Methodical design of a selector for automotive semi-automated gearbox

Francesco Cappello, Luca Ciulla, Antonio Mancuso

Dipartimento di Meccanica e Aeronautica, Università di Palermo

Abstract

The integration between the *Knowledge Based* model of the design process and the *Parametric Variational CAD* solid model of a component permits to control the design by means of a few parameters and to automate the design steps, simplifying and quickening the modification of design and redesign. Particularly this representation allows to capture the aims of the designers and to keep them in time, giving advantage to the designer himself and to those which will review the work, constituting for this a patrimony of knowledge for the company.

The procedure is applied to rationalise the design process of a selector for automotive semi-automatic gearbox, used instead of the classic lever actuator in order to simplify and speed up the shift motion, keeping unchanged the mechanical components.

1. INTRODUCTION

The increasing request of quality products, from a more and more demanding market, has driven companies toward a simultaneous development of the design and of the manufacturing process, in other words toward a Concurrent Engineering (CE) approach. Backbone of this philosophy is a methodical design approach integrated with Computer Aided Engineering (CAE) tools. Only by means of the methodical design, characterised by an explicit formulation of a coordinated group of activities and by a logic structure of all the phases of the design development, the formulation of a system of transparent and repeatable operations can be carried out and an easy management of the interaction between available resources and tools could be achieved. Thus the use of CAD/CAM software and in general of CAE tools becomes more rational, then Time to Market (TTM) and manufacturing costs can be squeezed. Moreover, by means of a methodical design, a global survey of the entire design process can be obtained, so that the knowledge related to it, can be stored to be represented both outside and, especially, inside the company.

Aim of the present paper is to rationalise the design process of a selector for automotive semi-automatic gearbox. The selector is a component which simplifies the selection and clutch motions of the gears with respect to a classic lever actuator, so a single actuator to automate the gearbox is needed. A knowledge-based model of the design process and a 3D parametric model of the component are proposed, and an interaction between these models is developed, in order to control the design by means of a few parameters. Such kind of work permits to improve the communication activities related to the process development, to move toward the automation of the design process and to accelerate the redesign activities.

2. METHODICAL DESIGN

In the last years designs are developed looking for systems of rules and instructions directed to establish the way for the development of the design activities and for the coordination of the interactions between technical available tools [1]. In fact the rational use of design/production software (generally CAD/CAM and CAE tools) causes an abatement of TTM and manufacturing costs. This approach permits also to transfer the knowledge on the whole design process both outside and inside the company.

The main advantages of the methodical design with respect to the traditional one can be summarised in the following points [2]:

- global vision of the design process; this permits to schematise all the design phases with high advantage of synthesis;
- rationalisation, due to the possibility to make objective, and thus to optimise, the choices;
- economy and rapidity;
- reliability, due to the decomposition of the process in phases, each estimable singularly, and, eventually, optimised or modified separately;
- predisposition to the computer use.

These highlights show that the methodical design must be understood as a tool or, even, an essential technology for a CE approach. The design process starts from the needs of the market and it is articulated in three main phases (Fig. 1):

- *design analysis*: identification of the market needs in order to obtain a high quality product;
- *conceptual design*: formulation of several solutions satisfying the specifications;
- *detailed design*: phase of the final decisions (e.g., on the shape of each component) and of the realisation of the related design documents (virtual prototypes, simulations, calculations, drafts, etc.) [3]. Fig. 2 shows methods, tools and techniques used in the mentioned design phases [4], [5], [6].

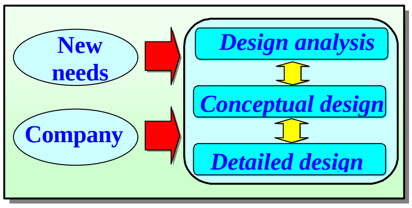

Figure 1: Phases of methodical design.

Design Phases	Methods, Tools, Techniques				
Design analysis	Market search	Quality Function Deployment			
Conceptual design	Functional analysis	Brainstorming, Case-based, Knowledge	Morphological Matrices	Decisional matrices	CAD systems
Detailed design	CAD systems	Parametric modelling	Spreadsheet	KBS	

Figure 2: Methods, tools, techniques for design

Particularly the use of CAD systems, parametric modelling techniques and knowledge based systems (KBS), relative to the detailed design, constitute the main object of interest for this work [7].

3. CAD AND PARAMETRIC MODELLING

Modern CAD systems have modified the mechanical design approach, allowing to generate tridimensional models of objects, to be employed in all the phases of the product realisation, i.e. draft, design, analysis, simulation, manufacturing.

These systems are feature-based; they have the very important characteristic to be able to vary the parameters defining the features, and thus to regenerate automatically the solid model, according to the imposed constrains; for this reason these CAD systems are called parametric. The dimensional variability allowed by the parametric CAD could be effectively used in the design of a component by means of a variational approach. The parametric-variational (P/V) modelling allows thus to obtain a regenerable model, under the control, e.g., of relationships (control functions) associating each isostatic dimension to the values of some control variables (Fig. 3). Then the designer, managing a few parameters, can control the more significant characteristics of the model, modifying it depending on the requirements [8].

These relationships are linked to quantities or characteristics not necessarily geometric, and they are connected to prescriptions of the modelled object. Modifying these variables the recalculation of the controlled dimensions occurs and, therefore, the automatic regeneration of the solid model can be done.

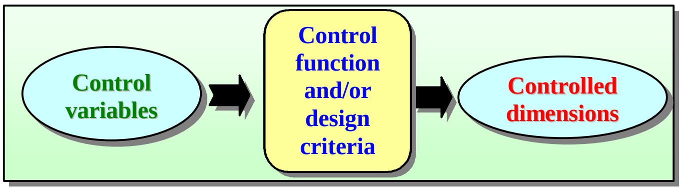

Figure 3: Parametric control through control functions and/or design criteria.

Such kind of P/V models can be even used to obtain rapidly similar products, with other suitable relationships [8]. In this way a double objective is achieved:

- the more repetitive activities performed by designers and draftsmen are reduced to the minimum, releasing precious resources and improving the work quality.
- the potentialities offered by these CAD tools are milked at the best, since the last are easily integrable with the more diffuse systems of office automation, as spreadsheets and database.

However the determination of the mathematical models, giving the influence of the control variables on the solid model, is not always easy. Often the dimensions of a component are influenced simultaneously by several variables, related to the former. Then the design of a dimension is not more sequential, but involves iteratively tools and knowledge according to given criteria. Furthermore the numerical result of a design is generally revised, considering factors which are often controllable only empirically (availability of tools, observance of unified dimensions, etc.) or numerically (e.g. FE analyses). In these cases the parametric variational control is made not by mathematical models, but by true design criteria (Fig. 3), which, opportunely structured and automated, permit to utilise, likewise, the potentialities of the parametric modelling [4].

4. KB SYSTEMS

The structuring of the knowledge basis can be faced with different kinds of models. The main representation models can be classified in two categories: the first are the so-called “descriptive models”, characterised by very simple and intuitive formalisms, and then gifted of good communicativeness; the second are the "formal models" characterised, besides, by more rigid formalisms, typical of the programming languages [9].

The IDEF0 (Integrated DEFinition language) functional modelling technique belongs to the first category and is based on a combination of graphics and tests represented and organised in a systematic way in order to facilitate the understanding, to support activities of analysis, to encourage potential changes, to specify requirements, to support and integrate activities of design [10]. An IDEF0 model is constituted by hierarchically organised charts, which show, with progressively more elevated detail level, functions and their mutual interactions in the considered context.

The IDFE0 modelling technique permits, if it is used in a systematic way:

- to deal with the analysis and design of complex systems, including men, machines, materials;
- to produce documentation simultaneously to the process development, constituting a basis for the integration of new systems or for the improvement of the existing ones;
- to encourage activities of communication between analysts, designers, managers, etc.;
- to have an objective viewpoint of the problems to face;
- to obtain a simple management of complex designs;
- to furnish a reference model for the analysis of the company functions, technical information, resources.

Together with these advantages, connected to the simplicity of realisation and use of the model, there are some drawbacks, like:

- inaccuracy of the models from the semantic point of view, since input and output natures are not specified;
- statical behaviour of the model, which can not tolerate the evolution of a yet implemented scheme [11].

Generally the model of the complete design process, starting from a need and going to a design description satisfying it, can be simply schematised as in Fig. 4 [12].

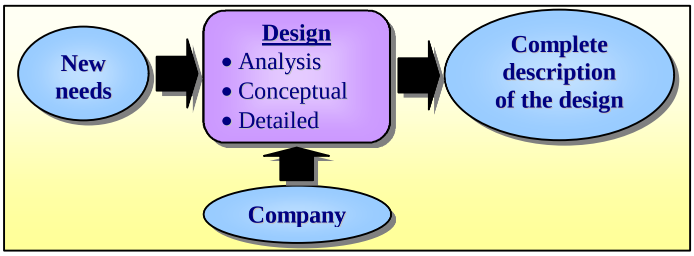

Figure 4: Description of the design process.

5. SELECTOR DESIGN

The necessity to build cars, able to satisfy the customer needs, has notably influenced the technical and productive choices of the companies. Thanks also to the racing, which favours the development of new technological solutions, the automotive factories have introduced on the cars innovations on mechanical components that seemed not improvable. The gearbox is one of it. In fact, to the classical mechanical transmissions with manual command, have been added, in the last years, many variations, electronically managed and propelled by servomechanisms.

Semi-automatic or robotised gearbox is intermediate between the classical mechanical transmission with manual command and the completely automatic one. The robotised gearbox is a manual one with added servomechanism. This solution not involves, in fact, modifications to the gearbox and components of the friction clutch with respect to a conventional manual gearbox, and has evident economic and productive advantages with respect to the complex automatic gearboxes (epicyclic gears, couple converter); furthermore, the choice and the engagement of the gear remains assigned, in many cases, to the driver. The lever is simply a joystick, which, through an electronic device and some actuators, drives directly the brackets inserting the gears. In some cases the command happens by means of little butterfly levers placed on the steering wheel, that allow to managing the transmission in safe.

Thus in this kind of semi-automatic gearboxes the mechanical interface between driver and transmission is replaced by an electronic one (joystick and electronic device), which excludes errors in the selection and engagement of the gear, and not transmit vibrations and noisiness coming from the engine. The shifting is much rapid thank to the electronic, controlling even the clutch [13]. Such kind of semi-automatic gearboxes allows easy to engage the gears sequentially, moving forwards or backwards the joystick or operating the butterfly levers, simplifying the shifting, keeping unchanged the mechanical components, as shafts, gears and clutches. The selection and engagement have to take place, besides, by means of simple actuators, with linear or rotative motion.

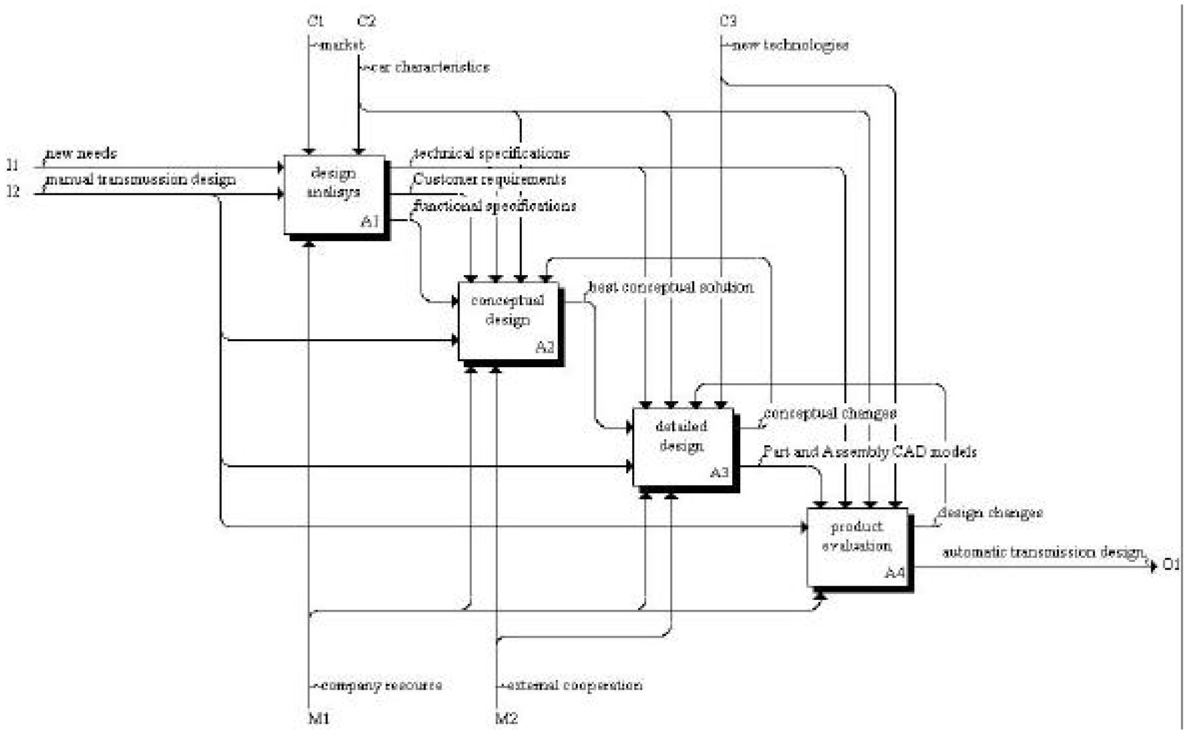

Figure 5: Methodical design of an automotive transmission

Fig. 5 shows the first level of the IDEF0 functional decomposition of the "Methodical design of the selector for automotive semi-automated gearbox". The diagram shows the main phases of the design. Particularly it can be observed the crossing from a conceptual solution, validated by the *Customer Requirements*, to the detailed phase of the design.

Fig. 6 shows the scheme of this conceptual solution. The cylindrical central body is the selector drum; it allows selection and engagement of the gears by means of the discrete rotations imposed by an outer actuator. At a given rotation of the selector corresponds the release of the inserted gear and the engagement of the contiguous one. The transmission of the loads happens through the coupling with transversal slots, disposed on the drum, and stakes integral with the brackets, working on the gears. The position of the drum is assured by a sphere stop.

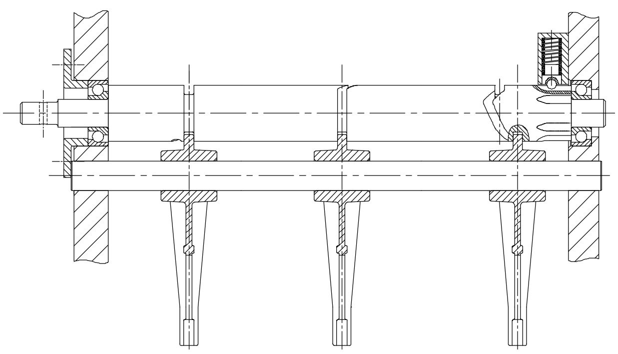

Figure 6: Adopted conceptual solution.

The phases of the detailed design of selector drum and stakes, not inserted in this paper, include:

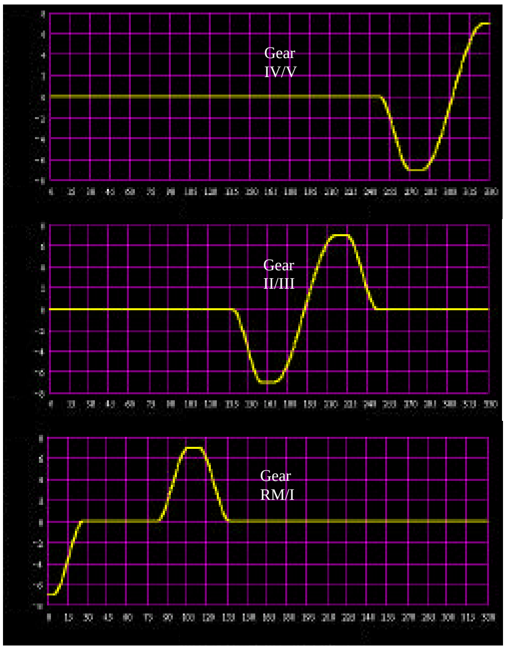

Figure 7: Slot development;
abscissa: drum rotation [degrees]
ordinate: bracket translation [mm]

- Functional design of the slots: determination of clutch locations and choice of the mean pressure angle of the slots;
- Sizing of the stake: calculation of the diameter taking into account contact pressure, strength and stiffness;
- Geometric sizing of the drum: determination of the diameter and analytical definition of the slot profile;
- Mechanism analysis: kinematic and strength analyses.

In Fig. 7 the planar mean profiles of the slots of a 5 speed + RM gear selector are shown. The profiles are constituted by rectilinear segments (joined with curves), corresponding to the positions of coupling and neutral. The curves are defined by parametric cubic polynomials and can be fitted to different engagement strokes and geometric characteristics of the stakes. Furthermore segments and curves can be referred to an opportune coordinate system in order to establish the tool path of the NC machine used for the execution of the slots.

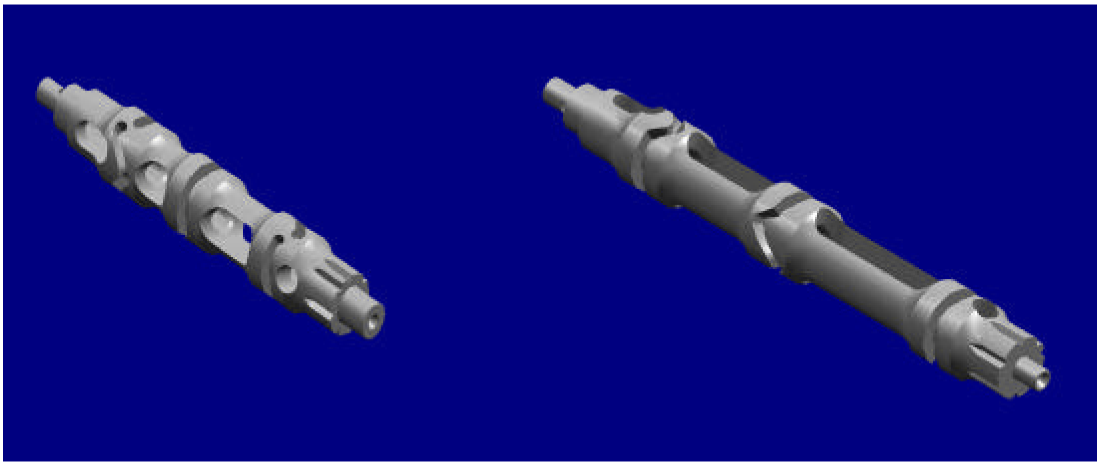

Figure 8: Models of the selector

The parametric modelling of the selector drum allows to obtain a tridimensional model, whose regeneration, managed with a control layout, results reliable. Fig. 8 shows two 3D models of the selector obtained by this model, with different input variables.

The redesign of the selector drum starting from different design parameters, as strokes and loads, gearbox sizes, gear locations, etc., are notably quickened, with respect to e.g. [14], integrating the CAD model into the model for the management of the knowledge basis. This integration is shown in Fig. 9. In environment AI0 WIN 3.2, it constitutes the management interface of the selector drum model and the spreadsheets, linked to it, and therefore permits an automated and rapid redesign.

In Fig. 9, from the first block, it is possible to run the file performing all the phases of the drum sizing and giving the component sizes to the parametric control layout, organised as a database. In this last it is possible to insert all the remaining independent dimensions of the drum. From the last block, can be generated the drum model, as a new design [7].

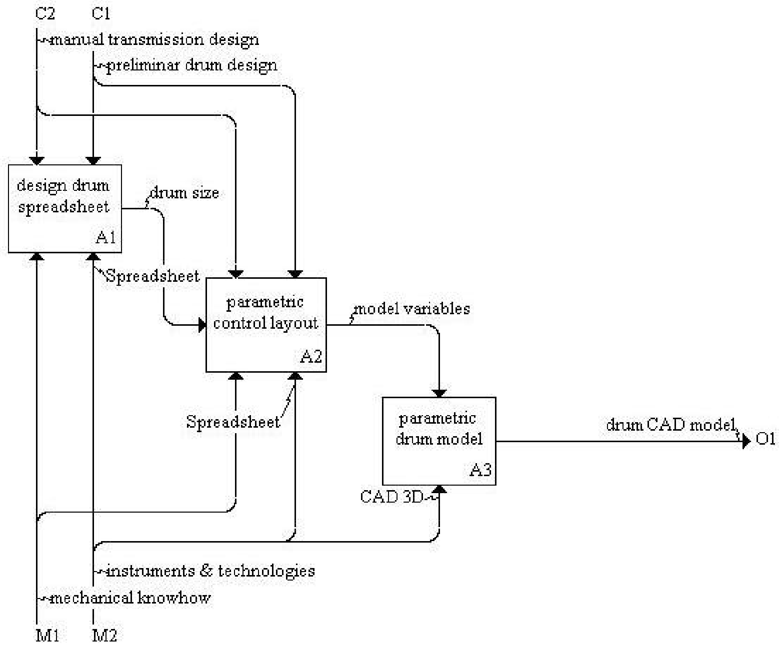

Figure 9: Parametric design of the drum

6. CONCLUSIONS

Methods and tools for the formalisation of the design processes have been investigated, in a *Concurrent Engineering* approach. The use of new 3D design tools and advanced technologies as the parametric *feature based* modelling, can offer to a company a real advantage, not achievable by means of traditional technologies, if a new set up of design process and production of technical documentation is performed. The scope of this philosophy is to represent the design process allowing to capture the aims of the designers and to keep them in time, giving advantages to the designer himself and to those which will review the work.

This systematic approach to the design, integrated to a 3D parametric CAD and to a codification *knowledge-based* tool, permits to obtain a model useful for the redesign phase. With this kind of models a number of repetitive activities performed by the designers and by the drafters are highly reduced, releasing precious resources for the company and improving the quality of the work.

The technical documentation can be used in other ways, e.g. to analyse critically the activities performed in the company, encouraging modifications useful for their optimisation; it also constitutes base for advanced systems of design led by the knowledge.

The above mentioned concepts have been applied for the rationalisation of the design process of a selector for gearbox with semi-automatic command, whose characteristics arise from functional and conceptual analyses.

It has been obtained the completely integration, by means of an interface module, between the parametric variational solid model and the knowledge based model, able to regenerate automatically the model according to the variation of design parameters.

REFERENCES

[1] V. Hubka, E. Eder, *Design science*, Springer, London, 1992.

[2] G.F. Biggioggero, E. Rovida, *Disegno di macchine. Note di progettazione metodica*; Città Studi Edizioni, Torino 1998.

[3] W. Hsu, I.M.Y. Woon, Current reserch in the conceptual design of mechanical products, *Computer Aided Design*, Vol. 30, No. 5, pp. 377-389, 1998.

[4] D.G. Ullman, *The mechanical design process*, McGraw-Hill, 1997.

[5] P. Citti, A. Mazzarenghi, D. Bongini, Quality and safety in mechanical design, *Proc of Int. Seminar on Principles and Methods of Engineering Design*, Napoli, October 1997, pp. 137-160.

[6] N. Cross, *Engineering design method*, John Wiley & Sons, 1999.

[7] L. Ciulla, *Progettazione metodica di un selettore per cambio di velocità a comando semiautomatico per uso automobilistico,* Degree thesis , Relators: F. Cappello, A. Mancuso, Università degli studi di Palermo, A.A. 1999-2000.

[8] M. Vezzani, C. Culla, G.B. Semplici, La progettazione mediante CAD parametrici-variazionali, *Proc. of II Seminario Italo-Español, Progettazione e fattibilità dei prodotti industriali*, Vico Equense (Napoli), June 1998, pp. 215-225.

[9] F.B. Vernadat, *Enterprise modeling and integration*, Chapman & Hall, London, 1996

[10] Draft Federal Information Processing Standard Pubblication, 183; Integration Definition for Functional modeling (IDEF0); December 1993.

[11] G. Concheri, V. Milanese, An engineering knowledge base management tool for dynamic representation of product data, *Proc. X International Conference ADM*, Firenze 17-19 Settembre 1997, pp. 445-454.

[12] L. Candy, Representations of strategic knowledge in design, *Knowledge-Based Systems*, No. 11, pp. 379-390, 1998.

[13] Magneti Marelli, *Sistema elettronico di controllo della trasmissione: "Selespeed per Ferrari 355 F1", Costruzione e funzionamento.*

[14] F. Cappello, A. Mancuso, N. Scimeca, "*Methodical Design Approach Using Parametric and Associative CAD System: the Design of the Front Suspension of a Racing Car*"*;* 6th Int. Design Conference DESIGN 2000 Dubrovnik May 2000.