Validation cycles for electrical systems from a Seal's perspective – Discussion of LV124 compared to established seal test sequences

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Seals in electrical systems in automotive applications face various challenges. This often goes beyond established and mostly well-known areas in automotive sealing systems. The need to tackle these challenges is accelerated by the current shift towards E-mobility.

One significant challenge are validation cycles for electrical systems or components. Compared to established approaches on sealing system validation, some test cycles are much more severe regarding thermal loads. This can lead to sealing system failures in the respective test run, provoked by non-representative failure modes. To avoid incorrect conclusions on the sealing systems' performance, it is mandatory to review the test parameters critically.

To review the thermal loads within this paper, test cycles from the standards LV 124 for electrical components, DIN 3761 for radial shaft seals and ISO 1817 for oil compatibility testing are compared. The latter two are established validation cycles for sealing systems with elastomeric seals. Equivalent test temperatures and test durations are calculated and the resulting thermal loads are compared. Afterwards some examples of sealing system failure modes in LV 124 cycles are shown and discussed.

In conclusion, the paper discusses challenges and risks of electrical validation cycles for sealing systems and gives advice on how to handle such requirements.

1 Introduction

One significant challenge for sealing systems are validation cycles for electrical systems or components. In this paper, the LV 124 standard for electrical or electronic components is used as an example. LV 124 is not focused on sealing systems, but on electrical components in general, and some of its test cycles are more severe than established sealing system test cycles. Especially for oil-elastomer sealing contacts, this can lead to failures of the sealing system by failure modes that do not correspond to the field.

The paper gives an overview of the sealing systems in scope, chemical and thermal degradation of elastomers and Arrhenius' approach on aging behaviour. Afterwards, the relevant test cycles in LV 124, DIN 3761 and ISO 1817 are introduced, test parameters defined and compared regarding thermal load.

2 Sealing system definition

In this paper sealing systems with static and dynamic seals are considered. As example for static seals O-rings are used, as example for dynamic seals radial shaft seals. Both kinds of seals are depicted schematically in Figure 1, with the basic description shown below [1], [2].

- DS: primary sealing interface (Dichtspalt)
- DK: seal body (Dichtkörper)
- N: secondary sealing interface (Nebenabdichtung)
- D: retention / torque transmission (Drehmomentabstützung)

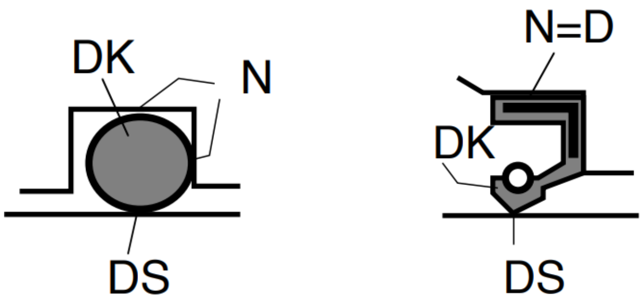

Figure 1: O-ring (left) and radial shaft seal (right) [1]

In the scope of this paper, the seal body consists of an elastomer compound and the fluid to be sealed is transmission oil.

3 Degradation of elastomer compounds

Elastomer compounds age during the service life of the component they are installed in. The main factors are chemical and thermal degradation [2].

Chemical degradation of elastomer compounds

According to Müller and Nau, the chemical degradation is degradation of the base elastomer by contacting fluids. The chemical degradation can involve formation of extra cross-links between polymer chains, scission of cross-links of the main chain or other molecular modifications. Also, components of the elastomer compound can be extracted from the compounded elastomer [2].

Thermal degradation of elastomer compounds

“High temperature accelerates the chemical modes of attack or may initiate new modes” [2]. This assessment according to Müller and Nau is especially important for oil-elastomer contacts combined with high temperatures. Under these conditions, the chemical degradation of elastomer compounds can differ from a model based on Arrhenius’ equation. Practically, a completely different failure mode than intended can be provoked leading to incorrect conclusions.

Thermo-chemical degradation within the scope of this paper

In the scope of this paper, the contacting fluids are transmission oil on one side and ambient air on the other side. In some cases the elastomer is fully immersed in transmission oil. Therefore, the main influence on the thermo-chemical degradation of the elastomer compound are the test temperature and the test duration.

Failure mechanisms of sealing systems

Damages and resulting sealing system failures caused by thermo-chemical degradation can be plenty: Swelling, cracking, hardening and deformation, amongst others [2], [3]. The result can be leakage of the sealed fluid to the environment. Depending on the severity of the fluid loss, this can mean customer claims, harm to the environment or failure of the aggregate that is sealed.

As the main requirement for all sealing systems is leak tightness, the most obvious system failure is leakage. Leakage however, can be caused by many failure modes besides thermo-chemical degradation, for example wear, improper interfaces or outside damage. Knowledge of the precise failure mechanism is of great importance when discussing sealing system failures.

4 Validation cycles

Subsequently the LV 124 and two established standards for the validation of sealing systems are introduced. The focus in this paragraph lies on test cycle parameters that are critical regarding thermo-chemical degradation of the sealing system.

4.1 LV 124 – L-02: High-temperature endurance test

LV 124 is a standard jointly developed by German vehicle OEMs. Its full title is: "LV 124 – Electric and Electronic Components in Motor Vehicles up to 3,5t – General Requirements, Test Conditions and Tests". Its intent is to ensure the proper system function over lifetime for electrical or electronic components. Therefore, LV 124 includes tests on the electrical function, as well as mechanical, environmental and so-called lifetime tests. It has to be noted, that LV 124 is not focused on sealing systems but on the whole component. LV 124 consist of two parts. LV 124-1 describes electrical requirements and tests and is not in scope of this paper. LV 124-2 contains environmental requirements and test cycles. They are clustered as follows:

- mechanical requirements and tests
- climatic requirements and tests
- chemical requirements and tests
- life time tests

Most critical for sealing systems regarding thermo-chemical degradation are the life time tests, especially the L-02, which is described subsequently. Depending on the application's temperature collective, high thermal loads in the test cycle can result. The test temperature and test duration for the LV 124-2 L-02 are calculated using Arrhenius' equation [4].

For each temperature of the application's temperature collective $T_{Feld,i}$, an acceleration factor $A_{T,i}$ is calculated via equation (1).

$$A_{T,i} = e^{\left(-\left(\frac{E_A}{k}\right)*\left(\frac{1}{T_{Test}+273{,}15}-\frac{1}{T_{Feld}+273{,}15}\right)\right)} \quad (1)$$

In LV 124 the following definitions and values are used:

- $A_{T,i}$ acceleration factor of Arrhenius' model
- E_A activation energy $E_A = 0.45$ eV
- k Boltzmann constant ($k = 8.617 \times 10^{-5}$ eV/K)
- T_{Test} test temperature in °C
- $T_{Feld,I}$ field temperature in °C acc. to temperature collective
- -273.15 K absolute zero temperature

The test duration t_{test} is calculated by using the acceleration factors with equation (2).

$$t_{test} = t_{Betrieb} \sum_i \frac{p_i}{A_{T,i}} \quad (2)$$

- p_i percentage of run time at $T_{Feld,i}$
- $t_{Betrieb}$ operating time in the field $t_{Betrieb} = 8000$ h

Table 1 shows an example of a temperature collective in LV 124. This temperature collective is applied as input parameter for the LV 124-2 L-02 cycle within this paper.

Table 1: temperature collective; example from LV 124

Temperature $T_{Feld,i}$	Percentage p_i
-40	6%
23	20%
85	65%
135	8%
140	1%

The parameters calculated accordingly for the LV 124-2 L-02 high-temperature endurance test are the following. Depending on the defined operation mode, the shaft can rotate at maximum speed of the application.

- test duration t_{test}: 1895 h
- test temperature T_{Test}: 130°C
- operation mode: dynamic (component operating)

These parameters will be used for comparison within this paper. It has to be noted, that there is no fixed temperature collective in LV 124, as it is application specific and varies accordingly. The collective in Table 1, however is a realistic assumption for automotive applications within the engine compartment.

4.2 ISO 1817 – Oil compatibility test

ISO 1817 describes a method to determine fluid compatibility of elastomers. The complete title is “ISO 1817 – Rubber, vulcanized or thermoplastic - Determination of the effect of liquids” [5]. It is commonly used to evaluate oil-elastomer compatibility and is the foundation for the validation of static seals such as O-rings. ISO 3601 [6] for O-rings references on ISO 1817 for oil compatibility. While ISO 1817 gives test durations 24 h, 72 h or multiple 24 h-intervals, ISO 3601 gives a maximum duration of 72 h.

However, common durations for oil compatibility tests are 168 h (short term) and 1008 h (long term). Test temperatures vary with 150°C for the short term test and 130°C for the long term test. For the comparison within this paper, the long term oil compatibility test is regarded, the parameters for comparison are defined below. As the cycle consist of one single temperature and duration, a calculation according to LV 124 as described in paragraph 4.1 is not necessary.

- test duration t_{test}: 1008 h
- test temperature T_{Test}: 130°C
- operation mode: static (oil immersion)

4.3 DIN 3761 – Performance test

For radial shaft seals “DIN 3761 – *Rotary shaft lip type seals for automobils” [7]* is commonly applied. DIN 3761-10 describes a so-called performance test for radial shaft seals. As test temperatures the “maximum temperature” and the “mean stressing temperature” are defined as relevant. The test cycle is a 24-hour period that consists of three segments. First, 14 hours at mean temperature and afterwards 6 hours at maximum temperature, both combined with the shaft rotating at maximum application speed. Finally, 4 hours of cool down at shaft standstill. A test duration of 10 days is given in DIN 3761-2. However, as it is common to run 15 days, this duration is defined for comparison within this paper.

- overall duration: 15 days
- test parameters:
  - mean temperature: 125°C; 14 hours per day max shaft speed
  - max temperature: 140°C; 6 hours per day max shaft speed
  - cool down phase: 4 hours per day shaft standstill

To get a single set of parameters for comparison, the approach according to LV 124-2 L02, described in paragraph 4.1 is applied. The duration of the cool down phase at shaft standstill was not taken into account. The following parameters will be used as test cycle according to DIN 3761 within this paper.

- test duration t_{test}: 331 h
- test temperature T_{Test}: 130°C
- operation mode: dynamic (component operating)

5 Comparison of thermal loads

In the following paragraph, the thermal loads of the test cycles introduced above will be compared. The thermal load in the scope of this paper is the combination of test temperature T_{Test} and test duration t_{test}. They are summarized for the cycles according to LV 124-2 L-02, DIN 3761-10 and ISO 1817 in Table 2.

Table 2: Thermal load overview

	Temperature T_{Test} [°C]	Duration t_{test} [h]	Operation mode
LV 124-2 L02	130	1895	dynamic
ISO 1817	130	1008	static
DIN 3716	130	331	dynamic

Figure 2 visualizes the thermal loads show in the table.

Compared to the oil compatibility test according to ISO 1817, the test duration in LV 124-2 L-02 and thus the thermal load is nearly 2 times higher. However, the oil compatibility test according to ISO 1817 is a static test, so there is no additional heat or stress from operation as it is the case in LV 124-2 L-02.

Compared to the test cycle for radial shaft seals according to DIN 3761, the thermal load in LV 124-2 L-02 is about 6 time higher. Both tests are dynamic, in this paper's scope with rotating shaft. Shaft rotation leads to an over temperature at the sealing edge, which is an additional, local thermal load not reflected in the test temperature T_{Test}. However, it must be taken into account during the sealing systems' evaluation, as it influences thermo-chemical degradation of dynamic sealing systems.

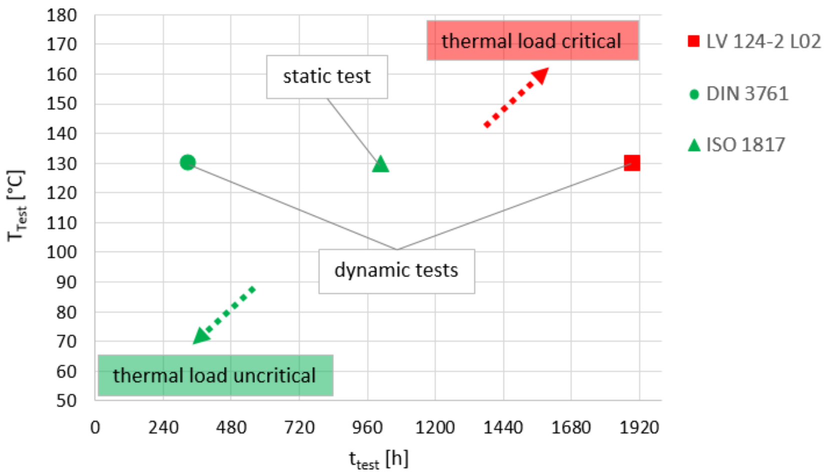

Figure 2: Comparison of thermal loads

6 Impact of thermal loads on sealing systems

As shown above, the thermal load in LV 124-2 L-02 is significantly higher than in established test cycles for sealing systems. Subsequently, the impact of the thermal loads in LV 124-2 L-02 is exemplified by sealing systems with O-rings (static) and radial shaft seals (dynamic).

All sealing systems shown below passed the established sealing system test cycles according to ISO 1817 and DIN 3761 successfully. Additionally they operated flawlessly in the application during system and vehicle testing.

However, if based solely on the results of the LV 124-2 L-02 cycle without critical reflection, the conclusion would have been that each sealing system did not fulfil the requirements. Subsequently, during development, investigations on corrective actions for this artificial problem would have been necessary, leading to increased effort and cost.

6.1 Impact on sealing systems with static seals

For many static sealing systems, O-rings are used. Figure 3 shows examples of O-rings from an LV 124-2 L-02 test cycle. Due to the high thermal load, the elastomer deformed and hardened during the test cycle and tore during disassembly. While hardening, the elastomer loses its elastomeric properties and the O-ring cannot safely uphold its active sealing mechanism.

The result in the test run can be leakage. Even if leak tight an analysis of the sealing system after the test run would lead to a critical rating, necessitating corrective actions. A critical reflection on the test parameters can avoid such unnecessary consequences.

Figure 3: O-ring: hardening due to high thermal load

6.2 Impact on sealing systems with dynamic seals

For many dynamic shaft sealing systems, radial shaft seals are used. Figure 4 shows an example of a radial shaft seal after a LV 124-2 L-02 test cycle. The sealing edge is discoloured and hardened. When deformed, cracks in the hardened surface show. During hardening of the sealing edge, its elastomeric properties are lost. The active pumping mechanism and thus the sealing systems’ function can fail.

The result in the test run can be leakage. Even if no leakage occurred, an analysis of the sealing system after the test run would lead to a critical rating, demanding for corrective actions. This can be avoided by critical reflection on the test parameters.

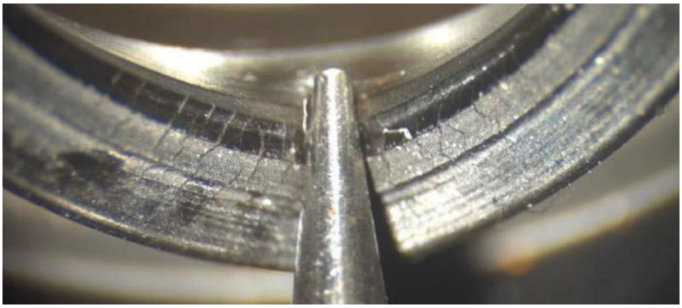

Figure 4: Radial shaft seal: hardening due to high thermal load

7 Summary and conclusion

In this paper, established sealing system test cycles were compared to “electrical” component test cycles regarding thermal load. Example for an “electrical” cycle was LV 124-2 L-02, which is not a seal-specific test but is critical towards the applied sealing systems. It was shown that in LV 124-2 L-02 thermal loads are 2 to 6 times higher than in established sealing system test cycles according to ISO 1817 and DIN 3761.

LV 124-2 L-02 applies Arrhenius’ model to accelerate the test duration. This model however should not be applied on oil-elastomer contacts combined with the specific test parameters in LV 124-2 L-02. If it is applied nonetheless, the high thermal load can provoke non-representative failure modes of sealing systems. For sealing systems, the most obvious failure is leakage; however, leakage can be triggered by a wide array of failure modes. If triggered by a non-representative failure mode, the conclusion taken from the test can be incorrect, leading to unnecessary corrective actions. This is a risk when applying “electrical” test cycles on sealing systems without reflection.

Therefore, thermal loads on sealing systems in the LV 124-2 L-02 and “electrical” test cycles in general, must be critically reviewed. In case of too high thermal loads, a separate validation plan for the affected sealing system has to be prepared. This validation plan has to achieve application specific, fitting thermal loads to meet the system requirements without provoking non-representative failure modes. In parallel, single components of the sealing system should always be analysed after each test run. Combined with system test results, this enables a review on the actual deterioration modes or failure mechanisms of the sealing system in application.

8 References

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