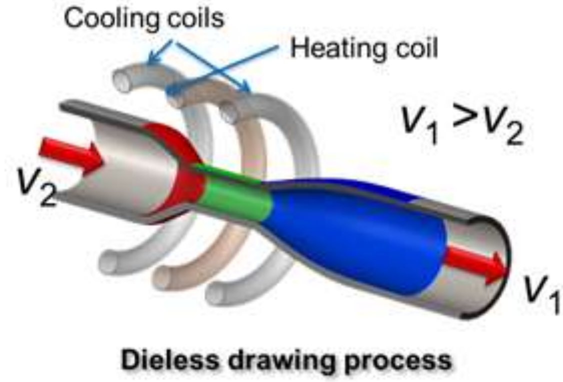

Figure 1. Schematic of dieless drawing process.

$$v_1(t) \cdot R_1(t)^2 = v_2(t) \cdot R_0^{\,2} \tag{1}$$

$$r_{area}(t) = 1 - \frac{v_2(t)}{v_1(t)} = 1 - \frac{A_1}{A_0} = 1 - \frac{(R_1(t))^2}{(R_0)^2} \tag{2}$$

$$R_1(t) = R_0 \cdot \sqrt{\left(v_2(t) \middle/ v_1(t) \right)} \tag{3}$$

1.2. Principle and mechanism of shape control in dieless darwing

The control mechanism of the variable sectional profile refers to the incremental forming. A Fuzzy Logic Control (FLC) algorithm is implemented to maintain reduction ratio by adjusting $v_1(t)$ and $v_2(t)$ as volume constancy law. The FLC algorithm is adopted for two main reasons. First, FLC is simplification for the complexity of the dieless tube-drawing parameters. The FLC strategy can be easily changed by modifying membership functions and rules according to the characteristics of the dieless tube-drawing process. As an example, to produce desired profile with high reduction ratio without failure requires low flow stress which is obtained by reducing feeding speed. Secondly, the FLC is able to be updated with new input parameter and rule to become more intelligent to control the dieless tube-drawing process as the research progress in the dieless tube-drawing.

The control approach is begun with deciding an asymmetric surface profile function ($R(x)$). When drawing process starts, the $v_1(t)$ increases over $v_2(t)$ to produce reduction in radius ($R(t)$) and elongation in drawing direction (x). **Figure** 2**2** shows the schematic of desired profile control algorithm on the dieless tube-drawing process by showing reduction from original position (0), reduction condition at a, and reduction condition at $\boldsymbol{b}$. After reduction reaching at point $\boldsymbol{a}$, the deformation of the workpiece produces an $x_a(t)$ and $R_a(t)$. The radius is compared with $R_{\mathrm{Ref.}}(t)$. The reference radius at point $\boldsymbol{a}$ ($R_{Ref.(a)}$) is calculated by substitute $x_a(t)$

to $R(x)$. It is assumed that $x_a(t)$ and $x_{Ref.(a)}$ are equal. **Eq.4** shows the equation to calculate $x_a(t)$ and $x_{Ref.(a)}$ which is obtained by integration of $v_1(t)$. The assumption of $x_a(t)$ and $x_{Ref.(a)}$ also was used by previous researchers to make a mathematical model to calculate $v_1(t)$ [15, 16]. A radius error is utilized as an input for fuzzy logic control to adjust $v_1(t)$ and $v_2(t)$ (**Eq. 5**).

$$x_a = x_{\mathrm{Ref.(a)}} = \int_0^a v_1(t) \cdot dt \qquad (4)$$

$$\text{Radius error} = R_1(t) - R_{Ref.}(t) \qquad (5)$$

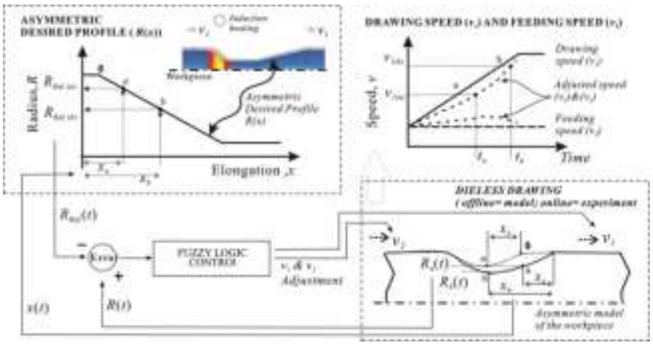

Figure 2. Schematic of profile control in the dieless tube-drawing using fuzzy control**.**

1.3. Vision-based fuzzy control for dieless drawing process

In taper forming process the control strategy is to control the drawn radius. The real time drawn radius is monitored by using machine vision sensor as shown in **Fig3**. The sensor data are compared with target profile as radius error for fuzzy logic input. Another fuzzy input is reduction ratio during the process to anticipate the control action according to the reduction ratio in order to prevent local unsteady deformation. While the fuzzy output have three variable; gain (to modify the membership function of Δv_1), Δv_1, and Δv_2.

In order to verify reliability of the online control system using adaptive fuzzy control and machine vision system, various forming target is performed.

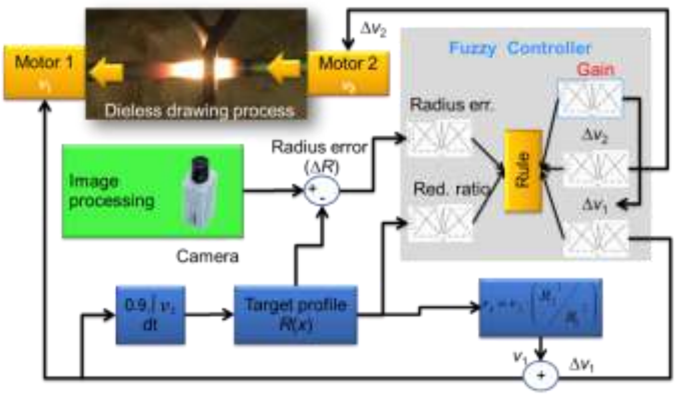

Figure 3. Configuration of the online control system for the dieless tube-drawing process

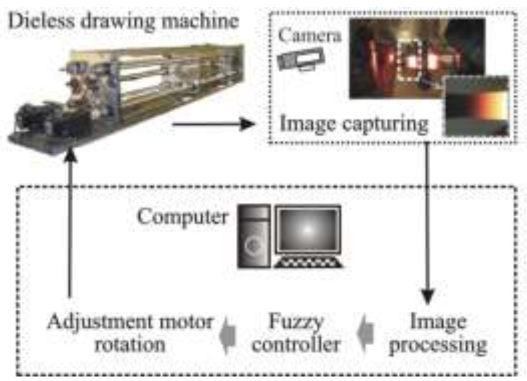

Figure 4. Schematic of vision based fuzzy control for dieless drawing process.

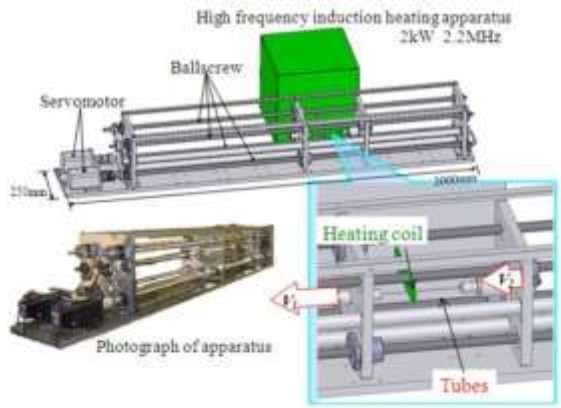

Figure 5. Dieless drawing apparatus.

2. Experimental Method

The horizontal dieless drawing machine system developed in this study consists of a machine vision sensor, and a computer for fuzzy control, and a machine body including two servo motors, clamping device for a workpiece, and induction heater, as shown in **Figs.4 and 5**. Clamping specimens are connected to the servo motor using a ball screw to drive at the speeds v_1 and v_2. The servo motors controls v_1 and v_2. A high-frequency induction heating apparatus with a 4 mm induction coil width (Hl) was used for local heating. A water-cooling system was used to maintain a narrow temperature distribution with a cooling distance (Cd) of 7.5 mm. The machine vision system employs a commercially available CCD camera for image acquisition. The image is processed to obtain information of the drawn tube diameter during dieless drawing. Image processing and the fuzzy algorithm were conducted in LabVIEW software. The output from the fuzzy controller is connected to servo motors to adjust rotation speed. In this study, stainless steel SUS 304 tubes with an outer diameter of 5 mm and a thickness of 1 mm are used. The maximum processing temperature is 1100 °C.

3. Results and discussions

3.1. Speed path for dieless drawing process

There are a significantly difference between speed path that generate by using conventional method and vision-based adaptive fuzzy control to produce desired shape as shown in **Fig. 6** In this experiment, feeding speed was kept constant. Conventional method calculates drawing speed by using volume constancy law as expressed in Eq... The equation correlates between target shape and drawing speed. While vision-based adaptive fuzzy control generates drawing speed according to drawn radius that measured using vision sensor. Therefore if measured radius is lower than reference, adaptive fuzzy reduces drawing speed and reversely.

3.2. Variable cross sectional profiles

The experimental result of similar target using different control method was shown in **Fig. 7** vision-based adaptive fuzzy control produces higher accuracy of final profile compare with conventional method. The profile using conventional method shows low accuracy especially on the flat area and taper area. It is due to the deformation behavior also influence by changing of reduction ratio. This phenomenon is neglected using volume constancy law.

The advantage of vision based fuzzy control is when is ability to recognize changing of profile from taper to flat part and from flat to taper part. Due the dynamic of deformation is very complex. The deformation on dieless drawing process is free deformation, therefore deformation length depends on reduction ratio. Moreover reduction in not only for making variable sectional profile but also another side.

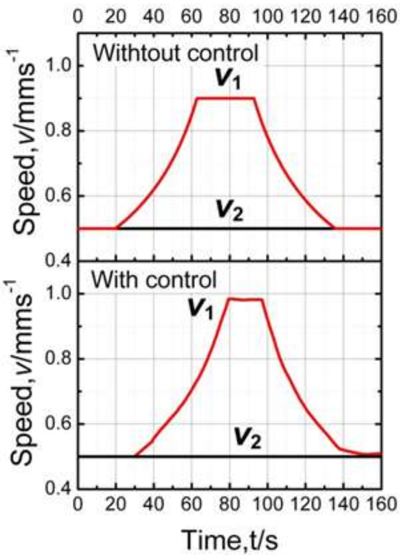

Figure 6. The speed path for two different conditions
(a) without control, (b) with vision base fuzzy control.

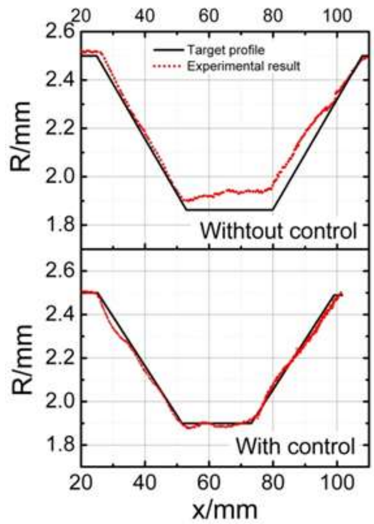

Figure 7. The result of variable sectional profile (a) without control (b) with control system

The increasing reduction ratio of the desired variable cross sectional profile is shown in **Fig. 8**. At low reduction ratio, the shape has good accuracy. However at high reduction ratio the

ISBN 978 979 8510 61 8

oscillation of the profile was observed. It is due to the high sensitivity of high reduction ratio to the fluctuation of the drawing speed and the characteristics of high reduction ratio.

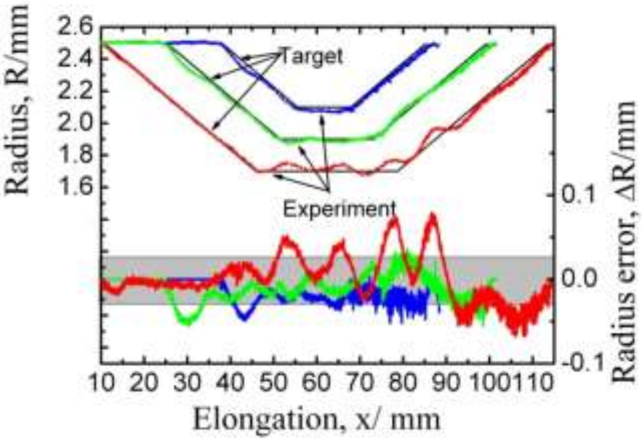

Figure 8. Variable sectional profile under different reduction ratio.

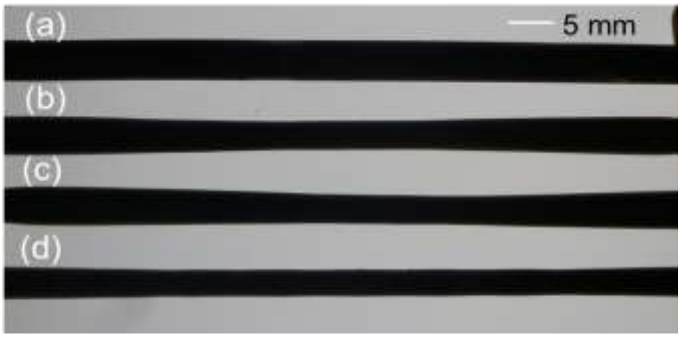

Figure 9. Photograph of variable sectional profile under different reduction ratio. (a) original tube, (b) Max. reduction ratio 30 %, (c) Max. reduction ratio 40 %, (d) Max. reduction ratio 53 %

4. Conclusions

In this paper described implementation of vision-based adaptive fuzzy controller to fabricate variable profile of the tube. The proposed adaptive fuzzy using machine vision is able to increase dimensional accuracy of taper shape under various reduction ratios for the given range. The adaptive fuzzy controller using machine vision sensor is applicable various taper targets. Further research should be intended to develop fuzzy supervisory system and to stabilize cooling system

5. Nomenclature

A_0 : Original cross section area, mm^2
A_1 : Drawn cross section area, mm^2
Cd : Cooling distance, mm
Cl : Cooling length, mm
D : Diameter, mm
G : Gain
Hl : Heating length, mm
R_0 : Original radius, mm
R_1 : Drawn radius, mm
$R_{Ref.}$: Reference radius, mm
$\boldsymbol{e_R}$: Radius error, mm

Δe_R : Increment of radius error, mm
$\bar{e}_R$: Average radius error, mm
σ_e : Standard deviation of error, mm
r_a : Reduction ratio, %
t : Time, s
v_1 : Drawing speed, mm/s
v_2 : Feeding speed, mm/s
x : Elongation, mm
Δv_1 : Increment of drawing speed, mm/s
Δv_2 : Increment of feeding speed, mm/s

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