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Three-stage process for improving roll bending quality

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ABSTRACT

Continuous pyramidal three-roll bending process has the simple configuration. However, two planar zones exist near the leading and trailing edges after a conical roll bending. This paper proposes a three-stage process to improve the geometrical quality of a bent cone for providing an alternative process for the manufacture of the crowns of Francis turbines for hydro plants or the towers of wind power plants. The process was simulated under the commercial software LS-DYNA with an explicit scheme and ANSYS with an implicit scheme. The geometrical quality of the bent cone was improved after the final stage of the process.

1. Introduction

Both continuous conical and cylindrical roll bending are usually used for three-roll and four-roll bending machines. Hua and his colleagues took intensive research on the four-roll bending machine process including the discuss of the working principle and the mechanism of the continuous process [1], the development of a mathematical model to better understand the mechanism of the single pass and multi passes of four-roll bending processes, the calculation of the bending force on the rolls and the driving torque and the power of the process [2,3], the influence of the linear strain hardening of the material on the plate/roll contacts, the applied forces and the position set-up [4]. The four-roll bending machines have the advantage of eliminating the planar zones close to the leading and the trailing edges of the plate. This advantage is significant in the cylindrical roll bending process where the plate is thin, it is however not efficient for conical bending [5], especially if the plate to be bent is thick. Despite the two planar zones near the leading and the trailing edges of the plate, the three-roll bending process is always practiced in manufacturing and the analyses of the process has been established by Bassett and Johnson [6]. Yang and Shima developed the relationship between the bending moment and the curvature of the work piece [7]. Shin et al. developed a two-dimensional model based on finite element analysis for the relation between the displacement of the central roll and the desired curvature of the bent plate [8]. Fan and Meng applied a two-dimensional model for simulation in the cases of small ratio of the thickness over the width of the plate [9]. Gandhi and Raval [10] and Gandhi et al. [11] also give this relation with the effect of springback for single pass and multi passes [10,11] and parametric studies were reported by Tailor et al. [12]. With the evolution of computer science and technology, powerful computational technology now makes three-dimensional modeling possible. The finite element method is widely used in solid mechanics as well as in other disciplines, and commercial software, such as the well-known commercial software ANSYS and LS-DYNA, is easily accessible for efficient analyses through numerical simulations. Three-dimensional modeling based on the finite element method can be found in

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Nomenclature

$\boldsymbol{F}$	internal force vector
$\boldsymbol{G}$	gap vector between the leading and trailing edges
H	whole height of the desired cone
L_i	whole length of the inner roll
L_o	whole length of the outer roll
$\boldsymbol{M}$	mass matrix
$\boldsymbol{P}$	body force and external load vector
$\boldsymbol{Q}$	residual vector
R	bottom radius of the desired cone or radius of the desired cylinder
R_i	radius of the inner roll
R_o	radius of the outer rolls
R_{po}	outside radius of the plate section
R_{roll}	radius of the asymmetrical bending machine
$\boldsymbol{U_{lg}}$	displacement vector of the leading edge
$\boldsymbol{U_{tg}}$	displacement vector of the trailing edge
d	distance between the axes of the outer rolls
dp	displacement of the top of the inner roll
f	body force density
h	real height of the desired cone
i	subscript, $i = 1, 2, 3$
j	subscript, $j = 1, 2, 3$
l_i	available length of the inner roll
l_o	available length of the outer roll
n	normal
r	top radius of the desired cone
r_{pi}	inside radius of the plate section
t	plate thickness; time; traction
$\boldsymbol{x}$	coordinate vector
$\dot{\boldsymbol{x}}$	velocity vector
$\ddot{\boldsymbol{x}}$	accelerator vector
ϕ	angle of the desired cone
θ_{len}	angular length of the plate section
θ_{xy}	angle with XY plane
θ_{xz}	angle with XZ plane
θ_{yz}	angle with YZ plane
ρ	density
$\boldsymbol{\sigma}$	Cauchy stress

recent publications, such as the modeling and simulation of the kinematic conical roll bending process [13] with conical rolls, and the non-kinematic conical roll bending process with conical and cylindrical rolls [14,15].

Large and long tubular sections used in industry are usually assembled with several cylindrical and conical segments, for example, the manufacturing of the crown of a Francis turbine. Since the manufacturing of a crown (Fig. 1a) by the conventional foundry process takes an unacceptably long time, an alternative process capable of achieving an approximate hydraulic profile and accelerating the manufacture speed is required. With the three-stage cone forming process proposed in this paper, a crown can be manufactured by assembling several cone segments; for example, three cones of different sizes (Fig. 1b). Since the top edge of a cone will be connected to the bottom edge of another cone in the assembly, the curvatures of the two cones must match properly. In fact, because all the cones are connected to each other, all the cone segments must have high quality curvatures. During the first stage, a plate passes in the conical bending machine to form a cone with a gap between the leading and trailing edges. During the second stage, the leading and trailing edges of the bend cone are forced to join together, and during the third stage, the completely closed cone is rerun through the conical bending machine in order to eliminate the planar zones close to the leading and the trailing edges.

This paper is organized as follows: first, a recall of the geometrical configurations of the three-dimensional model is presented, followed by a description of the modeling and simulation of the process; next, the numerical simulation results are discussed, and finally, conclusions are drawn, and future work is proposed.

2. Geometrical configuration

The front view of a simplified model of a pyramidal three-roll bending machine with cylindrical rolls is in Fig. 1. The model consists essentially of a plate, one inner roll and two outer rolls. The two outer rolls in symmetrical position are iden-