

Method of Metamodel-based Multidisciplinary Design Optimization for Development of a Test Miner

Tae Hee Lee and Min Uk Lee*
School of Mechanical Engineering, Hanyang University
Seoul, Korea

Jong-Su Choi, Hyung Woo Kim and Sup Hong
Maritime & Ocean Engineering Research Institute, KORDI
Daejeon, Korea

ABSTRACT

A deep-ocean test miner has not only coupled relationship between component systems, but also various 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 a deep-ocean test miner is formulated and performed. Finally, results and advantages of the proposed design methodology are discussed.

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

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 can be a self-propelled crawler equipped with collector, crusher and pumping unit. It collects mineral resources, especially manganese nodules, while traveling on cohesive soil at a depth of about 5000 meters in the deep-sea. Transportation system conveys the manganese nodule collected from the mining vehicle system to a mother station through a flexible hose and buffer, i.e. intermediate raising unit. The mother station stores the collected mineral resources and controls each subsystem with utility equipments. It is verified by using axiomatic design that the mining vehicle system is a core component and must be designed first among these systems (Choi *et al.* 2008). In this paper, we mainly consider the design of a test miner composed of collector, crawler and chassis structure *et al.* There are a variety of objectives and design constraints related to a mining vehicle system. A collector is required to pick up manganese nodules efficiently regardless of size of manganese nodules. The crawler should travel reliably on soft soil of the deep-ocean consuming as small amounts of energy as possible. The frame structure supporting the vehicle system must be strong and stiff enough to maintain the shape in

deep sea pressures of about 500 bars. Moreover, there are physical interactions between each part of the system. For example, the collection rate of collector depends largely on the traveling performance of the crawler. In design of both collector and crawler, velocity can be identified as a primary common design variable. Width and length of frame structure are directly related to overall size of both collector and crawler. For this reason, the deep-ocean mining vehicle system cannot be designed according to the objective of one part. Therefore, an optimization technique that can control systematically conflicting design objectives related to the mining vehicle system should be used to find the optimum design parameters.

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 (Balling, RJ, and Sobieszczzanski-Sobieski, J, 1996). Thus MDO can reflect a variety of design requirements of the design process. For MDO of a test miner, we need simulation models representing responses for design requirements.

To evaluate the motion of the vehicle, we employ a dynamic simulation model of the crawler moving on cohesive soil (Hong *et al.* 2002). We simulate dynamic responses of the crawler because it is very expensive to physically investigate the traveling performance by means of real-size prototype. Also a 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 the process of 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 models, the so-called metamodels, such as kriging model (Sacks *et al.* 1989) replacing the expensive simulation model. A metamodel can provide a mathematical relationship between design variables and responses by means of a few pre-trying simulations. It is helpful to save computational costs for the dynamic analysis during optimization process. For a collector mounted on the crawler, we have accomplished physical experiments to investigate the collection rate under the mining condition as close as possible to the actual environment. But it is not easy to conduct physical experiments for every request of MDO. For the collection rate, the response surface model (Myers and Montgomery, 1995) is built from a few physical experimental data. By