

Design Multi-Stage Draw by Improved Dynamic Programming

2010-01-0987

Published
04/12/2010Zi-Qiang Sheng (Steven)
Buckstech International Inc.

Copyright © 2010 SAE International

ABSTRACT

Multi-stage draw process is an important stamping method to make complex sheet metal parts for automotive industry. Due to complexity, its development is challenging and time consuming. In this study, the multi-stage draw development is modeled as a multi-stage decision making process. Based on sheet metal incremental plastic deformation theory, drawability and failure criteria, a dynamic programming type solution is proposed and demonstrated by FEM simulations on a rectangular geometry with high reduction ratio. Due to the recurrence nature of dynamic programming, the method provides a possibility of automatic process design of multi-stage draw.

Key words

multi-stage draw, progressive die, transfer die, design method, dynamic programming

INTRODUCTION

Stamping is an important manufacturing method for the automotive industry. For its efficiency and flexibility, multi-stage draw is a major process to make auto stamping with concave shapes, e.g. a larger cavity with a high ratio between height and width. The process can be seen in the form of progressive die, in which small size work pieces are carried through each station by a strip [1], or in the form of transfer die, in which relative larger work pieces are moved through each die set by transfer units. In the multi-stage draw, the workpiece is formed through different stages with decreasing draw reductions. In its development, blank shape, draw geometry and tool design of each station are to be determined. Since the input for following draw stage is the output - the workpiece drawn from previous draw stage, a draw design in previous stage affects not only the result of following draw but also the success of final draw. Due to this

cascading effect and already complicated large plastic deformation in deep draw itself, the design of multi-stage draw is regarded as the most formidable process development [1]. The normal industrial practice begins with an experience based initial design then to validate the design sequentially through each stage through trial and error iterations either by prototype tests or by FEM simulations [1,2]. Since the adverse effect of early draw on the following stage and many variables to be determined in each stage, an incorrect application of experience could either lead to prolonged process development or a request of an unnecessary design change on part geometry or sheet material. In order to make light weight stamping, the stamping geometry becomes increasingly complex to reduce the assemblies while the chosen sheet material becomes less formable to increase the strength weight ratio. This trend only adds more challenges in the multi-stage draw development. Under this background, the development of a method, which can guide designer to find a solution, becomes necessary.

Due to the aforementioned cascading effect of earlier stage on the following stage, the design of multi-stage draw can be treated as a multi-stage decision problem and the dynamic programming is a suitable method to solve the problem [3]. In this study, after modeling the multi-stage draw design as a multi-stage decision making problem, an improved dynamic programming, which designs the multi-stage draw in both reverse and sequential order, is proposed. In the method, FEM simulation is used to virtually trial out each design.

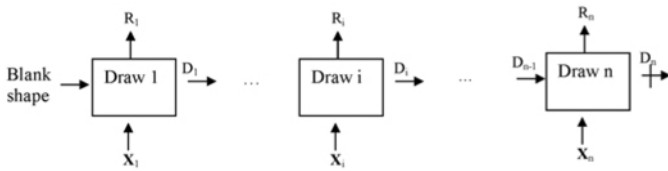


Fig.1. multiple step draw design problem

MULTI-STAGE DRAW DESIGN DESCRIPTION AND DYNAMIC PROGRAMMING SOLUTION

The multi-stage draw design starts from a final draw shape, which can be obtained from the part geometry by adding addendum or trimmed off section [1]. The multi-stage draw design becomes a process of determining initial blank shape and intermediate draws. The draw design of any earlier stage affects the result of following draws and an optimal forming situation in the earlier stage, e.g. a lower tendency of fracture, doesn't prevent fracture tendency the following draw, if the material drawn in the earlier stage is insufficient for the following draw. On the contrary, the final draw result does not affect any previous draws. Thus, the multi-stage draw can be regarded as a multi-stage decision making process and can be solved by dynamic programming [4].

DESCRIPTION

Since final draw shape can be generated from final part geometry by adding up trimmed portion, the multi-step draw design can be treated as a final value problem [1, 3]. For an n-draw development, the geometry of final draw can be represented by vector D_n . At i^{th} draw, the input is the formed work piece D_{i-1} from $i-1^{\text{th}}$ draw. The design of i^{th} draw is to determine the design vector X_i , such as the geometry of tool components, binder force etc.. With the designed tool geometry and process parameters at i^{th} draw, the work piece D_{i-1} is drawn to be the work piece D_i , this process can be described as:

$$D_i = f(X_i, D_{i-1}) \quad (1)$$

The success of i^{th} draw is judged by an effective index R_i .

$$R_i = R(X_i, D_{i-1}) \quad (2)$$

Fracture and wrinkling are two major failure types in deep draw. A joint index for fracture and wrinkling risk is proposed to reflex the failure risk as below [4]:

$$R_i = w * (\max(\text{norm}(wr_i(j))) + (1 - w) * \text{norm}(fr_i)) \quad (3)$$

$j=1, \dots, m$, represents wrinkling at different portion of the part, e.g. at wall and corner, which have different wrinkling resistance [5]. $\text{norm}(wr_i(j))$ is a wrinkling index, which is a wrinkling value normalized with a critical value, e.g. the absolute ratio between minor strain and major strain or thickening or stress [5, 6]. $\text{norm}(fr_i)$ is a fracture index, which is a fracture risk value normalized with a critical value, e.g. the major stress in the FLSD curve, which is a strain-path independent criterion, or thinning percentage, which is a simplified criterion [7,8]. w is the weight of wrinkling risk.

IMPROVED DYNAMIC PROGRAMMING

As a final value multiple stage decision problem, only the final draw shape is the known while other parameters, such as initial blank shape, the number of draws, draw shape of each step and tool design for each stage, are to be determined. A drawability based initial draw design is determined first to allow following suboptimization solution on determining each draw design. The achieved draw design is then fine tuned in a sequential order.

Tab.1. suggested draw ratios for deep drawing of cylindrical shape without intermediate annealing [9]

Number of draws	Relative sheet thickness $s_0/d_0 \times 10^2 = 2$
1	2.08
2	1.37
3	1.32
4	1.28
5	1.25
*10	1.10

*Note: draw 10 is added for defining minimum draw ratio D_{rmin} at a possible maximum draw number

DETERMINATION OF INITIAL DESIGN

To start suboptimization, an initial design needs to be determined. A sheet material drawability based method is proposed here to generate an initial design. The severity of the i^{th} draw can be defined by the draw ratio, which is the ratio between diameter of the workpiece to be drawn and that of the workpiece drawn from it. The draw ratio is extended to the irregular shape geometry by calculating the maximum ratio among all the feature dimensions:

$$DR_i = \max\left[\frac{L_{i-1}^j}{L_i^j}\right], j = 1, \dots, m \quad (4)$$

For example, for the cylinder geometry, only one dimension, the diameter of cylinder, exists and thus $j=1$ and then L_{i-1}^1 and L_i^1 are the diameter of $i-1$ th draw workpiece and that of i th draw workpiece, respectively. For the rectangular shape, $j=2$ and two dimensions are the width and length of the geometry. The draw ratio for each draw can be determined experimentally and previous study show the draw ratio decreases with the increase of draw stages [9]. An exponential relation is proposed to describe the draw stage and corresponding draw ratio as following:

$$DR_i = \beta i^\lambda \quad (5)$$

β and λ are constants that can be determined by curve fitting the empirical data. For example, for the sheet material SAE1006, the β and λ are determined at 1.826 and -0.237 , respectively. The relation can be used to interpolate draw ratio within the experimental tested stage range and to extrapolate draw ratios for the draw stages outside of the experimental range.

The product of draw ratio of each draw also equals to the total draw ratio, see equation below:

$$DR_{total} = \frac{L_0^*}{L_n^*} = \prod_{i=1}^n DR_i \quad (6)$$

L_0^* and L_n^* are the critical dimension of the blank diameter and that of the n th draw, respectively.

The initial draw design can be generated from [equation 4,5,6](#). The initial blank shape can be generated either by empirical equations [9] or by one-step reverse FEM calculation [1].

DESIGN EACH DRAW BY SUBOPTIMIZATION

To solve a multi-stage decision problem, suboptimization concept and principal of optimality are used by the dynamic programming. Obeying increment plastic deformation theory, the total deformation of sheet material is an accumulation of plastic deformation at each step. Then the failure risk increase at each stage leads to an increase of failure risk in the final part. Thus separability and monotonicity requirement for the application of dynamic programming method is met [3].

The suboptimization concept is to solve the stage with least impact of other stage first. Thus the suboptimization begins with final draw n for n -draw design. At each draw design, classic optimization methods, such as DOE based response surface, gradient search or simplex method, can be used to find a set of design variables X_i and geometry of workpiece drawn from previous stage D_{i-1} to have a minimum failure risk R_i to achieve certain amount of draw reduction Dr_i . The process continues until the draw 1 and can be expressed in a recurrence relationship as:

$$f_i^*(X_i, D_{i-1}) = \min[R_i] + f_{i+1}^*(X_{i+1}, D_i) \quad (7)$$

For an acceptable design, following constraint is applied:

$$F = \sum_{i=1}^n f_i \leq 1 \quad (8)$$

During the suboptimization, the number of draws is to be adjusted by introducing a concept of allowance of failure risk, which is the amount of failure risk allowed to be developed at this stage. It is assumed that the failure risk increases with the increase of draw ratio, e.g. thinning and wrinkling increase with draw ratio increase at same forming condition. The binder (pressure pad) effect on the failure is expressed by λ_i^{fr} . For the stage without binder, $\lambda_i^{fr}=1$. With binder, the extra restraining force is from the contact friction and added

one unbending for the in-die sleeve contact. Thus, λ_i^{fr} shall be larger than 1 and can be determined with consideration of contact pressure, friction coefficient and binder geometry. The fracture risk allowance is relation with draw ratio and binder coefficient as:

$$\frac{\text{norm}(fr_i^{cap})}{\text{norm}(fr_{i-1}^{cap})} = \frac{\lambda_i^{fr} Dr_i}{Dr_{i-1}} \quad (9)$$

$$\sum_{i=1}^n \text{norm}(fr_i^{cap}) = 1 \quad (10)$$