J. Software Engineering & Applications, **2009, 2: 350-353**
doi:10.4236/jsea.2009.25046 Published Online December 2009 (http://www.SciRP.org/journal/jsea)

Multi-Objective Incomplete Probability Information Optimization Reliability Design Based on Ant Colony Algorithm

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Received April 19th, 2009; revised June 3rd, 2009; accepted June 15th, 2009.

ABSTRACT

In view of incomplete probability information multi-objective question, it used probabilistic perturbation method and Edgeworth series technique to study reliability optimization design. The first four moments of basic random variables are known under condition. It used the Ant Colony Algorithm to design cutting head roadheader, the optimized result indicated that cutting head load fluctuation and compared energy consumption were reduced obviously at the same time. This result enhanced roadheader operational reliability and energy effectively.

Keywords: *Optimization Reliability, Multi-Objective, Probabilistic Perturbation Method, Incomplete Probability Information*

1. Introduction

Cutting head is the key component and important part of roadheader which affects the roadheader efficiency and load exceptional change. There are many published reports on the cutting head's reliability optimization research overall the world, such as Zhang Xin from Shandong Scientific and Technical University has studied on cut truncation tooth arrangement and multi-objective optimizations [1,2]; Li Xiao-huo from Liaoning Technology University has studied on cut head swinging cutting and cut head design [3–5]; Ma Hong-wu from Datong coal mining has studied on the cut head diameter influence to roadheader [6]; Guo wu from IMM company has studied on S150 cutting head [7]. The majority of scholars use the conventional routes to research cut head reliability optimization design, these methods are under design variable and parameter to follow the normal distribution. Due to the complexity in real project and insufficient data message, it is prone to make errors by conventional design [8–10]. This paper uses the stochastic perturbation method and Edgeworth progression method [11–14] to discuss cutting multi-objective reliability optimization which distributes the random parameter obedience willfully.

2. The Reliability Design of Perturbation Method

To calculate reliability or failure probability, it needs to know the probability of density function or joint probability of density function. As lack of the tentative data, it is mostly very difficult to obtain reliability or failure probability by integral computation. Under the situation that unable to determine the distribution generally, the first to fourth moments (average value, variance and covariance, third-order moment, fourth-order moment) of design variable are determined easily as it has enough data, then it achieves reliable target, unknown function of state probability distribution is transformed to the standard normal distribution expression by application fourth-order moment technology, Edgeworth progression and corresponding experience correlation formula [14], finally it may determine the structural element reliability.

$$F(y)=\Phi(y)-\Psi(y)\left[\frac{1}{6}\frac{\theta_g}{\sigma_g^3}H_2(y)+\frac{1}{24}\left[\frac{\eta_g}{\sigma_g^4}-3\right]H_3(y)+\frac{1}{72}\left[\frac{\theta_g}{\sigma_g^3}\right]^2H_5(y)+\cdots\right]$$

$H_j(y)$ is j Stage Hermite multinomial, its recurrence relation is :

$$\begin{cases} H_{j+1}(y) = yH_j(y) - jH_{j-1}(y) \\ H_0(y) = 1, H_1(y) = y \end{cases}$$

The real distribution of random parameter could be approached precisely by the Edgeworth progression. It usually takes the progression of first to fourth items to obtain good approximation. But it only take the progression of first to fourth items, sometimes it will cause reliability to present R>1 situation because the approximate distribution function and the real distribution function exist deviation. The computation practice indicated that following experience correlation formula obtained result to approach in Monte Carlo numerical simulation under R >1 situation; the Edgeworth progression may obtain precise solution enough on condition of R < 1.

$$R^*(\beta) = R(\beta) - \frac{R(\beta) - \Phi(\beta)}{\left\{1 + \left[R(\beta) - \Phi(\beta)\right]\beta\right\}^{\beta}}$$

As known above, this method is fit for random parameter distribution generally during the equation development. It is more useful for the actual project.

3. Styling Ant Colony Algorithm and Optimize Calculate

When the design requirements is $P\{g(X) \geq 0\} \geq R_0$, it is $R = P\{g(X) \geq 0\} \geq R_0$, R_0 satisfies the probability values of the restraint, R obtains by the fore-mentioned Edgeworth progression or experience correlation formula. The probability optimization design model may be solved by model transformation as follows.

$$\min \quad f(X) = E\{f(X)\} = f(\overline{X})$$

St.

$$\left.\begin{array}{l} R \geq R_0 \\ q_i(X) \geq 0, (i = 1, \cdots, l) \\ h_j(X) = 0, (j = 1, \cdots, m) \end{array}\right\}$$

1) Initialize the population. Produce N to answer at random in the independent variable defined area to build the population, calculate adaptation degree of the individual, arrange order according to the size, and to give the same pheromone initial value to them. Produce M ants, including G overall ants, L some ants.

2) Overall Search. Seek overall ants to operate exploring. Through crossed and variable operating, produce new G ants to replace the present population G ants.

3) Some Search. Seek some ant to operate excavating one by one, calculate N individuals to choose probability Pi (x), choose L individual as the goal, optimize and search for the goal individual, and lead individuals to better position.

4) Pheromone is evaporated. Carry out pheromone to volatilize after changing and taking.

5) Check the condition of stopping. Finish one search, population is checked to be satisfied with disappearing terms. If it is satisfied, export and solve optimally at present. Otherwise, it transfers to the step 2). The next is to be searched, until disappearing or meeting the request of schedule.

4. Multi-Objective Optimization Reliability Design for Cutting Head of Roadheader Model

4.1 Design Variable Choose

Transversal spacing top, circumferential distribution angle δ, way speed v, rotational speed n are design variables:

$$X=[x1, x2, x3, x4]^T = [top, \delta, v, n]^T$$

4.2 Objective Function Establish

In the design of cutting head according to the load fluctuation and compared to the energy consumption computational method, it makes the smallest cut angle of Ra, sway resistance Rb, longitudinal force Rc, the load torque coefficient of variation Mc, energy consumption Hw. It takes objective function of cutting head multi-objective optimization reliability design.

This article uses the linear weighted sum law to transform the multi-objective optimizations for the simple target optimization. Considered various simple targets have the equal status. It realizes the multi-objective standardizations. The transformed objective function expression is:

$$F(x) = \frac{f_{R_a}(x)}{f_{R_a}} + \frac{f_{R_b}(x)}{f_{R_b}} + \frac{f_{R_c}(x)}{f_{R_c}} + \frac{f_{M_c}(x)}{f_{M_c}} + \frac{f_{H_w}(x)}{f_{H_w}}$$

The formulas: $f_{R_a}(x)$, $f_{R_b}(x)$, $f_{R_c}(x)$, $f_{M_c}(x)$, $f_{H_w}(x)$ are respectively simple goal optimization functions. The denominator is the simple goal optimum value.

4.3 Constraints Determine

Considering the actual situation, it establishes fuzzy reliability constraints.

1) Bolt between cutting head and the cutting head axis is intensity fuzzy reliable restraint:

$$\tau = 4P / (m_1 \pi d^2) \quad (1)$$

Use the stochastic perturbation method and Edgeworth progression method, then the max shear stress reliability design restraint is:

Table 1. Optimal solution and goal function value

t_{op}	δ	v	n	
3.601	42.021	2.937	38.265	
routine calculation Ra	routine calculation Rb	routine calculation Rc	routine calculation Mc	routine calculation Hw
54.734	28.611	27.327	23.136	4.861
the optimize Ra	the optimize Rb	the optimize Rc	the optimize Mc	the optimize Hw
51.101	25.457	26.65	22.726	3.685

$$g_1(X) = R_\tau - R_{\tau 0} \geq 0 \quad (2)$$

2) Truncation tooth fatigue fuzzy reliable restraint:

When the load changes function of number $N > 10^6$, by reliability design request $R_{\tau 1}$, it obtains reliability restrain:

$$g_2(X) = R_{\tau c} - R_{\tau 1} \geq 0 \quad (3)$$

3) Transversal spacing nominal optimum value scope:

$$g_3(X) = x_1 - 2 > 0 \quad (4)$$

$$g_4(X) = 6 - x_1 > 0 \quad (5)$$

4) Circumferential angular interval scope:

$$g_5(X) = 15 - x_2 > 0 \quad (6)$$

$$g_6(X) = x_2 - 60 > 0 \quad (7)$$

5) Sway speed scope:

$$g_7(X) = x_3 - 1 > 0 \quad (8)$$

$$g_8(X) = 6 - x_3 > 0 \quad (9)$$

6) Rotational speed scope:

$$g_9(X) = 15 - x_4 > 0 \quad (10)$$

$$g_{10}(X) = x_4 - 80 > 0 \quad (11)$$

7) Truncation tooth distributed limit:

$$g_{11}(X) = \beta_m - 85 > 0 \quad (12)$$

8) Cutting power limit:

$$g_{12}(X) = P_e - P_j > 0 \quad (13)$$

9) The installs truncation tooth spacing limit:

$$g_{13}(X) = L_k - 80 > 0 \quad (14)$$

4.4 Optimizations Resolvent

According to the algorithm described above, it optimized and asked for resolving. The parameter is established based on the most different long λ corresponding half step by step, the overall situation searches for step count k =40, Utilize Mab7.0 software to establish calculating algorithm procedure. The experiment indicated that the spiral drill weight reduced 16.77% and transported the efficiency enhanced 7.05% through the optimization design.

It carried on multi-objective optimization design to cutting head of roadheader by compilation optimization design procedure, obtained optimal solution and the optimized goal function value in Table1.

5. Conclusions

This article proposed a practical efficacious device to design cutting head which obeyed the willfully distributing random parameter reliability optimization. The cutting head reliability optimization multi-objective reliability optimization design method can reduce design cycles and save experimental funds, raise design level, and enhance forecast accuracy. The practice indicated that cutting head load fluctuation and compared energy consumption were obviously reduced at the same time. This result enhanced roadheader operational reliability and energy effectively.

6. Acknowledgments

The study is partially financial supported by the program Ministry of Education Doctor Fundation of China (20060147001); Chinese coal machine equipment company scientific research foundation; Outstanding youth scientific research fund in Liaoning technology university; Scientific research plan of outstanding young teacher in Liaoning technology university mechanical engineering institute; Graduate student scientific research fund in Liaoning technology university; Dalian Science and Technology University of structure state key laboratory open fund (G0818); Liaoning Province safety production development plan 2009.

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