Accelerated testing of track vehicle torsion bar

Jan Furch[1], Quy Hung Nguyen[2], Jiri Stodola[3]

[1,3]University of Defence in Brno, Czech Republic

[2] Institute of Mechanical Engineering, Vietnam

Introduction

When test acceleration is accomplished with a single stress only, the models are life stress models, where the damage per unit time of the test is appropriately accelerated by increasing the level of stress.

The three most frequently used relationships are [1]:

a) inverse power law model, used for test acceleration when stresses other than constant temperature are considered, such as electrical, mechanical, chemical (corrosion) and others;

b) Arrhenius reaction rate model, used for constant temperature stresses, based on the effect that the absolute temperature has on a failure mechanism;

c) Eyring model which is used in cases where the acceleration is achieved with temperature and moisture stress levels. The model is derived from quantum mechanics.

With all acceleration models, test data can be analyzed using established analytical models to determine characteristic accelerated life parameters. Using the acceleration factors, the parameters corresponding to use environments are determined and used for reliability projections as needed. The acceleration models should, if possible, be verified by plotting the test data.

Objectives

Planning lifetime tests

Planning lifetime tests can be divided into experimental-technical measurement planning and statistical test planning [2].

Experimental-technical measurement planning

The common fundamental principles for correct execution of an experiment apply. The most important of these principles is as listed the inverse power law is applicable to:

- The boundary conditions and limits must be exactly defined and kept.
- For lifetime tests this is especially important for the load spectrum.
- The technical measurement process for the registration and control of the boundary conditions must be established along with their accuracy. Depending upon the resources, more information is acquired at the test stand than actually needed.
- If longer testing times are expected, then the use of automated and/or computer controlled measured value gathering and control equipment should be strived for.
- For a determination of the lifetime, the exact specification of a limit value is necessary, at which the nominal function is no longer fulfilled. If the damage is a continuously changing value, as for example a leak volume for a seal.
- The control equipment must be built up in such a way that the primary failure cause can even be determined after the failure effect. This is important since each failure mode is assigned its own characteristic reliability parameters [2].

Statistical test planning

Accelerated life tests are component life tests with components operated at high stresses and failure data observed. Test planning means picking stress levels and sample sizes and test times to produce enough data to fit models and make projections. It is good design practice to put more of your test units in the lower stress cells, to make up for the fact that these cells will have a smaller proportion of units failing.

In statistical test planning, the first step involves determining the size of the inspection lot. The inspection lot size is in close connection with the confidence levels and the statistical spread of the measured values. If fewer components are tested, then the result of the statistical assessment becomes more uncertain. For an accurate result, it is necessary that a sufficient quantity of components is tested. This can increase the time and effort involved in a test immensely. Fig. 1 shows the influence of number of test units on the reliability. It is obvious that with the diminishing of sample size, the reliability is decreasing.

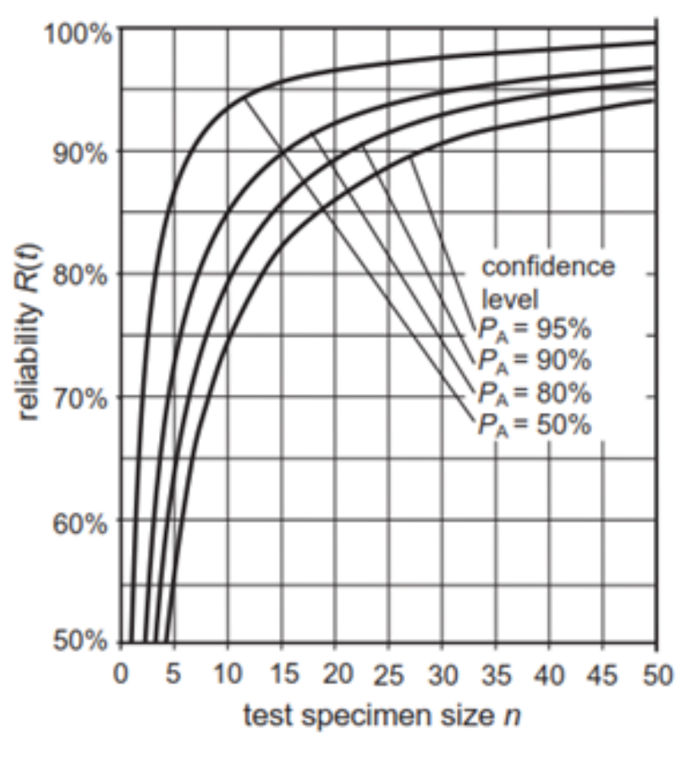

Fig. 1 Minimal reliability R(t) as a function of the test specimen size n and the confidence level PA, if at the point in time t no failure has occurred [2]

Another important point in statistical test planning involves establishing a suitable test strategy. Possible strategies include:

a) complete tests,

b) incomplete (censored) tests,

c) strategies for shortening test times.

Method

Before starting an accelerated life test, it is advisable to have a plan that helps in accurately estimating reliability at operating conditions while minimizing test time and costs. To design the plan for the accelerated life tests it is necessary to establish the following parameters:

1. The acceleration model: For accelerated life tests where the failure mechanism is a mechanical one (the fatigue failure), the most adequate one is the IPL model. The inverse power law (IPL) model is commonly used for non-thermal accelerated stresses. This model was calculated by the formulas (1) - (3).

With the inverse power law, the characteristic that represents product reliability related to time, such as characteristic life, mean life, mean time to a failure, is represented as [1]:

$$L(S) = C^{-1} \times S^{-m} \tag{1}$$

where: L(S) = is the life or other predetermined time duration as a function of stress; C is one of the model parameters (C > 0) to be determined; S represents the stress level; m is the another model parameter, dependent on stress behaviour, also to be determined.

The power law model is simple when expressed or plotted in logarithmic form, where it becomes a straight line with the slope representing the value of parameter m, and the value of the intercept with the y-axis is a function of the constant S: (where the y-axis is the function)

$$\ln[L(S)] = -m\ln(S) - \ln(C) \tag{2}$$

The inverse power law is applicable to all distributions regularly used in reliability. The test acceleration factor is then:

$$A_{S\_IPL} = \frac{L(S_{Use})}{L(S_{Test})} = \frac{C^{-1} \times S_{Use}^{-m}}{C^{-1} \times S_{Test}^{-m}} = \left(\frac{S_{Test}}{S_{Use}}\right)^{m} \tag{3}$$

where: AS---IPL is the acceleration factor of stress by inverse power law; L (SUse) is the life as a function of stress in actual use; L(STest) is the a function of stress applied in test.

Parameter C in the test acceleration cancels out, but the parameter m shall be determined for the item and the stress type. The parameter m in the inverse power relationship is a measure of the effect of the stress on the life. As the absolute value of m increases, so does the effect of the stress. Negative values of m indicate an increasing life with increasing stress. An absolute value of m approaching zero indicates small effect of the stress on the life, with no effect (constant life with stress) when m = 0.

2. The available test time: Choose the duration of the accelerated life test 360000 cycles.

3. The number of units subjected to accelerated life tests: suppose 20 specimens.

4. The distribution law of the number of cycles until failure used in accelerated life testing: choose Weibull distribution and give shape parameter.

5. The stress under normal use condition and maximum in accelerated condition: the twist angle in normal condition is 30and the maximum angle is 50° (during the experiment only 40°).

6. The accelerated life test plan: choose three levels best compromise plan. This plan recommends three stress levels: a high stress level, which is the maximum allowable stress value that you specified during setup, a low stress level and a middle stress level.

The test plan was realized using the ALTA software, introducing the aforementioned parameters.

The recommended test plan suggested stress levels to be used in the test and the recommended allocation of units to each stress level.

Table 1 Recommended test plan [1]

Stress level	Stress value [°]	Unit allocation [%]	Unit allocation [Qty]	Probability of failure [-]
Low stress level	40	47.3	9.46	0.211
Middle stress level	45	25	5	0.648
High stress level	50	27.7	5.54	0.99

Results

Test rig construction

The test rig was built to test three torsion bars at three different twisting angles to determine the number of cycles to failure at every stress level. A complete test rig equipped with a complete measuring system has been designed and manufactured to measure the moment acting on torsion bar and the corresponding twist angle. The measured parameters are used to evaluate vehicle suspension characteristics. A lifetime of a torsion bar is predicted using the accelerated test in a fatigue test bench. Torsion bars involve repeated torsional loading. Torsional fatigue tests are performed on an axial-type machine. A typical torsional fatigue testing machine is shown in Fig. 2.

The test rig consists of a hydraulic power unit, hydraulic cylinder - actuator, and a controller. MTS SilentFlo™ Hydraulic Power Unit 505.30 delivers superior performance in servo hydraulic testing applications. The MTS Model 493.02 FlexTest SE Controller made by MTS is a fully digital Proportional, Integral, Derivative, Feedforward (PIDF) servo controller. It provides complete control of one servo hydraulic channel or station in an MTS test system.

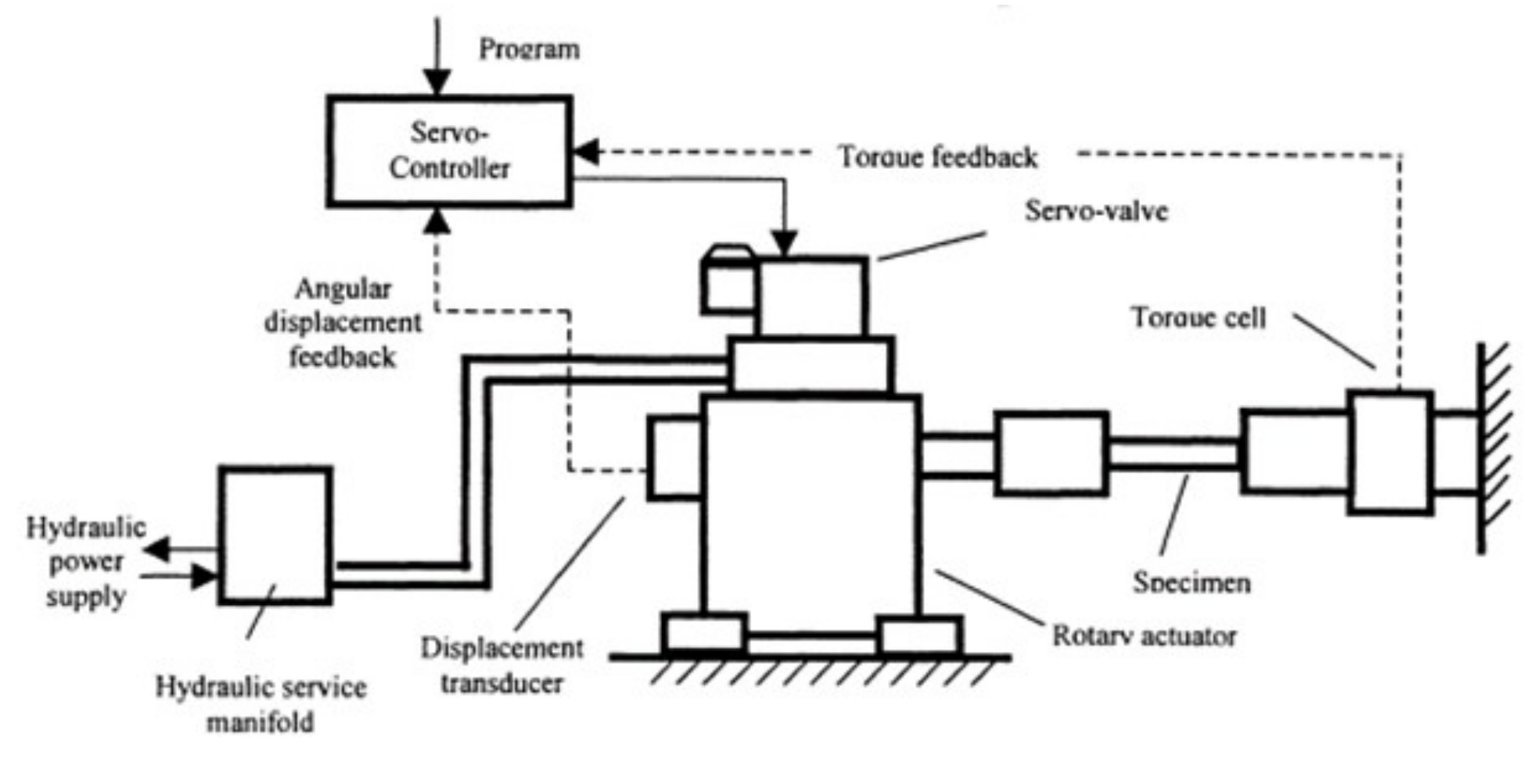

Fig. 2 Hydraulic torsional fatigue system [7]

Table 3 Twist angle and torque of torsion bar

Twist angle, [°]	15	25	30	40	53
Twisting moment, [kNm]	7.7	13.0	15.5	20.6	-

Model of torsion bar suspension

While a track vehicle is travelling on road, it is subject to excitation from the road. Vertical motion of the road wheel causes the torsion bar to twist around its axis and is resisted by the bar's torsional resistance. The resistance of the torsion bar to twisting has the same effect as the coil spring used in conventional suspension systems.

From the model of torsion bar suspension as shown in Fig. 3, the vertical force exerted on the road wheel and transmitted through the axle arm to the torsion bar is determined by the formula [8]:

$$\frac{\beta}{R\cos(\beta_0 - \beta)} P_W = \frac{GJ}{L} \tag{4}$$

where P_w - vertical force transmitted from road wheel to the hull; G - shear modulus of torsion bar material; J - polar second moment of torsion bar cross-section $J = \frac{\pi d^4}{32}$; d - diameter of torsion bar; β - twist angle of torsion bar; β_0 - setting angle of torsion bar; L - active length of torsion bar.

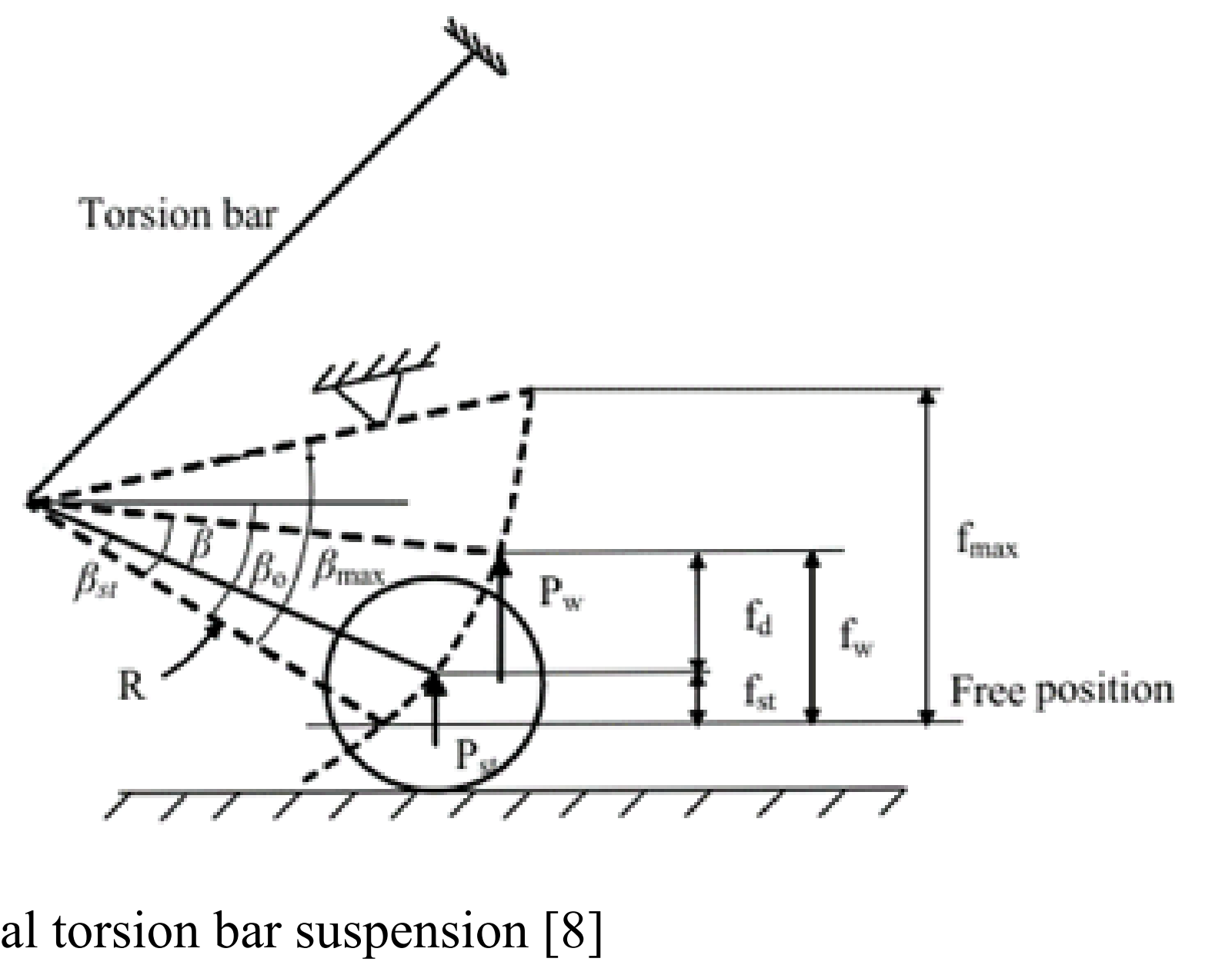

Fig. 3 Individual torsion bar suspension [8]

$$T = P_W R\cos(\beta_0 - \beta) \tag{5}$$

therefore

$$T = \frac{GJ}{L}\beta = C\beta \tag{6}$$

where T – twisting moment on torsion bar; R – radius of road wheel arm; C - torsional stiffness of the torsion bar.

When a shaft is subjected to a torque or twisting, a shearing stress is produced in the shaft. The shear stress varies from zero in the axis to a maximum at the outside surface of the shaft. Shear stress τ in the torsion bar is given by:

$$\tau = \frac{T}{J} r = \frac{Gr}{L}\beta \tag{7}$$

The specifications of the individual torsion suspension are shown in the Table 4.

Table 4 Specifications of torsion bar suspension

Parameters	Values
Torsion bar diameter, [mm]	52
Torsion bar active length, [mm]	1960
Radius of road arm (swing arm), [mm]	250

Table 5 Values of twisting moment and shear stress at twist angle

	Twist angle		Torque, [kNm]	Shear stress, [MPa]	Equiv. stress, [MPa]
	angular [°]	[rad]			
Setting	0	0	0	255	
Static	14.8	0.258	7.6	276	21
	25	0.436	12.9	466	211
	30	0.524	15.4	559	304
	40	0.698	20.6	745	490
	45	0.785	23.1	838	583
	50	0.873	25.7	931	676
Strict	53	0.934	27.5	996	741

Test rig simulation

In this article, the model of the test rig was built and tested using MSC Adams software. The virtual model allows simulating the torsion bar at the large twist angles that the test trig cannot. In this model, the torsion bar was represented by a 3D beam comprised of a single FE part of twelve nodes. One end is constrained with the ground and the other end is constrained with the swing arm.

The FE part is a wholly Adams-native modelling object with inertia properties and is accurate for very large deformation cases of beam-like structures. The FE part differs from the linear flexible body option within Adams Flex in two significant ways. Firstly, it has the ability to accurately represent large deformations which the linear modes approach cannot. Secondly, its modelling does not require an FEA produced file like the modal neutral file. The FE Part also differs from the beam force element in that it possesses inertia properties [9].

For the test rig model and through the experiment, the following data were applied: torsion bar diameter - 52 mm, torsion bar active length - 1960 mm, shear modulus of torsion bar material - 80.23 kN/mm^2.

Table 6 Comparison of experimental and simulation results

Twist angle in [°]		15	25	30	40	53
Twisting moment	Experiment	7.7	13.0	15.5	20.6	-
	Simulation	7.6	12.7	15.2	20.3	26.9

It is clear from the table that the results of physical tests and simulation have an insignificant difference.

Discussion

This article deals with the accelerated life test for a torsion bar of the track vehicle. Majority of mechanical damages of structural elements occur due to material fatigue during its normal operation. Fatigue is a major failure mechanism of mechanical parts. At the same time, this type of damage is considered to be the most dangerous one, the crack initiation in structural elements is difficult to predict, and it leads to damage of the elements.

The primary purpose of an ALT is to estimate the life distribution and quantities of interest in a use condition. This estimation involves extrapolation from higher stress levels by using an acceleration model and thus includes the model error and statistical uncertainty.

For the torsion bars of tracked combat vehicles with stringent functionality specifications, the reliability is very high. Therefore, their life testing under nominal conditions requires much time and resources. In response to this problem, ALT finds an application to obtain timely information on the reliability of the products.

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Acknowledgments

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