Automatic Dimensioning of Cylindrical Parts in an Intelligent Feature-Based Design System

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Abstract: This paper describes a method for automatic dimensioning of cylindrical parts represented by features. The identification of the entities in the part that need to be dimensioned is performed based on the part's features, which contain information about the part's geometry and the assembly relations between parts. The dimensioning analysis is based on the concept of functional dimensioning, which presupposes that the position of the part in the assembly is known, and then the dimensions to be controlled are determined, and they are assigned automatically to the part by the system. The dimensions are determined with the aid of an expert system.

1. INTRODUCTION

The assignment of dimensions to a drawing is an important design activity, since dimensions are responsible for the way in which a part will function in the assembly, and it should meet the requirements of the product. Of course, the dimensions also influence part manufacture.

There are many recommendations in standards that help the dimensioning activity. Such recommendations also standardize the way of representing mechanical parts. Adequate dimensioning of a product to be manufactured leads to necessary and sufficient dimensions that guarantee its proper operation after its manufacture. The dimensioning task depends on the experience of the designer and his/her vision of the product, and in the case of less experienced designers, inadequate dimensions may be the result. Therefore, it would be important that a CAD system could assign dimensions to parts based on their functions in the assembly.

With the application of features in CAD systems, the information in the model is no longer treated as lines and circles, but as engineering entities such as a shaft, a hole and a chamfer. With the use of such entities, it becomes possible to identify the assembly relations that may exist between the entities, and in this way the functional dimensions may be obtained automatically.

This paper describes a method for automatic dimensioning of cylindrical parts represented by features. A modeling system is used to model parts and assemblies, and the method consists of traversing the assembly's data structure in order to identify the contacts between parts. Based on the information about the contact surfaces, the more important dimensions for each part are determined with the help of an expert system.

2. BACKGROUND

In the manufacture of mechanical parts, dimensions and tolerances are two important attributes used to describe the geometrical and functional properties of a part. According to Yeun et al. (1988), the dimensioning task presupposes the knowledge of the function of the part in the assembly, so that the function is performed adequately. Thus, the assembly enables the verification of the actual dimensions that have to be controlled (i.e. the ones that should receive tighter tolerances).

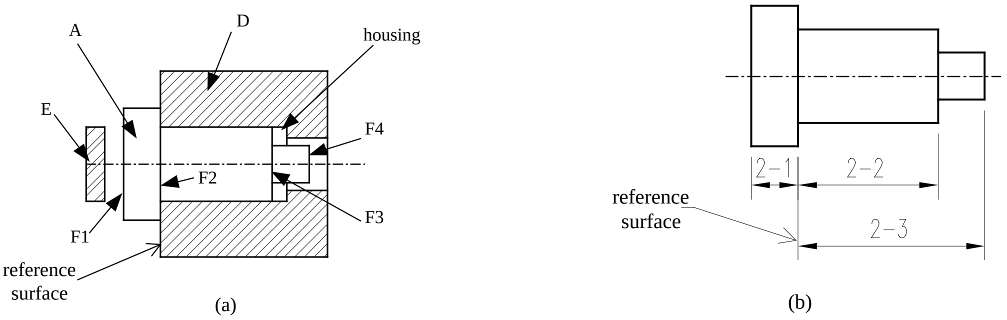
Yeun et al. (1988) proposed an automatic dimensioning system using a CSG solid modeler, through the modeling of one part. The dimensioning information is extracted from this CSG model, and is performed according to the standards. Those authors mention that automatic dimensioning is obtained directly from the solid modeler, which can generate adequate dimensions for a given solid without any explicit specification of a dimensional reference by the user.

Panchal et al. (1992) developed a system to perform dimensioning, called CATAP, which includes the assignment of design tolerances. The tolerance information is stored in a database, and the user selects it interactively. The identification of the dimensions to be controlled is done through the interpretation of DXF files, which include files that represent each part in the assembly, while one file represents the assembly. By interpreting lines, arcs and circles, features such as a shaft and a hole are identified. By comparing the location of the lines, the software identifies the assembled parts that will receive tighter tolerances.

Zhang (1996) proposes the approach of "simultaneous tolerances for design and manufacture", which aims at assigning tolerances based on both the function specified for the product and on the manufacturing problems that are likely to occur.

Ropion (1974) presents two examples that show the importance of the analysis of the assembly to obtain the design dimensions for each part. On those examples, one part is used in different applications, which results in different dimensions.

In figure 1(a) part A is assembled on part D, and face F2 must be in contact with part D; face F1 may be at any position, but it must not interfere with part E. There must exist some clearance between face F3 and the bottom of the housing in part D. Lastly, face F4 must not go beyond the end of part D.



(a) (b)

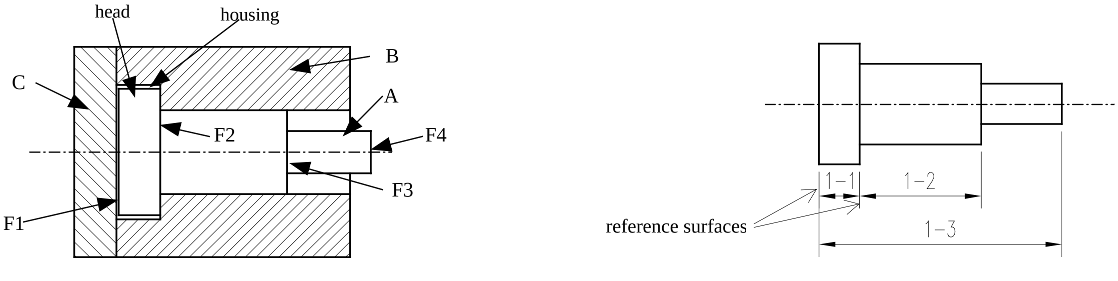
Figure 1. *(a) Working conditions of an assembly; (b) Resulting axial dimensions for part A (Ropion, 1974)*

Based on the above description of how this assembly operates, an analysis is performed in order to determine the necessary dimensions of the part, taking the contact face F2 as the reference surface:

- Dimension 2-1: Considering that face F2 is constantly in contact with part D, it is necessary to constrain the position of face F1 with respect to F2, linking both faces;
- Dimension 2-2: This dimension corresponds to the length of the cylindrical shaft limited by face F3, and this face is constrained by the depth of the housing in part D. This dimension is also a function of the contact face F2, which locates part A;

- Dimension 2-3: Similarly, face F4 must be linked with the contact face F2, which links parts A and D

In the example illustrated in figure 2(a), part A is positioned in part B and constrained axially by cover C; the head of part A (i.e. the cylindrical shaft with the largest diameter) must have a small play in its housing. Therefore, contact is possible with faces F1 and F2; face F3 must always be within part B; face F4 must be beyond the end of part B by a certain length, so that the part is used properly. The minimum value of this length is set.



(a)

(b)

Figure 2. *(a) Another example of an assembly; (b) Resulting axial dimensions for part A (Ropion, 1974)*

The resulting dimensions are as follows (see figure 2(b)):

- Dimension 1-1: This is the length of the head, which must be compared with the depth of the housing of part B (figure 2(a)) in order to allow the necessary play;
- Dimension 1-2: Face F3 must not go beyond the end of part B, and this is prevented by face F2 at the bottom of the housing. Therefore, the position of face F3 should be constrained by a dimension that connects it to face F2;
- Dimension 1-3: Face F4 must go beyond the end of part B by a fixed amount, which will be minimal if face F1 is in contact with cover C. Thus, the contact with face F1 must be considered, which results in the link between faces F4 and F1.

The method for automatic part dimensioning is based on the reasoning depicted above. A description of this development is given in the next sections.

3. METHODOLOGY

In order to determine the functional dimensions of a part, it is necessary to model the assembly to which the part belongs. Therefore, it is necessary a system that allows the representation of a group of parts, and that the system provides mechanisms to analyze and describe the assembly relations, enabling the determination of the functional dimensions.

The system that was used in this work to model assemblies is FeatCAD, which is described in (Maziero 1998, Maziero et al. 2000). This is an intelligent feature-based design system, which aims at supporting the design activity, taking into account the assemblability and manufacturability of the parts. Geometrical and technological information can be stored in this system, and this information includes the representation of assemblies of parts. After the parts are assembled, it is possible to identify and store the assembly relations (i.e. the contact surfaces) between the parts, which are used to generate a description of the assembly.

In order to determine the contact surfaces, the algorithm traverses the data structure that represents the part, searching for faces with diametrical and axial contact with the other parts in the assembly. After the contacts are identified, they are registered in the product's data structure.

In order to identify the contact surfaces, the shaft/hole couplings and axial contact surfaces are searched in the assembly, because they are the critical parts for machining and assembly. Surfaces that do not have contacts usually do not need a rigorous dimensional control.

Finally, the information about the contact surfaces is used for the assignment of dimensions, which is done with the help of an expert system.

4. IMPLEMENTATION

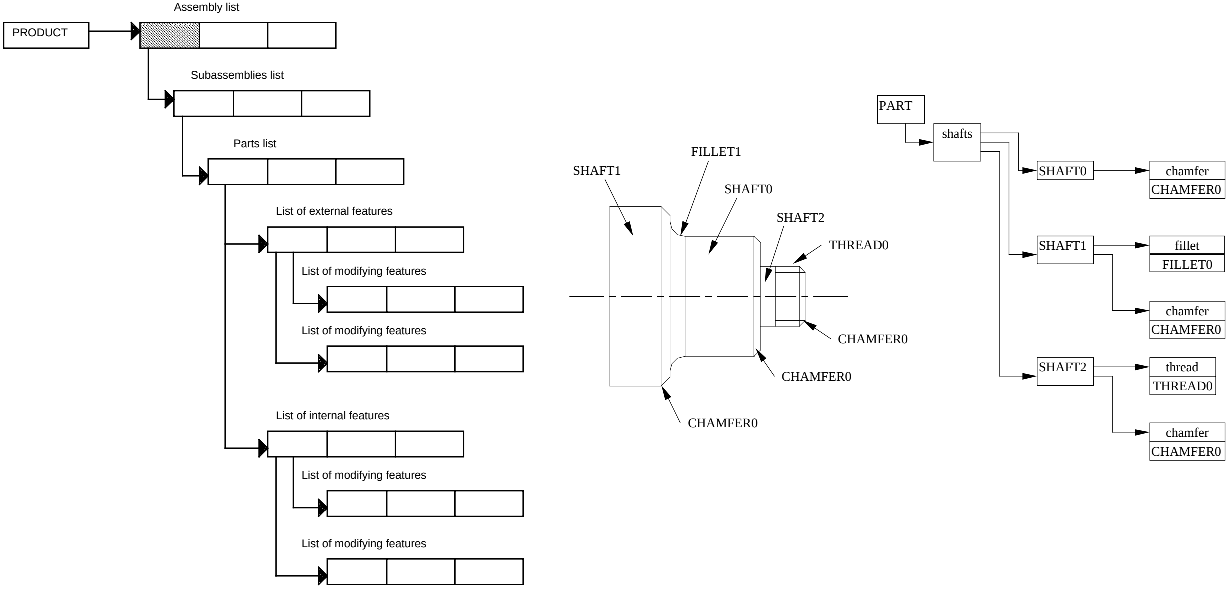
A description of the steps involved in the implementation of the automatic dimensioning method in the FeatCAD system is given in this section.

4.1. Information Representation

The FeatCAD system (Maziero 1998) allows the representation of cylindrical parts through axisymmetric features, and other tasks can be performed on the representation. According to their shape, cylindrical features are classified in this system as: *simple*, *compound* and *high level* features. An example of a compound feature is a *circular pattern of holes*, while a *bolt* is an example of a high level feature. Simple features may be *elementary* or *combined*. A *threaded hole* is an example of a combined feature.

Elementary features may be *basic* or *modifying*. The basic features are a *shaft* and a *hole*, whereas modifying features are those that alter the basic features, such as a *chamfer*.

The structure illustrated in figure 3(a) shows the system's structure, in which an assembly may be composed of many subassemblies, which in turn may have many parts. Each part may be composed of basic features (shaft and hole), and modifying features may be associated with each of them. Figure 3(b) illustrates an example part and its data structure.



(a) (b)

Figure 3. *(a) The data structure; (b) An example part*

4.2. Identification of the Dimensions to be Controlled

Since the functional dimensioning depends on the contact surfaces, and the parts considered in this problem are cylindrical, the contacts occur either at the cylindrical surface of the feature (shaft/hole coupling), or at its bases. When the contact occurs at the cylindrical surface, this is called *diametrical contact* (figure 4(a)). In the case where the contact occurs on the bases of the cylinder, this is referred to as *axial contact* (figure 4(b)).

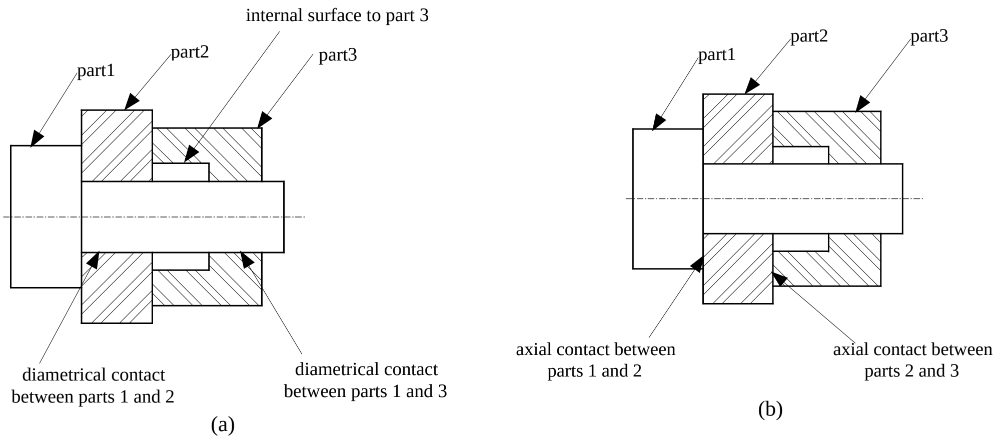


Figure 4. *Assembly with (a) diametrical contacts and (b) axial contacts*

The diametrical contacts reveal surfaces that must have their diameter dimensions controlled. If a part has a diametrical contact with the surface of another part, these surfaces must receive a dimension and a tighter tolerance so that it functions properly when assembled.

The axial contacts reveal the surfaces that must be controlled on the axial direction of the part. If a part has an axial contact surface with another part, this surface becomes a reference surface. In the case that a part has contacts with two surfaces that belong to two different parts, both surfaces must have a dimension between them, so that when the parts are assembled, they occupy the adequate position in the assembly. An example of this situation is given in figure 5.

So, all dimensions in a part that end in surfaces that have contact with the surface of another part, are dimensions that must receive, besides the basic dimension, tighter tolerance specification. On the other hand, dimensions that link a surface to any other surface are considered as secondary dimensions.

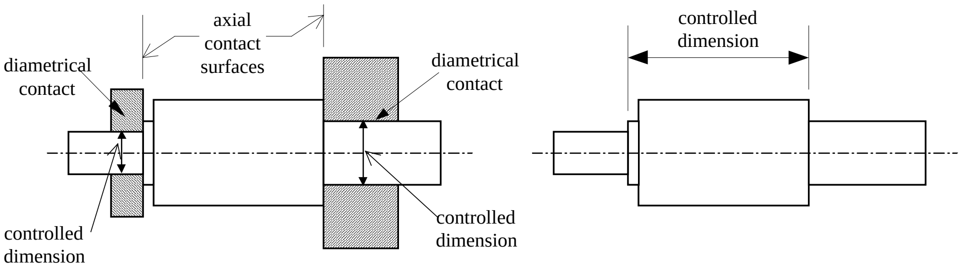


Figure 5. *Assembly that results in a controlled dimension*

4.3. Intra and Inter-Feature Dimensions

When performing detail design, the first phase corresponds to the execution of the graphical representation using basic dimensions, i.e. problems related to the functionality of the couplings are not considered. In order to assign tolerances, first it is necessary to identify the most important elements in the assembly, and which of them should have a controlled dimension.

As shown above, in the analysis of cylindrical parts, two types of dimensions become very important: the diametrical and the axial dimensions. These dimensions may be intra or inter-feature dimensions. The intra-feature dimensions refer to only one feature in a part. For instance, the diameter of a shaft feature belongs to this category, and this can be observed in dimensions D1, D2 and D3 in figure 6. On the other hand, an inter-feature dimension associates two features. For example, the axial dimensions L1, L2 and L3 in figure 6 are considered inter-feature dimensions. It should be noticed that even dimension L1 is considered here an inter-feature dimension, although it represents exactly the length of a single shaft feature.

The intra-feature dimensions are considered attributes of a feature, whereas the inter-feature dimensions are attributes of the part.

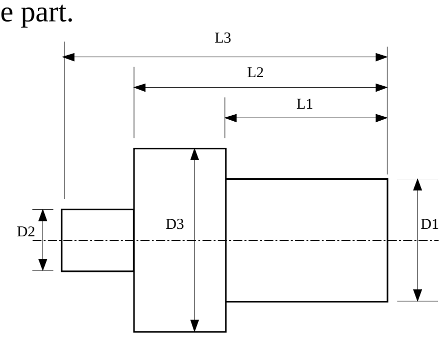


Figure 6. *Intra-feature and inter-feature dimensions*

4.4. Diametrical Dimensions

As mentioned above, in order to perform functional dimensioning, it is necessary to identify which of the shaft/hole couplings effectively have diametrical contact (see figure 4(a)).

The parts that have effective contact are considered an assembly pair, and so they must have an additional piece of information, which is the tolerance of this coupling. On the other hand, the parts that do not form an assembly are assigned a basic dimension and a standard tolerance, which is specified by the user for all the diametrical dimensions that are less important.

The FeatCAD system identifies automatically the features that have contact (i.e. the features whose basic diameters are equal). Then, these features are assigned intra-feature dimensions.

If the shaft and the hole are superposed as shown in figure 4(a), in the case of parts 1 and 2, and parts 1 and 3, these are considered assembly pairs. However, the surface in part 3 that does not have contact with part 1 is assigned a basic dimension and a standard tolerance.

As a result, the diametrical dimensions to be controlled are shown in figure 7, which correspond to D13, d21 and d31.

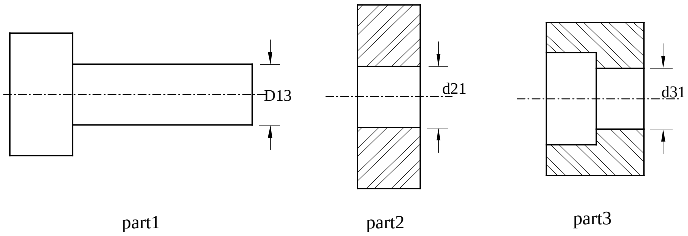


Figure 7. *Diametrical dimensions to be controlled in the parts in figure 4(a)*

4.5. Axial Dimensions

The axial dimensions are identified based on the axial contacts that occur between the parts. In figure 4(b) an assembly is represented where two axial contact surfaces are identified, i.e. one between part1 and part2, and the other between part2 and part3. These surfaces are identified through the analysis of the assembly. The assignment of axial dimensions is done after identifying the features with diametrical contact.

The FeatCAD system searches for the coincident faces of the features in different parts that coincide. The system begins the search with a part in the assembly, searching for another part that has a feature with a face that coincides with one of the features in the first part. If there is any coincident face, this one becomes a reference surface for dimensioning.

Figure 8 illustrates the axial contact surfaces identified in each part in figure 4(b), and these surfaces become reference surfaces. The reference surfaces in this figure are: F12 in part1, F21 and F22 in part2, and F31 in part3. Surfaces F12 and F21 coincide, as well as F22 and F31 (see figures 4(b) and 8).

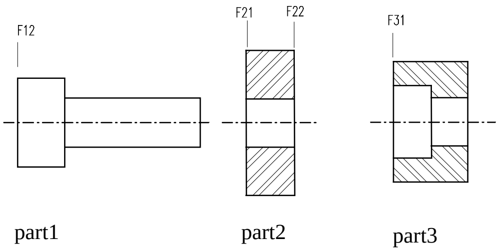


Figure 8. *Axial contact surfaces in the assembly shown in figure 4(b)*

The assignment of the axial dimensions is, however, a little more complicated than diametrical dimensions. The diametrical contact occurs if there is: (i) contact between two surfaces in two features (shaft/hole) belonging to two distinct parts; (ii) superposition between features. This is sufficient to characterize that the diametrical dimension must be controlled. In the case of axial dimensions, controlled dimensions result from the analysis of each assembly and its operation.

The application of the algorithm described in (Maziero 1998) to an assembly model allows the identification of these surfaces as axial contact surfaces. However, before performing the actual dimensioning, it is necessary to choose the dimensions in the part that are more important, and this is done considering the assembly that the part belongs to.

4.6. Assignment of Axial Dimensions

In the case of axial dimensions to be controlled, a more rigorous analysis must be performed in order to determine which should be in fact the axial dimensions, and what these dimensions represent. In order to perform this analysis, the reference surfaces that were identified during the assembly analysis must be known. These surfaces are considered as a starting point for determining the location of the axial dimensions in the part.

The reference surface may be positioned at any location in the part, depending on how the part is assembled. Since this analysis is performed on a single part, some concepts are pointed out below in order to obtain dimensions that take into account the reference surfaces.

A dimension is defined as having an initial point, a final point and a basic value (figure 9), and the positive difference between the points corresponds to the value of the dimension. Tolerances may be assigned to this dimension.

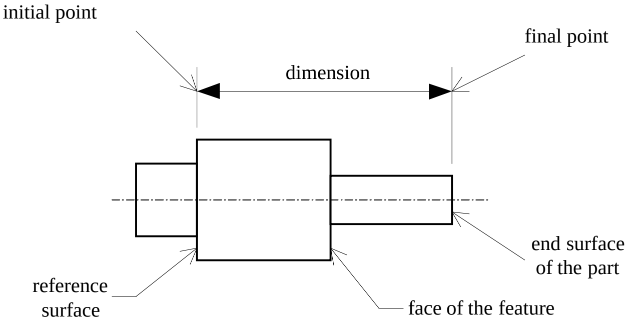


Figure 9. *Definition of a dimension*

A reference surface is taken as the initial surface of a dimension (e.g. face F12 in figure 10(a)), and the face of a feature (or of a part) may become the final surface of a dimension (figure 10(a)). Thus, dimensions L1 and L2 stem from the initial point in F12, and the final point of L1 corresponds to the final face of the shaft, which coincides with the final surface of the part on the right-hand side. The final point of L2 is located on the initial face of the shaft feature located on the left-hand side of the part.

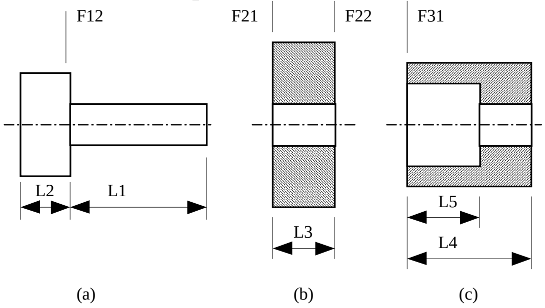


Figure 10. *Axial dimensioning with one or two reference surfaces*

In the case of a part whose two end surfaces are also reference surfaces (such as faces F21 and F22 in figure 10(b)), one will contain the initial point and the other the final point of the dimension, resulting in dimension L3. Figure 10(c) illustrates the situation of a part with only one reference surface (F31) that coincides with the end surface of the part. The reference surface then contains the initial point for dimensions L4 (external) and L5 (internal).

If there is more than one reference surface, and these surfaces are not located on the ends of the part, they may contain the initial point of a dimension and the final point of another dimension. For instance, in figure 11, reference surfaces F1 and F2 are not located on the ends of the part. Thus, dimensions L1, L2 and L3 originate from the initial point in F1. Dimension L4 connects both reference surfaces, and either of those surfaces can be assigned the initial or final point of the dimension. Dimension L5 has its initial point on face F2.

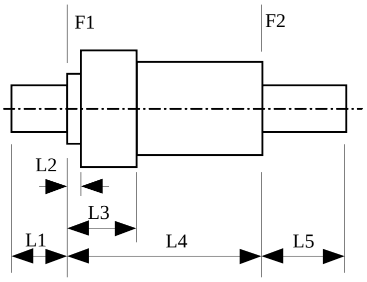


Figure 11. *Axial dimensions with two reference surfaces*

It should be noticed that the dimensioning criterion illustrated in figure 11 consists of considering the position of the face of the feature that is nearer the reference surface as the final point of the dimension, and the initial point as being located in the reference surface itself (this is the case of dimensions L2 and L3, as well as dimensions L1 and L5).

4.7. Algorithm to Identify Axial Dimensions

In order to identify the axial dimensions, an algorithm was implemented that determines the existing contacts between the parts in the assembly (Maziero et al. 2000). Initially a procedural algorithm identifies the assembly references and the features to be dimensioned, and then an expert system performs the identification of the dimensions to be assigned, and those that should receive tighter tolerances.

This algorithm works as shown in figure 12. Initially, the algorithm obtains the first assembly reference in the part (i.e. an axial contact surface) that is nearest the absolute coordinate system, and searches for a shaft that is located to the left of this reference. If such shaft exists, the initial face of this feature (i.e. the one on its left) contains the final point of this dimension, and this information is stored in the product's data structure.

Then the algorithm checks whether there is another shaft located on the left of the reference, and also to the left of the previously identified shaft. If this shaft exists, a new dimension is created linking the reference with the initial face of this shaft. Otherwise the search is done toward the right of the reference, in the same manner. If a shaft is found on the right-hand side, this information is sent to the expert system, which decides whether the dimension should be assigned or not.

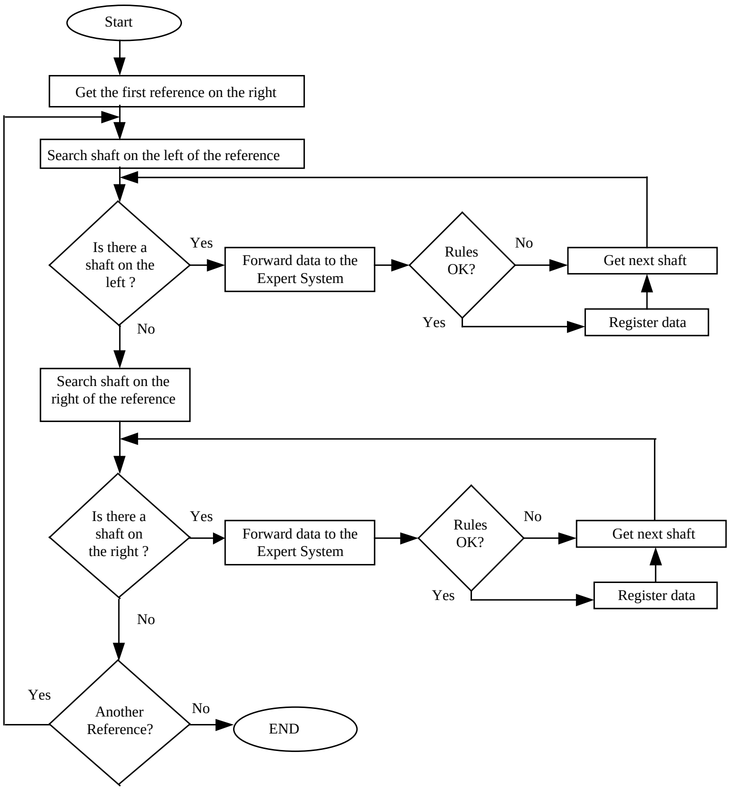


Figure 12. *Flowchart that describes the steps for the identification of axial dimensions*

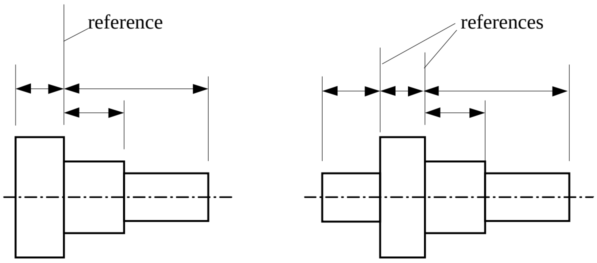
4.8. Knowledge Base for Dimensioning

The knowledge base for dimensioning considers the following: (i) the analysis of the assembly references of the part (that contain the initial point of the dimension); and (ii) the analysis of the shaft features that do not superpose the reference surface.

The assignment of dimensions to a part is subdivided into two types: (i) when the part has a single reference surface for assembly (figure 13(a)); and (ii) when there is more than one reference surface for assembly (figure 13(b)). In this paper, the assignment of the axial dimensions takes into account the external dimensions relative to the shaft features. Some of the rules in the knowledge base are presented below.

(a) Dimensioning with one reference surface:

RULE 1: Dimensioning to the right-hand side and one reference surface (figure 14)
IF (NumberOfReferences = 1) & (MediumPoint = InitialPoint) & (FinalPoint > InitialPoint) & (ReferenceType = external) THEN Flag = 0 Direction = 1



(a) (b)

Figure 13. *Assembly references for dimensioning (a) dimensioning with one reference; (b) dimensioning with two references*

If the part has only one axial contact surface, it has a single reference for dimensioning (NumberOfReferences = 1). In this case, the “MediumPoint”, which is the average of the distances between two references on a single part, is considered equal to the initial point of the dimension. The condition (ReferenceType = external) considers that the dimensioning is for an external feature (in this case, a shaft). If this dimension has its final point on the right-hand side of the reference surface (FinalPoint > InitialPoint), the dimension is accepted (Flag = 0), with its direction towards the right-hand side (Direction=1).

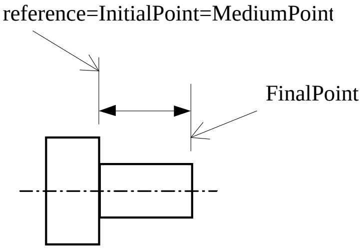


Figure 14. *Dimensioning with a single reference*

(b) Dimensioning with more than one reference surface:

RULE 2: Dimensioning to the left-hand side if there is more than one reference surface, and this dimension refers to the first reference (figure 15(a))

```
IF   (NumberOfReferences > 1) & (MediumPoint = InitialPoint) & (FinalPoint < InitialPoint)
     & (ReferenceType = external)
THEN     Flag = 0
         Direction = -1
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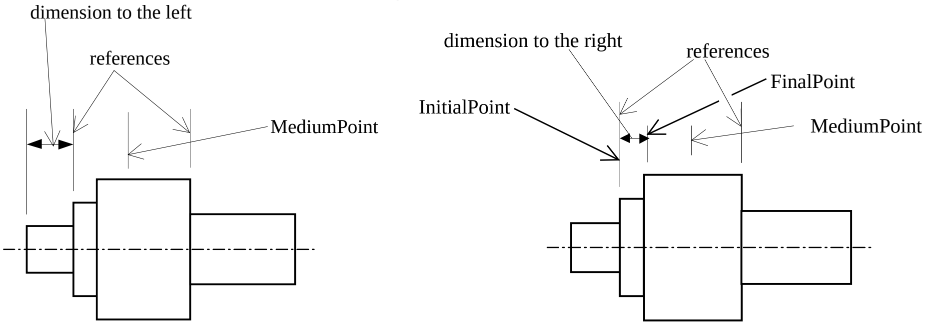
For the first reference surface, the medium point is considered equal to the initial point of the dimension (MediumPoint = InitialPoint). In this case, the dimension is inserted to the left-hand side of the first reference of the part (see figure 15(a)).



(a) (b)

Figure 15. *Dimensions (a) to the left of two references and (b) to the right of two references*

RULE 3: Dimensioning to the right-hand side if there is more than one reference (figure 15(b))

```
IF    (NumberOfReferences > 1) & (MediumPoint > InitialPoint) & (FinalPoint > InitialPoint)
      & (ReferenceType = external) & (FinalPoint < MediumPoint)
THEN      Flag = 0
          Direction = 1
```

In this case, the dimension is inserted to the right-hand side of the first reference surface. The element to be dimensioned has a smaller length than the medium point between both references (i.e. MediumPoint > InitialPoint; FinalPoint > InitialPoint; FinalPoint < MediumPoint). Therefore, the resulting dimension is towards the right (Direction = 1).

5. EXAMPLE

An example is presented in this section, in which an assembly was modeled in the FeatCAD system, and this is shown in figure 16. The part that is considered for the dimensioning analysis is the stepped shaft. After the assembly analysis was performed, the dimensions were assigned automatically, based on the information about the identified contacts (see figure 17).

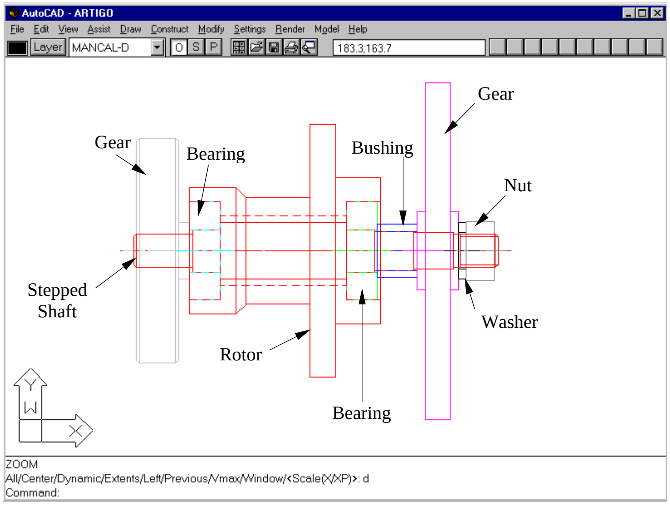


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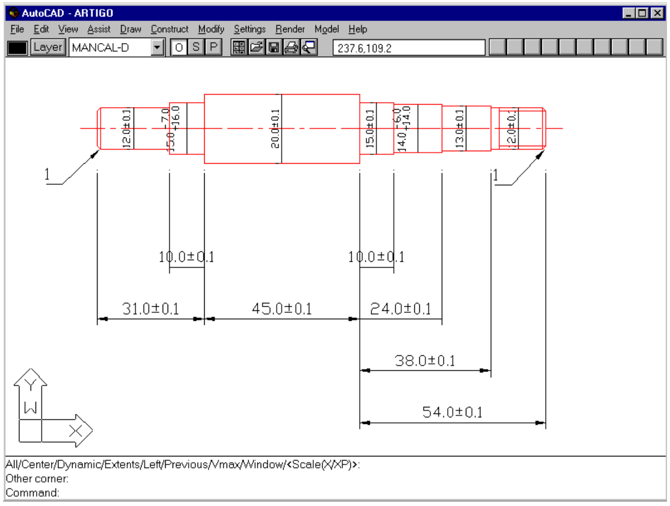
Figure 16. *Assembly of parts modeled in the FeatCAD system*



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All/Center/Dynamic/Extents/Left/Previous/Vmax/Window/<Scale(X/XP)>:
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Figure 17. *Complete dimensioning of the stepped shaft*

6. CONCLUSIONS

The activity of computer-automated dimensioning, besides speeding up the process of detail design, enables the storage of detailed information about the design, allowing a complete analysis of the design information. This information (i) may be quickly obtained in the case of future manufacturing demand; and (ii) may be used by different departments in a Concurrent Engineering environment.

In order to perform automatic dimensioning, the system must have: (i) information about the assembly, and (ii) an intelligent module that allows analyses to be performed on the assembly model in order to assign dimensions and tolerances. In this work an expert system shell was used, whose knowledge base contains rules to identify contacts in the assembly, and to perform automatic dimensioning.

The proposed dimensioning system is advantageous economically, since the dimensions are obtained quickly, which reduces the execution time of detail design. Also, since the dimensions indicate the functional surfaces, these help the designer see the really necessary dimensions.

Since functional dimensioning characterizes the operation of the parts, it is believed that the designs dimensioned through this system will have greater reliability, and will be executed in a shorter time.

Traditionally the assignment of dimensions is a time-consuming activity, and it depends significantly on the experience and understanding of the problem by the designer. Even when some software today allows automatic dimensioning (p.ex. SolidWorks (1999)), such dimensioning process refers to some dimensions that were used to model the part, not taking into consideration the interaction between the parts that compose the assembly.

One of the limitations of the proposed approach is that the implementation of the expert system takes a long time, and demands a significant amount of people.

7. EQUIPMENT AND SOFTWARE USED

The FeatCAD system runs on a Pentium 100 microcomputer, and it was developed under the graphical platform AutoCAD for Windows. The programming language used was C++, and the expert system shell used was CLIPS.

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