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Metamodel-based Multidisciplinary Design Optimization of Ocean-Mining Vehicle System

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ABSTRACT

Deep-ocean mining vehicle system has not only coupled relationship between component systems, but also a variety of design requirements of each system to accomplish the specified multi-tasks. To meet the multi-objectives of the complex system, multidisciplinary design optimization (MDO) is performed. Metamodels such as kriging model and response surface model are employed to reduce computational costs for MDO and to facilitate the automation and integration of component systems in a design framework. After verifying accuracies of metamodels, metamodel-based MDO for deep-ocean mining vehicle system is formulated and performed. Finally, results and advantages of the proposed design methodology are discussed.

KEY WORDS: Deep-ocean-mining vehicle system; kriging model; metamodel; multi-disciplinary design optimization (MDO); response surface model.

INTRODUCTION

Recently, deep-ocean mining system has received growing recognition for development of plentiful marine mineral resources. It consists of mining vehicle system, transportation system, and mother station. The mining vehicle system is a self-propelled crawler equipped with collector, crusher and pumping unit. It collects mineral resources, especially manganese nodules, while traveling on cohesive soil of about 5000 meters deep-sea. Transportation system conveys the manganese nodule collected from the mining vehicle system to mother station through flexible hose and buffer, i.e. intermediate raising unit. Mother station stores the collected mineral resources and controls each subsystem with utility equipments.

Among these systems, mining vehicle system is a core component because it actually undertakes to pick up manganese nodules. There are a variety of objectives and design constraints related to mining vehicle system. Collector is required to pick up manganese nodules efficiently regardless of size of manganese nodules. Crawler should travel reliably on soft coil of deep-ocean under consuming as small amounts of energy as possible. Frame supporting vehicle system must be strong and stiff enough to maintain the shape in pressures of approximately 500 bars of deep sea. Moreover, there is physical coupling between each part of the system. For example, collection rate of collector depends largely on traveling performance of crawler. In design of both collector and crawler, velocity can be identified as a primary common design variable. Width and length of frame structure is directly related to overall size of both collector and crawler. For this reason, deep-ocean mining vehicle system cannot be designed according to objective of one part. Therefore, optimization technique that can control systematically conflicting design objectives related to mining vehicle system should be performed.

The multi-objective design requirements naturally lead to the concept of multidisciplinary design optimization (MDO). MDO is an optimization technique that can provide a synthetic optimum solution of a coupled system while satisfying complicated design constraints. Thus MDO can reflect a variety of design requirements to design process. For MDO of ocean-mining vehicle system, we need simulation models representing design requirements. To evaluate motion of the vehicle, we employ a dynamic simulation model of crawler moving on cohesive soil. We simulate dynamic responses of crawler because it is physically very expensive to investigate the traveling performance by means of real-size prototype.

However, one dynamic analysis of crawler is quite time-consuming because of its numerical complexity and nonlinearity. The considerable computational cost of dynamic analysis can be a burden in multidisciplinary design optimization since many dynamic analyses are usually executed during optimization process. Therefore, it is necessary to reduce the number of actual complex dynamic analyses. For this reason, we use approximation model, the so-called metamodels, such as kriging model replacing the expensive simulation model. Metamodel can provide mathematical relationship between design variables and responses by means of a few simulations. It is helpful to save computational costs for dynamic analysis during optimization. For a collector mounted on crawler, we accomplish physical experiment to investigate the collection rate under the gathering condition as close as actual environment. For collection rate, response surface model is built from physical experimental data. By using response surface model, we can evaluate approximately collection efficiency at any design points.