Robotics and Computer-Integrated Manufacturing 35 (2015) 84–95

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim

Concurrent tolerance allocation and scheduling for complex assemblies

K. Geetha [a,*], D. Ravindran [b], M. Siva Kumar [c], M.N. Islam [d]

[a] Department of Mechanical Engineering, SACS M.A.V.M.M Engineering College, Alagarkovil, Madurai 625301, Tamil Nadu, India
[b] National Engineering College, K.R. Nagar, Kovilpatti 628503, Tamil Nadu, India
[c] Sree Sowdambika College of Engineering, Chettikurichi 626134, Aruppukottai, Tamil Nadu, India
[d] Department of Mechanical Engineering, Curtin University, GPO Box U 1987, Perth, WA 6845, Australia

ARTICLE INFO

Article history:
Received 23 March 2014
Received in revised form
5 March 2015
Accepted 6 March 2015
Available online 16 March 2015

Keywords:
Tolerance allocation
Scheduling
Lagrange's multiplier method
Genetic algorithm
Tolerance cost model
Tolerance machining time model
Quality loss cost

ABSTRACT

Traditionally, tolerance allocation and scheduling have been dealt with separately in the literature. The aim of tolerance allocation is to minimize the tolerance cost. When scheduling the sequence of product operations, the goal is to minimize the makespan, mean flow time, machine idle time, and machine idle time cost. Calculations of manufacturing costs derived separately using tolerance allocation and scheduling separately will not be accurate. Hence, in this work, component tolerance was allocated by minimizing both the manufacturing cost (sum of the tolerance and quality loss cost) and the machine idle time cost, considering the product sequence. A genetic algorithm (GA) was developed for allocating the tolerance of the components and determining the best product sequence of the scheduling. To illustrate the effectiveness of the proposed method, the results are compared with those obtained with existing wheel mounting assembly discussed in the literature.

1. Introduction

There has been extensive research on tolerance allocation due to its relationship with product cost, quality, and functionality. Tolerance allocation involves allocating a component's tolerance based on its known critical dimension tolerance to meet the functional requirements of a product. There are an infinite number of combinations of component part tolerance values within process tolerance limit that can satisfy functional equations. However, some combinations of part tolerances are better than others. The aim of tolerance allocation is to compute the best possible combination of component part tolerances based on a given set of objectives associated constraints.

1.1. Methodologies

Various methodologies have been used to solve the tolerance allocation problem in the literature. The most frequent methods, namely Lagrange multiplier, heuristics, and metaheursitic methods, are dealt within the following section.

1.1.1. Lagrange multiplier method

This method is the most popular among analytical methods for allocating the tolerances of component parts for a known assembly tolerance value. It is most suited to single-process optimization problems. This method eliminates the need for multiple-parameter iterative solutions and allows consideration of alternative cost-tolerance models. It can handle both worst-case and statistical tolerance accumulation models [1–6]. Details of the available models are discussed later in this section. The drawbacks that limit its usage are (i) the allocated tolerance values may be beyond the process precision limits, (ii) it cannot be easily adopted to alternative process selection; and (iii) it is a time-consuming and tedious process. Siva Kumar et al. [7] developed a closed-form equation for tolerance allocation and compared its performance with that of Lagrange multiplier method.

1.1.2. Heuristic method

In this method, the best combination of component part tolerances is determined using nonmathematical techniques, such as rules of thumb, past practices, and current standards [8,9]. As this method is only suited to limited cases, a very few studies have used it to solve optimum tolerance allocation problems. However, a considerable number of studies have used other methods, such as the Branch and Bound algorithm [10] and Design of Experiments [11], to minimize the manufacturing costs of assemblies.

* Corresponding author.
E-mail addresses: gee130372@ymail.com, kitchu7122002@rediffmail.com (K. Geetha).

http://dx.doi.org/10.1016/j.rcim.2015.03.001
0736-5845/

1.1.3. Metaheuristic method

In this method, near optimal allocated tolerances of component parts are obtained by dividing the process tolerance limits into a number of discrete points and randomly selecting a discrete tolerance for each component. The assembly tolerance is then determined with a tolerance accumulation model. The mathematical function and its constants of tolerance cost models are well known before the allocation. Two metaheuristic methods used extensively in the literature are simulated annealing [12] and genetic algorithms (GAs) [1,13–22].

1.1.4. Cost function model

Various cost-function models have been proposed to calculate manufacturing costs. These include reciprocal [23], reciprocal squared [24], reciprocal power [25], exponential [26], reciprocal power/exponential hybrid, polynomial and fourth-order polynomial [27], reciprocal power with setup cost [2], and exponential with constant [28]. These functions can be classified into two categories: a discrete cost function (DCF) and a continuous cost function (CCF). DCF models [2,29–32] have a relatively large number of model fitting errors, do not consider the value range of cost tolerance curves, and require manual formulation. Therefore, most studies have focused on the CCF tolerance model, which provides a closed-form solution to the optimization problem.

Taguchi introduced the concept of quality loss of a product. According to this concept, all the critical parameters (including the dimensions) of a product should be at their target values to ensure the product's best performance. If parameters deviate from their target values, the performance of the product deteriorates, and the product loses quality. A large number of studies have considered the sum of quality loss and manufacturing cost as an objective function [13,30,31,33–43].

1.1.5. Tolerance accumulation model

The tolerance accumulation model is a mathematical model that estimates the combined effect of component part tolerances on assembly tolerance. A number of tolerance accumulation models are available, and they are classified into two groups: (i) worst-case (WC) models and (ii) statistical models. The WC tolerance accumulation model considers the possibility that all the component part dimensions are at their extreme limits (i.e., maximum or minimum) simultaneously; thus, it is based on the worst-case scenario. Statistical tolerance accumulation models are based on the premise that the chance that all the component part dimensions will be at their extreme limits simultaneously is very small. Consequently, a statistical model places little significance on dimensions that have a low probability of occurring. As a result, individual tolerance values are greater when a statistical model is applied than when a WC model is applied. Statistical tolerance accumulation, such as the root sum square (RSS) method, has been used by a number of researchers [5,31–33,44].

1.1.6. Example product type

The ability of tolerance allocation methods to determine tolerance differs according to the product type. For example, the Lagrange multiplier method is more suited to a simple product than a complex product. Only a few authors [13–15,33,66,67] have considered simple assembly products comprised of only two mating component parts as an example problem. To evaluate functional performance requirements, most researchers have focused on complex assemblies that have several critical dimensions and are controlled simultaneously within certain variation ranges [1,4,5,10,16,28,45–56]. A relatively small number of authors have examined nonlinear assembly products that consist of more than two components and are arranged nonlinearly [1,2,10,17–19,32,40,57].

1.2. Process planning and scheduling

Process planning and scheduling functions play a vital role in the profitability, utilization, and delivery time of a product [58]. The method proposed by the authors was applicable to Holonic manufacturing system with dynamic changes in volume and a variety of products. Xinyu et al. [59] suggested a GA-based approach for the integration and optimization of process planning and scheduling. Li et al. [60] developed three strategies (i.e., Pareto, Nash, and Stackelberg) for computer-automated process planning and scheduling in a systematic way. Guo et al. [61] used both a combinatorial optimization model and a modern evolutionary algorithm, the particle swarm optimization (PSO) algorithm, to solve integrated process planning and scheduling problems. Hengyun et al. [62] proposed a particle swam algorithm to minimize production makespan. Xinyu et al. [63] developed a hybrid approach (a GA and a local search strategy) to solve integrated process planning and scheduling problems. Xinyu et al. [64] introduced an integrated process planning and scheduling mathematical model.

In the literature, tolerance allocation and scheduling problems are usually dealt with separately. Many papers of tolerance allocation have focused on either minimizing the tolerance cost [1–6,8–13,15–29,31,32] or minimizing the tolerance cost and quality loss cost [13,31,33–38,40–43]. As a result, later scheduling [58–65] produces a non-optimum solution because the machining time and processing time of a component play a vital role in the scheduling process, which depends on the allocated tolerance of the components. Considering the tolerance allocation and scheduling separately provides misleading information about the manufacturing cost because tolerance allocation aims to minimize the tolerance cost based on the distribution of tolerance among the components of an assembly. However, in scheduling, the machining time plays a vital role in determining the machine idle time cost. Only a few authors [14,36] have considered both tolerance costs and machining time when allocating tolerance to components. No significant effort has been made to simultaneously address tolerance allocation in the context of job-shop scheduling. Therefore, in the present study, both the tolerance cost and machine idle time cost were optimized by considering the component/operation sequence. Singh et al. [28], Prabhaharan et al. [17], Singh et al. [46], Sivakumar et al. [47], and Li et al. [63] showed that the GA provided a good solution to tolerance allocation and scheduling problems as compared with other optimization techniques. The ability of a GA to identify different solutions, given the same objective value, offers engineers a range of solutions from which they can then select the optimal one. Moreover, realizing the complexity of the problem, a GA algorithm is introduced both in allocating the best tolerance for each component of an assembly and in obtaining the best product sequence.

2. Problem definition

Heavy competition in the global market forces manufacturers to reduce their manufacturing costs and improve their productivity. It is a challenging task for engineers to find the ways and means to solve the above problem. Selection of tolerance within the known process tolerance limits in a given process-machine combination influences the manufacturing cost and the productivity of the known complex assembly's critical tolerance. Infinite number of tolerance values between the process tolerance limits makes the problem a non polynomial hard problem. Besides the tolerance cost, the specified tolerance values determine the machining time required to make the component in a machine.