INTERNATIONAL DESIGN CONFERENCE - DESIGN 2004
Dubrovnik, May 18 - 21, 2004.

DESIGN 2004

AUTOMATING THE PRODUCT DESIGN CYCLE FOR CUSTOM MADE PRODUCTS

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Keywords: product design cycle

1. Introduction

The reduction of development time and cost is a very important task in every manufacturing industry, especially for those making products to order. These companies are designing their products according to customer specifications, by modifying existing product lines. They need to reduce all design effort and automate the design cycle, using current practices and tools and by replacing old tools and legacy systems.

In Fig. 1 the information flow is shown from the time the customer requirements are known until the time the final product – transformer- is delivered. This figure illustrates all the intermediate steps of the industrial cycle, such as design study, data sheets, drawings by computer aided design (CAD), bill of materials (BOM), manufacturing software system (MSS), production and quality control (QC). The aim of the computer-based environment developed is to reduce this industrial cycle [1].

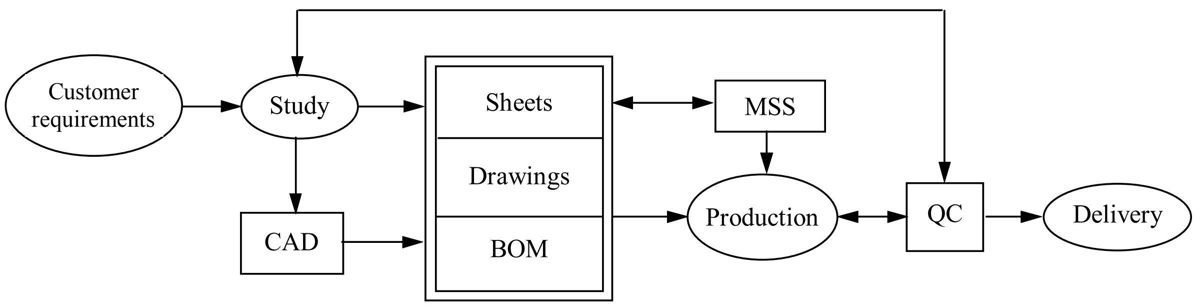

Figure 1. Information flow for product configuration

The objectives of transformer design engineers are satisfaction of customer requirements, cost reduction, standardisation and simplification of transformer construction and continuous adaptation to the new demands of the market. Driven by such issues, the need for a computational design tool to support representation and managing engineering information becomes more crucial [2].

2. Overview of 3-D parametric solid modelling

In 3-D Parametric Solid Modelling, dimensions are parameters of the model. When the model has been created, a real value corresponds to each dimension needed for the definition of the model. When this value changes, the geometry of the model also changes. In Solid Modelling, models are based on informationally complete, valid, and unambiguous representation of objects [3].

The 3-D Parametric Solid Modelling are feature-based. A feature is a higher-level representation of the geometric elements and attributes of the model, such as protrusions, cuts, holes, etc [4, 5]. The final solid model results from a sequence of features.

Among the various functions that have been implemented in the reported applications, are:

- Solid models, called *parts*. In case of sheetmetal designs, a module of parts that includes special features such as bending, forming, etc can be used.
- *Surface* models, which contain no mass.
- *Assemblies*, which consist of *components* such as parts, surfaces and other assemblies (that called subassemblies).
- *Drawings* and *reports*.
- *Manufacturing* operations, which can produce the *cutter location data files* and the *G-codes* of a part or assembly.
- *Relations* between dimensions and/or parameters.
- *Family* models creation of a part or assembly.

3. Top-down design methodology

Top-Down methodology is a problem solving mechanism whereby a given problem is successively broken down into smaller and smaller sub-problems or operations until a set of easily solvable (by computer) sub-problems is arrived at. In a 3-D Parametric Solid Modelling System, some main criteria and product specifications are initially fixed in the higher hierarchical level. These specifications must be successively inherited by every lower level product component, without loosing their explicitness [6]. Top-Down design is the best method to harness and control the associative design tools when conceptualising and building large assemblies.

The basic structural tools for Top-Down design methodology are skeleton models, which are usually surface models. They act as 3-D layouts of the assembly and may be used to represent space requirements, mounting locations, and motion. They also act as a channel for passing important design criteria from one subassembly to another.

In a 3-D Parametric Solid Modelling System, Top-Down analysis consists of six fundamental steps [7]:

- Defining design intent.
- Define preliminary product structure.
- Introducing skeleton models.
- Communicating design intent throughout the assembly structure.
- Continued population of the assembly
- Managing part interdependencies.

4. Transformer design objectives

The process of electric utilities restructuring, privatization, and deregulation has created a competitive, global marketplace for energy. In this new and challenging environment, there is an urgent need for the transformer manufacturing industry to improve transformer design and to reduce cost, since high quality, low cost products have become the key to survival.

The application concerns a custom-made distribution transformer. The technical characteristics are: power of 630 kVA, three phase, oil immersed, magnetic circuit of shell type, and wound cores. The main subsystems of a transformer are the active part (consisting of cores and windings), the frame (in which the active part is assembled), the tank, the corrugated panel (used for cooling), the cover and the conservator tank. Most of the external parts plus frame are constructed from sheetmetals. With the exception of conservation tank, all other basic subsystems are custom made, and their final shape results from customer needs. The final assembly file is constructed via constraints in order to place the components and relations so as to make crucial information and relationships parametric. Apart from the part and assembly files (components), drawings, bill of materials and manufacturing files have to be created.

5. Transformer 3-D parametric solid modelling

The process of finding the optimum technical and economical transformer is implemented with the help of a suitable computer program, which gives enough alternative values to appropriate variables, so enough candidate solutions are calculated. For each one of the candidate solutions, it is checked if all the specifications (limits) are satisfied, and if they are satisfied, the cost is estimated and the solution is characterized as acceptable. From the acceptable solutions, the transformer with the minimum cost is selected, which is the optimum technical and economical transformer [8]. Once the selection of the transformer has been made, the geometry of its active part is calculated. The resultant dimensions act as a driver for the input parameters of the whole assembly file.

The final assembly model of a distribution transformer can be specified from 7 input parameters, evaluated from industry's design department. Due to the dependence of transformer's final shape from the dimensions of the active part, the first 6 input parameters refer to it. In Fig. 2, the dimensions of outer and inner core are presented. All of these dimensions can be described from 5 independent parameters: *F1*, *Eu*, *K*, *Gp* and *D*. The sixth parameter of the active part results from the width *W* of the windings.

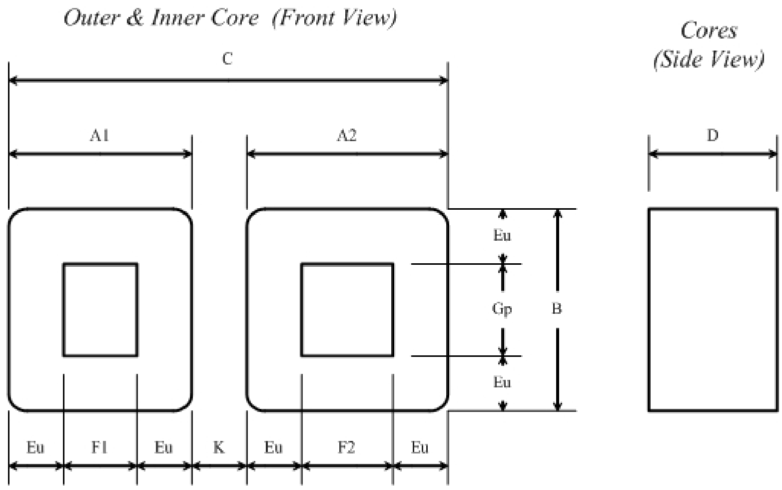

Figure 2. Dimensions of outer and inner core

The seventh (last) input parameter defines the size of the conservator tank (a family model with 3 available standard types). Once the active part dimensions have been defined, the size of the basic subsystems (frame, tank, tank bottom, cover) can be calculated. For the resizing of the components and their proper placement in the assembly models, more than 150 simple relations are used. However, the calculation of the exact shape of corrugated panel, plus the number and distance of cover's peripheral holes, is a more complex task.

The length and width of corrugated panel can be directly derived from the tank size. For the height value, it must be noticed that the width of panel's sheetmetal must be an integer multiple of 100mm, plus the total height of the system tank – tank bottom must have a minimum value, which comes up from input parameters. Due to these limitations, the lower possible height of corrugated panel can be found. The place and geometry of sheetmetal corrugations is extracted as a result of 2 factors: a) the number of corrugations, which is calculated from the interaction of the minimum distances of corrugations from corners, the distance between corrugations (which is standard), and the size of corrugated panel (which is already known to us), and b) the power of transformer (in kVA), which demand a standard total area of the corrugated panel. In Fig. 3, two shapes of a 630 kVA transformer using different input values are presented. It can also be noticed that the larger diameter conservation tank of the left assembly contains the oil indicator, while the right one does not. This result is an additional capability of the family models in a 3-D parametric design system.

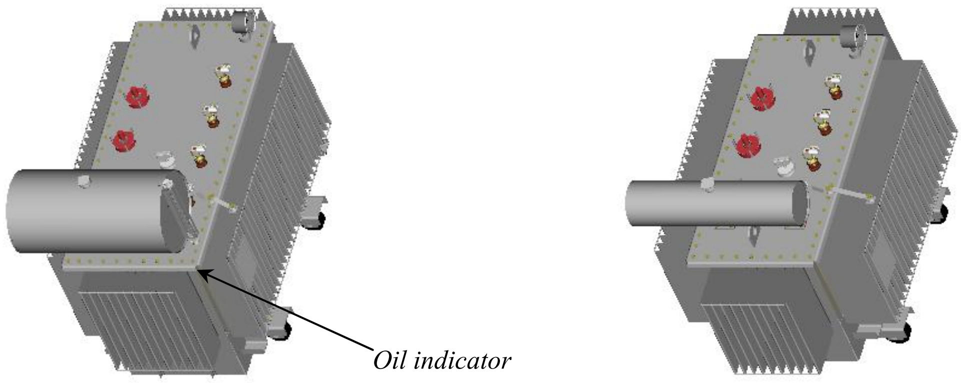

Figure 3. Assemblies with different input parameters

The peripheral holes on the cover must have a standard distance between them. However, this is impossible to happen in most cases, because the input parameters and the implied cover size have random values. For this reason, the distance between the three nearest holes on each side of tank's corner can be reduced to a specified limit. From the difference between the ideal and the calculated holes distance, the new one can be found. This algorithm, which is shown in Appendix 1, is not applied only in the cover part, but also in the upper tank flange and the peripheral corner of upper tank. Through to the variable number of holes that can be generated, the quantity of the assembled screws and nuts needs to be variable too, and in any case equal with the holes quantity. This can be managed with the use of a reference pattern in the assembly. As a result, the total number of parts in the whole assembly is variable. A typical value for the total parts quantity is 450 (without the skeleton models).

The complete transformer documentation should include all the necessary drawings of parts or assemblies, and the bill of materials that contain all the helpful information about a subsystem (list of parts including part name, quantity, code number, dimensions, weight, etc). Parametric design enables automatic update of the drawing in case of modification of a part or assembly, and vice-versa. In addition, the bills of materials are also updated. For the needs of our application, 33 drawings and 7 bills of materials have been created. In Fig. 4 a typical drawing is shown.

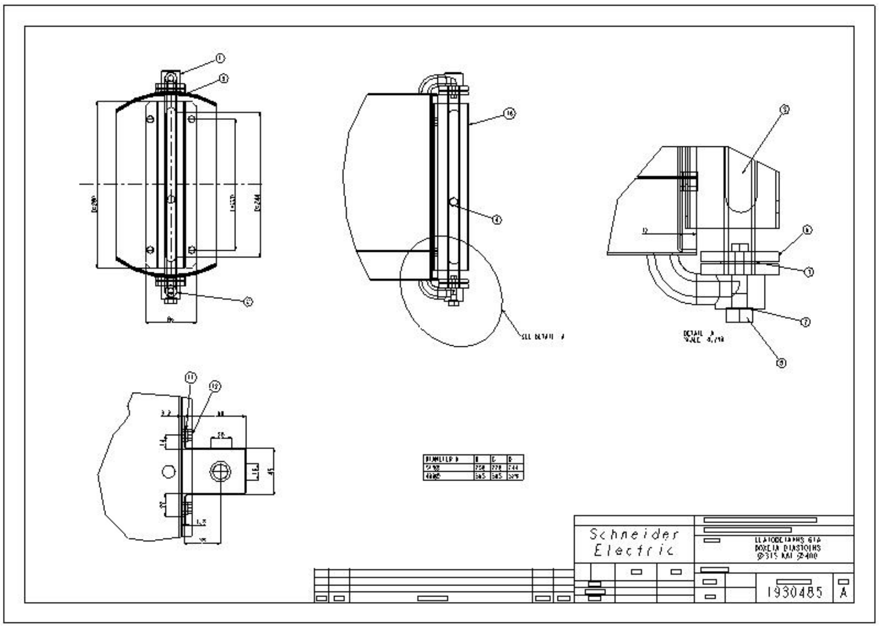

Figure 4. Drawing of oil indicator

The necessary data for the production department can be generated in the CAD department, and they are calculated through the manufacturing module of the parametric system. Manufacturing operations can be simulated graphically, allowing the definition and modification at every important parameter such as the primary and final shape of the model, the workcell, units, tools, tool paths, and feeds. Cutter location data files and the final part program have been produced for all the 28 different sheetmetal models that are used in the final assembly.

6. Evaluation of proposed model

The benefits that arise from replacing the existing 2-D Parametric Design System (a kind of legacy system developed in house) with a 3-D Parametric Solid Modelling System is the reduction of cost and development time, combined with additional flexibility and enhanced capabilities. In a 3-D system the whole procedure of the industrial cycle (study, design, and manufacturing) can be integrated in one tool. This reduces the cost and time and ensures the compatibility of the processes. Moreover, the file of each model is unique and independent of the application that is used, and its modification affects immediately the whole system. If a model must change a number of its attributes due to problems that can be presented in any step of the industrial cycle, the new model is updated automatically in all other steps of the procedure.

A solid model contains all necessary information of a real part. The user can explain the geometry of the model better to a non-related person of computer design. He is also able to check and automatically extract any crucial model information such as customized cross sections, mass, area, volume, inertia tensors, and interferences between components in an assembly. Additionally, a 3-D Design System can manage better the concurrent design of a complex assembly, and can directly work with other modern techniques, just like finite element analysis and virtual reality.

The only limitations for using a 3-D Solid System in the company is its high initial cost, and the learning time needed, since the design philosophy of a solid system is completely different compared with a 2-D system. However, the knowledge of parametric modelling in current system can reduce significantly the required time.

7. Conclusions

The development of a tool that automates the product design cycle for custom made products is presented. The 3-D Parametric Modelling System which has been used in this application reduces time and cost and integrates the whole production procedure, generating parametric parts and assemblies, drawings, bill of materials, and part programs.

As future research objectives, the direct connection with the specialised software used in the design department, the modelling of all types of company's products, and the addition of the welding data in the 3-D model, will complete the full integration in product design cycle.

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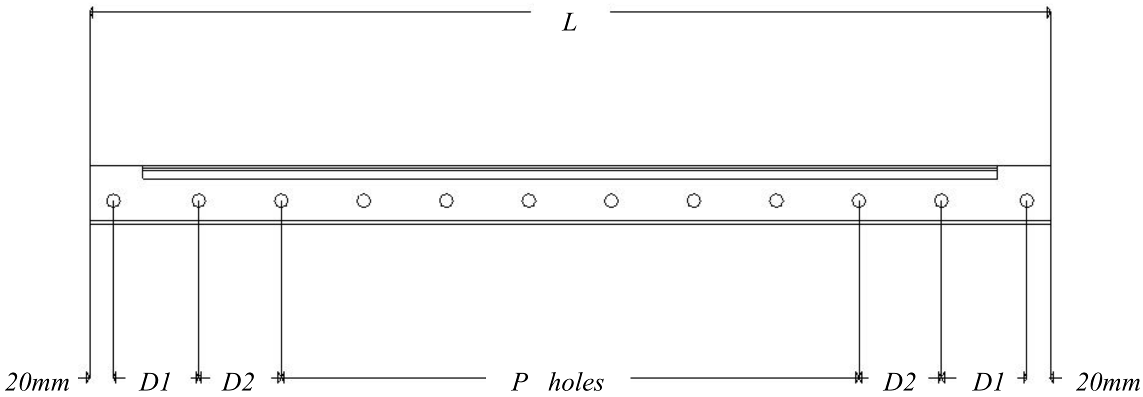
APPENDIX A: Peripheral Holes Algorithm




```
MGB=(L-40)/70
LGB=(L-40)-FLOOR(MGB)*70
IF LGB==0
        D1=70
        D2=70
        P=FLOOR(MGB)-3
ELSE
        P=FLOOR(MGB)-2
        IF LGB>=40 & LGB<70
                D1=55+(LGB-40)/2
                D2=70
        ENDIF
        IF LGB>=10 & LGB<40
                D1=55+(LGB-10)/4
                D2=55+(LGB-10)/4
        ENDIF
        IF LGB>0 & LGB<10
                D1=55
                D2=50+LGB/2
        ENDIF
ENDIF
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