

1ST IFIP TC-5 WORKING CONFERENCE ON CAI
IFIP-TC5 ULM, GERMANY. NOVEMBER 14-15 2005

TRIZ APPLIED FOR ECO-INNOVATION IN DESIGN FOR DISASSEMBLY

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Abstract

Eco-innovation is the field that supports the development of new products and services by means of considering environmental aspects from the first stages of design. This way the environmental impact of new products is reduced, contributing to a sustainable society development.

In the engineering context, disassembly may be defined as the organized process of taking apart a systematically assembled product (assembly of components). Products may be disassembled to enable maintenance, enhance serviceability and/or to affect end-of-life (EOL) objectives such as product reuse, remanufacturing, and recycling.

The objective of this paper is to present a new method of eco-innovation that combines Design for Disassembly and TRIZ.

Keywords: Engineering Design, TRIZ, Design for Disassembly (DFD), Eco-Innovation.

1. Introduction

Today, a company that wishes to stay in the market for a long time must innovate. The general definition of innovation does not constrain the content of change [1]. There can be different types of change: product change, process change, or management system change [2-4].

Environmental factors are becoming increasingly more important in product design. Sustainable society development is the pursued objective. For this reason, some companies embark upon environmental projects such as implementing the ISO 14000 standard, eco-designing, or innovating in product development process regarding environmental aspects. In the literature the latter is called eco-innovation [5-7], sustainable development innovation with regards to R&D or Environmental New Product Development (ENPD) [8-10], or Environmental Innovative Product Design (EIPD) [11]. In this paper the term eco-innovation is used. What all authors agree upon is that to do eco-innovation in product development, environmental aspects should be considered in the product definition phase and the conceptual design phase. Based on this, eco-innovation is defined in this paper as:

“Development of new products considering environmental aspects from the first stages of design to reduce the environmental impact”.

The steps to follow to eco-innovate are:

1. The environmental aspects that will be considered are determined.
2. Innovation in the design of new products to make them more environmentally friendly.
3. The environmental impact of the proposed solutions is assessed.

To determine the aspects that will be considered in design, the following eco-design methods are being used: Life-cycle Design Strategy (LiDS) wheel [12], Eco-compass [13], and ECODESIGN PILOT (Product Investigation Learning and Optimisation Tool) [14].

For the moment, the Design for Disassembly (DFD) methodology has not been used for the determination of environmental aspects [15]. De Caluwe [16] suggested that DFD can be used to obtain specific environmental improvements.

Regarding creative methods for idea generation, the following ones are being used in eco-innovation [17]: Brainstorming, Product Ideas Tree diagram (PIT), TRIZ tools, and Mind Maps. TRIZ tools are considered to have a high potential for eco-innovation by some authors [18-20]. There are also methodologies that integrate TRIZ and eco-design to do eco-innovation, such as ECODESIGN PILOT + Innovation Module TRIZ [19] and Eco-Compass + TRIZ [20].

The assessment step has not been greatly addressed for the moment. In the assessment, other cost related and marked demand aspects should be considered besides environmental ones [21].

This paper discusses the parameters that condition DFD (Section 2), presents an overview of TRIZ tools (Section 3), explains a new method of eco-innovation that combines Design for Disassembly and TRIZ (Section 4), shows an example of the new method (Section 5), and finally conclusions are drawn regarding the benefits of using the method.

2. Design for disassembly (DFD)

Life cycle analyses indicate that a large proportion of the entire cost associated with the product can be attributed to the product design process. It has been proved that disassembly process optimisation accounts for a scarce 10-20% of all disassembly related gains. The major proportion of disassembly related gains (80-90%) tends to be determined at the product design state [22]. According to standard EN ISO 14021:1999, the use of the term “design to disassemble” refers to the design of a product that can be separated at the end of its life-time, in such a way its components and parts are reused, recycled, recovered as energy form, or of some other way separated from the remainders flow [23].

Hence, it is of industry wide interest to develop methods and tools to incorporate environmental considerations into product design [24]. DFD is therefore a key strategy within the area of design and sustainable product development.

The parameters that affect the disassembling process are determined by the activities made before, during and after [25]; on the other hand, there is also a series of factors that affect the product’s design, when it is conceived taking into account its disassembly. All these factors have been transformed in six groups, selected from references [25], [26], [27] and [28]:

- Product structure.
- Type and number of joints.
- Characteristics of the part to disassembly.
- Final use of the parts.
- Visibility of the joining element.
- Disassembly conditions.

The analysis of these parameters shows that the designer should determine the following items:

- Type and number of joints.
- Characteristics of the part to disassembly.
- Visibility of the joining element.

Nevertheless, the designer will be conditioned by the product strategy in the following parameters:

- Product structure.
- Final use of the parts.
- Disassembly conditions.

3. TRIZ methodology tools

TRIZ tools set can be divided into analytical and knowledge based tools. The former ones look for the correct approach to the problem, and the latter ones give useful ideas to solve this problem. These tools are [29]:

- Principles (contradictions).
- Effects.
- Ideality.
- Evolution of the Systems.
- Standards (S-fields transformations).
- ARIZ.

Principles: They are used to solve the contradictions, i.e. the design trade-offs. Contradictions can be technical or physical:

- **Technical contradiction**: it occurs when, trying to improve a design aspect (or parameter), another one gets worse. To eliminate the contradiction, the contradiction matrix is used. The input data to enter into the matrix are the contradicting parameters, and the outputs are the inventive principles to eliminate the contradiction [30].
- **Physical contradiction**: physical contradictions are those that involve a characteristic that should exist or should be increased because of a reason, and at the same time, should not exist or should be reduced for another reason. In other words, the characteristic is in contradiction with itself. To eliminate the contradiction, the effects and principles are used.

Effects: Altshuller [29] observed that a considerable percentage of solutions apply the advantages of a same known physical effect. These effects can be physical, chemical or geometrical.

Ideality: From the point of view of ideality, the ideal product can perform its function without existing. No ideal system exists though, and therefore the objective is to push the system towards benefits increase and reduction of cost and other harmful effects of the system [31].

Evolution of the Systems: There are a number of generic technology evolution trends that determine the evolution of all technical systems [32].

Standards (S-fields transformations): Standards are rules for solving commonly occurring inventive problems.

ARIZ: ARIZ is an acronym for the Russian phrase "Algorithm for Inventive Problem Solving"; ARIZ is a logical structured process that incrementally evolves a *complex problem* to a point where it is simple to solve. ARIZ, therefore, is best used for complex problems [33].

4. TRIZ applied for eco-innovation in design for disassembly

To achieve eco-innovation, DFD and TRIZ are the pillars used for the new methodology (figure 1). The new methodology consists in applying TRIZ tools, i.e. effects, contradictions, and ideality, to the parameters that condition DFD.

Figure 2 shows the proposed methodology to apply TRIZ to the DFD parameters. As it can be observed, it consists of four phases:

1. Definition of the DFD parameter.
2. Generation of ideas, with three sub-phases: 2.1, 2.2, and 2.3.
3. Evaluation of the obtained ideas.
4. Optimisation.

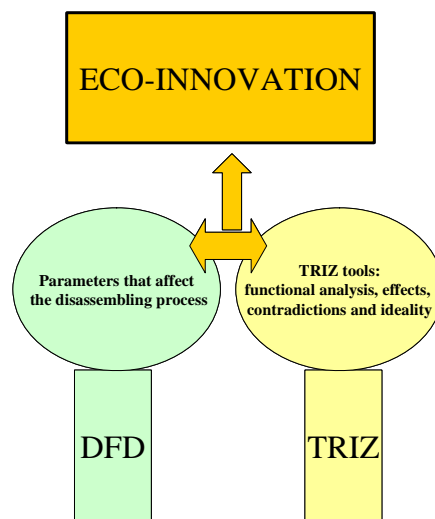


Figure 1: Eco-innovation with DFD and TRIZ

Phases 1, 2, and 3 involve the application of TRIZ to DFD. Phase 4 is a TRIZ step. Phases 1 and 2 are further explained next:

① This first phase consists in correctly DEFINING the DFD parameter that will be used for ideas generation. A parameter that affects DFD is selected and studied as follows:

Functional analysis of the parameter to determine the systems, sub-systems, and components interacting with it.

An identification of resources required or used by the parameter is also done, including items such as where the information is taken from, energy sources, components interacting with it.

Following such a process, the parameter is perfectly defined, and ideas generation becomes easier to be carried out. This is why this phase of definition is highly important.

② The second phase is GENERATION OF IDEAS. Ideas are generated with the use of three TRIZ tools: principles, ideality principle, and effects.

2.1.- Principles: For the generation of ideas with inventive principles, technical or physical contradictions are created in the DFD parameter.

Technical contradictions: The objective is to identify, among the 39 engineering parameters [34], which parameters have an influence on the considered DFD parameter. Then, possible contradictions that could occur between them are identified. Once the contradictions are generated, the inventive principles are used to solve the contradictions and produce ideas.

Physical contradictions: The objective is to study if, in the chosen parameter, physical contradictions take place: separation in time, separation in space, system transition to subsystem or separation based on one condition. After this, ideas are generated.

2.2.- Ideality principle: From the point of view of ideality, a parameter should fulfill its function by itself, without the need of any other subsystems, systems, components, etc. From this philosophy, ideas are generated.

2.3.- Effect: In the definition phase number 1, the function or functions that the DFD parameter should fulfill were defined. Given this function and the resources that the parameter requires, solutions are generated taking into account physical, chemical, and geometrical known effects. To produce ideas the effects module of the TechOptimizer V.3 [35] is used.

2.4.- Solutions: In this sub-phase, the ideas are organized in solution groups.

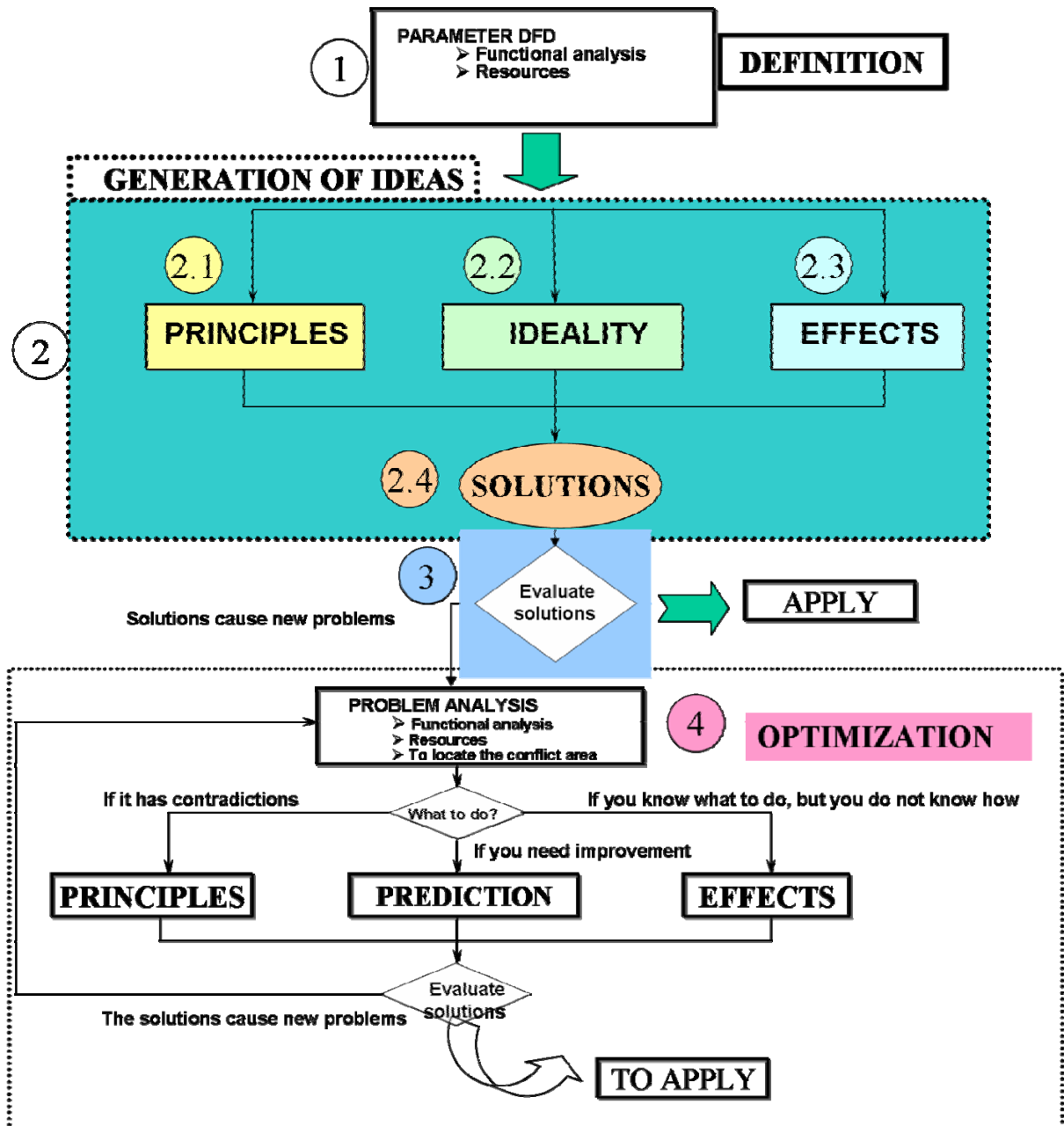


Figure 2: Methodology used to apply TRIZ Methodology to the DFD parameters. Adapted from [36].

5. Example of eco-innovation in DFD

The objective of this example is to see how the joint type can evolve using the methodology shown in figure 2.

5.1 Parameter DFD

The main function in DFD is to disassemble, and in order to meet this function, at least two components and one joining element are needed. To make this process easier the inverse function has been considered, see figure 3. With all this, we have:

- The components to join.
- The element assuring the joining force.

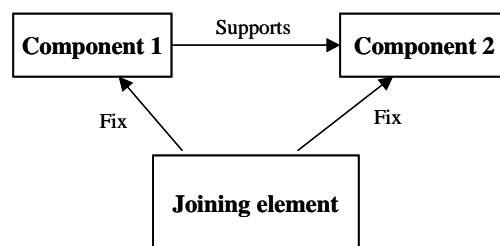


Figure 3: Functional analysis of one standard type of joint.

Once the problem has been analysed, the next step would be to generate ideas which can be obtained using the ideality principle, the effects (if we know what to do but we do not know how) and the principles (when we do not know what to do but a contradiction is defined).

5.2 Ideality

The ideal system, in this case, is the one which does not need any joining element since the parts or components to join would provide the joint themselves. In order to search for solutions to the problem of the ideal system, the designer's know-how, the effects or the inventive principles can be used.

5.3 Effects

Altshuller observed that most of the solutions were based on the advantages provided by a known effect. These effects may be physical, chemical or geometrical. To achieve some ideas, commercial TRIZ software has been used [35].

5.4 Contradictions

By analysing the joining element using the technical and physical contradictions we can generate ideas.

5.4.1 Technical Contradictions

Firstly, the 39 engineering parameters have been analysed [29] in order to find which of them may have an effect on the type of joint. After this analysis, the initial number of parameters has been reduced to the 30 parameters included in table 1.

Secondly, the possible contradictions among the 30 parameters have been identified. To accomplish this, the fact that the improvement of one parameter worsens another one has been taken into account.

The contradictions matrix selects the inventive principles in order to break the contradiction. As an example, if one joint with a heavy component which must be disassembled is considered, a low disassembly speed will be obtained due to the weight, but when disassembling the speed must be as fast as possible, resulting in a contradiction. In order to break this contradiction, 2, 8, 15 and 38 (see figure 4) inventive principles might be used. Their meanings are:

- 2. - Taking out.
- 8. - Anti-weight.
- 15. - Dynamics.
- 38. - Strong oxidants.

1.- Weight of moving object 3.- Length of moving object 5.- Area of moving object 7.- Volume of moving object 9.- Speed 10.- Force 11.- Tension/ pressure 12.- Shape 13.- Stability of object 14.- Strength 15.- Durability of moving object 17.- Temperature 19.- Energy spent of moving object 21.- Power 24.- Loss of information	25.- Waste of time 26.- Amount of substance 27.- Reliability 29.- Accuracy of manufacture 30.- Harmful factors acting on object 31.- Harmful side effects 32.- Manufacturability 33.- Convenience of use 34.- Repairability 35.- Adaptability 36.- Complexity of device 37.- Complexity of control 38.- Level of automation 39.- Productivity
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Table 1: Engineering parameters which may affect the type of joint.

When designing using these inventive principles, the trade-off among the parameters may be eliminated.

Gathering the suggestions of principles to use in order to break the contradictions, it can be observed that the 40 inventive principles must be used.

		1	9
		weight of moving object	speed
1	weight of moving object		2, 8, 15, 38
2	weight of stationary object		

Figure 4: Partial example of the contradictions matrix.

5.4.2 Physical contradictions

By applying the following principles [29] the contradictions may be eliminated:

- Separation in time.
- Separation in space.
- System transition to subsystem.
- Separation based on one condition.

As an example, from the point of view of the physical contradictions, one joint of parts must exist in order for a design to work, but the joining element must not exist for the disassembly at its End-Of-Life (EOL). Hence, the principle of separation in time must be taken into account when searching for solutions which may eliminate that contradiction.

Besides, solutions may be found using effects or instead, the relationship between the principle of separation in time and the 40 inventive principles may be taken into account.

5.5 Ideas achieved

Table 2 shows some ideas which have been achieved. It can be said that TRIZ methodology provides traditional and innovative ideas. The traditional ones are based on the designer's know-how. These traditional methods may be put in order, from greatest to least disassemblability, in adherence, velcro, collets, clips, slip fit, bolted, force fit, welded with the same material and welded with another material or glued.

On the contrary, the innovative ideas are those which escape from the knowledge of the designer, and therefore, break his psychological inertia. For example: joint of shape-memory materials, electric, pneumatic, magnetic forces, etc.

IDEAS	DISASSEMBLY
To heat or to cool the parts	Expansion of parts: shrinking on hot
	Localised heat (bear)
	Bimetals
	Heat adhesion
To deform a body	To deform a body to disassemble.
	Collets
	Shape-memory material (it is activated with electricity, etc.)
	Torque transmission by flexible elements
To exercise pressure on another body	Balls (keyed point)
	Cames, keys
	Deformation of an elastic body producing a joint
	Shape-memory material (keyed point)
	Retractable joints
Force magnetic joint.	Electrorheological fluids, when applying magnetic or electric field increases its viscosity
	A magnetic field moves a part that makes the closing of the joint
Force electric joint	Attraction between two bodies
	The voltage moves a part. E.g. it closes the door of the washing machine
Joint by adhesion	Adhesives (chemical joint), glues
	Velcro, velcro but in metallic
Pneumatic or hydraulic force	An element expands and it exerts the pressure of joint
Fixation by solidification of a substance	E.g. A liquid passes to solid. E.g. solid in ambient temperature
The parts to join carry out	In this case, the most obvious solutions would be the ones by

IDEAS	DISASSEMBLY
themselves the joint	force fits, or by shape, etc.

Table 2: Some of the ideas obtained using TRIZ methodology.

5.5.1 Evolution of type of joint parameter

By means of the table 2, and putting the ideas into order by the type of joints, the possible evolution of the type of joint parameter is obtained, see figure 5.

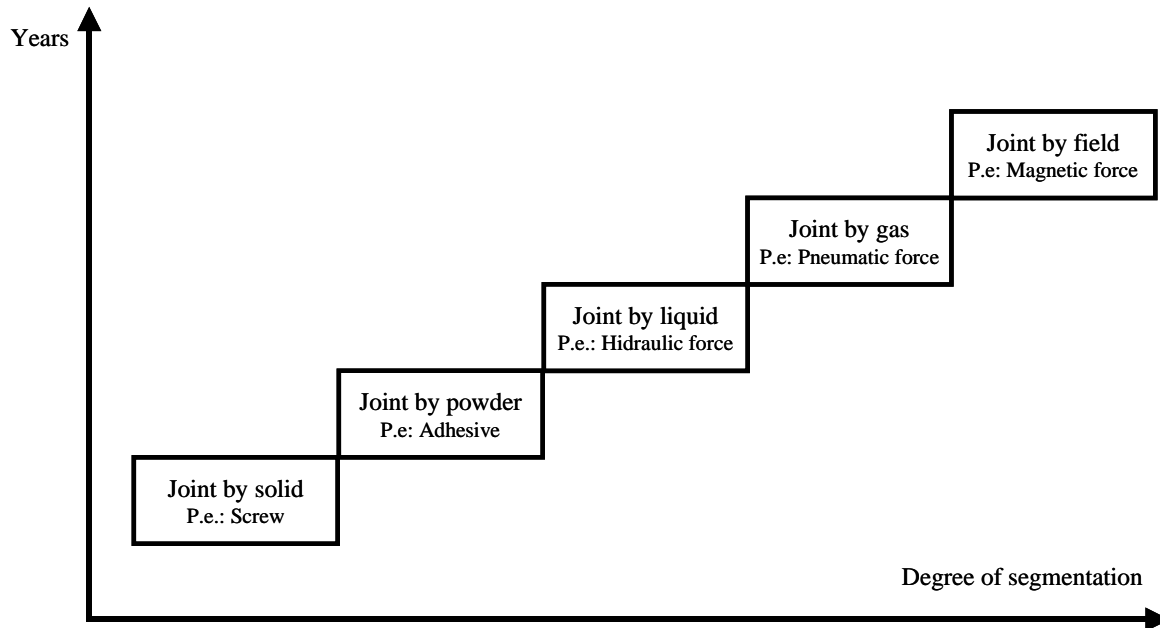


Figure 5: Evolution of type of joint parameter.

This evolution coincides with other ones mentioned by [37], [38] and [39], in which the evolution passes through solid, liquid and gas matter-states and other fields.

As it can be observed in figure 5, it seems that a possible type of evolution is based on the segmentation of the element which assures the joint. Nevertheless, in table 2 is observed that some combinations are possible, for example: in a joint of parts where the joining element is a shape-memory material (solid joint) electricity must be provided for in order to activate it (joint by field).

5.6 Innovation with joint parameter

Once the possible evolution of the type of joint parameter is known, the way of innovating is given by such evolution. For example, suppose that we want to innovate in an adjustable prop used in construction (figure 6). The prop is used to support compressive loading produced by a casing. It is easy to install. First, a quick mounting in height is done using some holes in the tubes and needle hook. Then, a fine regulation is made (final tightening) using a screw-nut mechanism. To release the joint it is only necessary to unscrew the nut (figure 6), normally by hitting it with a hammer.



Figure 6: Adjustable props

Once the basic functioning of a prop is known, if innovation is sought after from a DFD perspective using the type of joint parameter, then the steps of figure 7 are followed.

First, the situation of the product is defined within the evolution chart of figure 5. Where is it situated? It is a screw-nut joint, e.g. a fixation by solidification.

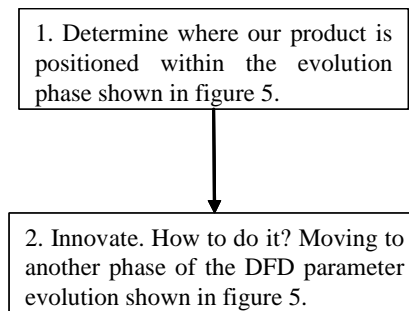


Figure 7: Chart with the steps for innovation with DFD parameters

Secondly, innovation is realised, but how? It is simple. What should be done is to innovate producing a new design in which the joint mechanism is not a fixation by solidification or in which the joining-disassembling force is not mechanical. The evolution chart of figure 5 is used for support. Checking this chart a designer could think about:

- Designing a mechanism with a powder-based joint system. How could this be achieved? If no ideas pop up in the designers mind by checking the chart (table 2), ideas should be looked for in the next evolution phase of the parameter.
- Designing a mechanism with a liquid-based joint system. How could this be achieved? For example, with a hydraulic prop, a system such as a hydraulic cylinder.
- Designing a system with a gas-based joint mechanism. For example, a balloon-like system that supports the loading. It is inflated with air to support the loading and to dismount it one just needs to deflate.

- Designing a mechanism with an electrical or magnetic joint system. For example, a magnetic prop that supports the loading is designed. To activate it the magnetic field is activated, and to deactivate it (dismounting) the magnetic field is deactivated.

It can occur that a product has already covered all the evolution phases of the considered parameter, e.g. clutch-break (figure 8). In this case, if the group of solutions in table 2 is observed, it can be noticed that innovation would happen with the combination of evolution phases. For example:

- A joint of pieces in which the joint element is made of a material with shape memory (fixation by solidification) which requires to be activated by an electrical field (force field joint).
- Another possible combination is using rheological fluids (liquid joint), which would be activated by an electrical field (force field joint) to vary its viscosity and get more or less viscous.

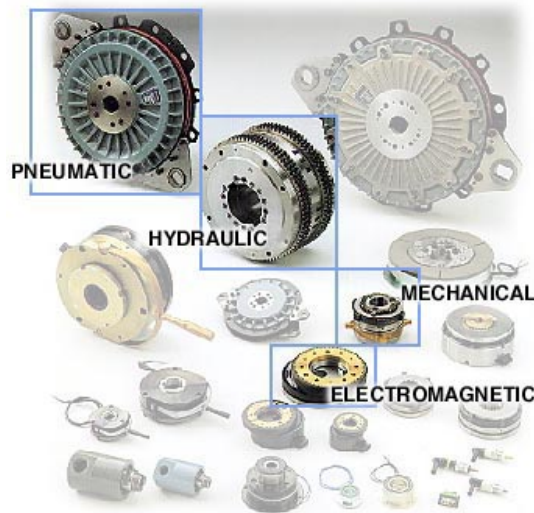


Figure 8: Types of clutches and brakes from the GOIZPER Scoop.

6. Conclusions

With the application of the TRIZ methodology to improve DFD, ideas with a great potential for application are obtained.

Regarding the TRIZ tools it should be stated that:

- The effects TRIZ tool involves a great support in the generation of ideas because of the structuring process of ideas that it proposes and the visual images that it shows.
- The level of abstraction required to produce ideas using the 40 inventive principles is higher than the level required to use the effects or separation principles.

When the theoretical development phase of this methodology is finished, a software tool that supports the designer in the application of this methodology in the conceptual and optimisation phases of design will be implemented.

Finally, it should be noted that the definition of the environmental assessment process has to be developed yet and the DFD of innovative solutions. When those are ready, it will be possible to state that the solutions can be made eco-innovative.

7. Acknowledgments

The authors are thankful for the funding provided by the Spanish Ministry of Science and Technology (Ministerio de Ciencia y Tecnología), project DPI2002-04357-C03, with FEDER funds, by Mondragón Corporación Cooperativa (MCC), and by the Escuela Politécnica Superior (EPS) de Mondragón. We also thank the help of Belinda López-Mesa, Assistant Professor at the Universitat Jaume I.

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