Research on Mechanical Product Radical Innovation Design Process on the Stage of Fuzzy Front End Based on TRIZ

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Abstract: As a high-efficiency technology innovation, radical innovation (RI) can be applied for modern enterprises to achieve leaping-over development. It’s the great significance for enterprises to upgrade technology and enhance the capability of the independent innovation. Based on TRIZ ideal final result (IFR) and technology evolution theory, the technology forecasting process of product technology system radical innovation is put forward. The paper offers a kind of innovation method for product radical innovation design on the stage of fuzzy front end (FFE), which establishes the process model of generating ideas and considers the result as the final high quality ideas. As a case study, the direct shift gearbox (DSG) is investigated. The study shows that the adoption of this method makes the application of the initial stage of product development feasible, which offers a support in both theory and method for product practical application development.

Key words: radical innovation (RI); technology forecasting; fuzzy front end (FFE); TRIZ

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1. Introduction

Since technological innovation theory has been put forward by Schumpeter, according to the difference of the innovation strength, the technological innovation is divided into the incremental innovation (II) and radical innovation (RI). Incremental innovation is the gradual and continuous innovation caused by improving and perfecting of the existing technology. Radical innovation is the process that the S-shaped curve on the mature stage is replaced by a new S-shaped curve in the technology orbit and the starting point of the new S-shaped curve is the mark that the radical innovation technology appears (Chandy & Gerard, 1998). Radical innovation, which is the major technological breakthrough and discontinuous innovation, can often open new market and potential application and it is usually regarded as the basis for new companies to enter the new market successfully based on a complete set of different principles of science and technology.

Product innovation realize through three stages of innovative design, manufacturing and commercialization.
Product radical innovation design is that the new ideas which will realize technology and products in the future is put forward on the stage of fuzzy front end (FFE) as well as change the new ideas into new principle of system or subsystems on the stage of concept design and construct the new structure adapting with the new principle of system or subsystems on the stage of technology design by using all of resources to upgrade the working principle of the existing product or create a brand-new technology and the working principle of product. The stage of fuzzy front end is the key stage for product radical innovation.

2. Literature Review

There are several studies for FFE. Hippie (2004) put forward the Theory of Inventive Problem Solving (TRIZ) used for different types of product innovation ideas on the stage of FFE. Gordon (2008) puts forward new product ideas generation on the stage of FFE, which is the engine of product innovation and it is the key whether can be success or not. Rice et al. (2001) presents that triggering opportunity identification and initial evaluation of radical innovations typically starts with technologists, who are the generators of radical ideas. Dieppe (2002) establishes that a model for continuous innovation has been developed from a variety of sources, which contains four key parts and arguably the most important part is problem solving and problem identification. Hauser (2005) point out that three separate strategies and processes are typically involved in the FFE for incremental, platform and radical projects. Zhang (2004) discriminates the concept of radical innovation on the stage of product FFE and systematically elaborate the contents and steps of FFE management. To achieve an effective radical innovation successfully, the process model for product technology system radical innovation on the stage of FFE should be studied.

This paper research the technology forecasting process of product technology system for radical innovation based on TRIZ ideal final result (IFR) and technology evolution theory and establish the process model of generating ideas for product technology system radical innovation on the stage of fuzzy front end. It offers a support in both theory and method for product practical application development.

3. Methodology

3.1 FFE of the Product Innovation Process

Figure 1 is the model of product innovation process (Koen, Ajamian & Boyce, 2002). The process is divided into three stages: fuzzy front end (FFE), new product development (NPD) and commercialization (COM). Fuzzy front end, which can output the creative new ideas, is the initial stage. The second stage is the new product development, which changes new ideas into new products, including conceptual design, detailed design and production manufacture etc. The final stage is the commercialization, which change products into benefits through the market. The generation of innovation ideas is the most important activity in the process of FFE. As the output of FFE, the demonstrated innovation ideas start the process of new product development and will directly impact the entire product design process. Opportunity identification, opportunity analysis, ideas generation, ideas evaluation and concept generation, which are the five main elements of FFE, decide the generation of innovation ideas (Koen & Ajamian, 2001). Tan (2008) divided innovation ideas of FFE stage into three types: raw ideas, possible ideas and high quality ideas. Possible ideas are acquired by estimation of raw ideas, and high quality ideas are got through the estimation of possible ideas. As the output of FFE, high quality ideas are just the input of NPD. The ideas of the output of FFE turns into new product after the process of NPD and is put into market from which the enterprises benefit.
3.2 The Model of Product Development for RI on the Stage of FFE

Figure 2 shows the model of product development for RI on the stage of FFE. Firstly, select the existing product which is already available on the market as the target product for RI, according to the enterprise self-condition and the situation of market. And then, take advantage of technology maturity prediction tools, which is supported by TRIZ, to predict the technology maturity of target product by means of patent analysis or market characteristics analysis. If the result of technology maturity prediction is that the product technology system lie in child or growth period, then incremental innovation is needed because of the evolutionary insufficiency of product main function. If the result of technology maturity prediction is that the product technology system lie in maturity period, new alternative technology should be found and radical innovation process enter. Moreover, if product technology system lies in maturity period, the product main function has been evolved fully and has stable and mature market, so it also can start disruptive innovation process. Analyzing the current technology evolution state of product core technology subsystems to determine whether the target product exists two technology opportunities of the Performance lead state (PLS) or performance deficiency state (PDS) for RI. The achieving radical innovation technical measures is determined by technology prediction, that is, the direction of technology evolution is constrained by changing principle and updating system of TRIZ ideal final result(IFR)in order to select the technical evolution direction and technical evolution route, driving the direction of technology system evolution, and thus put forward the innovation ideas. CAI contains all kinds of TRIZ tools and the corresponding repository, so it can support the generation of innovation idea expediently.

The innovation ideas of product radical innovation include raw ideas, possible ideas and high quality ideas. As is shown in Figure 2, the generation of three ideas constitutes the stage of FFE for product radical innovation development. The raw ideas of product radical innovation contain the choice of target product and the technology maturity prediction. And then, analyze the current technology evolution state of product core technical subsystems to determine whether the target product exists technology opportunities for RI so as to form the possible ideas. At last, the achieving radical innovation technical measures determined by technology prediction produce the high quality ideas.
3.3.3.1 The Radical Innovation of the Product Technology System

As is shown in Figure 3, a complete product technology system mainly consists of four parts of the power system, transmission system, execution system, control system (Victor & Eugene, 2000). There are two main methods for radical innovation of product technology system (Zhou & Shao, 2012): one is the working principle of innovating technical subsystems from the perspective of the execution system, and the other is the power system and control system of innovating technical subsystems from the perspective of the other three technical subsystems. Changing the technology principle of the technical subsystems create the brand-new technologies and working principle of products replacing the working principle of the existing product to achieve product radical innovation.

The product is realization of the function. According to the use of the function, the function of the product can be divided into the drive function, transmission function, executive function, and control functions (Deng, Britton & Tor, 1998), which can describe the basic functions of the product technology system. The important significance of the existence for the system is to realize the executive function which directly achieves the main function of the product technology system. The other function are consider as auxiliary functions that play a supportive role in realizing the main function in order to better achieve the main function of the product
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technology system. The product technology system contains a number of subsystems can achieve a certain function. These subsystems respectively achieve each of the sub-functions integrating to achieve the total function of the system.

3.3.2 Product Technology System Decomposition

For the technology can realize the function, the function tree method can be used to decompose function and the process of product function decomposition accompanies with the product technology system decomposition. Figure 4 shows the decomposition model of product technology system based on function tree. In the decomposition process of product technology system, product total function can be decomposed into function elements step by step, and then each function element is mapped to the technology.

Then we can summarize the decomposed function elements by using the vocabulary of the Stone function base (Stone & Wood, 2000) and conclude the drive function, transmission function, executive function, control function and the corresponding drive technical subsystems, transmission technical subsystems, executive technical subsystems and control technical subsystems. Because these functions and the corresponding technical subsystems play the necessary role in the constitution of the whole product technology system, this paper summarize them as core functions and core technical subsystems.

![Function Tree of Product Technology System](image)

**Figure 4 The Decomposition Model of the Product Technology System**

3.3.3 TRIZ Ideal Final Result (IFR)

Idealization is the essence for improving the product technology system. The goal of the product innovation is to constantly improve the level of the idealization of the product technology system. The purpose of the ideal final result (IFR) is that completing all the expected useful function of the product technology system, without any cost or harmful effect. For the current product technology system of achieving certain particular function, due to the limit of its core technology performance, there is also a certain limit for the level of the its idealization. The TRIZ ideal final result will significantly improve the useful function of the product technical subsystems, while reducing the cost and hazard, to break through the limit of the level of the idealization of the original technology system. The law of technology evolution in TRIZ is the tool to breaking through the limit for the level of the current idealization.
### 3.3.4 Technology Forecasting Process of the Product Technology System Evolution for RI

As is shown in Figure 5, \(P_s\) is a technology evolution route of the incremental innovation and \(P_d\) is a selected technology evolution route of carrying out the radical innovation. The current status \(a\) is located in the mature stage and the highest state \(a+1\) is located in the decline stage which product evolve along \(P_d\). The current state is closed to the technical performance limit, so it is necessary to look for or select the new alternative technologies.

If the current status \(a\) in the mature stage carry out the radical innovation to look for the new alternative technology, the potential state \(b\) of the alternative technology in the growth stage which product evolve along the technology evolution route. In order to calculate the potential state \(b\) of the alternative technology, first of all, the direction of technology evolution is constrained by changing principle and updating system of TRIZ ideal final result to select the technical evolution direction and technical evolution route. And then after the product technology system was decomposed, we can summarize the core functions and core technical subsystems and analyze the current technology evolution state of the product core technical subsystems. The enhanced core technology system selected from products core technology systems is carried out technology evolution forecasting. In this process, we can predict the potential state \(b\) of the alternative technology after carrying out radical innovation through this state is integrated into the product technology systems.

![Figure 5](image)

**Figure 5** The Technology Forecasting of the Product Technology System Evolution for RI

### 3.4 The Process Model for Product Radical Innovation Design on the Stage of Fuzzy Front End

Figure 6 is the process model for radical innovation design on the stage of fuzzy front end. The whole design process contains four main parts as follows:

1. **Opportunity identification**
   According to the history and actuality of enterprises themselves and the analysis of market condition, choosing a kind of product which is already available in the market to be the target product for RI. If the product technology system don’t lie in maturity stage, then the radical innovation isn’t suitable because product market isn’t mature and be reselected.

2. **Opportunity analysis**
   The core functions and core technical subsystems of the product technology system are summarized after technology system decomposition of the target product and analysis of each core functions and technical
subsystems. The current technology evolution state & user demand of the product core technical subsystems are researched to determine whether there are the technology opportunities for RI or not. If the current technology performance meet the users’ needs, there is technology opportunity of the performance lead state (PLS). If the current technology performance don’t meet the users’ needs, there is technology opportunity of the performance deficiency state (PDS).

(3) Ideas generation

The achieving radical innovation technical potential state are determined by technology forecast of product core technical subsystems, that is, the direction of technology evolution is constrained by changing principle and updating system of TRIZ ideal final result (IFR) in order to select the technical evolution direction and technical evolution route, and thus put forward the innovation ideas. If the direction of the technology system evolution does not meet the requirements of IFR, redefined the IFR or reselect the direction of the technology system evolution and technology evolution route.

(4) Idea evaluation and Concept generation

According to the enterprise actual situation, The achieved the technical potential state of product core technical subsystems are evaluated as the selected final innovation ideas that is the new concept for product radical innovation.

Figure 6  The Process Model for Product Radical Innovation Design on the Stage of Fuzzy Front End
4. Case Study—The Direct Shift Gearbox (DSG)

More comfortable, more saving energy and more dynamic driving is increasingly becoming the pursuit of driving automobile for people. Transmission, as the important part of automobile power transmission system, plays an important role in dynamic performance, driving comfort and fuel economy.

Automobile transmission divides into two kinds of manual transmission and automatic transmission. Because of power directly and high efficiency as well as mature technology and low cost of production, the modern automobiles which equipped with manual transmission still occupy a large proportion. But, with the driving comfort needs higher and higher, there is indisputable fact that the rate of the modern automobiles equipped with automatic transmission become more and more, especially when automatic transmission is also gradually to give consideration to the handling stability. However, because of its low efficiency and fuel consumption higher than manual transmission, how to combination the advantages of two traditional transmissions become a struggling focus for automotive engineers. Therefore, it will be quite necessary for modern motor corporations to develop a kind of more advanced transmission replacing the traditional transmission and directly compete with the other enterprises in the market. So, a type of new transmission project for RI has to be adopted and we should do technology forecast for RI in the FFE stage of product development.

The engineers for Volkswagen continuous research and development to seek the solution of the technology challenge. Volkswagen successfully launched direct shift gearbox (DSG), applying technology concept of radical innovation with the help of electronic hydraulic control technology. As the most advanced and revolutionary transmission system all over the world at present, for the first time in 2002, Volkswagen shows the technology of radical innovation to world in Wolfsburg.

![Figure 7: The Structure Chart of Direct Shift Gearbox (DSG)](image)

As is shown in Figure 7, DSG is different from the traditional automatic transmission system, which based on manual transmission instead of automatic transmission. It mainly consists of double clutches and gear sets, shift gear sleeve, double input shafts and electronic hydraulic control system and so on that constitute a complex shifting speed mechanism. It can complete shifting gears in a very short time and supply strong power output. Besides keeping flexibility of manual transmission and comfort of automatic transmission, it still can provide...
continuous power output for drivers to provide convenient, comfortable and highly dynamic driving control feelings.

As is shown in Figure 6, this paper proposes the process for DSG radical innovation in the FFE stage of product development.

Process 1: Opportunity identification-product selection and technology maturity forecast

According to the level of the technology and market investigation, the conclusions can be drawn that traditional manual transmission is in the stage of maturity. The evolutionary timing of manual transmission selected as the target product is suitable for RI process.

Process 2: Opportunity analysis-product technology system decomposition and analysis core technical subsystems current evolution state & user demand

As is shown in Figure 8, the technology system of traditional manual transmission is decomposed into several units, including 4 core functions and corresponding core technical subsystems.

Through data collection, processing and analyzing the core technical subsystems current evolution state, we can draw a conclusion that the urgent need of keeping flexibility and comfort of automobile transmission has been far beyond the technology performance limit of the traditional manual transmission. So there appears the state of performance deficiency state (PDS) in the automobile transmission technology system and exists the opportunity for RI.

Process 3: Ideas generation-technology forecast of the automobile transmission for RI

The selected technology evolution route of “Increase harmonious” can become technology forecast for RI based on the TRIZ final ideal result.

DSG contains two sets of automatic control clutch and the electronic and hydraulic can control the operation of two sets of clutch simultaneously. When transmission operating, a set of gears mesh and when it was close to shift gear, another set of gears has already been prepared, but the clutch is still in the state of separation. When shifting gear, a set of clutch will separate the working gears and at the same time, another set of clutch meshing has been pre-selected. These four actions are under the control and effect of the electronic control unit simultaneous, so shifting speed respond extra fast. During the time of the whole shifting gear, it can ensure that at least one set of gears output the power that won’t appear the condition of power interruption.

Phase 4: Idea evaluation and Concept generation

The technical potential state can be realized after evaluating the possibility of achieving the DSG technology in accordance with the actual situation of the enterprise that is the selected final innovation concept.
5. Conclusion

The stage of FFE play a quite important role in the process of NPD and the innovative result of this stage directly decides whether the development of new product is successful or not. Based on TRIZ final ideal result and technology evolution theory, a kind of innovation method is put forward, which establishes the process model for product radical innovation and considers it as the final high quality ideas of FFE. With the help of the process model, not only does the innovation concept gets clearer but the effectiveness of innovation and success rate of product development is also be improved. Therefore, it is feasible method for new product development for modern enterprises entering a mature market.

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