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CAMSHAFT TIMING-BELT RELIABILITY MODELLING

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AGENDA

- Aims & objectives
- Philosophy of the approach
- Camshaft timing-belt life modelling
- Use of the timing-belt life model & sensitivity analysis
- Discussion & conclusions

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Aims & Objectives of the Presentation

• To present a methodology for customer correlated life prediction modelling of automotive systems.

• To illustrate the practical application of this methodology with the camshaft timing-belt life model development -
model construction - calibration - validation

• To discuss the results obtained and to indicate direction for future development.

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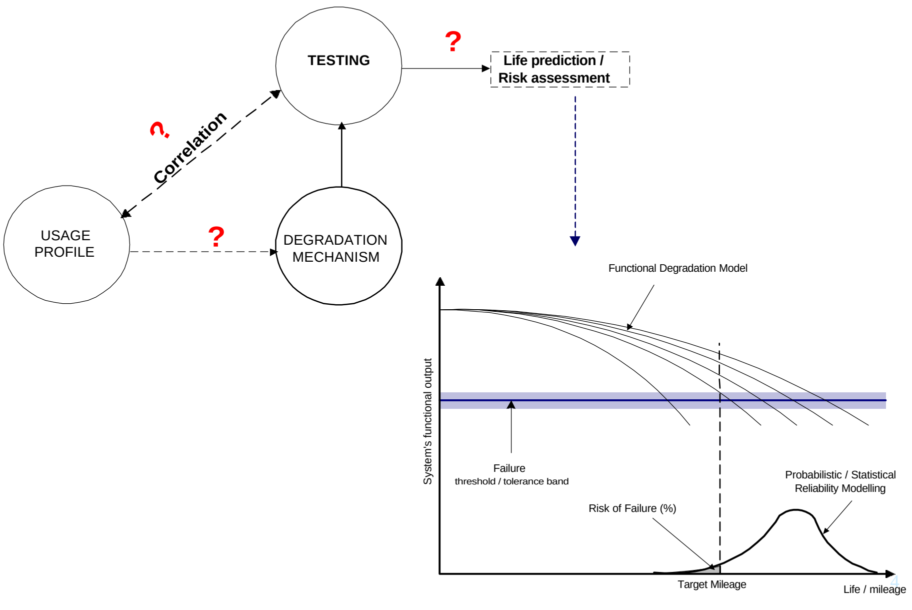
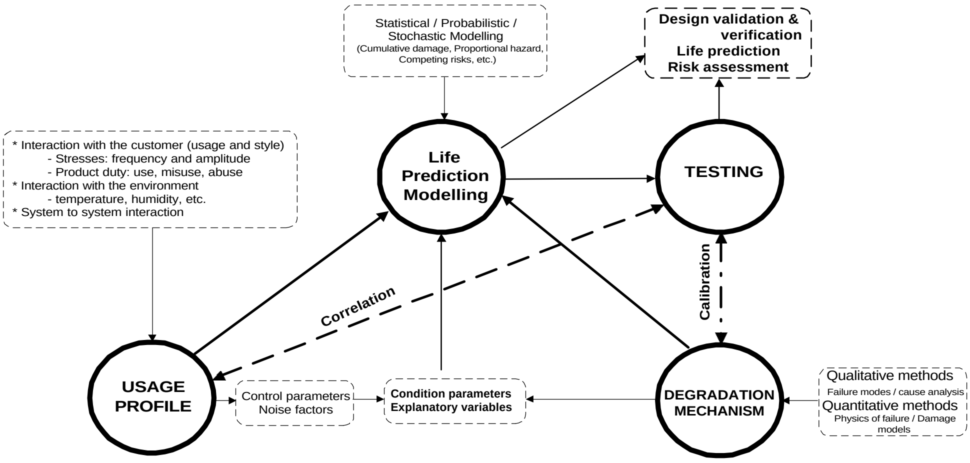
Philosophy of the approach (1)



Philosophy of the approach (2)

Customer Correlated Life Prediction Modelling



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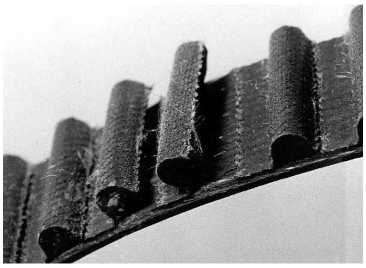
Timing-belt Failure Mechanism

TRC (Tooth Root Cracking) -
shear fatigue failure mechanism.



Factors influencing the fatigue life of the timing belt:

- Mechanical properties of belt material - tooth stiffness.
- Design layout - belt/pulley number of teeth, tensioners, angle of wrap, belt width.
- ***Tooth load - radial & tangential***
- ***Tooth deflection***
- Operating temperature, ageing at temperature

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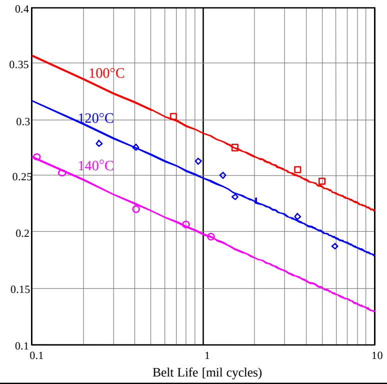
Timing Belt Fatigue Life Model

Dynamometer studies and modelling of the load sharing between teeth in fully meshed conditions showed a linear relationship between tooth deflection and log life.

$$\lambda = A - B \cdot \ln(N) \qquad N(\lambda) = e^{-\frac{\lambda - A}{B}}$$

Proportional hazard modelling for the effect of operating temperature



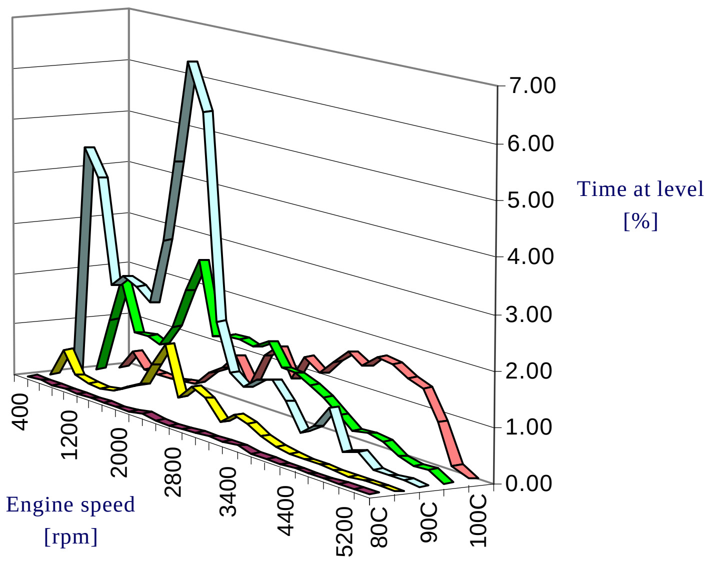
Arrhenius model was used for the influence of the belt operating temperature

Fatigue life of the timing belt:

$$N(\lambda;T) = C \cdot e^{\frac{D}{T}} \cdot e^{-\frac{\lambda - A}{B}}$$

$$N(\lambda;T) = 3.174 \cdot 10^{-13} \cdot e^{\frac{1.188 \cdot 10^{4}}{T}} \cdot e^{-\frac{\lambda - 0.2}{0.029}}$$

Customer Usage Profile



Timing-belt Life Modelling

- Number of load cycles during a time unit (1 hour) $$P_{n_i} = \frac{M_c \cdot 60 \cdot \omega_i}{M_b}$$
- Damage accumulated at a certain level - engine speed / operating temperature $$d_{i,j} = \frac{\alpha_{i,j} \cdot P_{n_i}}{N(\lambda, T_j)}$$
- Damage accumulated during a time unit

$$D_m = \sum_i \sum_j d_{i,j} = \frac{M_c}{M_b} \cdot \frac{60}{C \cdot e^{-\frac{\lambda - A}{B}}} \cdot \sum_i \omega_i \cdot \sum_j \alpha_{i,j} \cdot e^{-\frac{D}{T_j}}$$

- Timing-belt life model

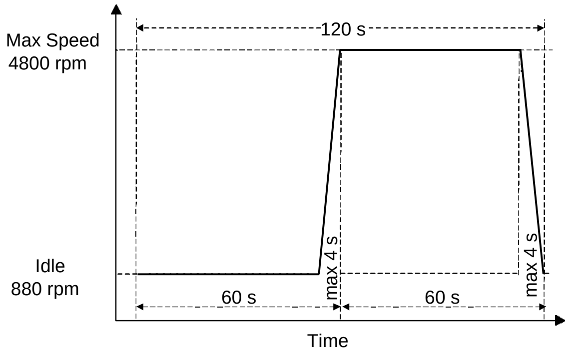
$$L = \frac{C_m}{D_m} = C_m \cdot C \cdot e^{-\frac{\lambda - A}{B}} \cdot \frac{M_b}{60 \cdot M_c} \cdot \frac{1}{\sum_i \omega_i \cdot \sum_j \alpha_{i,j} \cdot e^{-\frac{D}{T_{ji}}}}$$

C_m - cumulated damage at failure (Miner's constant)

Calibration of the Model

Objective: To assess the distribution of the cumulated damage at failure

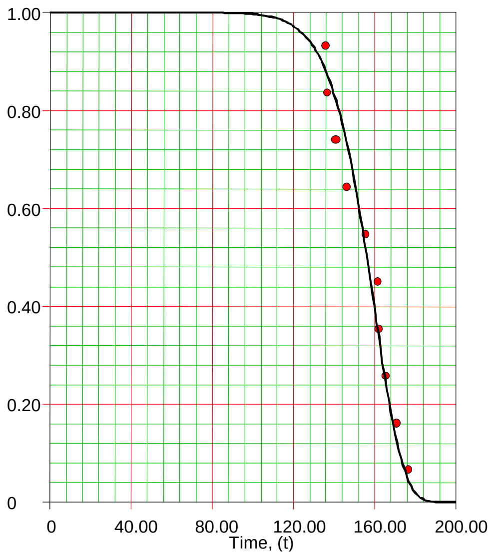
Engine Dynamometer Test Load Cycle:



***Belt operating temperature:* 120°C**

Belt No.	1	2	3	4	5	6	7	8	9	10
Hours to failure	795	800	825	856	910	946	950	970	1000	1035
Tooth cycles to failure [$x10^6$]	135.5	136.3	140.6	145.9	155.1	161.2	161.9	165.3	170.4	176.4

Weibull analysis of the test data



Percentiles of the distribution of cumulated damage at failure:

Median

$$C_{m50\%} = N_{50\%} \cdot D_m = 7.297$$

5th percentile

$$C_{m5\%} = N_{5\%} \cdot D_m = 5.671$$

1st percentile

$$C_{m1\%} = N_{1\%} \cdot D_m = 5.281$$

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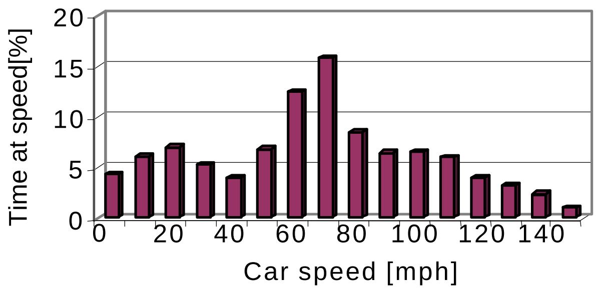
Use of the Timing-belt Life Model -

Life predictions under customer usage conditions

Aggressive Motorway Driving



- ***1st percentile*** $Lf_{1\%}$ = ***74,570*** miles
- ***5th percentile*** $Lf_{5\%}$ = ***80,078*** miles
- ***Median life*** $Lf_{50\%}$ = ***95,207*** miles

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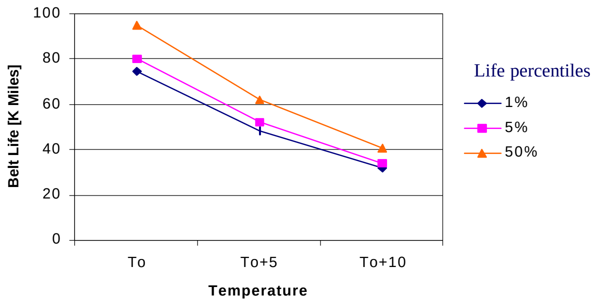
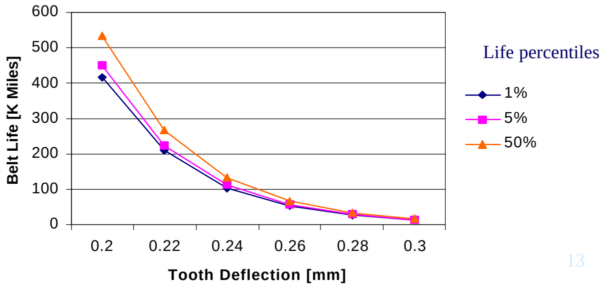
Sensitivity Analysis on the Life Predictions

Influence of belt operating temperature



Influence of tooth deflection (Cam-belt system design)



Discussion & Conclusions (1)

- Timing-belt life model can be used for life prediction or as a risk assessment tool, to validate the service intervals.
- Any engine dynamometer test can be used to calibrate the life model, i.e. there is no need to design a specific validation test for the timing belt!
  The only requirement is that tests should be carried out to failure.
- To achieve reliability improvement, actions can be taken on:
  - cam-belt system design, to reduce the tooth deflection.
  - belt operating temperature.
- Life model can be used to validate the reliability improvement.

Discussion & Conclusions (2)

- Development of the timing-belt life model illustrates the practical application of the “Customer Correlated Life Prediction Methodology”.

- Life modelling enables a better understanding of the stochastic nature of parameters and noises that define customer usage and their impact on the life of the automotive system.

- Customer correlated life prediction modelling gives a definite prospective for condition-based automotive servicing. The optimum moment for service can be determined by using stochastic damage accumulation and customer usage information from data logging.