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ORIGINAL ARTICLE

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A methodology for extracting dimensional requirements for a product from customer needs

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Abstract Dimensional requirements greatly influence the performance of a product, yet there is no systematic process for determining them. Often as a result, some dimensional requirements are overlooked at the design stage, which forces costly changes at a latter stage of product realisation (such as manufacture and assembly). A methodology is presented here which will assist extracting the dimensional requirements for a product from the customers' needs. It is suitable for use in a Concurrent Engineering (CE) environment and incorporates some of the existing methodologies used in CE viz. quality function deployment, tree diagrams (The New Seven Tools) and Pugh's concept selection method. It provides a systematic way of determining the dimensional requirements of a product and establishes clear links between customer needs and the dimensional requirements. These links will help the CE team to understand the product requirements and how they are to be satisfied through the dimensional aspects of a design.

Keywords Dimensional requirements · Concurrent engineering · Quality function deployment · Tree diagram · Pugh's concept selection method

1 Introduction

Traditionally, a designer identifies the critical parameters required to be controlled for the proper functioning of the design from the product design drawing. These are known as *functional requirements*, due to their relationship with the function of the product. The functional requirements, which are dimensional in nature, are the *dimensional requirements* of the product for which the designer sets the target values for each dimensional requirement based on experimental results, analytic solutions, handbook data or past experience. Although the dimensional requirements greatly influence the performance of the product, there is no systematic process for determining them. Often as a result, some dimensional requirements are overlooked at the design stage, which forces costly changes in a latter stage of product realisation (such as manufacture and assembly).

Concurrent Engineering (CE) is an engineering and management philosophy which attempts to eliminate or at least reduce the number and frequency of engineering changes by performing many stages of the product and production development processes at the same time (concurrently). A team approach to product development is the primary feature of the CE concept, and the proposed methodology can be an effective tool for the CE team for determining the dimensional requirements of a product in a systematic way.

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2 An overview of the methodology

A flow chart depicting this extraction procedure is shown in Fig. 1. This methodology incorporates some of the existing methodologies used in CE, viz. Quality Function Deployment (QFD), a tree diagram (The New Seven Tools) and Pugh's concept selection methods. The proposed methodology is explained with the help of a gear pump design example (Fig. 2) and it is assumed that the customer needs for a gear pump have been identified and analysed, and the performance specification finalised.

3 The integration of customer needs into the product design

Quality Function Deployment (QFD) is a structured and effective methodology that can be used to integrate customer needs into the product design. QFD was first

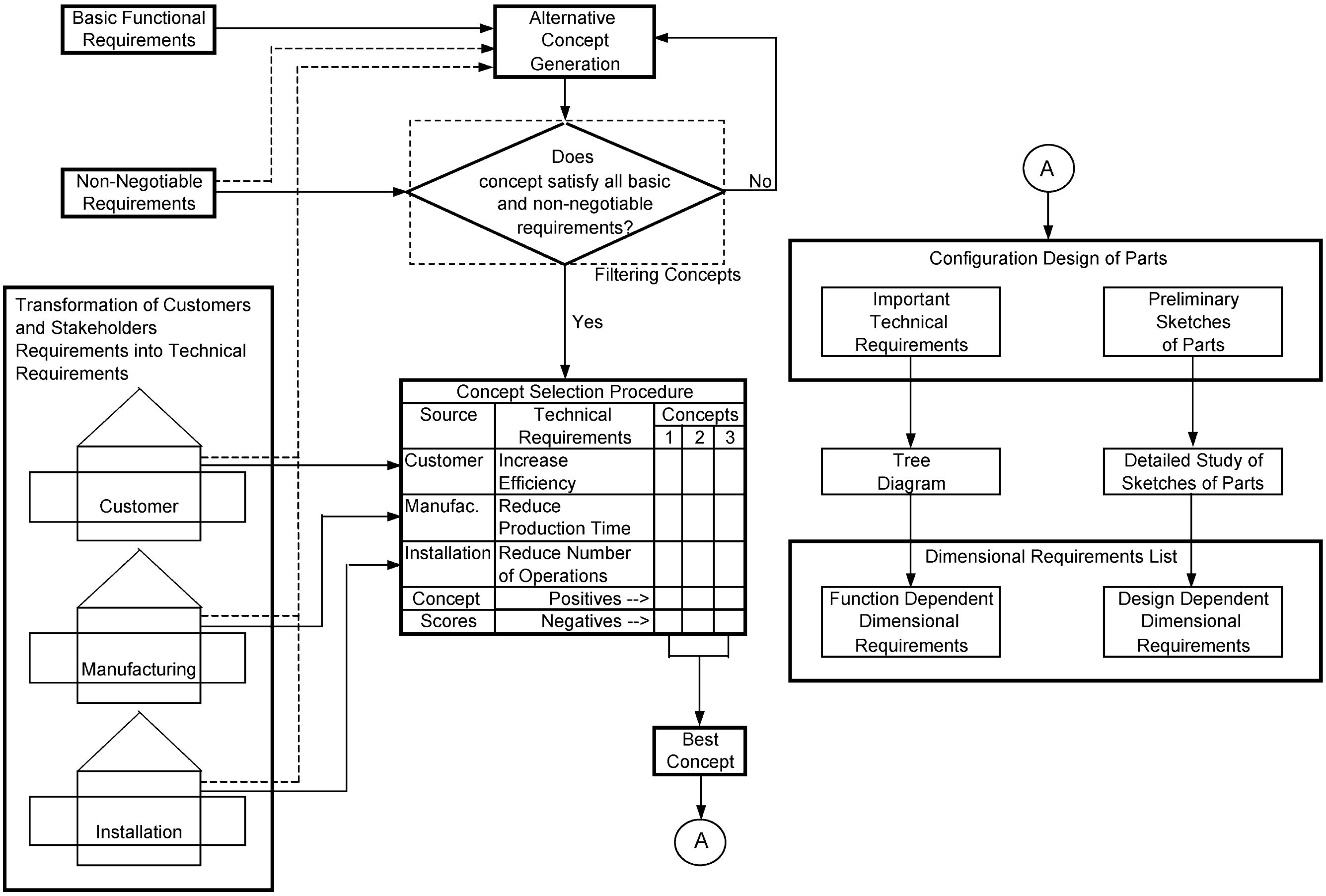


Fig. 1 The proposed methodology

introduced at the Kobe shipyards of Mitsubishi Heavy Industries Ltd. in 1972 [2]. Different formats of QFD are available; the two most popular are: (i) those promoted by the American Supplier Institute (ASI) in Dearborn, Michigan, and (ii) those promoted by GOAL/QPC in Methuen, Massachusetts. In this paper, the ASI format of QFD is used, details of which can be found in [3]. For details of the GOAL/QPC format refer to [4].

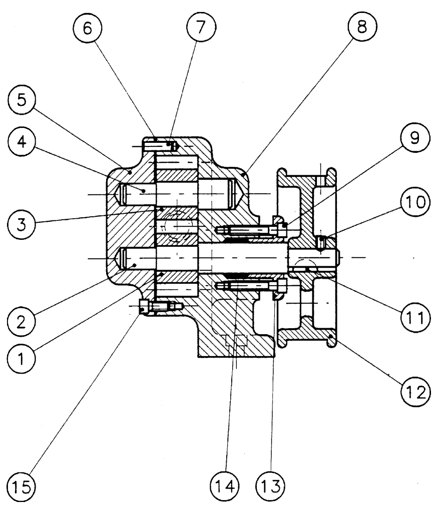


Fig. 2 The gear pump assembly (adopted from Farmer et al. [1] with permission)

3.1 Basic functional requirements

Basic functions are those which enable the product to do its job. The fulfilment of basic functions is the minimum requirement in product design; however, the basic functions are so basic that the customer seldom mentions them in interviews: they are known and expected. The presence of these requirements does little to promote significant satisfaction, but their absence leads to major dissatisfaction. An example of a basic function for a gear pump is to transport fluid. Different levels of basic functions can be derived with the help of a tree diagram, eg., (i) transport fluid at required rate and (ii) transport fluid at a required pressure.

3.2 Non-negotiable requirements

Non-negotiable requirements are dictated by relevant regulating bodies. Their purpose is to ensure competence in design for safe operation, both during production and in subsequent usage, and to minimise environmental damage. Among sources of non-negotiable requirements are: standards (national, international, company), codes of practice, regulations and laws. For a gear pump, an example of a non-negotiable requirement could be that the noise level is not to exceed 80 dB.

3.3 The spoken requirements of customer and stakeholders

It is noted that in a company the output of one department becomes the input or the customer of the next department. To differentiate between the external and the internal customers of a company, the term ‘stakeholder’ is used in this paper. *Customer* is the external customer or end user of the product, whereas *stakeholder* is the internal customer or functional department within the company. There will be many stakeholders in a project but due to limited resources, in most cases it will not be possible to analyse all their needs. For this reason the CE team selects the most important ones for the project. A number of techniques, details of which can be found in [2], can be used for this purpose.

The stakeholders can be ranked according to their importance, using the Pair Comparison technique [2], while the Pareto Distribution rule can be applied to reduce the stakeholders list to a manageable size [2]. The CE team will select the stakeholder types they want to investigate in the project on a consensus basis. There are a number of methods for capturing the spoken requirements of the stakeholder, such as one-on-one interviews, telephone surveys or postal questionnaires. Details of these approaches are given in [5]. For the gear pump example, eight possible stakeholders were identified. They are ranked and the requirements of the three most important viz. requirements of customer, manufacturing and installation, are selected for further investigation.

3.4 The transformation of customers and stakeholders requirements into technical requirements

Customers frequently express their needs in non-technical language and this means the needs stated are usually very general, vague and difficult to implement. Therefore, customer requirements have to be transformed into technical requirements, which should be measurable, and the company should be able to control them. QFD methodology is used for transforming customer/stakeholder requirements into technical requirements. For the gear pump example, three QFD matrices were built (Fig. 3).

3.5 Alternative concept generation

Alternative concepts are generated with the aim of satisfying the basic functional requirements of a product, its non-negotiable requirements and the technical requirements that represents the most important spoken requirements of the customer and stakeholders (Fig. 1). Two frequently applied methods or techniques for generating alternative concepts in a group environment are: (i) brainstorming [6], and (ii) techniques of synectics [7]. The concept generation process should produce as many concepts as possible because if a good idea is missed at this stage, there is the possibility that it will be missed forever.

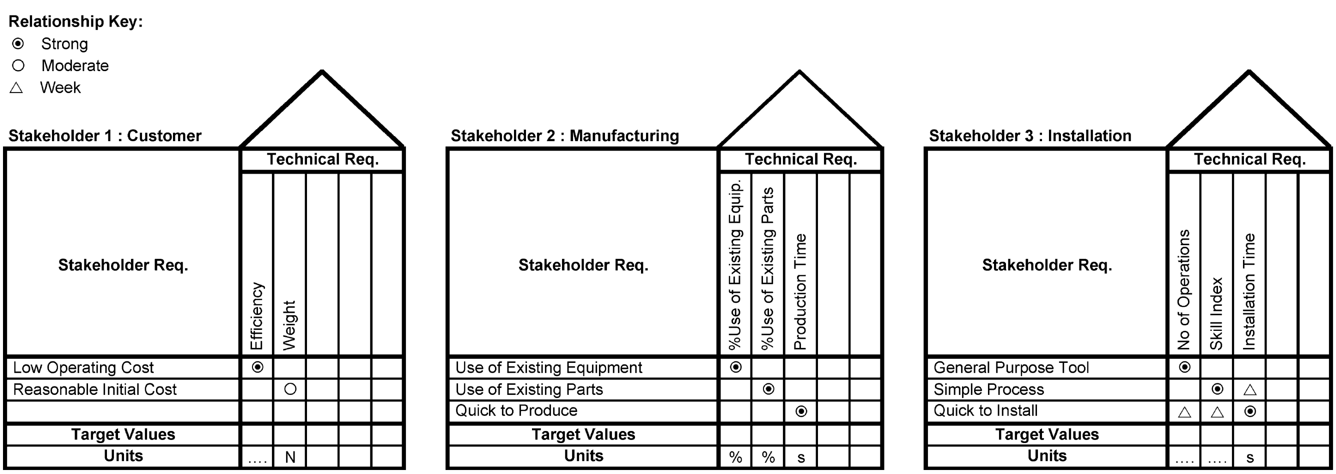
3.6 Filtering concepts

The objective of the filtering process (Fig. 1), is to identify those concepts that are worth developing further. It applies a GO/NOGO system comparison. To pass this filtering test a concept must satisfy all the basic functional and non-negotiable requirements. If a concept does not pass this test it can be modified and reconsidered or neglected. The concepts that survive this filtering process will be subjected to further detailed analysis.

3.7 The concept selection procedure

The concept selection procedure (Fig. 1) starts when the CE team judges that a sufficient number of concepts

Fig. 3 The transformations of stakeholders requirements of a gear pump into its technical requirements



have been generated. Of the methods available for comparing and evaluating the concepts, the following three are important: (i) Pugh's method [8], (ii) the Dominic method [9], and (iii) the Pahl and Beitz method [10]. Pugh's method for concept selection is a team-based activity which makes it particularly suitable for a CE environment. It uses a matrix format, known as *Pugh's Concept Selection Matrix*. Pugh's Concept Selection Matrix is applied to the gear pump example. Three concepts are evaluated against a number of criteria, which the CE team decides are the most important. These important criteria will be used later for the extraction of the dimensional requirements of the product. Concept No.1 is considered as datum, each concept is compared against the datum and the decisions are entered into the matrix (not shown). By analysing the entries in Pugh's Concept Selection Matrix, Concept No. 3 is selected as the best concept.

4 The extraction of dimensional requirements

Mizuno and Akao [11] published a list of possible technical requirements of a product. They called them quality elements and arranged them into seven groups. A close look at these technical requirements reveals that for a mechanical type product, quite a large number directly or indirectly depend on specified dimensions and tolerances. This is true because parts are physical entities; these entities, and their functions to some extent, can be controlled by dimensions and tolerances. The designer uses this fact for designing a product.

The present paper will concentrate on the technical requirements that are dependent on dimensions and tolerances of the design features. It is proposed that the CE team will consider each technical requirement in turn and ask the question "How does the design achieve/create/produce the technical requirement being considered?" The answers will provide the characteristics of the design which will satisfy the technical requirement under consideration. These answers will be recorded in a tree diagram starting from the left and moving to the right. After repeatedly asking the above question, the CE team will reach a stage where the answers will be dimensional in nature, i.e., size, form, orientation, location and/or surface texture. These requirements are dimensional components of a technical requirement or *dimensional requirements* of the product. For this exercise an in-depth understanding of design and the function of each component is necessary. A similar technique is well known in Value Analysis which has a more structured approach, known as a *FAST* (*Function Analysis System Technique*) diagram, details of which are given in [12].

An example of the above procedure applied to a gear pump design is shown in Fig. 4. It shows how some dimensional requirements of a gear pump were extracted from one of its technical requirements, viz. 'Increase Efficiency'. The analysis is based on the relationships given in [13] and [14]. The illustration given in Fig. 4 is for demonstration purposes only and for the sake of simplicity no attempt is made to include all the dimensional requirements which may follow from the technical requirement concerned. In this tree diagram, when moving from left to right, the HOW question forces more specific answers, whereas the WHY question can be used for checking the logic when moving from right to left. Figure 4 also demonstrates clear links between the dimensional requirements of a gear pump and one of its technical requirements. It is noted from Fig. 4 that at some stage, the design characteristics change from concept independent to concept dependent characteristics, although in some cases this line of demarcation may not be easily distinguishable. These dimensional requirements (Table 1) are related to the function of the product and are termed *function dependent dimensional requirements*.

As the design progresses more dimensional requirements have to be added for the proper functioning of the design. For example, for the mere functioning of the gear mechanism, the fit between the shaft and the gear wheel hole has to be an interference fit. These additional dimensional requirements are termed *design dependent dimensional requirements*. It is true that design dependent dimensional requirements are also related to the function of the product. However, these relationships are indirect and only come into effect through design. A list of some of the design dependent dimensional requirements for the gear pump example, which are determined from the proposed design, are included in Table 1. After considering all the technical requirements the CE team can identify the complete list of the dimensional requirements of the product, which will later be used for the functional dimensioning and tolerancing of the product.

5 The determination of target values for the dimensional requirements

The target value for each technical requirement has units consistent with the nature of the technical requirements. For example, weight (Newton), time (Second), noise level (Decibel), etc. In the tree diagram, shown in Fig. 4, it is interesting to note the change in the nature of the design characteristics. These changes require new target values expressed in relevant units. The hierarchical structure of the target values is a mirror image of the hierarchical structure of the design characteristics. The expertise of the cross-functional CE team will be the most beneficial in deciding these target values. In some cases the CE team may decide to determine some critical target values through tests. The Taguchi method [15] will be a useful tool for conducting the test. An example of the target values of some of the dimensional requirements of a gear pump is given in Table 1.

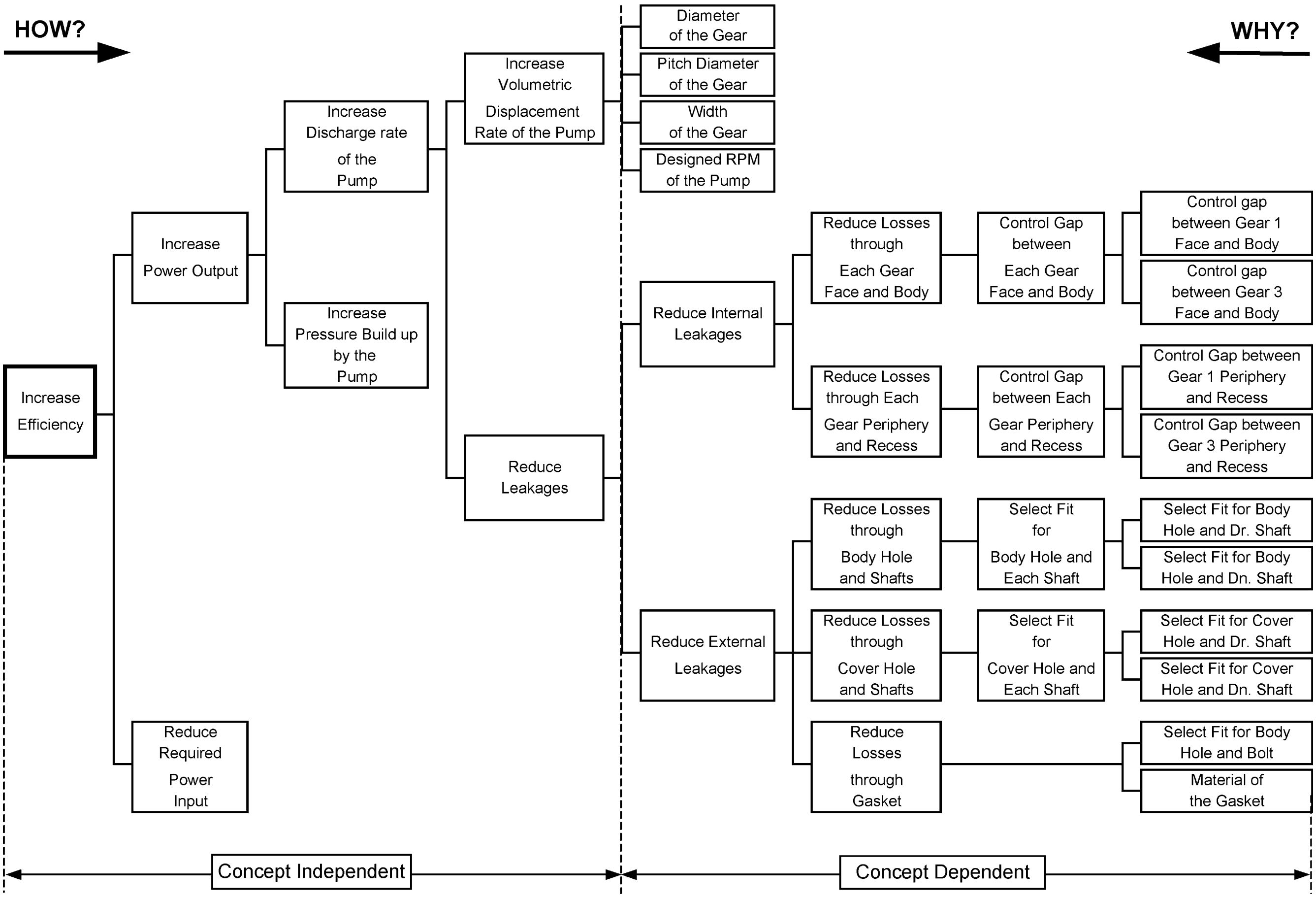


Fig. 4 The extraction of dimensional requirements of a gear pump from the customer needs

Table 1 List of dimensional requirements and their target values of a gear pump

Code	Dimensional requirements	Target values
	Function dependent dimensional requirements	
1.1.1	Control gap between the gear 1 face and body 8	Gap = 0.32 ± 0.265 mm
1.1.2	Control gap between the gear 3 face and body 8	Gap = 0.32 ± 0.265 mm
1.1.3	Control gap between the gear 1 periphery and body 8	Gap ≤ 0.4 mm
1.1.4	Control gap between the gear 3 periphery and body 8	Gap ≤ 0.4 mm
1.2.1	Select fit for the bearing and driving shaft	Close running fit
1.2.2	Select fit for the bearing and driven shaft	Close running fit
1.2.3	Select fit for the cover hole and driving shaft	Loose running fit
1.2.4	Select fit for the cover hole and driven shaft	Loose running fit
1.2.5	Select fit for the body hole and bolt	Precision Location fit
	Design dependent dimensional requirements	
2.1.1	Selected fit for the gear 1 hole and driving shaft	Drive fit
2.1.2	Selected fit for the gear 3 hole and driving shaft	Drive fit
2.2.1	Control flatness of the primary datum of the body	Flatness ≤ 0.025 mm
2.2.2	Control flatness of the primary datum of the cover	Flatness ≤ 0.025 mm
2.2.3	Select fit for the body and locating pins	Interference fit
2.2.4	Control angular play of the locating pins (body)	Angular play ≤ 3’
2.2.5	Select fit for the cover and locating pins	Close positional fit
2.2.6	Control angular play of the locating pins (cover)	Angular play ≤ 3’
2.3.1	Select fit for the stop and body	Loose location fit
2.3.2	Select fit for the stop and driving shaft	Slack running fit
2.3.3	Select fit for the stop and driving pulley	Normal running fit
2.3.4	Select fit for the body and sealing nut	H6g6
2.4.1	Select fit for the body and sealing nut	Slack running fit
2.4.2	Select fit for the cover hole and bolt head	Slack running fit

6 Conclusions

A methodology has been described for extracting the dimensional requirements of a product from customer needs. This methodology incorporates some of the existing methodologies commonly used in a CE environment. Although the application of the proposed methodology is time-consuming it provides a systematic process for determining the dimensional requirements of a product. The proposed methodology establishes clear links between the customers' and stakeholders' needs for a product and its dimensional requirements. These links will help the CE team to understand the product requirements and how they are to be satisfied through dimensional aspects of a design.

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