Clarification of a problem abstraction process for TRIZ technical contradiction model in preliminary design

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Abstract

Within the context of resolving innovative design problems, this paper proposes an innovation aid methodology comprises analysis, formulation and resolution of innovative design problems at the behavioral phase of preliminary design. The behavioral phase is characterized by the existence of induced effects, generally imposed by the technical system components structuring, often considered as a source of harmful effects that must be eliminated. Harmful effects are the sort of design problems frequently observed at the preliminary design behavioral phase, they could be formulated as one or more technical contradictions. Contradiction abstraction model has been developed in TRIZ theory (Russian acronym for "Teoriya Resheniya Izobretatelskikh Zadatch" Theory of Resolution of innovative problems). The contradiction model presents an effective resolution tool mostly used for innovative design problems resolution. The tool exploitation difficulty resides in the abstraction process that requires from the TRIZ theory practitioners additional time and experience. In this sense the work presented in this paper proposes an aid methodology for technical contradictions standardized formulating, (ie the problem abstraction according to TRIZ theory), then the resolution exploiting TRIZ contradiction matrix. A classification of the 39 TRIZ engineering parameters was proposed to assist technical contradictions standardized formulating. The developing of this approach involves a whole analyzing of the design process and the main elements of contradiction matrix.

Keywords
Innovative design problems, embodiment design, behavioral phase, induced and harmful effects, TRIZ theory.

1. Introduction

The Russian theory of inventive problem solving TRIZ created by Genrish Altshuller in 1960 states that innovations, in any field, are governed by certain repetitive patterns (Altshuller 1996). From this issue researchers started to investigate the possibility of TRIZ development and application in different fields as technical problem solving, product and technology innovation, technology strategy, business management and other areas (Sharma et al 2016). In addition to the various industrial applications of the theory, TRIZ has also integrated classrooms with many student training programs that tried to improve their creativity and enhance their ideation spirit (Nakagawa et al 2002). The use and the adaptation of TRIZ tools seem to be different and challenging according to each application area. As product designers we are trying to emphasize the TRIZ different tools possibility to be joined with the product design process. Our work is mainly based on developing a structured design process based on energy vision (Sallaou 2008), and supporting the innovation aspect through TRIZ tools integration. In our previous works we have integrated TRIZ su-field analysis and physical contradictions combined with functional analysis to resolve product design innovative problems (Hmina et al 2014), we proposed also a methodology exploiting TRIZ scientific effects with energy flow analysis; for system component definition in conceptual design(Hmina et al 2016).

We are focusing in this paper on resolving innovative problems in the embodiment design phase. We propose an innovation aid methodology comprises analysis, formulation and resolution of innovative design problems at the behavioral phase of preliminary design. The work is expanded along three axes: the first introduces the TRIZ abstraction process; the various tools and models of the theory, the second axis involves the proposed methodology development and the third presents an illustration of the proposed approach through a case study "implementation of innovative technical solutions for the harmful effects arising from increasing the performance of a wind turbine rotor».

2. TRIZ abstraction process

2.1. Abstraction methodology

The TRIZ theory has mentioned the necessity of knowledge abstraction to solve all such problems avoiding trial and error process. TRIZ has provided access to this abstraction through the use of different tools and methods. Knowledge abstraction is carried out according to TRIZ through the process shown in the figure below (Figure 1). The first step is to go of the specific problem to the abstract problem being based on predefined abstract forms of TRIZ, then from the abstract form of the problem to abstract solutions applying associated tools, the last step is solutions specification.

Figure 1. TRIZ abstraction process

The main difficulties encountered in this process occur during abstraction and specification stages.

2.2. TRIZ abstraction models

So that we could abstract the problem we first need to specify an appropriate abstract form to the problem then select the corresponding tool to this form. Different forms of abstract problems are represented in TRIZ theory by following models.

- Su-Field model ;
- Technical contradictions model ;
- Physical contradictions model.

Thus, for each model the theory has associated resolution tools to help looking for abstract solutions.

- Standards ;
- TRIZ contradiction matrix ;
- Separation principles.

In this paper we will be interested to the abstraction process with technical contradictions model, to then propose an abstraction aid methodology that simplify the abstraction process in order to exploit the "contradictions Matrix" tool.

2.3. Abstraction process through technical contradictions model

2.3.1. Abstraction process

Analogically to the TRIZ abstraction process, abstraction process with the technical contradiction model comprises the following steps:

- Problem formulating as a technical contradiction ;
- Technical contradiction resolving with the TRIZ contradiction matrix;
- Resulting solutions specification.

We aim to facilitate the transition from specific design problem to abstract design problem, (ie appropriately formulate the through one or more contradictions). The development of our approach initially requires an analysis of the TRIZ contradiction matrix elements that would be presented in the next paragraph.

2.3.2. TRIZ contradiction matrix elements

TRIZ contradiction matrix consist of two main elements: The 39 engineering parameters at its axes; and the 40 principles of innovation are representing the corresponding abstract solutions to each selected technical contradiction (Figure 3).

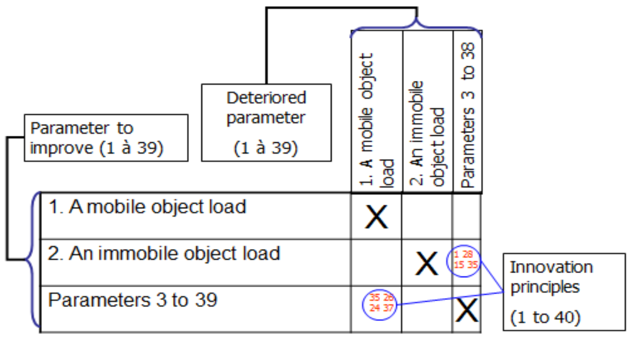

Figure 2. TRIZ contradiction matrix

Exploiting the matrix requires a standardized formulation of the contradiction representing the design problem which is not always obvious. The difficulty lies in selecting the two engineering parameters that exactly match the problem.

2.3.3. TRIZ Technical contradictions formulating

A technical contradiction in the design field is generally expressed as the following two forms:

*« Improving a **useful function** leads to an amplification of a **harmful effect».***

*« Reducing a **harmful effect** leads to a decreasing of a **useful function».***

The two formulations above provide that technical contradictions are generally expressed in terms of effects. Those effects are linked in the product design field to induced effects of the embodiment design phase. TRIZ matrix exploitation requires a standardized formulation of the contradiction, which necessarily include two engineering parameters in conflict as follow:

*« Improvement of **engineering parameter "1"** leads to **engineering parameter "2"** deterioration »*

The complexity of abstraction arises during the conflicting engineering parameters selection. Within this context we propose an approach to support abstraction process in behavioral phase according to the following steps:

- Syntactical analysis of technical contradiction formulating;
- Identification of design problems in behavioral phase;
- TRIZ engineering parameters classification.

3. Proposed methodology to resolve innovative design problems in preliminary design

3.1. Preliminary design problems

3.1.1. Design problem definition

A problem generally is defined as "an unresolved issue in any field that comes with a number of difficulties, obstacles". In the design field a design problem comes from the limitations constraints on the problem variables these external constraints can be imposed by an outside environment or related to internal system components (Sallaou 2008). Throughout a design activity the designer has to resolve problems of various innovation levels (Altshuller 1996). We mean an innovative design problem when one is before a major improvement or a new concept. Resolving these problem types requires having a large time and extensive experience. In this regard the TRIZ theory has suggested various resolution tools to use depending on the problem. This work focuses on solving problems of behavioral design stage (Embodiment design) through the integration of suitable tools from TRIZ.

3.1.2. Embodiment design

Embodiment design is the second phase of preliminary design it consist on evaluating and developing concepts of solution resulting of the previous phase (Conceptual design). This phase also involves selecting the optimal structure of the concept and makes the choice of components and their dimensioning. An analysis of induced effects is performed after the choice of components, this precise analysis that will be integrated with those models and those to be eliminated by the implementation of technical solutions.

3.1.3. Design variables, models and criteria

In design each problem has a formulation based on various parameters associated with the system components. These parameters are the variables introduced at the design stage of the system. There are several types of variables, mainly those involving physical variables or not, classified as follow (Vernat 2004):

- Physical variables;
- Variables aspect or description;
- Esteem Variables;
- Symbolic Variables.

These variables are arranged in models expressing a design solution behavior. Models are mainly composed of criteria, design variables, and auxiliary variables.

3.1.4. Induced effects problems and their expression

A design problem results in most cases by the improvement of design criteria expressed as functions of design variables, hence improving a criteria amounts to augmentation or decreasing of one or more design variables (Parametrical analysis). In a mechanical system modification (increase or decrease) of a variable to improve criteria necessarily involves unwanted modification of other related variables, that often results induced effects. This conflict between variables provides induced effects problems that could be modeled as technical contradictions.

3.2. TRIZ engineering parameters classification

3.2.1. TRIZ engineering parameters classification according to the design task

We adopt the design variables classification based on energy analysis (Sallaou 2008). In the table below we differentiate between variable types that characterize the nature of a variable and variable class representing the set of belonging of the different variables.

Table 1. Variables classification in design

Variable type	Variable class
Temporal variables	Design variables
State variables	Auxiliary variables
Properties variables	Dual pertinent variables
✓ Geometric	Criteria
✓ Physic	Models
✓ Functional	

✓ Operational ✓ Economic	

The previous classification of design variables has enabled us to analyze and arrange the 39 TRIZ engineering parameters, in terms of our classification based on energy vision. According to this vision all 39 engineering parameters could be classified as follow:

Table 2. TRIZ engineering parameters classification

The 39 TRIZ engineering parameters	temporal variables
	state variables
	Energy flows
	Properties variables

This classification will allow us subsequently to easily and precisely express the technical contradiction related with an induced effect. The aim is to properly formulate the corresponding technical contradiction for an induced effect. This formulation is based on selecting variables to modify (increase or decrease), then the precision of variables that will be influenced. Each pair of variables (modified variable- influenced variable) will generate different induced effects. This couple of variables represents the tow engineering parameters corresponding exactly to the technical contradiction related to the set of induced effects.
Being based on the proposed classification of the 39 engineering parameters previously performed, we were able to elaborate a technical contradictions standardized formulating sheet that assists analysis of the design problem and contradictions formulating. The letter will be explained in the next section.

3.2.2. Elaboration of a technical contradictions standardized formulating sheet (TCSFS)

The elaborated sheet guides the design variables modification analysis, and organizes the task of technical contradictions formulating. As shown in the figure below, the sheet comprises three classes of variables representing engineering parameters (Temporal variables, state variables properties variables). Energy flows and power are represented in the sheet as a combination between tow dual pertinent variables (Temporal variables and state variables), taking for example the mechanical energy flow is expressed as the product of Force and speed (F*V).
The designer select the parameter to be improved and precise the deteriorated parameters, then starts induced effects analysis. Directly the technical contradictions involved are clearly presented in the sheet. A case study will be presented letter to illustrate the TCSFS exploitation.

	Improved parameter												Deteriorated parameter														
Variables	Temporal variables				State variables				Properties variables				Temporal variables				State variables				Properties variables						
Parametres	V	ω	q	.	F	C	P	T	S	V	W	.	V	ω	q	.	F	C	P	T	S	V	W	L	Produced effects	Induced effects	Technical contradiction
																											Technical contradiction 1
																											Technical contradiction 2
																											Technical contradiction 3

Figure 3. Technical contradictions standardized formulating sheet (TCSFS)

We note that Induced effects arising from a couple of conflicting variables could be found by using induced effects identification tables (Sallaou 2008).

3.3. Proposed methodology

Based on the entire analysis performed in this work we have we propose a methodology to resolve induced effects problems, the letter consist on the principal following five steps:

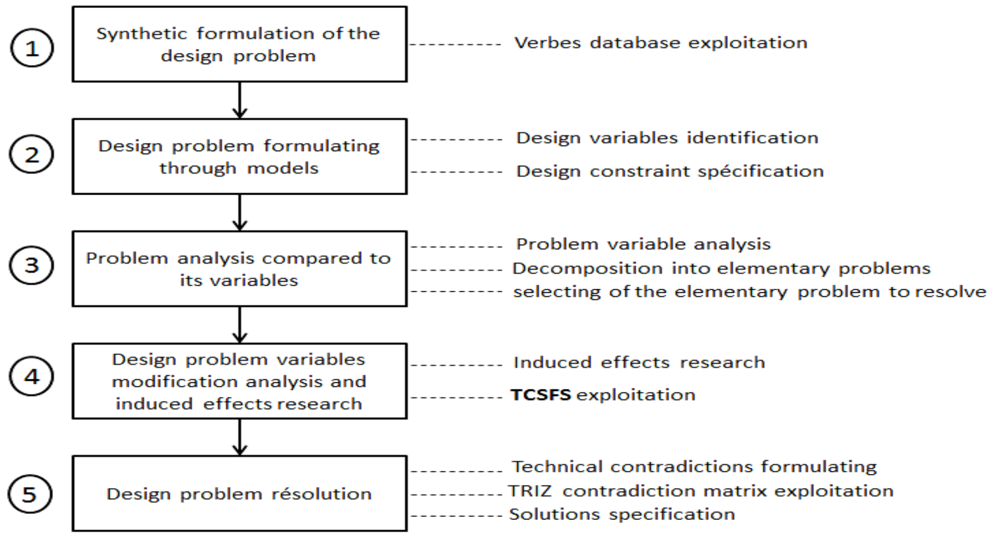

Figure 4. Proposed methodology to resolve induced effects problems in preliminary design

The next section illustrates the methodology through a case study development.

4. Case study

In this case study we treat the problem of a wind turbine performance improvement. The design problem will be solved according to the five steps of the proposed methodology as follow.

1. Synthetic formulation of the design problem

Problem : " increase the power of the wind turbine"

2. Design problem formulation through models

Power model: $P = ½ \rho \ Cp \ A \ V^3$

Design constraints specification: A (Blade section): cte ; ρ : cte V (Speed) : 15m/s

The factor influencing the power is: Cp (Power coefficient).

3. Problem analysis compared to its variables

The parameters influencing Cp according to studies are:

- Cp increases with the blade surface increasing;
- Cp varies with the blade profile;
- Cp increases with the system controllability increasing.

The selected elementary problem to be resolved according to the design constraints that keeps the blade profile unchanging, and also retains the system controllability invariable is: « To increase the wind turbine power by increasing the blade surface ». The following step will concern the selected problem resolution; the letter is initiated by induced effect research through the design problem variables modification analysis.

4. Design problem variables modification analysis and induced effects research

❖ Induced effects research

Increasing the blade surface while keeping the same profile causes:

- **Buckling** of the wind turbine mat because of the increased **weight** of the system.
- **Flexing** of the blades because of the increase of their **lengths**.
- **Noise and vibrations** due to the increase in **speed** at the ends of the blades.

❖ **TCSFS exploitation**

	Improved parameter												Deteriorated parameter														
Variables	Temporal variables				State variables				Properties variables				Temporal variables				State variables				Properties variables						
Parametres	V	ω	q	.	F	C	P	T	S	V	W	.	V	ω	q	.	F	C	P	T	S	V	W	L	Produced effects	Induced effects	Technical contradiction
Increasing the blade surface while keeping the same profile																							↗		- Deformation of the turbine mat	- Buckling of the turbine mat	Technical contradiction 1
									↗															↗	- Deformation of the turbine blades	- Flexion of the blades	Technical contradiction 2
													↗												-Friction Wind / blades	- Vibrations - Noise	Technical contradiction 3

Figure 5. Technical contradictions standardized formulating sheet exploitation

We have analyzed the design problem by identifying the different harmful effects of increased blade surface, as presented in the sheet below, we selected the improved parameter that is surface S (blue color), and then the deteriorated parameters that are weight W, lenth L and speed V (red color).The design problem is then expressed as three technical contradictions, whose standard expression is described in the next section.

5. Design problem resolution

❖ Technical contradictions standarized formulating

Technical contradiction 1: EP 1 → surface, EP 2 → Weight, IE : Buckling
Technical contradiction 2: EP 1 → surface, EP 2 →Length, IE : Flexion
Technical contradiction 3: EP 1 → surface, EP 2 → Speed IE : Vibrations, noise
We note that (EP : Engineering parameter , IE : Induced effects).

❖ TRIZ matrix exploitation and solution proposition

The induced effects research stage generated the three Technical contradictions above; each one is specific to an induced effect and defined by two engineering parameters. We will proceed by the resolution of the first technical contradiction.

Technical contradiction N°1: Pd1→ surface , Pd2 → Weight

The TRIZ matrix proposes the four innovation principles below :

- P2: Extraction;
- P17: Change of dimension;
- P29: Hydraulics and pneumatics;
- P4: Asymmetry.

After a reflection on all the principles proposed by the matrix. One of the suggested principles is:

<u>Principle 29: hydraulic and pneumatic</u>

« *Replace the solid parts of an object by gas or liquid, in particular by inflatable parts which can be filled with water, hydrostatic and hydro reactive, air cushion»*

- ❖ **Solutions specification**

The result of this principle could be interpreted as follows:

<u>Introduce into the blades a lower weight substance</u>

To specify the abstract solutions proposed by the principles of the matrix, we have used the patents; we have selected for our problem the following two solutions:

- ✓ Propeller blade

The soluion provide a propeller blade of minimum weight with maximum resistivity to alternating bending moments.

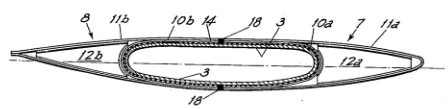

Figure 6. Patent 2,981,337

The blade is made by slight and thin metal foils, the center of the blade contains a tube filled with air to minimize the weight of the entire blade. The sides of the blade are reinforced by elements from slight materials such as Titanium and surrounding the tubular core, so as to have a strong blade, resistant to bending and with low weight.

- ✓ A composite materials blade

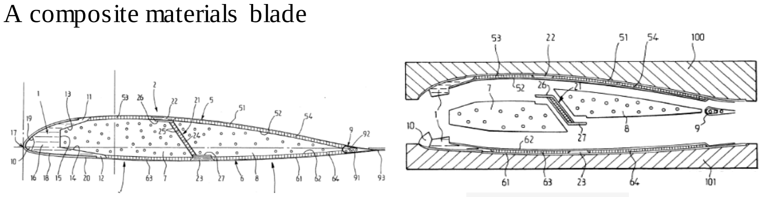

Figure 7. Patent Ref EP0256916 A1

The same approach could be proceeded to resolve the rest of contradictions and propose other solutions for the design problem.

5. Conclusion and perspectives

Within the context of innovative design problems solving, we focused in this article on induced effects problems characterizing the behavioral phase of preliminary design. We have been based on TRIZ abstraction process to develop our methodology, the letter emphasize induced effects problems formulation and resolution through the TRIZ contradiction matrix. The focus was on how to organize the technical contradiction standardized formulating process in the design field to simplify the TRIZ technical contradiction model exploitation. For this aim we opted for a whole design problem parameters (variables, models, criteria) analysis to come out with a classification of the 39 TRIZ engineering parameters. This classification mainly based on an energy vision helped us to expand our methodology supported with design variables modifying analysis. We will be subsequently interested in challenges related to induced effects research, then to problems of TRIZ specification stage. The work of this article falls within the context of developing a global design approach to support innovative design problems solving, devoted to the field of product design teaching.

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