10 Design for Quality

10.1 Applying a Systematic Approach

Nowadays product quality is defined in a much broader sense than it used to be. Apart from fulfilling the required technical functions, careful attention has to be paid to the requirements of safety, use, ergonomics, recycling and disposal [10.4], as well as production and operating costs (see Section 2.1.7, Figures 2.15 and 7.2). It is important to recognise that poor product quality can result from shortcomings in design as well as in production.

Achieving product quality appropriate for the market starts with the design process [10.2, 10.19]. Quality cannot be achieved simply though testing and improving a product—it has to be built in from the beginning of the design process and maintained throughout the production process. Just as design commits a large proportion of a product's costs (see Chapter 11), up to 80% of all faults can be traced back to insufficient planning, design and development [10.26]. Furthermore, up to 60% of all breakdowns that occur within the warranty period are caused by incorrect or incomplete product development.

Ensuring quality and improving quality are team activities. These activities have to address all aspects of product development, starting with product planning and marketing. Quality is influenced decisively during design and development, and has to realised during production. The basis for quality procedures and terminology is the international standard DIN ISO 9000–9004 [10.12–10.16].

The systematic approach along with the selection and evaluation methods described in this book support quality assurance in product design and development [10.2, 10.3, 10.33].

Introducing the steps of the systematic approach into the overall product creation process, with its project management and project teams, supports a holistic approach to product quality (see Section 4.3). The process chain shown in Figure 4.5 presents an integrated product creation process with overlapping phases undertaken by project-specific teams made up of specialists recruited from the areas shown and from supplier organisations. This brings together expert knowledge, ensures continuous consideration of customer requirements and, in particular, provides short and direct information transfer paths. The latter ensure an iterative and continuous coordination of the design activity. Interdisciplinary project-specific teams also guarantee balanced assessments and decision making, both of which are important prerequisites for achieving high quality.

Of the basic rules, principles and guidelines of embodiment design, the following contribute directly to quality assurance.

Clear and simple solutions help the reliable prediction of the effects of working principles and the behaviour of construction structures, thereby reducing the risks from unintended disturbing factors (see Sections 7.3.1 and 7.3.2).

The principles of *direct safety* (safe-life, fail-safe, redundancy) and of *indirect safety* (safety systems, safety devices) provide important opportunities to achieve durability, reliability, accident prevention and environmental protection (see Section 7.3.3).

Fault free design supports failure reduction through design measures such as compensating for disturbing factors (principle of balanced forces), selecting working principles and working structures in which the properties are largely independent of the disturbing factors (principle of division of tasks, see Section 7.4.2), and choosing interfacing elements that do not require close tolerances (see Section 7.4.5).

Force transmission between parts often results in mismatched deformations (differences in magnitudes and directions) causing additional stresses. These can be avoided by applying the *principle of matched deformations*, i.e. force directions and geometries are determined such that the interfacing surfaces deform in the same directions and with the same magnitudes, thus ensuring a uniform load transmission (see Section 7.4.1).

The *principle of stability* ensures that when a system or component is subjected to disturbing factors, the effects of these are compensated for or reduced (see Section 7.4.4).

The *principle of self-help* attempts to utilise the operating and disturbing effects to support the main function. It can also produce a self-protecting solution that compensates for excess stresses or alters the load paths when overloading occurs (see Section 7.4.3).

Design to allow for expansion and creep means that thermal and load related expansions of parts, with or without the effects of time, are reduced by the appropriate selection of materials or allowed for by suitable guides. These measures ensure that there are no residual stresses, no jamming and no other disturbances to the operation (see Sections 7.5.2 and 7.5.3).

Design against corrosion and to minimise wear attempts to avoid or minimise corrosion and wear—or at least make them safe for operation—by preventing the causes (primary measures); or by selecting appropriate materials, by applying surface finishes, and by specifying simple maintenance measures (secondary measures) (see Sections 7.5.4 and 7.5.5).

Careful *design for production and assembly* not only reduces production costs and times but also provides an essential basis for quality assurance. Production and assembly are the areas on which quality methods and measures have traditionally focused (see Sections 7.5.8 and 7.5.9).

Design for minimum risk attempts to anticipate possible future problems, due to either gaps in knowledge or unforeseen disturbing factors, in such a way that should such problems arise during testing, they can be dealt with easily using simple additional measures (see Section 7.5.12).

Design to standards strongly supports quality assurance, because the application of standards ensures the use of proven technology and procedures, supports maintenance, and introduces internationally agreed quality features (see Section 7.5.13).

When considering product quality in its broadest sense, embodiment design guidelines such as *design for ergonomics, design for aesthetics and design for recycling*, are also important (see Sections 7.5.6, 7.5.7 and 7.5.11).

By rigorously applying systematic design methods, product quality is positively influenced, with hardly any additional costs, through: the avoidance of failures and disturbing factors; the provision of simple and clear working and construction structures; and the unambiguous realisation of the desired product properties. Such *primary measures* are to be preferred over extensive analysis and testing.

In addition to these design methods, a range of systematic tools support quality. The *requirements list*, for example, ensures that none of the essential demands and wishes are overlooked. This list is therefore of particular importance for quality assurance (see Section 5.2). For a preliminary selection of solutions, a *selection chart* is available (see Section 3.3.1), for a more detailed assessment and for identification of weak spots, *Cost-Benefit Analysis* or a similar procedure can be used (see Section 3.3.2). *Fault tree analysis* can be used to assess the effects of disturbing factors and possible failures (see Section 10.3).

Procedures and computer-based tools have been developed to help designers *analyse and define tolerances* that maximise the quality and minimise the cost of complex parts and assemblies (see Section 7.5.8 and [10.29]).

Computer-supported *reliability analyses* are used to predict component and machine lives and the likelihood of failures, thus supporting quality improvement [10.5, 10.24].

Computer-based *optimisation procedures* are important for optimising technical systems to meet complex sets of objectives and constraints.

To analyse the stresses and deformations of structures under mechanical and thermal loads in order to optimise them for safety, material utilisation and other characteristics, the *Finite Element Method* (FEM) has been widely introduced. FEM and all analytical procedures to verify calculations and define preliminary embodiments support quality assurance.

Despite the possibilities that systematic design offers designers to improve quality, companies have introduced additional quality management procedures. *Total Quality Management* (TQM) and *Total Quality Control* (TQC) represent a quality philosophy that engages all those involved in the product creation process in a continuous and holistic *quality engineering* process [10.20–10.22, 10.25–10.27]. TQM is foremost an organisational management instrument focusing on the following areas of operation: quality aware management, staff development, customer relations management, supplier integration, responsibility to society, process-orientated organisation structures, quality-directed auditing, and goal planning that encourage quality [10.25]. TQM also provides individual methods that complement the systematic design approach.

First of these is *Failure Modes and Effects Analysis* (FMEA), which is used to analyse possible failures and the risks involved in a more extensive way than can be done with Fault-Tree Analysis. Because of its importance, FMEA is discussed separately (see Section 10.4).

A further method is *Quality Function Deployment* (QFD), which is used to translate the often vague customer requirements into ones that are clearly formulated, and where possible quantified, and that are related to the different company departments [10.3, 10.9, 10.10, 10.17, 10.23, 10.25]. QFD thus helps to refine and complete the requirements list, making it an important part of a systematic product planning process. Because of its importance in industrial practice the method is described in more detail in Section 10.5.

Another systematic approach is the *design review*, which is a team-based activity used at the end of the various design phases to check results and assess progress [10.33]. These checks and assessments are also used to estimate and reduce risks.

Figure 10.1 summarises the main product- and process-related failures that can occur along with some of the essential measures that can be used to mitigate them.

It can be concluded that the systematic approach proposed in this book contains all the fundamentals for applying quality engineering. The special methods of TQM should be seen as complementary to this systematic approach and not the other way round [10.6, 10.8, 10.18, 10.33]. If the search for suitable principle solutions has not been undertaken rigorously and if the appropriate rules, principles and

Product-related failures	**Possible mitigating measures**	
Geometry · Space problems · Faulty interface configuration	· 3D modelling · Design reviews · Statistical tolerancing	[10.33] [10.33]
Function · Inadequate or deficient function fulfilment · Inadequate breakdown behaviour · Interfacing problems	· Fault-Tree Analysis · Failure Mode and Effect Analysis (FMEA) · Quality Function Deployment (QFD) · ISO 9001 (Validation)	(see 10.3) (see 10.4) (see 10.5) [10.5]
Layout · Kinematic problems · Strength problems	· Experiments · Field tests · Simulations - Finite Element Method (FEM) - Multi-Body Simulation (MBS)	
Process-related failures		
· Inadequate document management · Inadequate configuration management · Inadequate variant management · Inadequate change management · Inadequate version management	· ISO 9001 · Engineering Data Management System (EDMS) · Product Data Management (PDM) · Digital archive	[10.5]

Figure 10.1. Possible failures of design and development with measures to mitigate them

embodiment guidelines have not been applied to their full extent, the methods of TQM will not be able to rectify these fundamental deficiencies.

10.2 Faults and Disturbing Factors

The design process involves a series of creative and corrective steps. Selection and evaluation methods (see Section 3.3) as well as tests and calculations help to identify and remove weak spots. Even so designers can make mistakes, or their knowledge may not be sufficient to identify or exclude links that are faulty or prone to disturbances. When designers are aware of the information they lack and the uncertainty in their decisions, they can avoid severe technical and economic consequences by designing to minimise risk (see Section 7.5.12).

Often malfunctions are not caused by design faults but by *disturbing factors*. According to Rodenacker [10.28] disturbing factors can be caused by variations in the input variables, that is, by quality differences in the material, energy and signal flows entering the system (see Figure 2.14). When these influence the output of a system adversely, it may be necessary to compensate for them by modifying the type of solution, e.g. through a control system. The basis for this is determined by the selected working principles and the way they are combined. One should always aim for a robust concept, in which the outputs are independent of the quality of the inputs. The efficiency of a friction wheel drive, for example, strongly depends on the quality of the friction surfaces, which can have a negative effect on the quality of the overall product.

Disturbing factors can be identified in the *function structure* when the allocation and connection of the subfunctions lack clarity. They show up in the *working principle* when the selected physical effects do not produce the expected results. Because of variations in *material properties* along with shape, position and surface deviations introduced during *production* and *assembly*, the selected *embodiment* can result in unexpected effects. Finally, *external disturbing factors* such as temperature, humidity, dust, vibration, etc. can cause effects that should not be neglected. It may therefore be necessary to suppress the effects of disturbing factors to avoid the danger of fault propagation.

Preventative measures can reduce the malfunctions caused by disturbing factors but cannot exclude them altogether. Examples of measures include the principles of fault-free design (see Section 7.4.5 and [10.30]) and the other embodiment principles (see Section 7.4) and guidelines (see Section 7.5).

Extensive suggestions to achieve improved precision in machines are given by Spur [10.29]. He defines a machine as a “precision system” that is determined by the precision of: the material properties; the component geometry; the assembly geometry; the machine motions; the control system; along with its precision during operation.

Important prerequisites to prevent faults and disturbing factors, or at least limit their effects, are the identification and estimation of possible faults and disturbing factors as early as possible in the product development process. The following sections describe some established methods.

10.3 Fault-Tree Analysis

The influence of faults and disturbing factors can be determined systematically by *Fault-Tree Analysis* [10.11]. The Fault-Tree Analysis uses Boolean algebra to make an estimate of faults, their consequences and causes in safety critical systems. This method is based on causality, i.e. every event has to have at least one cause. An event (disturbance) only occurs when its cause arises.

From the conceptual phase, designers know what overall function and individual subfunctions have to be fulfilled. The established function structures can thus be used to identify all the functions to be checked. These functions are then negated one by one, that is, assumed to be unfulfilled. By reference to the checklist (see Section 7.2), designers can seek out the possible causes of these potential faults or disturbances. The OR or AND relationships of these causes and their effects can then be examined.

The conclusions help designers improve their designs and, if necessary, re-examine the solution concept or modify production, assembly, transport, operation and maintenance procedures. Let us take a concrete example.

The design of a safety blow-off valve for a gas container (see Figure 10.2) must be checked for possible design faults during the *conceptual phase*. From the requirements list and the function structure, it is possible to specify the operating conditions depicted in Figure 10.3. The blow-off valve is intended to open when the operating pressure p_{op} exceeds 1.1 times the nominal working pressure p_{nom}, and to close again when the container is under nominal pressure. The main func-

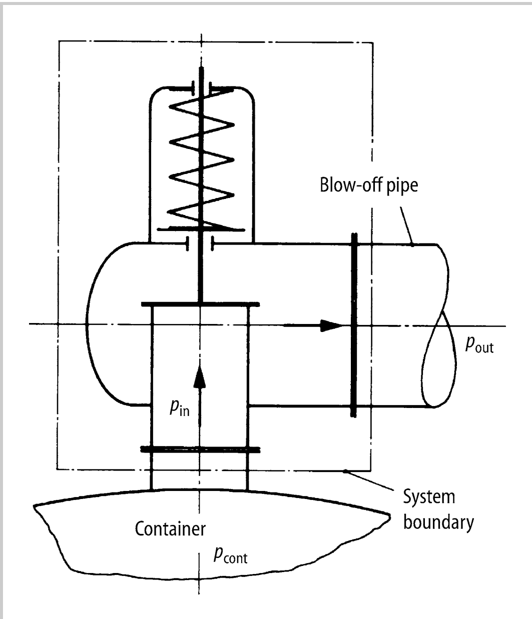

Figure 10.2. Safety blow-off valve for a gas container

tions are therefore "open valve" and "close valve". The overall function can also be described as "limit pressure". Let us now assume a possible failure of the overall function, namely "valve does *not* limit pressure" (see Figure 10.4). The valve functions shown in Figure 10.3 and their timing are negated. Each has an OR relationship with the overall function. Each fault thus identified is next investigated in terms of its possible causes. The fault we have chosen to investigate in more detail is "does not open" (see Figure 10.5).

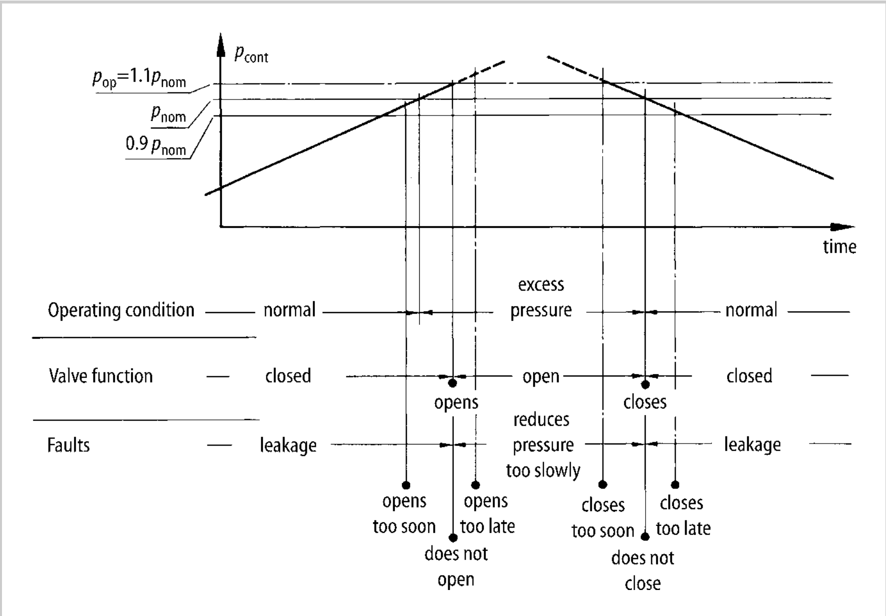

Figure 10.3. Operating conditions, valve main functions and faults of the safety valve

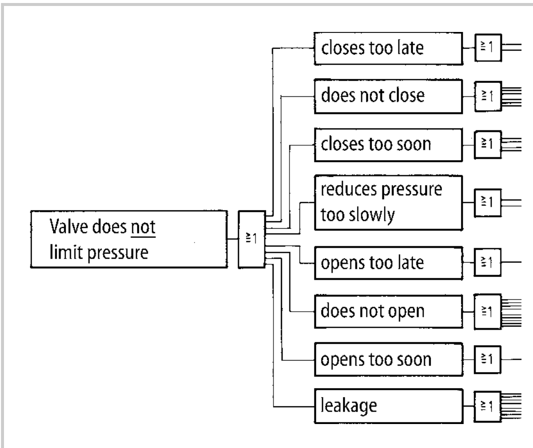

Figure 10.4. Construction of fault-tree based on faults identified from Figure 10.3

An identified cause may be associated with further causes with which it has an OR or an AND relationship, and these may have to be scrutinised accordingly.

Figure 10.6 shows a selection of further causes of malfunctions and some of the remedies identified at this stage. Often these cannot be clarified in more detail until the embodiment phase. Grouping the remedial measures according to the

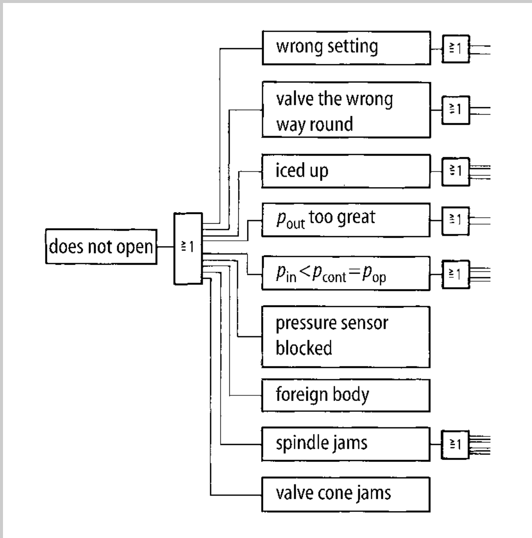

Figure 10.5. Detail from completed fault-tree (Figure 10.4) for the fault "does not open"

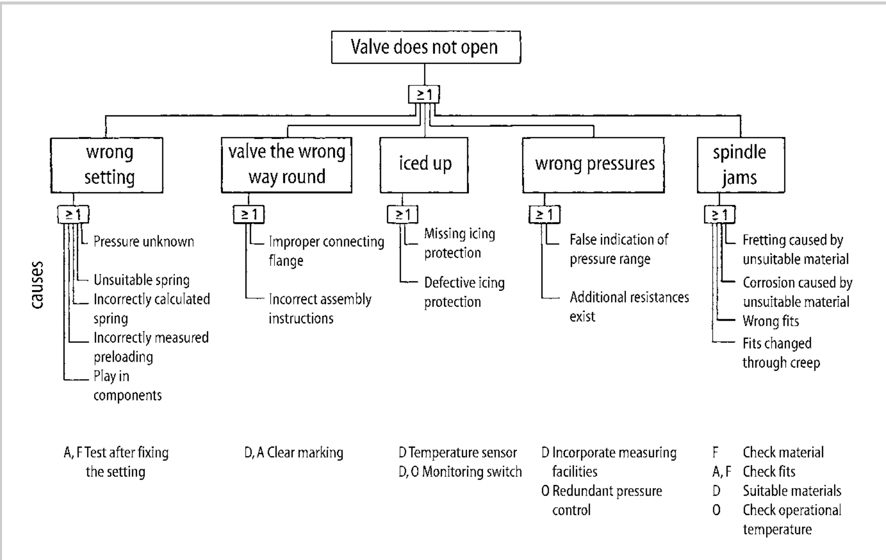

Figure 10.6. Causes of and remedies of malfunctions, after Figure 10.5: D = design; P = production; A = assembly; O = operation (use and maintenance); F = formal procedure required

departments involved simplifies their execution. On the basis of the information gained from a fault-tree analysis, designers are able to improve and complete the requirements list (see Figure 10.7) before they proceed to the embodiment phase. As a result, the design will be greatly improved and potential faults avoided.

The second example concerns the *embodiment phase*. A packing ring shaft seal is used to prevent the leakage of pressurised cooling air in a generator connected to a turbine (see Figure 10.8). This large diameter seal interfaces with a sleeve that acts as a thermal barrier. The seal has to withstand a pressure difference of 1.5 bar. Possible malfunctions of this assembly have to be analysed.

The overall function is "prevent leakage of cooling air". At the beginning of the investigation, it is useful to clarify the subfunctions that have to be fulfilled by the various parts. When no function structure has been established, one can use a table such as the one shown in Figure 10.9. For the "prevent leakage" function the following subfunctions are essential:

			Requirements List *for* *Safety blow-off valve*	1st issue 1/9/73 *Page* 1
Changes	*D W*	*No.*	*Requirements*[x)]	*Responsible*
1.9.73		22	Valve head with plane sealing surface (valve without taper)	
"		23	No rigid joint between valve head and spindle	
"		24	Easy maintenance or exchange of sealing surfaces	
"		25	Valve lift limited	
"		26	Damping of valve movement	
"	W	27	Installation in a closed, ice-proof area	
"		28	No sliding seals, avoid friction	
"		29	Ensure foolproof mounting (e.g. different flange sizes for inlet and outlet)	
			x) Requirements were revised after construction of fault-tree	
			Replaces *issue of*	

Figure 10.7. Revision of requirements list after fault-tree analysis

- generate compression force
- seal yet allow sliding
- remove frictional heat.

Next these subfunctions are negated and, at the same time, possible causes of malfunctions are sought (see Figure 10.10).

The results of the Fault-Tree Analysis point, first of all, to a malfunctioning of the thermal barrier *2* caused by unstable heat patterns (see Section 7.4.4). The frictional heat generated at the sliding interface can only flow away through the barrier into the shaft. This causes the barrier sleeve to heat up and expand. This increases the friction and at a certain temperature the barrier sleeve lifts off the shaft. This results in additional air leakage and damage to the shaft surface caused by the barrier sleeve slipping on the shaft. This layout is bad and the design principle needs improving. Either the barrier should be removed and the seal connected to the shaft so it rotates with the shaft (removal of heat through the housing *5*) or a sliding ring seal with radial sealing surfaces should be used.

Further necessary design measures:

- The connection of housing *5* to frame *6* is insufficient and the housing can start rotating with the shaft due to the pre-loading of the packing ring seals against the shaft. The compression force from the pressure difference is too low for the O-ring seal *7* to transfer the moment through a frictional connection. *Remedy:* reposition seal *7* towards the outer diameter of housing *5*; even better would be an additional form-fit connection to transfer the moment.

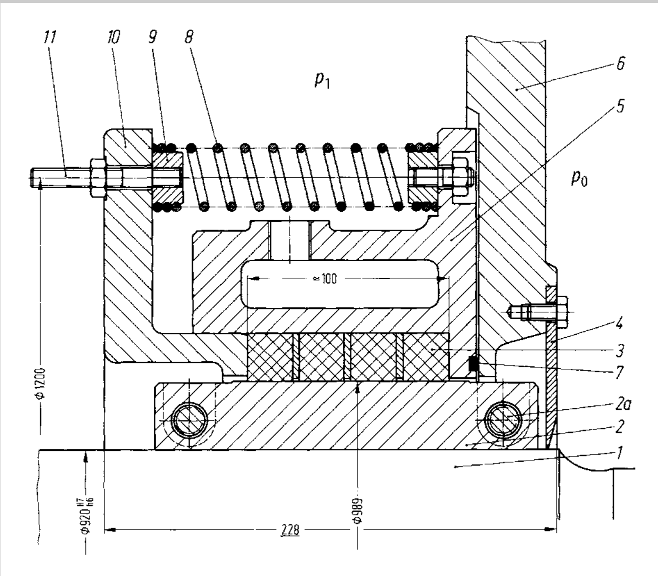

Figure 10.8. Packing ring shaft seal in a generator

Nos.	Components	Functions
1	Shaft	Transmit torque, carry sleeve, dissipate frictional heat
2,2a	Sleeve (barrier)	Provide rotation and seal surface, protect shaft, dissipate frictional heat
3	Packing rings	Seal medium yet allow sliding, carry compression force and provide sealing pressure
4	Scraper ring	Protect against splashed oil
5	Gland housing	Carry packing rings, carry and transmit compression force
6	Frame	Carry components *4* and *5*
7	O-ring	Seal p_1 from p_0
8	Tension spring	Generate compression force
9	Spring support	Transmit spring force
10	Transfer ring	Transmit compression force, carry tension spring
11	Bolt	Preload springs and adjust loading

Figure 10.9. Analysis of the components in Figure 10.8. to identify their functions

- With the current layout, the loading of springs *8* cannot be adjusted. *Remedy:* include sufficient space.
- For reasons of safety and simplicity, it is advantageous to use a compression rather than a tension spring.

Basically, designers should not only include design measures to improve the embodiment, but also measures to improve production, assembly and operation (use and maintenance) procedures, where these seem necessary. In certain cases it might be necessary to enforce specific test procedures (see Figure 10.10).

In summary, the following procedure should be followed to identify and rectify faults and disturbing factors:

- Identify and negate functions.
- Search for causes of possible malfunctions from: a function structure that lacks clarity; a less than ideal working principle; a less than ideal embodiment; less than ideal materials; and less than ideal inputs caused by variations in the material, energy and signal flows. In line with the guidelines given for the embodiment design phase, further influences that might cause undesired system behaviours should be sought in the following areas: loading, shape changes, stability, resonance, wear, corrosion, sealing, safety, ergonomics, production, quality control, assembly, transport, operation and maintenance.
- Determine the prerequisites for malfunctions to occur, e.g. through OR and AND relationships.
- Introduce suitable design measures by choosing another solution or making improvements to the existing solution. Quality control measures during production, assembly, transport, operation and maintenance can also be introduced. Preference, however, should always be given to the removal of a cause through an improved solution.

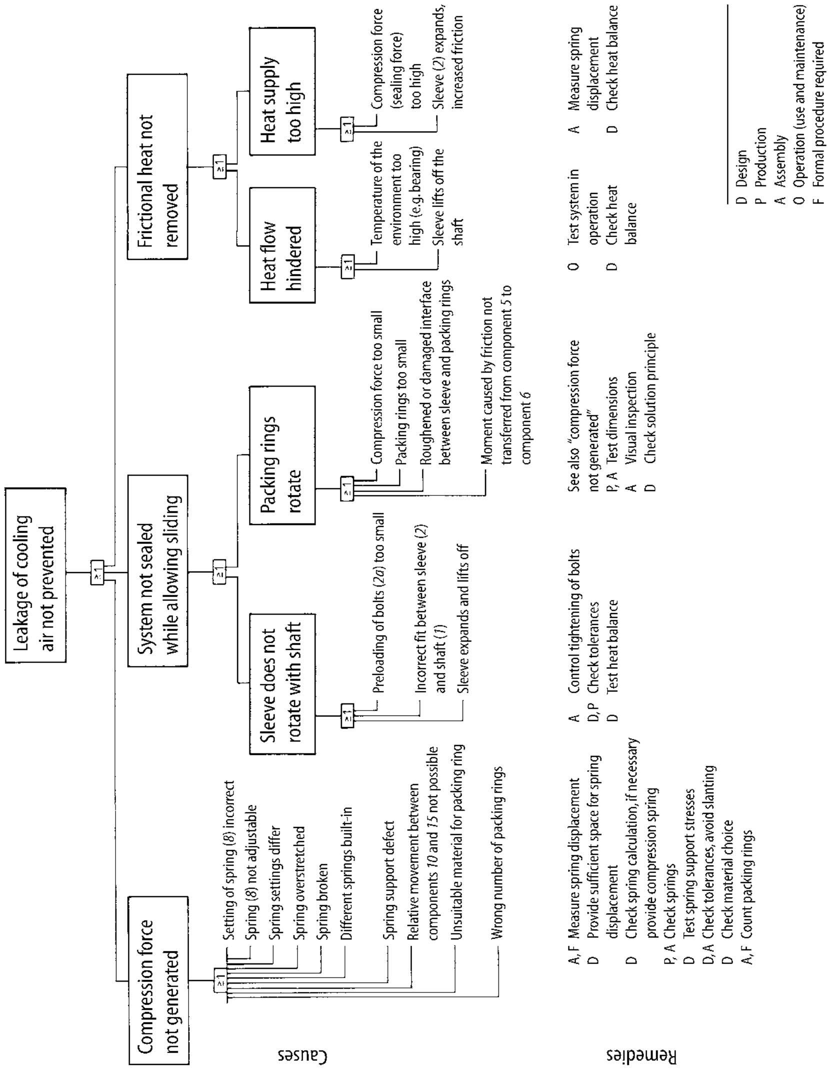

Figure 10.10. Fault-tree analysis of the shaft seal in Figure 10.8

It has to be noted that because of the effort required to complete a full Fault-Tree Analysis, this method is usually limited to important areas and critical processes. It is desirable that designers incorporate this way of thinking into their normal work patterns so that they can apply it almost unconsciously.

10.4 Failure Mode and Effect Analysis (FMEA)

FMEA is a formalised analytical method for the systematic identification of possible failures and the estimation of the related risks (effects) [10.19, 10.26, 10.32]. The main goal is to limit or avoid risk. An FMEA involves a direct analysis of failures and their consequences and causes. This means that only direct relationships between causes and consequences are identified. This method is usually applied during the development of new products. A distinction is made between a design or development FMEA and a process or production FMEA. The design FMEA is used to verify whether the functions set out in the requirements list are fulfilled. The process FMEA is used to verify whether the planned production process can produce the required product characteristics.

Figure 10.11 shows an FMEA chart with an example in which possible failures are listed together with their consequences, causes, risk numbers (RN), proposed test measures, and suggested and applied remedial measures. The chart also shows the following steps of FMEA:

1. Risk analysis of each component (or process step) regarding:
   - potential failures (failure types)
   - failure consequences
   - failure causes
   - planned measures to avoid failures
   - planned measures to detect failures.
2. Risk assessment:
   - estimation of the probability of occurrence
   - estimation of the effects of the failure on the customer
   - estimation of the probability that the failure can be detected before delivery (a high probability of detection implies a small risk and thus a small numerical value).
3. Risk number calculation: (RN) > 125 is considered critical.
4. Risk minimisation: development of measures to improve the design of the product (or its production process).

The assessment of risk using risk numbers is important. They provide estimates of: the probability of occurrence; the severity of failure; and the difficulty of detection. The latter requires an experienced assessment team to maximise the probability

TU-Berlin	Failure Mode and Effect Analysis Design (product)-FMEA ☒ Process-FMEA ☐								Component name **Cylindrical cam**					
	Name/ Department/ Supplier/ Telephone Institute for Machine Design-Engineering Design								By (Name/ Department/ Telephone) Mr Wende					
Failure location/characteristic	**Failure type**	**Failure consequence**	**Failure cause**	**Current situation**					**Suggested remedial measures**	**Improved situation**				
				Proposed test steps	O	S	D	RN		Applied steps	O	S	D	RN
Shaft	Shaft fracture	Complete breakdown	Type of loading not identified correctly		3	10	10	300	Determine loading using suitable calculations	Proof of strength of the shaft	1	10	10	100
Bearing	Play in bearing assembly	Imprecise function fulfilment	Slackening of shaft nut during operation (impulse loading)		3	8	10	240	Additional locking of the shaft nut		1	8	10	80
	Sealing leakage	Early wear of bearing	Sealing not as required		2	5	10	100	Use of radial shaft seals recommended by DIN		1	5	10	50
Shaft-hub-connection (flange-bolt connection)	Insufficient frictional fit	Shear stress in bolts	Layout error (friction values neglected)		2	6	10	120	Application of a sufficiently high safety factor		1	6	10	60
	Precision of fittings	Joining not possible or centering insufficient	Design fault		2	5	1	10	Check tolerance calculation		1	5	1	5
	Failure of bolts	Complete breakdown	Type of loading not identified correctly		3	10	10	300	Suitable calculation for loading situation	Appropriate bolt dimensions	1	10	10	100
Cylindrical cam	Surface pressure too high	Pitting in the running surface	Lever pressure on surface too high		7	8	10	560	Suitable combination of materials and adapted geometry		2	8	10	160

O: Occurrence **S:** Significance **D:** Detection **RN:** Risk number

Probability of occurence
(failure can exist)

very low = 1
medium low = 2–3
medium = 4–6
medium high = 7–8
high = 9–10

Effect on customers

effects hardly noticeable = 1
failures not important (little trouble to the customer) = 2–3
reasonably serious failure = 4–6
serious failure (annoying for the customer) = 7–8
failure with large negative effects = 9–10

Probability of detection
(before delivery to customers)

high = 1
medium high = 2–5
medium = 6–8
medium low = 9
low = 10

high = 1000
medium = 125
no risk = 1

Figure 10.11. FMEA chart with an example of the shaft, bearing and cylindrical cam of the design discussed in Section 7.7 (Figure 7.160)

of detecting a failure. FMEA is qualitative in nature and is a method for evaluating quality. Staff from design, development, production planning, quality control, purchasing, sales and customer service should be included in an FMEA team, for the same reasons as for their inclusion in a Value Analysis team (see Section 1.2.3). Apart from evaluating possible malfunctions caused by failures and disturbing factors, FMEA encourages early cooperation between the various departments involved in product development. Fault-Tree Analysis is intended to assist designers alone, whereas FMEA also functions as a means of handing over to production and supporting the overall quality assurance process.

After a period of use, the information in the FMEA records and analyses of the FMEA charts provide valuable insights into successful quality measures that can be used in subsequent products.

For the production process, an additional process FMEA is carried out using the same charts. This evaluation of the production processes, however, is often contained indirectly in the design FMEA, because production issues should already have been taken into account during the design process.

10.5 Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is a methodology for quality planning and quality assurance [10.1, 10.9, 10.10, 10.17, 10.20–10.22, 10.25, 10.31]. It supports a systematic customer orientation of product and process planning. The customer requirements are translated into technical requirements. These in turn are translated into organisational processes and production requirements. The main question is whether all the functions required by the customer can be realised.

The QFD methodology is a four-step procedure as shown in Figure 10.12. Similar to FMEA (see 10.4), QFD also assists with the integration of the main activities in the product creation process.

The main working chart of QFD is the so-called "House of Quality". An example of this chart for the manual winding device shown in Figure 10.13 is provided in Figure 10.14. The chart documents clearly the translation of customer requirements (referred to as the "what"), which are often vaguely formulated, into technical requirements (also referred to as target requirements or the "how") of the product to be developed. The roof of the house shows if the technical requirements interrelate with each other and the strength of any interrelationship. The matrix in the middle of the chart shows the interrelationship between the customer requirements and the technical requirements. Weighting factors can be added to the customer requirements, as well as an estimation of competing products from the point of view of the customer. Underneath the central matrix, target values for the technical requirements are plotted along with a technical assessment of competing products (benchmark). At the very bottom the weighted values (priorities) of the technical requirements are listed.

This basic scheme can also be applied to the subsequent phases of the product creation process. The "how" of one House of Quality becomes the "what" of the following one [10.6, 10.10].

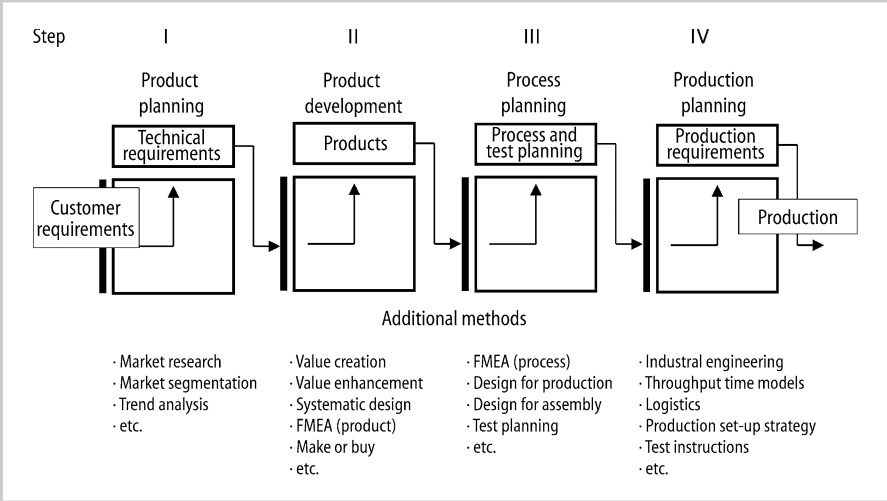

Figure 10.12. QFD as an integration tool

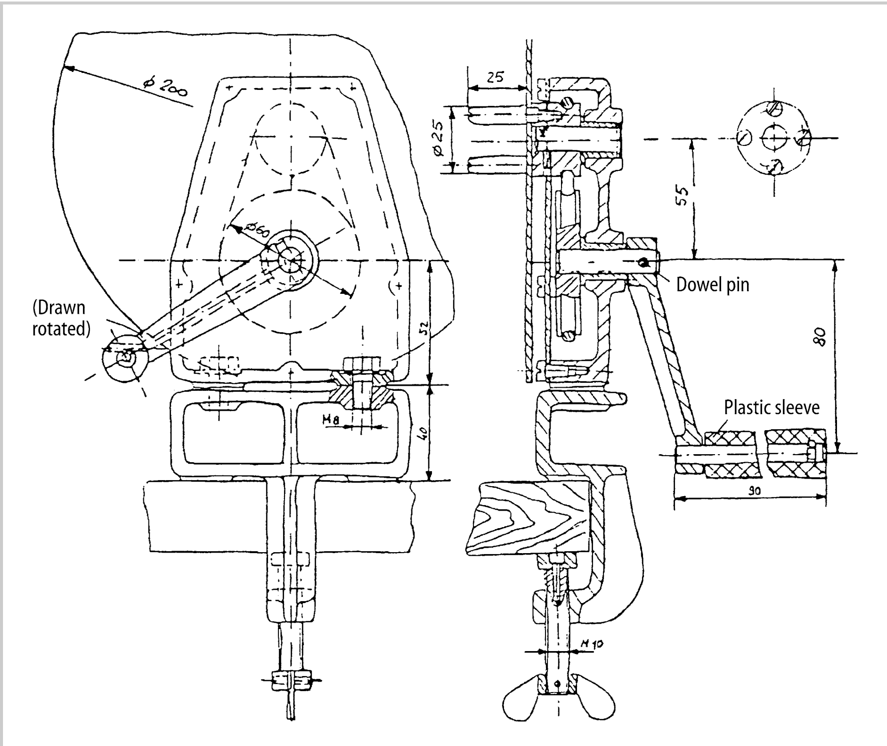

Figure 10.13. Rough layout of a manual winding device for perforated strip

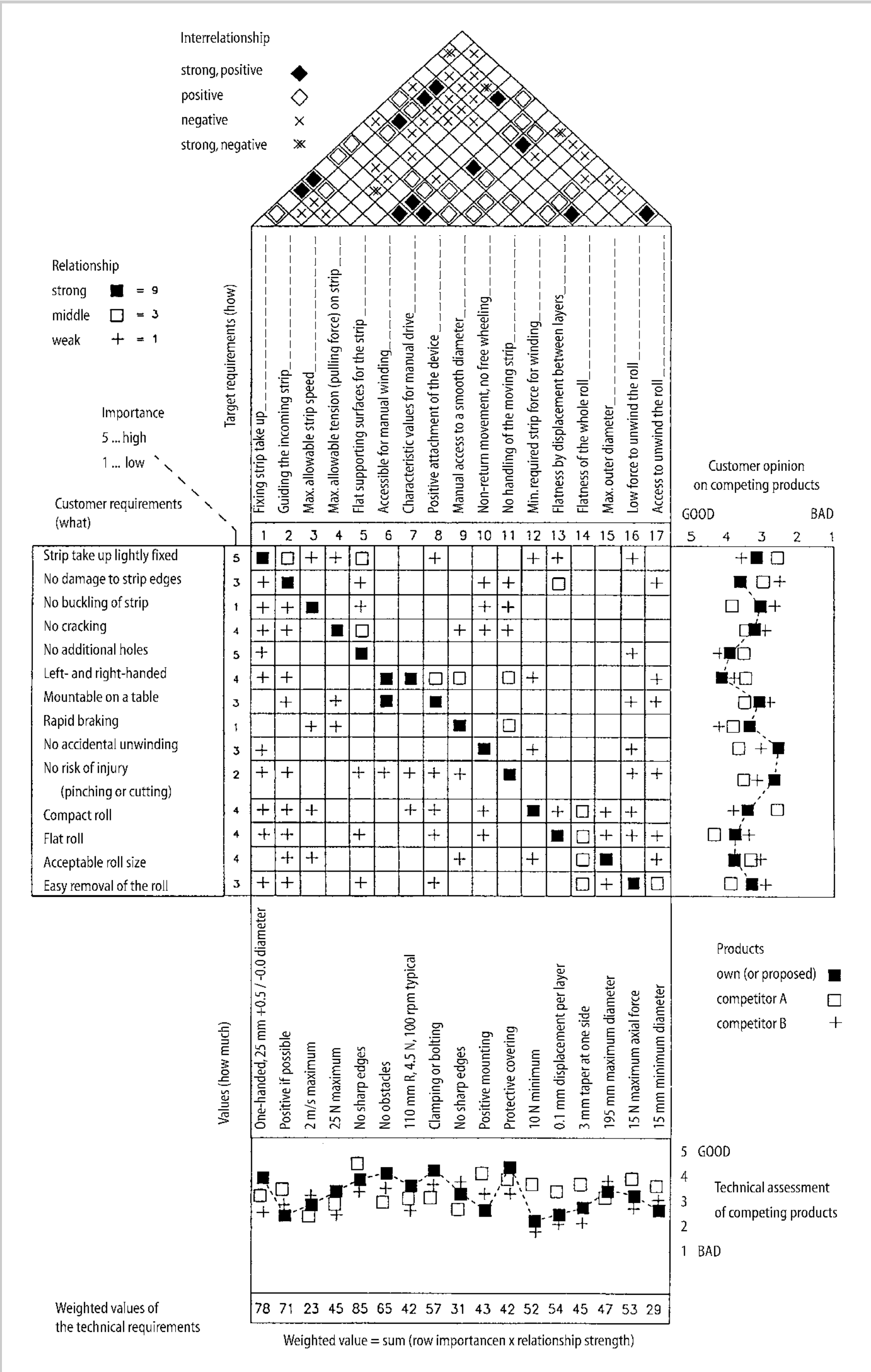

Figure 10.14. House of Quality for the example shown in Figure 10.13

In the context of the systematic approach, the use of QFD provides the following benefits:

- improved formulation of requirements lists through a better representation of customer requirements
- identification of critical product functions (customer-oriented function structures)
- definition of critical technical requirements and identification of critical components
- recognition of future development goals and cost targets on the basis of customer requirements and analyses of competing products.

The extensive effort needed to undertake every stage of this planning activity in detail is only justified for major long-term projects. These projects, however, should also start with the much simpler and quicker methods of task clarification and requirements formulation presented in Chapter 5.