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	Rules for the Design of Storage and Retrieval Machines Mechanisms	07.1997 (E)

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1 Object and scope

These rules deal with the proper interpretation of safety relevant mechanisms in storage and retrieval machines. To determine a guaranteed theoretical life expectancy for travel and hoist drive units, the mechanisms shall be classified in appropriate groups.

2 Terms and definitions

Load lifted
The load lifted comprises the dead load and the pay or partial load.

Dead load
The dead load comprises the total mass (kg) of the lifting carriage and of its accessories, operator, resistance of the lifting carriage to motion and proportionate weight of the load carrying means (ropes, chains, etc.).

Pay load
The pay load comprises the maximum mass (kg) of the goods to be handled, load make-up accessory (e.g. pallet), packaging material and load safeguarding material (e.g. shrinking foil, etc.).

Dead mass (kg) of the storage and retrieval machines
Mass (kg) of a storage and retrieval machine without payload or partial load.

3 Classification of mechanisms according to operating conditions

The decisive operating conditions for storage and retrieval machines are:

- class of operating time and
- load spectrum

3.1 Class of operating time

The class of operating time indicates the average period per day during which a mechanism is in operation (see table 1). The total operating time in hours is determined by the ratio of the annual operating time to 250 working days per year. A mechanism is considered to be in operation when it is in motion.

The higher classes of operating time apply only in such cases where a mechanism is operated more than one shift per day.

Class of operating time	Average operating time per day in hours	Calculated total operating time in hours
V 1	≤ 2	3.200
V 2	≤ 4	6.300
V 3	≤ 8	12.500
V 4	≤ 16	25.000
V 5	> 16	50.000

Table 1: Class of operating time

3.2 Load spectrum

The load spectrum indicates to what extent a mechanism or part thereof is subject to maximum stress or whether it is subject to smaller loads only.

For an exact classification into groups, the cubic mean value k referred to the load to be lifted is required. Under the assumption that the life of the mechanism is inversely proportional to the third power of the load it is calculated by using the following formula:

$$k = \sqrt[3]{(\beta_1 + \gamma)^3 \cdot t_1 + (\beta_2 + \gamma)^3 \cdot t_2 + \ldots + \gamma^3 t_\Delta}$$

In the formula:

$$\beta_i = \frac{\text{Effect of pay or partial load}}{\text{Effect of permissible load}}$$

$$\gamma = \frac{\text{Effect of deadload}}{\text{Effect of permissible load}}$$

$$t_i = \frac{\text{Operating time under pay or partial load}}{\text{Total operating time}}$$

$$t_\Delta = \frac{\text{Operating time under deadload only}}{\text{Total operating time}}$$

Following FEM 9.511, four load spectra are distinguished. For storage and retrieval machines the load spectra listed in table 2 are used, which are determined by the definitions given and by the ranges covered by the cubic mean values k.

Load spectrum	Definitions	Cubic mean value
L 2 (medium)	Mechanisms or parts thereof, rather often subject to maximum loads, but usually to small loads	$0{,}50 < k \leq 0{,}63$
L 3 (heavy)	Mechanisms or parts thereof, often subject to maximum loads and usually to medium loads	$0{,}63 < k \leq 0{,}80$
L 4 (very heavy)	Mechanisms or parts thereof, usually subject to almost maximum loads	$0{,}80 < k \leq 1{,}00$

Table 2: Load spectrum

The limit values listed in table 2 for the cubic mean values of k can be calculated from the following ideal load spectra:

Load spectrum L 2 (medium)
Relation of deadload to payload $\gamma = 0,2$

1/6 of the operating time under maximum load = deadload + 1/1 payload

	$t_1 = 0,167$	$\beta_1 = (1 - \gamma) = 0,8$
1/6 of the operating time under deadload + 2/3 payload	$t_2 = 0,167$	$\beta_2 = 2/3\ (1 - \gamma) = 0,533$
1/6 of the operating time under deadload + 1/3 payload	$t_3 = 0,167$	$\beta_3 = 1/3\ (1 - \gamma) = 0,267$
1/2 of the operating time under deadload only	$t_\Delta = 0,5$	$\gamma = 0,20$

The result is:

$$k_2 = \sqrt[3]{(0{,}80 + 0{,}20)^3 \cdot 0{,}167 + (0{,}533 + 0{,}20)^3 \cdot 0{,}167 + (0{,}267 + 0{,}20)^3 \cdot 0{,}167 + 0{,}20^3 \cdot 0{,}5} \approx 0{,}63$$

Load spectrum L 3 (heavy)
Relation of deadload to permissible load $\gamma = 0,4$

50 % of the operating time under maximum load = deadload + 1/1 payload

	$t_1 = 0,5$	$\beta_1 = 1 - \gamma = 0,60$
50 % of the operating time under deadload only	$t_\Delta = 0,5$	$\gamma = 0,40$

The result is:

$$k_3 = \sqrt[3]{(0{,}60 + 0{,}40)^3 \cdot 0{,}5 + 0{,}40^3 \cdot 0{,}5} \approx 0{,}80$$

Load spectrum L 4 (very heavy)
Relation of deadload to permissible load $\gamma = 0,8$

90 % of the operating time under maximum load = deadload + 1/1 payload

	$t_1 = 0,9$	$\beta_1 = 1 - \gamma = 0,20$
10 % of the operating time under deadload only	$t_\Delta = 0,1$	$\gamma = 0,80$

The result is:

$$k_4 = \sqrt[3]{(0{,}20 + 0{,}80)^3 \cdot 0{,}9 + 0{,}80^3 \cdot 0{,}1} \approx 1{,}0$$

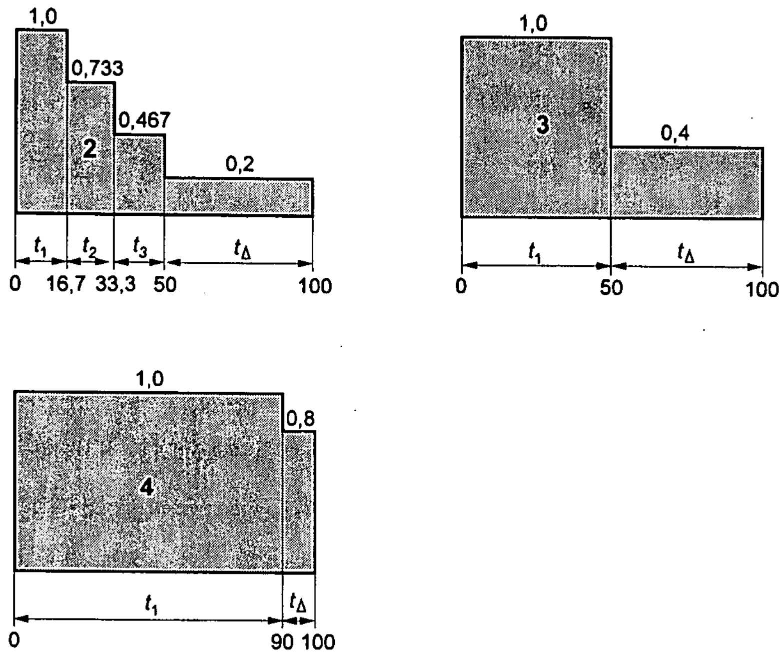

Figure 1

3.3 Classification of mechanisms

By applying the classes of operating times and the load spectra, the mechanisms are classed into 3 groups: 3_m, 4_m and 5_m, as shown in table 3.

Load spectrum	Cubic mean value	Class of operating time				
		V 1	V 2	V 3	V 4	V 5
		Mean operating time per day in hours				
		≤ 2	≤ 4	≤ 8	≤ 16	> 16
L 2	0,50 < k ≤ 0,63			3_m	4_m	5_m
L 3	0,63 < k ≤ 0,80		3_m	4_m	5_m	
L 4	0,80 < k ≤ 1,00	3_m	4_m	5_m		

Table 3: Classification of mechanisms into groups

The result of the classification of mechanisms into groups according to table 3 is that the same life, expressed in years, may be expected for these mechanisms under all load spectra and mean operating times per day.

Transition between the individual fields of the table is possible using the following basic rules:

- horizontal transition: for identical load spectra, the next highest mechanism group is selected by doubling the mean daily operating time.
- vertical transition: if a mechanism group is not available, a lower load spectra shall be achieved e.g. by reducing the rated load or operating time class.
- diagonal transition: for an identical mechanism group, the transition to a higher load spectrum implies a reduction of the class of operating time. For example, by transition to the next lowest load spectrum, the doubling of the mean operating time per day by maintaining the same group of mechanisms can be achieved (progression 1,25 since $1{,}25^3 \approx 2$).

NOTE: The load spectrum can be changed by the actual load being lower than the maximum load possible or by reducing the amount of time needed with maximum load.

4 Classification of hoist mechanisms

For hoist mechanisms the cubic mean value k_H is calculted by using the following formula:

$$k_H = \sqrt[3]{(\beta_{H1} + \gamma_H)^3 \cdot t_{H1} + (\beta_{H2} + \gamma_H)^3 \cdot t_{H2} + \ldots + \gamma_H^3 \, t_{H\Delta}}$$

where:

$$\beta_{Hi} = \frac{\text{Effect of pay or partial load}}{\text{Effect of dead load + payload}}$$

$$\gamma_H = \frac{\text{Effect of deadload}}{\text{Effect of dead load + payload}}$$

$$t_{Hi} = \frac{\text{Operating time under pay or partial load}}{\text{Total operating time}}$$

$$t_{H\Delta} = \frac{\text{Operating time under deadload only}}{\text{Total operating time}}$$

Example for the classification into groups of a hoist mechanism
A hoist mechanism, payload 1000 kg, for a storage and retrieval machine equipped with a telescopie load fork, is operated four hours daily without any interruption according to class of operating time V 2, table 1. For a deadload of 1600 kg (weight of the lifting carriage and of the telescopic fork) the following load spectrum applies:

65 % of the operating time with 1600 kg deadload and 1000 kg payload	t_{H1} = 0,65 β_{H1} = 1000/2600 = 0,385
35 % 0f the operating time with 1600 kg deadload (combined working cycle)	$t_{H\Delta}$ = 0,35 γ_H = 1600/2600 = 0,615

The cubic mean value would be

$$k_H = \sqrt[3]{(\beta_{H1} + \gamma_H)^3 \cdot t_{H1} + \gamma_H^3 \cdot t_{H\Delta}} \quad = \sqrt[3]{(0{,}385 + 0{,}615)^3 \cdot 0{,}65 + 0{,}615^3 \cdot 0{,}35} \quad = \quad 0{,}9$$

According to the k range in table 2 and 3 a load spectrum 4 (very heavy) applies. With the class of operating time V 2 the table 3 shows group of mechanisms 4_m.

For a payload of 1000 kg the hoist mechanism used shall at least satisfy the conditions of the group of mechanisms 4_m.

5 Travel mechanisms

The applicable load spectrum of a travel mechanism (or one of its components) is defined by the ratio of each partial load to the maximum load.

5.1 Load spectrum considering the payload influence

For the classification into groups the cubic mean value k_{F1} referred to the total weight of the storage and retrieval machine is required. It is calculated by using the following formula:

$$k_{F1} = \sqrt[3]{(\beta_{F1} + \gamma_F)^3 \cdot t_{F1} + (\beta_{F2} + \gamma_F)^3 \cdot t_{F2} + \ldots + \gamma_F^3 \, t_{F\Delta 1}}$$

where:

$$\beta_{Fi} = \frac{\text{Payload or partial load}}{\text{Deadweight of S / R machine + payload}}$$

$$\gamma_F = \frac{\text{S / R machine deadweight}}{\text{Deadweight of S / R machine + payload}}$$

$$t_{Fi} = \frac{\text{Operating time with payload or partial load}}{\text{Total operating time}}$$

$$t_{F\Delta 1} = \frac{\text{Operating time with deadweight of S / R machine only}}{\text{Total operating time}}$$

NOTE: Because of the ratio between payload and deadweight of the storage and retrieval machine the load spectrum value can be assumed as $k_{F1} \approx 1$.

5.2 Load spectrum considering the travel motion

Three types of load are defined for the travel mechanisms of storage and retrieval machines:

- accelerating periods
- periods at constant speed
- deceleration periods

For further calculation it is assumed with sufficient accuracy that the periods of acceleration and deceleration are identical and that during these periods the mechanisms are subject to identical loads.

Maintaining a motion at a constant speed subjects the mechanisms to relatively low stresses.

The period during which the machine travels at a constant speed is the sum total of the periods resulting from:

- Positioning speed,
- Average speed,
- Maximum speed.

The influence of the travel motion is taken into account by applying the cubic mean value k_{F2}, which is calculated as follows:

$$k_{F2} = \sqrt[3]{\alpha_1^{\,3} \cdot t_b + \alpha_2^{\,3} \cdot t_{F\Delta 2}}$$

where:

$$\alpha_1 = \frac{\text{Accelerating load}}{\text{Accelerating load + settled load}}$$

$$t_b = \frac{\text{Acceleration + deceleration period}}{\text{Overall travel period}}$$

$$\alpha_2 = \frac{\text{Settled load}}{\text{Accelerating load + settled load}}$$

$$t_{F\Delta 2} = \frac{\text{Operating period at constant speed}}{\text{Overall travel period}}$$

The overall travel period is the period during which the travel mechanism is in motion.

The settled load is the effect of the forces necessary to keep a constant velocity, eg. forces due to rolling friction, pull of the trailling cable, etc.

The settled load and the acceleration load are calculated for the storage and retrieval machine deadload + payload.

For calculation of the times the FEM 9.851 can be used.

5.3 Classification of travel mechanisms

The cubic mean values k_{F1} (payload influence) and k_{F2} (travel motion influence) determined above are combined into one total mean value

$$k_F = k_{F1} \cdot k_{F2}$$

For an exact classification of the travel mechanisms for storage and retrieval machines into groups the cubic mean value k_F is required, which determines together with the class of operating time (table 1) the classification of mechanisms according table 3.

Example for the classification of a travel mechanism into groups

On an storage and retrieval machine for a payload of 1600 kg (deadweight 10,700 kg) the travel mechanism is operated 8 hours daily, which corresponds to the class of operating time V 3 in table 1.

From an analysis of the average cycle period a value of t_b = 0.3 ($t_{F\Delta 2}$ = 0.7) results for the acceleration (deceleration) periods.

t_{F1} = 0,5 $t_{F\Delta 1}$ = 0,5

(The storage and retrieval machine is mainly used for single cycles.)

Load conditions are: α_1 = 0,9 α_2 = 0,2

$$k_{F1} = \sqrt[3]{(0{,}13 + 0{,}87)^3 \cdot 0{,}5 + 0{,}87^3 \cdot 0{,}5} \quad = \quad 0{,}94$$

$$k_{F2} = \sqrt[3]{0{,}9^3 \cdot 0{,}3 + 0{,}2^3 \cdot 0{,}7} \quad = \quad 0{,}61$$

$$k_F = 0{,}94 \cdot 0{,}61 \quad = \quad 0{,}57$$

In accordance with the k ranges listed in table 2 the load spectrum L 2 applies. With the class of operating time V 3 the table 3 shows group of mechanism 3_m.

Therefore, the travel machanism used must at least satisfy the conditions of group 3_m of mechanisms.

6 Life under Full Load

In a similar manner as for ball bearings, the required lifetimes under full load can be determined for the individual groups of mechanisms by applying the cubic mean values k_H (hoist mechanism) and k_F(travel mechanism)

$$L_h = k^3 \cdot T_G$$

where:
L_h lifetime under full load
k cubic mean value
T_G calculated overall operating period (see table 1)

Example:
Mechanism group 3_m for travel mechanism, class of operating time V 2:

$$L_{hF} \quad > \quad 0{,}63^3 \cdot 6300 \text{ hours} \quad = \quad 1600 \text{ hours}$$
$$L_{hF} \quad \leq \quad 0{,}80^3 \cdot 6300 \text{ hours} \quad = \quad 3200 \text{ hours}$$

Depending on the actual k_F value calculated, the life time under full load of the mechanism to be used must be between 800 and 1600 hours.

For instance, a required minimum life of the travel mechanisms under full load of

$$L_{hF} \quad = \quad 0{,}7^3 \cdot 6300 \text{ hours} \quad = \quad 2161 \text{ hours} \quad < \quad 3200 \text{ hours}$$

results from a calculated k_F value of 0.7, which corresponds to the group of mechnism 3_m.

The classification of the mechanisms according to table 3 shows an identical life expectancy in years for all groups. This applies on condition that the life of the individual components depends on the third power of the load.

When classified according to the 3 groups of mechanisms, the storage and retrieval machine mechanisms must have a minimum life as shown in table 4.

Group of mechanism	hours
3_m	3200
4_m	6300
5_m	12500

Table 4: Life of the storage and retrieval machine mechanisms under full load

The table 4 applies on condition that under full load forces or torques are understood as resulting from

a) deadload + payload in the case of hoist mechanisms according to clause 4

b) deadweight of storage and retrieval machine + payload in the case of travel mechanisms according to clause 5.1

c) settled load + acceleration load as effect of payload in the case of travel mechanisms according to clause 5.2

Quoted FEM-Documents

FEM 9.511 (06.1986)
Rules for the Design of Series Lifting Equipment; Classification of mechanisms

FEM 9.851 (08.1978)
Performance Data of storage and retrieval machines, Cycle times

Modifications

In comparison with the edition of 02.1978, the following modifications have been made:

a) Clauses 1 and 2 have been inserted as new clauses, clause 3 has been formulated in general terms. Clause 4 (old edition: 3.2) deals with hoist mechanismsm, clause 5 (old edition 3.3) with travel mechanism.

b) Clause 2 of the old edition has been left out.

c) Classes of operating time, load spectrum and classification into groups for hoist and travel mechanism have been combined. Classes of operating time V 0,12 - V 0,5, load spectrum L1 and mechanism groups 1_{dm} - 2_m have been deleted, since they are not relevant in praxis for storage and retrieval machines.

d) Examples have been adapted in accordance to the modified values.

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