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Applications of evolutionary algorithms to sheet metal forming processes: A review

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Abstract- Metal forming processes are compression-tension processes involving wide spectrum of operations and flow conditions. The result of the process depends on the large number of parameters and their interdependence. The selection and optimization of various parameters is still based on trial and error methods. In this paper the authors presents a compressive study of application of evolutionary strategies to optimize the geometry parameters such as die design and punch design, process parameters such as forming load, blank holder pressure and coefficient of friction, the spring back, hammering sequence etc. Evolutionary algorithms offer many advantages over traditional methods. These are widely used now days for sheet metal industry.

Keywords- Sheet Metal Forming, Evolutionary strategies, Genetic algorithm

Metal Forming

Sheet-metal working processes have been associated with mankind since the Iron Age, when human beings first discovered that metals, especially gold and silver, can be shaped in the cold state by repetitive hammering to form thin sheets for making bowls and plates, containers, decorative items, etc. Household machines, kitchen utensils, record players, electrical appliances, toys, computers, switches and locks are some of the common household products that contain a large number of metal stampings. In stamping, drawing, or pressing, a sheet is clamped around the edge and formed into a cavity by a punch. The metal is stretched by membrane forces so that it conforms to the shape of the tools. The membrane stresses in the sheet far exceed the contact stresses between the tools and the sheet, and the through-thickness stresses may be neglected except at small tool radii. Out of these processes drawing or deep drawing process is more complicated and important with reference to the automotive industry. It is very useful in industrial field because of its efficiency. In deep drawing a sheet metal blank is drawn over a die by a punch with radius. As the blank is drawn radially inwards the flange undergoes radial tension and circumferential compression [1]. The latter may cause wrinkling of the flange if the draw ratio is large, or if the cup diameter-to-thickness ratio is high. A blank-holder usually applies sufficient pressure on the blank to prevent wrinkling. Radial tensile stress on the flange being drawn is produced by the tension on the cup wall induced by the punch force. Hence, when drawing cups at larger draw ratios, larger radial tension are created on the flange and higher tensile stress is needed on the cup wall. Bending and unbending over the die radius is also provided by this tensile stress on the cup wall. In addition, the tension on the cup wall has to help to overcome frictional resistance, at the flange and at the die radius. As the tensile stress that the wall of the cup can withstand is limited to the ultimate tensile strength of the material, the draw ratio possible in deep drawing is usually limited to about 2.1 or 2.2, to draw deeper cups recourse being made to special drawing processes such as hydro-forming, hydro-mechanical forming, counter-pressure deep drawing, hydraulic pressure-augmented deep drawing, etc. These processes are relatively slow (compared with the deep drawing or redrawing process) and the draw ratios are limited to 3.5 or 4 at most. However, a conventionally-drawn cup can be redrawn twice or more to obtain draw ratios of the order of 5, 6 or even larger values.

Need of Optimization in Metal Forming

The metal forming process is a complex operation requiring a simple geometry to be transformed into a complex one. The main goal of optimization in metal forming is to produce sound products through optimal process design, since the process material and die variables significantly influence the process. Classical approaches such as trial and error are tedious, ill-structured, time consuming and costly. Dynamic programming can handle continuous and discrete variables, but is limited since the process normally involves large amount of process variables with wide range of values that may be active in the optimization problem. Also, derivative based approaches are not suitable since the objective function may possess multiple stationary points. Several authors have shown that the GA based approaches can be used to deal with these complex real world problems [1]. An outline of evolutionary computation applications in metal forming industry reported in this paper. These approaches have been shown to offer a more structured approach to process optimization problems. They also offer the benefit of cataloguing the optimal solutions for future re-use. This can save design time and effort for future problems. However the main problem experienced using GA in this environment is due to the expensive function evaluations. Since objective functions are often analytically unknown, function evaluations can only be achieved through costly computer simulations. The slow convergence criteria to near-optimal solution with very small tolerance accompanied with the large population of solutions required for the evolutionary process result in expensive evaluations.

Advantages of Evolutionary Algorithms

Evolutionary algorithms always work with population, facilitating simultaneous search and optimization. These work with probabilistic approach rather than deterministic. These algorithms are often viewed as global optimization methods although convergence to a global minimum is only guaranteed in a weak probabilistic sense. A global optimum is not guaranteed, although near optimal solutions are found easily. However, one of the strengths of evolutionary strategies is that they perform well on noisy functions where there may be multiple local optima and evolutionary strategies tend not to get stuck on a local minimum. Another strength is that these methods do not require a gradient of the objective cost function as a search direction. These approaches show certain advantages over the classical optimization procedures e.g. they are robust, highly parallelizable, and suitable for optimizing multimodal functions without requiring gradient information[1]. Evolutionary strategies with self-adaptation mutation operators are used to tackle the nonlinear structural optimization problem. Another important feature of evolutionary strategies is that they can compute multiple, independent objective function evaluations simultaneously in an effort to accelerate the search process. Thus, this approach can take advantage of parallel and distributed computing multiprocessing architectures.

Optimization of Hammering Sequence

In an incremental forming process, a sheet metal is progressively bent by a set of comparatively simple hammer and die. The sheets are formed into a great variety of shapes by repeating local deformation due to the hammering. This process is expected as an approach of flexible forming for small lot production. Since the degree of freedom for deformation in the incremental forming is large, it is not easy to determine the hammering sequences. The use of the finite element simulation for the determination is unrealistic because it takes an extremely long computing time to calculate local deformation due to the hammering repeatedly. The hammering sequences are generally determined by a trial and error experiment. The development of a method for determining the hammering sequences is required for the establishment of incremental forming processes [1].The genetic algorithms have been recently applied as an approach for combinatorial optimization problems in the field of manufacturing. It is impossible in the combinatorial optimization problems to obtain the solution from the differentiation of the objective function because the design variables have discontinuous values. In the genetic algorithms, the combination is optimized on the basis of probabilistic transition rules. In addition, the genetic algorithms can deal with a complicated objective function in the optimization because the differentiation of the objective function is not necessary.

Optimization of blank dimensions to Reduce Springback in the Flexforming process

The sheet metal forming process involves a combination of elastic–plastic bending and stretch deformation of the work piece. These deformations may lead to a large amount of spring back of the formed part. It is desired to predict and reduce spring back so that the final part dimensions can be controlled as much as possible. Ayres suggested the use of a multiple step process to reduce spring back in stamping operations. Liu proposed to vary the binder forces during the forming process thereby providing tensile pre-loading to reduce the spring back in the formed part. Techniques that are used in practice to reduce spring back include stretch forming, arc bottoming and the pinching die technique[2]. However, all these techniques transmit high tensile stresses to the walls of the deforming part thereby increasing the risk of failure by tearing, mainly in parts with complex geometries. Several analytical methods have been proposed to predict the change in radius of curvature and included angle due to spring back for plane-strain conditions and simple Axisymmetric shapes. These methods are approximate and associate the source of spring back to non-uniform distribution of strain and bending moment upon unloading. The finite element method (FEM) is used widely to predict spring back in research and industry. Chinghua studied the influence of process variables of the methods used in practice to reduce spring back by an optimization technique for U channel parts. Karafillis and Boyce developed a deformation transfer function for changing the shape of the tool to compensate for spring back in sheet metal forming using FEM [2]. The objective of this study was to estimate and reduce for spring back of axisymmetric part manufactured by flexforming process. The manufacturer selected the die and blank dimensions based on the experience and trial-and-error. However, the dimensions of the final part could not meet the design specifications due to its spring back after forming. Thus, finite element analysis was used to predict spring back in the existing manufacturing set-up. Then GA is used to optimize it.

Optimization of metal forming processes

Nowadays, the finite element method (FEM) has proven its efficiency and usefulness simulating steady and non-steady metal forming processes. It allows to test and to compare several process candidates. When the modeling approaches are deterministic requiring the introduction of several input data such as geometry, mesh, non-linear material behavior laws, loading cases, friction laws, thermal laws, etc., then the computation of process evolution and final results is called a direct problem. Since efficient numerical methods have already been developed, these direct problems using FEM have reached some level of maturity. Then it becomes possible to solve more complex problems, namely the inverse problems[3]. The goal of these inverse problems is to determine one or more of the direct problem input data, leading to a given result. One of these inverse problems deals with the initial geometry and tool shape design parameters in forming processes. It consists in determining the initial shape of the work-piece in one stage forming or the shape of the forming tools in multi-stage forming, in order to provide the desired final geometry of the forged piece. This problem can be formulated as an optimization problem. The goal is to minimize an objective function considering among other factors the total forming energy and the gap between the FEM results for the final geometry and the desired one. The development of inverse techniques has resulted in several realizations in 2D and 3D optimization algorithms where the geometry parameter update considers gradients and sensitivity analysis of the objective function. Recently, evolutionary genetic algorithms have been proposed in order to optimize shape design parameters in forming processes[3]. Then the optimal solutions are not gradient dependent and consequently do not present numerical errors resulting from non-accurate sensitivity calculations. Furthermore, shape and non-shape, discrete and continuous variables can be simultaneously optimized using genetic algorithms.

Optimal designs of metal forming die surfaces

Computer-based systematic approach for optimum design of geometric and process parameters in industrial sheet metal forming simulations is proposed here. Today, most of the automotive Industry uses sheet metal forming simulations during the vehicle development process in order to accelerate the design cycles and to reduce development costs [4]. The simulations are applied to assess the feasibility of part geometries during the product design phase, to try out prototype and production tooling during the die development process, and to optimize process parameters for maximum efficiency, reliability and quality. Therefore, many similar simulations must be carried out with different process parameters and different tool geometries. Furthermore, it is not sure whether the optimal process parameters and tool geometries have been found, even after having carried out several simulations. There is thus an urgent need for a reliable integrated computer-based optimization approach to modify geometry and process parameters and to automatically find their optimal combination. Recent evolutionary strategies simulated annealing and genetic algorithms have attracted attention amongst the engineering design optimization community. This has given rise to the Evolutionary Automatic Design [EAD] of process and geometry parameters [4]. Important phases are fast parametric design of the tool surfaces, the choice of actuator design variables and relevant objective cost functions by practical process engineers, and the integration of evolutionary strategies into the computer-based systematic approach. The main components of an integrated computer based system are: (1) an automatic parametric tool design generated from the CAD surface data of the sheet metal part; (2) the optimum design problem (objective function, design variables and constraints involved in the optimization); (3) the evolutionary strategy as optimization algorithm; and (4) the integrated objective function evaluation by applying the implicit infinite element sheet metal forming simulation software package Auto Form-Incremental, where a single simulation may take anywhere from few minutes to several hours of computation on a single processor.

Summary

With the recent developments in sheet metal forming processes and composite materials that are being used now days, it is possible to form more complicated products. This involves more complicated process variables. The evolutionary algorithms have proved themselves more useful to be applied for optimization in these situations.

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