Simultaneous optimal selection of design and manufacturing tolerances for Knuckle joint using SA-PS algorithm

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Abstract—A systematic approach to tolerance synthesis involves consideration of the manufacturing cost as a function of tolerance. Allocation of manufacturing and design tolerances is an important step in product development. The focus of this paper is on the optimal solution of the least cost tolerance design. The modified exponential cost tolerance model has been considered. The SA-PS algorithm ,a nontraditional global optimization technique has been used as the solution methodology for its inherent advantages. Application of methodology is demonstrated on complex tolerancing product like Knuckle joint. Optimal result so obtained are compared with previous work done and found that individual tolerance and corresponding manufacturing cost is drastically reduced.

Keywords--- Simulated annealing, tolerance allocation, tolerance stack up ,constrained optimization

I. Introduction

IN the present study, a new stochastic optimization algorithm based on hybridization of Simulated Annealing[1] algorithm and Hook-Jeevs[2] pattern search (SA-PS) has been used to solve the problem of tolerance optimization through the least cost tolerance design[3]. The combined SA-PS[4] algorithm make simulated annealing more competitive with respect to computational requirement, yet its ability to escapes from the trap of local optimality is retained. The detailed algorithm is validated through some standard bench mark problems[5,6,7]. However, the suitability of the SA-PS algorithm from the point of view of tolerance optimization is evaluated. through an example Knuckle Joint Assembly.. In this case study the solution of optimal tolerance synthesis problem involving complexities, the valid process precision limits have been considered. In the objective function, the cost tolerance model varying from exponential models [8] and polynomial models suggested by Dong et al [9] has been considered. The constraints based on various stack-up conditions models[10,11,12] and those resulting from the stock removal considerations are included.

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The constrained optimization problem is handled using penalty function approach with normalized penalty term. The overall optimization problem is solved using SA-PS algorithm.

II. Knuckle Joint Assembly

In this section, the model developed for concurrent optimization of design and manufacturing tolerances is validated using a Knuckle joint assembly. This example has been taken from reference [13]. The knuckle joint assembly, as shown in the Figure 1 consists of five dimensions. Three dimensions constitute two inter related dimension chains with X_2 dimension being common to both.

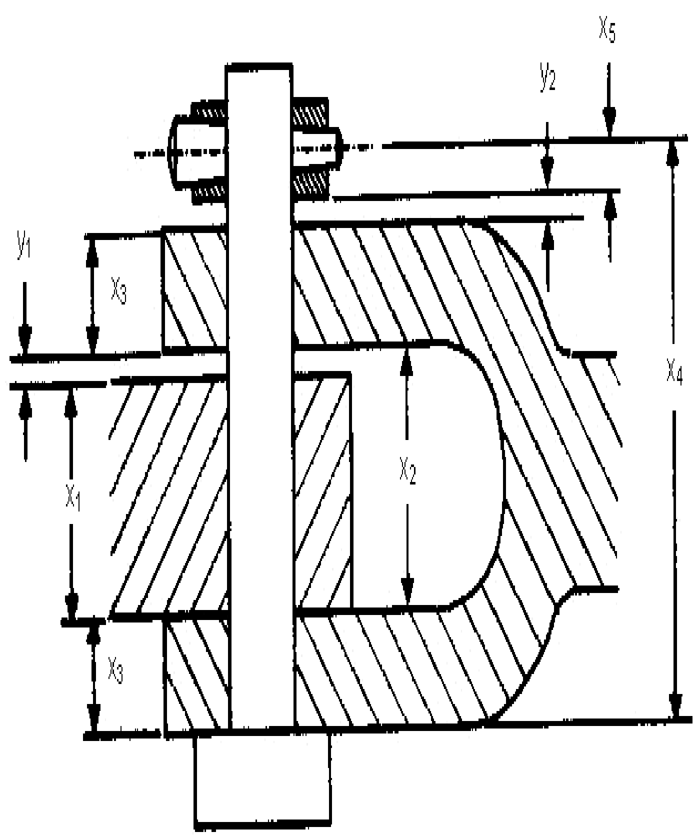

Fig. 1 Knuckle joint Assembly

III. OBJECTIVE FUNCTION

Minimization of total assembly manufacturing cost constitutes the objective function of the optimization problem

$$C = C_{x_1} + C_{x_2} + 2C_{x_3} + C_{x_4} + C_{x_5} \quad (1)$$

Where C_{x_i} = Cost of manufacturing X_i dimension with t_{ij} tolerance.

IV. ASSEMBLY RESPONSE FUNCTION

The two interrelated dimension chains give the following two assembly response functions

$$Y_1 = X_2 - X_1 \quad (2)$$

$$\mathbf{Y_2 = X_4 - (X_2 + 2X_3 + X_5)} \quad (3)$$

V. TOLERANCE STACK-UP CONSTRAINTS

From the equations of assembly response functions, two constraints based on worst case stack-up condition are formulated. Dimensions X_2 and X_3 are assumed to be produced on a single machine to avoid extra set-up the assumption that tolerance $t_2 = t_3$ will ascertain fulfillment of this condition. The permissible assembly tolerance on the assembly response Y_1 and Y_2 have been assumed to be equal to 0.3 mm. Thus the stack-up constraints can be expressed as given below:

$$t_1 + t_2 \leq 0.3 \quad (4)$$

$$t_4 + t_2 + 2t_3 + t_5 \leq 0.3 \quad (5)$$

$$t_4 + 3t_2 + t_5 \leq 0.3 \quad (t_2=t_3) \quad (6)$$

Where t_i is the tolerance achieved on dimension X_i

VI. OPTIMIZATION RESULTS

The optimization problem using objective function (Eq. 1) and constraints (Eqs 4-6), as discussed above is solved using SA-PS algorithm. The results of optimization along with reported in the reference [13] are listed in Table I.

VII. CONCLUSION

A close look to the statistical data (Table 2) suggests that optimization problem converges to global solution in first 50 iterations. In order to study the effect of seed numbers, various combinations were tried and found that there is no significant effect of initial seed number on the convergence rate. However, initial temperature does influence the accuracy of the solution; hence trial and error method has been used to find the suitable initial temperature and cooling schedule. The variation in objective function for 50 iterations (each temperature level is taken as one iteration) . Initially at the high temperature, the objective function approaches to minimum at faster rate in first few iterations. However after 23 iterations it reduces gradually and finally converges to minimum value at about 40^{th} iteration.) Comparison of results reported in Table I clearly shows that the concurrent optimization methodology presented in this work has a clear edge over the results reported in reference [13].

Optimal result so obtained are compared with previous work done by Singh et al has found that individual tolerance on different components and corresponding manufacturing cost is drastically reduced.

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TABLE I
OPTIMIZATION RESULTS

Dimension	Individual Tolerance (mm)	
	Singh et. al[13]	SA - PS Algorithm
X_1	0.1500	0.1500
$X_2 = X_3$	0.0841	0.08385
X_4	0.0200	0.0200
X_5	0.0276	0.0289
Accumulated tolerance Δy_1	0.2341	0.2338
Δy_2	0.300	0.3000
Minimum Manufacturing Cost ($)	407.44	404.87

TABLE II
STATISTICAL DATA FOR KNUCKLE JOINT

Parameters	Values
Initial Temperature	300^0C
Cooling Schedule	0.85
Error Limit	0.0001
Random Seed Number	11.22
Lower Bound Values	[0.01, 0.01, 0.02, 0.01]
Upper Bound Values	[0.15, 0.15, 0.20, 0.10]
Initial Trail Solutions	[0.01, 0.01, 0.01, 0.01]
Number of Iterations	50
Total Function Evaluations	23817
Accepted Function	12918
Computation Time	3.6 sec.