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Review

Frame weight and anti-fatigue co-optimization of a mining dump truck based on Kriging approximation model

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ABSTRACT

In order to reduce frame redundant weight caused by the traditional experience design and delay the crack initiation occurrences at local positions during early service period, a structural weight and lifetime co-optimization method for frame of a mining dump truck based on Kriging approximation model was proposed. Considered as the most sensitive factor to the frame fatigue life and weight, the thickness of several steel plates was chosen as design variables in terms of un-allowed change of structure shape, while achieving weight reduction and improving fatigue life were together regarded as the optimization targets. An experiment design with 20 sample points obtained by the Latin hypercube sampling method was conducted to figure out the sensitivity of design variables, whose response values were acquired through repeated simulations. Those data were supposed to set up the approximation model constructed based on the Kriging interpolation technique and its fitting precision was certified by comparison of the finite element computational results and the approximation model calculated ones. The non-dominated sorting genetic algorithm II (NSGA-II) was utilized to optimize the thickness of the steel plates based on the approximation model. The tolerance between the results of the simulation and the approximation model was less than 1% when using the optimal design variables and the weight of the optimized frame was lessened by 22.3% while the minimum fatigue life and maximum static stress were only decreased by 3.8% and 4.6%, compared with the initial frame. These optimized results were acceptable for frame lightweight almost without expense of fatigue life and static strength.

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1. Introduction

The mining dump truck is one kind of off-road vehicles to transport hundreds of tons of minerals daily on the mine surface road for quite a long time. The structural weight, fatigue performance and static strength of frame are considered as governing factors in the initial design stage. However, the frame, as the main bearing component, is usually designed in light of the traditional experience, resulted in redundant weight in virtue of excessive emphasis on fatigue safety. It is necessary to implement lightweight design and ensure structural fatigue life by optimizing thickness of steel plates.

Some researchers considered fatigue life requirements in the optimal design of structures [1–4]. M. E. M. EL-SAYED and E. H. LUND [3] used the load history combined with the structural finite element stresses and the material fatigue properties to calculate the fatigue life during the optimization process. M. Haiba et al. [4] presented a new structural optimization algorithm for different stress state and method of stress calculation based on fatigue life. However, fatigue life could be totally taken into account in the optimization stage, but it was still extremely difficult to balance fatigue life and structural weight. In the B. Jonsson's paper [5], weight optimization was conducted on a welded bogie beam structure, while fatigue analysis and test were applied to lightweight optimized welded structures. Zhang Chengcheng and Xue Caijun et al. [6–7] proposed a strategy for anti-fatigue optimal design based on design of experiment and response surface model technique. Ding Yanchuang and Zhao Wenzhong [8–9] performed the optimization design of welded bogie frame and considered welded joint fatigue damage as constraints, using Kriging approximation technique. In these studies, the fatigue life was almost treated as constraint or the object of the validation during the optimization process rather than a direct optimization target.

It is widely acceptable that topology optimization could be utilized to improve structural performances. However, some optimized results would be hardly adopted if the structural joint parts were distributed in the design area, because the position of some connection parts would be changed or disappear during the optimization process. In consideration of the un-allowed change of structural shape, one approximation model is constructed to optimize the welded steel plate frame, treating the weight and fatigue life as optimization objectives and thickness of plates as design variables.

Based on the simulated results and experiment work discussed in the author's previous publication [10], the aim of the present paper is to assess the potential of using the Kriging method to generate a reliable response surface for frame weight and anti-fatigue co-optimization. Twenty sample points of experiment design variables are generated using the Latin hypercube method and their response values are acquired through simulations. According to that database, the approximation model in use of the Kriging method is set up, and the accuracy of the approximation model is validated by simulation. Based on the approximation model and NSGA-II, the weight and fatigue life of the optimal frame are compared with the calculated results of the initial frame.

Fig. 1. Mining dump truck on the road.

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