CASE STUDY IN AD AND TRIZ: A PAPER MACHINE

Zhang Ruihong ruihong@eyou.com 86-22-26564871

Tan Runhua rhtan@hebut.edu.cn 86-22-26564037

Cao Guozhong cgzghx@263.net 86-22-26564871

Hebei University of Technology Tianjin P. R. C. 300130

ABSTRACT

For reducing the cost and improving the competition, the paper mills pay attention to increasing the production of the paper. Increasing the speed of the paper machine is an important way to achieve it. But many problems come forth with the increasing of the speed. Axiomatic Design is used to analyze the paper machine and get the mini-problems. Then Theory of Inventive Problem Solving (TRIZ), as an effective method, is used to obtain the solutions of the mini-problems.

1 INTRODUCTION

The paper machines are divided into two kinds:fourdrinier machines and cylinder mould machines (Long, 1997). They are both linkage machines and their sections are similar basically. Paper machine includes five sections, i.e., pulp transporting, forming, pressing, drying and finishing. Figure 1 shows five sections of the cylinder mould machine. The different of the two kinds of paper machines lies in forming. As a whole, the productivity of the fourdrinier paper machine is higher than the curved wire. But the cylinder mould machine has its advantages as following:

(1) simple structure, low investment, smaller workshop and lower power consumption;
(2) easy operation, easy management;
(3) producing multifold paper and paperboard.

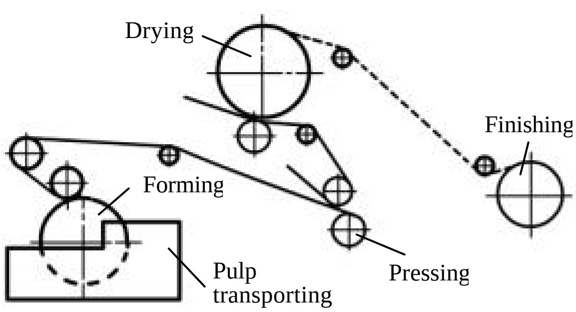

Figure 1 Sketch of cylinder mould machine

For these advantages and the status quo of the paper mills in China, the cylinder mould paper machine takes 90 percent market shares of the paper machine. For reducing the cost and improving the competition, the paper mills pay attention to increasing the production of the paper. Increasing the speed of the paper machine is an important way to achieve it. But many problems come forth with the increasing of the speed. Axiomatic Design is used to analyze the paper machine and get the sticking points of the problems.

The problems in the engineering design are classified two kinds: maxi-problem and mini-problem (Savransky, 2000). A product is a system. It includes many sub-systems. The maxi-problem is the change to the whole system. The mini-problem is the change to the sub-system. In the engineering 75 percent of the problems belong to mini-problems. This kind of problem can be solved by the current technology. It is crucial for an enterprise to solve the mini-problem and update the product continuously. But how can a mini-problem be found and solved? A systemic method is put forward to find by axiomatic design (AD) and solve mini-problem by invention problem solving theory (TRIZ). This method will be described in detail in section 2. In section 3 using this method the solutions of the mini-problems which are found during the improving design of a paper machine are obtained.

2 THE METHOD OF FINDING AND SOLVING MINI-PROBLEM

2.1 Axiomatic design

In 1990 N. P. Suh put forth the axiomatic design method. According to the axiomatic design, design activity can be divided into four domains: the consumer domain, the functional domain, the physical domain and the process domain. Corresponding to each domain the elements are customer needs (CNs), functional requirements (FRs), design parameters (DPs) and process variables (PVs). Figure 2 shows the relationship of them. The design process involves interlinking of these two domains by the zigzag mapping process and the multi level decomposition structure in each domain at every hierarchical level of the design process (Suh, 2001).

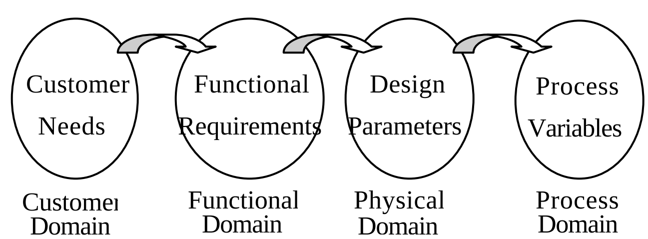

Figure 2 Four domains of the design activity

In the functional domain, the customer needs are specified in the terms of FRs and constrains (Cs). To satisfy the specified FRs, DPs are conceived in the physical domain. During the mapping process, the right design decision must be made by using the Independence Axiom — the first axiom. That is to say, the independence of functional requirements (FRs) must always be maintained, where FRs are defined as the minimum set of independent requirements that characterizes the design goals. When several designs that satisfy the independence axiom are available, the Information Axiom — the second axiom can be used to select the best design. That is to say, the design that has the smallest information content is the best design.

The mapping process can be expressed mathematically in terms of the characteristic vectors that define the design goals and design solutions. At a given level of the design hierarchy, the set of functional requirements that defines the specific design goals constitutes the FRs vector in functional domain. And the set of design parameters in the physical domain that has been chosen to satisfy the FRs constitutes the DPs vector. The relationship between these two vectors can be expressed as

$$\{\mathrm{FRs}\} = [A]\{\mathrm{DPs}\} \tag{1}$$

Where $[A]$ is a matrix defined as the design matrix that characterizes the product design. Equation (1) is a design equation for product design. The design matrix is of the following form for a square matrix (i.e. the number of FRs is equal to the number of DPs):

$$[A] = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \tag{2}$$

When the design matrix is either diagonal or triangular the design is satisfied the Independence Axiom. The former is called an uncoupled design. The later is called a decoupled design. Any other form of the design matrix is called a full matrix and results in a coupled design.

In the design process, the design goals are often subject to constraints (Cs). Constraints provide bounds on the acceptable design solutions and differ from the FRs in that they do not have to be independence. The constraints are broken down into several categories: (Tate, 1999)

(1) Critical performance specifications: constraints imposed on the attributes of the top level target objects or on the rate at which these transforms are performed
(2) Interface constraints: constraints imposed on the inputs and outputs that the system must accept (often at the top level, but also at lower levels if the design is a portion of an existing system)
(3) Global object constraints: constraints with the potential to affect all DPs in the design (or some significant fraction, such as all hardware) and which are broken down in an additive way
(4) Project constraints: constraints on the development resources allowed for design or redesign, or on the decisions made across projects (standardization, etc.)
(5) Feature constraints: constraints that apply to the choice of specific DPs within the system

Constraints can have different impacts on the design object. Some, like global and project constraints, can potentially impact the whole design and the choice of every DPs. Others, like interface, critical performance and feature specifications, impact only a subset of the DPs.

2.2 Contradiction and inventive principle in TRIZ

TRIZ was developed in Russia by Genrich Altshuller, a talented scientist and inventor, and his followers. Altshuller's work with TRIZ began in the 1940s and, to date, much experience in applying TRIZ application to various areas of human activity has been amassed (Altshuller, 1999). TRIZ is based on the study and application of the patterns of evolution of various systems - technological machines, manufacturing processes, scientific theories, organizations, works of art, and so on. Based on these patterns, methods have been developed for searching for creative solutions.

Throughout the history of human knowledge, there have been two conceptions concerning the law of development of the universe, the idealistic conception and the materialistic conception, which form two opposite world outlooks. TRIZ ideology is based on 2 major cornerstones: Contradiction and Ideality (Zlotin and Zusman, 1999). As it is well known, the Contradiction is the basic law of materialist dialectics, and the second cornerstone is the essence of the idealism. These two opposite philosophic approaches are united in TRIZ that use their mutual co-operation. Perhaps, this amalgamate predetermines the unique power of TRIZ. The concepts of Ideality and/or Contradiction should be consciously included in any process of solving the inventive problems. In this paper, we only consider the contradiction.

According to G.S. Altshuller an inventive situation is usually inherent in some groups of the technical and/or physical contradictions in the technique (Zlotin and Zusman, 1999).

(1) Technical contradictions

An action is simultaneously useful and harmful or it causes Useful Function(s) and Harmful Function(s); the introduction (or amplification) of the useful action or the recession (or easing) of the harmful effect leads to deterioration of some subsystems or the whole system, e.g., an inadmissible complexity of the system.

The technical contradiction represents the conflict between two subsystems of a system. For example, the product gets stronger but the weight increases.

(2) Physical contradictions

A given subsystem (element) should have the property A to execute necessary function and the property non-A /anti-A to satisfy the conditions of a problem. The physical contradiction implies inconsistent requirements to a physical condition of the same element of a technical system or operation of a technological process, i.e., the same key subsystem of a technique. For example, aircraft should fly fast (to get to the destination) but should fly slowly (for minimum change in velocity on landing).

Using the separation principle as follows can resolve the physical contradiction:

1) Space separation;
2) Time separation;
3) Separation based on the condition;

4) Separation of the whole and portion.

Technical contradiction is the main contradiction in the design process. In TRIZ, the 39 features (Ellen Domb,1998) are used to describe the technical contradictions and 40 inventive principles (Karen Tate and Ellen Domb , 1997) are given to solve the contradictions. Table 1 is part of the features. In the design process, two features are used to define the both sides of the contradiction. Then in the contradiction matrix (showed as Table 2) the numbers of inventive principles can be found. And these principles often provide the guideline to solve the problem for the designer. Some of the inventive principles and their explanations are showed in table 3.

Table 1 Explanation of the 39 features of the contradiction matrix

No.	Title	Explanation
	Moving objects	Objects which can easily change position in space, either on their own, or as a result of external forces. Vehicles and objects designed to be portable are the basic members of this class.
	Stationary objects.	Objects which do not change position in space, either on their own, or as a result of external forces. Consider the conditions under which the object is being used.
1	Weight of moving object	The mass of the object, in a gravitational field. The force that the body exerts on its support or suspension.
2	Weight of stationary object	The mass of the object, in a gravitational field. The force that the body exerts on its support or suspension, or on the surface on which it rests.
…	…	…
39	Productivity	The number of functions or operations performed by a system per unit time. The time for a unit function or operation. The output per unit time, or the cost per unit output.

Table 2 Contradiction matrix

Improving Features \ Worsening Features	Weight of moving object	Weight of stationary object	…	Extent of automation	Productivity
Weight of moving object				26, 35 18, 19	35, 3, 24, 37
…					
Difficulty of detecting and measuring	27, 26, 28, 13	6, 13, 28, 1		34, 21	35, 18
Extent of automation	28, 26, 18, 35	28, 26, 35, 10			5, 12, 35, 26
Productivity	35, 26, 24, 37	28, 27, 15, 3		5, 12, 35, 26	

Table 3 40 Inventive principles

No.	Title	Explanation
1	Segmentation	A. Divide an object into independent parts. B. Make an object easy to disassemble. C. Increase the degree of fragmentation or segmentation
2	Taking out	Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.
…		…
40	Composite materials	Change from uniform to composite (multiple) materials

2.3 Combining the axiomatic design and TRIZ

In section 2.1 the axiomatic design are introduced simply. In the design process, the mini-problem can be found at two situations. One results from the constraints; another results from the coupled design. Figure 3 shows the flow chart combining axiomatic design and TRIZ.

Some constraints can serve as filters, either allowing a DP to be chosen or necessitating its rejection. In this case, if DP doesn't meet the Cs, there is a mini-problem.

Alternatively they can serve as a source of sub-FRs. In this case, each constraint can be directly connected to some subset of the FRs. Then the FRs can be connected to some subset of the DPs. That is to say, the constraint can be embodied in the design matrix. According to the Independence Axiom, if the design matrix is not a diagonal or triangular the design is a coupled design. Then there is a mini-problem. After finding the mini-problem by axiomatic design, it can be transformed into the contradiction in TRIZ. If the contradiction is physical contradiction, the four separation principles can be used to solve it. If the contradiction is technical contradiction, the 40 inventive principles can be used.

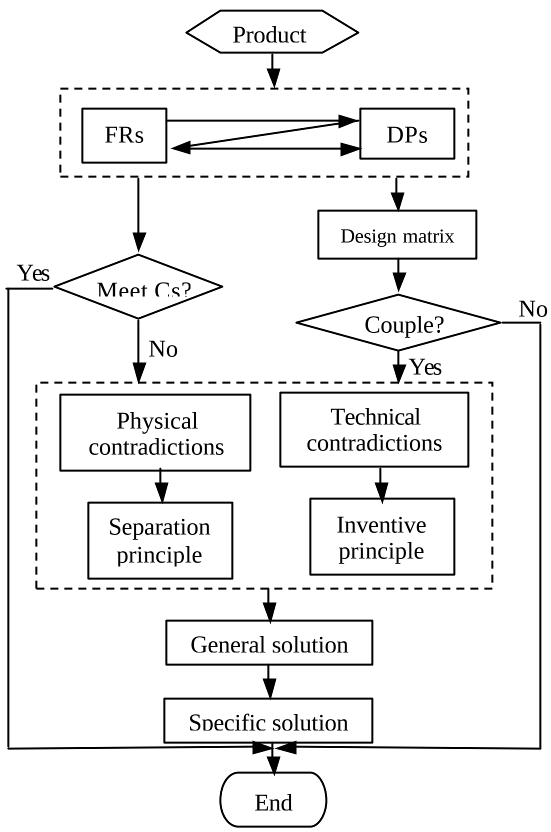

Figure 3 The flow chart combining axiomatic design and TRIZ

3 THE IMPROVING DESIGN OF THE PAPER MACHINE

3.1 Finding the mini problem

Using the axiomatic design a kind of cylinder mould paper machine in a machine shop in China can be described as follows.

FR: making paper DP: paper machine

Constraint: speed

FR1: pulp transporting DP1: head box

FR2: forming wet paper DP2: former

FR3: dewatering DP3: presser

FR4: drying DP4: dryer

$$\begin{bmatrix} FR1 \\ FR2 \\ FR3 \\ FR4 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} DP1 \\ DP2 \\ DP3 \\ DP4 \end{bmatrix} \tag{3}$$

The design matrix is a triangular, i.e., the design is a decoupled design. It meets the Independence Axiom.

The speed as a constraint is a project constraint. Now, the customer need demands to improve the speed for increasing the competition and the market share. The change of the speed will effect on each DPs. In this paper, we only discuss the former and dryer.

The forming of the wet paper depends on the coherence of pulp in the curved wire. When the speed is higher than a critical value, the centrifugal force is more than the coherence. Then the pulp deviates from the wire. This results in the failure of wet paper forming. So there is a mini-problem.

To the dryer the higher speed make the settling time of the wet paper too short to meet the demand of dryness. So there is a mini-problem too.

3.2 Solving problem

3.2.1 Improving of former

Problem description: hope to increase the productivity by increasing the speed, but the centrifugal force makes the pulp deviate from the wire.

Describing the problem with the 39 feature parameters is equal to:

How to improve *speed* but not increase *the loss of substances*?

The Contradiction Matrix suggests the following Inventive Principles:

10 — Preliminary action (Perform, before it is needed, the required change of an object (either fully or partially); Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery)

13 — 'The other way round' (Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it); Make movable parts (or the external environment) fixed, and fixed parts movable; Turn the object (or process) 'upside down')

28 — Mechanics substitution (Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means; Use electric, magnetic and electromagnetic fields to interact with the object; Change from static to movable fields, from unstructured fields to those having structure)

38 — Strong oxidants (Replace common air with oxygen-enriched air; Replace enriched air with pure oxygen; Expose air or oxygen to ionizing radiation; Use ionized oxygen; Replace ozonized (or ionized) oxygen with ozone)

The principle 10 recommends a starting point to solve the problem. Since improving speed makes the increase of the centrifugal force, a preliminary force can be provided to counteract the centrifugal. According to this way two approaches are obtained to solve the problem. One is bringing pressure from the outside of the wire. Another is vacuumizing the inside of the wire. Both make the pressure of the outside higher than the inside to counteract the centrifugal force partly.

The principle 28 recommends another starting point to solve the problem. Make the fiber of the pulp be the active particle with some kind of electric charge. Then the force brought by the electromagnetic field can counteract the centrifugal force partly.

3.2.2 Improving of dryer

Problem description: hope to increase the productivity by increasing the speed, but the dryer doesn't meet the demand. Increasing the number or the diameter of the dryer can meet the demand, but it will increase the complexity of the equipment.

Describing the problem with the 39 feature parameters is equal to:

How to improve *speed* but not increase *the complexity of equipment*?

The Contradiction Matrix suggests the following Inventive Principles:

10 — Preliminary action (Perform, before it is needed, the required change of an object (either fully or partially); Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery)

28 —Mechanics substitution (Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means; Use electric, magnetic and electromagnetic fields to interact with the object; Change from static to movable fields, from unstructured fields to those having structure)

4 — Asymmetry (Change the shape of an event from symmetrical to asymmetrical; If an event is asymmetrical, increase its degree of asymmetry)

34 —Discarding and recovering (Make portions of an event that have fulfilled their functions go away (discard by dissolving, evaporating, etc.) or modify these directly during operation; Conversely, restore consumable persons/systems of an event directly in operation)

Principle 10 recommends a starting point to solve the problem: preliminary drying. Such as, an infrared device (Smith, 2002) or a through-air dryer (Törnefalk-Svanqvist, 2002) is installed before dryer to dewater partly.

Principle 34 also recommends a starting point: restore consumable systems of an event directly in operation. Such as the dryer is coated with the material which is sensitive to heat to increase the heat conduction. The coating can be restored.

4 CONCLUSION

As the main part of the paper machine industry, the improving design of the cylinder mould paper machine is the urgent affairs in China. In this paper a design method is used to improve the design of the paper machine. Firstly, the mini-problems are found by the axiomatic design. Secondly, the mini-problems are transformed to the contradictions in TRIZ. Lastly, the solutions are obtained by using the inventive principles in Contradiction Matrix or the four separation principles. The solutions give the starting points to solve the problem. According to the solutions the designer can detail the design using his/her professional knowledge.

ACKNOWLEDGEMENT

The first author is grateful to the Chinese National Natural Science Foundation (No. 50175025), Natural Science Foundation of Tianjin (No. 003804611), for funding this work.

REFERENCES:

Long Yanquan, 1997, The Principle and Engineering of Papermaking. Light Industry of China Press.

Savransky, S. D., 2000, Engineering of creativity. CSC Press, New York.

Nam Pyo Suh, 2001, Axiomatic Design: Advances and Applications. Oxford University Press, New York.

Tate Derrick, 1999, A Roadmap for Decomposition: Activities, Theories, and Tools for System Design. Ph.D. Thesis, Department of mechanical Engineering, MIT.

G. Altshuller, 1999, The innovation algorithm. Technical Innovation Center, Worcester.

Zlotin Boris and Zusman Alla, 1999, TRIZ and Pedagogy. Http: // www.triz-journal.com.

Domb Ellen, 1998, The 39 Features of Altshuller's Contradiction Matrix. http: // www.triz-journal.com.

Tate Karen and Domb Ellen, 1997, 40 Principles with Examples. Http: //www.triz-journal.com..

Smith Thomas, 2002, Infrared and hot air dryer combination. United States Patent, 6412190.

Törnefalk-Svanqvist Louise, 2002, Through-air Drying for High Quality Tissue Paper. Mesto Paper Technology Days, Sanghai, China.