Selection procedures for manufacturing processes for design engineers

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SELECTION PROCEDURES FOR MANUFACTURING PROCESSES FOR DESIGN ENGINEERS

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In the process planning department of a major company, a tool was developed to improve communication with the design engineers of new production equipment. This communication tool consists of two parts. One part is a set of pictures showing the relative manufacturing costs in relation to classes of manufacturing processes. The manufacturing class indicates the method used to manufacture a specific part. A manufacturing class corresponds to the values of the factors required which determine the quality (fitness for use), including tolerance, surface roughness and heat treatment required, and therefore process times and costs. The main part of the tool is a set of pictures showing for particular basic shapes the sequence of different processes a part has to go through during manufacturing. These "Selection Procedures for Manufacturing Processes" give step by step the selection between different processes dependent on the tolerance, surface roughness, heat treatment and tool radius required. These selections can then directly be related to process times and therefore costs. It is expected that a reduction of 5% in costs for manufacturing of parts can be achieved by this communication tool for process planners and design engineers in the mechanization department.

INTRODUCTION

On the basis of an actual case in a major company, this paper describes how the possibilities of machine shop technology, and the related costs, can be passed on to design engineers of new production equipment in the mechanization department.[7] This knowledge must be presented in an accessible and conveniently arranged manner, so that it can be easily referred to during the design process. Of significance are the transfer points at which another manufacturing technology has to be incorporated into the manufacturing method, and at which the manufacturing costs will increase with a jump (see Fig. 4). Through the use of the communication tool "Selection Procedures for Manufacturing Processes", the design engineer can take this information into account during the design process. This contributes to quality-conscious design:[1,11] making a design with the functionality required at minimum total manufacturing costs and within the planned time.

Besides manufacturing costs, the total manufacturing costs of a new piece of production equipment also includes assembly costs. To a great extent, the time required for assembly, and therefore assembly costs, is determined by the number of parts that have to be assembled and, in the case of non-standardized parts, also by the accuracy with which the parts have to fit together. While designing on minimum total manufacturing costs, two points among others, are essential:

1. Use as many standardized parts as possible, but see if:
   - one standardized part can replace several other standardized parts;
   - several standardized and/or non-standardized parts can be replaced by a non-standardized part, but the accuracy with which this part has to fit together with other parts (fit tolerance) must not become too demanding (see point 2).
2. In the case of non-standardized parts, an optimum must be found between manufacturing costs and assembly costs, so that the total manufacturing costs become a minimum. By decreasing the number of parts, it is possible that close fit tolerances are necessary, which have a negative influence on the time required for assembly.

For determining this optimum, it is in the first place necessary to know the consequences of the accuracy of the parts on the manufacturing costs. It is just this subject that is elaborated in this paper.

The study on the communication tool was conducted in the mechanization department of a major company (approx. 1700 employees) which markets its own product range. The mechanization department's task includes the mechanization and automation of the production process, from research into the preliminary design of a piece of production equipment to the point where it is put into use, including the physical realization of the production equipment.

This paper focuses on the design of the mechanical part of the production equipment and the part manufacturing that follows. First, the functionality versus the producibility of a design of a piece of production equipment, including the use of basic shapes will be dealt with. Then the criteria for the communication tool will be considered, followed by determination of the manufacturing method, development of the communication tool and comments on the tool. The actual case will serve as an example.

FUNCTIONALITY VERSUS PRODUCIBILITY

During the design phase the main attention is on functionality of the design: can the piece of production equipment being designed perform the task, so that the function required is accomplished.[9]

In the design phase the design engineer draws up a concept of the piece of production equipment on the basis of the task this piece of equipment has to perform. This concept holds the modules needed to perform this task. Next, these modules are divided into sub-modules, after which these sub-modules are detailed into parts.[6] The costs of the manufacturing of the parts for this piece of production equipment are determined to a considerable extent by the selections made during the design phase. These selections concern the technical construction of the piece of production equipment, including for example the modelling of a part, the choice of dimensional tolerances and material properties.

The design engineer makes use of basic shapes when making detailed drawings of the parts (see Fig. 1). The idea of basic shapes is not new.[3]

A basic shape requires a specific technology, including the setup of the machine for turning, milling, grinding etc., clamping of the workpiece and specific cutting tools required. In the considerations that lead to the selection of basic shapes and the corresponding parameters, one aspect usually gets insufficient attention: the producibility of the design.[5] This is caused by the fact that:

- Design engineers have insufficient insight into the influence of design selections on the costs of parts manufacturing. This is a result of insufficient knowledge of the possibilities (and the difficulties) of the available technologies of the machine shop.
- Inadequate communication between the design engineer and the process planning department.
- Design engineers feel inhibited in their creativity if during the design phase the producibility of a design has to be taken into account.

It is the opinion of the authors that the basic shapes, as considered in this study, play a significant role in most companies. Therefore, the communication tool described in this article is applicable in a large number of companies, if necessary in adapted form.

CRITERIA FOR THE COMMUNICATION TOOL

To improve the insight of the design engineer into the way in which and the degree to which the design of the production equipment influences the costs of parts manufacturing, a communication tool had to be developed. From a preliminary study it became clear that this tool had to meet the following criteria:

- Readily accessible and conveniently arranged (low search time).
- Showing the information required: basic shapes related to the costliness of the manufacturing technologies. This is because the design engineer thinks in basic shapes when designing the parts.
- Easily adjustable in case of implementation of new or adaptation of existing manufacturing technologies, because that can lead to changes in the transfer points (jump in costs) at which another manufacturing technology has to be incorporated in the manufacturing method.

DETERMINING THE MANUFACTURING METHOD

For the development of the communication tool it is necessary to understand how the manufacturing method is determined.[2] The factors, or combination of factors, that are being used are decisive for the manufacturing costs of the parts.

The manufacturing method describes the manufacturing processes a part has to go through and the actions that have to take place there. In the process planning department the process planners determine the manufacturing method on the basis of their own experience. They aim to meet in the first place the requirements for quality, as stated on the part's drawing, while considering manufacturing costs. They do

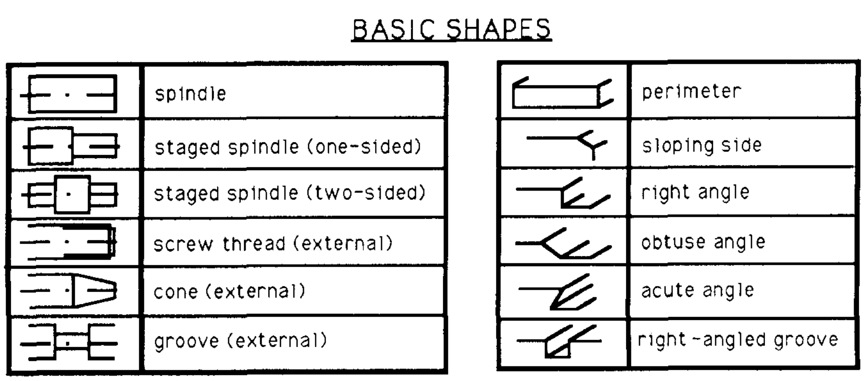

Fig. 1. A selection of basic shapes.[11]

not consider throughput time. In that case the factors that have an effect on the manufacturing method of a part are as shown in Fig. 2.

The formulation of the manufacturing method is a decision process, in which all these factors serve as input. The quality of the decision process is determined by the level of education, knowledge and experience of the process planner.[1,8–11] The combination of these factors leads to a manufacturing method. The weighting factors vary from factor to factor. The most important factors appear to be:

- kind of basic shapes;
- kind and size of the tolerance;
- surface roughness;
- yes or not heat treatment.

GRAPHS WITH "COST FACTORS"

The consequences of increasing dimensional tolerances on the manufacturing costs can be best represented in a graph.[4] More detailed and modified, these graphs can serve as an addition to the "Selection Procedures for Manufacturing Processes" introduced in the next section.

It is strongly recommended[4] that the selection of tolerances and surface roughnesses should only be justified by the functionality of the part concerned. Functionally not justifiable selections can lead to unnecessarily high manufacturing costs, as illustrated in Fig. 3. In this figure it is shown how for rotational symmetric basic shapes the manufacturing costs develop with increasing dimensional tolerance.

For the company where this study took place, a number of similar graphs have been composed, for example the relative manufacturing costs for a (staged) spindle in relation to the manufacturing class (see Fig. 4). The type of graphs used (see Fig. 4) show two distinctions with the graph displayed in Fig. 3:

- Each basic shape requires its own graph, because the manufacturing costs for each basic shape react differently to varying values of the cost-determining factors. Some basic shapes can be combined in one graph.
- Besides tolerance (in Fig. 4: TOL-L, TOL-D and STROKE), the influence of surface roughness (Ra) and yes or no heat treatment is taken into account. These are the most important cost-determined factors. Costs for materials are accounted for in the hourly rate of the machine shop.

In the graph (see Fig. 4) the relative differences in manufacturing costs is pictured at different values of the design requirements tolerance, surface roughness and yes or no heat treatment. The relative manufacturing costs, called "cost factors", are plotted with respect to the "manufacturing class". The manufacturing class indicates the manufacturing method for basic shapes if the basic shape is in accordance to the design requirements that suit that particular class. The transition from one manufacturing class to another corresponds to the transfer points (jump in costs) at which another manufacturing technology has to be incorporated in the manufacturing method.

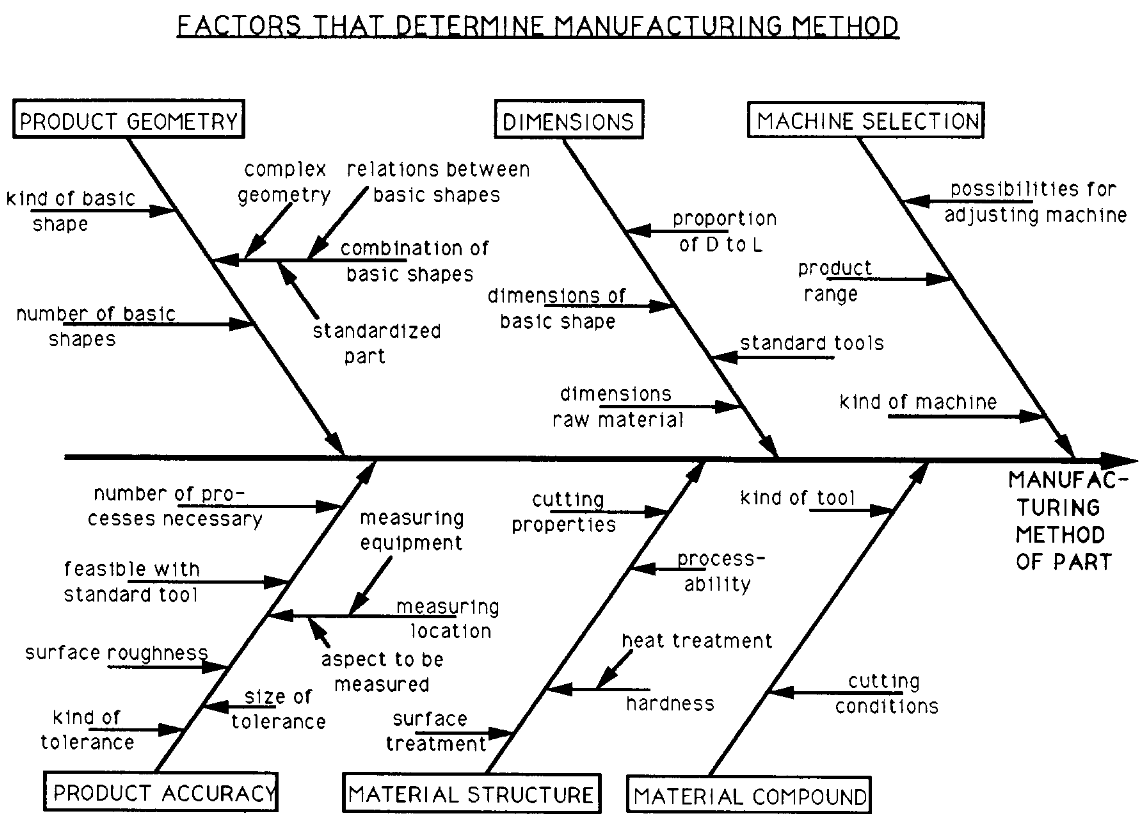

Fig. 2. Factors which determine the manufacturing method.

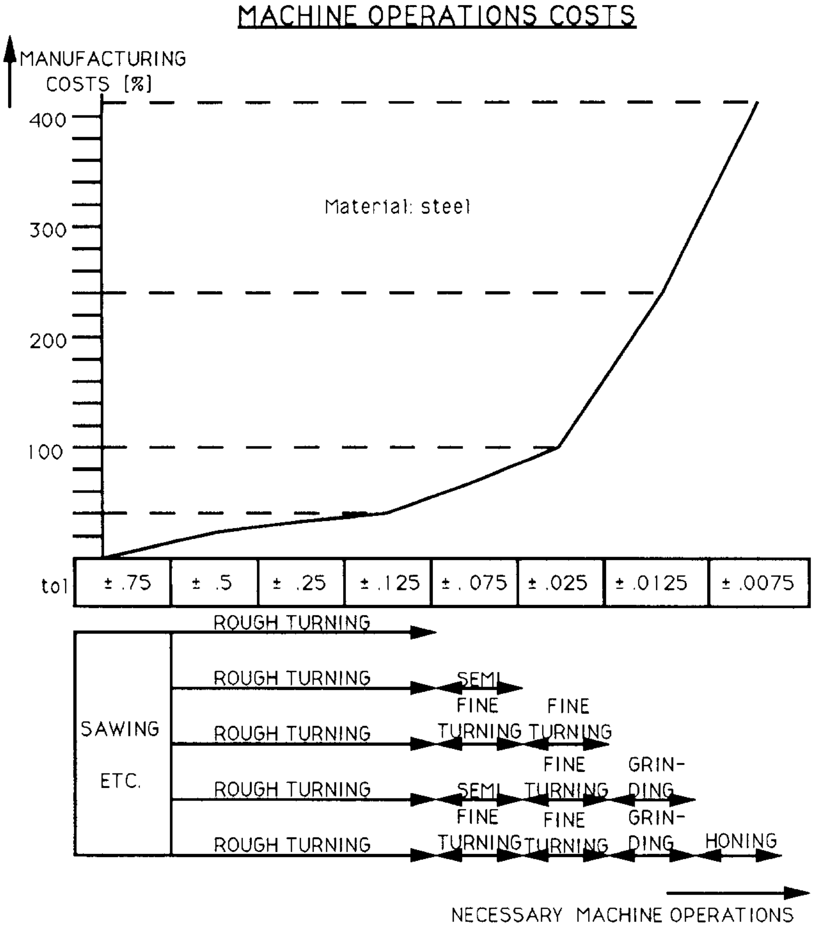

Fig. 3. Relative manufacturing costs for different values of dimensional tolerance.[4]

In the graphs the "cost factor" of a particular manufacturing class is chosen to have the value 1, as a reference value. The graph should be used as follows: Take the graph corresponding to the basic shape. Select the highest manufacturing class one or more factors fall into. The "cost factor" corresponding to this class will apply to the basic shape.

However, it should be mentioned that if the tolerance of the length is so close that a fine surface grinding process has to be carried out (manufacturing class 4), while the other requirements can be realized through a turning process (manufacturing class 1 or 2), then the "cost factor" will not quite be manufacturing class 4, but approximately 3.5. If the part has to undergo a cylindrical grinding process, then the part automatically falls into manufacturing class 3 or 4, dependent on the dimensional tolerance required. If a heat treatment is necessary, and the other design requirements are in accordance with manufacturing class 1, then the "cost factor" will fall into manufacturing class 1. The geometrical change caused by the heat treatment will always fall within the tolerance required.

In the company where the study is conducted, a distinction is made between three categories of materials: category A, B and C. The processability of the material becomes more difficult from category A to category C. With heat treatment and close tolerances, this causes significant differences in manufacturing costs, so these categories were also discerned in the graphs.

After testing these graphs, this tool appeared to be inapplicable, because these graphs were too difficult to use and, more important, the design engineer cannot deduce the reason why the chosen design requirements of a part will result in high manufacturing costs for the part. So he does not receive feedback on the impact of the design requirements on the manufacturing processes. A better communication tool had to be developed.

SELECTION PROCEDURES FOR MANUFACTURING PROCESSES

The communication tool that has been developed was to improve the insight of the design engineer in the manufacturing method. This communication tool consists of "Selection Procedures for Manufacturing Processes". Using it, which manufacturing technologies have to be incorporated into the manufacturing method can be found, and the reasons why. For some basic shapes this is shown in Fig. 5.

The selection procedures are arranged as a selection process, in which for each basic shape the relevant factors for determining the manufacturing method are taken into account. For each basic shape a selection procedure is drawn up, because:

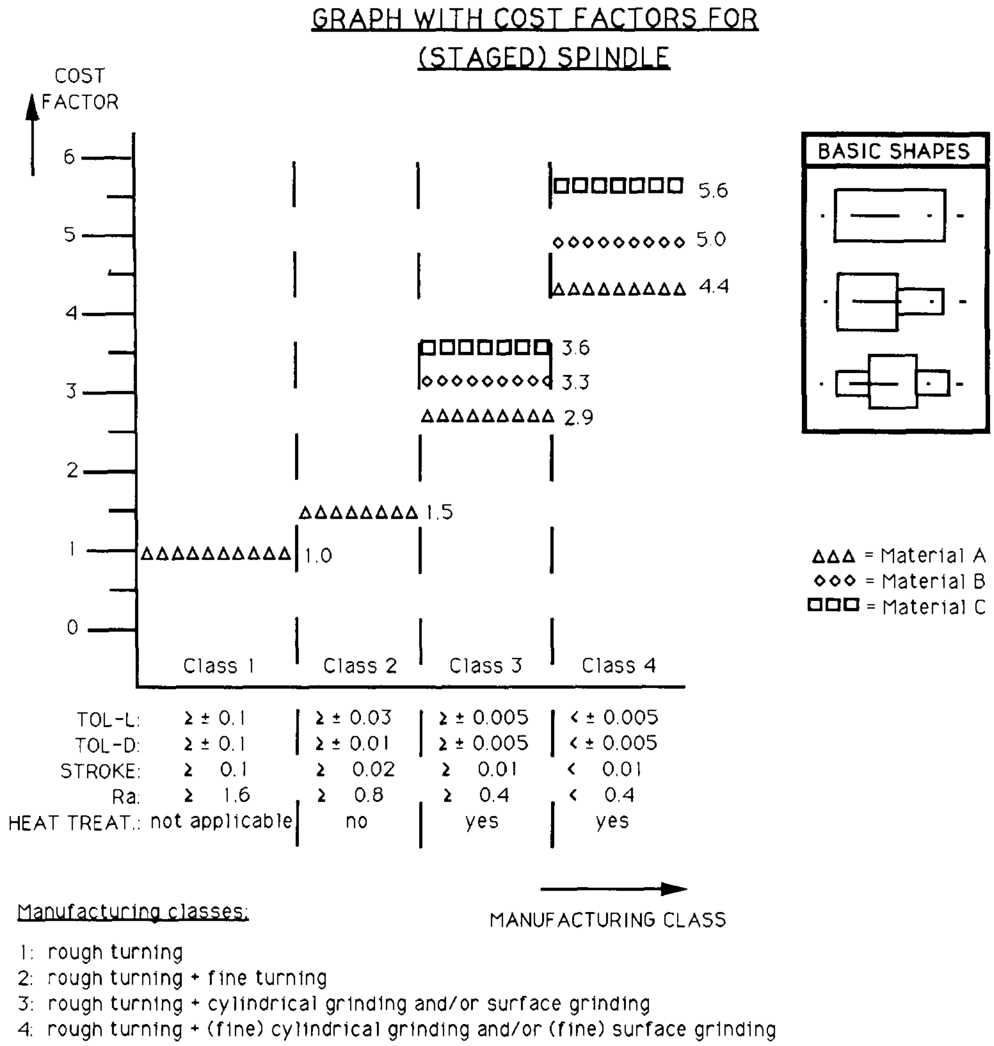

Fig. 4. Example of one of the graphs with "cost factors".

- The number of factors and their values, which lead to a certain manufacturing method, differ for each basic shape.
- The number of possible combinations of basic shapes is very large, which would lead to an enormous number of selection procedures.
- A design engineer can simply determine the consequences of the requirements a basic shape (has to) meet(s). Because of that the design engineer could consider to select another design solution.

N.B. If basic shapes show (almost) identical selection procedures, then these basic shapes are combined in one selection procedure. In the company where this study was conducted, this has led to twelve combinations of basic shapes, and therefore also twelve "selection procedures".

At every option in the selection process the way through the selection procedure is determined, on the basis of the factors mentioned (see Fig. 5). From the design requirements the basic shape has to meet, the manufacturing processes a part has to go through in parts manufacturing are found. Now the design engineer can also see how a manufacturing process can be avoided.

In a selection procedure an option can only be answered as affirmative if all factors which are relevant in this option are met. A negative answer to an option leads to higher costs. If the costs of a certain manufacturing process will be proportionally high, then this is indicated separately through a fill pattern (in Fig. 5: LAP, CYGR, SUGR(2 ×) and TUR). In the final layout presented to the design engineers, colours were used instead of fill patterns.

EXAMPLE

If the "selection procedure" is used on the basic shape shown in Fig. 6 (indicated in Fig. 5 through a dashed line), then it follows that the manufacturing method comprises the manufacturing processes of turning, cylindrical grinding and surface grinding.

So now the design engineer knows the manufacturing processes the part has to go through, because of the design requirements the basic shape has to meet, and the reason why. The order in which the manufacturing processes will be carried out during parts

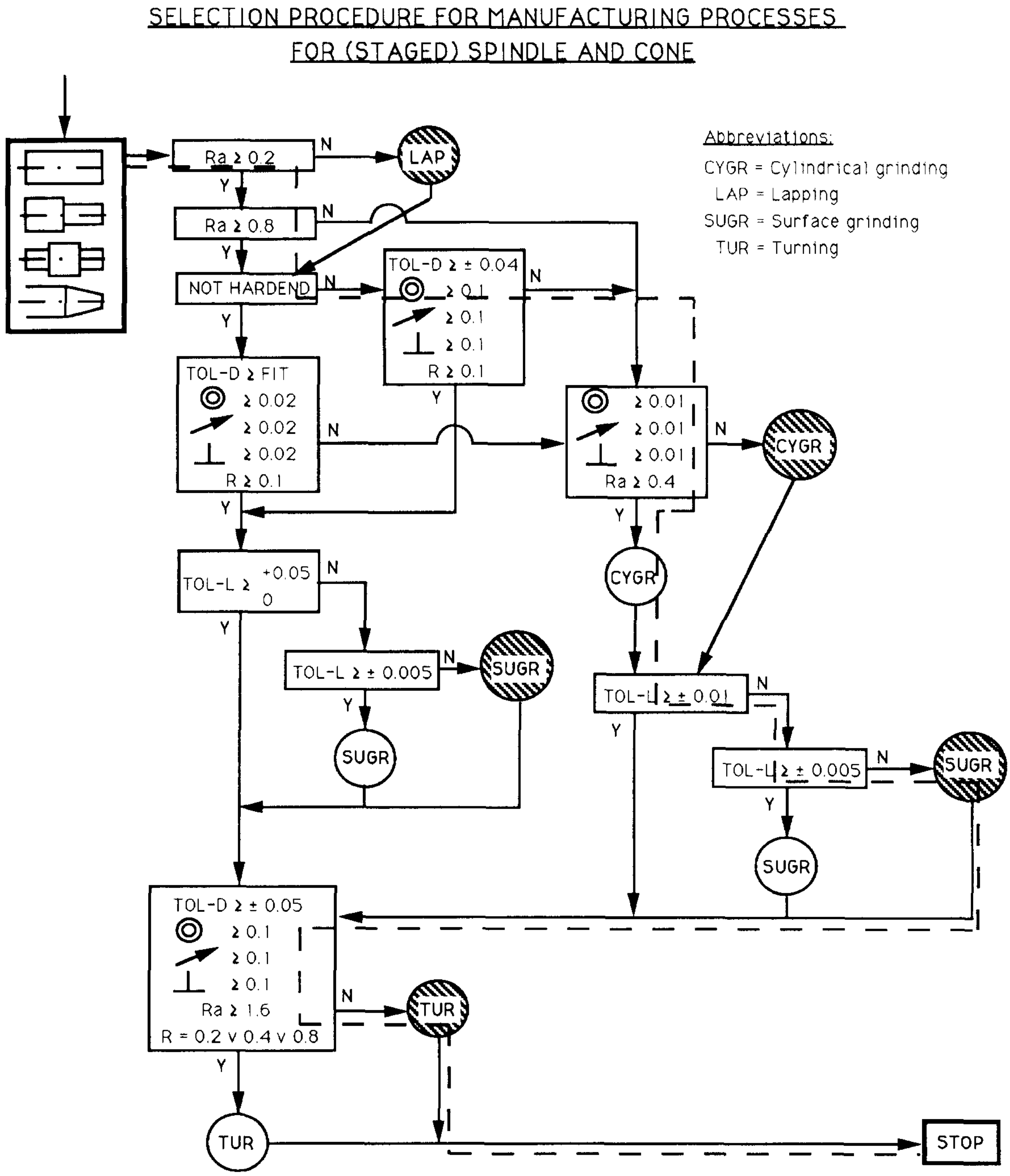

Fig. 5. Example of a selection procedure for manufacturing processes.

manufacturing cannot be deduced from the "selection procedures". This is justified by the facts that:

- Only the transfer points at which another manufacturing process is incorporated in the manufacturing method are of importance for the manufacturing costs, not the order in which the manufacturing processes will be carried out later.
- Design engineers are (somewhat) familiar with the order in which manufacturing processes have to be carried out.
- The (layout of the) "selection procedures" would become too complex.

The manufacturing method for the staged spindle in the example will be:

- Turning: rough turning with an allowance of ± 0.2 mm.
- Heat treatment.
- Cylindrical grinding: diameter and stroke to size.
- Surface grinding: length to size; the manufacturing costs for this manufacturing process will be proportionally high (surface grinding (SUGR) is indicated with a fill pattern), because of the design requirement tolerance of the length (Tol-Length 2) of ± 0.002 mm.

If the same example is compared to the graph with "cost factors" (Fig. 4), then it follows that the basic shape falls into manufacturing class 4, with a "cost factor" of 4.4, 5.0 or 5.6, dependent on the material the part is made of.

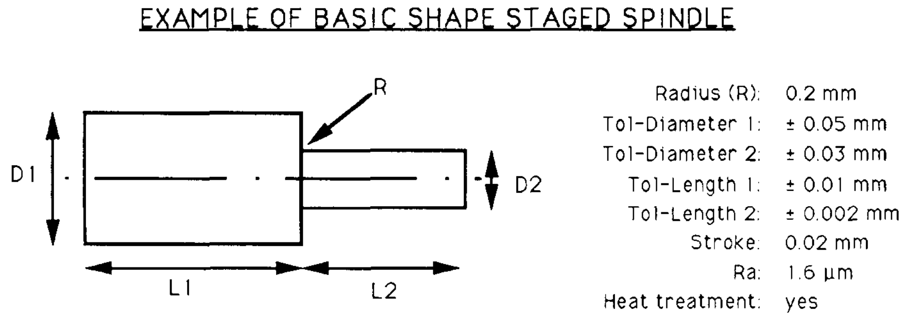

Fig. 6. Example of basic shape staged spindles.

The twelve "Selection Procedures for Manufacturing Processes" and the graphs with "Cost Factors" are collected in a "picture book" to be used by the design engineers.

COMMENTS

A small scale test was carried out, from which it can be concluded that the communication tool met with a positive response. Some additional comments to be made about the described communication tool are:

- Functionality of the design is the most important factor in the design process. When selection of the size of the tolerance is in doubt, play it safe. Conferring with the process planning department can be of help.
- In the initial stage of the implementation of the communication tool it is advisable to use the tool for all parts, and so for all basic shapes. This stimulates the design engineer to become familiar with the factors on the transfer points at which another manufacturing technology has to be incorporated in the manufacturing method. Having gained experience, application of the tool can be restricted to occasions in which reasonable doubt arises on making a selection with regard to the design requirements a part has to meet.
- The "Selection Procedures for Manufacturing Processes" can usefully serve as a training programme for design engineers. Using them, structured attention can be given to this aspect of producibility of a design during the training programme.
- The time required for the assembly of a piece of production equipment is not so much a result of the number of parts as a result of the complexity of assembly. The parts have to fit accurately together: the closer the tolerances, the greater the chance the parts do not fit precisely together, and in that way cause difficulties during assembly. That is why in principle tolerances should be chosen as wide as possible.
- Instead of feeling inhibited in their creativity when using this tool, the design engineer should see this as a new challenge, namely making a design with the functionality and quality required to minimum costs. Quality-conscious design should be a mechanization department's goal, so that the design engineer's performance can be reviewed on this factor.

CONCLUSIONS

The communication tool described in this paper "Selection Procedures for Manufacturing Processes", completed with graphs of the relative manufacturing costs collected in a booklet, supports quality-conscious design. The tool improves the insight of the design engineer into the way in which and the degree to which the design concept of a piece of production equipment is related to the costs of parts manufacturing.

On a small scale this communication tool was tested in the company where the study was conducted. A comprehensive test has yet to be carried out, but a provisional estimation shows possible savings of 5% in costs and capacity of parts manufacturing.

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