Development Mode Based on Integration of Product Models and Process Models

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Development Mode Based on Integration of Product Models and Process Models

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Abstract: Product development process modeling consists of two interrelated aspects: product model and process model. The coupling of these two aspects is very important to integrated product and process development, which not only avails to manage and control the whole process efficiently, but also avails to organize a multifunctional team to develop product concurrently and cooperatively. In this article, the integrated development architecture is established based on the detailed analysis of coupling relations between the product model and its corresponding process model. The integrated development method of coupling the product model main line and process model main line is presented. In this method, both the product model and process model are modified synchronously, and this modification is dynamic and mutual. The interrelationships and coupling mechanism between product model and process model are analyzed and established, and the algorithm was also given to evaluate the model coupling effect. Application verified that both the logicality of development processes and the completeness of model information were emphasized in the development architecture proposed here.

Key Words: product model, process model, integrating product and process development, development mode, coupling mechanism.

1. Introduction

Product modeling and process modeling are the two basic aspects of product development, and also are the research hotpots of the engineering domain currently. Establishing effective product development models not only permits one to manage and control the whole process efficiently, but also results in organizing the multifunctional team to develop product concurrently and cooperatively. The proposed product models and process models, such as structure-oriented product model, geometry-oriented product model, feature-oriented product model, knowledge-based product model, integrated product model, Petri net model, IDEF model, UML model, etc. [1,5], describe the product and its development process from different perspectives of product development. These models and methods promote the development of product design and innovation theory to a great extent. However, the interrelations between product model and its corresponding process model were ignored to some extent when these models were established. That is to say, the coupling effect between the models was ignored. This does not benefit the process collaboration, optimization, and information interaction. Therefore, conducting the research on model evolvement and integrated development mode is a requirement of integrated product and process development [2–4,6,7]. This article presents the integrated development mode based on the integration of product models and process models and establishes the integrated architecture of the product development process. The relations between the product model and process model were analyzed from the viewpoint of integration, and the coupling mechanism of models was also established. The logicality of the development process and the completeness of product model information were emphasized. Therefore, it can promote the development process evolvement efficiently and make the product development process optimal.

2. The Relations between Product Model and Process Model

Product model describes the product information and the relations among information. It is the digital and

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abstract definition of a realistic product. In general, product model data is determined by its structure and its content [1]. The structure is dependent on the nature of the product and the tools used to model the information as well as to build the necessary schemes for the database. The content is dependent on the particular product. Process model is the abstract description of the product development process, and it can be used to analyze, optimize, and establish the activity process of product development and to assist the management and monitoring of the whole process.

Based on different criteria, a product model can be further structured into sub-models, such as an outer model, inner model, and technology information model. The outer model can be further structured into a customer model, market model, environment model, supplier model, and so on. The inner model can be further classified into a requirement model, function model, concept model, design model, process model, and so on. The technology information model can be further classified into a failure model, material model, tolerance model, surface condition model, and so on.

According to the different decomposition of the process, there exist many different process models. For example, according to a product's life cycle, the process model can be further structured into sub-models, such as a design process model, manufacturing process model, assembling process model, using process model, disassembling process model, recycling process model, and so on. The design process model can be further classified into a concept design process, detail design process, and enhancement design process. The decomposition of process should result in process collaboration, management, and optimization. The greater the process granularity is, the greater is the degree of coupling among processes. However, the smaller the process granularity is, the greater is the discreteness of process, which can result in more difficulty in process programing.

Product development process modeling, in its complete sense, consists of two interrelated aspects: product model and process model. Product models are referred to product model databases and their associated management and access algorithms. Process models are also commonly referred to product development workflow or product modeling processes [1]. The basic requirement of integrated product and process development is that both the product model and the process model are integrated in one model frame. That is to say, it should realize the integration of the two models, i.e., coupling. The validity of coupling will determine the quality of product development.

Generally speaking, the requirements of product development and its realization are determined by the product model. Therefore, the direction of product development is also decided by the product model. During the development process, the product model evolves from an abstract model to a material model step by step, and this evolvement will result in the hierarchy and dynamic decomposition of the product model directly. Because the process model always hinges on the product process, the hierarchy of the process model can describe the dynamic variation of the product development process. The continuous proceeding of the process can change the state of the product model data continuously, by which the helical evolvement of product development can be promoted. During the practical development process, there exists a close coupling relation between the product model and process model. On the one hand, process has data pertinency. That is to say, many processes can deal with the same product model data. Therefore, the logical relation of data can be formed, and this relationship can reflect the development process of the product model data life cycle. On the other hand, the product model data has process pertinency. The product model data can be handled through the same process, and this can reflect the process relation among different design data. This process relation is the abstract logical relationship in higher hierarchy, and it can offer a new relation definition of different product model data.

3. Development Mode Based on Model Integration

3.1 Three Development Modes

There are three different development modes as shown in Figure 1.

1. The product model is the main line of product development. In this mode, product model is static, and process model is dynamic. The product model is the kernel of the development process. The process model is improved (or reorganized) continuously to adapt to the product model, by which the product development is completed.

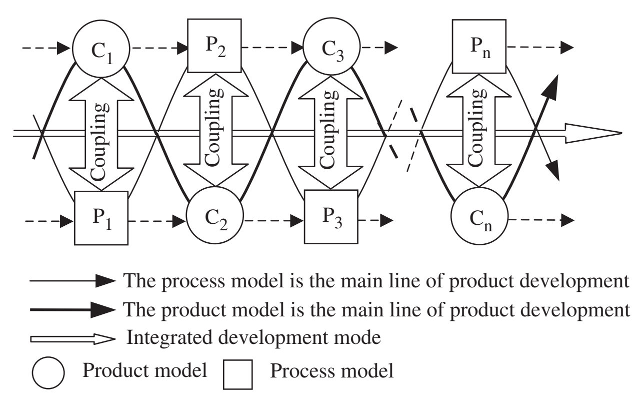


Figure 1. Development mode based on model integration.

2. The process model is the main line of product development. In this mode, the process model is static, and product model is dynamic. The process model is the kernel of the development process. The product model is modified based on the development environment to adapt to the process model.

In general, at one moment of product development process, one process state could map to one or more special product model. That is to say, one process model maps not only to one product model. However, one product model can be realized by only one process model. These are the uniqueness and non-uniqueness in the product development process.

In order to improve development efficiency and conserve design resources, the product development should be carried out with the integration of the product model and process model. The product model or process model is not to adapt to the other model passively. So, there exists the third development mode as follows.

3. Integrated development mode. In this development mode, the product model main line and process model main line are integrated. Based on the practical development environment, both the product model and process model are modified synchronously to adapt to each other. This modification is dynamic and mutual. The state of product model information and process model information change simultaneously. Based on this development mode, the integrated development architecture can be established as shown in Figure 2.

The process management system includes the following four functional components.

Process programing: When the entire process programing is carried out, the degree of influence of the interrelations among development processes on process flow, process time series, process proceeding mode, and process state should be taken into account. The product model information that can be acquired through the product data management system (PDMS) is the base of process programming. Effective process programming can analyze and forecast the essential reasons resulting in conflict, to avoid or reduce conflict in the development process.

Process management: Integrated product development is a complicated system engineering process, where the sociality, engineering, and economy are integrated in the development process. It breaks through the limitation of time and space. The main work mode of integrated product development is computer supported collaborative work (CSCW), and it can be depicted as concurrent, collaborative, distributed, and open. Therefore, it requires effective process management to carry out system collaboration, real-time monitor, synthetic optimization, ruly organization, and management. Through effective process management, it can offer right and complete product information for different development processes in the right time with the correct method.

Process control: It offers a mechanism to realize information exchange and sharing of grouping activities in distributed environment. By this mechanism, one can schedule the development activities and monitor the proceeding product development. In the practical development process, the process controller can control the executive sequence of the design process, confirm

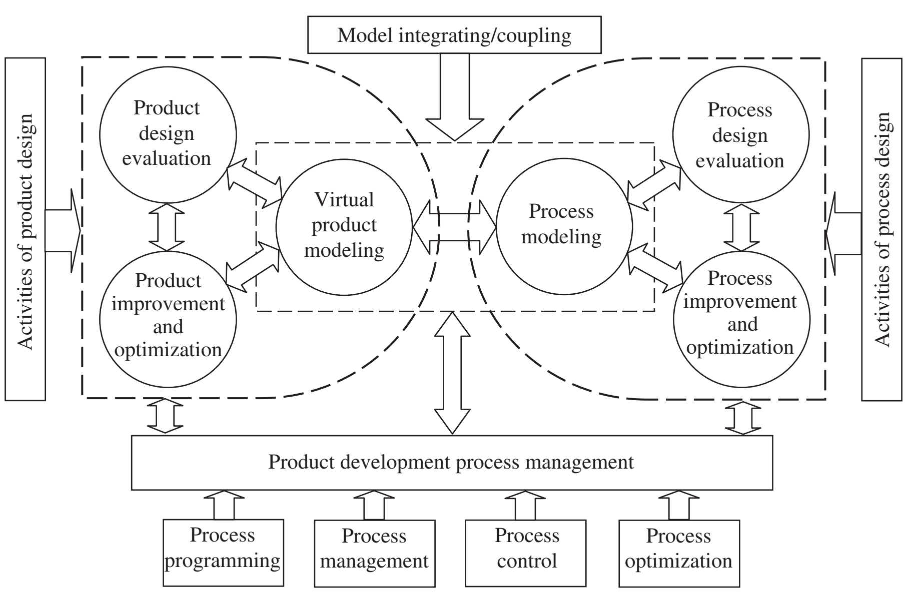


Figure 2. Integrated product development architecture based on model coupling.

their interrelations, and ensure the consistency of the development process and its objective.

Process optimization: By effective process optimization, potential design conflict can be limited in a controlled range that is set by the development team. The effective optimization and solution models can be established by using optimization algorithms, intelligent tools, and programing languages to ensure that the process proceeding is optimal in time and space.

Integrated development model emphasizes the interrelations and coupling relationships between the product model and process model, and makes the helical evolvement of the product be completed in the mutual adaptation between the product model and process model. The PDMS not only can offer an information exchanging interface and operation platform for this evolvement process, but also can integrate and manage all the information and all the processes related to the product. Therefore, in integrated development mode, the design activities can use all the design resources effectively, and can make fast responses to the variation of the development environment. PDMS is used to realize the unitive management, redundant control and synchronous maintenance of model information.

3.2 Time Series of Sub-models

To product model C_i, it has its realization process model P_i, leader process model P_k $(k=1,2,\ldots,i-1)$, and follow-up process model P_m $(m=i+1, i+2,\ldots,n)$, where P_{i-1} and P_{i+1} are called direct leader process model and direct follow-up process model, respectively.

To process model P_i, it has its current objective product model C_i, leader product model C_k $(k=1,2,\ldots,i-1)$, and follow-up product model C_m $(m=i+1, i+2,\ldots,n)$, where C_{i-1} and C_{i+1} are called the direct leader product model and the direct follow-up product model respectively.

The leader behaviors offer the preconditions and base for the results of the current behavior. The results of leader behaviors can determine the performance of current behavior. Current behavior offers the base for the implementation of follow-up behaviors. The implementation of follow-up behavior depends on one or more leader behaviors. Leader behaviors and follow-up behaviors are not unique. One behavior can have many leader behaviors, and different behaviors can have the same follow-up behavior. The division of leader behavior and follow-up behavior could offer the foundation for the concurrent implementation of development processes and for improving of the degree of concurrency.

The traditional serial mode is carried out in strict sequence. One behavior can be carried out only after its

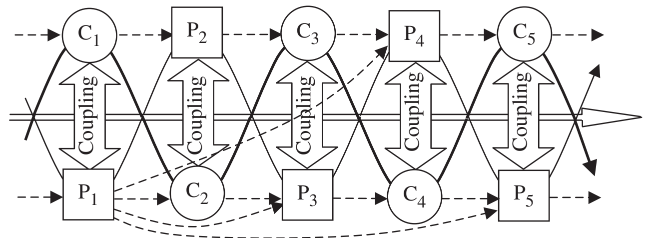


Figure 3. Concurrent development mode based on model integration.

leader behaviors are completed. All the follow-up behaviors are in a waiting state while their leader behaviors are carried out. Therefore, it is inevitable that much floating behavior and idle time results, which makes the development efficiency decreased and the development time prolonged.

Integrated product development requires that the sequence flow and idle times are reduced because the follow-up behavior can be carried out even though the leader behaviors have not been completed. At the same time, it requires that the independent process behaviors be carried out in parallel. When the leader behaviors are being scheduled, the behavior that has the most important influence on the follow-up behaviors should have higher priority and should be scheduled beforehand. Thus, these behaviors can be carried out prior to the other behaviors to ensure the leader behaviors, current behavior, and follow-up behaviors will be executed in parallel or partially in parallel. As shown in Figure 3, processes P_2, P_3, P_4, and P_5 can be carried in parallel or partially in parallel.

4. Relationships among Inner Elements of Product Model and Process Model

The activities described by the process model create the information described by the product model, and the information described by the product model is used by the process model to create new information [2]. The data of the product model and the data of the corresponding process model are identical. The variation of product model data will lead to a corresponding variation or reorganization of the process model data. However, the variation of process model data may not result in the corresponding variation of product model data.

The relationships between product model and process model and the relationships among inner elements of product model and process model can be depicted as shown in Figure 4 [2]. The realtionships include organizational relationships, interaction relationships and sequence relationships.

1. Organizational relationships. Organizational relationships exist among the product model information

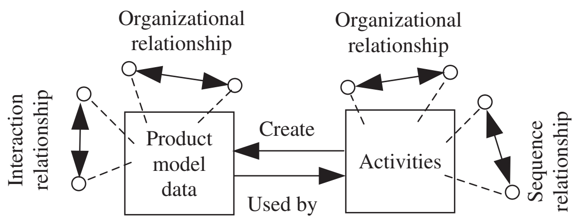


Figure 4. Relationships between process activities and product model data.

elements and process model information elements to organize the models into hierarchies.
2. Interaction relationships. Interaction relationships exist among product model information elements. They can depict the interdependent relationships among the information elements.
3. Sequence relationships. Sequence relationships exist among process model information elements. They can depict the logical relationships among the information elements. The chaos in logic will result in the failure of the product development process.

Identifying and analyzing the relationships between the product model and process model and the relationships among inner elements of the product model and process mode can help to organize the process mode and the data structure in a computer, and also can promote the effective coupling of models.

5. The Coupling Mechanism of Product Model and Process Model

5.1 Establishing Coupling Mechanism

A process model hinges on a product model. Therefore, a coupling mechanism is required to make the process model map to the corresponding product models. The model coupling mechanism was established and expressed by Figure 5.

Under the support of PDMS, the process model closely couples to its corresponding product model through the collaboration of the product model manager and process model manager. All the technology indices defined in the product model can be realized through the process activities. When the process activity is completed, the process evaluation should be implemented. After the output results are compared with the expected output results, the design information should be fed back to adjust the product model and process model, to improve the coupling state. This process should be repeated until the satisfactory process output is achieved.

The main coupling activities are shown as follows.

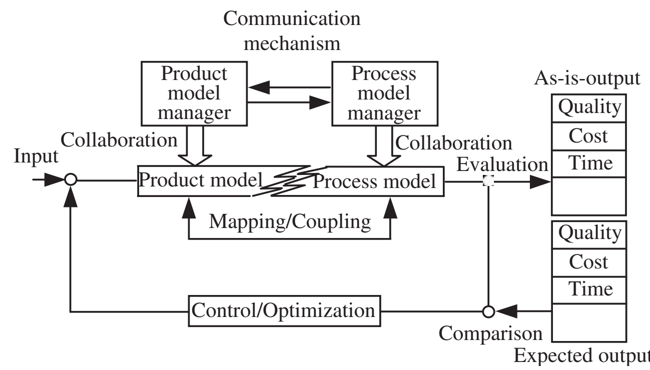


Figure 5. Coupling mechanism of product model and process model.

1. Initialization
   - Create a system plan of model coupling.
   - Identify the stages of the product development life cycle.
   - Identify process granularity.
   - Define process input and output.
   - Define process entrance and exit rule.
   - Define the model pointer.
2. Executing coupling
   - Execute plan.
   - Identify the operation project.
   - Define data acquisition and analyze plan.
   - Define product model data acquisition and feedback.
   - Perform coupling evaluation and analysis.
   - Renew model definition based on requirements.
   - Renew or reorganize model.
   - Repeat.
3. Finish coupling
   - Redefine model.
   - Establish new data dictionary of all models.

5.2 Collaboration Mode in Model Coupling

There exist three different collaboration modes in the proposed coupling mechanism.

1. Only the process model manager operates, and only the process model is adjusted.
2. Only the product model manager operates, and only the product model is adjusted
3. Both the process model manager and product model manager operate at the same time. The process model and product model are adjusted synchronously. Communication mechanisms exist between model managers to exchange information and negotiate.

5.3 Basic Requirements of Model Coupling

The following two basic requirements are required:

1. It is necessary that the models in the coupling process are synchronous.

2. It is necessary that all data in the two coupling models are the same and identical.

5.4 The Evaluation Algorithm of Model Coupling

The factors, such as quality, cost, development time, etc. can be selected as evaluation factors. Let $\{u_1, u_2, \ldots, u_n\}$ be a vector set of evaluation factors. To each factor in the set, define the value of the range and the degree of membership of the corresponding range's satisfaction degree. Let $\mu_i(v_i)$ be the degree of membership, and v_i be the corresponding value of u_i. The weight vector of evaluation factors can be given by experts and expressed as $\{w_1, w_2, \ldots, w_n\}$.

The evaluation method can be carried out step by step as follows.

1. If $v_i \notin \mu_i(v_i)$, then the feedback information is
   - The corresponding indices of the structure matrix.
   - The difference between the index and its lowest value.
2. If $v_i \in \mu_i(v_i)$, given the threshold of satisfaction degree and denoted by S_m, let $\mu_i(v_i)$ be the degree of membership of the evaluation factor, such that

$$S = \sum_{i=1}^{n} w_i \mu_i(v_i)$$

   - If $S \geq S_m$, the process is satisfied.
   - If $S < S_m$, it has to carry out the process optimization and information feedback. The optimization model is as follows:

$$\begin{aligned} &\text{Min } \|A - A'\|_{\text{P}}^{1} \\ &\text{s.t. } \sum_{i=1}^{n} w_i \mu_i(v_i) \geq S_m \\ &\mu_v^{\min} \leq \mu_i(v_i) \leq 1 \end{aligned}$$

where $A = w\mu(v)$, $A' = w\mu^{\max}$. $\mu^{\max}$ is the largest vector of degree of membership. $\mu_v^{\min}$ is the smallest vector of degree of membership. $\|A - A'\|_{\text{P}}^{1}$ is the norm where $P > 1$.

6. Application to Loader Development

Take the development of ZL50 loader as an example to illustrate the proposed integrated product and process development architecture. The whole development process can be divided into six processes, such as development programing, design evaluation, trial-manufacturing, identifying performance, identifying output, and manufacturing. Under the support of enterprise PDMS, the product model and process model were established. The coupling frame of all the development stages were established as shown in Figure 6. The integrated model system is shown in Figure 7.

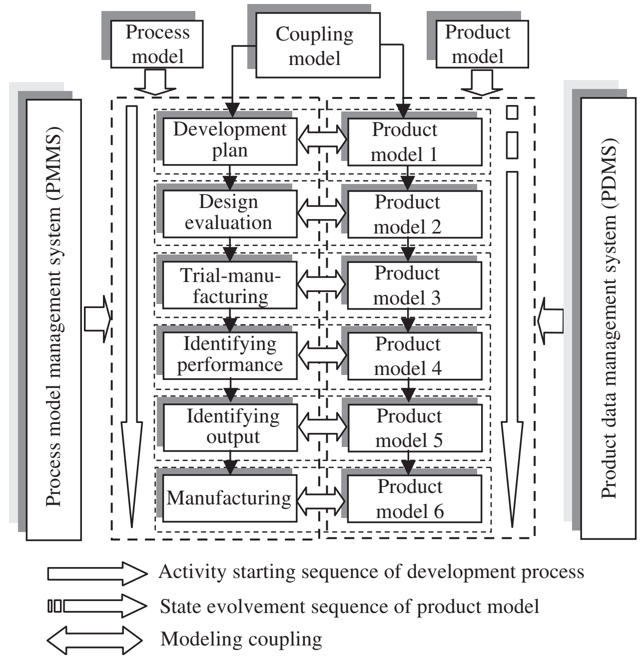


Figure 6. Integrated development frame of a loader.

The coupling of the product model and the course model is realized through the mapping between the model main parameters.

During the design process, the product models of the bucket are shown in Figure 8. There exist four model main parameters of the product. (1) The largest unloading altitude and unloading distance. (2) The outside load feature that takes affect on the bucket point. (3) The transmission angles of each working equipment and the inclination angle of the bucket. (4) The strength of equipment.

According to the model main parameters, four process modes were developed to optimize these parameters based on the coupling mechanism established above. (1) The special working position analysis process. (2) The simulation analysis process under symmetrical load and ultimate deflection load. (3) The constraint force analysis process of the nodes under symmetrical loading. (4) The finite element analysis process. The process models are shown in Figure 9.

As the technology documents were established on the base of the coupling of product models and process models, not only the logicality of process activities in time and space was emphasized, but also the consistency and pertinency of development information were taken into account. Therefore, it embodies the logicality of loader integrated development process and the completeness of product information. Compared with the traditional development mode, the

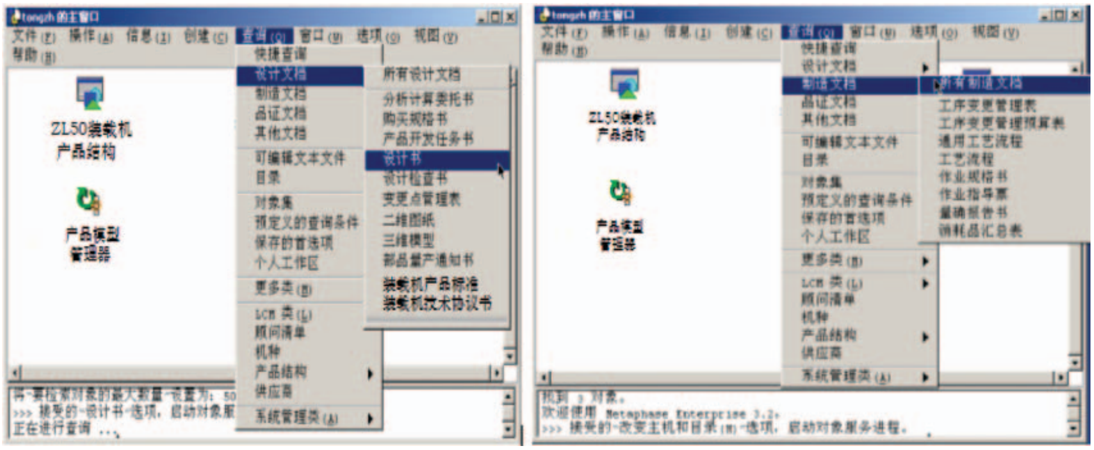


Figure 7. The integrated system of the loader development based on PDMS.

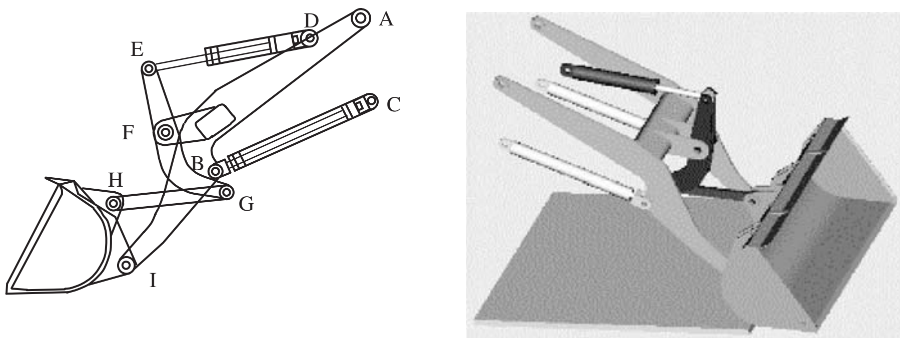
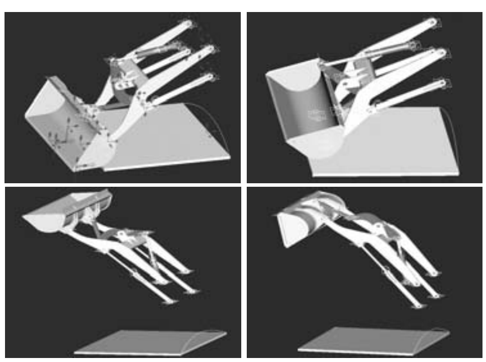
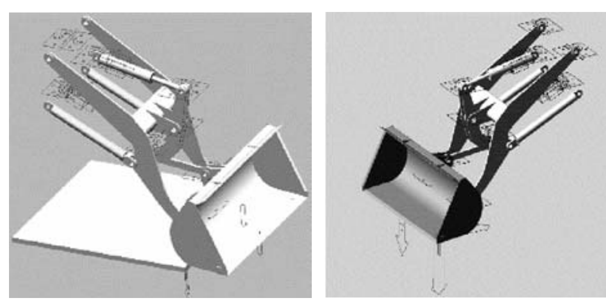


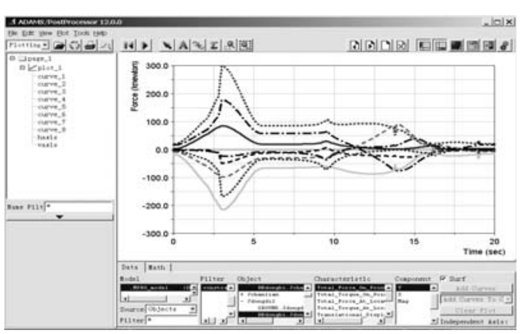
Figure 8. The product model of the bucket-tipping device of the loader.



Model 1. The special working position analysis.



Model 2. The simulation analysis under symmetrical load and ultimate deflection load.



Model 3. The constraint force analysis of the node X and Y under symmetrical load.

Model 4. The finite element analysis.

Figure 9. The design process model of the bucket-tipping device coupling with the product model.

new loader has superiority in development cost and development time.

7. Conclusions

The integrated product development architecture and model coupling mechanism were established to promote the integrated product and process development. The coupling state between the product model and its corresponding process model not only has very important influence on the entire development programing, but also has influence on the microcosmic aspects, such as constraint mechanism, dynamic characteristic, information interaction, collaborative optimization, etc. The integrated development architecture could ensure the logicality of product development in time and space. Therefore, the goal of the life cycle design is realized, which is to make the entire development process and system, and all performances of the product optimal.

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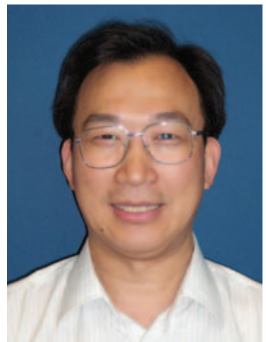
Dr. Hong-Zhong Huang



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