Reliability of Automotive Tier “X” Supplier: Lesson Learned from Early Failures
Agenda

- Introduction
- Reliability of Tier “X” Suppliers
- Engine Cooling Fan System
- Case Study
  - Vibration & Endurance
  - Field Data & Root cause
  - Proactive approach
- Summary
- Questions
Company Name “Y”

“Y” is one of the world’s leading automotive suppliers

82,800 EMPLOYEES

OPERATING IN
30 COUNTRIES

ARGENTINA EGYPT
IRELAND NORWAY SPAIN

BELGIUM FRANCE ITALY
POLAND THAILAND

BRASIL JAPAN ROMANIA TUNISIA

CANADA HUNGARY MEXICO TURKEY

CHINA INDIA MOROCCO UNITED KINGDOM

CZECH REPUBLIC INDONESIA NETHERLANDS

INDIA MOROCCO SOUTH AFRICA SOUTHERN STATES

134 PRODUCTION SITES

17 RESEARCH CENTERS

15 DISTRIBUTION PLATFORMS

35 DEVELOPMENT CENTERS

€14.5 BILLION IN SALES
“Y” activities

- Thermal Systems
  - Thermal Powertrain
  - Climate Control
- Powertrain Systems
  - Transmission Systems
- Electrical Systems
- Comfort and Driving Assistance Systems
  - Driving Assistance
  - Interior Controls
- Lighting Systems
- Visibility Systems
- Wiper Systems

Sample Presentation | ARDC Connect | Slide Number: 4
Thermal Systems (THS) activities

- Thermal Powertrain
- Climate Control
- Climate Control Compressor
- Thermal Front End
Introduction
Automotive market trends

- **Reliability as leading purchase reason**

- **Global scale suppliers**

- **Cost saving – efficiency – productivity**

- **Consequences on product/system reliability?**
Supplier Selection

Process Standardized at Group level

- Supplier analysis (robustness)
- Quality
- Financial health
- Supplier Quality Assurance

- Supplied product technical evaluation
  - Business group level
  - Product line R&D manager
  - Project manager
  - Cost / Efficiency / Quality
THS reliability activities

- **Raw Materials**
  (plastic, rubbers, metals…)

- **Software**

- **Sub components**

- **Sub systems**

  - Classic (Young Module, UTS)
  - New (Fatigue life curves)
  - Innovative (hardening, elasto-viscoplastic properties, expert material card)

  - Tests of new versions (criteria)
  - Comparative analysis of results (Round Robin)
  - Close relation with suppliers (and OEMs)

  - Reliability assessment
  - Subcomponent vs. system
  - Internal testing procedure
  - Valeo standard reliability targets
Engine Cooling Fan System

Scope and functionality

- To ensure a sufficient air flow through the heat exchangers for an adequate thermal exchange
- To maintain a constant optimal temperature of the engine / AC Loop
- *High Efficiency Fan System to Lower Electrical consumption*

Cooling needs:
To improve the thermal exchanges in extreme cases:
- High load of the motor
- Low water rate / load
- High ambient temperature

Air conditioning needs:
To ensure permanently a sufficient air flow to allow condensation:
- Relatively constant need
- Variations mainly associated with the ambient temperature

Usual sizing points: *slow running*
Engine Cooling Fan System

Sub components

- Shroud/support
  Guide the Air Flow
  Support the Fan

- Fan
  Create the Air flow

- Motor
  Drive the fan

- Flaps

- Wiring Harness

- Speed control
  PWM or Resistor

Brushed

Source: www.evworks.com

Brushless

Source: http://www.electrical4u.com/
Product Validation Plan (OEMs specifications)

- Mechanical Endurance (*vibration + rotation*)
- Electrical Endurance (*rotation only*)
- Aerolic and Electrical performances
- Qualification tests

- Mechanical stresses
- Operating Voltage
- Electromagnetic compatibility (EMC)
- Acoustic and vibrations (NVH)
- Water spray and corrosion
Case Study – Field early failures

Framework

- Nomination of new supplier of brushed electric motors
- In field failures of smaller system (*lower power, small car, small volumes*)

<table>
<thead>
<tr>
<th>OK part</th>
<th>NOK part</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="OK part image" /></td>
<td><img src="image2.png" alt="NOK part image" /></td>
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</tbody>
</table>

- Noise and function lost
- Not safety related
- > Allowed radius

radius
Case Study – Procedure

- Problem solving

Part I (experimental)
- Reproduction of the failure mode

Part II (operational)
- Field data analysis (risk assessment, proposed solutions)

Part III (predictive)
- Pro-active reliability investigation for bigger system (higher power, bigger production volumes)
Part I - Vibrations and Motor endurance

Reproduction of the failure mode:

- Bushes wear – axial play

Intense vehicle measurements campaign
  (wind tunnel, road data)

Failure mode reproduced on serial parts

Focus on electrical endurance
  (rotation only, no vibration)

- Vibration damage accumulated during the test?
- Jig geometry to blame?
Endurance test

Input => rotating fan only (no table excitation)
HS: high speed
LS: low speed
HS-LS activation

Output => vibration jig (right and left)

Are the vibration of the jig induced by fan rotation inducing any significant fatigue damage that can provoke the Failure of the DC motor?

Stabilized LS
Stabilized HS

OEM mission profile
Jig fatigue damage

- Generation of the endurance cycle equivalent PSD (on jig)

Start-up → FDS_1 → R1 repeats → Sum of the FDSs of all events → Equivalent PSD (iso-hours)
Stabilized HS → FDS_2 → R2 repeats
Switch → FDS_3 → R3 repeats
Stabilized LS → FDS_4 → R4 repeats
Fatigue Damage Spectrum → Mission Profile → Total FDS → Test Synthesis
Jig fatigue damage – Results Z axis

- Jig vibrations are not damaging (5 – 100 Hz)

- Root cause analysis
Focus on failed part

PDCA – FTA summary

User effect: problem identification
- Noisy/degraded part

Failure mode considered
- Bushing wear out

Root cause
- Unsuitable lubrication settings
- High ambient temperature
- Source: DC motor

Expected $\beta$ known from experience ($\beta > 1.5$)
Resume of crisis

- Issued from Isochrone curve (Hot countries)
  - Crisis period: from June to October

  - Start of crisis
  - End of crisis
  - Corrective action

Number of claims (ppm)

Production date
Part II - Field Data
Isochrones curves from OEM

- Moderate temperatures
  - Early failure
  - End of crisis
  - Production date

- Hot temperatures
  - First failure appears after 3 months in service
  - Production date

- Ppm / vehicle production date
- Number of claims (ppm)

- Graphs showing number of claims over time for different production dates and temperature conditions.
Part II

Isochrones curves
Seasonal effect

- Impact on isochrones curves

Month of deposit (failure): production date + month in service + shipping / storing (2 months)
Field Data

- Weibull regression line by mileage

The alignment of points with the regression line gives:
\[ \beta > 1.5 \]

Confidence bounds bilateral 90%

Censored parts = \( N^\circ \) parts delivered – \( N^\circ \) parts failed
Field Data

Forecasts

- **Scenarios (for worldwide driving pattern)**
  - 100 000 Km (warranty period)
    - 2 years 100 000 km
    - 3 years 100 000 km
  - Failure forecast
  - 150 000 km (mid life term) => which failure rate expected?
  - 240 000 km (end of life term) => estimation for recall (none/total/partial)
Field Data
Need of new corrective action?

State of the art:
- Initial early failures appear after 3 months in service
- After process adjustment, data available for returned part after 24 months of in-service life
- Failure mode unknown => probably « random failure » with secondary root causes
- Is the reliability OK or need to new upgraded solution?

Prediction procedure:
1. For each country, we know the Weibull parameters (beta and eta in Km) and the driving pattern for small cars
2. Estimation were based on stress-strength method (stress is based on Valeo Standard driving pattern for small cars worldwide)
3. With a conservative approach, we assume that DC motor now in service
   - Will fail with the same rate as before (same beta)
   - It will last longer (>24 month instead of 3 months)
Reliability forecast
Scale factor method

Early failure (3 months) Beta_1
Corrective action (> 24 months) Beta_2 = Beta_1

Reliability Coefficient $\alpha$
Reliability forecast

Weibull parametric analysis ("worst" hot country)

First failure at 3 months

**Stress:** driving pattern - small cars ($\beta_1$, Km/y)

**Strain:** 2p-Weibull ($\beta_1$, $\eta_1$)

Time (km)

F(t)

3 years 100 000 Km

Unreliability: 26.9%

Worst case scenario

First failure after 24 months

**Stress:** driving pattern / small cars ($\beta_1$, Km/y)

**Strain:** 2p-Weibull ($\beta_1$, $\eta_2$)

Time (km)

F(t)

3 years 100 000 Km

Unreliability: 1.3%

$\eta_2 = \alpha \times \eta_1$

Results based on conservative assumptions
Reliability forecast - Results

**Early failure**

<table>
<thead>
<tr>
<th>Countries</th>
<th>Beta</th>
<th>Eta</th>
<th>150000km</th>
<th>Warranty commitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1.55</td>
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<td>1.70</td>
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<td>2.10</td>
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<td>2.05</td>
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<td>Italy</td>
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<td>1.60</td>
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<td></td>
<td>1.60</td>
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</tbody>
</table>

Driving pattern tailored to each country

**After corrective action**

<table>
<thead>
<tr>
<th>Countries</th>
<th>Warranty Commitment</th>
<th>Mid Life</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 years 100 000 Km</td>
<td>5 years 150 000 Km</td>
</tr>
<tr>
<td></td>
<td>1.26%</td>
<td>0.55%</td>
</tr>
<tr>
<td></td>
<td>0.26%</td>
<td>0.26%</td>
</tr>
<tr>
<td></td>
<td>0.12%</td>
<td>0.12%</td>
</tr>
<tr>
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<td>0.08%</td>
<td>0.08%</td>
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<tr>
<td></td>
<td>0.03%</td>
<td>0.03%</td>
</tr>
</tbody>
</table>
Part III: Proactive Reliability

Wear out of brushes

Mounted component

Component under development

Early field failures – issue solved

Proactive reliability study

Reliability of brushes wear out

Internal Research Project

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Reliability of brushes wear out

Internal Research Project
Accelerated destructive degradation tests
- Preliminary test carried out at full speed
- Destructive analysis
- Decision making based on small sample size
- Influence of the temperature?
Correlation with validation test?

Criteria: reliability of brushes wear our related to:

- Total mission profile 15 years, 240 000 km
- Warranty commitment 3 years, 100 000 km
- Warranty extension? 5 years, 100 000 km

Stress-strength approach based on test/simulation results \((\text{beta and eta of brush duration})\) and field analysis/driving patterns

Driving pattern

Need to built a degradation model to estimate the reliability of the DC motor brushes
• Customer specification – electrical endurance

Brushes Degradation Analysis

- Ambient temperature
- Fan speed

Time (hours)

Time (minutes)

x N cycles

T1
T2
T3

High Speed
Low Speed

idle
idle
- Full speed, underhood temperature
- Destructive inspection of 1 sample at 100 / 200 / 300 / 730 hours
- 4 brushes motor → 4 points per inspection
- Each inspection is fitted to the lognormal or normal distribution
- Various percentiles are calculated for the obtained distributions
- Fit of the degradation model (power) to the degradation values for each individual percentage of the distribution

Calculation of percentile

100 %
brush temperature

Critical degradation

Brushes Degradation Analysis Results (lognormal distribution)
Part III

Brushes Degradation Analysis

Results (normal distribution)

1) Brushes temperature increased with time

2) Brushes wear increased with increasing time & temperature

3) Need of multi-stress analysis
Brushes Degradation Analysis

Further analysis

- Correlation specification – mission profile – warranty period

Further investigation:
- New degradation test plan (operative temperature, fan speed and activations)
- Multi-stress analysis
- Correlation between customer specification and fan system usage profile

RESULTS
- Reliability estimation (from bench to field)
**Brushes Degradation Analysis Model results**

<table>
<thead>
<tr>
<th></th>
<th>(Low speed + idle) cycle</th>
<th>(High speed + idle) cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+ (*), - (**)</td>
<td>Mean wear out rate (μm/h)</td>
</tr>
<tr>
<td>T1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3</td>
<td></td>
<td></td>
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</tbody>
</table>

(*) : brush wear on positive brush ; (**) : brush wear on negative brush ;

- Results analysis based on limited quantity samples (4 samples per temperature-speed)
- Low speed brush wear speed is constant at all temperatures of testing (<1mm / 1000h)
- High speed brush wear speed is increasing with temperature
- **Hypothesis of linear degradation model and Weibull life distribution, for high speed only, for 1 temperature cycle**
Brushes Degradation Analysis

Conclusions

- Reliability estimated from degradation model vs driving patterns
- Methodology to be used for internal qualification tests

![Stress - Strength interference form](image1)

- Bad design
- Reliability target achieved
Summary

- A reliability evaluation of suppliers should be tailored to their experience/background

- In case of warranty escalation, readiness and a robust procedure are needed

- A proactive mindset is nowadays necessary in order to anticipate potential issues
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