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Shape optimization of mobile phone folder module for structural strength †

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Abstract

The mobile phone has become thinner even while its functionalities are ever increasing. Therefore, the importance of structural design to prevent structural failure is of increasing importance. To address this situation, a systematic optimization approach for shape design of a mobile phone folder module is utilized in this research. The structural strength and the exactness of the folder module assembly are considered as performance requirement of the optimization problem. Five shape parameters of the folder module assembly are used as design variables. In this research, the finite element method (FEM) is used to acquire the structural strength of the folder module assembly, and the morphing technique is applied to change the shape of the finite element (FE) model. However, manually performing the morphing and FEM for the simulation model is complex and time consuming especially for a model with complicated shape such as the mobile phone. Therefore, shape optimization involving FEM is known to be very difficult task for actual industrial applications. To overcome this deficiency, two types of approaches are applied in this research. First, process integration and design optimization (PIDO) technology is applied to integrate and automate the analysis processes needed for evaluating structural performances. In addition, a metamodel that can substitute for expensive simulation is employed for the optimization process. From this research, an optimum design for the folder module of a mobile phone enhancing the structural strength is acquired. In addition to the optimum solution, a metamodel-based shape optimization procedure which is applicable to practical engineering problem is established.

Keywords: Metamodeling; Morphing; PIDO; Shape optimization

1. Introduction

The mobile phone market has become one of the most competitive markets. To compete more effectively, recent mobile phone products have included many types of components for various functionalities while still reducing the thickness of the products. However, there is a danger that increasing product thinness may cause structural failure. Another important issue is the speed of iterations of design solutions because of the short development time as is the case of other small electronic devices.

The finite element method (FEM), a numerical method solving problems of engineering and mathematical physics [1] has been implemented into computer software packages successfully. It is inexpensive compared with physical experiment, easy to handle, and reusable prompting many attempts to use it not only for an analysis of the structural performance but also for making a decision about structural design solutions. Despite its positive characteristics, there are many difficulties related with the use of FEM for design. The most serious problem is how to parameterize the shape of a design object. Because it is impossible to use the locations of many nodes as design variables, shape changes should be achieved by altering the shape parameters about the aspect of shape changes. Consequently, the morphing technique for the FEM is applied in this research. The morphing technique originated from the computer graphics technology, and it is able to parametrically change the shape of the object by controlling the representative parameters of an object [2].

Although the numerical efficiency of the FEM has greatly improved, the complexity of the simulation model is also increasing. Moreover, a design object of this research, the mobile phone has very complicate shape and structure requiring considerable numerical expenses for performing an impact analysis. In addition, the shape change of the FEM is very challenging task requiring many man-hours. To overcome this situation, two kinds of approaches were adopted in this research. First, by using the process integration and design optimization (PIDO) technology [3], various simulation processes for shape change and performance analyses of the

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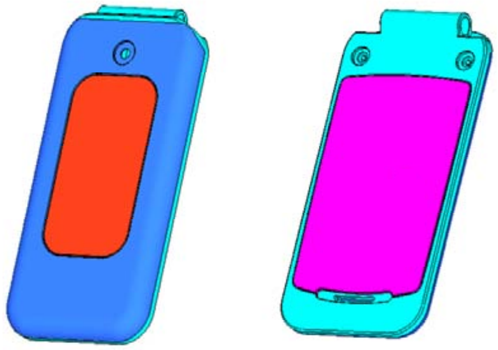

Fig. 1. Geometry model of mobile phone.

mobile phone were integrated and automated. In addition, the metamodel [4], which can simulate performance responses of actual FEM, was used for our shape optimization approach. These approaches proved their effectiveness for performing the shape optimization for the folder module of mobile phone.

This paper consists of 6 sections. In the second chapter, a design problem for mobile phone will be explained in detail. The third chapter explains the morphing technique to parametrically change a shape of the simulation model used in this research. In the fourth chapter, a PIDO technology and the metamodel-based optimization approach for enhancing the effectiveness of the design procedure will be described. The result of the shape optimization and concluding remarks are summarized in the fifth and sixth chapters, respectively.

2. Design problem formulation

2.1 Folder module of mobile phone

As mentioned earlier, a design subject of this work is the folder module of mobile phone. Folding type mobile phone consists of the folder module including the thin film transistor–liquid crystal display (TFT-LCD) panel and screen, and a main module including main chipsets and keyboard. The application model of this research is a dual window type model, which has not only the main window but also an external subsidiary window. The folder module of mobile phone is composed of 5 components: main and sub windows made of acryl sheet, folder upper and LCD guide rib made of polycarbonate material, and 2-in TFT-LCD panel. Among these 5 components, the most important component is the LCD panel. Therefore, preventing failure of the LCD panel is the most important issue of the structural design for the folder module. The folder module is graphically depicted in Fig. 1. Since this research considers the structural strength against an external impact, a loading condition is assigned as dropping 0.5 kg of steel ball at 0.12 m height above. To perform such an impact analysis, a well-known commercial FEM software LS-DYNA [5] is used in this research.

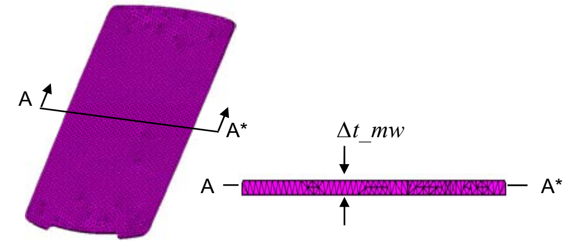

Fig. 2. Shape variable for thickness of main window.

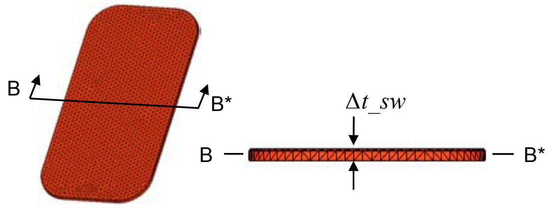

Fig. 3. Shape variable for thickness of sub window.

2.2 Design requirements

This research is for the design of the folder module considers structural strength. Accordingly, the most important issue of this work is assuring the applied stress for each component of the folder module is lower than allowable limit value. However, it has been confirmed that the applied stresses of all components except the LCD panel are sufficiently lower than allowable stresses from preceding experiments. In addition, it is getting better as the applied stress on the LCD panel is getting smaller. Therefore, minimizing applied stress on the LCD panel was considered as key design requirement in this problem. Another important design requirement is that the components are easy to assemble and overall specifications of the folder module assembly such as overall thickness and size are constant while the shape changes occur. Therefore, the invariability of overall thickness of the folder module was considered as another design requirement.

2.3 Design variables

In this research, a total of 5 types of shape parameters were used as design variables. All design variables were considered as deviations from the initial values of shape parameters. The first shape variable is a deviation of the thickness of main window. This variable is described in Fig. 2, and Δt_mw is used as an abbreviation of the name of this variable. The second variable is a deviation of the thickness of sub window and will be referred as Δt_sw, and it is depicted in Fig. 3. The third variable is for the thickness of the folder upper. While the folder upper has a complicated shape as shown in Fig. 4, the thickness at the center of C-C* section is defined as design variable. This variable will be referred as Δt_fu. The LCD guide rib has two types of shape variables. As shown in Fig. 5, the thickness and height of the rib covering the LCD panel are selected as shape design variables. These two variables will be

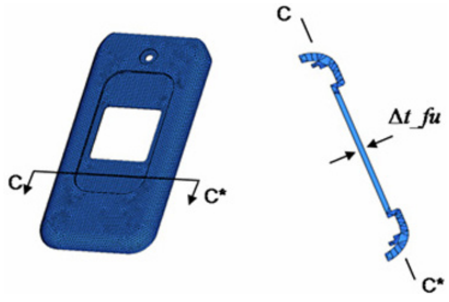

Fig. 4. Shape variable for thickness of folder upper.

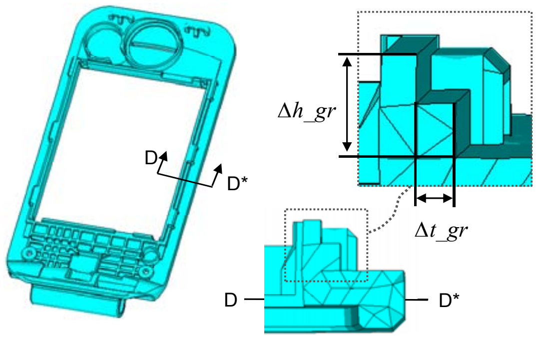

Fig. 5. Shape variable for thickness and height of guide rib.

referred as Δt_gr and Δh_gr, respectively. All design variables used in this research were selected under discussion with a professional design engineer at a practical work-site.

2.4 Formulation of optimization problem

An optimization problem for design of the folder module is formulated considering design requirements and design variables explained in sections 2.2 and 2.3. Among the design requirements, minimizing the applied Von Mises stress to the LCD panel was set as the objective function. Keeping the applied Von Mises stresses to other components less than allowable stresses were considered as design constraints, and maintaining the overall thickness of folder module as same as initial was also considered as design constraint. All shape parameters were used as design variables, and their upper and lower limits were determined by considering the design engineer's opinion. The formulation of optimization problem can be summarized as Eq. (1).

$$
\begin{aligned}
&\text{Find} && x_1, \cdots, x_5 \\
&\text{to minimize} && \sigma_{\text{LCD panel}}^{max} \\
&\text{subject to} && \sigma_j^{max} \le \sigma_j^{allow}, \quad j = 1, \cdots, 4 \\
& && T = T_{initial} \\
& && x_i^L \le x_i \le x_i^U, \quad i = 1, \cdots, 5
\end{aligned} \tag{1}
$$

where x_i denotes the design variables, $\sigma_{\text{LCD panel}}^{max}$ is the maximum stress applied to the LCD panel, σ_j^{max} and σ_j^{allow} are the maximum and allowable stresses applied on each component, T and $T_{initial}$ are total thickness of the folder module and its initial value, respectively. The overall thickness T is a sum of the Δt_mw, Δt_sw, Δt_fu, Δh_gr, and a bonding gap between the LCD panel and main window. The bonding gap can be changed moderately.

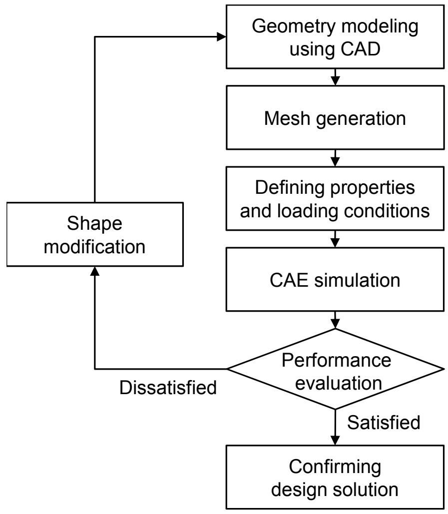

Fig. 6. Traditional procedure of shape design.

3. Shape modification using morphing technique

The morphing originated from the computer graphics, and it is a special effect in motion pictures and animations that changes (or morphs) one image into another through a seamless transition of the feature primitives, e.g. mesh nodes, line segments, curves, or points [2, 6]. The morphing can makes completely new images from their originals by changing geometrical attributes of the feature primitives. In this manner, the morphing for FEM also changes the shape of finite element (FE) models through a seamless transition. Namely, it never makes new nodes and elements nor removes current nodes or elements. It just moves locations of nodes and changes the shapes of elements of the FE models.

Traditional procedure of the shape design involving the FEM is shown in Fig. 6. First, design engineers make a geometrical model for a design object using computer aided design (CAD) tool. The geometry model is cleaned up for mesh generation and FE mesh is generated. After the mesh generation, mechanical properties and the loading conditions of the model are defined. Then, the simulation to acquire performance responses is performed. When the performance responses are given, the design engineers decide whether the current design satisfies all imposed requirements or not. The current design is confirmed as design solution if it satisfies all these requirements. However, if it does not satisfy any of them, shape modification for better design is needed. In this case, the engineers should make geometry model using CAD tool and repeat the remaining procedures again as shown in Fig. 6. Recently, a parametric CAD modeling feature is included in some of commercial CAD packages, so shape modification of the CAD model could be conveniently performed by using the

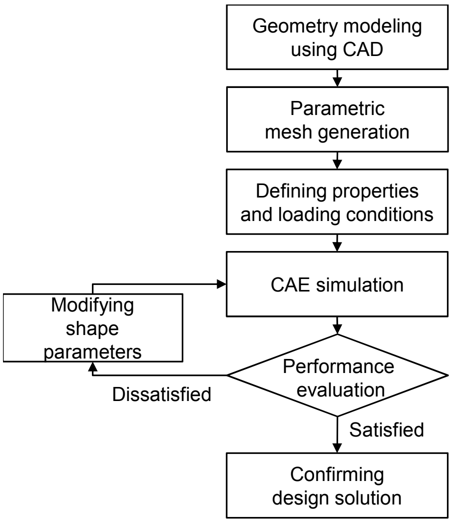

Fig. 7. Procedure of shape design using mesh morphing.

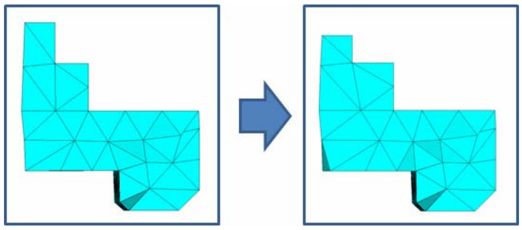

Fig. 8. Shape change of FE model by freehand morphing.

feature. However, in this case, redundant operations for mesh generation should be done by hand carefully. Design procedure is hardly possible to be automated. On the other hand, if the engineers employ a parametric FE model using a morphing technique, the shape modification is directly applied to the FE model. Thus, only the morphing and simulation process is repeatedly conducted, as shown in Fig. 7. Although the parametric FE modeling or the morphing technique can be applied for limited amount of shape modification, it is more applicable than parametric CAD modeling because it needs no additional mesh generation. Design procedure can be easily automated and workload for shape modification is drastically decreased by the morphing technique.

There are many kinds of commercial tools for the morphing of the FE model: Meshworks/Morpher [7], ParaMesh [8], Sculptor [9], and HyperMorph included in well-known FE preprocessor Hyperworks [10]. Among the various morphing tools, HyperMorph is used in this research. HyperMorph enables three kinds of morphing approaches. The first most general approach involves the domains and handles concept. The domains mean ranges of the finite elements for which the morphing is applied. The handles, usually located at the corners of the domains, are controlling the unit of the shapes of the domains. Users can change the geometrical properties of handles such as locations and directions, and can make additional handles if needed. When the handles are moved, the shape of the mesh changes according to the domain boundaries. Although the effective domains are difficult to set up, this approach is very powerful if it is available. The second approach is the volume morphing. The volume morphing sets the morphing domains as one or more morph volumes which are highly deformable six-sided prisms. The handles placed at the corners and along the edges of the morph volumes allow for the morphing of the volumes. This approach is quick and intuitive and most useful for making large and sketchy shape changes to complex meshes. The last approach is freehand morphing. This approach modifies the shape of FE model by moving the nodes directly without needing to create any entities such as the domains and handles. If the nodes which will move, the nodes which will stay fixed, and the affected elements are defined manually, this approach allows for rapid changes to any mesh without the creation of the domains and handles [11].

Because the shape of the folder module is very complex, it is difficult to make it available to create effective domains for mesh morphing. Therefore, the freehand morphing approach is used in this research. Fig. 8 shows the parametric changes of the shape of FE model by applying the freehand morphing approach.

4. Metamodel-based optimization approach with PIDO environment

4.1 PIDO technology

Recently in the area of practical engineering design, design requirements are getting diversified and the numbers of analysis processes are getting increased. Therefore, more effective simulation environment to deal with these difficulties are needed. PIDO tools have been developed to respond these reasons. The PIDO tools can create an integrated and automated simulation environment and enable to perform the simulation and design more effectively [3]. Moreover, several kinds of analytic design methodologies such as the parametric study, design of experiments, and optimization techniques are available. Consequently, the PIDO tools are helpful for design engineers to lessen their workload.

In this research, the commercial PIDO tool PIAnO [12] is used for process integration and design optimization. The PIAnO has a merit on the user friendly file parsing engine, so the process integration can be easily done by the PIAnO. The impact analysis involves three steps of analysis processes to acquire the stress curve applied on the LCD panel. Analysis processes and their input and output data specifications are shown in Fig. 9. Batch execution of the Hypermesh can be done with a pre-documented command file, so the command file was used as input data for whole analysis processes. The FE model to which the morphing is applied is generated from the first process, and the impact analysis for morphed model is executed at the second process. Finally, a post-process unit of the LS-DYNA finds the most vulnerable element of the LCD panel and documents the stress curve of the element as ASCII

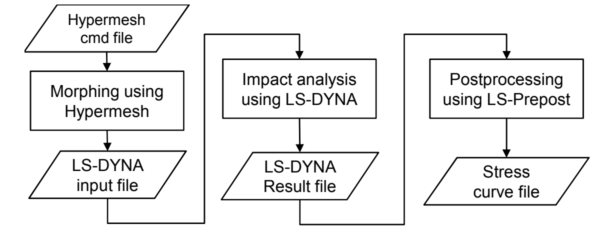

Fig. 9. Analysis processes of impact simulation.

file. This ASCII file was used as the output file of the whole processes.

4.2 Metamodel-based optimization procedure

As mentioned earlier, development term of mobile phone is under extreme time constraints and a nonlinear impact analysis is a very time-consuming process. Therefore, a metamodel-based optimization procedure is established for the design of the folder module of mobile phone. The metamodeling technique is classified by regression and interpolation. The regression tends to smooth out the data including numerical noise, so it is effective to approximate a noisy response involving random error. On the other hand, the interpolation is suitable for data from computer simulations and can capture the nonlinearity of the responses well. Representative regression metamodels are the polynomial regression (PR) [13] and support vector regression (SVR) [14], and for interpolation metamodel, the Kriging [15] is the most well-known metamodel. The radial basis function (RBF) [16] can be used for both regression and interpolation models based on its parameter setting.

The metamodel-based optimization procedure consists of three parts: performing design of experiments (DoE) for metamodel, generating metamodel, and an approximate optimization with the metamodel. Nonlinear impact analysis is performed only in the DoE part. Once the metamodel for performance response is built up, the nonlinear impact analysis is replaced by the evaluation of the metamodel. A metamodel is generated by the experimental points and their responses obtained from the DoE. According to Wang and Beeson [17], if the number of design variables is not excessive, 10 times the number of variables is adequate for total experimental points. Therefore, the number of experimental points drawn by the optimal Latin hypercube design (OLHD) [18] was set to 50 for this problem because the user can freely choose the number of sample size and this DoE method has an outstanding space-filling performance.

Among the various metamodeling techniques, the PR, RBF, and Kriging are available in the PIAnO. Three kinds of metamodels were made from the DoE results and the most accurate metamodel was selected for the approximate optimization. Since the interpolation metamodel such as the Kriging, cannot provide R^2 value, the cross-validation error value is used as a measurement for accuracy. To calculate the cross-validation

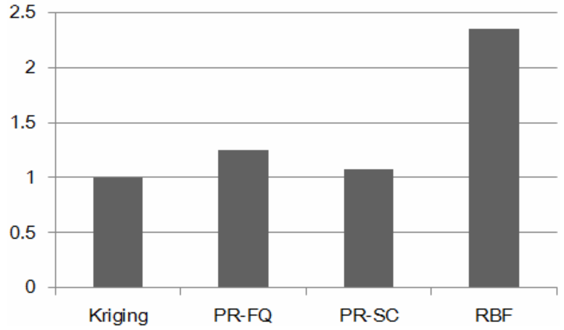

Fig. 10. Normalized cross-validation errors for metamodels.

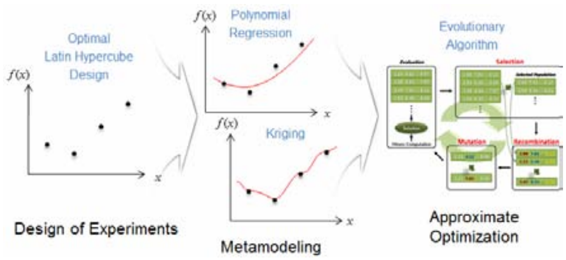

Fig. 11. Metamodel-based optimization procedure.

error, a metamodel is created beforehand by choosing and excluding a point from the whole experimental points and the difference between the actual value and predicted value from the metamodel is calculated at the excluded point. Repeating this process and calculating the differences for the whole experimental points, the cross-validation error is mean square value of the differences. Fig. 10 shows the normalized cross-validation error for each metamodel. In this figure, "PR-FQ" and "PR-SC" denote the full quadratic PR model and simple cubic PR model, respectively. As shown in Fig. 10, the error of Kriging metamodel was lowest. Therefore, the Kriging metamodel was adopted for the approximate optimization.

Since executing the metamodel is numerically inexpensive, any kinds of optimization techniques can be employed for approximate optimization. Therefore, one of the global optimization techniques, the evolutionary algorithm (EA) was used for approximate optimization. The EA is meta-heuristic optimization technique, and known as outstanding convergence performance [19]. This algorithm is also available in the PIAnO. The metamodel-based optimization procedure is described in Fig. 11.

5. Optimization results

An optimum solution satisfying all imposed requirements was obtained by the approximate optimization. One important issue of the approximate optimization is that the confirmation analysis should be executed for the approximate optimum solution because the resulting performances are calculated from the metamodel. The most important performance of the design problem, the maximum stress applied on the LCD

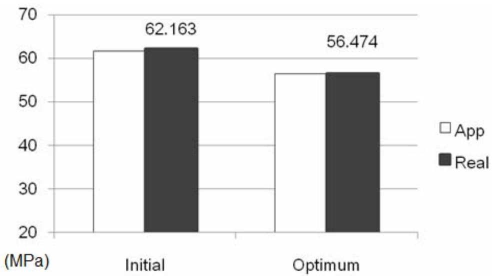

Fig. 12. Comparison of applied stress on LCD panel.

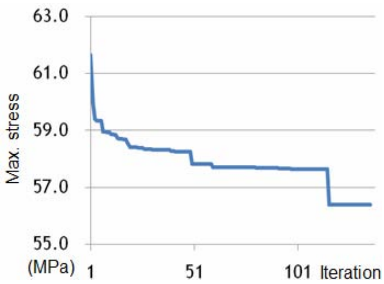

Fig. 13. Convergence history of evolutional algorithm.

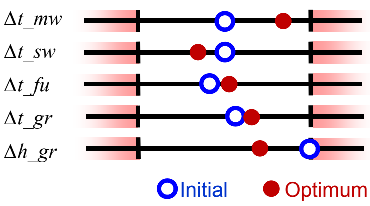

Fig. 14. Comparison of design variables.

panel was reduced by 9.15%, from 62.163 MPa at initial design to 56.474 MPa at optimum design. The change of the stress is graphically shown in Fig. 12. A convergence history of the EA is shown in Fig. 13. It converged after 136 iterations. The changes of the scaled design variables are shown in Fig. 14. In examining the changes of design variables, the main window is thicker, while the sub window and folder upper is slightly thinner than initial design. The thickness of the LCD guide rib is increased whereas the height is decreased. From the optimization results, it is concluded that the thicknesses of the components are optimally allocated considering the structural strength of the folder module. In addition, it was hard to predict how changes in the thickness and height of the LCD guide rib influence structural strength, but the results of approximate optimization show the behavior of the structural strength with respect to the thickness and height of the LCD guide rib.

6. Conclusions

Design optimization considering structural strength of the folder module of mobile phone was conducted in this research. The aim is to minimize the maximum stress applied on the LCD panel, the most important and vulnerable component in the mobile phone. The requirement for applied stress on the LCD panel was considered as objective function to minimize, and the requirement for packaging of the folder module was set as constraint of the optimization problem. Then, 5 shape parameters were used for design variables.

To alter the shape of folder module, the morphing technique was applied in this research. Several analysis processes for shape modification and impact analysis of the folder module were integrated and automated by the commercial PIDO tool PIAnO. Such an integrated environment and various types of analytic design approaches were helpful to effectively perform the shape optimization.

The other important issue of this research is to establish the metamodel-based optimization procedure for design of the folder module. Since the metamodel-based optimization procedure needs the numerical expenses only for acquiring the response of each experimental point in the DoE process, design engineer is able to not only reduce development term, but also estimate and control the time to get a design solution. As a result of the approximate optimization, the applied stress on the LCD panel was decreased by 9.15% compared with the initial design.

The usability of the morphing technique for shape design was demonstrated from the result of this research. In addition, the metamodel-based optimization procedure with PIDO environment showed that it can be effectively applied for design of practical industrial product. If further study on the sequential sampling method to improve the accuracy of metamodel is followed to this research, it is expected to enhance the usefulness of metamodel-based optimization approach.

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