EASA
European Union Aviation Safety Agency

Rolling Contact Fatigue (RCF)

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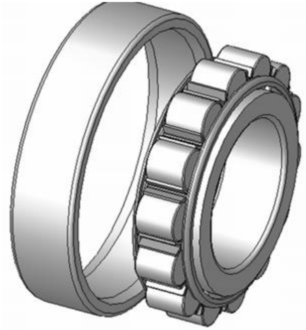
Contents

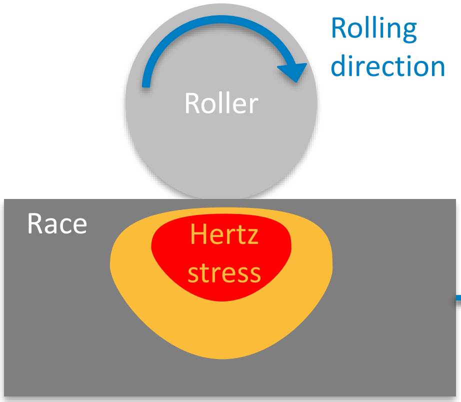
1. Introduction (1/2)

- RCF is a form of fatigue that occurs due to the cyclic strains arising from the loading present during rolling contact between two parts of an assembly. E.g. bearing race and a rolling element.

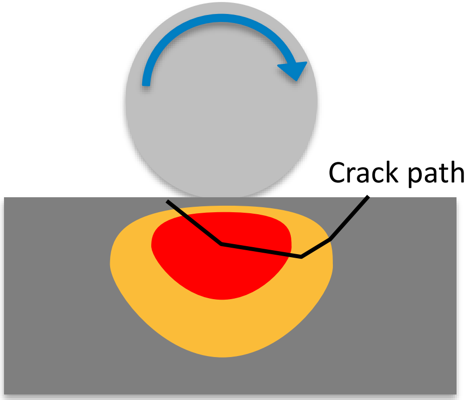
- Historically, RCF had been considered as a benign failure mechanism (i.e. leading to non-critical failure modes such as spalling).



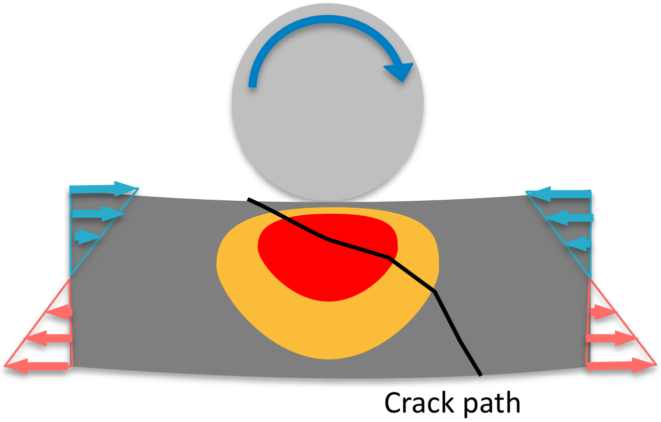
1. Introduction (2/2)



Failure case 1: RCF will typically lead to cracks returning to the surface lead to the release of particles, i.e. **spalling**.



Failure case 2: However, the combination of RCF and significant body stresses (e.g. bending of the race) can lead to **crack through the race** (Threshold criteria not fully characterised. Topic of research)



2. Certification specifications

Requirements:

CS 27/29.571 is addressing fatigue. As Rolling Contact Fatigue (RCF) is a form of fatigue, EASA consider that it already specifies the need for rotorcraft applicants to cover RCF, when applicable.

Acceptable means of compliance:

AMC1 27/29.571 on RCF were introduced in CS-27 amdt. 10 and CS-29 amdt. 11. These AMCs were added to ensure adequate consideration of RCF.

3. How to address RCF in certification?

STEP 1: Identification of PSEs subject to RCF

- Structural element (rotors, drives, controls, etc.),
- Subject to RCF,
- Whose failure is potentially catastrophic (considering worst possible failure scenarios)

STEP 2: Fatigue evaluation

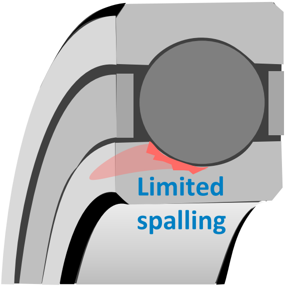
- Perform fatigue evaluation and define appropriate:
  - Inspection and/or retirement times.
  - Approved equivalent means (e.g. chip detection, VHM).

4. STEP 1: PSE identification

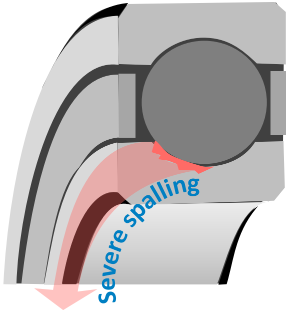
- Components subject to RCF generally include gears and rolling bearings.
- The applicant should identify parts whose failure is potentially catastrophic (CAT) upon the rotorcraft typically by means of design/safety assessments (i.e. FHAs, SFHAs and FMEAs).
- The evaluation of the candidate PSE should consider worst possible scenarios, without accounting for mitigations such as tests or detection means:
- Examples… (next slides)

4. STEP 1: PSE identification - examples

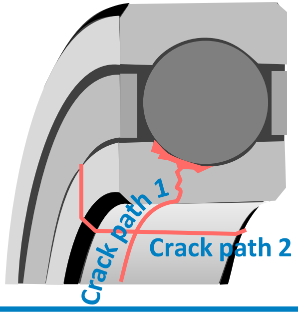
Example on a ball bearing (on inner race for illustration but to be extended to outer race and balls):



<u>Effects:</u> Could result in a loss of function if requiring very precise internal geometry OR if debris can remain trapped and result in jamming



<u>Effects:</u> Transfer of load, adequate support, alignment, etc, may no longer be ensured ? Further effects on other parts?



<u>Effects:</u> Transfer of load, adequate support, alignment, etc, may no longer be ensured ?
<u>Cause:</u> Usually only caused by initial spalling.

Are any of these cases CAT ?

NO → NOT a PSE

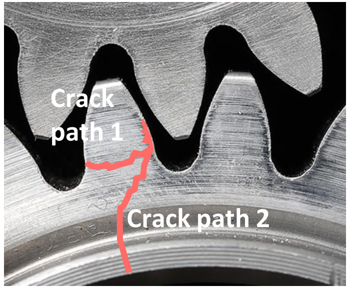
YES → PSE → STEP 2: Fatigue evaluation

4. STEP 1: PSE identification - examples

Example on a gear (Note: This exclude the root radius evaluation which is not considered a RCF case):

<u>Effects:</u> Usually only reducing the performance but no loss of functions are expected.

<u>Effects:</u> Transfer of load, etc, may no longer be ensured ? Further effects on other parts?



<u>Cause:</u> Usually only caused by initial spalling. <u>Effects:</u> Transfer of load, adequate support, etc, may no longer be ensured ? Further effects on other parts?

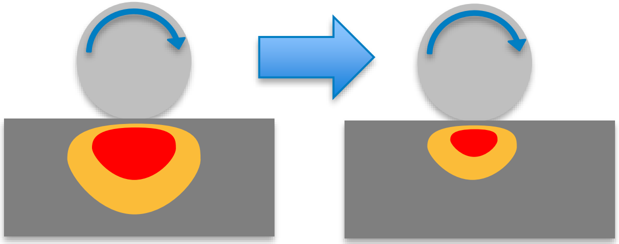
Are any of these cases CAT ?

NO → NOT a PSE

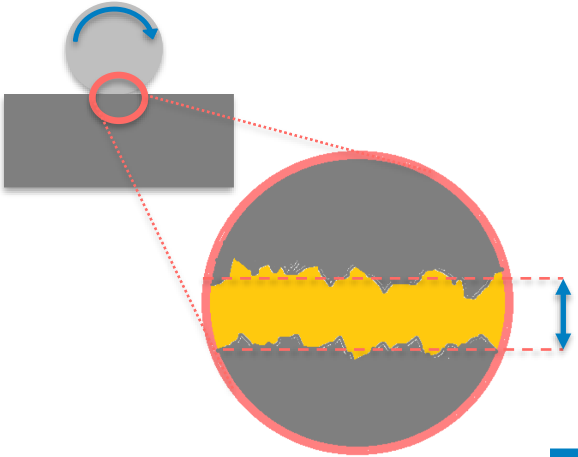
YES → PSE → STEP 2: Fatigue evaluation

5. STEP 2: Fatigue evaluation – Design reco.

Minimize the risk of crack initiation in RCF



- ✓ Minimize contact pressures.



- ✓ High surface finish standards.
- ✓ Good lubrication (including oil cleanliness and quality).

5. STEP 2: Fatigue evaluation – Approaches

What fatigue evaluation approaches are usually done when **spalling only** may result in CAT failure consequences?

Safe life		✕ Safe life alone: It is difficult to totally preclude cracking (i.e. spalling) due to RCF. ✓ Safe life combined with fail-safe: A life limit could be used to limit the probability of initiation of a spalling/crack due to RCF.
Fail-safe	Crack growth ("partial failure")	✓ It should be shown that the spalling will be timely detected (e.g. chip detection). Ultimate load capability is usually demonstrated for residual strength.

5. STEP 2: Fatigue evaluation – Approaches

What fatigue evaluation approaches are usually done when **through cracking** (from initial spalling) may result in CAT failure consequences?

Safe life		✕ Safe life alone: It is difficult to totally preclude cracking due to RCF. ✓ Safe life combined with fail-safe: A life limit could be used to limit the probability of initiation a spalling/crack due to RCF.
Fail-safe	No crack growth ("partial failure")	✓ It should be shown that the crack will not exceed a certain depth. Ultimate load capability is usually demonstrated for residual strength.
Fail-safe	Crack growth ("partial failure")	✓ It should be shown that the spalling propagating in parallel to the through cracking will be timely detected. Limit load capability is usually demonstrated for residual strength (+ limited exposure time below ultimate load capability) Case study
Fail-safe	Multi-load path ("complete failure")	✓ It should be shown that the loss of the primary load path is timely detected. Limit load capability is usually demonstrated for residual strength (+ limited exposure time below ultimate load capability)

5. STEP 2: Fatigue evaluation – Case study

Description of the case:

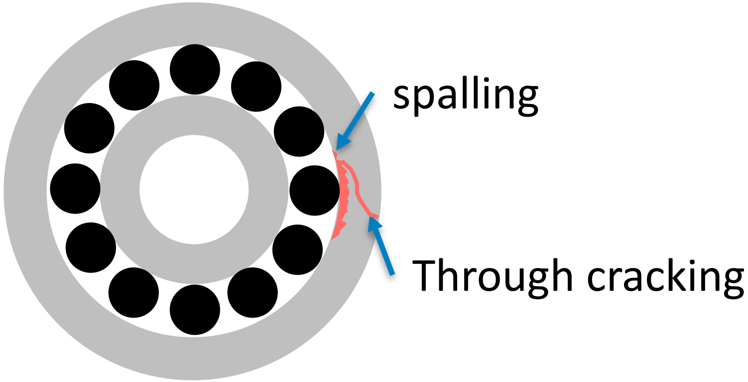
- Part studied: Planet gear with integrated outer race, inside a MGB

- Catastrophic failure mode identified related to RCF: Through cracking of the outer race caused by initial spalling

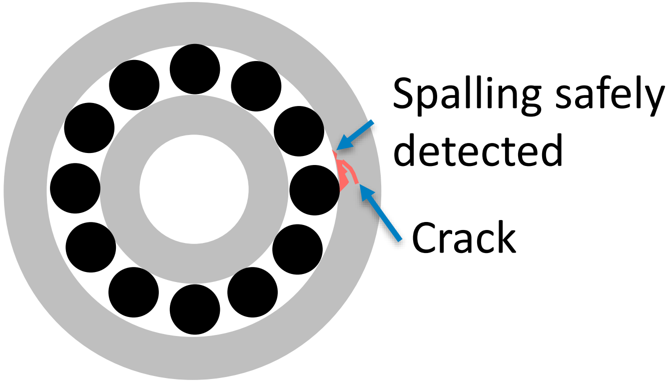
- Fatigue evaluation approach: Crack growth ("Partial failure") → It should be shown that the spalling propagating in parallel to the cracking will be timely detected. Limit load capability should be demonstrated for residual strength (+ limited exposure time below ultimate load capability)

- Monitoring means used: Chip detection system

Failure mode:



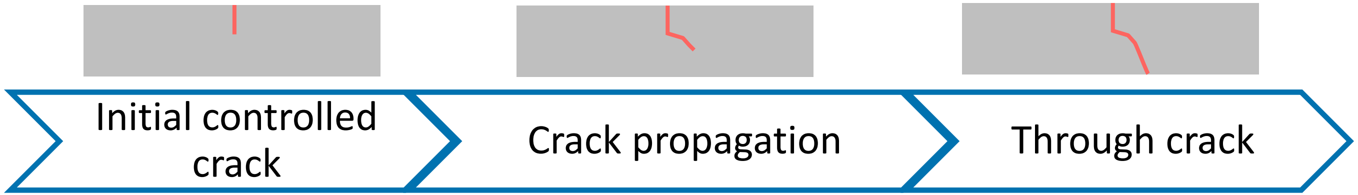
Fatigue evaluation approach:



5. STEP 2: Fatigue evaluation – Case study

Step 2.1: Evaluation of the time to failure (from initial crack to through cracking)

Perform a through crack propagation test or analysis correlated by test - as per §307



Pros:

- Tests with controlled initial crack allows correlations with analysis, opening the possibility of substantiation by analysis supported by test.

Cons:

- It requires justifications for the initial crack characteristics (depth/width/angle/shape)
- As we may observe variability in crack propagation behaviour with identical initial cracks, several tests may be needed.
- This test alone does not allow to evaluate the spalling behaviour.

5. STEP 2: Fatigue evaluation – Case study

Step 2.2: Detectability of spalling before through cracking: OPTION 1

- Take conservative assumptions on spalling propagation speed based on experience.

Pros:

- This approach is simple to apply

Cons:

- It may be severe

➕

- Perform a chip detection test using representative spall particles to evaluate the number of chip warnings that should be triggered before through cracking.

Pros:

- This approach is relatively short and allows multiple particle introduction points (not destructive).

Cons:

- It requires justification of the representativeness of the particle's dimensions
- It requires justification of the representativeness of the particle's introduction (e.g. inside the bearing when the gearbox is running) → This may be difficult for some designs

5. STEP 2: Fatigue evaluation – Case study

Step 2.2: Detectability of spalling before through cracking: OPTION 2

Perform a spalling propagation test with identification of chip warnings over time

Pros:

- The particles dimensions and particle's introduction are representative

Cons:

- This approach is relatively long and it is difficult to accumulate introduction points during one test.

6. LoI and change classifications

Level of Involvement:

Novelty
- May be novel, typically for 1st application of RCF evaluation and/or when a new approach is proposed.

Complexity
- May be complex, considering the complexity of the system, design and fatigue evaluation approach.

Criticality
- Critical, as targeting PSEs.

Change classification:

Major: Changes affecting PSEs are Major.

7. Conclusions

Typically, all rolling bearings and gears with potential catastrophic failure consequences should be considered for compliance demonstration to CS 27/29.571.

Different approaches considered feasible to address RCF.

EASA is considering launching additional research on RCF to better understand the drivers/thresholds to develop through cracking (e.g. minimum level of body stress to initiate this failure mode).

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Thank you for your attention!