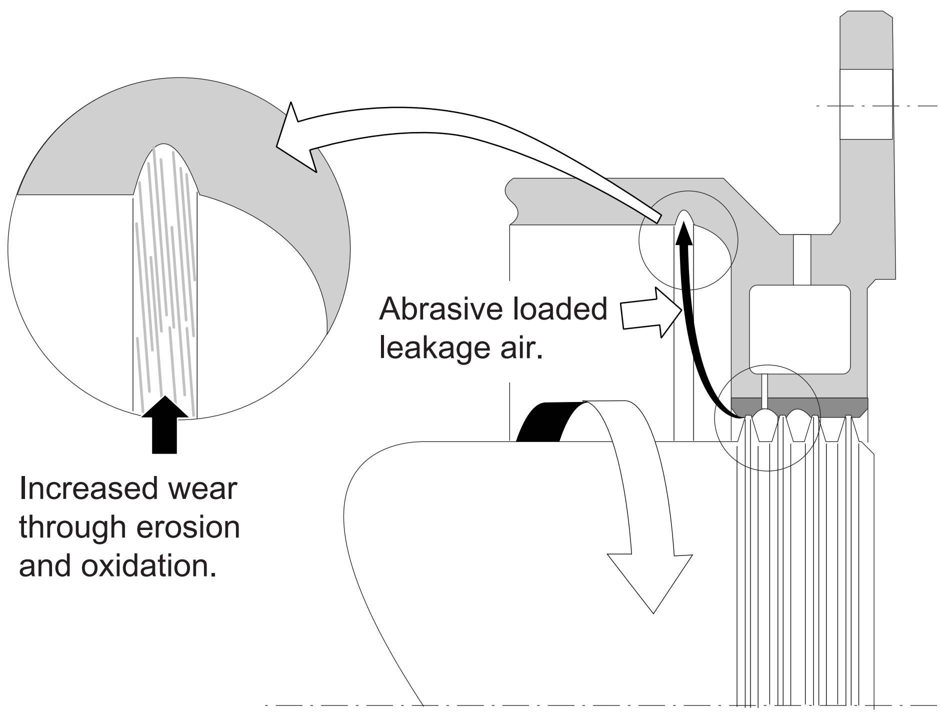
5. Effects and Mechanisms of the Operation Influences.

5.1 Mutual Influencing of Effects.

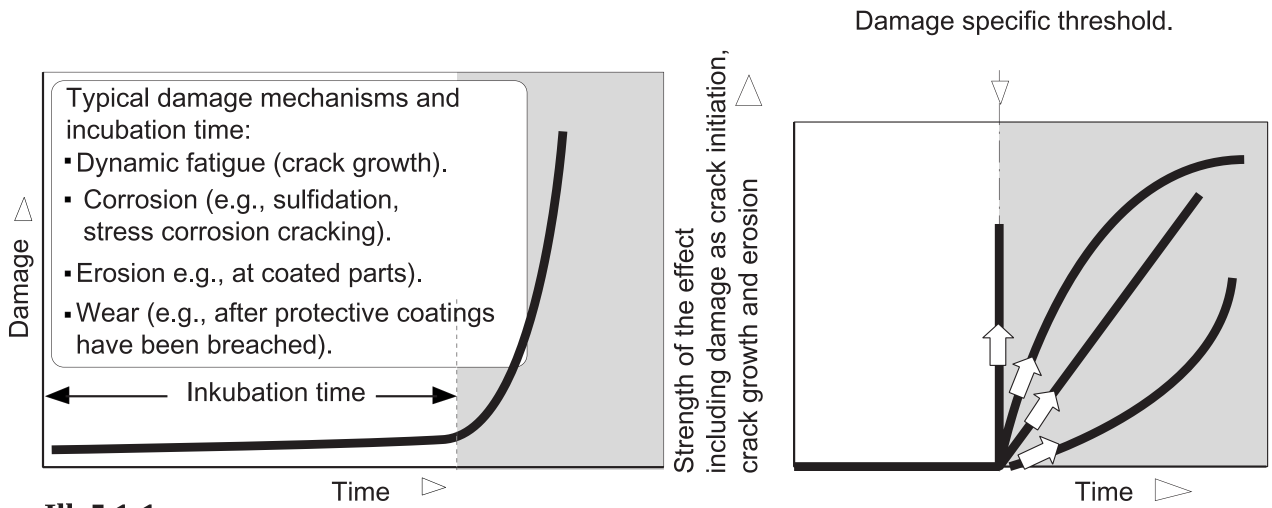


*This sketch shows the mechanism of an increased **erosion process in and around a labyrinth**.*

Erosive labyrinth abrasive from tip hard facing or rub-in coatings can be blown out of the labyrinth and get catched from neighbored casing regions. There the dust film will be spun around.
At sufficient high operation temperatures, it comes to a combination of erosion with the oxidation ot the always fresh and with this reactive metal surfaces. So the removal is markedly intensified and can penetrate several millimeter thick cross sections.

Already considering the consequences of single effects is not easy, the difficulty rises with several **effects which influence each other**. Usually this eludes the calculation and must be evaluated, corresponding the practice relevant experience. After this a **suitability proof** in operation tests should take place.
The example displayed above, shows the case at which the wear is dangerously intensified through the combination of a seemingly harmless erosive load and oxidation at the same time.

Influencing the trend of deteriorations/damges through different effects.



Ill. 5.1-1

***Ill. 5.1-1** (Lit. 5.1-1)**:** Similar to natural processes (e.g. in medicine and biology), the term **incubation time** refers to the time span between the start of an influence and its characteristic damaging effect (chapter 5.9.1). During the incubation time, damaging changes occur that do not appear to alter the macroscopic outer behavior of the engine in any damaging way. Typical damage mechanisms with pronounced incubation times include dynamic fatigue, erosion, and corrosion processes.*

During dynamic fatigue in metals, microscopic changes take place in the structure, including strengthening, weakening, and crack initiation, which cause macroscopic crack growth at the end of the incubation time.

During the incubation period of an erosive process, parts may begin to shatter or erosion particles can become stuck in the surface. These processes can considerably decrease material removal for a short time, which is a characteristic sign of erosion. There are even reported cases where the sticking particles increase the weight of the eroded sample (Ill. 5.5.1.1-5).

Often, protective oxide coatings form during the incubation time of corrosive processes. The incubation period ends when the medium can directly damage the base material.

Incubation time is used in order to achieve acceptable life spans or reliability for components with limited life spans. One example is the proportion of the life span that is taken up by the incubation time of engine parts under LCF stress.

***Threshold value** (Ill. 4.3-3) refers to the limit value of a damaging influence, beyond which damage actually occurs. Damage mechanisms with one or more damaging influences with different threshold values are quite common. With fatigue processes, fatigue resistance is a dynamic load threshold value. Dynamic fatigue fractures will only occur above this value. Similar threshold values can be observed in parts with internal and external notches (internal: e.g. micro-cracks, cavities, flaws; external: e.g. grooves, structural changes) with regard to a certain **stress concentration** (see Ill. 4.3-3).*

A classic example of threshold behavior is stress corrosion cracking (SCC, see chapter 5.6.3). The typical crack initiation occurs only after a certain tensile stress level has been reached with material conditions that are sensitive to the corrosive medium.

During erosion, a threshold value may be dependent on the hardness of the surface relative to the hardness of the erosion particles that are acting on it (Ill. 5.5.1.1-2).

Threshold behavior is of foremost importance for engine technology. This effect is used when designing fatigue resistant parts, estimating the acceptability of certain (unavoidable) weaknesses and flaws characteristic of the technology during design, and conducting risk assessments.

The way in which the temporal ***damage sequence*** *occurs after the incubation period can depend on various parameters, which must not necessarily by the same as the parameters that determine the threshold value.*

For example, if the damage sequence does not involve corrosion, but rather cyclical crack growth due to dynamic loads, other structural characteristics will most likely be the determining factors.

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***Ill. 5.1-2** : Sketch above (Lit. 5.1-1 and Lit. 5.1-2)**:** The material removal from a hot part surface can be highly accelerated by a combination of oxidation and erosion. Brittle oxidation layers are especially erosion sensitive at steep impact angles, such as those expected on leading edges of blades. The erosion material removal from the protective oxide coatings exposes reactive fresh metal surfaces which oxidize correspondingly heavily.*

*A similar scenario (Lit. 5.1-5) occurs when **dust particles are melted** in the combustion chamber and then strike and **stick** (glassing, Lit. 5.1-6) to the relatively cold cooled surfaces of the hot parts, especially the blades.*

*The melted dust can cramp and/or react with the relatively coarse oxide layers, creating a powerful bond. In this manner especially the **passage cross section at stators**/nozzles of the **high pressure turbine** can be so blocked, that the engine easily surges at power increase (Lit. 5.1-6).*

When the engine is shut down, these layers harden into brittle coatings with crack initiation and break off partly or completely along with the protective oxide layers (Lit. 5.1-7).

When engine operation is resumed, the fresh metallic surfaces oxidize especially heavily, and the process is repeated when dust again enters the engine.

***Sketch below:** Detatchable **shaft couplings with multi splines** are frequently used and are proven in gas turbines, especially in derivates. The splines are usually not very high loaded, have relatively loose sliding seats and are poorly lubricated. A big advantage is the **easy assembly** by pushing together. That benefits the assembly / disassembly of main shafts and accessories (sketch above „1“ to „6“). Pushed shaft connections are extremely reliable if at least the following conditions are guaranteed to prevent unacceptable fretting (sliding wear).*

- Suitable material combination (tribological system).

*- Sufficient lubrication. **It is especially dangerous, if the sealing of insert shafts succeeds in a manner, that in the development and approval phase, existing leakage oil lacks as lubrication medium**.*

- Limited vibrations (e.g., torsion vibrations).

- Sufficient aligning of the rotating components.

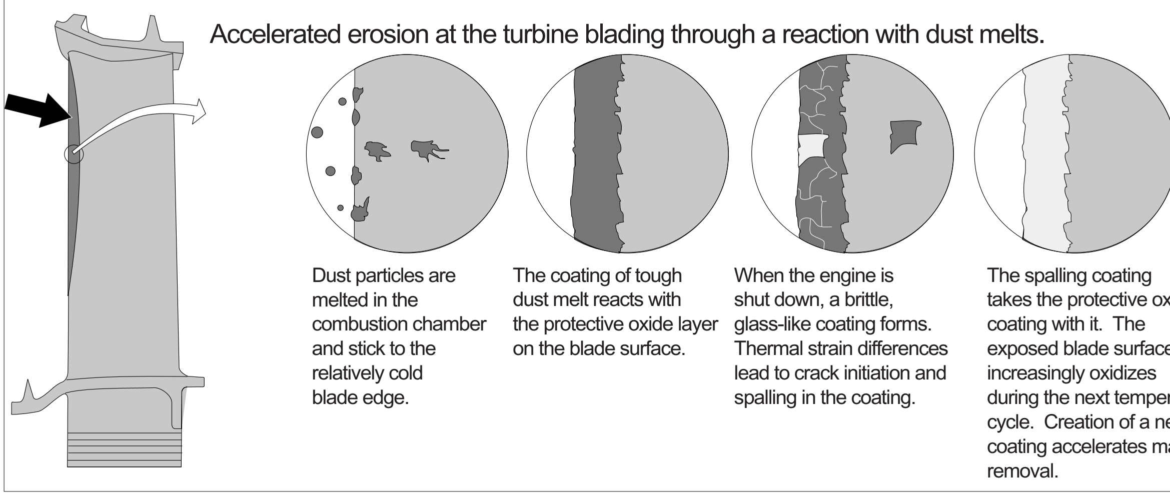
- Matched stiffneses, to minimize relative movements in the splining.

- No overloads during operation (e.g., through shock loads), respectively correct operation near dimensioning.

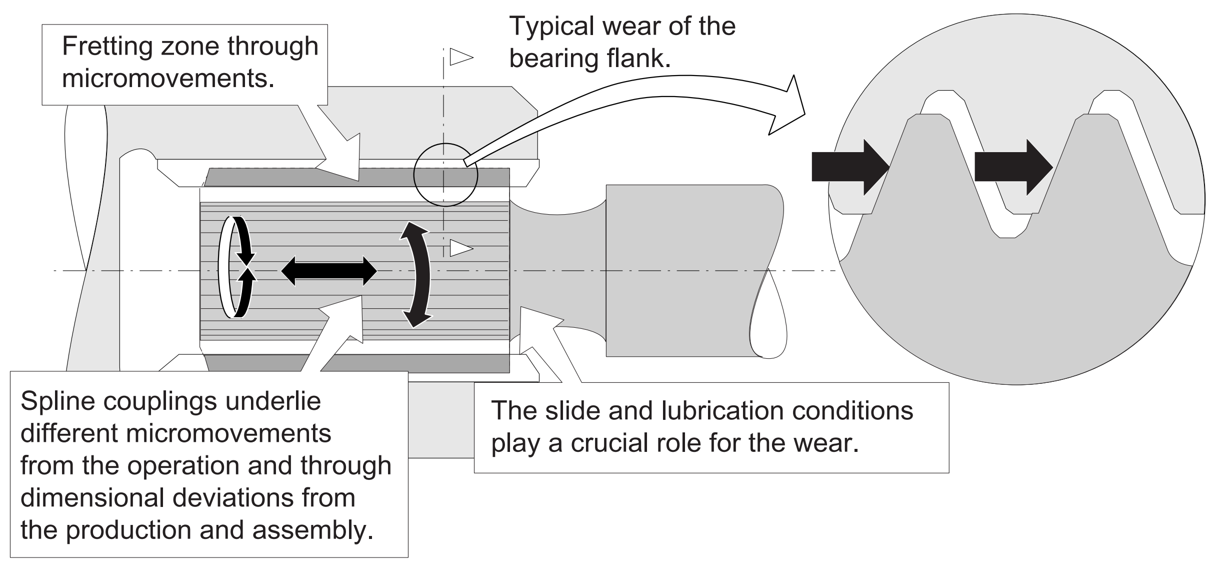
Are particular conditions not existing, wear in the splining must must be expected. Surface treatments like case hardening, nitriding or chromium plating are obviously not sufficient as protection. In contrast at least in the single case, vacuum coatings like sputtering or ion plating have brought markedly lifetime extensions (Lit. 5.1-8). A wear damage/failure frequently is only identified, when the coupling gets out of engagement (Ill. 5.9.3-1, Lit. 5.1-9 and Lit. 5.1-10).

Several influences can each other influence unexpected, weakening or intensifying.

Attack by erosion + oxidation.

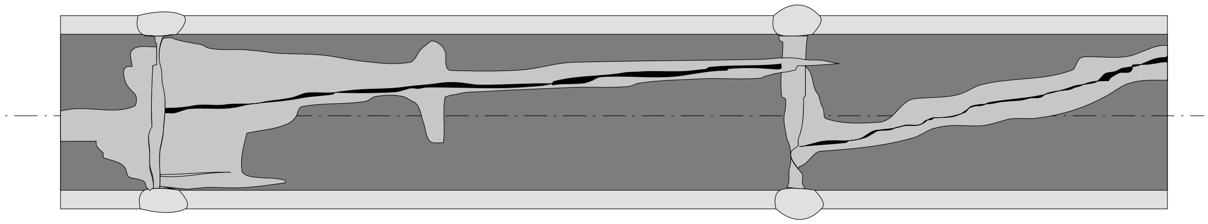


Clamping or loosening through wear + corrosion.



Ill. 5.1-2

Combined cavitation erosion at the inside of the relief line from a feed water pump.



Ill. 5.1-3

Ill. 5.1-3 *(Lit. 5.1-4): Do two failure mechanisms influence each other, its effect theoretically if at all only difficult to evaluate sufficiently reliable for the dimensioning. A typical example is the* ***cavitation erosion****. Thereby the erosion removes protecting reaction layers (e.g., oxides). With the fresh, highly reactive metal surfaces, now the fluid of the stream can intensily react. This ‘play’ repeats and it comes to a high removal velocity.*