

Chapter 5

Simultaneous Tolerance Synthesis for Manufacturing and Quality using Evolutionary Algorithms

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ABSTRACT

Tolerance plays a major role in the manufacturing industry, as it affects product design, manufacturing, and quality of the product. This paper considers product design, manufacturing, and quality simultaneously, and introduces a concurrent approach for tolerance allocation using evolutionary algorithms. A non-linear model that minimizes the combination of manufacturing cost and quality loss simultaneously, in a single objective function has been considered. In the proposed work, evolutionary algorithms (that is, Genetic Algorithms (GA), Differential Evolution (DE), and Particle Swarm Optimization (PSO)) have been used to determine the optimal tolerances at the minimum manufacturing and quality loss cost. The application of the proposed methodology has been demonstrated on a simple mechanical assembly.

INTRODUCTION

The functional performance and manufacturing cost of a product is majorly affected by tolerance design, which is one of the key aspects of mechanical design. By keeping this fact in mind dimensional tolerances are classified as design tolerances

and manufacturing tolerances. Moreover, the functional requirements of a mechanical assembly are taken care by design tolerances, whereas the process plan of manufacturing a part is dealt by manufacturing tolerances. It is important to note that tolerance plays a major role in the design and manufacturing of a part. For example, tight tolerances will lead to high manufacturing cost, while loose tolerances will lead to malfunctioning

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of the product. Preferably, one can imagine that for achieving the goal of minimal total cost and reduced lead time, the best technique for tolerance synthesis is to take into account the coupling between design, manufacturing, and quality.

Conventionally, tolerance synthesis is being carried out in two stages namely design and process planning stages, respectively. However, design engineers allocating design tolerances are often unaware of manufacturing processes and their production capabilities. This may be due to either a lack of communication between design engineers and process engineers, or a lack of knowledge of the manufacturing processes by the design engineers. The resulting process plans often cannot be executed effectively, or can only be executed at undesirably high manufacturing cost. When this happens, process engineers must modify the design tolerances. Furthermore, manufacturing engineers who allocate processes must typically work within the tolerance limits set by design engineers, which results in longer lead times. But in accepting tolerances set by design engineers, the process planners also limit the range within which they can set process tolerances. This, in turn, leads to tight process tolerances and higher manufacturing cost.

While considering total manufacturing cost, it is also important to take the quality loss also into account. In order to find the effect of quality, Taguchi had introduced quality loss function (Taguchi, 1989). In order to compare this important factor with the others that affect the design process, the quality loss can be translated in a hypothetical financial loss or a cost for quality loss. For reducing the quality loss tight tolerances are to be allocated, which leads to higher manufacturing cost. Therefore, it is essential to allocate tolerances simultaneously to balance manufacturing cost and quality loss that optimize cost of the product over life. The following paragraphs discuss some of the analytical methods developed for solving the tolerance allocation problems.

Non-linear optimization problem formulations of tolerance assignment were first introduced by Speckhart (1972), Spotts (1973), and Sutherland and Roth (1975). They proposed an exponential cost model, reciprocal squared cost model, reciprocal power model respectively, based on the production cost – tolerance data curve. Further the researchers focused on the mathematical modeling and optimization of tolerance related issues using conventional approaches. Later on, Ostwald and Huang (1977) formulated a technique for optimal tolerance allocation choosing one process variable at a time. Linear integer programming, with cost as the objective function and design requirements as constraints was considered in their approach. This technique is suitable where sequences and tolerances of operations are fixed. A different approach was proposed by Lee and Woo (1989) after considering process specific tolerances and optimized using integer programming. Chase et al. (1990), presented three methods such as exhaustive search, univariate search and sequential quadratic programming to solve the tolerance related problems. It is important to note that the limitation of the above methods is that the models assume the components were produced utilizing a single process, where as the present research focuses on the components that require more than one processes to complete a component. Few researches had tried to develop models for the components that require more than one process to complete the component. Some of the literature related to non-traditional optimization methods is explained below.

Chase and Greenwood (1988) introduced the reciprocal model with better empirical data fitting capability, considering both the continuous as well as discrete cost functions. Later on Zhang and Wang (1993) proposed mathematical models with the consideration of manufacturing process for continuous cost function and solved it utilizing non-traditional optimization technique called simulated annealing. In addition to this, Zhang

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