A model of evaluation of design for disassembly

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Abstract: In a new industrial model, the ecological factor will be allied to the economical and technological factors. According to it business strategies the new industrial paradigm cares for environmentally correct production processes and products. The product design activity, established in the beginning of the process has a great influence on the product's life cycle. Therefore, it is at this stage that solutions for the development of environmentally correct products must be found, those witch contemplate solutions for the product life cycle end, predicting the reutilizing, recovering and recycling of the products or of its parts. Therefore, disassembling the product before it is worn out seems to be necessary so that reutilizing, recovering, and recycling alternatives for the product become viable. This study presents disassembly design rules and proposes an evaluation model of the product design as to its disassembly at the end of its useful life cycle. It is presented as software, so that its application becomes easier for users.
Keywords: concurrent engineering, design for disassembly, product development process.

1. Introduction

The sustainable development implies that beyond leading the design process, with support of Simultaneous Engineering, it looks for conciliation with all phases of product's cycles of life into the environment, that is, Design for environment, with the pertinent ramifications: Design for recycling and design for disassembly (WEULE, 1993). According to the ambiental point of view each product is a problem because it consumes natural resources and it generates emissions for the environment. One of the main problems appears in the end of the useful life of the product, therefore when discarded, if it will not have recycling of all parts, everything will be garbage (TIPNIS, 1994). Project and make products without a preoccupation for it's discarding is not possible anymore nowadays. Inside of this perspective, the design for disassembly is presented as an excellent tool of the industrial ecology.

Some external factors exert pressure on the designers to demand greater attention for the environment aspects of the product (GRAEDEL & ALLENBY, 1995): limited raw material resources; increasing consumption, causing increase of residues; problems with the final discarding of the product; increasing expenditures for handily and disposal of the garbage; growth in the requirement for green products; national and international legislation demanding recycling. BEITZ (1993) says that to each step o product's process there must be tasks guided to the environment protection. Thus, a process has to represent a balance that must be reached between the addition of emissions, cost of recovery, use of energy and the ambient impact.

2. Design for disassembly

The design for disassembly is not a new design methodology, but it represents a set of principles and analyses to be incorporated in the conventional design process. Project one product thinking about the disassembly of the same may be arguable. It is important to emphasize that in all design details, the main function of the product must be always in the first plan, but when you add improvements to the function you will be adding value to the product. For JOVANE et al. (1993) the disassembly problem must consider that component of high quality they can be recouped and metallic parts can most be separate, reducing the contamination and increasing its recycled value.

Inside of the conventional design methodology the principles of the design for disassembly if apply in the phase of selection of solutions for the product, therefore to the measure that determined alternative do not take care of these principles, they can be eliminated (ASHLEY, 1993). These principles lead the project to get one better index of disassembly (ZÜSSMAN et al., 1994); (CHEN et al., 1993):

- **Principles that intervene with the function of the product:** linear and unified direction of dismount; structure sandwich with central element of union; structure of base for product; groups of standardized assemblies; to prevent not rigid parts; to integrate the parts; to project for easy manuscript, separation and cleanness; to prevent secondary finishing's as painting and covering; to prevent inserts; to maximize the integration of functions in a part;
- **Principles that intervene with the election of materials:** not to combine materials with different times of life; to combine not corrosive materials; to protect groups of assembly of the pollution or corrosion; to minimize the number of different materials; to use compatible materials; to use materials you recycle; to use soluble adhesives in water; to prevent the use of toxic materials; and
- **Principles that intervene with the dismount:** to make marks of operation for destructive tools of separation; to minimize number of union elements; to use detachable or easy elements of union to destroy; to prevent change of direction for dismount; to standardize and to simplify union techniques; to provide access and visibility to the points with separation; to make possible simultaneous separation and dismount; to simplify and to standardize adjustable components and interfaces; to identify separation points; friction material for easy identification; to choose easy unions to separate for parts that value has of I reuse; to use unions protected against corrosion; to use exactly so great of unions for adjacent parts; to provide access for tools with dismount.

3. The disassembly index (IC)

The disassembly index will go to determine the greater or minor easiness to disassemble the product, in each solution of project. For this they will be considered in the model the number of components of the product, the number of used unions, the different used materials, and the hierarchic level number that corresponds to the relative positioning of the components of the project. Moreover, also the difficulty of dismount for the use of union elements and for existing the felt directions and of dismount in the hierarchy of the components will be analyzed. To determine the disassembly index, initially it counting of the components, unions, materials and hierarchy (dismount levels) of the components for each solution and defined that to determine the disassembly index the addition of all must be made these elements, thus creating a counting index (IC):

$$IC = NC + NU + NM + NH \tag{1}$$

where: NC = number of components; NU = number of unions; NM = number of materials; NH = hierarchic level number.

Still it is necessary to know the difficulties produced for the elements of union and the hierarchic levels. Different unions produce different difficulties for the dismount. In the model, the disassembly difficulty (DDU) was defined adding the difficulties of dismount (Ddu) of each element of union used in the project:

$$DDU = Som(Ddu) \tag{2}$$

It has that to consider itself in the model, the disassembly difficulty of the components, produced for the some felt levels and directions and of dismount. For attainment of the value of the hierarchic difficulty it will be necessary to compare the all changes of direction of dismount (DDHd) and of felt of dismount (DDHs) for each component in the hierarchy. This comparison in the model will be made of the following form:

$$DDH = DDHd + DDHs \tag{3}$$

With this, the disassembly index for each solution will be gotten through the expression:

$$ID = IC + DDU + DDH \tag{4}$$

The value for the index of disassembly of one determined product will be always bigger that zero, and how much bigger the value for the solution, worse will be its dismount. It is observed that the disassembly index represents a global value for the project, but the model will individually supply to the value of the disassembly of the unions and the difficulty produced for the hierarchy of the components. Also the following relations will be supplied by the model:

- Number of unions (NU)/number of components (NC);
- Number of materials (NM)/number of components (NC);
- Maximum number of hierarchical levels (NH)/number of components (NC);
- Difficulty of disassembling unions (DDU)/number of unions (NU); and
- Difficulty of disassembling for hierarchical (DDH)/number of unions (NU).

How much lesser the value of these relations, better is the solution of project under the disassembly aspect. These relations are important, therefore they show critical points in the project, therefore exactly getting a lesser value for the disassembly index (better project), the relations between the some parameters can not be most favorable.

4. Model description

Developed software process three different objectives for the user, therefore beyond being used effectively to process the referring data to the determination of the disassembly index, also it will be had access to incorporate new data in the database of unions, materials and projects, and still, in the phase of selection of solutions, the same it could be used for consultation of the principles of design for disassembly. They are considered necessary for application of the model, the following elements: Component of the product: the process of manufacture, the material, the weight, the direction of dismount (right, left, top, low) and the direction of dismount (vertical, horizontal); unions: the material, the difficulty of dismount and the time of dismount; material: the cost of the material and the possibility of recycling; and hierarchy: how much bigger the hierarchy, greater the difficulty of disassembly of the product. The relations of anteriority and adjacency between the components will have to be considered.

After the processing of the data will be gotten a report, presenting the following data for each evaluated project: number of components; number of union elements; number of materials used in the project; hierarchic level number and the index of disassembly of the product. The menu Evaluation, for example, contains the Index of disassembly - requesting that the user indicates the project to have the calculated index of disassembly, after to identify to the project, the user it must pressure the icon of the window, so that the calculations are carried through and the results are presented in the proper window. The visual model is shown below (Figure 1).

5. Case Study

For application of the model two stabilizers of tension had been selected produced by different manufacturers, called here of product A and product B. The product A has it the following specifications: Power 800 VA, input voltage 220 V and output voltage 110 or 220 volts. The Product B presents the following specifications: Power 1000 VA, input voltage 220 V and output voltage 110 V.

The two products are conceptually much seemed, therefore they are used for the same function, to stabilize tension. Initially the product A it was drawn in AutoCAD software, having used the solid model so that one better visualization of the same was gotten and also so that it was possible to directly get the volume of each component. After, one became the cadastre of the components, unions of the project and hierarchy of the components of the Project. The visual model is shown below (Figure 2).

Product A specifications: Number of components = 23; number of unions = 36; number of materials = 7; maximum position in the hierarchy = 3; difficulty of dismount

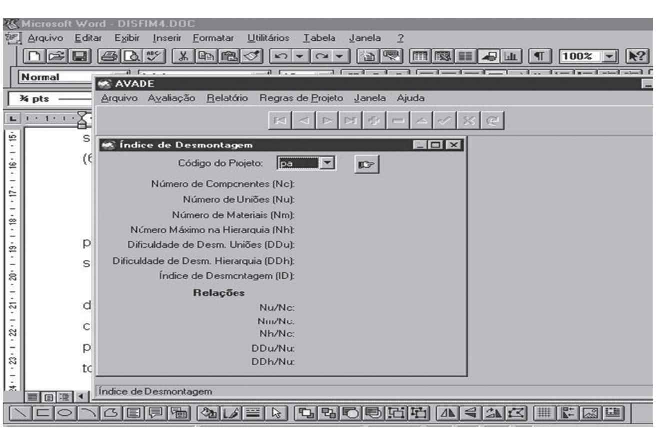

Figure 1. The disassembly index window.

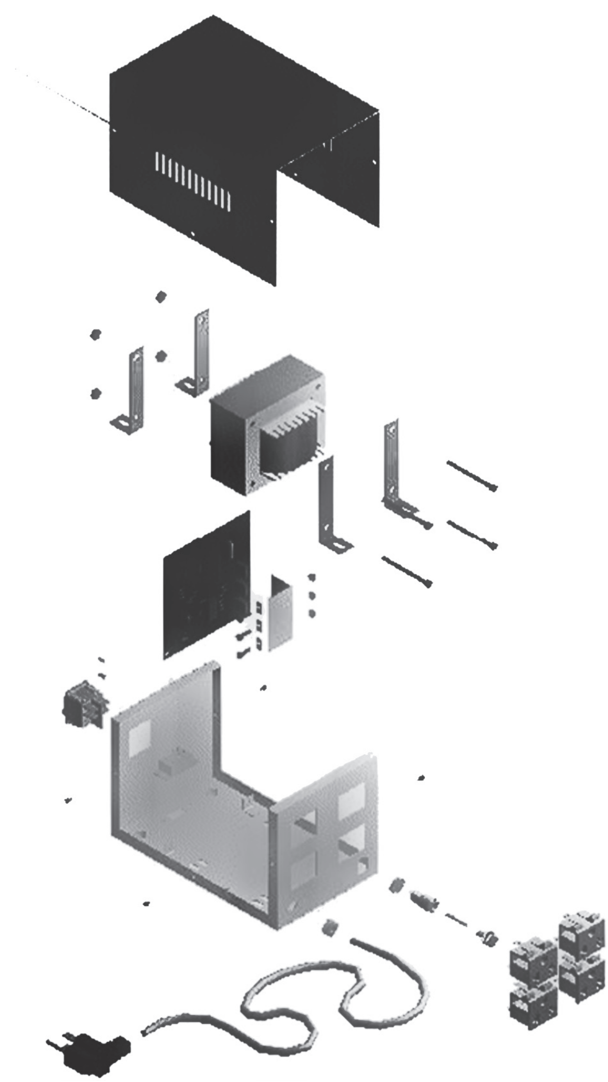

Figure 2. The product A solid model.

union = 24.2; difficulty of dismount hierarchy = 18; index of disassembly = 111.20.

For product B, presented in Figure 3.

Product B specifications: number of components = 18; number of unions = 30; number of materials = 6; maximum position in the hierarchy = 3; difficulty of dismount union = 19.20; difficulty of dismount hierarchy = 6.00; index of disassembly = 92.20.

The gotten results of the evaluation of each solution of project and the relations between the solutions are presented in Table 1.

Figure 3. The product B solid model.

The evaluation must take in account the some results first, observing itself the index of disassembly (ID). As example, the product B that presents minor index of disassembly (ID) in relation to the project A, but the result of the relation enters the number of unions and the number of components (NU/NC) is bigger. This indicates that the possibility of reduction of the number of used elements of union in the project exists. Also, the relation enters the number of materials and the number of components (NM/NC) is bigger, indicating that the number of used materials is no favorable in relation to the project A. The relation enters the hierarchic level number and the number of components (NH/NC) also is bigger, pointing one another possibility of improvement in project B. In such a way, it is perceived mainly that the evaluation must take in account all the gotten results, so that inside of the selected alternative, solutions are searched, for each time more, to minimize the disassembly index.

6. Conclusion

The design for disassembly is presented as indispensable tool in the search of the industrial ecology and represents one of the exits for the sustainable development. Through the dismount of products it is that one becomes possible the reutilizes, recovery and recycling of product parts. The construction of software is useful, therefore a great number of comparisons exist to be carried through for the evaluation of the dismount of the product. A verified advantage is that after the composition of the data base, many analyses can be generated from the information contained in the same. Software allows the designers to be constantly bringing up to date the database of materials and elements of union. For the application of the model, the designer must know in details the structure of the product, its components and the relations with the union elements. The biggest difficulty observed in the application is related to the necessity of the designer to have that to register all the information of the product in the database, a time that these data are not generated automatically. The diversity of existing elements of union and its forms of application were a fact observed during the accomplishment of the work, becoming necessary that the database of elements union is extended to each new project. It fits to point out, that the majority of the projects happen for evolution. In such a way, the application of the model is simplified, due to similarity between the projects.

Table 1. Comparison of the results.

Product	ID	DDU	DDH	NU/NC	NM/NC	NH/NC	DDU/NU	DDH/NU
A	111.2	24.2	18.0	1.57	0.30	0.13	0.67	0.50
B	92.2	19.2	16.0	1.67	0.33	0.17	0.64	0.53
A/B(%)	20.6	26	12.5	–16.0	–9.0	–24.0	4.6	–5.7

Also, the companies, in its majority, work with families of products, thus facilitating, the application of software.

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