Fatigue prediction for Gearboxes using winLIFE

Automotive gearboxes are high performance components, which need an optimisation in regard to

- reliable operation,
- minimum of weight and space ,
- cost-benefit relation.

To meet these requirements fatigue analysis considering the service loading is necessary and it is shown here, how winLIFE supports this process.

I. Basic design of the components

A gearbox normally is designed for a special torque and speed range and based on this data the first step in the design process is to make the basic construction of the gearbox including an analysis of all axles, bearings, gear wheels, clutches or torque converters.

The result of the first step is a design, which normally will not meet the space, weight and cost requirements. As a result a further optimisation process will follow. The goal is to save up those components, which are oversized in relation to the expected service loading.

II. Analysis of service loading

According to the vehicle data and the driving cycles the components of a gearbox are stressed very different. Measurements in cars or simulations considering real conditions are presuppositions to get these information.

A result of such analysis shows fig. 1: the duration of gear speed for a city bus. It is remarkable, that the load is very different in the gears. The first gear (it is mainly used only for starting) is used only for a short time. On the other hand the third and fourth gear together are used nearly 80% of the time. An economic design has to consider these different loading.

Depending on the structure of a gear box the loading is transmitted with different elements in every gear. The entry shaft transmits the total input torque while total operation time while other parts - e.g. gear wheels - only operate in one gear.

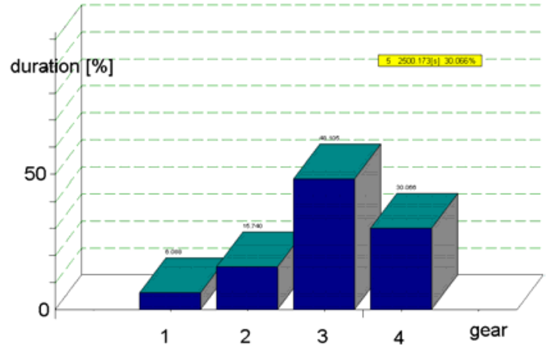

Fig.: 1: Percentage of time for gear speeds of a city bus in a city of Germany

So the very important first step is a deep analysis of the system to get information about the loading of every element in the gearbox.

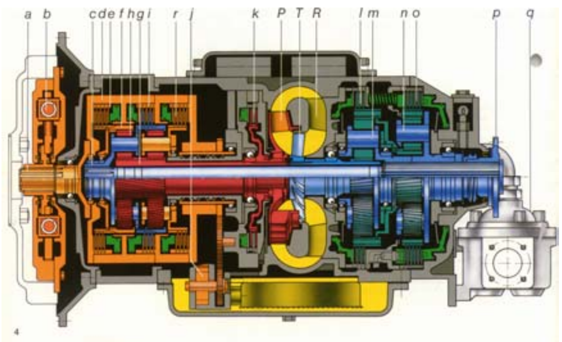

Fig. 2: City bus automatic transmission (Voith)

II.1 Service Loading for axles

In the case of axle-design the time history of the torque is needed to make a fatigue calculation. Normally these data are measured and a typical picture of a torque input into the main axle of a gear box is shown in figure 3.

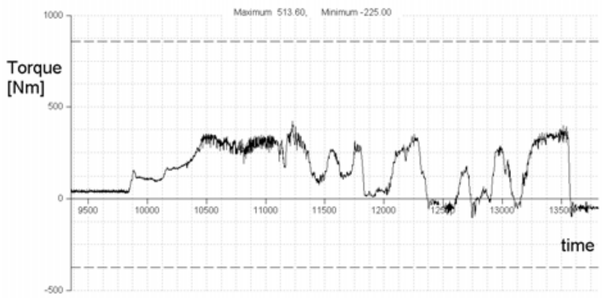

Fig. 3: Time history of the input torque for a fatigue calculation of axles.

WinLIFE can import ASCII-data and the very simple file design enables the user in only some minutes to transfer his data into a winLIFE readable file. Powerful interactive data correction options are available, which can be activated by the right mouse button and eliminate measurement faults like sparks, drifting or offsets of the signal.

Instead of load histories the use of load spectra is possible too. A generator of typical load spectra can be used in winLIFE. Data transfer form simulation programs like Mathlab/Simulink is possible too.

II.2 Service loading for gear wheels and bearings

In the case of gear wheels and bearings typically the torque/load speed characteristic is measured and can be a base for fatigue analysis. Fig. 4 shows this for a gear wheel on the main entry shaft.

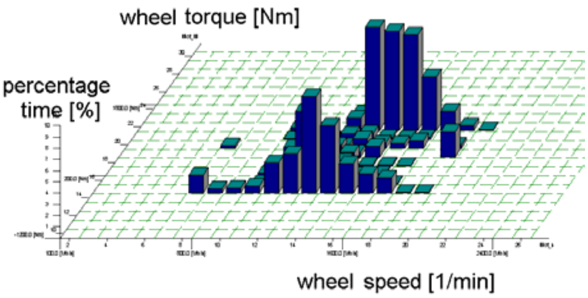

Fig.4: torque speed characteristic of a gear wheel

In the case of bearing instead of torque the load of the bearing is needed, what fig. 5 shows.

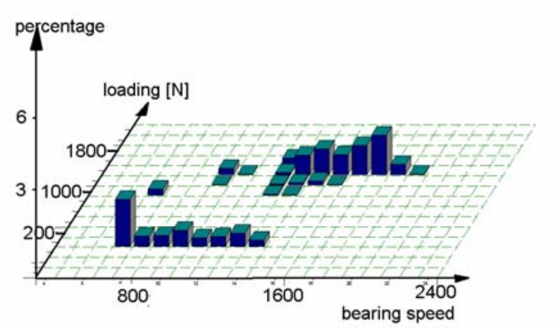

Fig 5: loading speed characteristic of a bearing

III. Fatigue Calculation

III.1 Axles

Numerous different methods of fatigue analysis on axles are available and can be used in winLIFE BASIC module or - only in special cases needed - winLIFE MULTIAXIAL module.

In most cases the **Nominal Stress Approach** will be used, because many engineers are familiar using this method and. A relation between the acting loading and the stress at the critical point is needed. Fig. 6 shows an example of an axle, where the notch stress τ is critical for fatigue. A relation between τ and T and the notch effect factor K_t is needed to do the first step of a fatigue life prediction.

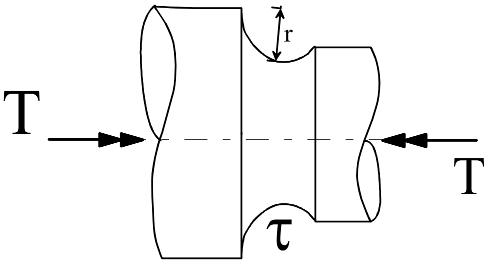

Fig. 6: critical area of an axle under torque loading

A connection with finite element analysis releases the user to make search for the critical point and determines the stress concentration factor K_t. In this case the theory of **Local Strain Approach** is used, where a calculation based on local stresses happens. This method leads to some advantages and should be used if a finite element analysis exists.

WinLIFE is shipped with a connection to MSC/NASTRAN for Windows or can be connected to other finite element programs so that the link can be done easily.

Next step is a rainflow count of the loading T to determine all those events, which are relevant for damage.

Fig. 7 shows a typical result of a rainflow counting of an input torque.

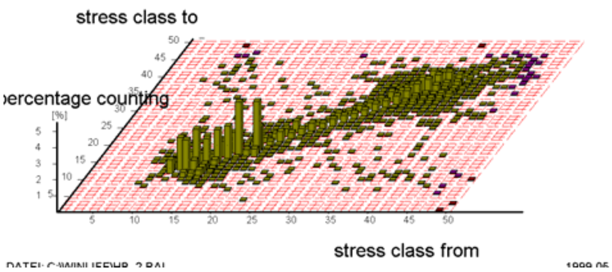

Fig. 7: typical result of a rainflow counting of an input torque

In the case of Nominal Stress approach a S-N-curve of the component is needed and WinLIFE enables to generate such a curve on the base of static material data and the data of the axle (surface, notch radius).

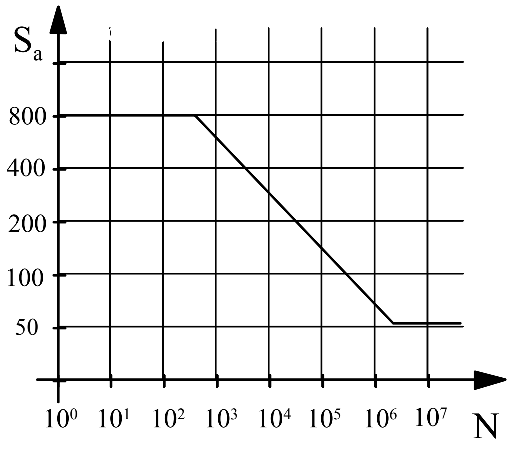

Fig. 8: S-N-curve for the critical point (notch) off the axle

In the case of **Local Strain Approach** an ε-N-curve and a damage parameter curve of the material is needed. A database including several material data is shipped with winLIFE and additionally a generator according to the Uniform Material Law is included too. This means, that the user will not have problems to get a life curve for a fatigue estimation.

III.2. Gear Wheels

Fatigue of gear wheels is calculated similar to the **Nominal Stress Approach**. Well known basic equations give the relation between the torque and the force F_n. This enables to calculate the bending stress in the base and the normal pressure in the face.

Fatigue of gear wheel base happens in result of the bending moment (fig. 9), which is performed by the force F_n. It leads to a bending stress, a crack and after a crack groth period finally wheel base break occurs.

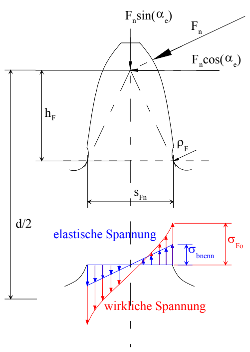

Fig. 9: Forces and stresses on a gear wheel

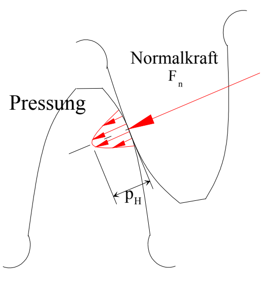

Fig. 10: Forces in the face of a tooth

Fatigue of gear wheel face is performed by normal pressure (fig. 10), which leads to pitting in the surface of the face. Consequence of pitting in the first stage is an increased noise and later a total damage occurs.

In a fatigue design process both - face and base - must be calculated and the lower fatigue life of both is the predicted life time.

To get fatigue life curves for a design process standards are established. For different groups of steel material - marked in fig. 11 (gear wheel face) and 12 (gear wheel base) by the numbers 1 to 4 - the total fatigue life curve related to the fatigue limit is shown. Normally the fatigue limit of the material is known and consequently based on the curves in picture 11 and 12 the total life curve can be calculated.

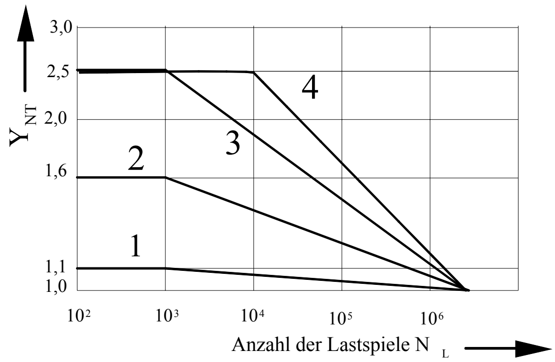

Fig. 11: Life curve for gear wheel face

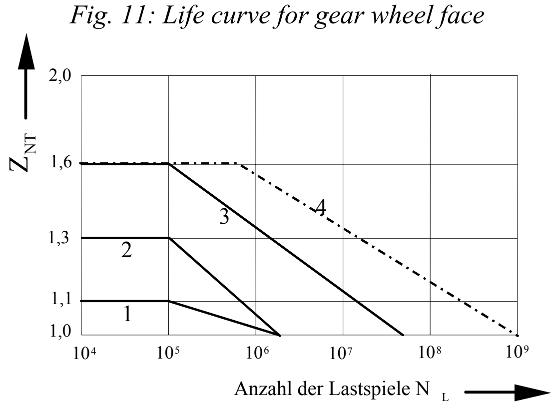

Fig. 12: Life curve for gear wheel base

III.3. Ball bearings

Fig.13: Cylinder bearing

Ball bearings are one of the first elements, which were analysed by fatigue methods.

Consequently there is a very long experience in fatigue analysis and every catalogue of bearings gives information data about life time. There are common accepted procedures for life prediction.

The main reason for fatigue of ball bearings is the local pressure between ball and outer ring similar to the phenomena which performs pitting in gear wheel.

The mathematics for life calculations are based on exponential equations too and a life calculation happens very similar to that of the **Nominal Stress Method**. The life curve is similar to the elementary type.

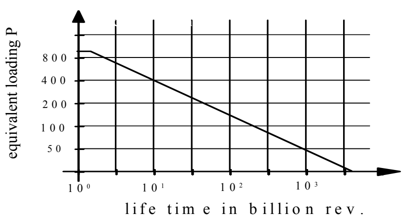

Fig. 14: characteristic of life curve for ball bearing

IV. Results

Using in winLIFE in a development process of a gearbox shows the following benefits:

Components, which are oversized or undersized can be identified and a redesign to equalise the fatigue life can be done. This leads to a reduction of weight, space and costs.

Fatigue life calculation gives a better understanding of the important parameters and helps to concentrate the development to the critical points,

Fatigue analysis helps in the dialogue with the quality control and the production, because the influence of sloppy work can be quantified to life time.

Fatigue design of gearboxes cannot totally substitute testing but it helps to find out the critical components in a very early stage of development when no prototype is available. Focusing tests to the previously by fatigue calculation as critical examined components means a reduction in testing time and costs.

V. Tools for fatigue life prediction of gearboxes

The following tools are needed:

- winLIFE BASIS
- winLIFE GEARWHEEL&BEARING

Only in special cases

- winLIFE MULTIAXIAL

In the case of using a finite element program together with winLIFE we recommend MSC/NASTRAN for Windows.

VI. Detailed Information

Further information you can get from:

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