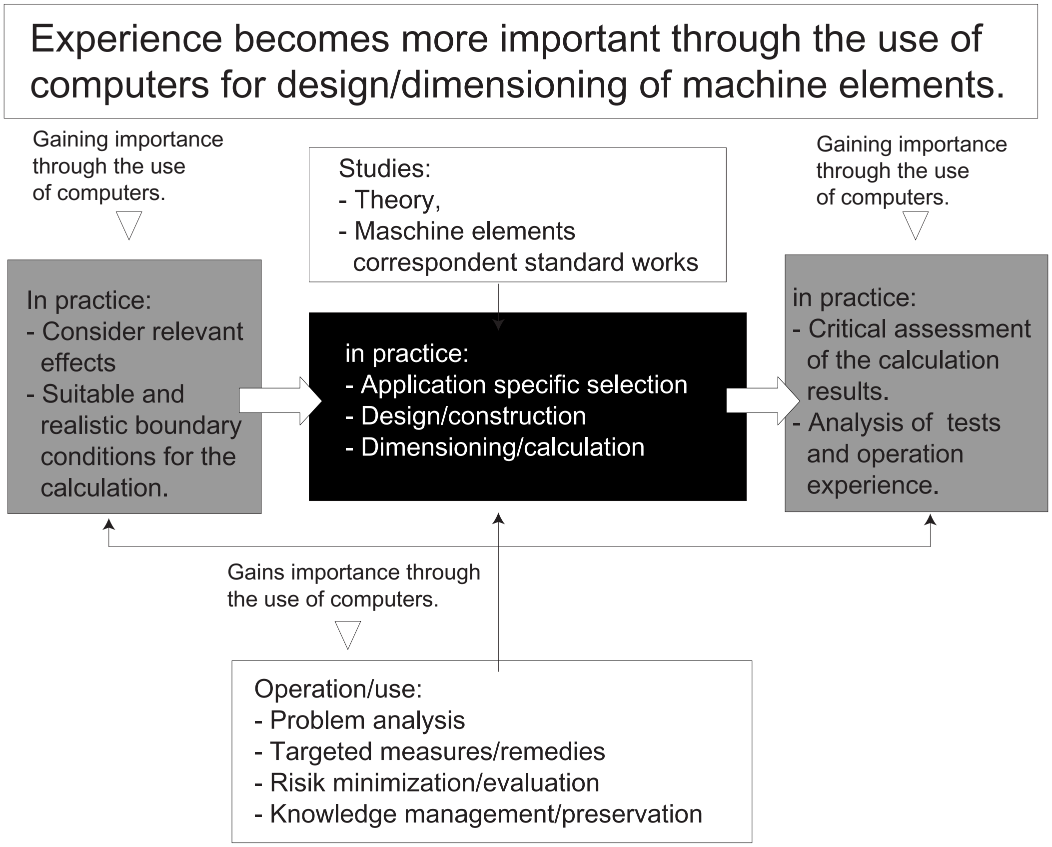
1. Introduction



Ill. 1-1

How spectacular failures could emerge? An example is the problem of broken wheel axles and collars at high speed trains. Looking coser to it we come to the conclusion, that obviously design and dimensioning don't protect agains catastrophic outages of machine elements. Aparently important **influences have been not known or not aware**. With this the task of this book is outlined. Besides the excellent special technical literature (e.g., Lit. 1-1 up to Lit. 1-3) for dimensioning and calculation of the machine element, there are handbooks for engineers and technicians (e.g., Lit. 1-4 up to Lit. 1-6). Above this however, are special, operation and component specific effects to consider (Ill. 1-2). Does these influence each other in different ways reinforcing (Ill. 1-3) or allevative, the effects will elude from the calculation. Such a shortcoming must be eased.

Often this shows first with **problems and failures in production and operation**. From this the correct conclusions must be drawn and iteratve considered in the desigen.

Thereto this book shall guide and so complement the standard books, which deal with the design/dimensioning. In many cases in specialis books problems are indirectly 'hidden' addressed in **parameters/variables, confidence coefficients and diagrams**. These must be identified and understood for a solution. This is especally true for **the failure case**. Here extensive specialist literature (Lit. 1-7 up to Lit. 1-9) and opportunity for further education (Lit. 1-7). It is rather focused at failure investigations. Further there are books to certain machines like combustion motors respectively its elements (Lit. 1-10). Important literature deals with macroscopic (Lit.1-11) and microskopic (Lit.1-12 bis 1-14) analysis of fracture surfaces as well as metallography (Lit. 1-12 and Lit. 1-14) and is concentrated at laboratory investigations/examinations like scanning electron microscopy (SEM) and metallography.

So a variaty rather **materials related literature for the review of failures** is available. It is usually more assigned to the metallography. However for a real problemanalysis it is clearly too onesided.

Above this design, operation loads, operation behaviour and design features play a crucial role. The experience shows, that for a mechanical engineer it is more easy to become acquainted with materials technology, than for the materials specialist with mechanical engineering. The mechanical engineer, especially the designer who frequently is also responsible for the problem elimination, misses so far a **suitable textbook**.

This gap shall be closed with the work on hand. The author goes back to his longtime experience, especially about turbo-aeroengines*) and from this derived statinary gas turbines *). Not without cause these are considered as high technology of the mechanical engineering. Problems and for its solution suitable strategies of these turbo-engines more and more also apply to the mechanical engineering, which becomes **light construction**. Hence these are from experience of use already in an early phase of the studies and later in the professional activity. Weight saving, performance increase, efficiency, sustainability and protection of resources are the driving influences. It suggest itself, to learn from these over decades gathered proven experiences.

The reader, especially the **student**, approaches and knowledges of the preventive (draft, design and dimensioning) and reacting (acute problems and failure cases) problem and failure prevention should be conveyed. This offers itself as emphasis of the subject matter at the **beginning of the studies**. Best in the frame of the subject ‘machine elements’. Thereby a cooperation as near as possible with the

*[1]) All volumes 1-5 of the series **„Aircraft Turbine Engine Safety - Problem Oriented Technology for Professional“** (ca. 4300 pages) are available in English language at Amazon®.

At the home page of the author **www.turboconsult.de** you will find some reading examples for free download.

*[2]) The book **„Industrial Gasturbines - Problem Orientated Guide Book for Operators“** can be also purchased at Amazon® and you will find some reading examples for free download at the home page of the author **www.turboconsult.de**.

Focus subjects for the mechanical engineer.

On hand is **volume 1A** (from 1A, 1B, 1C) of 4 also divided volumes, its focus are subjects which are of highest meaning for operation and design of machine elements. **Volume 2** (2A, 2B, 2C) deals with operation problems and failures of important machine elements as boltings rivets and elements in liqid and gas systems as bearings, seals, pipe lines and its monitoring. To these belong typical failure features, modes and causes. **Volume 3** (3A, 3B, 3C) covers influences of the production processes. **Volume 4** (4A and 4B) includes human factors, work environment, quality assurance, problems and failures of productio processes. Thereby special value is targeted at specific failure mechanisms of machine elements for a pointed remedy.

Systematic problem analysis:

Problems and failures of machine elements frequently develop in a complex coaction of several causative influences. To investigate these effective, comprehensible and documented a so called **problem analysis** offers itself. Today the approach are given in external trainings. Unfortunately seems the focus at management problems. However the designer/engineer is especially interrested in the clarification of technical problems. So the possibility of a targeted remedy for failure cases exists. Therefore it is essential to discuss the basics of a problem analysis with iits advantages and weaknesses.

Problem minimizing in design and dimensioning.

The experience shows, that just at the beginning of a project especially the danger of mistakes exists. Later these can only be corrected if at all, with huge effort. Frequently it is a matter of seemingly trivial effects, however these have not been considered. For example the tilting of a car during special evasive maneuvers.

A further subject is the safe life (-time). Here at high stressed/loaded elements/components of modern machines time depencdent effects must be considered. So corrosion pittings can trigger fatigue cracks with its notch effect.

Also so called simple constructions not seldom must be bought dearly with an increased technical and development effort.

Especially dangerous are **designs based on others** whose background is not known and/or not understood (e.g., safety aspects, license products).

Safety relevant considerations and effects.

To this belongs in case of a failing the absorbing of highly energetic fragments (containment) or the prevention respectively control of a dust explosion after the burst of a rotating part made from fiber reinforced plastic (FRP).

Also the considerations about the fail eafe-behaviour are early necessary. For this it is required to know the different approaches and constructive possibilities. A typical example are multiple statically indetermined connections, from which usually design hanbooks disadvise. To these count also double centered flange connections. However these can get unavoidable, for example to minimize the risk of a catastrophic failing due to overload.

New technologies.

Those have proved on areas of technological precursors like gasturbines and turbo aeroengines and are now on the brink of introduction into the general mechanical engineering with the trend to light construction. Often a satisfying attendance can not be found in the available machine element specific specialist literature. To this belong besides the advantages of such technologies also its problems, features and risks. As examples may be mentioned:

- Single crystal (SC) materials (superalloys).
- High strength titanium alloys.
- Intermetallic Phases.
- Sintered high strength materials, produced by hot isostatic pressing (=HIP).
- Thermal barrier coatings (TBCs).

Risks of technological developments.

Often it is not conscious, which dangerous consequences seemingly small, **not fully finished development steps mean** for the realization and effort. So a rivet joint at an aircraft fuselage can endanger a billion dollar project or as a „show stopper" even scupper. A spectacular case is the problem of diesel motors to satisfy the exhaust emission goals. This can mean for a 'world compmany' a multi billion dollar catastrophe.

A further field can be summarized under the keyword **„disimprovement"**.

Materials behaviour, also under consideration of composites and coatings.

Typical are:

- Loadspecific materials characteristics (influence of high speed deformation, dwell time). Creep effects and its consequences. As example serve titanium alloys: Drop of fatigue strength due to fretting. Stress corrosion cracking (SCC) in sea salt from 450°C. Solid metal induced embrittlement (SMIE) in contact with solid silver.
- Consequences of fracture mechanic effects at the component behaviour (influence of size, wall thickness, corrosion, critical failure/crack size, quality assurance, crack growth).
- Combination of operation influences.
- Testing and proofs.
- Systematic problem analysis.
- Component specific faiure modes.
- Monitoring of machines.
- Availability of semi finished products (weak points, faults, quality insurance).
- Influence of production processes.
- Repairability, possibilities and limits (friction welding? stripping and etching?)

Life(-time) limited components:

To these belong features/effects like:

- Load inducing noticeable plastic deformation („low cycle fatigue" = LCF).
- Dimensioning under consideration of crack growth („damage tolerant design").
- Thermal fatigue (TF, thermal mechanical fatigue = TMF).
- „Monitoring".
- Creep of hot parts.
- Evaluation of the deterioration/damage respectively remaining (service) life.
- Repair/further use („retirement for cause").

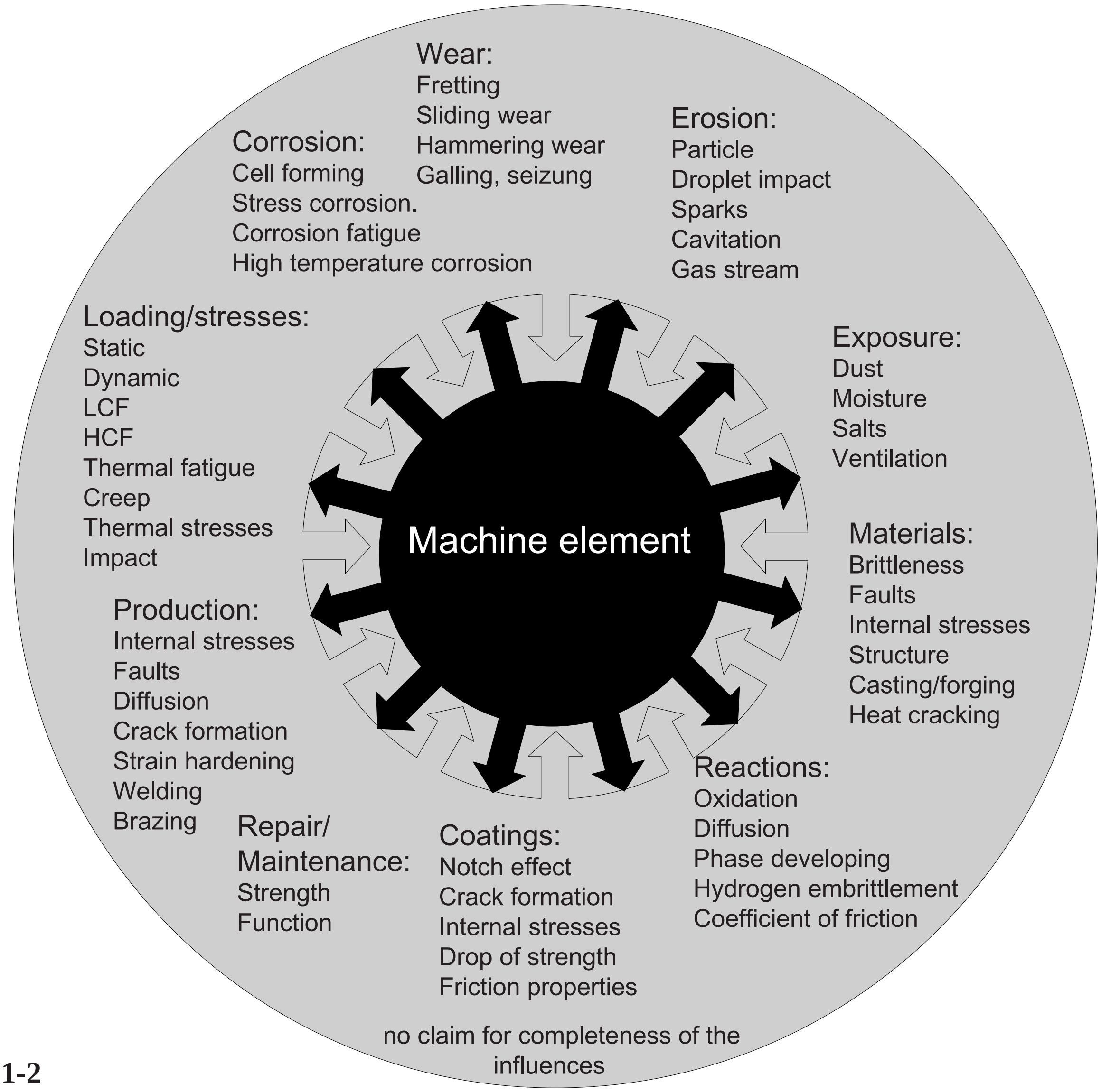
Repairability:

More complex and/or expensive parts/components as well as resources and environmental aspects demand an increased consideration of the repairability. An example are exchange parts of cars. It must be considered:

- Costs.
- Processes.
  - Suitability.
  - Availability.
  - Ecpediture of time.
- Material:
  - Changings during operation.
  - Tendency for galling/seizing.
  - Mode of deterioration/damage.
  - Materials combination, e.g., if coated.
- Accessability at the part (e.g., galvanic or thermal (spray) coatings, paintings).
- Dimensional requirements.
- Influence at the operation behaviour (e.g., dynamic fatigue, corrosion).

***Ill. 1-2**: **The operation behaviour of a machine element** arises from the alternating **coaction** of the external influences with its 'answer'. the external influences are often very versatile and by far not only characterized by mechanical loads. These can influence the results ot external loads, e.g., with a change of the load transmission at the contact surfaces. The interaction gets even more complex, if the outer influences cooperate (Ill. 1-2, chapter 5.1 and chapter 5.6.2). Not always can be expected, that the material keeps its properties which had been basis of the calculation over the whole operation time. This is not only true for possible deteriorations/ damages like crack initiation. Also the structure and with this the strength properties can change, especally under temperature influence (chapter 5.3, Ill. 5.3.2-6 and Ill. 5.6.1.4.2-2). **Naturally in spite of this problem is a calculation for the dimensioning of machine elements respectively for the selection of standard parts (norm) is indispensable**. The standard works of the machine elements (a selection shows Lit. 1-1 up to Lit. 1-6) already contain over years collected, extensive, experience based design data. These provide in diagrams/charts and characteristic values for the calculation. These often specify a scatter width, in which the designer chooses after evaluation of the application. Often exists a possibility, to supplement these with a consideration of the operation influences. The key is **operation experience**. Therefore this must be systematic evaluated and find entrance into the **design handbooks** which are mostly company internal. Here it depends on whether to identify the actually relevant operation influences with the associated failure mechanisms as certain as possible. For this a technical problem analysis (chapter 2) is an essential tool. Extremely helful is literature, which deals with **failure investigations** (Lit. 1-7 up to Lit. 1-14). Is there a lack of experience the possibility exists, to acquire it in **tests with sufficient operation near-service conditions**. Thereby it is necessary, that also operation/ operator particularities like utilistion time*

The influences at the operation behaviour of a machine element are so manifold and its coaction so complex, that its effects detract the exact calculation.

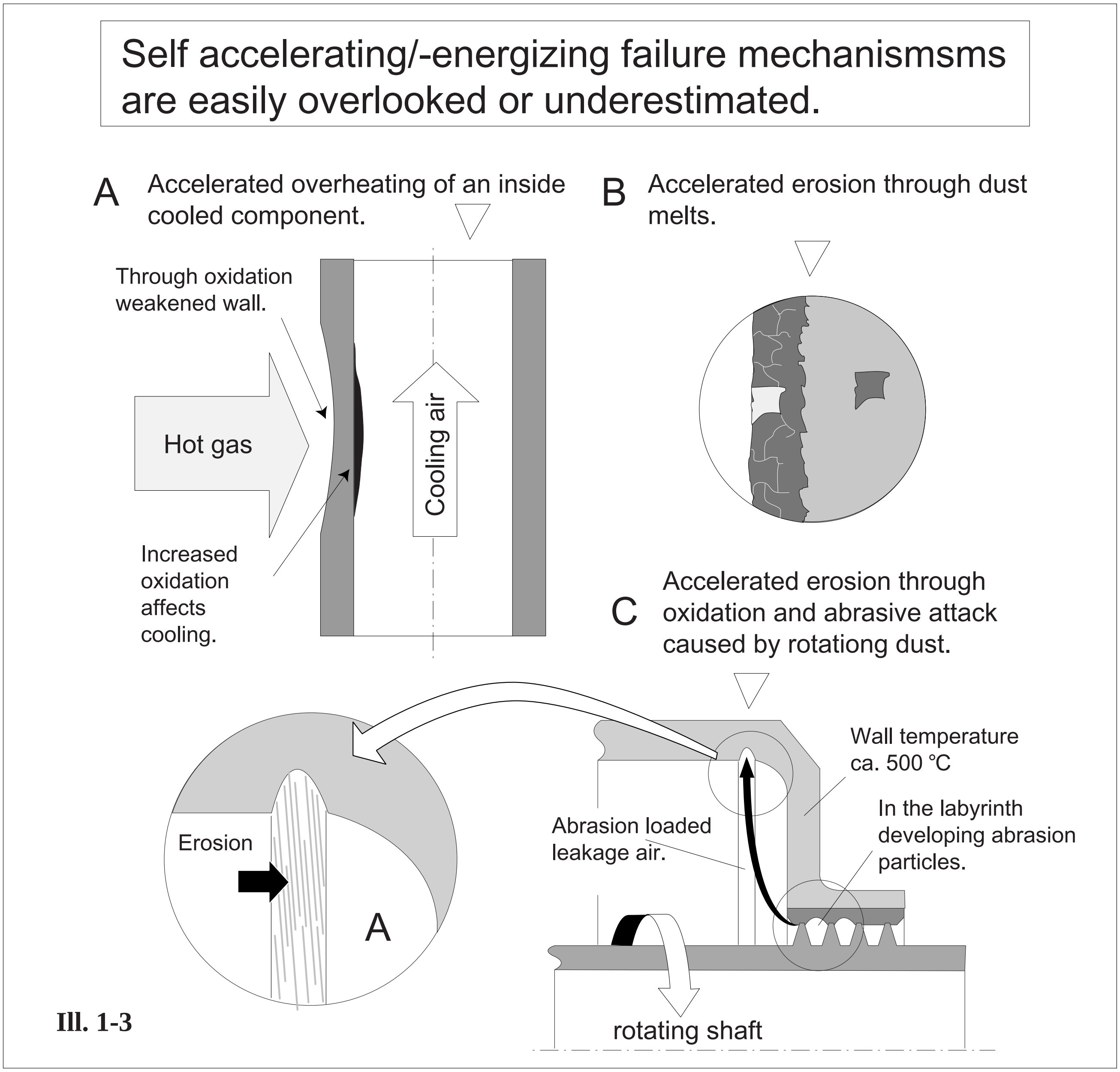


Ill. 1-2

intervals (e.g., with the influence of corrosion) and maintenance characteristics are considered. Naturally experience is time and cost extensive.

Ill. 1-3*: Frequently and in its effect astonishing a coaction of several operation influences can especially shorten the lifetime (chapter 5.1 and chapter 5.6.2) as the following examples show.*

*„**A**“: Increased gas temperatures demand at components of modern power plants like pipe lines of steam boilers or blades of gas turbines in intense* ***inner cooling****. If now arises at a*



Ill. 1-3

particular hot wall region on the side of the cooling media increased ***oxidation*** *or form* ***deposits****, these do act thermal insulating. This leads to further rise of the wall temperature and correspondent increased oxidation. So the danger of a failing by overheating grows exponential (Ill. 5.3.2-4).*

*„****B****“: Occurs melting of hot gas entrained dust, this can solidify and stick on colder components like pipe lines.* ***Reactions with existing, protecting oxide layers*** *lead during* ***cooling and chipping of the deposits*** *to the exposure of the reactive metallic surface (Ill. 5.1-2). Does this process repeat, an unexpected high speed of attack can be observed. So a lifetime, depending from the wall thickness,gets markedly shortened.*

*„****C****“: This failure mechanism is similar to „B“. Unlike, here develop reactive metallic surfaces through* ***particle erosion****. From a labyrinth escaping hard abrasion is catched in tne neigbored cavity and is* ***entrained by an intense rotating airstream*** *(Ill. 5.5.1.1-6). At sufficient high component temperature it comes to an accelerated abrasion through the combination of* ***wear and oxidation****.*