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The optimum routeing of pipes in a ship's engine room

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PREFACE

The investigations reported in the present monograph have been conducted by the IHC Holland N.V. and the Netherlands Maritime Institute.
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THE OPTIMUM ROUTEING OF PIPES IN A SHIP'S ENGINE ROOM

by

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Summary

This paper deals with a computer program which is in development and aims to be an aid to the designer in routeing the pipes inside a ship's engine room. The routeing, by the program, occurs in two phases. In the first phase all possible equivalent routes are determined subject to the assumption that the pipes have no dimensions and without considering any interferences. The method developed for carrying this out is based on the dynamic programming technique. In the second phase, the routes are fixed in such a way that no interferences occur. It is the intention to do this interactive by the designer with the aid of a display.
So far, the first phase has been solved completely and now we have to work out our ideas for the second phase.

1 Introduction

If one considers the types of work connected to piping arrangement design and fabrication of pipe systems, it is realized that a large part of this work consists of routine work and making use of data defined earlier in the design process.
Routine work and earlier defined data are characteristics of the type of problem that can be solved often with the aid of an electronic computer.
With this in mind one of the yards of IHC-Holland undertook a pilot study about computerized piping design. It became quite clear soon after the start of the study that the major problems were centered around the routeing problem.
This resulted in a separate study aiming at defining an algorithm for pipe routeing to show the feasibility of the project.
In late 1970 this algorithm was programmed and tested.
Basically it was a vector method, called "sprouts method" in [1] and [2], and could route a pipe, given starting and ending points, flange orientation and forbidden areas. The test program routed pipelines in a two dimensional plane at minimum distances from boundaries and took care of pipe bends.
The program showed the feasibility of routeing algorithms but had several disadvantages like the two-dimensionality, an incorrect definition of the best route and so on.
However, with this in mind and using the experience, an informal specification of a true three-dimensional routeing algorithm was defined of which the main characteristics were to be

- efficiency in computer time
- easy interference checking
- proper "best route" definition.

The development of a program having the required characteristics was started in 1973 by Mr. van der Tak, then with the Netherlands Ship Research Centre TNO.
The routeing problem is, however, just a part of a large piping design system under development by IHC Holland and the Netherlands Maritime Institute jointly for the whole Netherlands Shipbuilding industry.

This system consists of three main parts:

- the pipe scheme part
- the routeing part
- the isometric part.

All three parts are individual programs with their own administrative software, separate input output routines but using a common piping database.

2 Mathematical approach

The routeing problem can be formulated as follows:

Given
- dimensions of the engine room
- location of the apparatus
- the location and the orientation of piping flanges
- the flanges which have to be connected and the diameter of the pipes

Asked
- The routes of the pipes between the flanges which have to be connected, meanwhile observing forbidden zones, preference regions and other rules and limitations in such a way that the total piping system is the optimum one according to the optimizationcriterion.

The objective function, representing the optimizationcriterion, contains several terms which are provided with weighting factors, underlining the importancy of these terms.
The length of the pipes will be the most important feature of the objective function. Other features are for example, number of bends and measure of accessibility. To make the problem more manageable, the following assumptions are made

- all apparatus and forbidden regions, as gangways, control rooms etc., can be built up out of one or more rectangular blocks.
- only three orthogonal pipe directions are permitted.

If the last assumption has not been performed, the pipes would have to be routed so that they "cris-crossed" each other, resulting in a disorderly piping system which does not make an efficient usage of the space. So this assumption is of practical nature and is not really a limitation. On the contrary, the first assumption is clearly a limitation. Therefore the problem has to be solved on such a manner that it is possible to introduce different space reservations in a later stage. The main difficulty in the routeing problem is to route all pipes without the time and storage used by the computer becoming extremely high. The first pipes routed give no problems.

The problems only arise if many pipes are already routed. For example, the 500th pipe has to be routed in such a manner that there is no interference with the apparatus and the pipes already routed. It is possible, if more pipes are routed it will be more probable, that a new pipe can not be routed as well as it should have been possible when the other pipes were not routed before. It is even possible that by little movements of the already routed pipes, without resulting in a different value of the objective function, a new pipe can be routed better. However, it is an endless task to trace all possibilities. To avoid this difficulty a method is developed which has the property that the pipes are not placed early but still have a lot of play.

The solution of the problem is in two parts, namely:

First subproblem: global routeing

Design a piping system under the two extra assumptions
- the pipes are represented by vectors (having no dimensions)
- the interference between pipes is taken out of consideration.

Second subproblem: final routeing.

Using the information of the routes of the pipes acquired during the global routeing, this subproblem is to design a piping system in which the pipes have dimensions again and no interferences between pipes can occur.

A pipe containing more than two bends has an infinite number of equivalent routes. In order to make use of all these possibilities during the final routeing, a definition for the globally routed pipe is used which contains nearly all equivalent routes.

The first subproblem has already been solved.

The second subproblem has still to be implemented.

3 Optimization criterion

In designing problems there can be many alternatives which do not violate the conditions.

The designer has to choose one of these alternatives and usually he chooses based on his experience. However, a computer can not make a choice from experience. Therefore a carefully formulated criterion is needed on which the choice can be made.

Such a criterion may contain many aspects, like

- length
- number of bends
- measure of accessibility
- routes of preference
- costs of installations
- costs of maintenance, etc.

It is almost impossible for a pipe to be at the optimum concerning all aspects. To come to a decision in the cases where a pipe is not the optimum concerning all aspects these have to be weighed against each other. Therefore an objective function is created containing all aspects providing with weighting factors.

A pipe is called the optimum pipe when it is routed in such a way that the value of the objective function belonging to this pipe is not more than the objective value for any other pipe with the same terminals.

4 Global routeing

4.1 Routeing process

An orthogonal system of axes is put into the engine room in such a manner that one axis is parallel with the longitudinal direction of the ship, one is in the athwart-ship direction and the other vertical. In this co-ordinate system the pipes are only allowed to go in a direction parallel to one of the axes.

Apparatus and forbidden regions as well as the contour of the engine room are put in as rectangular blocks of which the sides are parallel to the axes. The complementary space can now be subdivided into rectangular blocks in which the pipes are allowed to go.

In this paper a block of the complementary space is meant when only the word block is used. The blocks are numbered and the common areas of adjacent blocks are determined.

The division into blocks have been done because now in each block a reference point can be appointed which is characteristic for the whole block. The optimum pipe route to any point of a block can be determined from the data of the reference point and the co-ordinates of the point considered. Thus for calculating the optimum route to a point of a succeeding block only the data of the reference point of the present block is needed. This property forms the basis for the searching process developed and will be given now in a more mathematical formulation.

Assuming that a pipe with starting point in block N_S and ending point in block N_E has been routed until block N_k thereby running sequentially through the blocks $N_S, N_1, ---,$ N_{k-1}. The reference point P of block N_k can now be determined. This point lies in the common area of the blocks N_{k-1} and N_k and is the point which can be reached via the blocks N_1 through N_k with minimum pipelength. The minimum pipelength needed to reach any point Q of block N_k is equal to the pipelength need to reach the reference point P plus the minimum pipelength needed to reach Q from P. For a two-dimensional explanation see fig. 1, the shaded areas are forbidden blocks, which are reduced to rectangles.

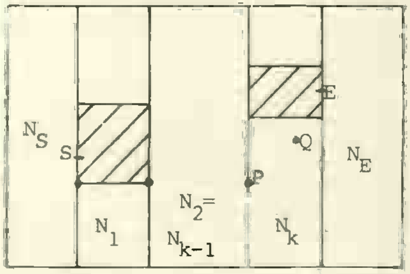

Fig. 1 Two-dimensional example

The above does not mean that there is no shorter pipe possible between the starting point and block N_k. It is always possible that a part of block N_k can be reached by a shorter pipe via other blocks. The property is only valid for pipes with the same block route. In the explanation of the property all the time is spoken about pipelength. The meaning is that this can be changed by value of the objective function. Because the length of a pipe is the most important term of the objective function and all other terms shall probably be dependent on the pipelength, the searching method, which has been developed on the basis of the property concerning the pipelength, shall be applicable for objective functions containing more terms than only the pipelength. Possibly some adaptations have to be introduced, but this will be dealt with later. Here the developed method is described by means of an objective function only containing the pipelength. The method is based on the dynamic programming technique.
During the process a tree is built up of which the nodes represent the blocks and the branches the routes through the blocks (fig. 2). The tree is expanding until an optimum route has been found. It is obvious that the process starts in one of the two terminals of the pipe to be routed.

For the description of the searching process the following terminology is introduced:

- node N_{k1} means node k on level 1
- the figures between the parentheses in the nodes are the blocknumbers
- B_{k1} is the blocknumber belonging to node N_{k1}
- two collections N_j^+ and N_j^-

  $i \in$ *N_j^+ if node Nij has already been explored

  $i \in N_j^-$ if node N_{ij} has not been explored yet.

For a clear understanding of the terminology used, the notations will also be declared by means fig. 2. Node N_{26}, representing block 13 (thus B_{26}=13), can be reached via the nodes N_{11}, N_{22} and N_{33}. This blockroute represents a pipe from the starting point in block 1, sequentially running through the blocks 3 and 8 entering block 13.
All nodes with level 1 have the same preceding blockroute and all other nodes have different blockroutes. Each time a node is explored a new level arises.
During the searching process that node will be explored which is at that moment the most promising one concerning the expected value of the objective function.

* $\in$ means is element of the collection
$\notin$ means is no element of the collection

Suppose now that m-1 levels have already been treated and that node N_{kl} has to be explored as the next one. This means that the pipe which has entered block B_{kl} has to be routed further. From block B_{kl} the pipe can enter all adjacent blocks. It is unnecessary to take into consideration the preceding block of B_{kl} as succeeding block because that blockroute represents a route which is never the optimum route. The rest of the adjacent blocks of block B_{kl} form the new nodes of the tree and have the same level. Because m-1 levels are already defined, the new nodes are represented by N_{im}, in which i goes from 1 until the number of nodes on level m, suppose n_m. The collections N_m^+ and N_m^- are determined.

$$N_m^+ = \phi$$
$$N_m^- = 1, 2, \ldots, n_m$$

Of each block B_{im}, belonging to node N_{im}, the reference point P_{im} is determined. As P_{im} lies also in block B_{kl} the minimum pipelength needed to reach block N_{im} via the given blockroute is a direct function of the co-ordinates of point P_{im}. If L_{kl} is the minimum pipelength to reach block B_{kl} via the blockroute given by the tree it can be said, that

$$L_{im} = L_{kl} + |x_{p_{im}} - x_{p_{kl}}| + |y_{p_{im}} - y_{p_{kl}}| + |z_{p_{im}} - z_{p_{kl}}|$$

The pipelength needed to reach the ending point from P_{im} can not be calculate – for if so the routeing problem would have been solved already – but from the co-ordinates an estimation of this length can be made.
As estimation is used

$$R_{im} = |x_{p_{im}} - x_E| + |y_{p_{im}} - y_E| + |z_{p_{im}} - z_E|$$

This is the pipelength needed to connect P_{im} with the ending point under assumption that the pipe may run everywhere. In any case the restricted piperoute from P_{im} to the ending point will not be shorter. Thus the minimum value of the objective function for the route of which the first part follows the route described by the tree and node N_{im} is

$$W_{im} = L_{im} + R_{im}$$

Of all nodes not yet explored the node with minimum value of W has the best chance to belong to the final optimum branch-node chain, representing the optimum blockroute. For that reason the node with minimum value of W is explored all the time. It is not a necessity that this node lies

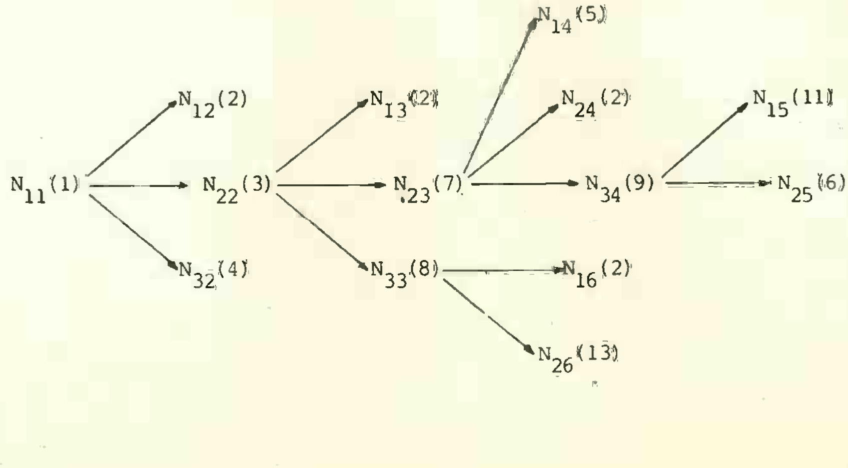

Fig. 2 Tree structure

on level m because a barrier may have appeared in the path of the most promising route. The new node for exploring has to be choosen out of all nodes which have not yet been explored.

Thus, it has to be a node belonging to one of the N^- collections.

To obtain quick comparison of the values of the objective function, the nodes with their objective values are ordered inside a level and the most promising nodes of the levels are ordered. The most promising node of a level is put into a vector *M*. In case two or more nodes have the same W-value the node is choosen for which the objective value of the already routed part L_{im} is the largest.

Thus as

$$L_{nm} = \max_{i \epsilon V} L_{im}$$

$$i \epsilon V \text{ as } \begin{cases} i \epsilon N_m^- \\ W_{im} < \{W_{jm}\}_{j \epsilon N_m^-,\, j \notin V} \\ W_{im} = W_{nm} \end{cases}$$

then is

$M(m) = N_{nm}$

Theoretically it is still possible that there are two or more nodes with the same L value.

In such a case it doesn't matter which node is choosen. All features of the nodes on level m have been determined now. At this moment the node which has to be explored next has to be fixed. This node will be the most promising node of vector *M*. Here again it is possible that two or more nodes of vector *M* have the same W-value. Again the node with the largest L-value is choosen and in case the L-values are also equal, it does not matter which one is taken.

The mathematical formulae is:

$$\text{if } L_{pq} = \max_{j \epsilon V} \left[\{L\}_{M(j)} \right]$$

$$j \epsilon V \text{ as } \begin{cases} \{W\}_{M(j)} < [\{W\}_{M(i)}] \\ \{W\}_{M(j)} = W_{pq} \end{cases} \quad i \notin V$$

then N_{pq} is the node which has to be explored next. In case block B_{pq} does not contain the ending point, the tree has to be expanded.

Consequently a new choice has to be worked up, and that means element p transfers from the collection N_q^- to the collection N_q^+ and a new M (q) has to be determined. When all nodes of level q are already explored M (q) gets the value 0.

Now the cycle is closed. The process here described is repeated until a node N_{pq} has to be explored representing the block B_{pq} in which the ending point lies. Then the block-route of the pipe is known. Precisely where the pipe is passing through the blocks, is still unknown.

Generally there are an infinite number of equivalent routes through the given blocks. The choice of one of all possible equivalent piperoutes is delayed until all pipes are routed globally. The degrees of play are used then for making sure that no interferences among the pipes occur. The fixing of the pipes will be an independent problem.

As criterion for the choice of a better pipe the value of L+R has been used, in which L is the pipelength already routed and R the minimum pipelength estimated to reach the ending point. The objective function in this case contains only the pipelength.

The searching process described here can be used for each optimization criterion as long as the value of the objective function in a point Q of a block B can be calculated from the data of the reference point of block B and the location of point Q.

Of course this means the objective function is subjected to limitations. However, it can be expected that all aspects can be considered by a careful choice of the objective function. All the time it is recommended to work with an objective value for the pipepart already routed and a minimum value for the pipe from the running point to the ending point. By taking the estimation of the minimum value of the rest of the pipe the number of branches decreases substantially. However, the property which has to be valid covers only that part of the objective function concerning the pipepart already routed.

It can be expected that in the future more and more aspects will be taken into consideration. From the program's viewpoint there is no objection at all, as long as the property mentioned above remain valid.

Some examples of how to put up some extensions in the system are described in the succeeding sections.

4.2 Example of global routeing

To get a clearer insight into the global routeing here a pipe will be routed in a two-dimensional space. The geography of the area selected is given in fig. 3. The rectangular blocks have been reduced to rectangles. The forbidden rectangles are shaded and the rest of the rectangles are numbered.

The pipe starts in point S with a flange orientation in the x-direction and ends in point E with a flange orientation in the y-direction.

During the global routeing, with an objective function only containing the length, the tree of fig. 4 arises.

In the figure the following notation for a node is used

$$k \begin{pmatrix} x_k & y_k \\ L_k & W_k \end{pmatrix}$$

in which

k	=	number of the rectangle in which the pipe enters
x_k, y_k	=	co-ordinates of the reference point
L_k	=	minimum pipelength needed to reach the reference point via the rectangles given by the branches
W_k	=	L_k + minimum pipelength estimated to reach the end E from the reference point, without considering the forbidden regions.

The level of a node is given by the digit above the branch to the node.

The optimum piperoute runs successively through the rectangles 4, 5, 6, 7, 8, 10 and 14. How the pipe runs exactly is not yet fixed at this stage. There is still an unexplored node, namely rectangle 2 of level 2, which can furnish a piperoute with the same length as the route already found. After exploring this node it will appear that there is no

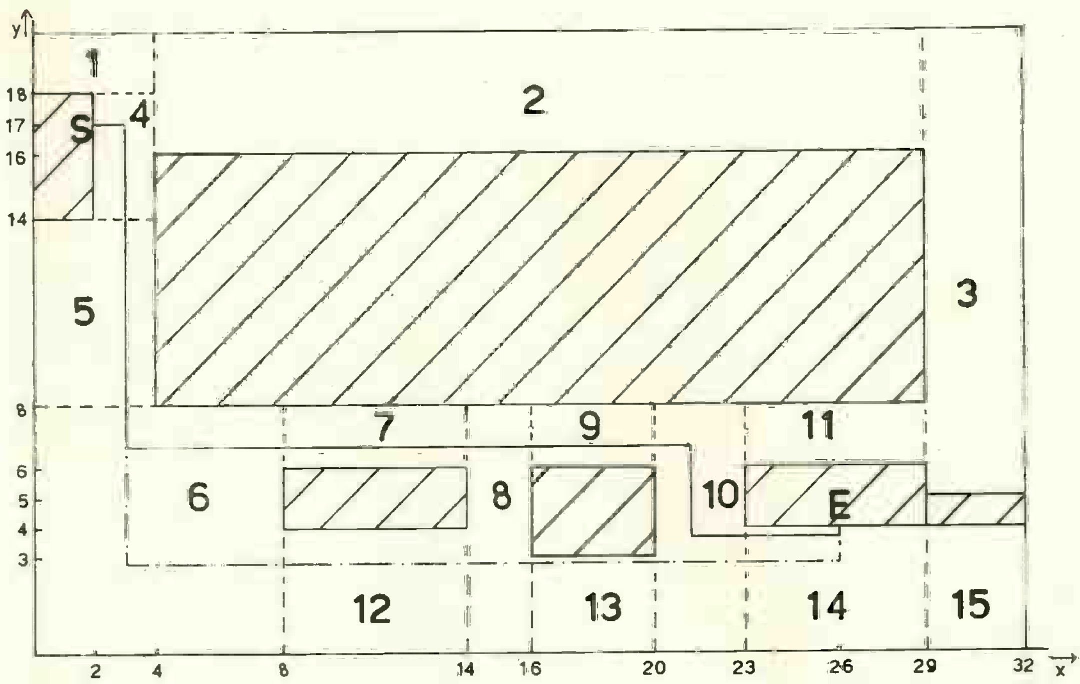

Fig. 3 Geography of the space

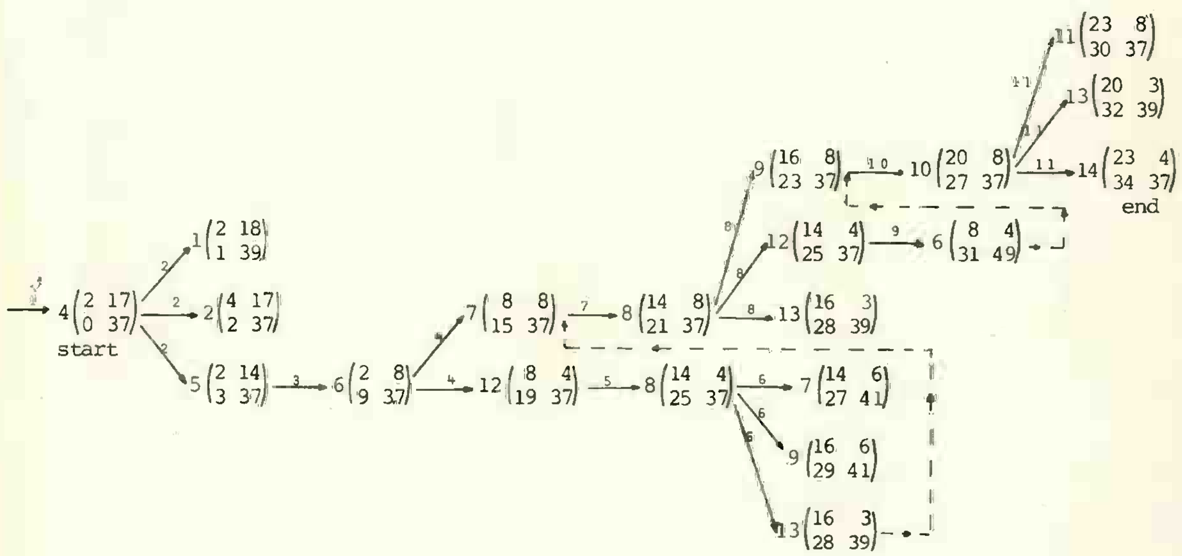

Fig. 4 Tree for the space of fig. 3

lalternative piperoute with equal pipelength. Until it will appear that there is need for alternative routes during the final routeing no time is wasted in finding them. In fig. 2 the drawn lines reflects one of the many possible routes. In case the number of bends was also put in the objective function with a sufficient high weighting factor the drawn line will not be the optimum route any longer but the route of which the last part is a dot and dash line.

5 Number of bends

Like the length, the number of bends to be placed in a pipe is of vital importance.

Generally the optimum pipe has minimum length and a minimum number of bends. Also it is possible that a little increase of the length is preferable as it results in saving one or more bends.

The easiest manner to obtain a minimum number of bends is to put the number of bends in the objective function. The weighting factor for the bends represents in fact the pipelength which may be used above the minimum pipe length for saving one bend.

However, it is not as simple as it seems at this moment. The searching method has been developed under the assumption that the property, described in section 4 is valid.

When the bends are put in the objective function as described above, the property is not valid any longer. Namely the minimum number of bends needed to reach a point Q

inside a block can not only be fixed by the number of bends needed to reach the reference point P of that block and the minimum number of bends needed to reach Q from P. The number of bends needed to reach a point inside a block can only be determined when the play for the pipe during the entering of that block is know.
It can be explained by means of a two-dimensional example. The geography of the space is given in fig. 5.

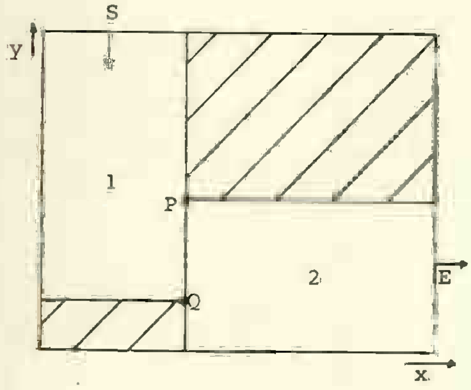

Fig. 5 Geography of the space

The pipe has to be routed from S to E. The directions of the flanges are given. Point P is the reference point of block 2. In spite of the block being reduced to a rectangle in two dimensions, the word block is still used to avoid confusion. To reach P at least one bend is needed. The pipe has to end in point E in the x-direction. Two bends are needed to reach E in the correct direction from the reference point P, where the pipe passes in the x-direction. The total objective value for the pipe will be the minimum pipelength and three bends providing with their weighting factors.
However, when the pipe passes the common area of block 1 and 2 on the level of the end E only one bend should have been placed. In other words the minimum objective value can not be derived correctly from the objective value of the reference point and the objective value of the pipepart inside the block. To make it possible, more data has to be given about the places where and with how many bends the pipe can enter the block. This can be done by means of a reference area, which holds all these possibilities.
From the definition of a rectangle by which the pipe can enter without extra bends, the possibilities of entering for the eight surrounding rectangles are known. Thus, it is not needed to give these rectangles with their possibilities separately. This will be explained with the help of fig. 6.

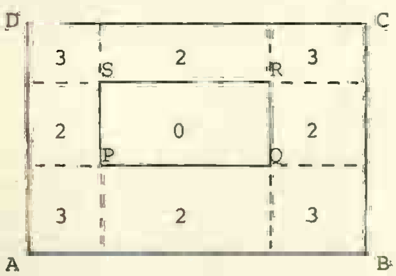

Fig. 6 Possibilities of passing

Only that side of the block through which the pipes enter the block perpendicular is drawn. The numbers inside the rectangles give the number of bends which have to be placed above the minimum when the pipe enters through any point of that rectangle.
Suppose the pipe can enter a block through any point of the rectangle ABCD. Now the definition of rectangle PQRS through which the pipe can enter the block with the minimum number of bends makes the definition of the other rectangles superfluous.
It is always possible by placing two bends more in the preceding block to enter the block through any point of one of the rectangles which have one side common with rectangle PQRS and by placing three bends to enter through one of the remaining rectangles.
Under the assumption that the common area between two blocks through which the pipe goes is a rectangle nearly all possibilities of entering can be described with only one of the six standard types (see fig. 7).

- i The pipe can enter with a minimum number of bends through a point P.
- ii The pipe can enter with a minimum number of bends through any point of a rectangle.
- iii The pipe can enter through a line in a rectangle with the minimum number of bends and through the rest of the rectangle with one bend more.
- iv The pipe can enter with a minimum number of bends through the left part of a rectangle and with one bend more through the right part of that rectangle.
- v The pipe can enter with a minimum number of bends through the right part of a rectangle and with one bend more through the left part of that rectangle.
- vi The pipe can enter with a minimum number of bends through a strip of a rectangle and with one bend more through the remaining part of the rectangle.

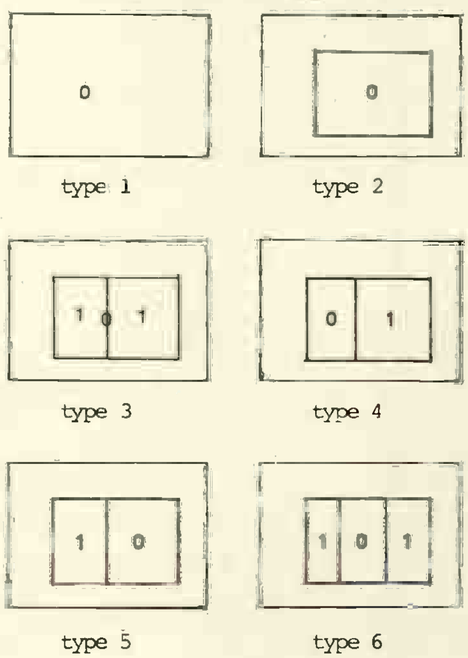

Fig. 7 Standard types of entering

In rare cases the passing can not be described with one standard type, it is always possible to do it with two or three standard types.
The developed routeing method is based on the property of

section 4 which means in fact that the value of the objective function of a succeeding node can be calculated only with the data of the preceding node.

When for each node the possibilities are given by means of one standard type, the data for the nodes arising when exploring, can be calculated. In cases the possibilities of entering can not be defined by only one standard type two or three nodes arise, representing the same block but a different way of entering.

By dealing in such a way the previously described searching process is also applicable where length and the number of bends, of course providing with weighting factors, have to be minimized.

6 Final routeing

6.1 Introduction

In paragraph 2 the reason has been given why the routeing problem has been divided into two subproblems. The two subproblems are not completely independent. The output of the first subproblem is the input for the second subproblem.

So it is obvious that the final routeing can not be approached before the first problem has been solved. On the other hand, the ideas of how to solve the final routeing problem will have had an influence on the way on which the output of the global routeing is given.

Especially the method of keeping the degrees of play until the final routeing is carried out, is of vital importance. By the fact that the global routeing problem had to be solved first not much time has been spent yet on the solution of the final routeing problem.

At this stage in the paper it can be said that the global routeing problem has been solved and that the attention can be directed at the final routeing.

6.2 Approach

Here some suggestions on how to solve the final routeing. Because the solution of the final routeing problem is still in its infancy, it is possible that some of the suggestions here will be ignored in the future. The commencement for the final routeing is that all pipes have already been routed globally. This means that for each pipe a bundle of pipes with equal objective value has been given.

In the final routeing problem the pipes gets dimensions and the interferences among the pipes are taken into consideration. The task is to choose the pipes inside their bundles in such a way that no interference occur. When it is possible to do that, a completely optimum piping system is achieved.

If the pipes are sucessively routed for final fixing then the old situation returns, namely the already routed pipes are fixed and the other pipes have to be routed so that no interferences occur.

It is much better to make use of the degrees of play of the pipes. This is possible by routeing parts of the space successively instead of pipe for pipe. This most suitable parts of the space for doing that are the rectangular blocks in which the engine room is already divided. By routeing a block finally parts of pipes are fixed. That means that the pipe has lost a part of its play. The more blocks that are finally routed the less play is left for the remaining pipeparts. Therefore it is surely preferable to start with the final routeing of the block which is the most difficult one to route. The difficulty of final routeing depends on the number of pipes to be routed and their play.

The final routeing of a block occurs as follows. It is known which pipes have to be routed through the block. Also for each pipe is known by which area the pipe can enter the block and by which area it can leave the block without resulting in a increase of the objective function. These areas can be reduced to a line, on which the centre of the pipe has to lie, or even to a point. By the choosing of a point in one of the areas, it can occur that a part of the other area can not be reached without an increase of the objective value. So the choosing of the points has to be done carefully. The pipe runs in the block between the choosen points parallel to the co-ordinate axes. The locations of eventually bends are not yet fixed.

The whole process of final routeing is suitable for doing it interactive by the designer at a display. The designer can ask for one block of the engine room. Then he can ask for the pipes to be routed inside that block with their areas of entering and leaving. Thereafter the designer can give his suggestion concerning the points of entering and leaving together with the locations of eventually bends. He gets the results of his suggestion directly and he can see by rotating the picture how the pipe runs. The display is an ideal aid for creating by trial and error a neat piping system in a block. After the pipes in a block have been routed, the consequences for the play of the pipes in other blocks have to be implemented. Then again the most difficult block is taken out to be routed finally. This process will be repeated until all blocks have been routed. When the whole engine room can be worked through without a pipe outside its bundle having to be choosen, the result will be an optimum piping system according to the optimization criterion. In practice however it can be expected that troubles arise while working through the engine room. At certain moment it can be impossible to choose the pipes inside their bundles in such a way, that no interferences occur. In that case it can be dealt with in several ways. A few guidelines will be given here.

- Already finally routed blocks can be routed anew in such a way that the difficulty disappears. However, it can be a time consuming affair for it is unknown which block has to be changed and how. Thereby it can have also consequences for other already routed blocks. In addition it is not guaranteed that it always leads to a solution.
- To route the pipe anew globally to get an equivalent route through other blocks.
  During this routeing blocks already finally routed are forbidden regions just like the block in which the difficulty occured.
- To route a minor pipe a little roundabout way. This has influence on the value of the objective function. Now it can not be said that the required piping system is the best, however, it will not differ much from the optimum piping system. The amount of deviation of the optimum piping system can be given.

Of course more guide-lines can be found, however, the result of a procedure has to be weighed against the efforts. When a case arises, it is possible to route already routed blocks, again and again in order to achieve a better piping

system. However be careful, as success is not assured because it can not bee seen whether the theoretical optimum piping system is realizable or not. Maybe there can be taken care of getting as less as possible troubles during the final routeing. It is obvious a block is difficult to route when there are many pipes and only a little play. Now it can only be said that the difficulty of routeing will depend on the number of pipes with their dimensions and play. Later when the program is operational a good measure can be analysed out of experiments.
For the moment the proportional occupation of the space by the pipes inside the block can be taken as measure. When the occupation of blocks is put in the objective function it is possible that the output of the global routeing will be such that the final routeing will be easier. Later, when a good measure for the effort to be put in the routeing of a block is achieved, the routeing of a block can be stopped as soon as the routeing of the rest of the pipes in the block is easier as the routeing of a different block. Then a new block is routed partly and so on. This way of going through the space will be the most efficient one, giving a minimum on troubles. However it requires a great organization as background. Only in a later stage when the program is ready can it be judged what is the most suited method in practice.

6.3 Example of final routeing
The suggestions of the previous section are examplefied as follows:
Fig. 8 shows the block to be routed. The play of the pipes, to be routed in this block, are given by the areas of entering and leaving. The numbers near the areas representing the numbers of the pipes.

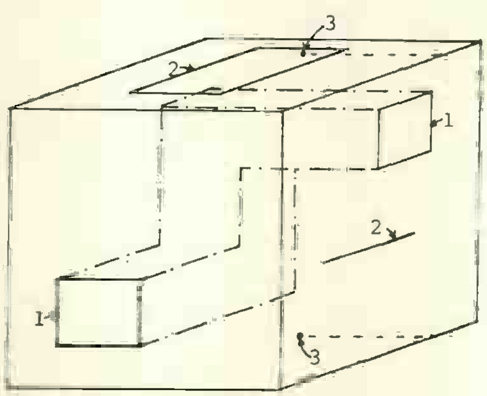

Fig. 8 A block before final routeing

For pipe 1, the whole bundle of equal piperoutes has been given. The centreline of the pipe has to lie inside the tube drawn. For ease of survey the tubes of the other pipes have not been drawn.

The routeing process:
Start with pipe 3 because this pipe has no play at all. After 3 pipe 2 has the fewest play. By the route of pipe 3 pipe 2 can not use all play it had originally. The optimum pipe 2, having only one bend, is fixed by giving a point Q_2. Indicate a suitable point Q_2 and look by rotating of the picture on the display whether pipes 2 and 3 have interference with each other or not. In case there is an interference a different point Q_2 has to be indicated. After pipe 3 has been routed with success it is the turn of pipe 1. This pipe is fixed by an independent choice of P_1 and Q_1. Again interference control is done by rotating of the picture on the display.

One of the many possible solutions of the final routeing of the block has been given in fig. 9.

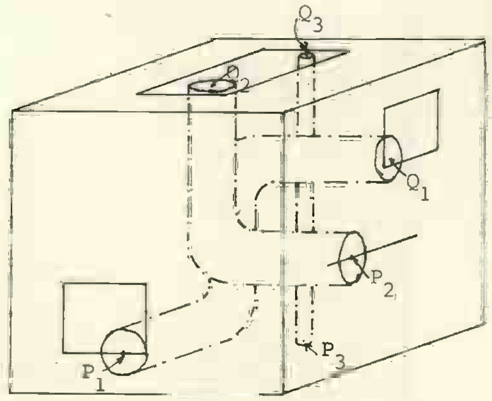

Fig. 9 A finally routed block

The great advantage of the late fixing of the pipes can be seen in this example. Suppose that pipe 2 had been routed before pipe 3, then it could have happened that pipe 3 could not be routed with minimum length by the location of pipe 2. In that case an optimum piping system would not have been achieved.

7 Future extensions

In practice there are often piping streets in which the pipes have to be routed by preference. This can be built into the program by multiplying the pipelength of the pipepart outside these streets with a factor more than one. By using different factors it is even possible to work with priorities of piping streets.
In the future probably different spacebodies are introduced. Also, it will be better to deal then with an extra "run direction" in the hull blocks, namely parallel to the hull.

8 Remarks

At this moment a program for global routeing is operational which furnishes for each routed pipe a bundle of pipes. All pipes of such a bundle are equivalent concerning the value of the objective function which contains the pipelength as well as the number of pipes provided with weighting factors.
In spite of the fact that the final routeing is not yet carried out probably with sufficient certainty it can be said which engine room is the best of two different arranged engine rooms. For the comparison of these two engine rooms the figures, achieved by summarizing the objective values of all global routed pipes, are used. This figure is namely the lower limit for the objective value of the whole piping system. Whether such a piping system is realizable or not can not be said and is only known after the final routeing has been carried out.
However it is to be expected that the objective value of the completely routed engine room will not deviate a lot of its lower limit. Therefore the above mentioned comparison

will give the correct result in the most of the cases.
Perhaps it will be possible in the future to place the appendages in the piping system already during the final routeing with the aid of the display. In any case, the results of the routeing program will be the input for many other programs as

– drawing of parts of the engine room from every wanted point of view with the omission of all desired objects;
– isometric drawings programs;
– post processors for pipe bend machines, etc.

We know that much work has to be done and many difficulties which no doubt still will arise have to be conquered but we also know that in case we succeed an excellent tool has been developed which forms the basis of all other engine room designing programs.

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