Classification of Cranes and Components

Why there is no need for M-Classes

Cranes move loads the mass of which is within their rated capacity. However there are wide variations in their duty. The crane design has to take into account the duty in terms of conditions of service, in order to reach an appropriate level of safety and useful life which is in line with the purchaser's requirements.

Classification serves as a reference framework between purchaser and manufacturer, by which a particular appliance can be matched to the intended service. It is also used to specify the service conditions of cranes or components which are designed for serial manufacture, and allows such items to be selected in accordance with their intended use.

1. Classification of crane duty for the crane as a whole

The two main parameters to characterize the crane duties are

- the total number of working cycles \( C \) during the design life (a working cycle commences when the crane is ready to hoist a load, and ends when the crane is ready to hoist the next load) and

- the state of loading (load spectrum factor \( K_p \)).

The load spectrum factor \( K_p \), is given by the equation

\[
K_p = \sum \left[ \frac{C_i}{C_T} \times \left( \frac{P_i}{P_{\text{max}}} \right)^m \right]
\]

where

- \( P_i \) represents the individual load levels, \( P_i = P_1, P_2, P_3 \ldots P_n \);
- \( P_{\text{max}} \) is the heaviest load (rated load for hoists) to be handled;
- \( C_i \) represents the average number of load cycles which occur at the individual load levels \( P_i \), \( C_i = C_1, C_2, C_3 \ldots C_n \);
- \( C_T \) is the sum of load cycles at all load levels, \( C_T = \Sigma C_i \);
- \( m = 3 \).

The international standard ISO 4301-1 classifies the total number of working cycles \( C \) into ten classes of utilization: starting with \( U_0 \) \((C \leq 1.6 \times 10^4)\) and doubling \( C \) from class to class up to \( U_9 \) \((4 \times 10^6 < C \leq 8 \times 10^6)\).

The state of loading is similarly classified into four classes ISO 4301-1:1986 [1] or six classes in ISO/DIS 4301-1:2015 [2]: starting with \( Q_{p0} \) \((K_p \leq 0.0313)\) and doubling \( K_p \) from class to class up to \( Q_{p5} \) \((0.50 < K_p \leq 1.00)\).

Using \( U \)- and \( Q_p \)-classes the duty of the crane as a whole may now be determined by a group classification \( A \) (duty class):

<table>
<thead>
<tr>
<th>( Q ) and ( U ) and total number of working cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classes ( Q ) and ( U ) and total number of working cycles</td>
</tr>
</tbody>
</table>

Table 1 — Classes \( A \) for group classification (ISO/DIS 4301-1:2015):
2. Mechanical and physical basics

Application of Table 1 assumes that a crane designed according to a specific duty class A (e.g. A5) shall fulfil the requirements of six combinations of U- and Q_p-classes (e.g. U3+Q_p5 … U8+Q_p0).

This assumption is based on the so called "Wöhler-Test":

For fatigue testing, samples are subjected to a cyclic load \( F(t) \) (see figure 1) until failure occurs.

\[
\begin{align*}
\text{Wöhler-Test} \\
F(t) & \quad A \quad F(t) \\
\text{Figure 1: Wöhler-Test}
\end{align*}
\]

The number of cycles \( n \) to failure shall be \( N_{F/A} \). The results of various tests with different stress magnitudes of \( \sigma = F/A \) can be shown in a log-log presentation, the so called "Wöhler-Diagram" (see figure 2). Equation (2) is valid for any \( \sigma_i \) in the inner linear section of the curve:

\[
\sigma_i^m \times N_i = \text{cons} \quad \text{or} \quad \left( \frac{\sigma_i}{\Delta \sigma_c} \right)^m = \frac{N_{\text{ref}}}{N_i}.
\]

A reference point in the curve is defined by \( \Delta \sigma_c \) and \( N_{\text{ref}} \).
When a sample is subjected to various cycles with different stress amplitudes the ratio of \( n_i/N_i \) (i.e. number of cycles at stress amplitude \( \sigma_i \) divided by the number of cycles to failure) is considered as "partial damage". The hypothesis of linear damage accumulation postulates that the total damage \( D \) is the sum of the partial damages. Using equation (2), equation (3) follows

\[
D = \sum \frac{n_i}{N_i} \leq 1 \quad D = \sum \frac{n_i}{N_{ref} \left( \frac{\sigma_i}{\Delta \sigma_c} \right)^m}
\]

and by further conversions (with \( \sigma_1 = \sigma_{max} \) and \( N_1 = N_{ref} \left( \frac{\Delta \sigma_c}{\sigma_{max}} \right)^m \))

\[
D = \sum \frac{n_i}{N_i} \times \sum \frac{n_i \left( \frac{\sigma_i}{\sigma_{max}} \right)^m}{1} \sim U \times Q.
\]

The relationship with equation (1) and Table 1 is obvious. In proofs of fatigue strength the damage \( D \) shall be lower than an admissible limit. For a given class (combination of \( U \) and \( Q \)) and rated capacity (maximum \( F \)) the designer therefore has to choose the appropriate material and shape of the detail under consideration (i.e. to define cross section \( A \), \( \Delta \sigma_c \), \( N_{ref} \) and \( m \)).

3. Application to components

The decisive and significant parameters in the Wöhler-Test and in fatigue are the number of cycles and the magnitude of the loads. Time is irrelevant because the duration of the test depends on the frequency of the oscillation.

Reasonable classification and design of components should relate load and utilization (i.e. load cycles) of the component to the working cycles \( C \) and state of loading of the crane.

Let us consider bending in the shaft of a driven wheel of a trolley (see figure 3):
X is the average displacement (travel distance), R is the wheel radius, L is the distance between wheel and bearing, $F_i$ is the wheel load during movement $i$.

![Diagram of wheel shaft](image)

**Figure 3: Wheel Shaft**

The bending stress is calculated as $\sigma_{hi} = \frac{F_i \times L}{W}$ with $W$ = moment of resistance.

The number of cycles of bending stresses is the same as the number of revolutions of the wheel. With a given specification of the average travel distance $X$, the total number of revolutions can be derived from the total number of working cycles $C$ of the trolley as

$$\sum n_i = \frac{2 \times C \times X}{2 \times R \times \pi}.$$  \hspace{1cm} (5)

Thus the proof of fatigue strength of the shaft may be carried out by specifying the number of working cycles $C$, the load spectrum factor for $F$, the travel distance $X$ and the geometric design values of $R$ and $L$. Again: time is irrelevant because the duration depends on the travelling speed which may vary per movement or working cycle.
Let us now consider fatigue of wire ropes in reeving systems:

Bending of wire ropes running over sheaves and drums is decisive for fatigue. Figure 4 shows a typical wire rope fatigue test. According to test results the relationship of rope force to number of rope bendings (corresponding to the Wöhler-curve, see figure 2) corresponds to approximately $m=2$.

With the additional requirement that the ratio of the rope bending diameter $D$ to the rope diameter $d$ increases with the total number of bendings $w_{\text{tot}}$ according to

$$
\frac{D}{d} \sim 1125^{\frac{1}{w_{\text{tot}}}}
$$

the relationship is approximately $m=3$. Therefore, this additional criterion is used in the proof of fatigue strength of wire ropes.

Thus the proof of fatigue strength of wire ropes may now be carried out by specifying the number of working cycles $C$, the load spectrum factor $K_p$ (see equation 1) and the relevant number of rope bendings per working cycle which depends on the reeving system. Again: time is irrelevant because the duration depends on the lifting height and hoisting speed which may vary per working cycle.


In ISO 4301-1: 1986 a table defines M-classes for group classification of mechanisms as a whole. (A similar table can be found in FEM 1.001 [4].)

<table>
<thead>
<tr>
<th>State of loading</th>
<th>Nominal load spectrum factor $K_m$</th>
<th>Class T of utilization of mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_0$</td>
<td>$T_1$</td>
</tr>
<tr>
<td>L1 — Light</td>
<td>0,125</td>
<td></td>
</tr>
<tr>
<td>L2 — Moderate</td>
<td>0,25</td>
<td></td>
</tr>
<tr>
<td>L3 — Heavy</td>
<td>0,50</td>
<td></td>
</tr>
<tr>
<td>L4 — Very heavy</td>
<td>1,00</td>
<td></td>
</tr>
</tbody>
</table>

This table resembles table 1, however the utilization class T is not given in cycles but in hours, where $T_0$ implies 200 and $T_9$ 100,000 hours of utilization.

The class T can of course be derived for a given component or mechanism: In the example of a wheel shaft discussed above class T results from working cycles $C$, distance $X$ and speed. But very different shafts with a considerable variety of fatigue governing revolutions will fall under the same class.
The selection of components based on M-classes may even be erroneous as the following two examples of use of ISO 16625 [3] prove:

Figure 5: Example of M-classes and load cycles C

According to ISO 16625, Hoist 1 and Hoist 2, intended to lift the same load with the same load spectrum and for the same operation hours (e.g. 1600h), can be classified in the same M-class, i.e. they are designed with the same rope and the same D/d-relation. Yet the number of lifting movements (load cycles C) resulting from the chosen lifting speeds \( v \) and lifting heights \( H \) differ by a factor of 10. There is also a factor of 10 between the number of rope bendings and thus in fatigue effects.
Both hoists are designed according to ISO 16625 for state of loading L4 (heavy duty), lifting height $H=7.5m$ and $C=50,000$ load cycles. Different lifting speeds of $6 \text{ m/min}$ (Hoist 1) and $8 \text{ m/min}$ (Hoist 2) result in 2,084 operation hours, i.e. class $T_4$ (Hoist 1), respective 1,563 operation hours, i.e. $T_3$ (Hoist 2). Thus Hoist 1 is classified in M6 and Hoist 2 in the lower class M5. Consequently ISO 16625 allows to select a thinner rope and smaller diameter of sheaves and drum for Hoist 2, even though both hoists were meant to perform the same task.

5. Upcoming meeting of ISO TC 96 cranes:

In consideration of the erroneous effects that might occur when M-classes are used to design and select components Subcommittee SC10 (responsible for ISO 4301-1 and ISO 8686:2012 [4]) deleted the definition of M-classes in the revision of ISO 4301-1:2015. At the ISO TC 96 plenary meeting in Warsaw 2013 a resolution was agreed upon, that subcommittees SC3 (responsible for ISO 16625) and SC10 should develop the standard "Proof of competence of wire ropes" in a joint working group. Since in a subsequent ballot on a new work item the majority of votes was not achieved (result was 7:7) an intensive and controversial discussion during the 2014 plenary resulted only in a decision to have a full day meeting for presentation of arguments at the meeting in Sydney in September 2015.
The examples and arguments listed in this article are intended to make the sometimes emotional debate more factual and to contribute to receive support from the members of ISO/TC 96 to start a revision of ISO 16625 after the ISO meeting in 2015. This revision (preferably to be developed by a joint working group of SC3 and SC10) should align the selection of wire ropes to a rope bending based classification and should use a correctly determined rope tension force based on the load assumptions of ISO 8686 series.

Quoted standards:

FEM 1.001 (10.1998) "Rules for the design of hoisting appliances", Booklet 2