

Intelligent location-dimensioning of cylindrical surfaces in mechanical parts

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Abstract

This paper presents an intelligent dimensioning approach to generate location-dimensions of the cylindrical surfaces in mechanical parts, for their two-dimensional drawing automatically from their three-dimensional part models based on feature extraction. The key issues include the strategies and methods to establish an order of priorities for location-dimensioning of the cylindrical surfaces in mechanical parts, to eliminate their location-dimension redundancy, to determine location-dimensioning scheme, to assign the necessary location-dimensions to suitable views, and to locate them in reasonable positions for each view using artificial intelligent techniques. Based on the approach, a corresponding software prototype was developed. Finally, it is demonstrated, from an example of location-dimensioning, that the location-dimensions of all the holes in the multi-spindle headstock of a modular machine tool, were generated successfully using this intelligent dimensioning software prototype. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Currently, CAD technology has been applied widely and two-dimensional graphic representations of parts can be generated quickly and automatically from their solid models, but dimensioning is still done interactively by users. Interactive dimensioning is time-consuming and it is easy to make mistakes. Some advanced computer-aided drafting systems have had the function for automatic dimensioning, based on the solid models of parts, but its dimensioning cannot be accepted according to drawing standards and the requirements of facilitating manufacturing, inspection, and assembling. For instance, there are many unnecessary or redundant dimensions. Some dimensions are not in the correct positions, and some cannot satisfy the requirements from datum feature and dimension chain for the ease of manufacturing, inspection, and assembling. After automatic dimensioning, a lot of interactive operations are still needed to obtain effective dimensions. Therefore, the operation is still complicated and time-consuming. Furthermore, the quality of dimensioning still depends on the designer's technical competence and experience.

In order to dimension parts correctly and automatically, an intelligent dimensioning system is needed. The main

elements and work flow of the intelligent dimensioning system designed are shown in Fig. 1 and illustrated briefly as follows.

1. Build a three-dimensional solid model for the machine part concerned using CSG (constructive solid geometry) tree structure and B-Rep (boundary representation) data structure [1].
2. Cluster the faces of the part into three groups: (a) plane, (b) cylindrical surface, and (c) other surface (including sculptural surfaces).
3. Dimension for each group respectively.

The first and the second groups are dimensioned by intelligent approach, and the third group is dimensioned interactively since this is more complicated. The intelligent dimensioning approach for the first group has been discussed in another paper [2]. The second group includes internal cylindrical surfaces (i.e. holes) and external cylindrical surfaces. Their dimensions fall into two main groups: size dimensions, such as diameters and lengths of cylindrical surfaces, and location-dimensions that position their axes or centers. Since their intelligent size dimensioning has been introduced in another paper [3] and the principle of location-dimensioning for external cylindrical surfaces is similar to that for internal cylindrical surfaces, this paper describes an intelligent dimensioning approach to generate location-dimensions

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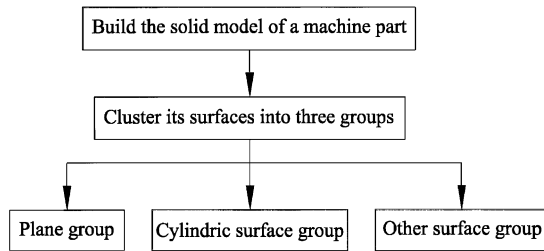


Fig. 1. Elements and workflow of intelligent dimensioning system.

for internal cylindrical surfaces (i.e. holes) automatically from their three-dimensional part models, based on feature extraction [4–10]. The key issues include the strategies and methods to establish an order of priorities for location-dimensioning of internal cylindrical surfaces in mechanical parts, to eliminate their location-dimension redundancy, to determine location-dimensioning scheme, to assign the necessary location-dimensions to suitable views, and to locate the dimensions in reasonable positions for each view using artificial intelligent techniques. Based on this approach, a corresponding software prototype was developed. Finally, it is demonstrated by means of an example of location-dimensioning of the holes in the multi-spindle headstock of a modular machine tool, that the location-dimensions of all the holes in it were generated successfully using this intelligent dimensioning software prototype.

2. Elements and workflow of intelligent location-dimensioning for holes

The elements and workflow of an intelligent location-dimensioning system, designed for internal cylindrical surfaces or holes in mechanical parts, are illustrated briefly as follows.

1. Establish an order of priorities for location-dimensioning of all the holes in a mechanical part according to the requirements of facilitating manufacturing, inspection, and assembling.
2. Eliminate their location-dimension redundancy and determine dimensioning scheme, i.e. determine the necessary location-dimensions from all the possible location-dimensions of the holes.
3. Assign the necessary location-dimensions to suitable views in the detailed drawing of a part.
4. Determine the reasonable positions of location-dimensions in each view, and dimension them.

The following sections will describe the above steps in more detail.

3. Order of priorities for location-dimensioning of holes

Location-dimensioning processes are similar to the

crystallizing process. The datum features (planes or axes of holes) must be determined first, like a crystallizing center, and the positions of main holes relative to the datum features are then dimensioned from them. Those main holes positioned can be taken as new crystallizing centers and other holes relative to them can then be dimensioned from them until all the holes in the mechanical part are positioned. Different ‘crystallizing processes’, i.e. selecting different datum features and dimensioning different holes from the datum, will result in different location-dimensioning schemes. However, the location-dimensions of all the holes should be positioned to facilitate manufacturing, inspection, and assembling. The reasonable location-dimensioning can be controlled by the order of priorities for location-dimensioning of holes. Therefore, the strategy and method to establish the order of priorities for location-dimensioning of all the holes in a mechanical part is very important and must be established carefully.

3.1. Establishing the order of priorities for location-dimensioning of holes

In a mechanical part with n -holes, there are the following number (N) of hole-pairs [11], the relative location-dimensions of which are possible to be dimensioned:

$$N = C_n^2 = \frac{n(n-1)}{2} \quad (1)$$

These hole-pairs can be expressed as a vector, D :

$$D = \{d_1, d_2, \dots, d_i, \dots, d_N\} \quad (2)$$

Each hole-pair, d_i , can be: the one between a hole and a datum hole or an auxiliary datum hole; the one between the holes with transmission relationship; the one between the center hole of a set of holes lying on a same circle and the hole not in the set; the one between the center hole of a set of holes lying on a same circle and the hole in the set; the one between the holes lying on a same circle; the one between a hole in a set of holes lying on a straight line and a hole not in the set; the one between the holes in a set of holes lying on a straight line; or others. These eight types of hole-pairs have different weights (w_j) for the priority of location-dimensioning, which can be expressed as:

$$W = \{w_1, w_2, \dots, w_j, \dots, w_8\} \quad (3)$$

where $0 \leq w_j \leq 1$ and

$$\sum_{j=1}^8 w_j = 1.$$

Their values were selected by us, then adjusted, based on many practical dimensioning, and determined until all the dimensioning met the requirements with these values.

After analyzing the type of every hole-pair, an $8 \times N$

matrix (M) can be formed as follows:

$$[M] = \begin{bmatrix} m_{11} & m_{12} & \dots & m_{1N} \\ m_{21} & m_{22} & \dots & m_{2N} \\ \vdots & \vdots & & \vdots \\ m_{81} & m_{82} & \dots & m_{8N} \end{bmatrix} \quad (4)$$

The element of the matrix, m_{ji} , is equal to one when d_i belongs to the j -th type of hole-pair, and, otherwise, is equal to zero. Thus, the priority of each hole-pair, V_i , can be calculated as:

$$V_i = \sum_{j=1}^8 m_{ji} w_j^2 \quad (5)$$

It is possible that a hole-pair belongs to one type twice or more times. For instance, a hole-pair may belong to two sets of holes lying on two circles, respectively. Thus, its priority becomes much higher if the weight is not squared. In order to prevent these hole-pairs from obtaining unreasonable priority, the weight is squared to reduce the increment of its priority for maintaining correct order of priorities of different hole-pairs. The hole-pair with the larger value of V_i has priority for dimensioning.

3.2. Establishing the order of priorities for location-dimensioning of hole-pairs with the same priority value

After calculating the priority of each hole-pair, it is possible to get more than one hole-pair with the same value of priority (V_i). In this case, the priority for location-dimensioning of the hole-pairs should depend on the order of priorities of the two holes in the pairs, since the hole in the pairs can be the one that has transmission relationships with other holes, the center hole of a set of holes lying on a same circle, the one lying on a same circle with other holes, the one lying on a same straight line with other holes, or others. These five types of holes have different weights (g_k) for priority, which can be expressed as:

$$G = \{g_1, g_2, g_3, g_4, g_5\} \quad (6)$$

where $0 \leq g_k \leq 1$ and

$$\sum_k^5 g_k = 1.$$

Their values were selected first by us, then adjusted based on many practical dimensioning, and determined until all the dimensioning met the requirements with these values.

If there are h holes in the hole-pairs with the same priority value (V_i), a $5 \times h$ matrix (E) can be formed after analyzing

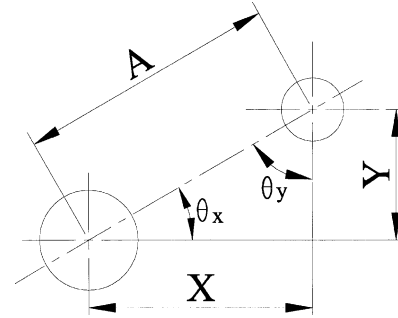


Fig. 2. Five possible location-dimensions between two holes.

the type of each of h holes, as follows:

$$[E] = \begin{bmatrix} e_{11} & e_{12} & \dots & e_{1h} \\ e_{21} & e_{22} & \dots & e_{2h} \\ \vdots & \vdots & & \vdots \\ e_{51} & e_{52} & \dots & e_{5h} \end{bmatrix} \quad (7)$$

The element of the matrix, e_{kl} , is equal to the number of times that hole H_l belongs to the k -th type of holes. For instance, the second hole, H_2 , has transmission relationships with two holes. In this case, the hole belongs to the second type of holes twice, and the element, e_{22} , equals to two. Thus, the priority of each hole can be calculated as:

$$U_l = \sum_{k=1}^5 e_{kl} g_k^2 \quad (8)$$

The reason for squaring the value of g_k is the same as that for Eq. (5). For each of the hole-pairs with the same priority value, there are two related holes, which have their corresponding priority values (U_l). The hole-pair with larger root-mean-square of priority values of its two related holes has priority for dimensioning.

4. Eliminating location-dimension redundancy

4.1. Location-dimension redundancy

There are five possible location-dimensions for determining the relative location between two holes: the one along X-coordinate axis, the one along Y-coordinate axis, the distance between the centers of the two holes, the angle between the centerline and X-axis, and the angle between the centerline and Y-axis, as shown in Fig. 2.

In fact, only two of them are needed and the other three are redundant. If the datum planes are used, location-dimensions of the hole are the two along two coordinate axes as shown in Fig. 3(a). If the two holes have a transmission relationship, it is normal to dimension the distance between their centers and the one along a coordinate axis as shown in Fig. 3(b) and (c). Sometimes, the one along another coordinate axis is also dimensioned with brackets as an auxiliary

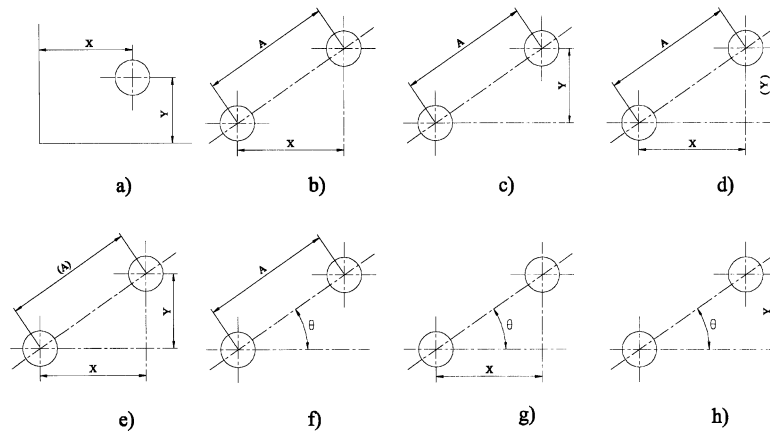


Fig. 3. Eight combinations of necessary location-dimensions between two holes.

location-dimension to facilitate manufacturing, as shown in Fig. 3(d). If two holes are machined in a coordinate boring machine, it is better to give two coordinate location-dimensions and to dimension their center distance with brackets as an auxiliary location-dimension as shown in Fig. 3(e). Besides, their two location-dimensions can also be a combination of an angular dimension with the center distance or a coordinate dimension as shown in Fig. 3(f)–(h).

For a part with n holes, there are $2n$ coordinate location-dimensions, $n(n-1)/2$ center-distances, and $n(n-1)$ angular dimensions, that is, $n(3n+1)/2$ location-dimensions in total. Since each hole needs only two location-dimensions, it is enough to position $2n$ location-dimensions, and other dimensions are redundant. If holes lie on a same circle or same straight line, their necessary location-dimensions will even be less than $2n$. For instance, there are four holes in Fig. 4, which have eight coordinate location-dimensions, six center distances and twelve angular dimensions, i.e. 26 possible location-dimensions in total. However, it is enough to position only three location-dimensions, since three holes lie on a same circle and are equally spaced, one of them lies on a coordinate axis of the circle, and the fourth hole is the center hole of the circle. The other 23 location-dimensions are redundant. Therefore, the second key problem is how to select the necessary location-dimensions from those possible to eliminate the location-dimension redundancy.

4.2. Dimensioning feature vector of holes

As illustrated in Fig. 2, each hole has five possible location-dimensions. The dimensioning feature of the i -th hole can be expressed as:

$$S_i = \{s_1, s_2, s_3, s_4, s_5\} \quad (9)$$

where s_1, s_2, s_3, s_4 , and s_5 are the dimensioning features of five possible location-dimensions (i.e. $X, Y, L, \theta_X, \theta_Y$) respectively, and can be 'F', 'FF', 'R', 'FR', or 'N'.

1. Dimensioning feature 'F' indicates that this location-

dimension originates from a datum feature or a fixed hole. If there are two 'F' in its vector as shown in Eq. (9), the position of this hole has been fixed and there is no need to add any other location-dimension to it.

2. Dimensioning feature 'FF' is only used for s_3 , and indicates that its two center distances with two fixed holes have been dimensioned. If s_3 is 'FF', even if other elements in its vector are not 'F', its position is fixed.
3. Dimensioning feature 'R' indicates that this location-dimension originates from a non-fixed hole. In this case, its position is determined relatively, but not fixed.
4. Dimensioning feature 'FR' indicates that this hole has the same type of location-dimensions (i.e. X, Y, L, θ_X , or θ_Y) with a fixed hole and a non-fixed hole respectively.
5. Dimensioning feature 'N' indicates that this location-dimension has not been positioned.

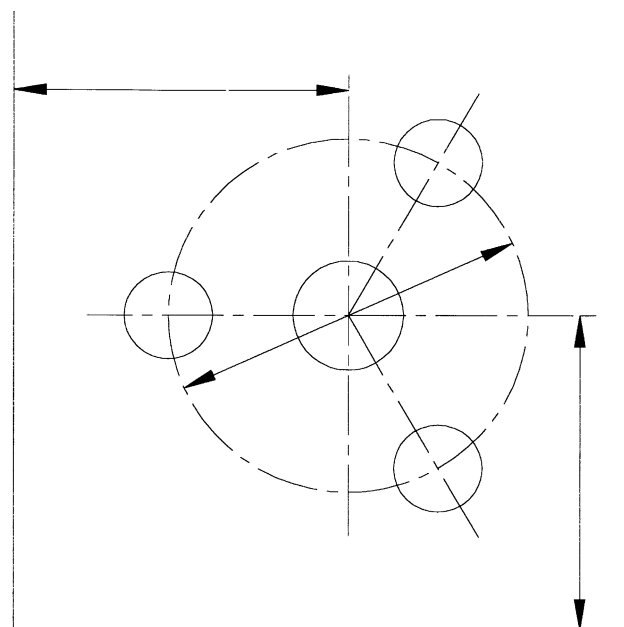


Fig. 4. Necessary location-dimensions of the three holes.

4.3. Strategies and methods for eliminating the location-dimension redundancy

In the beginning of location-dimensioning, five elements in the dimensioning feature vector of each hole are all 'N', i.e. $S_i = \{N, N, N, N, N\}$, since no location-dimension has been positioned. The datum holes and the two coordinate location-dimensions of each datum hole from the datum feature of design or manufacturing are first determined interactively by the user. The auxiliary datum holes, if needed, and the two coordinate location-dimensions of each auxiliary datum hole from the datum holes, are also determined interactively by the user. Thus, 'F' will be assigned to s_1 and s_2 in their dimensioning feature vector, i.e. $S_i = \{F, F, N, N, N\}$. Then, based on the order of priorities of hole-pairs, the one with largest priority value(V_i) will be considered to be dimensioned first. Let the two holes in the pair being dimensioned be A and B. The possibilities will be as follows.

4.3.1. Hole A and Hole B are not fixed

In this case, the feature of the location-dimension being dimensioned in the vector of Holes A and B will be changed from 'N' to 'R' if their original feature are 'N', from 'F' to 'FR' if their original feature are 'F', or kept as 'R' or 'FR' if their original feature are 'R' or 'FR'. Then, the tag numbers of Holes A and B and the type of the location-dimension being dimensioned (i.e. X, Y, L, θ_X , or θ_Y) will be stored into a database called 'relative dimension database'.

4.3.2. Hole A is fixed but Hole B is not fixed

In this case, there is no need to modify the dimensioning feature vector of Hole A. However, the vector of Hole B will be modified, based on the existing dimensioning features in its vector, as follows.

1. In the case that there is no 'F' in its vector: the feature of the location-dimension being dimensioned will be changed from 'N' to 'F' if its original feature is 'N', or from 'R' to 'FR' if its original feature is 'R'.
2. In the case that there is one 'F' or 'FR' in its vector already and s_3 is not 'F' or 'FR'.
 - If the feature of the location-dimension being dimensioned is not 'F' or 'FR', the feature of the location-dimension being dimensioned will be changed from 'N' to 'F' if its original feature is 'N', or from 'R' to 'FR' if its original feature is 'R'. Thus, Hole B becomes fixed, and the tag number of Holes A and B and the type of the location-dimension being dimensioned (i.e. X, Y, L, θ_X , or θ_Y) will be stored in a database called 'location-dimension database', and related treatments will be performed. The related treatments are called as 'complementary treatments', and include searching the holes in 'relative dimension database', which are not fixed and have relative location-dimensions from Hole B with dimensioning

feature 'R', changing their dimensioning features from 'R' to 'FR', moving the tag numbers of Hole B and these related holes and the types of these location-dimensions from 'relative dimension database' to 'location-dimension database'. If these holes become the holes with two 'F' or 'FR' in their vectors, they become fixed and the 'complementary treatments' for those related to the new fixed holes will be performed until no hole needs 'complementary treatment'.

- If the original feature of the location-dimension being dimensioned is 'F', no processing will be made and Hole B is still not fixed.
3. In the case that there is one 'F' or 'FR' in its vector already and s_3 is 'F' or 'FR'.
 - If the location-dimension being dimensioned is not the center-distance, the feature of the location-dimension being dimensioned will be changed from 'N' to 'F' if its original feature is 'N', or from 'R' to 'FR' if its original feature is 'R'. Thus, Hole B becomes fixed, and the tag numbers of Holes A and B and the type of the location-dimension being dimensioned will be stored in 'location-dimension database', and related 'complementary treatment' will be performed.
 - If the location-dimension being dimensioned is the center-distance, the feature of the location-dimension being dimensioned will be changed from 'F' or 'FR' to 'FF'. Thus, Hole B becomes fixed, and the tag numbers of Holes A and B and the type of the location-dimension being dimensioned will be stored in 'location-dimension database'. The related 'complementary treatment' will be performed for those holes having relative location-dimensions from Hole B with dimensioning feature 'R', 'FR', or 'FF' changed from 'FR'.

4.3.3. Hole A is not fixed but Hole B is fixed

In this case, the treatment is similar to that for condition 2.

5. Typical location-dimensioning schemes for holes

According to the requirements from manufacturing, inspection, and assembly, there are some typical location-dimensioning schemes for holes.

5.1. Typical location-dimensioning schemes for the holes with transmission relationships

The information about transmission relationships of holes is inputted by the user. Apart from some special dimensioning scheme required interactively by the user, the location-dimensions for the holes with transmission relationships are dimensioned by a center distance and a larger coordinate location-dimension.

5.2. Typical location-dimensioning schemes for the holes lying on a same circle

A set of holes lying on a same circle is identified automatically by a program. The identifying method is as follows.

1. Compute three coefficients of the equation for the circle every three holes lie on. In a mechanical part with n holes, there are P sets of three holes and $P = C_n^3 = n(n-1)(n-2)/6$. A fitted circle can be constructed by passing the centers of three holes in the i -th set by solving the following set of equations [11]:

$$\begin{cases} (x_{i1} - a_i)^2 + (y_{i1} - b_i)^2 = c_i^2 \\ (x_{i2} - a_i)^2 + (y_{i2} - b_i)^2 = c_i^2 \\ (x_{i3} - a_i)^2 + (y_{i3} - b_i)^2 = c_i^2 \end{cases} \quad (10)$$

where $\{x_{ij}, y_{ij} | j = 1, 2, 3\}$ are the coordinates of centers of three holes in the i -th set.

2. Merge the sets with the same three coefficients (a_i, b_i, c_i) into a larger set.
3. Check whether the center of any hole outside this set is the center of fitted circle. If yes, this set of holes is determined as a set of holes lying on a same circle.

Sometimes, more than one sets of holes have the same center as shown in Fig. 5(a). In a set, the diameters of holes can be equal to each other, or not, as shown in Fig. 5(b). The holes in a set can be equally spaced, or not, as shown in Fig. 5(c). For a set of holes lying on the same circle, the diameter of the circle, or the radius of the circle if the center hole of the circle has transmission relationship with one in the set, should be dimensioned. If the holes in the set are equally spaced and one of them lies on a coordinate axis of the circle or the angle between a coordinate axis of the circle and the centerline linking the center of circle and the hole in the set is a special one, such as 30° , 45° , or 60° , there is no need to position any other location-dimension. Otherwise, the second location-dimension needs to be positioned. The second location-dimension can be a coordinate dimension if the hole has transmission relationship with the center hole of the circle, or, otherwise, an angle between a coordinate axis of the circle and the centerline linking the center of circle and the hole in the set.

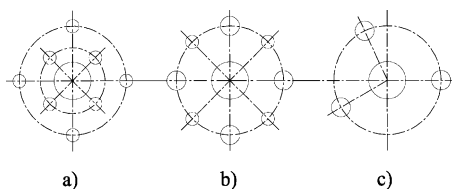


Fig. 5. Different sets of the holes lying on the same circle.

5.3. Typical location-dimensioning schemes for the holes lying on the same straight line

A set of holes lying on the same straight line is also identified automatically by a program. The identifying method is similar to the above method and as follows.

1. Compute three coefficients of the equation for the straight line every three holes by solving the following set of equations [11]:

$$\begin{cases} A_i x_{i1} + B_i y_{i1} + C_i = 0 \\ A_i x_{i2} + B_i y_{i2} + C_i = 0 \\ A_i x_{i3} + B_i y_{i3} + C_i = 0 \end{cases} \quad (11)$$

where $\{x_{ij}, y_{ij} | j = 1, 2, 3\}$ are the coordinates of centers of the three holes in the i -th set. If there is the solution for it, a fitted straight line can be constructed passing the centers of three holes in the i -th set. If there is no solution, the three holes do not lie on a straight line.

2. Merging the sets with the same three coefficients (A_i, B_i, C_i) into a larger set.

For this kind of set, the position of the straight line that the holes lie on should be first dimensioned. If the straight line is the centerline of the part, its position has been fixed and there is no need to dimension it again. If the straight line is parallel to a coordinate axis, its location can be determined by dimensioning the position of one hole in the set. Otherwise, it is necessary to dimension the positions of two holes in the set, or the position of one hole in the set and the angle between a coordinate axis and the straight line. The positions of other holes in the set can, thus, be determined by adding the center distance or one coordinate dimension between the hole already dimensioned and the hole being dimensioned. The dimensioning method has three types: parallel dimensioning, chain dimensioning, and combined parallel and chain dimensioning as shown in Fig. 6(a)–(c), respectively. With parallel dimensioning, a number of dimensions originate from a same datum feature, and sometimes the dimensions are too long and cannot be measured

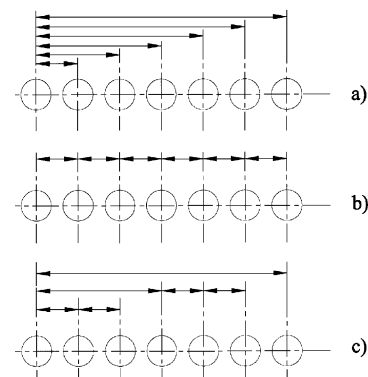


Fig. 6. Three types of location-dimensioning for the holes lying on the same straight line.

easily. With chain dimensioning, the possible accumulation of tolerances over the length of the part will endanger the correct functioning of the part if there are many chains, but the dimensions will be measured conveniently. The combined parallel and chain dimensioning has the advantages of both parallel dimensioning and chain dimensioning.

6. Process of determining location-dimensioning scheme for holes

After introducing above background, the process of determining location-dimensioning scheme for holes can be described as follows.

1. Set all the elements of location-dimensioning feature vectors of the holes in a part as 'N', i.e. $S_i\{N, N, N, N, N\}$.
2. Determine datum holes and auxiliary datum holes interactively, and put the tag numbers of these holes and the types of their two coordinate location-dimensions (i.e. X, Y) into 'location-dimension database' and assign 'F' to their s_1 and s_2 , so that the location-dimensioning feature vectors of these holes become $\{F, F, N, N, N\}$. The datum hole can be a hole for dowel pin and auxiliary datum hole, if needed, can be a hole for main spindle.
3. Identify the sets of holes lying on a same circle, assign 'R' to s_3 of location-dimensioning feature vectors of the center hole and every hole in each set, and put the tag numbers of holes in each hole-pair of the center hole and every hole in each set and the type (i.e. center distance L) of these location-dimensions into 'relative dimension database'. If the center hole of a set is fixed and the center distance between the center hole and one of the holes in the set or the diameter of the circle the holes lying on has been determined, the center distance dimensions between the center hole and every hole in the set are determined and their s_3 will be assigned by 'FR'.
4. Identify the sets of holes lying on a same straight line, assign 'R' to s_1 or s_2 of location-dimensioning feature vectors of every holes in each set if the straight line is parallel to Y or X -axis, and put the tag numbers of these holes and the types (i.e. X or Y) of these location-dimensions into 'relative dimension database'. If one coordinate dimension (X or Y) of one of the holes in a set parallel to coordinate axis Y or X has been determined, the X or Y coordinate dimensions of other holes in the set are determined and their s_1 or s_2 will be assigned by 'F'. If the set is not parallel to any coordinate axis and the positions of two of the holes in the set are fixed with two 'F' or 'FR' in their location-dimensioning vectors, s_4 or s_5 of location-dimensioning feature vectors of other holes in the set will be assigned by 'F' or 'FR'.
5. Establish the order of priorities for location-dimensioning of the holes in the part using the method described in Section 3.
6. Modify the elements of location-dimensioning feature

vectors of the holes, one-by-one, according to the order of their priorities, based on the method described in Section 4 until there are two 'F' or 'FR', or one 'FF' for s_3 in every vector. Thus, in 'location-dimension database', tag numbers of holes in the hole-pairs for all the necessary location-dimensions and the types of these necessary location-dimensions (i.e. X, Y, L, θ_X , or θ_Y) are stored. The next step is to dimension all these necessary location-dimensions in reasonable positions of suitable views in the detailed drawing of the part.

7. Positioning location-dimensions for holes

7.1. Rules of positioning location-dimensions

The location-dimensions of the holes must be distributed in a view that shows all the related holes with their circle. If there are more than one views that satisfy this requirement, the view with fewer dimensions will be selected for positioning the location-dimension. After each location-dimension has been assigned, the next step is to locate the dimensions in reasonable positions of each view. This is implemented by an expert system [2,3] according to the requirements from drawing standards [12]:

1. As far as possible, locate the dimension close to the holes to be dimensioned.
2. Avoid the intersection between dimension lines and/or projection lines and the superimposition between the dimension line and centerlines, symmetrical lines, outlines or their extensive lines as far as possible.
3. Distribute the dimensions uniformly as far as possible.
4. Locate the dimensions outside the view with small area and many lines as far as possible.

7.2. Forbidden zones

In order to satisfy the above rules, forbidden zones [3] are used. After a linear dimension is positioned, a forbidden zone enclosed by centerline, dimension line and two projection lines will be set up as shown in Fig. 7(a) and (b). After an angular dimension is positioned, a triangle containing the angular dimension will be set as a forbidden zone as shown in Fig. 7(c). If the dimension is placed outside dimension line, the forbidden zone will include the extension zone as shown in Fig. 7(d). In order to avoid the superimposition between the dimension line and centerlines, symmetrical lines, outlines or their extensive lines, a forbidden zone with certain depth will also be set up along centerlines, symmetrical lines, outlines and their extensive lines. After the forbidden zones have been set up, other dimensions cannot be positioned in them. For instance, since Dimension A has been positioned and a forbidden zone has been set up, Dimension B will be placed outside the forbidden zone and

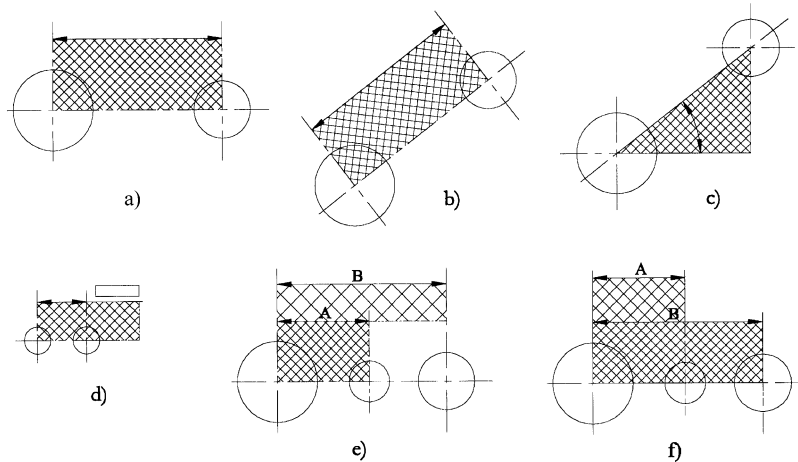


Fig. 7. Forbidden zones.

a new forbidden zone will be set up based on the existing zones as shown in Fig. 7(e).

7.3. Methods of positioning the location-dimensions

The location-dimensions can be positioned according to the following procedure.

1. Set up four dimension distribution zones, like four quadrants, for each view, based on the centerlines of the part as shown in Fig. 8(a). For easy reading, dimensions will be placed so that they can be read from the bottom or right-hand side of the drawing. The dimension lines and projection lines in every dimension distribution zone should be extended outwards. The method for identifying the outward direction is shown in Fig. 8(b). A radial line can be constructed passing the middle point of the centerline of the two holes. A line perpendicular to the centerline can be constructed from the middle point. The direction (A) of the line with outward component on the radial line is identified as the outward direction. If the line is superimposed on the radial line, its projection lines and dimension line will be positioned according to the rules as shown in Fig. 8(a). For instance, if the centerline is superimposed on a radial line with 45° in the first quadrant, the location-dimension will be positioned like

Dimension B as shown in Fig. 8(a). If the centerline is superimposed on a radial line between 45 and 90° , the location-dimension will be positioned as Dimension C.

2. Arrange the dimensions with the same orientation in an order from the shortest to the longest dimension for the order of positioning them outwards. For instance, in Fig. 7(e), Dimension A is positioned first and Dimension B is placed based on Dimension A, so that there is no intersection between their dimension lines. If Dimension B is placed first, there is an intersection between a projection line and a dimension line as shown in Fig. 7(f).
3. Place the necessary dimensions one-by-one based on the following rules.
 - 3.1. If there is no forbidden zone on both sides of the centerline of the two holes, its location-dimension line will be placed outwards, based on dimension distribution zone it lies in as described in Step 1.
 - 3.2. If there is a forbidden zone on the outward side, its location-dimension line will be placed on the inward side. However, if the dimension line is placed inwards, it cannot be beyond the range of dimension distribution zone it lies in.
 - 3.3. If there are forbidden zones on both sides, their depths will be compared with each other, and its dimension line will be placed on the side with shallow forbidden zones.

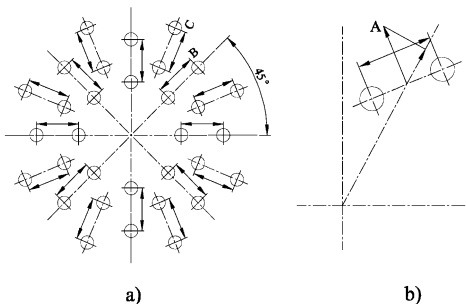


Fig. 8. Four dimension distribution zones and their dimensioning.

8. An example of location-dimensioning for holes

According to the above approach, a software prototype for intelligent location-dimensioning was developed. By using this prototype software, many parts have been dimensioned successfully. Here, as an example, the location-dimensioning of holes in the multi-spindle headstock of a modular machine tool by this software prototype is shown in Fig. 9, which omits the outlines of the part and the dimensions for diameters of the holes and tolerances in order to

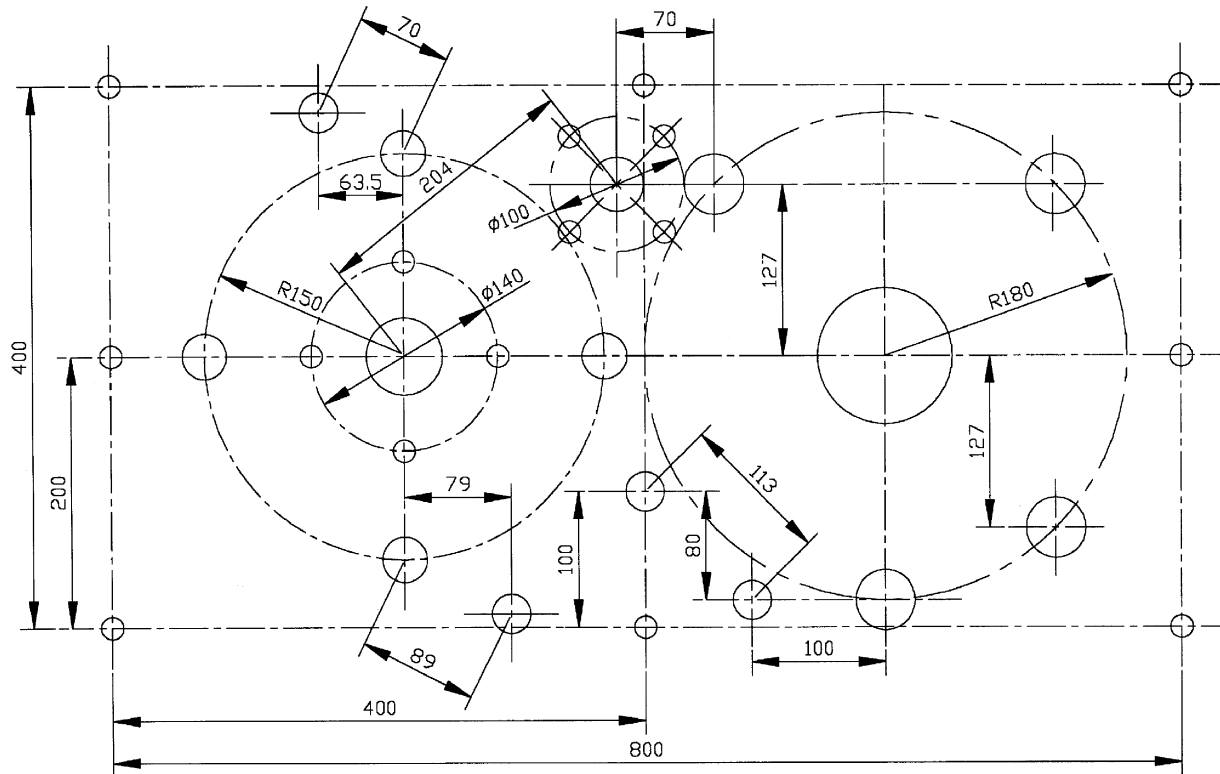


Fig. 9. Location-dimensioning of the holes in the multi-spindle headstock.

illustrate it clearly. This part has 31 holes, among which 15 holes with numbers have transmission relationships with each other as shown in Fig. 10, and the other holes are for fasteners and other purposes.

Its intelligent location-dimensioning can be summarized as follows.

1. The information about the locations of all the holes in the part and the hole-pairs with transmission relationships are read or extracted from the solid model of the part.
2. Holes O_1 and O_2 are a pair of dowel pin holes and selected as datum holes interactively.
3. Hole 1 is the hole for an input shaft connected with power source and selected as auxiliary datum hole interactively.
4. The software prototype identifies the sets of holes lying

on the same circles and the sets of holes lying on the same straight lines parallel to X or Y -axis, puts the necessary location-dimensions of holes into the 'location-dimension database' according to the methods introduced in Section 6, and places the necessary location-dimensions in the reasonable positions of the suitable view based on the methods introduced in Section 7.

9. Conclusions

Automatic location-dimensioning for holes by computer has to satisfy drawing standards and the requirements of facilitating manufacturing, inspection, and assembling. This paper develops an intelligent dimensioning approach to generate location-dimensions for cylindrical surfaces in the two-dimensional drawing automatically from a three-dimensional model of the mechanical part based on feature extraction. The key issues include strategies and methods to establish an order of priorities for location-dimensioning of cylindrical surfaces in mechanical parts, to eliminate their location-dimension redundancy, to determine location-dimensioning scheme, to assign necessary dimensions to suitable views, and to locate the dimensions in reasonable positions of each view using artificial intelligent technology. Based on this approach, a corresponding software prototype was developed. It was demonstrated, from an example of location-dimensioning for a more complicated set of holes,

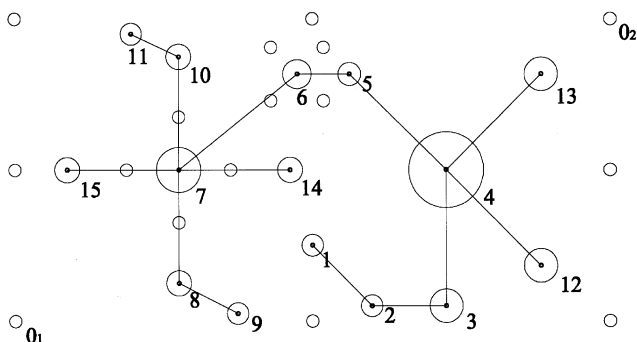


Fig. 10. Transmission relationships among the holes.

that the location-dimensions of all the holes in it were generated successfully using this intelligent dimensioning software prototype. This approach and software prototype is feasible and can be used as a base for developing commercial software for intelligent location-dimensioning.

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