Eco-design with TRIZ Laws of Evolution

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Abstract

Sustainability is one the most recent theme designers have to deal with and sustainability parameters are quickly gaining the top of the list of the requirements any product has to fulfil. Due to standards, legal regulation and customer growing awareness of environmental issues, engineers cannot avoid turning their everyday activities from design to eco-design. By the way, a significant drop of environmental impact of products cannot be achieved by simply adding a 'green' constraint to the already overpopulated list of design constraints.

To answer to this issue a plurality of methods are available helping the designer (or pretending to) to assess product lifecycle or to provide suggestions on how to innovate the product or process according to sustainable goals.

Within this context, the present work describes a way of using TRIZ concepts and tools in order to both assess and innovate a technical system so that some practical activities to ensure sustainable results can be easily embodied into everyday design practice. The main novelty on the operative level consist of an original method based on a set of Guidelines derived from Laws of Technical System Evolution (LTSE) in order to assess the value of existing solution (e.g. using Resources and Functionality as a metric of evaluation), to understand the most promising directions of improvement and to improve said solution also according to sustainability requirements.

The paper will show the way Guidelines are applied with practical examples and an industrial case study will be presented and discussed.

Keywords

Eco-design, LTSE, Resources, Eco-guidelines

1. INTRODUCTION

Eco-design represents a challenge technicians are trying to face since the cost of products or processes has started being calculated including the total environmental cost.

From a TRIZ point of view eco-design is mainly a matter of Resources (exploitation or saving), and a design properly based on this concept can lead to notable "green" results even without using any ad-hoc "green" methodology.

There are several reasons, not necessarily technical, why actual systems generally make a bad use of resources, the most frequent are the following:

- Starting requirements are overestimated due to a lack of knowledge or excessive assurance or useless extra features;
- Design of sub-systems is done separately and, as a result, some resources will be inefficient or redundant and sub-systems will scarcely interact one each other;
- Unsolved problems bring over complication of product or process and imply poor cooperation of parts and several elements not contributing to the final function the system has to perform.

These and some other causes deeply impact on sustainability of the final result of design. Actual products waste a significant amount of material, energy and space that could be saved to decrease their impact on the environment. Thus, an adequate methodology to address eco-design issues must be as strong in assessing as-is situation as in providing new answers to push evolution toward the right direction.

Nowadays design methods dedicated to sustainability can be divided in two groups: the firm are focused on eco-assessment through statistical elaboration of past data (e.g. Life Cycle Assessment, Life Cycle Design Strategy Wheel), the latter, mainly experience driven, are intended for innovating the system to gather a better eco result (e.g. Ten Golden Rules, Companies Eco-Guidelines) [1-11].

What is missing is an in integrated method answering both issues with a systematic, practical and efficient method. The aim of this paper is to fill in this gap with a step by step procedure developed on the base of TRIZ fundamental concepts and tools. In particular the schema represented by the LTSE and their corollaries has been adopted to elaborate an operative set of Guidelines and some suggestions in form of "rules". The Guidelines constitute a new way of performing the statement and solution of a problem concerning sustainability, for which it's not necessary to master TRIZ tools to gather good results.

2. BACKGROUND

The attempt to integrate TRIZ tools in an eco-design framework comes both from eco-design experts and from TRIZ community.

From eco-designer perspective, a comparison among eco-guidelines and TRIZ problem solving tools (especially 40 Inventive Principles [18]) has been performed to find out similarities rather than integrations. Sometimes it is used in combination with other improvement eco-tools, such as Eco-Compass [19].

Some researchers from the TRIZ community put particular attention to the analytical stage of assessment, not completely and effectively covered by TRIZ, at least in its classical version. This lack could be overcome by integrating TRIZ with other methods such as Lean [12-14] TPS or LCA [15], QFD, Taguchi method, FMEA, Design for manufacture, for assembly, for disassembly, Axiomatic design [16], etc.

Some other works have been done in the past, concerning the search for analogies among Problem

Solving tools and rules and suggestions coming from Design for Disassembly, Sustainability or Reuse [17] or with the aim of interpreting the 40 Inventive Principles in an ecologic perspective [18]. Jones and Harrison [19] used the Functionality concept and the Matrix Parameters within the Eco-compass method to highlight contradiction dealing with sustainability. Mann in [20] introduced TRIZ trends and evolutionary radar plots to assess and compare the sustainability of existing technical solutions. In general, known works are either focused on assessment of sustainability of present technical solutions or propose the use of classical TRIZ problem solving tools (mostly Inventive Principle and the Matrix) on an ecologic problem.

Nowadays there is not an integrated design approach that builds sustainability in each step (since the very first) of product/process development differentiating from any inadequate end-of-pipe methods.

In such a context, the authors propose to consider some TRIZ fundamentals, mainly Laws of Technical System Evolution and Resources, to obtain an independent set of eco-guidelines to support both assessment and improvement of products and processes from an eco-design perspective.

3. TRIZ TOOLS ADOPTED

Laws of evolution [21,22]

Law 1. Completeness of the parts of the system
Every technical system should consist of four components: engine, transmission, control unit and working unit. If any component is missing, the technical system does not exist, if any component fails, the system does not survive.

Law 2. Energy conductivity
Prerequisite to viability of a system is the free flow of energy through all system parts. As every technical system transforms energy, this energy should circulate freely and efficiently through its four main parts.

Law 3. Harmonizing the rhythms of parts of the systems
Prerequisite to viability of a technical system is coordination (or purposeful de-coordination) of rhythms (e.g. vibration frequencies, periodicity of operation, etc.) of all parts in a technical system.

Kinematic laws defining how technical systems evolve regardless of conditions (technical or physical factors):

Law 4. Increasing the degree of Ideality of the system
All systems evolve towards the increase of degree of Ideality.

Law 5. Uneven development of parts of a system
The development of parts of a system proceeds unevenly: the more complicated the system, the more uneven the developments of its parts. Uneven development of the parts is a reason for the occurrence of technical and physical contradictions and hence inventive problems.

Law 6. Transition to a super-system
During evolution, technical systems merge and form bi- and poly-systems. When a system exhausts the possibilities of further significant improvement, it is included in a super-system as one of its parts and a new development of the system becomes possible.

Dynamic laws defining how technical systems evolve according to technical or physical factors:

Law 7. Transition from macro to micro level
The development of working organs proceeds, at first, on a macro and then on a micro level.

Law 8. Increasing the S-field involvement
Non S-Field systems evolve to S-Field systems. Within the class of S-Field systems, the fields evolve from mechanical fields to electro-magnetic fields. The dispersion of substances in the S-Fields increases. The number of links in the F-fields increases, and the responsiveness of the whole system tend to increase.

Resources [21-24]

The concept of resource is crucial to conceive more sustainable products. A good exploitation of resources can be an effective check parameter to assess the real efficiency of a system. Looking at the way the initial system uses resources, and what type of resources are still to be exploited it is also possible to modify the system to make it better.
Due to the fact that the proposed method strongly uses the concept of resource we propose some TRIZ definition and classification.
For TRIZ any system that has not reached Ideality still have some substance or field resources, that are:

- Any substance or anything made of a substance (including waste) that is available in the system or its environment.
- An energy reserve, free time, unoccupied space, information, etc.
- The functional and technological ability to perform additional functions, including properties of substances as well as physical, chemical, geometric and other effects.

The concept of resource was born from the assumption that a system possesses more capabilities of what is necessary for normal functioning. The formal concept was introduced in Ariz85 (point 2.3) by Genrich Altshuller in the form of “substance field resources”. In this form a first classification is provided:

- Internal resources: things, substances, and fields reachable in the conflict area or operative zone during or before conflict time or operative period.
- External resources are things, substances, and fields near the conflict area or phenomena that occur before conflict time.

Altshuller indicated also super-system or other accessible, inexpensive resources, and resources coming from temporary modifications of the object.
Later, this concept was expanded to include other types of resources such as functions, information, space, time, change, etc.
A further classification was introduced with readily-available and derived resources to distinguish ready-available resources for solving a problem from those usable only after some sort of modification.
Igor Vikentiev introduced a definition of differential resources (resources produced by the difference in the properties of a substance or field, such as the voltage created by a difference in electrical potential); Zinovy Royzen suggested change resources (resources produced by a change to the system). Vladimir Gerasimov and Dr. Simon Litvin introduced the concept of a super-effect – an additional benefit (resource) resulting from innovation that often goes unrecognized.

4. METHODOLOGY PROPOSAL

In eco-design it is a common practice to under evaluate the importance of resources; actually, most of the methods focus only on Material and Energy and with quite a superficial attitude. For instance the “companies' guidelines” for the choice of material are limited to a simple classification that goes from good materials to be used freely to awful materials not to be taken into account.

For any TRIZ user it's clear that any resource should not be discarded beforehand and it's not always true that a "bad" resource represent a bad solution, e.g. an infinitesimal amount of a toxic material may solve a problem in a better way for the environment than using generally prescribed material. Evaluating resources without considering their contribution to the function to perform or to the potential combination with others or super-effects means reducing the solution space and missing potential breakthrough ideas.

Starting from these considerations and working on the Laws of Technical System Evolution, 8 Guidelines have been created to reach the goal of assessing and eco-innovating system in a more efficient way. The guidelines, being extracted from the laws of evolutions, are ordered according to the natural evolution path of any system. The first two are focused on measurement and evaluation of the resources used in the systems, while the followings are aimed at reducing resource consumption, increasing efficiency also by means of new technologies and physical effects.

The procedure explained in the followings is intended for non TRIZ experts and some practical rules are given for each step (Table 1).

GUIDELINES		RULES	
N.	Name	N.	Short Description
ASSESSMENT			
G1	System modelling	R1.1	Main Function identification
		R1.2	Physical description
G2	Resource assessment	R2.1	Resources exploitation indexes
		R2.2	Analyze present/past system condition
		R2.3	Identify external resources
INNOVATION			
G3	Resource saving	R3.1	Use IFR concepts
		R3.2	Reduce Energy conversion to zero
		R3.3	Explore other technologies
G4	Components interaction	R4.1	Make the actions resonant
		R4.2	Coordinate Fields
G5	System dynamization	R5.1	Dinamyze the system
G6	System simplification	R6.1	Eliminates useless components
		R6.2	Solve contradictions
G7	External resources exploitation	R7.1	Merge technical systems
		R7.2	Shift to super-system
G8	Fields cooperation	R8.1	Increase S-Field involvement

Table 1 - Eco-guidelines and rules.

G1. System modeling

This first phase recommends a problem reformulation to a higher abstraction level, removing specific features and modelling it by an easy schema. This schema has to be able to identify the Main Function and the required input resources able to change the object into the desired product.

R1.1. Main Function identification. Classic theories of Design modelling, like Energy Material Signal (EMS) [25] model, are recommended frameworks to identify the right abstraction level of the system. EMS model describes a system like a transformer of Energy, Material and Signal. The main useful function is identified by analyzing the Minimal Model (tool-transmission-source-control) in order to identify which changes have transformed the object into the product (Figure 1).

R1.2. Physical description. In order to have a clear map of the system it is fundamental to understand its functioning from a basic point of view. In particular the scientific laws (i.e. physical, chemical, etc.) on which the technology of the system is based must be identified and compared with the laws characterizing its natural behaviour. In other words we must clearly identify the role of the system from the point of view of the natural laws preventing the object to turn into the product by itself. To do so we distinguish Technical Effects that are caused by the system, from the Natural Effects due to the nature of the object and its environment. Figure 1 shows the schema used to find out the Main Useful Function (MUF) according to R1.1 and R1.2.

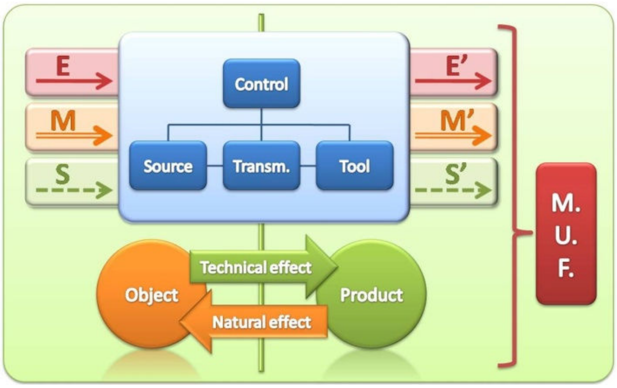


Figure 1 - EMS with Minimal model and Object-Product transformation Effects are used to define the MUF

G2. Resource assessment

Once defined what is the real task for which the system exists, we can proceed to understand the way resources are used. There are three directions to look for to accomplish this goal:

- Identify actual level of resources exploitation;
- Analyse hidden potential resources of the system;
- Identify available external resources.

R2.1. Resources Exploitation Indexes. Energy, material and space are analyzed one by one separately. Resource exploitation is assessed by means of three specific indexes that compare the actual system, the best known system and the ideal system. Table 2 shows how to calculate such indexes.

	I_1	I_2	I_3
Energy	E_{best} / E_{curr}	E_{ideal} / E_{curr}	E_{ideal} / E_{best}
Material	M_{best} / M_{curr}	M_{ideal} / M_{curr}	M_{ideal} / M_{best}
Space	S_{best} / S_{curr}	S_{ideal} / S_{curr}	S_{ideal} / S_{best}

Table 2 - Indexes comparing current system configuration (curr) with the best in class (best) and the ideal (ideal)

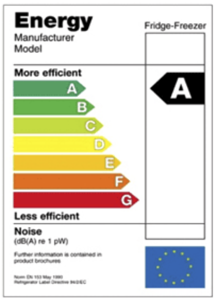
I_1 measures the gap of efficiency existing between the system under investigation and the best available on the market. Analogously, I_2 compares the resources of the current system versus the ideal one. I_3 can be used to evaluate the gap between the best in class system and the ideal one. These indexes permit to highlight the margins of improvement of system according to the specific resources. Comparing I_1, I_2 and I_3 we create a picture of resources used by our system, the best competitors' and the ideal one.

Let see for example the case of the energy (E) exploitation:

$$I_1 = E_{best} / E_{curr}$$

where:

- $\mathbf{E_{best}}$ is the energy used by the most efficient system on the market or the highest value reported in the standard efficiency tables (for an example see Fig.2).
- $\mathbf{E_{curr}}$ is the total energy used by technical system during standard functioning (to provide all functions).



Etiquette Label Energie

Figure 2 - European freezer efficiency standards

Table 3 shows what is meant for current, best and ideal systems for Energy, Material and Space in the case of a home vacuum cleaner.

	curr	*best*	*ideal*
E	…for creating suction flow passing through the filter	…for creating suction flow in the best vacuum cleaner	…to collect only dust particle into the filter
M	… required by the entire system	…required by the entire system	… to contain only dust
S	…required by the entire system	…required by the entire system	…to contain only dust

Table 3 - Determination values to calculate indexes for a vacuum cleaner.

R2.2 Analyze present/past system conditions. Use check lists and resources classification to identify all available (ready, differential, derivative, etc.), resources hidden in the system (e.g. instead of waste exhaust gas from an engine put again into the engine to create a turbo effect, use body energy due to vibrations during a march to recharge equipment's batteries, vapor ejected from an iron can be saved and used into the iron boiler etc.)

Analyze past conditions in order to understand how resources have been modified since now.

R2.3 Identify external resources. Use check lists and resources classification to identify all available (ready, differential, derivative, etc.), resources in the system environment.

G3. Resource saving

Guideline 3 offers indications to choose between current and future technologies in competition.

R3.1. Use IFR concept. Technical system should not only be a suitable power conductor, but should also operate with minimal energy losses (such as losses incurred by transformation, production of useless wastes, and withdrawal of energy with ready-made artifact). System should use energy only to provide the main useful function in according to **IFR concept**.

R3.2. **Reduce Energy conversion to zero.** It is desirable to use one field (i.e. one kind of energy) for all processes of system operation and control. As the technical system evolves, each new subsystem should use energy that circulates in the system, or energy that is available free of charge (energy of the environment, wastes of another system). The "*Reduce Energy conversion to zero*" Trend of evolution should be taken into account.

R3.3. Explore other technologies. G1 and G2 force the examiner to assess the scale of phenomena through which the Main Function is performed between tool and object. In order to find systematically a list of alternative technologies, making the same function and working at a different detail level, use **TRIZ Standard 3_2_1**: "*Efficiency of a system at any stage of its evolution can be improved by transition from a macro level to a micro level: the system or its part is replaced by a substance capable of delivering the required function when interacting with a field*".

If the substances of the parts can be replaced, then the field with sufficient controllability should *gradually replace the field with insufficient controllability in the following order: gravitational, mechanical, thermal, magnetic, electric, and electromagnetic***.** Replacement of fields is carried out together with replacement of substances or introduction of the admixture that secure good power conductivity (the substance should be transparent for the chosen field).

A specific Patent analysis, (better if based on FOS and using semantic parsers) is strongly suggested.

G4. Components interaction

This Guideline aims at improving technical system efficiency, changing functioning and behavior of the system. Such a change is produced by coordinating rhythms of technology used by the system with the ideal rhythm of the desired solution; in other words we want to coordin total environmental ate the rhythm of the Main Function that tool performs on the object with the physical natural laws of the object.

R4.1. Make the actions resonant. Replace continuous actions with periodic or pulsating actions, and then to resonant so that the technical system operation is optimized through mere modification of its component (dimension, mass, and frequency). Nothing is introduced into the system in order to improve the main useful function and efficiency according to the energy conservation. The frequencies of vibration, or the periodicity of parts and movements of the system should be in synchronization with each other, or coordinated (or de-coordinated) with natural frequency of the product.

R4.2. Coordinate Fields. Frequencies of fields used in technical systems should be coordinated or de-coordinated. If two effects are incompatible (e.g. transformation and measurement), one effect should be exerted when the other effect pauses. More generally, a pause in one effect should be filled by another effect.

G5. System dynamization

R5.1. Dynamize the system. Try to dynamize the system or some subsystems:

- *Allow a system or object to change to achieve optimal operation under different conditions.*
- *Split an object or system into parts capable of moving relative to each other.*
- *If an object or system is rigid or inflexible, make it movable or adaptable.*
- Increase the amount of free motion, then pass to liquid, gas and some kind of field; i.e., pass to a more flexible, rapidly changing, and adaptable structure (e.g. blade cut, flexible cut, water cut, laser cut).

G6. System Simplification

When a new system appears, at first complexity raises up and resources exploitation is inefficient, uncontrolled, and not harmonized (expansion phase). Afterward, energy consumption tends to be optimized; global efficiency grows while system is simplified by trimming components and transferring functions to the super-system.

R6.1. Eliminates useless components. If they exist, eliminate useless components. **Trimming** activity can be associated to a traditional TRIZ functional analysis. Systems at the beginning of their existence increase the number of parts, thus they are using resources in a not very reasonable way. In this phase it is useful to build a functional model of system by suitable diagrams, so it is possible to provide trimming of components, unifying more functions under a lower number of components, this means that system is simplified through a convolution (we try to advance the convolution phase of system taken into account, see figure 3).

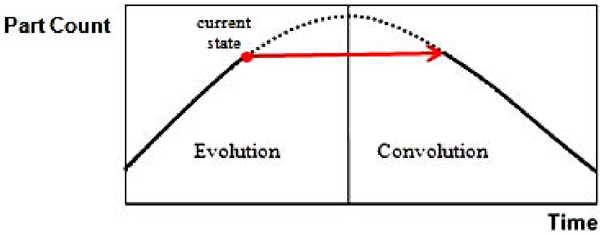


Figure 3 - A new path of evolution, where the system evolves from the current state of evolution (not yet complete) directly to an advanced convoluted phase

R6.2. Solve contradictions. Find and eliminate contradictions due to the uneven development of parts of a system using traditional TRIZ Separation Principles.

G7. External resources exploitation

If the system already reached its maximum development, it will aim to delegate functions from inside the system to outside to the super system; next step of development continues at super system level, or in the environment.

R7.1 Merge technical systems. Merge technical systems and anticipate **future bi- and poly-systems**

R7.2 Shift to Super-system. Implement the concept of Ideal System that is a system that does not materially exists anymore, while its function is still performed. To do this try to transit the system to super-system.

G8. Fields cooperation

R8.1. Increase S-Field involvement. Develop the system increasing the S-Field involvement.

The new fields are introduced as fields that cooperate with the main field already existing in order to realize the same Main Function. This integration is useful when different fields can work together with synergism.

5. CASE STUDY- VAUUM CLEANER

In order to show how the guidelines work, a vacuum cleaner used to remove dust on a carpet has been selected as case study. The vacuum cleaner taken into account is the one shown in figure 4.

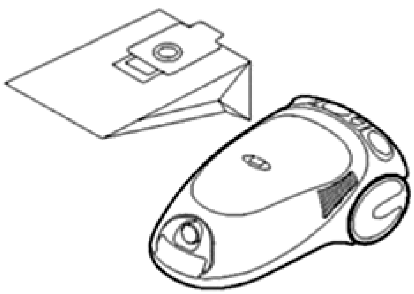


Figure 4 - A classical vacuum cleaner with paper filter

G1. System modelling

R1.1. Main Function identification.

EMS model suggests to visualize two different flows:

- Electric energy (electric current) is converted by the system in kinetic energy (velocity of air).
- Dirty air in input is transformed in clean air.

A vacuum cleaner is a system able to create an air flow by depression (converting electric energy), and this air moves dust particles towards the filter; in this way dirty air is filtered and dust particles are separated from air. The Main Function identified is: move dust particles (from carpet to the filter). The tool is the air and the object is the dust particle.
The product of the system is the dust particles moved/dragged.

R1.2. Physical description.

The physical law avoids to obtain the desired product: the force of gravity and the force of adhesion keep dust on the carpet

G2. Resource assessment

R2.1. Resources Exploitation Indexes

At first an evaluation of the Energy assessment is proposed; first step needs of calculating the efficiency in terms of Energy according to the European standard test for vacuum cleaners on a carpet test (dust mass=0,035kg, height from carpet to filter= 0,4m and time test= 180s).

Table 4 and 5 show the amount of considered resources and the resulting indexes.

	current	*best*	*Ideal*
Energy	324 k J	<150kJ	0,14 J
Material	5 kg	2 kg	Minimal quantity of material to contain 35g of dust (i.e. a plastic bag < 1g)
Space	30 dm^3	8 dm^3	Space/volume to contain 35g of dust (20 cm^3)

Table 4 - Amount of resources used by current, best in class and ideal system

	I_1	I_2	I_3
Energy	0.46	4.3*10^(-7)	9.3*10^(-7)
Material	0.4	2*10^(-4)	5*10^(-4)
Space	0.27	6.6*10^(-4)	2,5*10^(-3)

Table 5 - Indexes values for the vacuum cleaner

The selected Vacuum cleaner doesn't belong to the optimum class of European efficiency standards as I_1 shows (I_{1_Energy}= 0,46). Even if it were the best on the market (I_1=1) the other indexes show a radical different situation. In particular I_2 and I_3 are quite zero as a consequence of the low efficiency of the Main Function: "the system removes a small quantity of dust through an huge air flow".

Material and Spatial assessment:

Although the system evaluated is compact and light the indexes I_2 and I_3 are lower because the ratio between volume occupied only by the dust and the volume occupied from the whole vacuum cleaner is lower, as well as the ratio between the weight of the plastic bag (to contain the small quantity of dust) and the weight of vacuum cleaner. Also for material and spatial assessment the evaluations are almost the same even if we take into account the best vacuum cleaner on the market.

R2.2 Analyze present/past system conditions

Analyze environment conditions in order to understand how dust is created how it falls down naturally or how it disposed on the carpet for the test.

New resources internal to the system are:

- Dust (full/empty bag) - the dust could attract other dust particles by their residual charge.
- Exhausted air could be used to accelerate fresh air inside the suction duct (by injecting exhausted airflow of vacuum into the suction port).
- Air humidity could be used to compact dust
- Heat (produced by functioning) could be used to heat the air creating a greater lifting force (upward vertical)
- Fan rotation could be used in accordance with a brush.

R2.3. Identify external resources

Some external resources, useful for cleaning or to maintain clean a room, could be:

- an electrostatic carpet attracting dust particles
- a charged floor to direct dust particles where you want
- a blow dust particles towards a window

G3. Resource saving

R3.1. Use IFR concept

We have to think to a vacuum cleaner with lower pressure losses, that implies short pipe, big diameter, low roughness, efficient engine, etc.

Applying the IFR means to investigate the dust particle's behaviour before their removal; how to increase collection by means of reciprocal interactions from particles. By such a way pressure and air flow could be saved.
The highest abstraction level of IFR suggests: *dust particle moves by itself from the carpet to a "filter"*.

The following rules R3.2-4 could help designer to find technologies, physical effects and principles to be used in order to realize IFR target. (*to create for example a muddle of dust on the floor to be easily swept out, etc.).*

R3.2. Reduce Energy conversion to zero

The current system converts electric energy into kinetic energy, thus it performs only one conversion.

Could you think a system that used only electric or mechanical energy, without conversion?

- Dust removal system using static electricity (JP60156565).
- Travelling-waves which can lift and convey charged particles (US3930815).
- High-frequency waves (ultrasonic, megasonic, etc.) push away dust (US6058945).

R3.3. Explore other technologies

Decrease the interaction between tool and object means reduce the interaction between *air* and *volume around dust particles*. Thus in this case shifting from macro to micro means that the air will interact in a smaller space around the particle, then with the external surface of the particle, then again with a portion of external surface of the particle and so on.

The author suggest to perform a specific patent search, and to use the *TRIZ pointer to effects*. Here only some exemplary results are reported:

- dielectrophoretic forces
- electrostatic forces
- force of buoyancy
- polarization
- sublimation
- chemicals
- thermal field
- Etc.

G4. Components interaction

R4.1. Make the actions resonant

You have to coordinate the MF of the system, air *drags* dust particles, with the physical law avoiding us to obtain the desired product: *dust particles are kept down*.

The dust particles trapped by the carpet fibres are subjected to gravity, friction and adhesion forces that constrain it into the carpet. To coordinate function and object you can move from continue action to pulsating action, then to resonant action. In the current system dust particles are dragged by a continue action, so move towards a pulsating one. It could be figured out an agitation device (e.g a vibrating brush) able to hit the carpet with a certain frequency or a pulsating air suction flow to better move dust particle away from the carpet.

R4.2. Coordinate Fields

The functioning of the vacuum cleaner requires the brush to be moved back and forward several times during the cleaning activity. So it is possible to coordinate functions according to the movement of the brush, exploiting pauses: e.g. pulsating suction user can more easily move brush between a suction peak and the following one.

G5. System dynamization

R5.1. Dynamize the system

Vacuum cleaner modifies suction power according on the surfaces to be cleaned (smooth floor, wrinkled floor, carpet, etc.) or depending on the different zones of the room (corners, flat surface, space under furniture, etc.); dynamization acts in order to reduce energy consumption when and where not needed.

G6. System simplification

R6.1. Eliminates useless components

Examples of already existent trimmed products are:

- Electric broom
- Robot vacuum cleaner

R6.2. Solve contradictions

Some contradictions were found and here just two examples are reported:

- I want to increase the suction power but I do not want to lose the ease of handling. A possible solution comes by separating in time. We can use a pulsating suction so the suction forces of the single pulse can be greater and the user can more easily move the brush between a suction peak and following one.
- I want to increase the suction ability but I do not want to increase the power used by vacuum cleaner. It is possible to reuse the exhausted airflow for pushing the air in the suction duct.

G7. External resources exploitation

R7.1. Merge technical systems

Mono-bi-poly system:

- Multi-suction ducts
- Suction duct combined with blowing duct
- suction duct and blowing+ heating duct
- etc.

R7.2. Shift to Super-system

It could be suitable to shift the function of cleaning/sucking to the building itself as for central vacuum cleaner systems, or to an electrostatic carpet able to attracts and collect dust particles.

G8. Fields cooperation

R8.1. Increase S-Field involvement

The current field used is mechanical, so to increase efficiency it is possible to add other fields to the existing one. For example mechanical field can cooperate with:

- Thermal field to help dust particles floating in the air
- Electrostatic field added to the suction duct in order to improve the pickup ability
- Electric device with combined corona electrodes for removal of dust from gases
- Chemical: dust is removed by primarily spraying an alkaline solution to air flow
- High-frequency wave device to move dust before sucking
- etc.

6. SUMMARY

TRIZ methodology has been evaluated as a potential allied for existing eco-design methods. Some TRIZ tools, such as Ideality, Resources and Laws of technical evolution, have been re-organized in the form of practical eco-guidelines for product innovation. The overall procedure, has been clarified by means of one case study dealing with a vacuum cleaner.

Guidelines have been applied and checked with success by authors into the area of household appliances and then proposed to students of the University of Bergamo in order to evaluate how the method works also without a TRIZ experience. The good results obtained encourage us to further develop the method.

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