Proceedings of ICAD2006
4th International Conference on Axiomatic Design
Firenze – June 13-16, 2006
ICAD-2006-04

DECOUPLING PROCESS OF A COUPLED DESIGN USING THE TRIZ MODULE

Gwang-Seob Shin
s@hyundai-motor.com
Mechanical Design and Production Engineering,
Hanyang University
Haengdang-1-Dong 17, Seongdong-Gu, Seoul
133-791, Korea

Gyung-Jin Park
gjpark@hanyang.ac.kr
Division of Mechanical and Information Management
Engineering, Hanyang University
Sa-1-Dong 1271, Ansan City, Gyeonggi-do
425-791, Korea

ABSTRACT

Axiomatic Design has been developed as a general design framework during the past two decades and TRIZ has been developed as a design tool for over 50 years. Axiomatic design is quite excellent in that design should be decoupled. When a design matrix is established, the characteristics of the design are identified according to the coupling properties. If the design is coupled, a decoupling process should be found. However, axiomatic design does not specifically indicate how to decouple a coupled design. In this paper, the decoupling process is classified into six patterns. It is demonstrated that each pattern could be solved by an appropriate TRIZ module. The method is applied to the conceptual design processes of a tape feeder and the beam adjuster of a laser marker, and the results are analyzed.

Key Words: Axiomatic Design, TRIZ, Decoupling Process

1 INTRODUCTION

Currently, conceptual design is receiving much attention in industries. The capability of creating a new design becomes more important than ever before because the engineering environment is rapidly changing. A good design has a large impact on the entire engineering process.

One useful design methodology is axiomatic design. It consists of two axioms for general design [1]. The first axiom is the Independence Axiom. It states that the independence of functional requirements (FRs) must always be maintained, where FRs are defined as the minimum set of independent requirements that characterize the design goals [2]. The second axiom is the Information Axiom, and it states that among those designs that satisfy the Independence Axiom, the design with the smallest information content is the best design [3].

TRIZ is a Russian acronym for the theory of inventive problem solving. TRIZ was created and developed in former USSR by the Russian engineer and inventor G.S. Altshuller. TRIZ is a science that studies evolution of technical systems to develop methods for inventive problem solving. The main distinction of TRIZ from creative methods that are based on the trial and error approach is that the TRIZ offers directed and algorithmic searching of solutions instead of chaotic generation of ideas [4~6].

Axiomatic design has the advantage in deriving the initial design [7~8]. When a design matrix is established, the characteristics of the design are identified according to the coupling properties. If the design is coupled, a decoupling process should be found. However, axiomatic design does not specifically indicate how to decouple a coupled design. In the papers of Kai [9~10] and Kim and Cochran [11], characteristics of the two theories are analyzed and the possibility of common use is discussed. The example using both theories at the same time was also studied [12~13]. In those researches, the searching process is carried out for an uncoupled design from an initial coupled design. TRIZ modules are utilized for the searching process.

In this research, TRIZ is employed for a decoupling process of a coupled design. The coupling phenomena are classified into six patterns. Each pattern could be decoupled by an appropriate TRIZ module. A table, which matches the relationship between the decoupling process and the TRIZ module, is proposed for effective application of the two design theories. The proposed method is applied to the conceptual design processes of a tape feeder and the beam adjuster of a laser marker, and the results are analyzed.

2 AXIOMATIC DESIGN AND TRIZ

2.1 INTRODUCTION OF AXIOMATIC DESIGN

A design is completed through continuous interactions between the goal set by the designer and the method for attaining the goal. Design is the form of a product or process that can satisfy the functional requirements (FRs) that the designer wants. In other words, it is a process of mapping functional requirements into design parameters (DPs). Mapping is choosing a relevant design parameter, which satisfies a given functional requirement. The mapping process is illustrated in Fig. 1.

According to the axiomatic principle, the design process proceeds in hierarchies as illustrated in Fig.1. Designers begin the design from comprehensive functional requirements. A design can decompose functional requirements into many hierarchies. But the decomposition of functional requirements must be carried out at the same time with the decomposition of design parameters. The zigzagging between functional requirements and

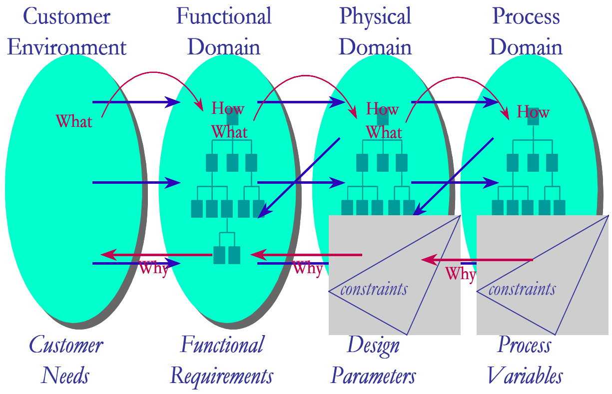

Fig. 1 Concept of domain, mapping and spaces

design parameters is necessary because the two sets of each level are connected and mutually dependent.
Axiomatic design provides a framework for choosing a good design. The two design axioms are the "tools" that are helpful for the creation of a new design. The first axiom tells us about the selection of a functional requirement. The second axiom shows a quantitative method of judging which design is more desirable. The design axioms are defined as follows:

Axiom 1: The Independence Axiom
Maintain the independence of functional requirements.

Axiom 2: The Information Axiom
Minimize the information content.

The two axioms present the most fundamental means needed to choose the best design.
For a design to be acceptable, the design must satisfy the first axiom. A design matrix is defined to pursue the relationship between FRs and DPs as following:

$$\mathbf{FR} = \mathbf{A}\,\mathbf{DP} \qquad (1)$$

where **FR** is a vector for functional requirements, **DP** is a vector for design parameters and **A** is a design matrix. If we have three FRs and DPs, Eq. (1) can be shown as following:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & O & O \\ O & X & O \\ O & O & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \qquad (2)$$

where X means a relationship exists and O means there is no relationship.

When the Independence Axiom is satisfied, the design matrix has the form of a diagonal matrix or a triangular matrix. The diagonal matrix in Eq. (2) represents a perfectly uncoupled design and is the most desirable form. In this case, just one DP affects each FR because a modification on each DP only has influence on the corresponding FR. The triangular matrix represents a decoupled design. This form of design is also a proper design, but the DPs need to be rearranged in a specific order so as to satisfy the FRs. On the other hand, an uncoupled design does not require a specific order. The third form of a design is a coupled design. This pattern of design is undesirable because when a DP is modified, multiple FRs are changed. There is no effective solution for undesirable change on the FRs.
The Information Axiom is related to the complexity of a design and implies that the simpler design is the better one. In the Information Axiom, the DPs are selected according to information content. The information content is defined by the probability of success to satisfy corresponding FRs. For example, the information content for the i-th functional requirement is defined as:

$$I_i = \log_2 \frac{1}{p} \qquad (3)$$

where p is the probability of success for the i-th functional requirement. The total information content is the summation of the information quantities. When multiple solutions satisfy the Independence Axiom, the Information Axiom can be well exploited. A solution with minimum information is selected [14].

2.2 Introduction of TRIZ

TRIZ is a Russian acronym for the theory of inventive problem solving. TRIZ was created and developed in the former USSR by the Russian engineer and inventor G.S. Altshuller. TRIZ is a science that studies evolution of technical systems to develop methods for inventive problem solving [15]. In other words, it is to solve one's own problem and achieve innovation by applying problem-solving principles used for distinguished inventions or inventors. The basis of TRIZ is the hypothesis that 'most of the innovative solutions for technological problems can be found through analogical reflection of certain patterns or principles derived from previous cases of inventions.' To prove this hypothesis, patent cases have been investigated and a huge number of patent cases have been analyzed until now [15~16].
TRIZ is composed of several analysis techniques. Among them, an effect module sorts out physical, chemical and geometric principles by function for convenient use by inventors. By using various principles in the module, inventors have a higher possibility for new inventions [17].

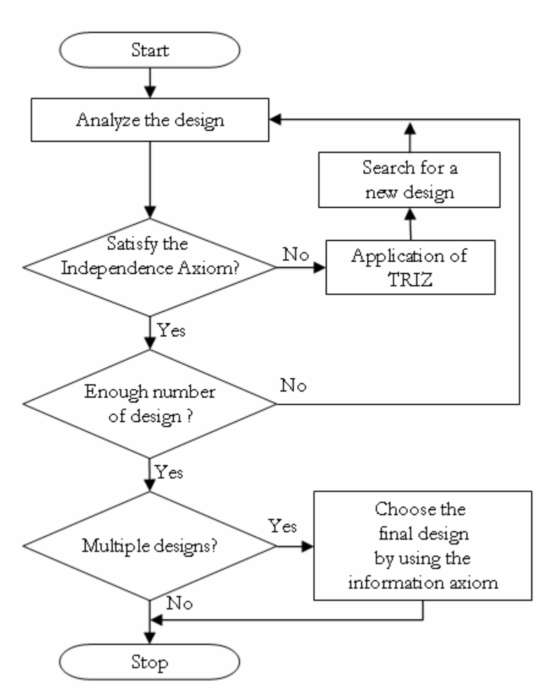

Fig.2 Flow chart of the proposed design process

Substance-field analysis is one of analyzing tools in TRIZ to model systems for solving problems [18]. In the sense that every problem in technological systems occurs from interaction among substances in a field, a system can be expressed as a triangular model composed of interacting substances and fields. To formulate such a model, we need to clarify insufficiency in beneficial interactions and the occurrence of harmful ones. Thus, substance-field analysis is an important analyzing tool in problem solving [19~21]. A standard solution expresses the direction of problem solving using the same substance-field model for problems presented through substance-field analysis (in case there are a pair of substances and a field between them and their interaction is harmful or insufficient or the effector is absent). There are a total of 76 patterns of standard solutions, and five steps from step 1 for composition and decomposition of substance-field model to step 5 for the application of the standard solution. Breaking them down into smaller parts, the solutions are divided into 18 groups from 1-1 the composition of substance-field to 5-5 the acquisition of substance particles and 76 standard solutions from standard solution 1-1-1 to 5-5-3. To draw an actual solution, we should select the optimal standard solution, and from the solution, derive effective ideas by solving real problems.

Algorithm for Inventive problem solving (ARIZ) is the latest technique of classical TRIZ developed by Altshuller. It is made by rearranging all classical TRIZ techniques. That is, ARIZ is a thinking process for solving the most complex ones among engineering problems. Specifically, it is an algorithm of problem solving by transposing a technological contradiction into a physical contradiction and again clarifying the ideal final solution. A major characteristic of this process is that, aiming at the resolution of contradictions in a complicated problem, it solves the problem through efficient use of currently available resources. Further details are in references [17~21].

3 THE USE OF TRIZ ACCORDING TO THE AXIOMATIC DESIGN PATTERN

When a design is analyzed axiomatically at the early stage of conceptual design and it is found not to be a coupled design, we need to adopt a better pattern of design. For this, design parameters are added or changed frequently. In adding or changing design parameters, if the designer relies on only one's experiences, it may not be a satisfactory design.

In such a situation, we can draw a design using either axiomatic design or TRIZ or combining the two complementarily to each other. Fig. 2 shows a design process that uses the two axioms and TRIZ together. When a design does not satisfy the Independence Axiom, it is a coupled design and a new design is required. The coupled designs are classified into six patterns and TRIZ modules are utilized according to the pattern. If multiple designs are produced, a final design is chosen. To choose the final design, the Information Axiom is employed. The six patterns are as follows:

3.1 COUPLED DESIGN WITH INSUFFICIENT DESIGN PARAMETERS (AD1 PATTERN)

When we have insufficient design parameters compared to the number of functional requirements, it is named as the 'AD1' pattern. An example is as following:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & O \\ O & X \\ O & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix} \qquad (4)$$

In the case of AD1, it is difficult to derive a satisfactory design by adjusting the insufficient number of design parameters. We need to add design parameters to satisfy the Independence Axiom. An applicable TRIZ module for this is the science and technology effect module. This module classifies various science and technology principles for reuse. In addition, there are 76 standard solution groups in the substance-field model (SFM). Among them, the following ones are applicable.

1) Standard solution group 5-1: Group 5-1, which is one of the 18 groups of TRIZ standard solutions, introduces substances under constraints. For example, standard solution 5-1-4 introduces the vacuum or bubble of an expanding structure. An example is hauling a crashed airplane by using an inflatable bag.

2) Standard solution group 5-2: Group 5-2 introduces fields under constraints. For example, we can use an existing field first in standard solution 5-2-1. If gas is contained in liquid oxygen, it is separated by rotating the liquid.

3) Standard solution group 5-4: Group 5-4 uses physical effects. For example, in standard solution 5-4-1, when an object has to alternate its physical state, the object performs the transition by itself. A sample case is the use of a shape memory alloy for

making heat-sensitive values. Summaries on the standard solutions are in references [21].

3.2 When functional requirements are added (AD2 pattern)

Sometimes functional requirements should be added to an uncoupled or decoupled design. The pattern is represented in Eq. (5). In Eq. (5) is added to an uncoupled design.

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ (FR_3) \end{Bmatrix} = \begin{bmatrix} X & O \\ O & X \\ (O) & (O) \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix} \qquad (5)$$

Such a case is named as the 'AD2' pattern. Design parameters should be added to satisfy the new functional requirements. Applicable modules in the TRIZ substance-field model are as follows:

1) Science and technology effect: The science and technology effect module can be used to add new design parameters. The science and technology effect module sorts out physical, chemical and geometrical principles by function for convenient use of inventors. For example, to cool down substances, we can use principles such as adiabatic expansion, phase transition, Joule-Thomson effect, rank effect, magnetic calorie effect and thermal electron phenomenon. Referring to these principles, we can derive new design parameters more efficiently.
2) Standard solution group 1-1: Group 1-1 solves problems by a substance-field model. For example, standard solution 1-1-2 solves a problem through transition to a composite substance-field model if it is possible to add a given substance. In a problem that requires detecting very tiny liquid bubbles, if a fluorescent material is added to the liquid in advance, the bubbles can be detected by using light.
3) Standard solution group 2-1: Group 2-1 is transition to a complex substance-field model. For example, in standard solution 2-1-1, efficiency is reinforced by forming a substance-field model that is transformed and connected to the substance-field controlled independently. A sample case is a tractor that can change the center of gravity on a steep slope.

3.3 Decoupled design with large off diagonal terms (AD3 pattern)

The design equation of a decoupled design can be as following:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & O & O \\ O & X & O \\ O & X & x \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \qquad (6)$$

where $X >> x$. In Eq. (6), when DP_2 is determined for FR_2, FR_3 is almost determined because X is very large compared to x. Thus, FR_3 may not be satisfied by changing DP_3 since the influence of DP_3 on FR_3 is very small. This case is named as the 'AD3' pattern.
In such a case, the following groups in the substance-field model are helpful in deriving adequate designs.
1) Standard solution group 3-2: Group 3-2 is transition to a micro level. For example, standard solution 3-2-1 reinforces system efficiency through transition from the macro level to the micro level. For fine adjustment, the use of thermal expansion of metal rods is more efficient than the use of precise screws.
2) Standard solution group 5-3: Group 5-3 utilizes state transition. For example, standard solution 5-3-3 improves system efficiency using physical phenomena generated from state transition. If an object is moved over an icy surface, the ice reduces friction. Besides, standard solution group 2-2, 2-3, 3-1 and 4-3 are applicable.

3.4 Coupled design with technological contradiction (AD4 pattern)

In TRIZ, contradictions are divided into technological contradictions and physical contradictions. A technological contradiction means that the improvement of a property deteriorates another property. As in Eq. (7), if DP_2 is changed to improve functional requirement FR_2, FR_2 is improved but FR_3 can be deteriorated. This is a technological contradiction, which is named as the 'AD4' pattern.

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & O & O \\ O & X & X \\ O & X & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \qquad (7)$$

A coupled design in the AD4 pattern should find another design parameter that satisfies the Independent Axiom. The TRIZ contradiction matrix is used for this. The contradiction matrix is to select improved and deteriorated properties in a given problem situation and to derive conceptual solutions using inventive principles at the crossing point. For example, if an electric switch is enlarged for higher reliability, it becomes longer and more difficult to be installed. In this case, we set the level of reliability for the improved property and the length for the worsened property, and find inventive principles at the crossing point in the contradiction matrix. Inventive principles at the crossing point are the dynamic level, preliminary reaction, sphere and asymmetry. These principles and their relevant cases are much help in planning new designs.

Table 1 AD-TRIZ relationship table

Axiomatic Design Pattern	Related TRIZ modules
AD1	Effect, SFM 5-1, 5-2, 5-4
AD2	Effect, SFM 1-1, 2-1, 4-2
AD3	SFM 2-2, 2-3, 3-1, 3-2, 4-3, 5-3
AD4	Contradiction table
AD5	Separation rules
AD6	ARIZ, SFM 1-2, 2-4, 4-1, 4-4,4-5,5-3

3.5 Physical contradiction coupled design (AD5 pattern)

In TRIZ, a physical contradiction means that a design parameter needs to increase in a situation and to decrease in another situation [10]. As in Eq. (8), if DP_2 is changed to improve FR_2, FR_2 is improved but FR_3 can be improved or deteriorated depending on the situation. This is a physical contradiction, which is named as the 'AD5' pattern. In such a coupled design, the value of the design parameter to be changed is found according to the principles of separation in TRIZ. Separation can be the separation of time, the separation of space, the separation between the whole body and parts and separation according to conditions. As an example of the separation of time, piles used in foundation work need to have a sharp end to be driven into the ground but need to have a blunt end for high bearing power. In such a case, a small amount of explosive is put in the sharp end of a pile and after the pile has been driven into the ground the explosive is detonated to make the end blunt. In this way, the pile has a sharp end easy to be driven in, and at the same time, a blunt end not easy to be taken off.

3.6 Other coupled designs (AD6 pattern)

In some coupled designs, if DP_2 is changed to improve FR_2, FR_2 is improved and FR_3 is affected but not in the patterns of AD4 or AD5. Two or more design parameters are coupled in a complicated way. Such coupled designs are named as the 'AD6' pattern and an example is as following:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & X & X \\ O & X & X \\ O & X & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \qquad (8)$$

This pattern solves problems using harmful complete systems in the substance-field model or ARIZ [21]. ARIZ sorts out all classical TRIZ techniques together. A harmful complete system is a situation that produces a harmful or an unwanted effect. A standard solution applicable to this situation is the decomposition of the substance-field model in group 1-2. Recommended methods for isolating the harmful effect are by using an insulator, blocking the harmful effect with an opposite field, protecting it with a safety substance that leads away the harmful effect and modifying the substance so that it becomes insensitive to the harmful effect.

Table 1 shows the TRIZ modules to solve each pattern. Using the relationship table, we can find uncoupled designs or better designs more efficiently.

Fig. 3 Chip mounter

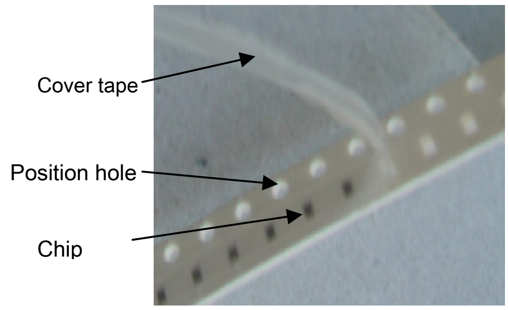

Fig. 4 Cover tape and chip

4 EXAMPLE PROBLEMS

4.1 Design to improve tape feeder

The tape feeder is a device for feeding various electronic components on a circuit board. As illustrated in Fig. 3, it is included in a chip mounter and feeds parts. As illustrated in Fig. 4, components to be installed on the chip mounter are contained in the reel tape. A cover tape is attached to the reel tape. To feed parts, the tape feeder peels off the cover tape and feeds parts to a certain position so that the chip mounter head can get the parts continuously as illustrated in Fig. 5. For the current tape feeder, the following FRs and DPs are defined:

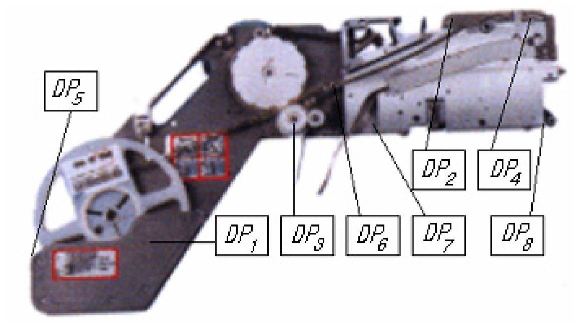

Fig. 5 Tape feeder and DPs

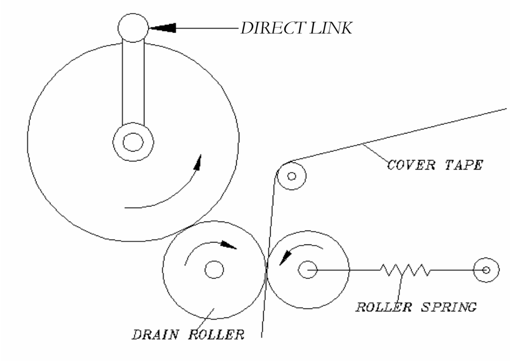

Fig. 6 Current design of the tape

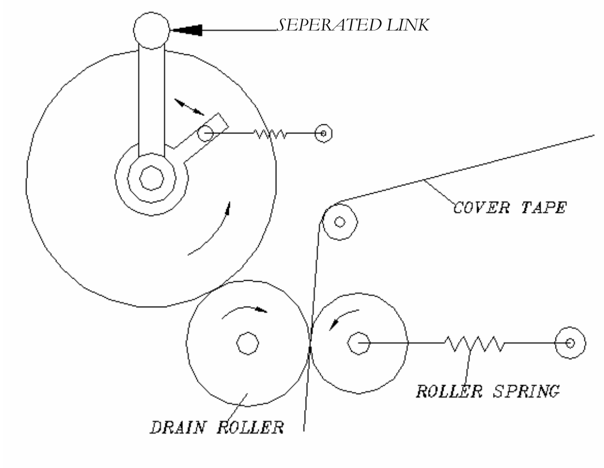

Fig. 7 New design of the tape feeder

FR_1 : Install the tape reel
FR_2 : Fix the component on the picking position
FR_3 : Peel the cover tape
FR_4 : Move the component as pitch distance
FR_5 : Change the empty reel
FR_6 : Guide the empty tape
FR_7 : Guide the cover tape
FR_8 : Change the pitch distance

DP_1 : Pocket reel
DP_2 : Tape guide
DP_3 : Drain roller
DP_4 : Sprocket, Ratchet
DP_5 : Rear pocket
DP_6 : Tape path of frame
DP_7 : Post of reel plate
DP_8 : Push lever link

Each design parameter is marked in Fig. 5. The design equation is

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \\ FR_5 \\ FR_6 \\ FR_7 \\ FR_8 \end{Bmatrix} = \begin{bmatrix} X & O & O & O & O & O & O & O \\ O & X & O & O & O & O & O & O \\ O & O & X & X & O & O & O & O \\ O & O & X & X & O & O & O & O \\ O & O & O & O & X & O & O & O \\ O & O & O & O & O & X & O & O \\ O & O & O & O & O & O & X & O \\ O & O & O & O & O & O & O & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \\ DP_5 \\ DP_6 \\ DP_7 \\ DP_8 \end{Bmatrix} \quad (9)$$

Eq. (9) is a coupled design. FR_3 and FR_4 are coupled as illustrated in Fig. 6. FR_3 is a function that peels off the cover tape. Intense strength is required to hold the cover tape and peel it off, but the strength is propagated to the tape in the connected part.

As a result, the parts are not supplied accurately and the position becomes slightly irregular.
To maintain the correct position of the part supply, the cover tape should be pulled on gently but the cover tape may not be peeled off due to the shortage of the force. If it is pulled on too strongly the position of the fixed parts may be shaken. This problem belongs to the AD4 pattern which is related to technological contradictions. Thus, we can plan an improved design by using the contradiction matrix [16]. The improved property is Property No. 27 reliability and the worsened property is Property No. 4 the length of a fixed object. In the contradiction matrix, the inventive principles for the two properties are No. 5 dynamic level, No. 29 air and fluid system, No. 28 redesign and No. 12 identical electric potential.
We can plan a design by referring to cases linked to each inventive principle. Among them, the inventive principle of No. 15 dynamic level is to optimize the properties of substance or external environment to the best condition at each operating step as found in cases such as the automotive electric-powered mirror and the chair and handle adjusting device. A new design is made by using the principle of the dynamic level, in which the link that moves forward the tape is separated from pulling the cover tape as illustrated in the left side of Fig. 7. Using this method, we can adjust the force for the drain roller to push the cover tape and the force to turn around the cover tape differently.

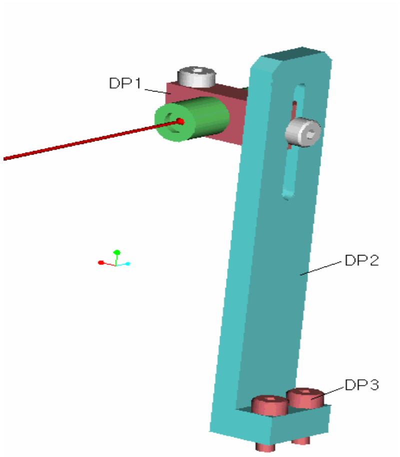

Fig. 8 Beam adjuster and DPs

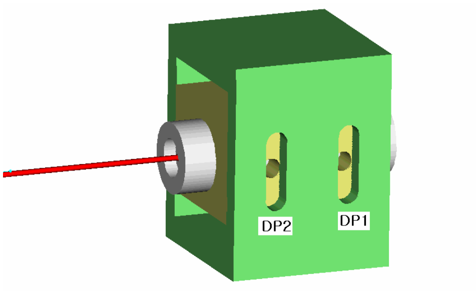

Fig. 9 New design No. 1

Then the design equation is

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \\ FR_5 \\ FR_6 \\ FR_7 \\ FR_8 \end{Bmatrix} = \begin{bmatrix} X & O & O & O & O & O & O & O \\ O & X & O & O & O & O & O & O \\ O & O & X & O & O & O & O & O \\ O & O & O & X & O & O & O & O \\ O & O & O & O & X & O & O & O \\ O & O & O & O & O & X & O & O \\ O & O & O & O & O & O & X & O \\ O & O & O & O & O & O & O & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \\ DP_5 \\ DP_6 \\ DP_7 \\ DP_8 \end{Bmatrix} \quad (10)$$

We can separately adjust the force of holding the cover tape and the force of pulling the tape. Even if the force of pulling is controlled, the force does not reach the part due to the separated link. As a result, an accurate position can be maintained. The new design is employed for a new product.

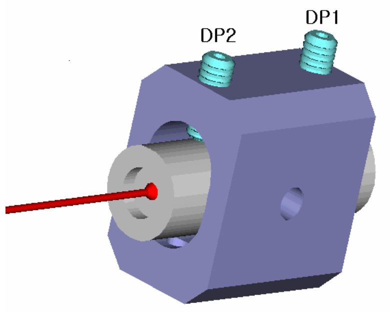

Fig. 10 New design No. 2

4.2 DESIGN OF A LASER MARKER BEAM ADJUSTING DEVICE

A laser marker beam adjusting device adjusts the diode laser with the path of a YAG marking laser [22]. The vertical and horizontal positions and the angle of the beam adjusting device should be adjusted to the right datum point of marking. In many cases, it is not easy to use an adjusting device due to fine errors made in the manufacturing process. Sometimes, the problem is not solved even with the use of high-precision components or investment of a long assembly time. Therefore, it requires a design that can adjust the position and angle of the adjusting device precisely. The current design is illustrated in Fig. 8 and the FRs, DPs and constraints are defined as follows.

FR_1 : Align the vertical position of the diode laser beam.
FR_2 : Align the vertical angle of the diode laser beam.
FR_3 : Align the horizontal position of the diode laser beam.
FR_4 : Align the horizontal angle of the diode laser beam.
FR_5 : Fix the beam alignment.

C_1 : Install space
C_2 : Manufacturing cost

DP_1 : Vertically moving component
DP_2 : Supporting block
DP_3 : Fixing screw

The design matrix is

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \\ FR_5 \end{Bmatrix} = \begin{bmatrix} X & O & O \\ X & O & O \\ O & X & O \\ O & X & O \\ O & O & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \quad (11)$$

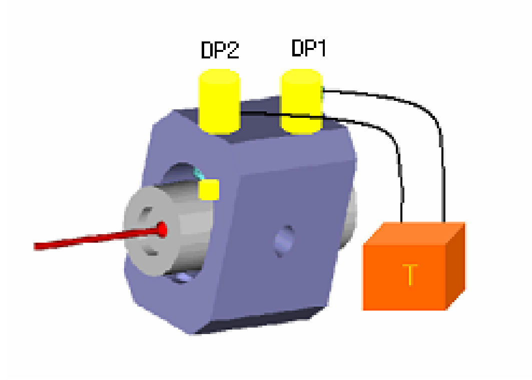

Fig. 11 New design No. 3

In the current design, the vertical shift block should be moved to adjust the vertical position. Then the preset vertical angle changes accordingly. Likewise, when adjusting the horizontal position, the movement affects the horizontal angle and this makes it difficult to adjust them simultaneously. It is attributed to the AD1 pattern and a part of Eq. (11) can be

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} X \\ X \end{bmatrix} \{DP_1\} \qquad (12)$$

A TRIZ module for Eq. (12) is a substance-field model 5-1-2 in Table 1. In this module, when it is difficult to change the system to meet requirements, the device is changed to interacting subdivided elements for application. When this design is applied and a new concept that distinguishes between the design parameter for deciding the vertical position and that for deciding the horizontal position, we can obtain a basic first design as

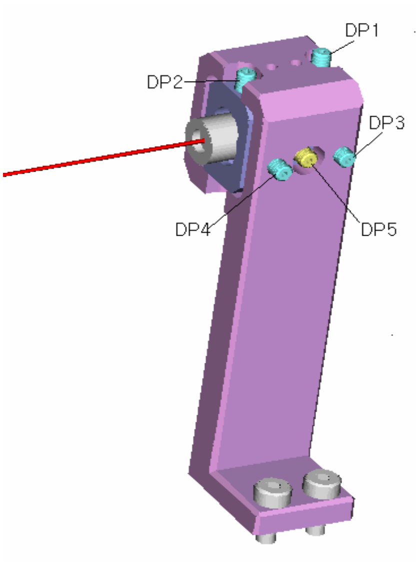

Fig. 12 Final expanded design

illustrated in Fig. 9.

The proposed first design in Fig. 9 has the design parameter of the rear joint for adjusting the vertical position from which the beam starts and that of the front joint for adjusting the vertical angle. A screw can be fastened to each hole and each position can be fixed after adjustment. The design matrix for this design is as in Eq. (13).

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} X & O \\ X & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix} \qquad (13)$$

Eq. (13) is a decoupled design and it has the AD3 pattern. The first conceptual design can be improved further by using appropriate TRIZ modules applicable to the pattern. Eq. (13) for the improved design is design pattern AD3. Among applicable modules in Table 1, substance-field model 3-2 reinforces system efficiency at a certain stage of system development through transition from the macro level to the micro level. Two new designs are derived as illustrated in Figs. 10 and 11. In the two designs, the rear screw for adjusting the vertical starting position of the beam is separated from the front screw for adjusting the vertical angle of the beam. In Fig. 10, a fine adjustment is enabled by the screw without direct change of the beam. Actually, the design is reinforce by transition to a micro level. The third design in Fig. 11 uses a coil, the temperature of which is adjustable, instead of a screw to control the position at a more microscopic level by adjusting the length of the metal bar. This design can determine the position more precisely than the design in Fig. 10.

The last task is choosing one of the three derived designs. The third design is excellent, however, the constraint for the cost is violated. Therefore, it is discarded. The designs in Figs. 9 and 10 are compared by using the Information Axiom. When the information contents are compared, the one in Fig. 10 has less information [22-23], thus the design in Fig. 10 is selected as the final design. The design in Fig. 10 is expanded to the entire system and the final design in Fig. 12 is made [24].

5 CONCLUSIONS

Recently a number of engineering designs are being suggested and efforts are being made to improve design methods. In this context, various decoupling methods for coupled designs are developed by using TRIZ modules. From the research, the following statements are concluded:

(1) TRIZ modules can be exploited well for the decoupling process of coupled designs.
(2) The coupled manner is classified into six patterns according to design equations and characteristics. In addition, TRIZ modules applicable to each pattern are identified. A flow chart is defined to use design axioms and TRIZ modules.
(3) As an example, a conceptual design of a tape feeder for the chip mounter is developed. The initial design is identified as a coupled design. The coupled design is decoupled by using a TRIZ and a new design is obtained.

(4) An auxiliary beam adjusting device used in laser markers is designed. The current design is found to be coupled. The coupled design is decoupled by using TRIZ. In this case, multiple designs are made and the final design is determined based on the developed flow chart.

Acknowledgements
This research was supported by the Center of Innovative Design Optimization Technology which was funded by the Korea Science and Engineering Foundation. The authors are thankful to Mrs. MiSun Park for her correction of the manuscript.

6 REFERENCES

[1] Suh, N.P., 1990, *The Principles of Design*, Oxford University Press, New York.

[2] Suh, N.P., 2001, *Axiomatic Design: Advances and Applications*, Oxford University Press.

[3] Do, S.H. and Park, G.J., 1996, "Application of Design Axioms for Glass-Bulb Design and Software Development for Design Automation," *Transactions of the ASME*, September, Vol. 123, No. 3, pp. 322-329.

[4] Savransky, S.D., 2000 *Engineering of Creativity*, CRC Press, New York.

[5] Altshuller, G., Shulyak, L., Fedoseev, U., 1998, *40 Principles Triz Key to Technical Innovation*, Technical Innovation Center Inc., Worcester, MA.

[6] Lee, K.W., 2002, "Development of Mosquito Trap with Effect of Air Cleaning by Using Theory of Inventive Problem Solving(TRIZ)," *Journal. of KSPE*, Vol. 19, No. 6, pp. 155-159. (in Korean)

[7] Lee, K.W. and Park, G.J., 2000, "A Structural Optimization Methodology Using the Independence Axiom," *Transactions of the Korean Society of Mechanical Engineers (A*), October, Vol. 24, No. 10, pp. 2438~2450. (in Korean)

[8] Shin, M.K., Hong, S.W., and Park, G.J., 2001, “Axiomatic Design of the Motor Driven Tilt/Telescopic Steering System for Safety and Vibration," *Journal of Automobile Engineering*, August, Vol. 215, No. 2, pp. 179-187.

[9] Kai, Y., Hongwei, Z., 2000, “Compatibility Analysis and Case Studies of Axiomatic Design and TRIZ,” *TRIZ Journal*, August.

[10] Kai, Y., Hongwei, Z., 2000 “Enhancing Robust Design with the Aid of TRIZ and Axiomatic Design,” 2000, *International Conference on Axiomatic Design*, June 21-23, No. 11, Cambridge, MA.

[11] Kim, Y.S., and Cochran, D.S., 2000, “Reviewing TRIZ from the Perspective of the Axiomatic Design,” *Journal of Engineering Design*, Vol. 11, No. 1, pp. 79~94.

[12] Kai, Y., 2004, “The Method for Uncoupling Design by Contradiction Matrix of TRIZ, and Case Study,” *ICAD 2004 Third International Conference on Axiomatic Design*, No. 11, Seoul, Korea.

[13] Shin, G.S. and Park, G.J., 2004, “Conceptual Design of a Beam Splitter for the Laser Marker Using Axiomatic Design and Triz,” *Journal of KSPE*, Vol. 21, No. 5, pp. 166~173.(in Korean)

[14] Frey, D.D., Jahangir, E., Engelhardt, F., 2000, “Computing the Information Content of Decoupled Designs,” *First International Conference on Axiomatic Design, Proceedings of ICAD2000*, pp. 151~159.

[15] Altshuller, G.S., 1999, *The Innovation Algorithm*, Technical Innovation Center, Worcester, MA.

[16] Savransky, S.D., 2000, Engineering of Creativity: Introduction of TRIZ Methodology of Inventive Problem Solving, CRC Press, Boca Raton, LA.

[17] Kim, I.C., 2001, The Formula of Invention and Patent, HyunsilGwa Miraesa, Seoul.(in Korean)

[18] Park, Y.T., Park, S.D., 1999, Science of Invention and Patent, HyunsilGwa Miraesa, Seoul, 1999.(in Korean)

[19] Lee, H.S., Lee, K.W., 2001, "Design of Super Water-Saving Toilet System by Solving Physical Contradiction in Theory of Inventive Problem Solving (TRIZ)," Journal of Korea CAD/CAM, Vol. 6, No. 3, pp. 193-197. (in Korean)

[20] Mann, D.L., 1999, “Axiomatic Design and TRIZ: Compatibility and Contradictions,” TRIZ Journal, June and July.

[21] Salamatov, Y., 1999, TRIZ: The Right Solution at the Right Time: A Guide to Innovative Problem, Insytec B.V.

[22] Shin, G.S., Yi, J.W., Kang, B.S. and Park, G.J., 2002, “Axiomatic Design of a Beam Adjuster for a Laser Marker,” ICAD 2002 Second International Conference on Axiomatic Design, MIT, USA.

[23] Park, G.J., 2006, Analytic Methods for Design Practice, Springer-Verlag, New York.(in preparation)

[24] Shin, G.S. and Park, G.J., 2004, “Supplementary beam adjuster for laser device,” *Korean Patent*, No. 10-0453984-0000 (in Korean)