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The simulation of the multi-pass and die-less spinning process

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Abstract

In the ending of the twenty century, the numerical simulations of metal forming are developed rapidly and widely, while the simulation of conventional spinning process still lacks detail compared to experimental work. One of the major reasons is the extremely dynamic contact conditions in the spinning process, the techniques of static-explicit FEM for the quasi-static forming process cannot handle spinning problems easily.

This investigation applies the dynamic-explicit FEM code, LS-DYNA, to simulate the multi-pass and die-less spinning processes. With the applications of the mass scaling factor, contact algorithm, and adaptive control technique; reasonable results and some defects in the simulations are observed and discussed. The different variations in the feed rate of roller, direction of roller, and roller type were simulated. Effects on the predicted load-deformation relationship, the full history of deformation states and corresponding strain energy distributions are assessed. The suggested model is compared with experiment report, and shows a good availability for solving metal forming processes in the industrial works.

Keywords: Spinning; Dynamic-explicit; Multi-pass; Die-less; Mass scaling factor

1. Introduction

Spinning is a cold-forming operation where a rotating disk of sheet metal is progressively shaped over a mandrel to produce rotationally symmetrical shapes. Localized pressure is applied through small roller, which traverses the entire surface of the part to produce the progressive deformation. Although the spinning process is a traditional manufacturing technique, it is still a popular and common topic to study. In the past decade, the correspondent experimental works and various analysis methods [1–6] were adopted to model the spinning process. For saving the cost of tool design and manufacturing time, the numerical simulation is more efficient and available. Thus, in the past, the slab method, the upper bound method and the slip-line field method were used to simplify the problem, there were so many valuable results and experiences in reports, but, most of them were focused on shear spinning or tube spinning processes. The studying of the conventional spinning process seems rather few. Meanwhile, in the shear spinning process, the outer profile of the mandrel should be identical with the inner shape of the workpiece to be formed. If the material has sufficient rigidity to maintain the formed shape of the product, there is no need to use a match profile mandrel; such operating is called as the die-less spinning.

This investigation tries to build up a simple dynamic finite element model for the multi-pass and die-less conventional spinning process, and will be able to provide a good reference guide for the works in spinning forming. A one-pass model is built up according to the experimental works by Xia et al. [7], the corresponding results are compared and discussed. The suitable techniques in simulations are thus suggested.

2. Basic theory

2.1. Finite element method

The Cauchy's equation of motion is the basis of the dynamic-explicit finite element formulation [8], considering the body force density b_i and surface traction (or contact force) t_i, is given by

$$\int_V \rho \ddot{u}_i \delta \dot{u}_i \, dV + \int_V \sigma_{ij} \delta \dot{u}_{i,j} \, dV = \int_V \rho b_i \delta \dot{u}_i \, dV + \int_S t_i \delta \dot{u}_i \, dS \tag{1}$$

Eq. (1) can be written in the finite element form as

$$\boldsymbol{M}\ddot{\boldsymbol{u}} + \boldsymbol{F} = \boldsymbol{P} \tag{2}$$

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where $\boldsymbol{M}$ is the lumped mass matrix, $\boldsymbol{F}$ is the internal force vector, $\boldsymbol{P}$ is the body force and surface traction (or contact force) vector, $\ddot{\boldsymbol{u}}$ is the nodal acceleration vector.

Eq. (2) is solved by the explicit time integration procedure, using the central difference method, that is, when knowing the solution at step n, the solution of step $n+1$ is evaluated by

$$\boldsymbol{u}^{n+1} = \left(\frac{\boldsymbol{M}}{\Delta t^2}\right)^{-1}\left[\boldsymbol{P} - \boldsymbol{F} + \frac{\boldsymbol{M}}{\Delta t^2}(2\boldsymbol{u}^n - \boldsymbol{u}^{n-1})\right] \quad (3)$$

where Δt is the time increment, the procedure requires no iterations, and no solver for stiffness matrix. For the stability of the solution, Δt must be limited within the size

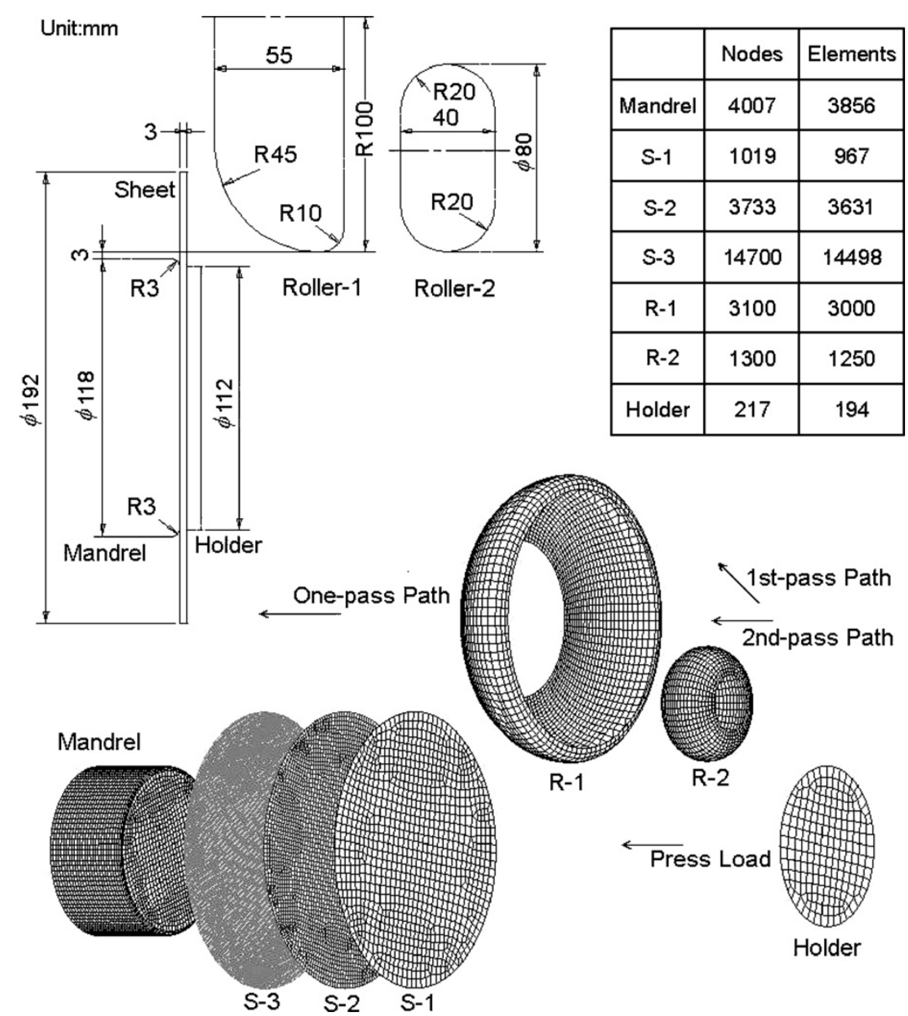
$$\Delta t = \frac{L_\mathrm{e}}{c} = \frac{L_\mathrm{e}}{\sqrt{E(1-\nu)/(1+\nu)(1-2\nu)\rho}} \quad (4)$$

L_e represents the characteristic length of solid element, c, E, ν, and ρ are the sound speed in the material, modulus of elasticity, Poisson's ratio, and the mass density, respectively. The stable time increment can be increased by introducing the artificial mass density of material, or defined a constant time step, which is called the mass scaling technique [9,10]. No matter how much a process can be accelerated, it must have no noticeable inertia effects or dynamic effects in the solution.

2.2. Contact algorithm

The treatment of contact conditions along interfaces has always been an important technique in metal forming simulations. The most general and most used interface algorithm is the penalty method [8,10], which is adopted in the explicit program LS-DYNA, too. The method consists of placing normal interface springs between all penetrating nodes and the contact surface, no special treatment of intersecting interfaces is required. In applying the penalty method, the procedure is described as follows:

(1) The possible contact nodes are checked for penetration through the tools surface.
(2) If the node does not penetrate, nothing is done. If it does penetrate, an interface force is applied between the node and its contact point. The magnitude of this force is proportional to the amount of penetration. This may be considered as the addition of an interface spring.



	Nodes	Elements
Mandrel	4007	3856
S-1	1019	967
S-2	3733	3631
S-3	14700	14498
R-1	3100	3000
R-2	1300	1250
Holder	217	194

Fig. 1. The finite element models and relative dimensions.