CHAPTER 7

A part description model for the preliminary design

Michel Tollenaere, Philippe Belloy, Serge Tichkiewitch
Laboratoire Sols, Solides, Structures
INPG / UJF / URA CNRS 1511 , 38041 Grenoble, France

The model presented in this chapter is based on a feature concept in a simultaneous engineering context. We have particularly developed, in addition to the usual features, some specific features we call 'skin features' and 'skeleton features'. These last one respectively represent:

1 the functional surfaces of the parts, that are integrated elements of the technological solutions chosen by the designer in order to answer to the required functions. These surfaces are given with their tolerances, their accessibility areas...
2 the material flow which has to link the skin features in a same part.

These features allow the description of the product into a structure we think to be minimal in order to be able to question the different trades. In particular, we show how, starting with the intermediate objects composed of skins and skeletons, the toolers and the forgers can propose some more pertinent constraints.

Decreasing both the cost of mechanical parts and the time to market involves new design methods. These methods must take into account the whole set of constraints which can appear at any time of the product life. After we have described why the actual organisation of design, qualified of linear design, cannot answer to theses specifications, we show how the features allow a dialogue between the different trades who are involved at a time or an other during the life of the product. An integrated design modeller will be proposed, and its use and profit are shown through the design of a car gear-box component.

R. Soenen et al. (eds.), *Advanced CAD/CAM Systems*

7.1. DESIGN METHODOLOGY

7.1.1 . The bounds of the linear design

The traditional organisation of design and manufacturing of mechanical products is based on a chain of actors who have each a well defined task. We successively find marketing actors, minding the needs, having to evaluate the considered market for the product, and so, giving the first specifications. Then the designers (usually called draughtsmen in France) transform these specifications into an admissible answer during preliminary project. This last actor may ask a mechanical engineer to check some important dimensions or to simulate the behaviour of the product for some critical situations. The following actors are specialists of prototyping, then of planning, manufacturing, selling, maintenance, and perhaps of recovery, recycling or destruction. So the very design phase is centred on the draughtsman work, the designer. He starts from specifications, that is to say all the functions the product must respect, in association with the environmental and marketing constraints.

Let's have a look on the work of the designer who has to realise an hydraulic jack, at the time when the main characteristics of the jack has been defined, that is to say that the dimensions of the body, the piston, the rod are known. He has now to close the jack chamber, allowing the assembly of the piston and the rod, and to ensure a possibility for the oil exchange. His thermodynamic knowledge remembers him that the maximum output of the jack is given with a minimal volume of unexchanged oil. The study of these basic functions oblige him to foresee a specific structure "body / cover" in order to allow the assembly, but this involves in addition two secondary functions : fixing the cover to the body and oil-tightness between these two parts. The reasoning of the designer is so to analyse the basic functions, to propose technical solutions in order to respect these basic functions, and in some cases, to deduct new functions he has to take into account. Each eligible association function-technical solution conduct to a variant for the final product. Some of them quickly have to be set aside, others ask some more thorough study [BIG 88].

When the choice of the technological answers is done, (for our demonstration, let's imagine that we have retained : a short cylinder to centre the cover to the body, a toric joint for tightness, screws for fixation, thread hole for hydraulic junction, and cavity for the rod wrapper), the designer must finish the detailed project. He has now to define the geometry of each part. Knowing the functional surfaces which are linked with the technological solutions, the designer' task consists of adding some connecting shapes in order to define part volumes. Indeed, with the actual tools for design, the complete geometrical shape has to be defined in order to compute mechanical stresses, to evaluate planning for manufacturing, ..., in fact, to continue the linear design process. Possible results of the later design process are given in figure 1. The first shape for the cover has been think with a casting rough while the second typically has been foreseen by tooling.

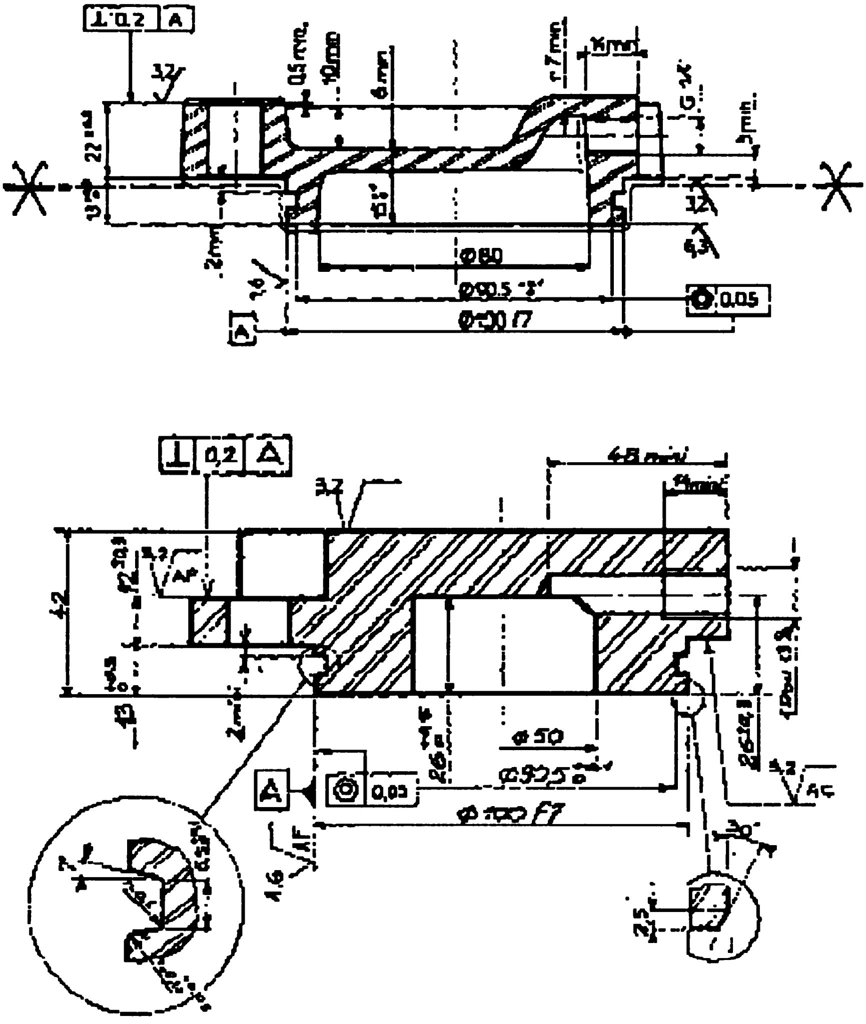


Figure 1 . Two possible answers for the same cover of an hydraulic jack.

Here is the beginning of some interesting problems :

1 which shape has to be to really chosen ? Certainly the first one if thousand of covers are to be manufactured, obviously the second for a unit part. But which is the right choice for 47, 128 or 562 covers ? The answer is the result of an economical study that the process man can only do. But is it possible to question him so early ? And is it also possible to evaluate all the variants ?

2 though we have taken into account a specific manufacturing process, are these parts effectively the best we can imagine with such a process ? Do not dream, because our designer cannot be also tooler, founder, stamper, or metal former.

3 where is the semantic of the technological solutions into the graphical result

of the technical drawing ? The draughtsman yet thinks about a specific hole when he decides that he must have a hole for a screw and that the associated plan used to receive the head of the screw has to be done with a blade linked with the drill. Is it useful to discover this again in order to obtain the cost of the tooling ? Is it also useful to search about the tooling of the toric joint groove for the only reason that we have only three coaxial cylinders and two perpendicular planes ?

Present design tools, which are simply graphical tools, conduct to a waste of information which is very harmful to the rest of the design process. Moreover, it obliges the draughtsman to take some decisions which obviously concern the manufacturer, with the only goal to complete the geometrical definition. It couldn't be admitted for him to deliver an uncompleted design that could be source of various interpretations.

7.1.2 . The stakes of simultaneous engineering

We have just seen that one of the draughtsman's problems is that he has not the ability to treat with the maximum of efficiency the questions which are relevant of manufacturers' knowledge. The reasons of this incapacity are the missing in competencies about other than his own areas or in know-how about trades, and the missing of understanding about consequences that are linked with their decisions. Designers must be able to deal with a problem with a specialist's viewpoint. If we want to talk about the body of a car, are the mathematical equations of the surface of real interest ? A designer will rather be interested in the reflection of the light on it, the stamper will evaluate the maximal strain rate during sheet-metal forming, and the die maker will compute the required tool trajectory. Every body has his own sight, vocabulary, definitions, and must have directly access to his own features.

All these different sights are based on descriptive models allowing the part representation for a specified application. Associated computing models allows to solve the corresponding problems.

Simultaneous engineering must allow to resolve a part of the problems linked with the missing of an actor competencies. The goal is to permit to every trades, concerned at a time or an other with the product definition, to intervene for a just need [TIC 93].

To be able to do this, everybody must :

1 understand the intents of the others,
2 speak into their own language to remain impressive.

A simultaneous engineering tool has to allow :

1 to stock the semantic,
2 to associate it with geometry,
3 to manage the multiple access data [SRI 92],

and above all :

4 to have a possibility for language comprehension,
5 to manage the translation between trades [BRO 93],
6 to permit the multiple sights,
7 to have a possibility for information propagation.

We show here how the object oriented languages allow to realise such a design system, by the creations of :

1 features, or characteristics, materialising the semantic of a trade,
2 knowledge structures on these features,
3 methods, in order to propagate these knowledges.

With the study of the knowledge of the manufacturers, we also show that a translation of these knowledge into the context of the designer allows to take into account at the earliest time the imperatives linked with the production process and so, to optimise the product. It is with this sense that we talk about ***"integrated design"*** [TIC 91].

7.2 . THE DESIGN MODEL

A mechanical product is often made of a lot of parts which compose a mechanism ; the links between the parts are of particular interest on a functional viewpoint.. A mecanism made of a single part is called a structure. At the higher level of abstraction, mechanisms are often represented by kinematic schemes whose goal is to describe the laws for the relative motions between parts. A kinematic scheme is realised with kinematic joints, or pairs, and with links between these joints : these links materialise the parts (or a package of parts in the case of an union). Kinematic connections are associated with functional surfaces, the physical realisation for these connections.

It is in such a context we have realise a design modeller which allows to describe a product starting with its kinematic description, and to extract from this description the useful information for the part design. The description of this modeller will be done with the use of an example of design relative to a selector fork on a gear-box. So, the corresponding product is the gear-box whose kinematic scheme is given in figure 2.

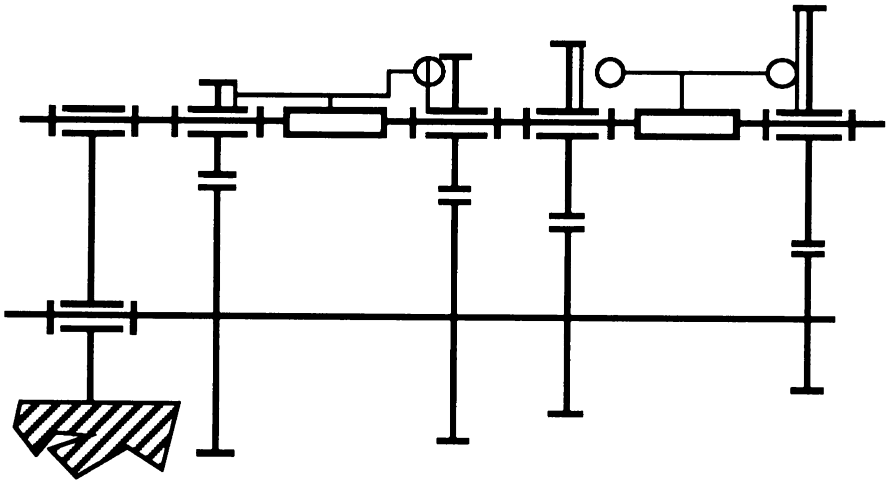


Figure 2. Simplified kinematic schematic of a gear box (command excluded)

Our model in order to describe the products is based on the use of traditional features. We find the part features, the geometrical features and the kinematic features. Part features group the knowledge we have on each part of the mechanism. Geometrical features are the basic geometrical element, mathematically well defined. Constraints are associated to these features : parallelism, perpendicularity, coaxiality... Kinematic features are also current features, but we have attached technological realisation attributes on each.

Into such a modeller, the cinematic scheme associated with the selector fork of the gear-box, and described by these connections :

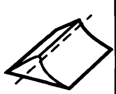
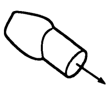
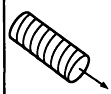
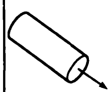
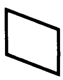
1 a rotational joint with the casing,
2 a ball and socket joint with the command device,
3 the gears are driven by a couple of cylindrical joints pushing and pulling the synchronizer.

It is presented in the A appendix in the form of the computer model. We can see the connections and the other elements of the gear-box : command device, case, synchronizer.

The model we propose to describe the mechanical part is more original. It is based on functional surfaces of the parts and aims to define how the links between these surfaces are realised. In the next section, we shall present two specific features : the **skins** for the functional surfaces and the **skeleton** for the links between these surfaces.

7.2.1. Skin features

Functional surfaces are most often tooled and usually bear the localisation of the boundary conditions of the structure analysis. Though they can also be specific design surfaces (in an esthetic meaning), they are often the materialisation of the mechanical connections. These surfaces are so specific features. Rather than using CSG or B-rep models, we prefer a "skin" based representation similar to the TTRS *(Technologically and Topologically Related Surfaces)* model [CLE 93]. In the TTRS model, a technological surface is classified according to the possible motion that leaves it invariant in 3D space. This criteria leads to make a surface an instance amongst the seven following classes :

TTRS name	Any surface	Prismatic surface	Surface of revolution	Helical surface	Cylindrical surface	Planar surface	Spherical surface
Symbol							
Possible motion	None	Linear translation	Axis rotation	Helical motion	Coaxial rotation and translation	2 translations and an orthogonal rotation	3 rotations

When one associates two surfaces to build a part, there are in fact 28 instances of association. These technological and topological associations of surfaces give the possibility to link the previously defined surfaces with relations about position and quotation. In our model, we have defined the concept of "single skin", a single skin being a TTRS surface with its geometrical tolerance, its surface aspect, its own quotation (a diameter for a boring for instance). The B appendix is a hard copy of the screen which shows the inheritance tree of the skin classes as given into SMECI. We also have defined the concept of "compound skin", allowing the local association of single features.

For the example of the selector fork, this representation leads to consider the following set of "skin" features. Feature A materialises the functional ball and socket joint : it is made up with a male spherical shape associated with the fork. The rotational joint between the fork and the casing is materialised by a composite feature : a bore B and a bore C. The function requires to set up a coaxial relationship between the two features. The rotational joint with the synchronizer are materialised by association of compound boring skin and plan skin (D and E mark on figure 3). A appendix, the description of a part, is a screen copy showing the interface given to the user in order to create or modify skin features and to add quotation relations.

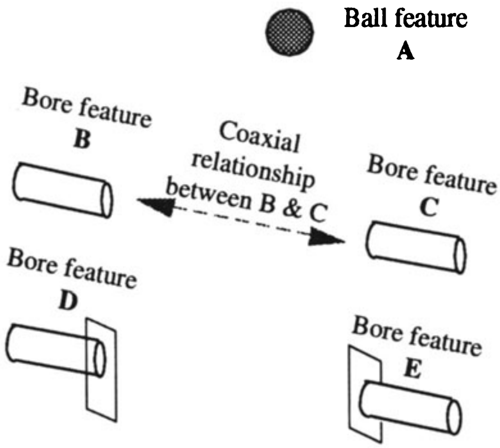


Figure 3. Functional features representation.

7.2.2 . How to link skin features in order to built a part :

Taking as a base a "skin" based model for part description brings out to the following questions : how to constitute a solid definition from disparate pieces of surfaces ? Which facilities are required to handle the model ? During the design process, a designer usually deals with sketches, drafts… which are all excepted 3D solid models. On the other hand, it is a truism that the design of mechanical part is highly dependant on the manufacturing process. It also depends on the expected stresses and strains that seem acceptable. We can verify that the dependence between the shape, the material and the manufacturing process is very strong.

Our work aims at offering a tool for preliminary design of parts, and so we suggest the concept of ***skeleton*** to represent uncompleted definition of part in preliminary stage of the design process. A skeleton is made up of a set of linear or at least 2D entities which prefigures the architecture of the final part. It will be materialised by a flow of material on the final product. Our research proves the benefit of such a concept in a concurrent engineering design environment. We have to note that a different concept of skeleton has been introduced by Lenau [LEN 93]. Lenau's skeleton classes the functional entities for a mechanical part in terms of their architecture and their topology.

The skeleton describes how non functional shapes of a part will be constituted. It appears to us that knowing the skeleton is a necessary step to perform the whole design of the part. On the other hand, knowing the skeleton allows many actors to put constraints on the future shapes. So the skeleton of a part (composed of the skin features ans skeleton features) appears as the minimal structure which gives a unity to a part and which permits the user to question the other people. Of course, we are interested in how the different actors could act at the same time in a parallel design process. Another interesting issue of our research is to give answers to such questions : what is to be change in the part solid description when one decides to change manufacturing technology ? What can be reused in the previous design data ? The minimal structure (skin and skeleton) seems to be the starting of the manufacturer's intervention.

7.2.2.1. Graph description level

Given a set of functional features, it is possible to link the features in a graph description. Attention must be pointed on the fact that as the skeleton prefigures the place where the material will stand, skeleton entities can be directly linked to any functional feature by defining a new skeleton entity : though skeleton entities can either be nodes or links of the graph.

7.2.2.2 Geometric skeleton features

To allow computations, skeleton features must be defined by geometric data. Those data are made of :

1 a kind of geometrical features amongst line, circular arc, circle, spline for linear shapes, plane, surface for 2D skeleton features. (B appendix shows a graph of the skeleton feature classes from our model).

2 constraints of link with the functional features ; the most usual constraint is a hooking point onto the feature. This point has to be defined in the area where the matter will be when we will describe the volume of the part. Figure 5 shows the conceptual state of the selector fork at this step of the design. This state is in correspondence with the second figure in the A appendix.

7.2.2.3. Taxonomy of skeleton features

Working on a set of mechanical parts, we have identify and classify two kinds of skeleton entities according to their topological dimension : linear skeleton features and planar ones.

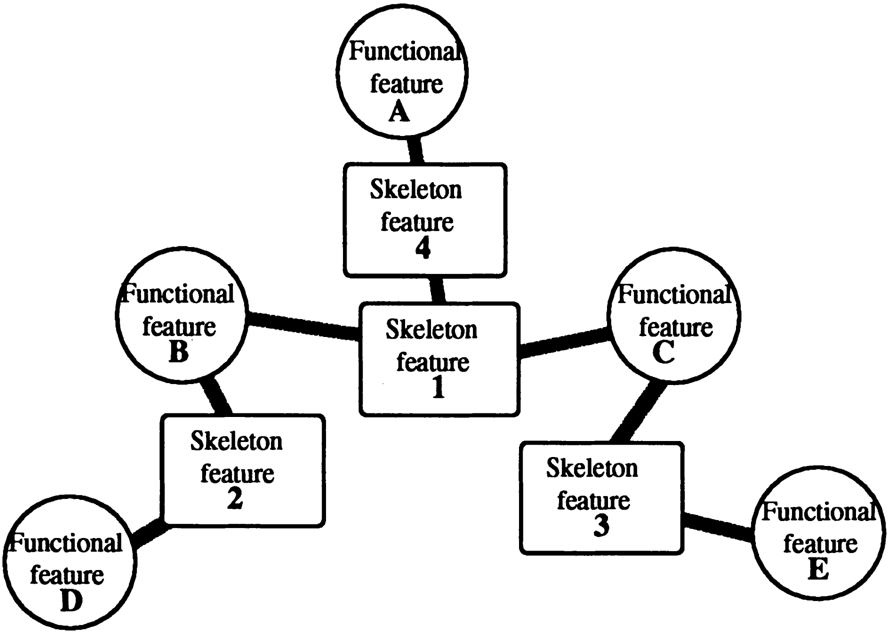


Figure 4. Skeleton graph : preliminary design (disks represent skin features while rectangles represent skeleton features)

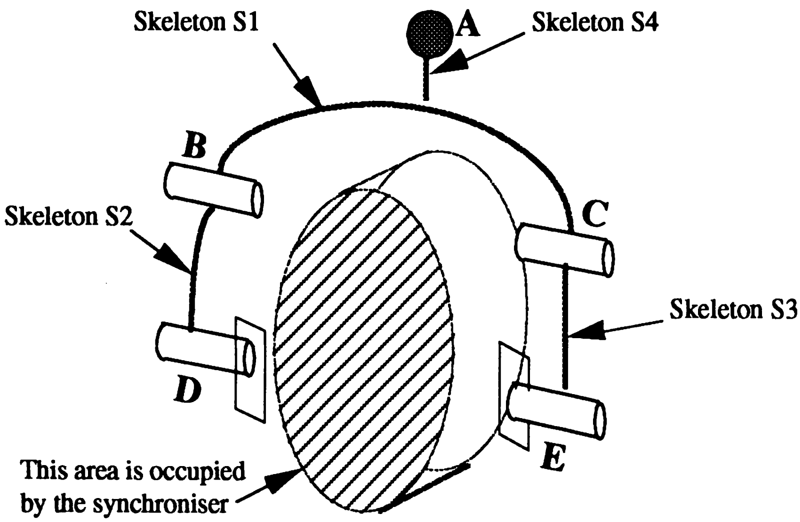


Figure 5. The selector fork and its skeleton features

The figure in B appendix shows the inheritance graph of the features we have implemented in the software prototype. The root class is named skeleton. It is unentreatible, that is to say that no object can be created with its only definition. Its attributes are :

1 a link attribute, which defines the connected skin or skeleton features. This attribute allows to construct the graphs given in appendix.
2 a geometrical shape attribute, for the geometrical parameter defining the shape and the position of the skeleton feature. The geometry defined by these attributes may be transferred to a CAD modeller. This attribute is specialised in any class in order to respect the under sheets of the root skeleton features. By example, this attribute can only be a line for the object names S-straight-line.

The *line-skeleton* class has a "section" attribute that allows to define the section of the matter at any point of the skeleton. A section is a geometrical shape which owns integrated attributes for areas or inertial matrix ; these last attributes can be valued during the design, and this before we know how are the types of the selected sections. If we imagine that a skeleton element has to be loaded with single bending, a maximal displacement constraint has to be transformed into a minimal IGz value, using mechanical behaviour. On the other hand, those sections are strongly constrained by the manufacturing knowledge. Presently, we have constant section for any skeleton feature, but we can imagine some evolving sections. As identically, the class plate-skeleton is defined with a thickness attribute. A first volumic representation is so available when the skin and skeleton features are known for a part.

7.3 . TRADE CONSTRAINTS ON THE MODEL

Starting from the skeleton part description, in the state of the figure 5, we have checked the information (also called constraints) that actors can bring. We have focused on the following trades :

1 cutting tools, process planning and machining manufacturing
2 stamping as the selected process to obtain raw part.
3 structural analysis results.

However, we think that our approach is generic enough in order to be transposed to other trades (sheet-metal forming process, soldering...).

7.3.1 . Machining constraints

Features to be machined are usually functional features so that in machining, what is to be obtained is known without the skeleton knowledge. Unfortunately knowing just a set of features does not bring any information on how it will be possible to machine the features: fixtures possibilities are unknown, accessibility to the feature is unknown, part stiffness is also unknown so that part warping under machining stresses and machining resulting precision is difficult to estimate. In the previous fork example, knowing the skeleton allows requests such as part deflexion to estimate machining accuracy when drilling features D and E. With answers to these requests, we can formulate constraints about section inertia taking into account the wanted precision between the drilling of the D and E features. This kind of request most be cheap in a concurrent engineering environment and it seems unrealistic to use any 3D Solid finite element analysis software tool. Starting with the technical data (by example the CETIM Guides) and with the research done into process planning [VIL 90] [GAM 90] [BRI 92], we have elaborate a lot of relevant production rules for the preliminary design. Two kinds of rules have been defined : the constructive rules, which enhance the model, and the validation rules, which permit to be secure about the designer's quality of work. Later on, we present two rules about the quality of a skin feature for the type boring whose first is relative to the operation induced by the request quality for the boring.

1 Constructive rule

If a bore skin feature is realised by a drilling operation,
no boring operation exists for the previous feature
and the feature quality is better than H9 quality
Then a boring operation is required for the feature

2 Validation rule

If a bore skin feature is realised by a drilling operation,
no boring operation exists for the previous feature
and the feature quality is better than H9 quality
Then Ask the designer
Whether the present quality is functional and
if it can be modified and equal to 9
Then Modify feature quality to be H9
Else make a boring operation for the feature

7.3.2. Stamping constraints

Stamping is a manufacturing process that induces constraints both on the shapes and material of the stamped parts. The main constraints come from the possible extraction of the part from the dies and the ability of the material flow to fill the dies efficiently : this induces draughts, web, flashe... The skeleton of the part (with skin features and skeleton features) is sufficient to question the stamper in order to obtain some constraints for the next step of the design : for exemple, the skeleton can induce the position of the die parting plan and in consequences the direction of the strike. This choice guarentees we have a good stability of the blocker into the die, whatever the detail of the part geometry. Of course, this parting plan has some influence on the design as it obliges the direction of the draughts, it decides also if we can preform holes and borings or if we must consider the tooling of them after stamping. In any case, the stamping knowledge is strongly linked with the tooling one : the draughts of the stamper part and the position of the blockers for the tooling are directly closed by example.

1 Rule 1

If a boring skin feature is such as its axis is not parallel to the strike direction od the stamper process **Then** we have to add a plug to the boring (as this boring cannot be sketche with a web).

2 Rule 2

If a boring skin feature has a plug, **Then** we must tool it with a drill .

3 Rule 3

If during the tooling, a point for a blocker has to be taken on the flash, **Then** we have to verify the general tolerances allowed to the tooler (because of the significance of the relative position betwenn the two dies).

7.3.3. Mechanical analysis results

In such a context of integrated design, we must have new tools for physical analysis and theses tools have to be fast. These tools have to give some information on mechanical constraints or deflections without knowing the complete geometry of the part, but they must be used in the first steps of the design, just when we know the skeleton. The results of course cannot be the exact field of stresses but the value of the minimal for a section or an inertia. They also have to be usable for the entire life cycle of the part, as stresses during tooling could be critical for the required precision. The present physical model has such a capacity, that we have to show in few example. Skin features are the main elements for the transmission of the efforts : they must be size in a first approach with a static analysis using the contact pressure. These computations do not ask a great knowledge on the geometry of the part, and are often realised with the initial choice of the joint [BOH 93]. We must have the knowledge of the skeleton in order to size some integral operators (area, inertia...) in accordance with the expected deflections or levels of stresses. These operators are used in a second time to choose the dimensions of the characteristics of a section when we have to fix the type of these sections. Fast computer analysis tools are so very important during design and have to be used in association with the manufacturing knowledge in order to conceive and to size a mechanical part with the most judicious manner.

7.4. DESIGN PROCESS

Previous sections have described the different features that the designer can handle, we show in this section how they may be handled. The mechanical designer has at disposal an interface in order to create, modify or kill previous features. For any state of its product model, he can ask the help of the stamping and tooling expertise in order to increment his job (constructive rules) or to verify the matching of his job with the rules of the art (verification rules). The designer is transformed into a conductor, using some help in manufacturing or analysis without being himself a specialist of these domains : he can request such help by example in order to choose the skeleton, evaluate the section or the thickness of the skeleton features, transform a tooled part into a stamped part, as we have focused our work on these points today. The design process could be schematised as in figure 6.

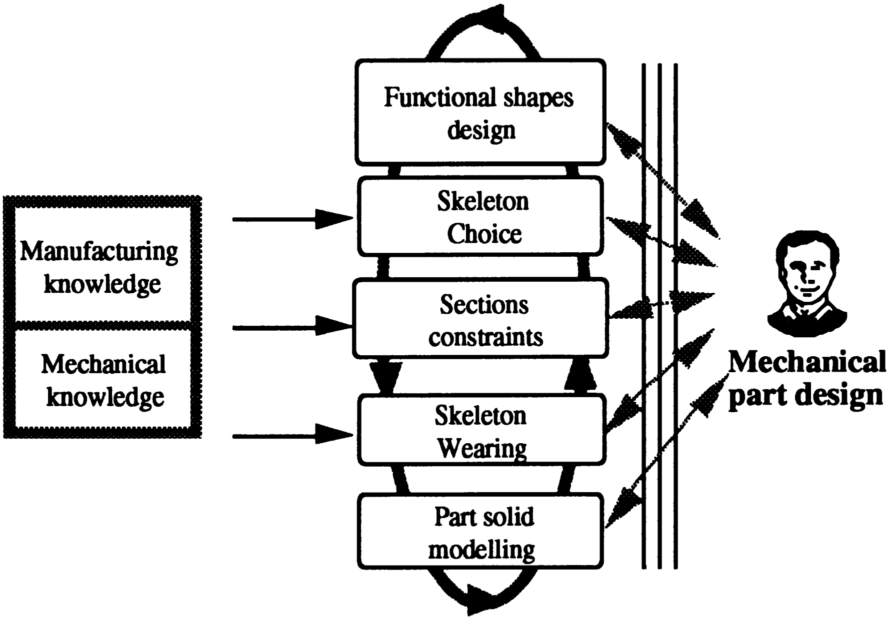


Figure 6. The design process model

Requests for graphic display can be interpret at any time in order to transfer the current state of the known geometrical elements towards a CAD modeller.

7.5. EXPERIMENTS OF THE SOFTWARE PROTOTYPE

Implementation of the software prototype is SMECI[1] based. Geometric features can be transferred into Euclid *IS* to take profit of a powerful commercial CAD software. The prototype contains a set of feature classes in order to describe the components of a system or part (cinematic, skin, skeleton, section,...) and a second set for the manufacturing features (stamping, tooling, tools and tooling operations...). The developed interface allows to build mechanisms with their parts and their relations. The visualisation can be done with graph using the icon of the features as nodes and relation between features as links (appendix A).

The specification and implementation of the manufacturing production rules are in progress.

7.6. OPEN ISSUES

Our goal during this research is to be able to give to designers an integrated tool in term of manufacturing trades (stamping and tooling). At any time the corresponding constraints are accessible and give information on the state of the design. With such

1 SMECI is an AI package including object based language, inference engine... provided by ILOG (France)

an approach, we hope to minimise the sources of no quality and to avoid the go and return between departments. A part description model has been proposed, using features, and run today into a computer system. The knowledge is always growing such as the number of production rules. In a parallel time, we develop an interface between our modeller and the CAD system Euclid *IS* . This interface is useful to transfer geometric features and so to visualise the part in order to add to the trade knowledge the know-how of the draughtsman who usually has a fifth sense to forecast not so bad sizing of part with its eyes.

7.7. ACKNOWLEDGEMENTS

This work has been supported by Matra Datavision Company that authors greatly want to thank.

7.8. REFERENCES

[BIG 88] BIGAND M., Générateur automatique de géométries admissibles en optimisation de forme, Thèse de Doctorat de l'Université Paris VI, Avril 1988

[BOH 93] BOHATIER C., GUILLOT J., TROUSSE B., "Approche Fonctionnelle de la Conception et Définition d'un atelier de Conception Intelligent", *International Symposium on design in 2000 and beyond. Strasbourg* (Novembre 1992).

[BRI 92] BRISSAUD D., Système de conception automatique de gammes d'usinage pour les industries manufacturières, Thèse de doctorat de l'Université Joseph Fourier, Grenoble, janvier 1992, France

[BRO 93] BRONSVOORT W. F., JANSEN F. W., "Feature modelling and conversion - Key concepts to concurrent engineering", *Computers in Industry* (21) 1993, p 61-86

[CLE 93] CLÉMENT A., RIVIÈRE A., "Tolerancing versus nominal modeling in next generation CAD/CAM system", *Proceedings of the 3rd CIRP Seminars on Computer Aided Tolerancing*, Cachan, France, April 27-28, 1993, p 97-114.

[GAM 90] GROUPE GAMMA, *La gamme automatique en usinage,* Edition Hermes, 1990, France.

[LEN 93] LENAU T., MU L., "Features in integrated modelling of products and their production", *Int. J. Computer Integrated Manufacturing,* 1993, vol. 6 n°1&2, p 65-73.

[SRI 92] SRIRAM D., SHAMIN A., LOGCHER R., "A transaction management framework for collaborative Engineering", *Engineering with Computer,* Vol 8, N°4, 213-232

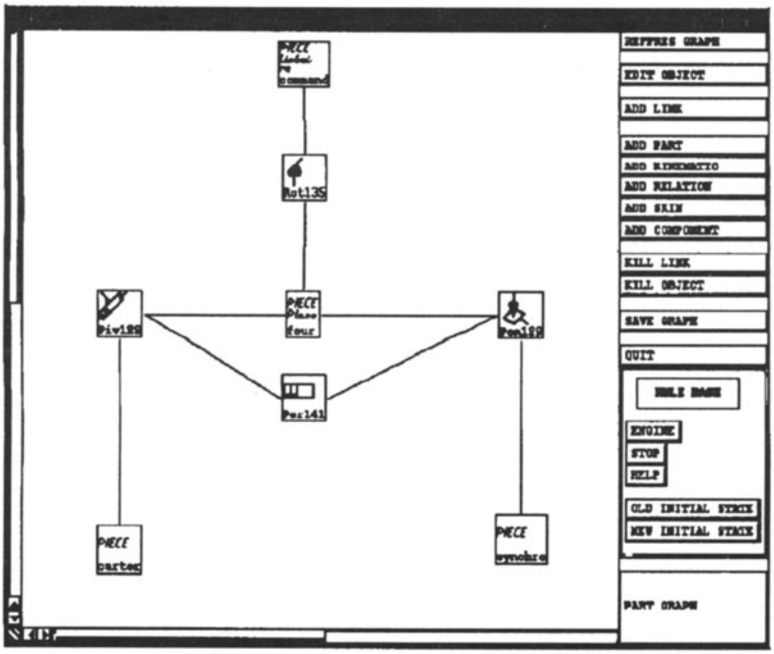
[TIC 91] TICHKIEWITCH S., "Integrated computer aided design for mechanical part", *Advances in computer science application to machinery, Proc. of the international conference on CAD of Machinery,* September 1991, Pékin, China.

[TIC 93] TICHKIEWITCH S., TOLLENAERE M., "Toward integrated design process" *Colloque COMES 93* Clermont Ferrand 17, 18 Mai 1993, France.

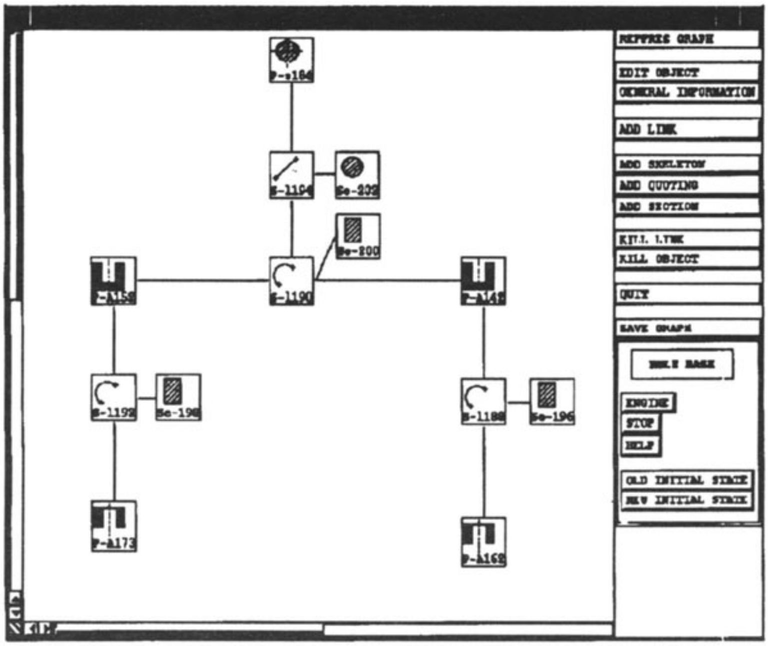
[TOL 92] TOLLENAERE M., "Quel modèle produit pour concevoir ?" *International Symposium on design in 2000 and beyond.* Strasbourg (Novembre 1992).

[VIL 90] VILLENEUVE F., Génération Ascendante d'un processus d'usinage. Proposition d'une formalisation de l'expertise. Application aux entités alésages. Thèse de l'école centrale paris, février 1990, France.

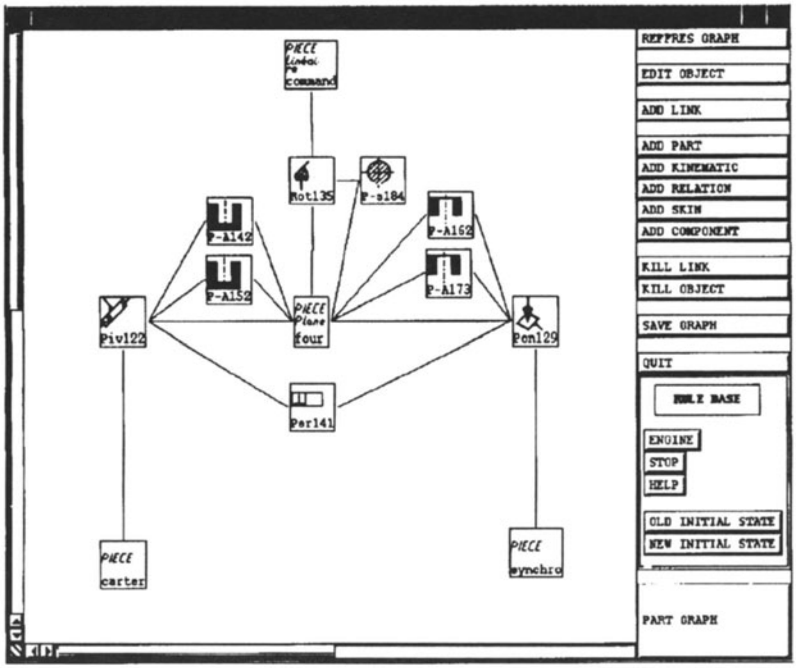
Appendix A



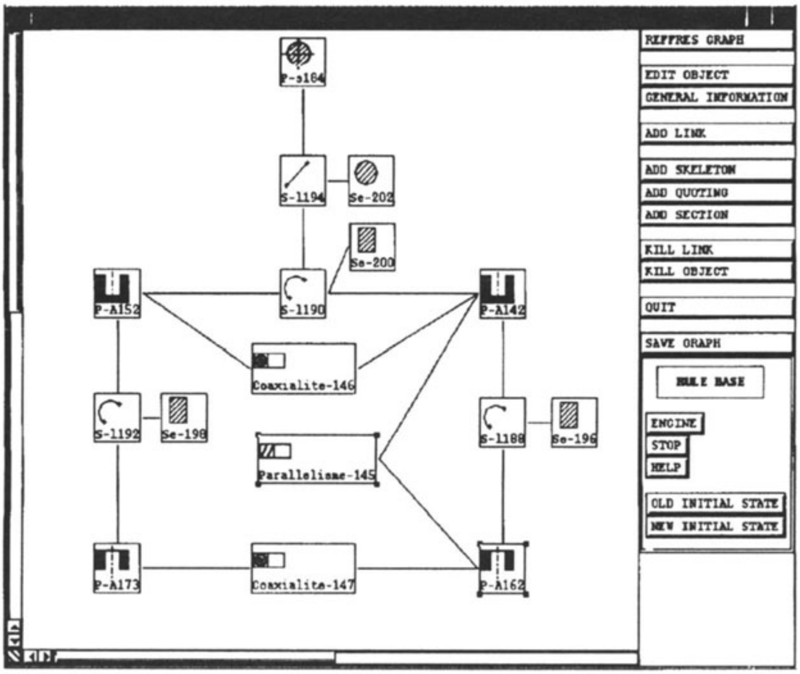
Example of mechanism



Example of part

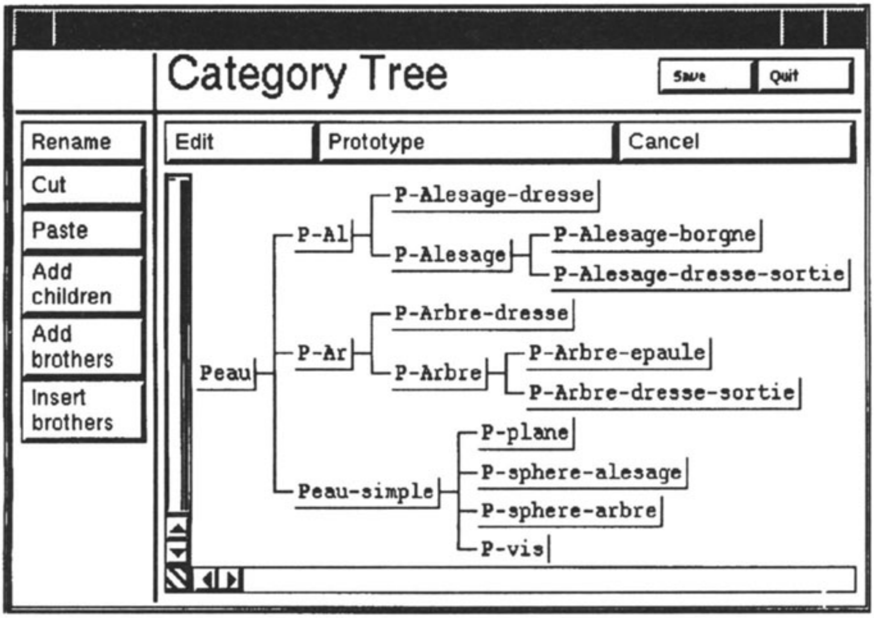


Constraints on mechanism

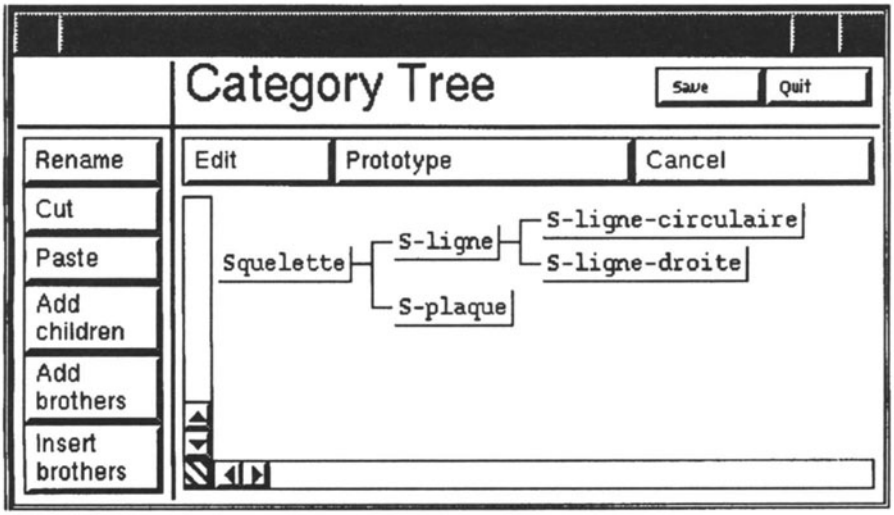


Constraints on part

Appendix B



Skin features



Skeleton features