Reliability prediction of concentrated electrical and tribological contacts, considering wear mechanism and acceleration possibilities

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Abstract

Especially aerospace and aviation is known for highly reliable systems. This presentation starts with some praxis-oriented examples of reliabilities of a human body, an airplane, a flight-taxi, a car and a nuclear power plant. Focus is on advantages using safety methods. The V-shape model helps to keep the overview. In top down view functions, requirements and safety goals are address.

In bottom up perspective engineers are confronted to choose best design, to fulfil functions and required reliability. Therefore, a **comparison of different design solutions** in a decision matrix and **prediction of reliability rates** is shown. For selected design further verification and lifetime and reliably calculation considering wear mechanism and test acceleration possibilities are shown.

From engineering point of view methods show a very systematic, practical and helpful way of comparison different design solutions, in evaluation and selection of best solution in an early state. Design engineers know which design suits best, predict reliably and further required verification. Furthermore, methods enable the evaluation in the loop and use of V-shape-model on different levels especially in an early state and on component level.

1. Introduction and motivation

Engineering challenges are to choose best design in an early stage. In meantime familiar with automotive and aviation processes I had during my last years in aviation same important lessons learned.

Scope is to give a **practical oriented overview** how **best design** can be chosen, how **reliability** can be **predicted** and how first tests on competent level preferred under **accelerated conditions** can be done. In short it helps to make design decisions easer, to minimize changes in late development state.

Contacts are heart pieces and Achilles sinew in engineering. After a general picture of used processes (design, reliability) a **comparison and verification** of designs of mechanical contacts and electrical contacts is shown.

2. V-shape model top down view: functions, requirements and safety goals

Required safety level on system level breaks down o sub-systems and required safety level of components. A Fault Tree Analysis (FTA) shows architecture and system structure. Redundancies help to avoid high safety goals in component level.

3. Bottom up perspective: design processes

Design eengineers are challenged to choose best, robust and reliably design in an early state. To know and evaluate life time limiting failure mechanism. Following processes are helpful

3.1 Design process and selection according VDI 2222

Strength of methodology
- systemic way to find a good solution
- evaluation of design and document path
- required parts and interfaces are known

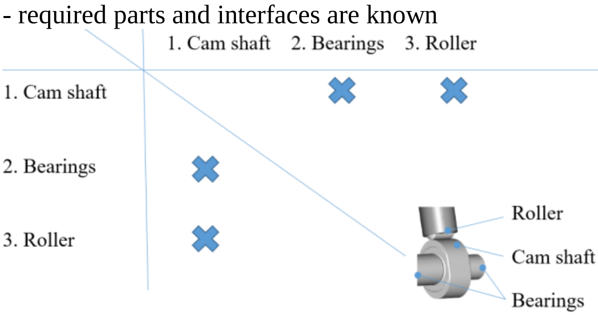

Figure 1: Bill of materials (BoM) and to be considered contacts/interaction/interfaces (easy schematic)

Drawback of methodology is the missing evaluation of reliability. Reliability of chosen solution is not considered.

3.2 Evaluation of lifetime and reliability

System and its components have to fulfill required functions under environmental conditions over requested lifetime. The V-shape model helps to visualize development process steps. Specification of system functions leads to required functions for sub-system and definition of requirements. Verification/passed testings of requirements helps to close the cycle. Focus of this work is simulations (SiL) of design and verifications loops on component level.

3.3 Reliability prediction (MTBF)

Sources of failure rates are
- own experience/data basis or supplier information preferred categorized according to possible failure mechanism
- simulation and lifetime modelling [3]
- handbooks, standards, literature [4], [5], [6]
- testing and field, monitoring and smart systems (IoT, industry 4.0)

Handbooks give usually rates out of unexpected failures in field. Unfortunately, boundary condition and failure mode are usually not exactly defined or just not comparable. According to experience rates are on "save side", later test results are usually much better. However, lacking of betters results in early design stage, given failure rates can be used for comparison of solutions and first prognoses and fail tree analyses (FTA).

4. Prediction and verification of concentrated contacts

Wear map shows [3] design can avoid many wear mechanisms. However, lifetime limiting wear mechanism is fatigue:

4.1 FEM and lifetime model

After design is found FEM-models and post processing routines supports further investigations. The damage accumulation model proposed by Ioannides and Harris [1] or ISO 281 [2] for the prediction of lifetime of rolling bearings has been applied to predict rolling contact fatigue. Described influences are:

4.2 Influence of load

As expected in fatigue life tests, the typical characteristic of a Wöhler curve is also found in rolling contact. The same failure mode (fatigue) and lifetime model allows the transferability of the time-accelerated tribometer experiments under increased stresses (figure 2).

4.3 Friction force

Friction force is measured on test rig and considered in FEM simulation.

4.4 Roughness/textured surfaces

Roughness and lubrication state have a significant influence on the determined lifetimes. At low lubricating film parameters $\Lambda<0.3$ surface roughness at the low film thicknesses significantly reduces the lifetime and increases distributions. The shorter lifetime in mixed friction are caused by the high local stresses of the roughness contacts. Results show the great importance of surface quality under mixed friction conditions.

4.5 Residual stresses

Residual stresses are generated by shot-peening. Stress distribution of residual stresses are measured and considered in stress based model. The expected increase in fatigue life due to the applied residual compressive stresses was confirmed by the experiments. In addition, compressive residual stresses reduced the lifetime distribution.

4.6 Results and discussion

The fatigue under rolling stress could be determined with the help of the stress-based fatigue life model and simulation. The test results confirmed the expected influence of the stresses on fatigue life [3].

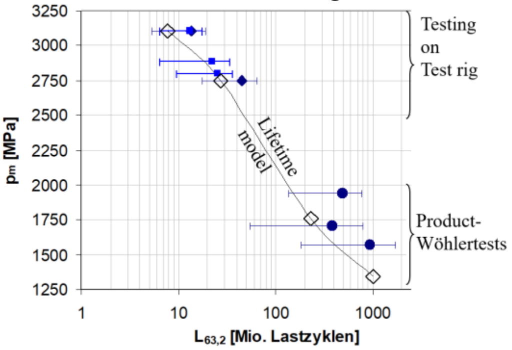

Figure 2: Accelerated life times on test rig compared to field test. Lifetime limiting failure mechanisms on all failures is fatigue because of mechanical load. Lifetime-model according Ioannides, Harris [1] allows transferability between test rig and field results.

5. Lifetime prediction of electrical contacts

Similar to tribological failures in electrical contacts also life time limiting failure mechanism are in focus. In electronics additional failure mechanism are observed. One established acceleration method is:

5.1 Lifetime testing and model according Arrhenius

Addressed are **temperature related failures** e.g. due to diffusion, electromigration processes. Accelerated life times testing uses higher temperature and model according Arrhenius. In temperature range between 75-125 °C this results in the raw estimation rule: 10 °C temperature increase reduces lifetime by factor 2/halves the lifetime. However only valid if failure mechanism with a specific combination of activation energy/operating temperature leads to failure of a component. Model is only applicable for diffusion processes, if the temperature of the application is lower than the permissible maximum limit temperature of the test object and if the expected failure mechanisms in the test is the same as in normal operation.

Consequence, electronics **cooling and thermo-management** helps to reach required lifetime. Field results demonstrate reliability gains through improved cooling. Results suits to lifetime gains predicted in MIL Handbook 217-F. Further advantage: known failure mechanism and limits built bridges to data collection, smart service and diagnose.

Other acceleration methods for environmental testing are Inverse-Power-Law, Coffin-Manson (thermal cycling), Peck or Lawson (humidity-thermal), HALT, HASS), Burn-in, Run-in, Screening.

6. Conclusion

Described design and reliably **processes** help to find and decide for **best design** solution and to **fulfil reliability goals** under consideration of requirements and influences. Furthermore, it is a documentation of development process.

SIL and testing on component level helps to verify design in an early stage. Processes are described on two examples. First on tribological rolling bearing contact. Life-time limiting failure mechanism is fatigue. Design is tested under **accelerated condition**. Results are compared to field test (also to consider further influences on system level e.g. technology, processes, handling). A life time model helps to correlate results between test and field. Lifetime **models** are required for virtual samples and simulation on system level (SIL).

Second example investigates an electrical contact. **Influence of temperature**/temp. related failures are estimated/extrapolated using Arrhenius model.

7. References

[1] Ioannides, E.; Harris, T. A.:Fatigue Life Model
[2] ISO 281: Rolling bearings
[3] Gless, Michael: Wälzkontaktermüdung bei Mischreibung, Diss, O.v.G. Univ. Magdeburg, 2009
[4] FIDES Reliability Methodology for Electronic Sys.
[5] MIL Handbook 217-F
[6] IEC-61709 Electronic Components Reliability