

Engineering Design

A Systematic Approach

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A Systematic Approach

Third Edition

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Translators and Editors

 Springer

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Preface

Sadly, just one year after the publication of the fourth German edition in 1997, my co-author Wolfgang Beitz died after a short but severe illness. His many outstanding contributions to engineering design, including his contribution to this book, were honoured in a memorial colloquium held in Berlin. It would have made me very happy if he had been able to see the continuing success of our book, including its translation into Portuguese. Our collaboration was a perfect one—always fruitful, always beneficial. I am deeply grateful to him.

The book, “Pahl/Beitz—Konstruktionslehre”, has now been translated into eight languages and recognised as an international reference text. For reasons of continuity, our publisher Springer wanted to publish a fifth German edition of the book. To assist with this task two former students of Wolfgang Beitz became involved: Professor Dr.-Ing. Jörg Feldhusen and Professor Dr.-Ing. Karl-Heinrich Grote, both of whom have continually promoted and expanded his ideas. Professor Feldhusen worked for many years as a senior designer in the automotive industry and is now at RWTH Aachen University, succeeding Professor Dr.-Ing. R. Koller. Professor Grote has considerable experience of teaching design and running projects as a Professor in the USA, and is now at the Otto-von-Guericke University in Magdeburg. He succeeded Professor Beitz as the Editor of the *Dubbel Handbook for Mechanical Engineering*.

Gerhard Pahl
Darmstadt

Authors' Forewords

Sixth German Edition

The fifth German edition, which was published in March 2003, was so well received that just a year later a sixth German edition was required. The opportunity was taken to add some new developments to the chapter on size ranges and modular products.

The authors would like to reiterate their thanks to all those involved in both editions.

G. Pahl, J. Feldhusen and K.-H. Grote
Darmstadt, Aachen and Magdeburg, April 2004

Fifth German Edition

For the fifth German edition we have retained the well-established pattern of the previous editions, but updated it with new material. Because of its widespread use, the basics of electronic data processing*, including CAD, have been moved into the chapter on fundamentals. The chapter on the product development process has been expanded and strengthened by adding new perspectives. As a result, Chapters 1–4 now fully represent the necessary basic knowledge, including cognitive aspects, needed to underpin a systematic approach to engineering design. Chapters 5–8 describe the application of this basic knowledge to product development from the task clarification phase, through conceptual design up to the final embodiment and detail design* phases, supported by many detailed examples. Chapter 9 describes some important generic solutions including composite structures*, mechatronics and adaptronics. Basic knowledge about machine elements is, as always, assumed. Chapter 10 covers, as in previous editions, the development of size ranges and modular products. The increasing importance of achieving high quality is reflected by additions to

* The starred topics do not appear in this third English edition and as a consequence some chapter numbers have changed—see Editors' Foreword.

Chapter 11. The important theme of estimating costs can be found, as before, in Chapter 12. Because the basics of data processing technology have now been included in the chapter on fundamentals, Chapter 13 focuses on general recommendations for designing with CAD*. Chapter 14 provides an overview of the recommended methods, and reports on experiences of using the approach in industrial practice. The book closes with a definition of terms* as they have been used in this book. The index supports a rapid search for specific themes.

In this way, the systematic approach to engineering design has been brought to a level that provides a basis for successful product development. Throughout, fundamentals have been emphasised and short-term trends avoided. The approach described also provides a sound basis for design education courses that help students move into design practice. The literature has been updated, offering those who are interested in more detail or in the historical background a rich source of information.

The authors have to thank many individuals. Frau Professor Dr.-Ing. L. Blessing, successor to Professor Wolfgang Beitz, kept the original figures and made them available to us. Professor Dr.-Ing. K. Landau, TU Darmstadt, helped us update the literature on design for ergonomics. Professors Dr.-Ing. B. Breuer, Dr.-Ing. H. Hanselka, Dr.-Ing. R. Isermann and Dr.-Ing. R. Nordmann, all from TU Darmstadt, contributed to the sections on mechatronics and adaptronics with suggestions, examples and figures. In this connection we also thank Dr.-Ing. M. Semsch for his contribution. Emeritus Professor Dr.-Ing. M. Flemming, ETH Zurich, greatly supported us with suggestions and figures on the themes of composite construction* and structronics. Last but not least, we thank all those hardworking assistants, such as Frau B. Frehse at the Institut für Maschinenkonstruktion-Konstruktionstechnik, Universität Magdeburg, who prepared and re-worked the electronic transformation of the text and figures. Finally we warmly thank our publisher Springer, in particular Dr. Riedesel, Frau Hestermann-Beyerle, Frau Rossow and Herr Schoenefeldt for their continuous support and for the excellent printing of the text and figures.

G. Pahl, J. Feldhusen and K.-H. Grote
Darmstadt, Aachen and Magdeburg, June 2002

Fourth German Edition

The third edition of our book proved to be so popular that after a relatively short time a further edition was required. A reprint was not considered appropriate as several important new concepts and methods for the product development process had emerged, and these could

not be ignored. Furthermore recently published findings needed to be taken into account.

The structure and content of the third edition forms the basis of the fourth edition. The topic of product planning has been extended through the integration of methods such as portfolio analysis and scenario planning. New sections have been introduced on effective organisation structures, on applying simultaneous engineering, on leadership and on team behaviour. The increasing importance of quality assurance has reinforced the need to adopt systematic engineering design as a primary measure. This should be extended through the application of secondary measures, such as Quality Function Deployment (QFD) using the House of Quality. Developments in the area of sustainability have led to modifications in the section on design for recycling. Because of its general technical and economic importance, a new section on design to minimise wear has been introduced. The method of target costing has been included in the chapter on design for minimum cost. Finally, the chapter on CAD required updating*.

The third edition, slightly abridged, has been translated into English, *Engineering Design: A Systematic Approach* (2nd Edition, Springer-Verlag, London), under the leadership of Ken Wallace, who was supported by Luciënne Blessing and Frank Bauert. We thank them warmly. A Japanese translation has also been published, and a translation into Korean is in progress. These translations significantly increase the international influence of *Konstruktionslehre*.

The employees of both our institutes have again supported our work on the fourth edition in their usual trusted and willing way. For their help we are deeply grateful. Our publishers have again to be thanked for the excellent advice we have received, as well as for their careful realisation of the book. Finally, we thank our wives for their continuous understanding, for without their support this book would never have been possible.

G. Pahl and W. Beitz
Darmstadt and Berlin, January 1997

Editors' Foreword

Background

The first German edition of *Konstruktionslehre* was published in 1977. The first English edition entitled *Engineering Design* was published in 1984 and was a full translation of the German text. Both the German and the English editions of the book rapidly became established as important references on systematic engineering design in industry, research and education. International interest in engineering design grew rapidly during the 1980s and many developments took place. To keep up-to-date with the changes, a second German edition was published in 1986. It was too soon after the publication of the first English edition to consider a second edition. However, since the translation was being extensively used to support engineering design teaching, a slightly abridged student edition entitled *Engineering Design – A Systematic Approach* was published in 1988.

When preparing the student edition, the opportunity was taken to review the translation and the contents of the first edition. No changes in terminology were thought necessary and the contents were the same as the first English edition except for the removal of two chapters.

The first chapter to be removed was the short chapter on detail design. It must be emphasised that this does not mean that detail design is considered unimportant or lacking in intellectual challenge. Quite the reverse is true. Detail design is far too broad and complex a subject to be covered in a general text. There are many excellent books covering the detail design of specific technical systems and machine elements. For these reasons, the German editions did not discuss technical aspects of detail design, but only dealt with the preparation of production documents and the numbering techniques required to keep track of them.

The second chapter to be removed dealt with computer support for design, including CAD. Again, this chapter was clearly not removed because the topic is unimportant. Computer support systems are used universally and develop rapidly. Many specialist texts are available.

In 1993 an updated and extended third German edition of *Konstruktionslehre* was published. It was considered timely to produce

a second English edition to bring the translation into step with the latest thinking. The new layout of the German edition was incorporated, along with the important discussions of psychology and recycling. The new chapters on design for quality and design for minimum cost were included, but, for the reasons given above, the chapters on detail design and computer support were again omitted.

The third German edition also contained a new chapter that described selected standard solutions (machine elements, drives and controls) in line with the systematic approach and concepts presented in the book. This knowledge is covered comprehensively in the translation of the German *Dubbel* [*Dubbel Handbook for Mechanical Engineering*, Springer-Verlag, London, 1994]. This chapter was therefore also omitted.

There are now six German editions of Pahl/Beitz (4th 1997; 5th 2003; 6th 2005)—so it is timely to produce a third English edition. The structure has changed compared to the previous English edition and is described below.

Structure of the Third English Edition

Introduction—Chapter 1

The book starts with the historical background to modern systematic design thinking in Germany. The work of influential design researchers and practitioners is reviewed briefly.

Fundamentals—Chapter 2

This chapter discusses the fundamentals of technical systems and of the systematic approach, including cognitive aspects. The fundamentals of the use of computers to support product development were omitted for the reasons mentioned above.

Product Planning, Solution Finding and Evaluation—Chapter 3

In this chapter the flow of work during the process of planning is described, see Figure 3.2, along with general methods for finding and evaluating solutions that can be used not only for planning but also throughout the product development process. These methods are not linked to any specific design phase or type of product and include a range of intuitive and discursive methods.

Product Development Process—Chapter 4

This chapter presents the flow of work during the product development process and describes the main phases: Task Clarification; Conceptual Design; Embodiment Design; and Detail Design. The authors' overall

model is shown in Figure 4.3. New to this edition is a discussion about the effective management and organisation of the design process.

Task Clarification—Chapter 5

This phase involves identifying and formulating the general and task-specific requirements and constraints, and setting up a requirements list (design specification). The steps of this phase are shown in Figure 5.1.

Conceptual Design—Chapter 6

This phase involves (see Figure 6.1):

- abstracting to find the essential problems
- establishing function structures
- searching for working principles
- combining working principles into working structures
- selecting a suitable working structure and firming it up into a principle solution (concept).

This chapter concludes with two detailed examples of applying the proposed methods to the design of a single-handed water mixing tap and an impulse-loading test rig.

Embodiment Design—Chapter 7

During this phase, designers start with the selected concept and work through the steps shown in Figure 7.1 to produce a definitive layout of the proposed technical product or system in accordance with technical and economic requirements.

About 40% of the book is devoted to this phase and the authors discuss the basic rules, principles and guidelines of embodiment design, followed by a comprehensive example of the embodiment design of the impulse-loading test rig introduced in Chapter 6.

The chapter on detail design has again been omitted, but a new Section 7.8 outlining the steps of this phase has been introduced (see Figure 7.164).

Mechanical Connections, Mechatronics and Adaptronics—Chapter 8

This chapter is new to the English series of Pahl/Beitz. Three classes of generic solutions are presented in a way that is consistent with the systematic approach presented in this book. Because of their overriding importance in mechanical design, mechanical connections are the first class to be discussed. Because of their growing importance, the other two classes are mechatronic and adaptronic systems.

The decision was taken to leave out drives, control systems and composite structures as these are covered extensively in the English literature.

Size Ranges and Modular Products—Chapter 9

This chapter presents methods for systematically developing size ranges and modular products to meet a wide range of requirements while at the same time reducing costs. In this edition the concepts of product architecture and platform construction are introduced.

Design for Quality—Chapter 10

The chapter on design for quality now includes a discussion of Quality Function Deployment (QFD).

Design for Minimum Cost—Chapter 11

This chapter now includes a section on Target Costing.

Summary—Chapter 12

The short final chapter provides a summary of the ideas covered in the book. Figures 12.1 and 12.2 provide a quick reference to the main steps in the design process and the appropriate working methods.

Every design must meet both task-specific and general requirements and constraints. To remind designers of these during all stages of the design process, a set of checklists is used throughout the book. An overview of these checklists is provided in Figure 12.3.

Translation Issues

The aim of the translation has been to render each section of the book comprehensible in its own right and to avoid specialist terminology. Terms are defined as they arise, rather than in a separate glossary, and their meanings should be clear from their usage. On occasions other authors have used slightly different terms, but it is hoped that no misunderstandings arise and that the translation is clear and consistent throughout.

Some terms, however, require special mention. The German methodology includes a standard concept introduced with the German prefix 'wirk'. Translators have used a number of different English terms to translate 'wirk', including 'active', 'working' and 'effective'. After careful consideration, we decided to continue to use 'working' as in the previous English edition, so, for example, 'wirkprinzip' becomes 'working principle', 'wirkort' become 'working location', 'wirkfläche' becomes 'working surface' and 'wirkbewegung' becomes 'working motion'. In

English ‘working’ does not immediately convey fully the correct German meaning. In German, the ‘wirk’ prefix is used to focus on the principles, locations and surfaces, etc. that ensure the desired physical effect takes place. So, for example, ‘wirkort’ (working location) is where the physical effect takes place using two or more ‘wirkflächen’ (working surfaces) and a ‘wirkbewegung’ (working motion). ‘Wirkprinzip’ brings these ideas together as the ‘working principle’. For example ‘clamping’ is the working principle that can realise the friction effect by preventing certain working motions through an appropriate combination of suitable working surfaces (see Figure 2.12).

The term ‘drawing’ is used in this book to represent the output of either a traditional design approach, i.e. a physical drawing, or a modern computer-supported approach, i.e. a CAD model or drawing.

Of the four phases of the product design process, only the terminology used for the third, ‘embodiment design’, requires some explanation. Other translations, in a similar context, have used layout design, main design, scheme design or draft design. The input to this third phase is a design concept and the output is a technical description, often in the form of a scale drawing or CAD model. Depending on the particular company involved, this drawing is referred to as a general arrangement, a layout, a scheme, a draft, or a configuration, and it defines the arrangement and preliminary shapes of the components in a technical artefact. The term ‘layout’ is widely used and was selected for this book. The idea to introduce the term embodiment design came from French’s book, *Engineering Design: The Conceptual Stage*, published in 1971. Embodiment design incorporates both layout design (the arrangement of components and their relative motions) and form design (the shapes and materials of individual components). The term ‘form design’ is widely used in the literature, and its meaning ranges from the overall form of a product in an industrial design context, to the more restricted form of individual components in an engineering context. This book tends towards the latter usage.

There are numerous references to DIN (Deutsche Industrie Normen) standards and VDI (Verein Deutscher Ingenieure) guidelines, a few of which have been translated into English. Examples are the DIN ISO standards and the translation of VDI 2221. In important cases, references to DIN standards and VDI guidelines have been retained in the English text, but elsewhere they have simply been listed along with the other references. In technical examples, DIN standards have been referred to without any attempt to find English equivalents.

The original text includes many references. Most of these are in German and therefore not of immediate interest to the majority of English readers. However, to have omitted them would have detracted from the authority of the book and its value as an important source of reference. The references have therefore been retained in full but grouped together at the end of the book, rather than at the end of each

chapter as in the German text. An English bibliography has been added by the Editors, as well as an overview of the main engineering design conference series and journals.

It must be stressed that nothing was deleted that detracted from the main aim of the original German book, that is, to present a comprehensive, consistent and clear approach to systematic engineering design.

Acknowledgements

Donald Welbourn was responsible for encouraging the translation of the first English edition in the late 1970s, and he helped and supported the task in numerous ways. Many of the challenges that arose with the translation and terminology at the time were resolved with the help of Arnold Pomerans.

We first worked together on the translation of the second English edition, and Frank Bauert assisted us with the new figures. Nicholas Pinfield from Springer provided encouragement and support throughout.

For the third English edition, we worked jointly on the overall task of translation and editing.

John Clarkson helped with the compilation of the English bibliography. Anthony Doyle and Nicolas Wilson from Springer contributed enormously to the overall production of the book and their help and patience are gratefully acknowledged. Sorina Moosdorf from L^AT_EX in Germany was responsible for the detailed task of typesetting the book. She and her colleagues did an excellent job.

Finally, and most sincerely, we must thank Professor Pahl, Professor Feldhusen and Professor Grote for trusting us with the translation of the book.

As with the previous two editions, it is hoped that this translation faithfully conveys the ideas of *Pahl/Beitz – Konstruktionslehre* while adopting an English style.

Ken Wallace and Luciënne Blessing
Cambridge and Berlin, November 2006

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