MECHANICAL FAILURE INVESTIGATION / CASE STUDY 01

BEYOND STATIC STRENGTH

Alternator mounting bracket fatigue

Engine vibration | Local fatigue resistance | Corrective design

EXECUTIVE SUMMARY

01

The Challenge

Explain premature cracking of an alternator mounting bracket that may be statically adequate but fatigue-vulnerable.

02

Key Observation

Published investigations link engine-induced vibration, high dynamic stress, critical crack locations and redesign benefits.

03

Root Cause / Mechanism

Reconstructed dual mechanism: elevated alternating stress combined with a notch and reduced local surface fatigue resistance.

04

Engineering Solution

Combine improved load path and modal behavior with a smoother root transition and controlled surface quality.

05

Results & Evidence

Illustrative equivalent amplitude: 234.7 to 138.7 MPa (40.9% lower). Not a measured outcome.

06

Key Learning

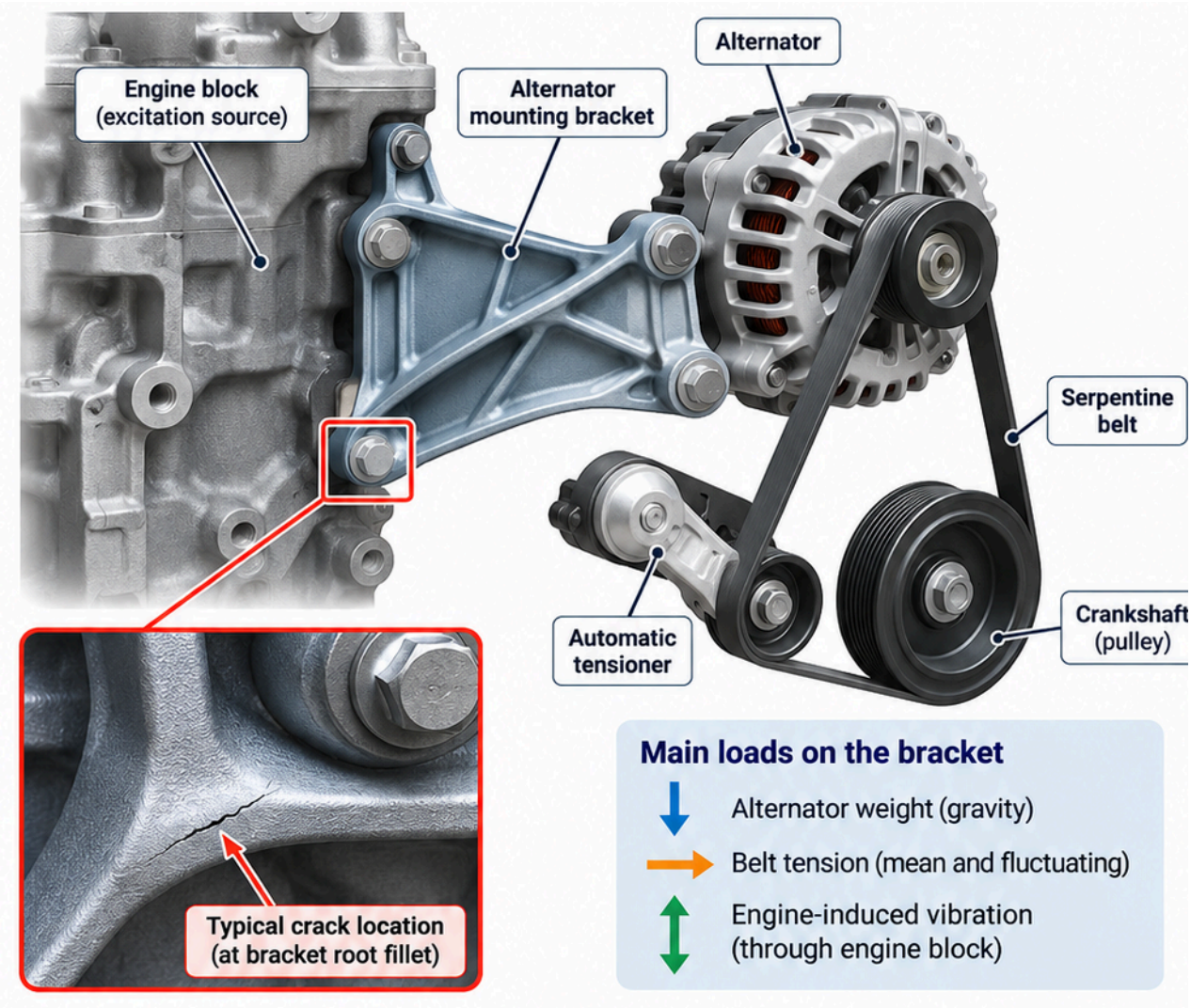
Fatigue is governed by local stress demand versus resistance; frequency coincidence alone does not prove causation.

STUDY / NON-PUBLICATION • NO NEW CAD OR FEA • SOURCES DISCLOSED AT END

01 The physical problem

A belt-driven accessory supported by a vibration-excited engine

System schematic | conceptual, not OEM geometry



Load paths and candidate fatigue-critical regions

- **Static / mean loads**

  Accessory gravity, belt mean tension and mounting reactions establish the operating stress state.

- **Alternating loads**

  Engine-order base vibration and belt-tension fluctuations produce cyclic stress at the bracket.

- **Local vulnerability**

  Root radii, holes, machining marks and joint compliance can magnify or redistribute local fatigue demand.

The drawing explains the physics. It is not a reproduction of a proprietary product or a verified CAD configuration.

02 Evidence and competing hypotheses

Separate published observations from scenario-specific assumptions

Evidence hierarchy

PUBLISHED

Alternator-bracket vibration fatigue and successful redesign reported by Lu & Zhong (2019).

PHYSICS

Engine orders, resonance, bolted-joint contact and fatigue stress-life theory are established.

CONSTRUCTED

105 MPa nominal stress, Kf = 1.90 and surface factor 0.85 are selected for this study.

Hypothesis register | after Stages 7–10

H1	Engine vibration / dynamic stress	Supported as a mechanism
H2	Notch and local fatigue weakness	Selected scenario; unverified
H3	Bolt loosening / joint slip	Plausible, not established
H4	Material defect or residual stress	Alternative, no case evidence
H5	Belt-tensioner nonlinear excitation	Plausible interacting pathway

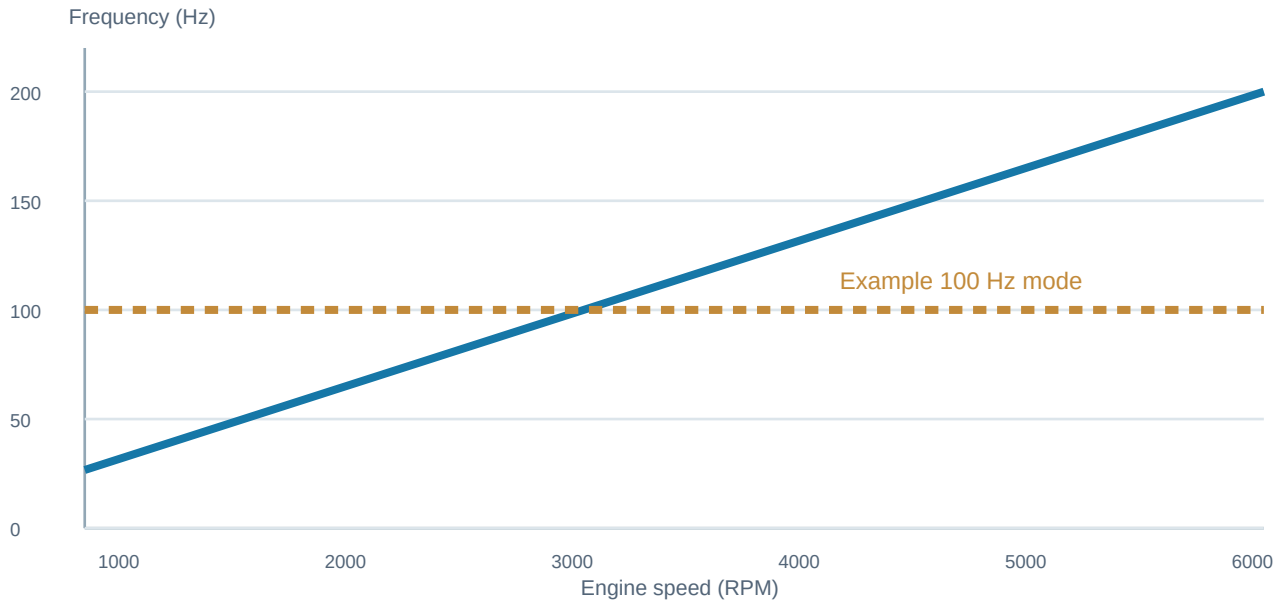
Evidence warning: the reconstructed scenario is not a forensic reconstruction of one measured failure.

03 Dynamic excitation and resonance

Why static adequacy does not imply fatigue durability

Engine-order excitation

For an idealized four-cylinder, four-stroke engine, two combustion events occur per crankshaft revolution. Second-order excitation is f = 2 × RPM / 60. Actual block response also contains other orders and broadband content.



What resonance does and does not prove

- **Frequency coincidence is only a screening clue**

  Damage requires modal participation, adequate excitation amplitude and elevated local cyclic stress.

- **Local stress is the relevant response**

  The mode with the largest accessory displacement need not produce the highest stress at the crack site.

- **Belt and engine excitation can coexist**

  Crankshaft torsional fluctuations, tensioner friction and joint dynamics may add harmonics or alter response.

A measured acceleration spectrum and stress FRF would be required to identify a real resonance-driven fatigue mechanism.

04 Joint integrity: competing mechanism

Preload loss can modify dynamics but is not automatically the initiating cause

Three distinct physical processes

Elastic joint compliance

Changes effective support stiffness and natural frequencies without gross slip.

Microslip / fretting

Partial local interface motion can dissipate energy or damage surfaces.

Rotational self-loosening

Transverse relative motion can reduce retained preload under certain conditions.

Simple friction-capacity screening

For a fully clamped idealized interface, gross slip resistance is approximately mu × sum of retained clamp forces. Three bolts at 10 kN each and mu = 0.20 give 6 kN of nominal friction capacity. This does not resolve eccentric

6.0 kN

Idealized friction capacity

0.60 kN

Illustrative applied shear

A loose bolt discovered after cracking may be a cause, a consequence, or a parallel symptom. Without preload history, fretting evidence and crack-origin inspection, joint loosening remains unconfirmed.

05 Fatigue mechanism and stress-life analysis

Stage 9 | one transparent, constructed combined-mechanism scenario

Selected input register

Material	S355 steel, published uniaxial stress-life regression
Nominal alternating stress	105 MPa (assumed dynamic demand)
Theoretical notch factor Kt	2.20 (assumed geometric severity)
Notch sensitivity q	0.75 (assumed)
Fatigue notch factor Kf	1 + q(Kt - 1) = 1.90
Surface factor ks	0.85 (assumed resistance penalty)
Mean stress	0 MPa (R = -1 reference)

Calculation chain

Equivalent smooth-specimen amplitude

$$S_{eq} = K_f \times \sigma_{nom} / k_s = 1.90 \times 105 / 0.85$$

234.7 MPa Illustrative baseline

Using the published S355 regression $\sigma_a = 456.46 \times N^{(-0.045)}$, the illustrative constant-amplitude life is approximately 2.63 million cycles. This is not measured bracket life. The regression must not be extrapolated to extremely long lives.

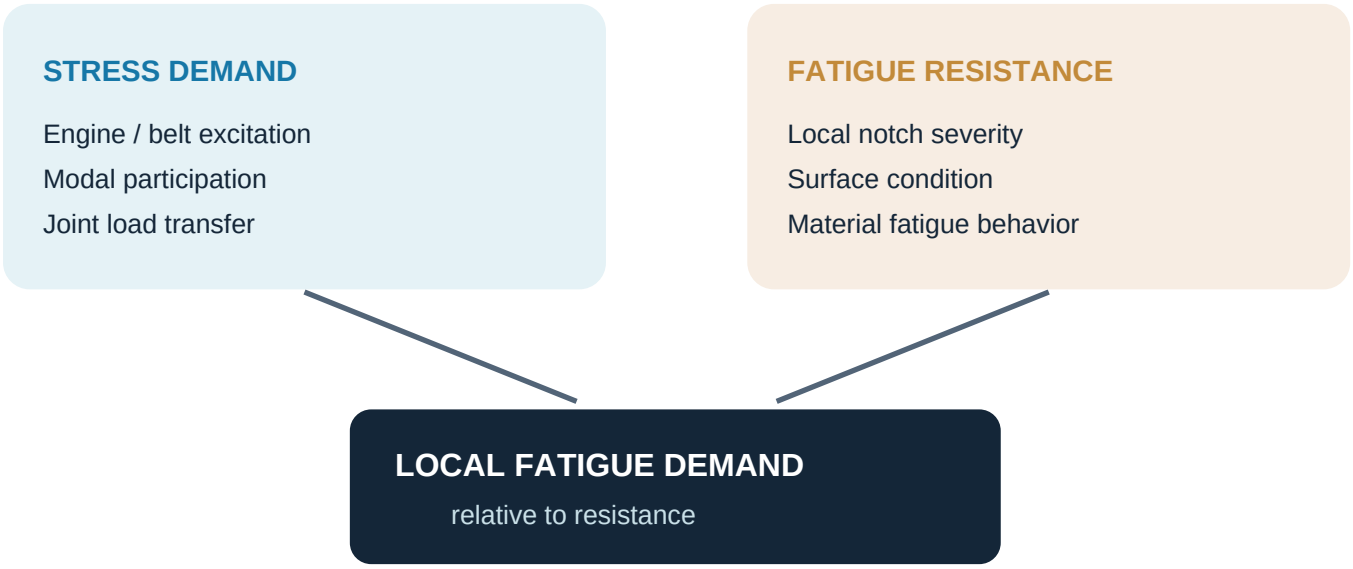
Stress sensitivity | calculated, not measured



06 Causal testing and counterfactuals

Stage 10 | distinguish a consistent story from proof

Demand–resistance causal structure



Counterfactual scenarios

A | Combined baseline 105 MPa, Kf 1.90, ks 0.85	**234.7 MPa**
B | Remove notch penalty 105 MPa, Kf 1.00, ks 1.00	**105.0 MPa**
C | Reduce cyclic demand 70 MPa, Kf 1.90, ks 0.85	**156.5 MPa**
D | Improve both 70 MPa, Kf 1.30, ks 0.95	**95.8 MPa**

10-million-cycle mean-curve reference amplitude: about 221 MPa. This is not a validated design allowable.

07 Corrective design and sensitivity

Stage 11 | address both the load path and the local fatigue weakness

Three corrective concepts

A | Improve load path

Rib / gusset / support adjustment to reduce nominal dynamic stress.

B | Improve local detail

Larger transition radius, surface finish and manufacturing controls.

C | Integrated redesign

Combine lower cyclic stress with improved notch and surface resistance.

Illustrative equivalent fatigue amplitudes



PREFERRED CONCEPT / COMBINED REDESIGN

40.9% lower calculated fatigue-demand indicator

Design targets, not measured improvements. Modal shift, joint preload and fatigue durability still require verification.

08 Conclusions, limitations and sources

What this investigation establishes—and what it does not

Engineering conclusion

The selected scenario explains premature alternator-bracket cracking through two interacting contributors: elevated engine-induced cyclic stress and reduced local fatigue resistance at a geometric transition. A combined redesign addresses both, outperforming either single-mechanism concept under the declared assumptions.

What remains unverified

- **No component-specific measurement**

  Excitation, damping, actual stress history, bolt preload and crack-origin evidence are unavailable.

- **No new CAD, FEA or testing**

  The scenario is a literature-informed study, not a simulated or validated production bracket.

- **Fatigue extrapolation**

  Basquin regression, Kf and surface correction are screening approximations; long-life extrapolation is invalid.

- **Alternative mechanisms**

  Joint degradation, defects, residual stress and belt dynamics cannot be excluded.

Selected technical sources

01 Lu & Zhong (2019), Vibration Fatigue Analysis and Optimal Design of Alternator Bracket.
https://qikan.cmes.org/jxqd/EN/10.16579/j.issn.1001.9669.2019.05.037

02 Londhe & Sen (2010), Finite Element Analysis of FEAD Bracket and Correlation with Test, SAE 2010-01-0493.
https://saemobilus.sae.org/papers/finite-element-analysis-fead-bracket-correlation-test-2010-01-0493

03 Dantas et al., Evaluation of multiaxial high-cycle fatigue criteria under proportional loading for S355 steel.
https://www.sciencedirect.com/science/article/pii/S1350630720315612

04 NASA-STD-5020B, Requirements for Threaded Fastening Systems in Spaceflight Hardware.
https://standards.nasa.gov/

Final classification: internally consistent educational reconstruction; not an independently validated root-cause finding.