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Guideline /

Rail dependent storage and retrieval systems – Consideration of accidental kinetic energy action in compliance with EN 528

Part 1, Pallet racking

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1 Introduction and aims

The Machinery Directive of the European Commission requires an evaluation of possible hazards and risks on the basis of which appropriate measures shall be taken to avoid or minimize the risks.

With regard to the operation of S/R Machines in a rack environment among others the following risk can be observed (for a full risk evaluation see EN 528:2008 at the time of publication of this Code).

The chance that a faulty operation will take place causing a hazardous situation while an automatic Storage and Retrieval (S/R) machine is moving in the rack down aisle (X-) direction is evaluated to be negligibly small, when complying with EN 528. Therefore such accidental load cases need not to be considered. This is for instance not the case in case for pallet racking, when the load handling device with telescopic forks is entering a rack compartment, with accelerating speed in cross aisle (Z-) direction. Or in case of shuttle racking when a shuttle is moving in rack down lane direction.

The velocity of the moving "object" can be of that magnitude (accelerations and velocities have been increased substantially in the last decade) that one has to consider the kinetic energy character with the need for absorption of that energy, when a collision is a possibility (as a result of the risk assessment). Energy absorption is possible by the rack structure, the S/R Machine and the stored goods being involved in the impact.
This is the basis for clause 5.6.3 in EN 528 : 2008, saying:

> *"**Limitation of forces***
>
> *The drive unit for extending the load handling devices shall be fitted with a friction clutch or other device to limit the drive force, and so minimise the risk of injury to persons and damage to the machine and associated storage equipment.*
>
> *The racking supplier shall be advised of the kinetic energy and additional forces to be able to calculate the resulting forces."*

Considering a "kinetic energy" action is not common practice in the design of steel structures. In case such an action has to be considered, e.g. in case of building columns in a warehouse with fork lift truck travel, an equivalent quasi-static impact force is specified. See EN 1991-1-7: 2006 – clause 4.4 ([1]).

When considering the list of potential hazards specified in EN 528, it is evident that a kinetic energy action due to a collision between a moving load handling device of the S/R Machine (loaded or unloaded) and rack structure or stored ULs in the rack, is a likely possibility. In order to determine from this collision impact an equivalent (quasi-static) collision force needed to design the equipment involved, it is necessary to have structural information from the S/R Machine and from the rack structure.
Activities have been undertaken to investigate this collision interaction between S/R Machine and rack structure with stored goods. An extensive analytical and experimental research project on this issue is performed at the TU München, resulting in the report: "Untersuchung von dynamischen Regalbelastungen" [2]).

The aim of this Code of Practice is to give a practical design approach for EN 528: 2008, clauses 4.1.1 and 5.6.3, based on the equivalence principle, which can be used until such time as an Addendum to EN 528: 2008 is published.

The recommendations given in this Code are based on the results of research (ref. [2]). However, it should be recognized that in order to give design rules suitable for use in engineering practice certain simplifications and approximations to the real situation are introduced. Consequently, this Code represents a reasonable approximation to actual behaviour but the peculiarities of particular applications may imply some inaccuracies. In case a more detailed consideration is deemed necessary, reference is made to [2], which describes a complex approach.
In Annex A a simplified method is given for the situation that due to the accidental collision the Unit Load is sliding over the supporting beams and hits the safety back stop.

An Excel sheet "Simplified model for collision force and the safety back stop" can be ordered with the Code to calculate the force imposed on the safety back stop for this situation. FEM provides the Excel-sheet for convenience only. FEM gives no warranty, express or implied, as to the accuracy, reliability and completeness of any information, formulae or calculation provided through the use of the model and does not accept any liability for loss or damage of whatsoever nature, which may be attributable to the reliance on and use of the model. Any Result must be subject to further detailed calculations. After purchase, the software can be downloaded from XXX . If the download fails – e.g. because of an internal firewall – please contact support to order a copy of the software. This service is subject to additional fees. To use the downloaded file, Microsoft Excel 97 (or above) is required. FEM provides the software as-is. FEM is not responsible for any modification, alteration or other changes by the user.

Finally it is recommended to consider application of, where possible, additional safety devices in order to minimize the potential kinetic energy impact and to achieve a cost effective solution.

2 Scope

The European Machinery Directive requires an evaluation of possible hazards and risks on the basis of which appropriate measures shall be taken to avoid or minimize the risks. For S/R Machines in a rack environment guidance is given by EN 528. The relevant hazard is given in EN 528:2008, 4.1.1.

This Code of Practice gives a practical design approach for pallet racking to comply with EN 528:2008 - clause 5.6.3. In particular by calculation methods for the resulting force from possible collision of a moving mass with other objects from the kinetic energy concerned, and only due to a possible faulty operation when the load handling device enters a rack compartment, causing a collision with a rack down aisle beam, an already placed Unit Load (UL) or the safety back stop. The kinetic energy has to be absorbed where a friction clutch or a “direct speed feedback” does not or insufficiently function, because the velocity is too high at the instant of the collision.

This Code also specifies the relevant deformation limitations to ensure continued safe support of the UL’s involved.

This code does not apply to devices for limiting possible horizontal movement of a UL due to manual picking operations.

3 Documents referred to

The following referenced documents are indispensible for the application of this document. For dated references only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 528:2008	Rail dependent storage and retrieval equipment – Safety requirements
EN 1990:2002	Eurocode – Basis of structural design
EN 1991-1-7:2006	Eurocode 1 – Actions on structures – Part 1-7: General actions – Accidental actions:
EN 15512:2009	Steel static storage systems – Adjustable pallet racking systems – Principles for structural design
EN 15629:2008	Steel static storage systems – The specification of storage equipment
prEN 16681:2013	Steel static storage systems – Adjustable pallet racking systems – Principles for seismic design
EN 15878	Steel static storage systems – Terms and definitions
FEM 9.223	Basic data and criteria for the construction of automated high bay warehouses with distribution systems
FEM 9.841 FEM 10.2.10	Storage systems with rail dependent storage and retrieval equipment - Interfaces
FEM 10.2.08:2011	Recommendations for the design of static steel pallet racking in seismic conditions

4 Abbreviations and definitions

For terms and definitions of steel static storage systems in general: see EN 15878. Some which are important for this Code are repeated.

4.1 Abbreviations

LHD	Load handling device
LMA	Load make-up accessory (e.g. pallet, box, tote)
S/R Machine	Storage and retrieval machine
UL	Unit load (LMA with load)
WMS	Warehouse Management System

4.2 Accidental action (see EN 1990)

Action, usually of short duration but of significant magnitude, that is unlikely to occur on a given structure during the design working life.

NOTE: In practical terms, a load case with an accidental action is analysed with a load factor of 1.0 and with the possibility of residual deformations after unloading.

4.3 Axis

x- axis = Down aisle direction
y- axis = Vertical direction
z- axis = Cross aisle direction

4.4 Quasi-static force (see EN 1990)

Dynamic force represented by an equivalent static force in a static model

4.5 Safety backstop (see EN 15629)

Component used to prevent unintentional UL movement or accidental collision of a moving object with other ULs or equipment when the UL is placed or removed from its storage location.

Type (a) safety device, which protects against unintentional load movement within the racking and prevents ULs from protruding into or falling into an operating aisle or from falling into an area accessible to people, when the UL is placed or removed from its storage location.

Type (b) safety device to prevent accidental damage, usually placed at the back of a storage compartment, to prevent the accidental collision of a UL (e.g. pallet with load) or of the telescopic fork tips with other equipment, such as sprinklers, when a UL is placed in the storage compartment.

NOTE 1: Type (a) is the type where EN 528 speaks of (physical) back stop

NOTE 2: In this Code, as well as in FEM 9.841 / FEM 10.2.10, the term “safety back stop” is used instead of “back stop” to make a difference with a “buffer back stop”, which is a component used as an aid for forklift truck drivers to deposit the UL in the correct position in the racking

NOTE 3: The horizontal clearance between a UL adjacent to a safety backstop should be sufficient to prevent any colliding during daily depositing operations. See also EN 528: 2008, Clause. 5.10.1.

4.6 Shuttle as load handling device

Electrically-powered machine, operated from a S/R Machine or other specific handling equipment, and used to store ULs in depth (z direction) within special lanes.

4.7 Specified load (see EN 528)

Load with specified characteristics (e.g. mass, dimensions with their tolerances, pallet or container, quality, packaging, etc.) which the machine has been designed to carry and the storage system has been designed to operate.

4.8 S/R Machine

All kinds of machines from fully automated to manually operated and restricted to the rails on which they travel, which embody lifting means, for storage and retrieval ULs. (see also EN 528, Scope).

4.9 System designer (SD) / Planner (FEM 9.223)

The person or institution responsible for the overall design and functionality of the system, this can be the logistic consultant or the general contractor or the client himself and shall be defined on a project by project basis.

NOTE: For more information and responsibilities see FEM 9.223.

4.10 Unit load (UL)

See specified load.

5 Symbols

$F_{Initial\ impact}$	the resulting quasi-static force applied by the S/R machine at the instant of collision (see Annex A).
F_{BS}	quasi-static collision force due to $F_{Initial\ impact}$ between the UL and the back stop
F_{Drive}	maximum quasi-static force induced by the drive unit
$F_{DF,beam}$	dynamic friction force between the moving UL in the rack and the supporting beams
F_{col} =	quasi static force due to $F_{Initial\ impact}$ acting on a rack component.
$F_{SF,beam}$	static friction force between the UL in the rack and the supporting beams
F_{beam}	quasi-static collision force to one beam
E_{Drive}	energy resulting from the force of the drive unit
$E_{kin;d}$	the kinetic energy action to be considered in the design as specified by the System Designer in cooperation with the S/R machine supplier
γ_F	partial safety factor

For the “simplified method” given in annex A, the symbols are defined in that Annex.

6 Possible hazardous situations with regard to a possible Kinetic Energy action (incomplete and for example)

6.1 Hazardous situations to consider in a project

The system designer in cooperation with the supplier of the S/R machine is responsible for the specification of the hazardous situations to be considered for a specific project. This clause gives guidance.

6.2 Prevention

Prevention of possible hazardous situations is a priority. An example of a situation which will cause hazardous situations are pallets of insufficient quality. Therefore the installation of a pallet quality control system at the entrance of a storage system is recommended to limit the risk of handling LMAs with not allowed damage (e.g. pallets with broken or bended lower timber boards).

NOTE: Solutions to detect LMAs of insufficient quality are only effective in case refusal of such pallets is accepted by the end user. In case this is not acceptable an alternative is to use slave LMAs (see figure 6.2).

6.3 Single deep storage and first pallet position for double deep storage for pallet racking

The S/R machine might position incorrectly or is not able to detect the mismatch or fault, without a warning signal to the WMS, for example due to:

1. wrong calibration of the measuring sensor or a fault of this sensor (e.g. laser, encoder with toothed belt drive, encoder with pull rope)

2. “abuse” of camera or sensor position, e.g. by unintentional stepping on it or hitting it during maintenance or between the maintenance intervals during operation.

The following accidental situations shall be considered due to the in Z-direction moving load handling device:

1. Hitting the front of an already stored UL.

   For single deep storage the speed at the instant of impact is relatively small and therefore the possible load case with a kinetic energy action need not to be considered.

2. Hitting the load make up accessories which is deflected too much or broken with maximum velocity in z - direction by the moving load handling device (see figure 6.1). If possible such situation shall be prevented (see 6.1).
   In this case the velocity of the load handling device is in general of that magnitude that the kinetic energy action has to be considered

3. Hitting the safety back stop with an already stored UL, when this UL slides over its supports due to ta collision described above. This is not possible in case of double deep storage with staggered beam principle (see figure 6.2).

The worst case position with regard to the collision force shall be considered for each element: The pair of beams, beam to upright connection, safety back stop and upright frame.

6.4 Double deep storage for pallet racking

The S/R machine might position incorrectly or is not able to detect the mismatch or fault, without a warning signal to the WMS, for example due to:

1. wrong calibration of the measuring sensor or a fault of this sensor (e.g. laser, encoder with toothed belt drive, encoder with pull rope)
2. "abuse" of camera or sensor position, e.g. by unintentional stepping on it or hitting it during maintenance or between the maintenance intervals during operation;
3. the necessity for the S/R machine supplier to set the nominal position of the telescopic fork somewhat lower compared to the single deep situation, to minimize the risk of hitting the deflected pallet at the 2nd deep position.
   As a consequence the chance is higher to hit the 3rd beam, compared to the chance of hitting a UL when picking from its single deep rack position.

In all such cases it is possible that a third beam or a stored UL at the 2nd deep position can be hit by the moving load handling device, with maximum velocity in z - direction. Therefore in case of double deep pallet racking, the following situations shall be considered:

1. Hitting the 3rd beam (see figure 10.1-c) by an unloaded LHD, in case of a staggered beam principle.
2. Hitting the front of an already stored UL (see figure 10.1-a2).
3. Hitting the load make up accessories of the second deep position which is deflected too much or broken. The use of for instance shims / fork spacers, top hats or "slave" pallets (see figure 6.2) might prevent this.
4. Hitting the safety back stop by an already stored UL, when this UL slides over its supports due to collision possibility (2) mentioned above.

The worst case position with regard to the collision force shall be considered for each element: 3rd beam, connection 3rd beam to upright, safety back stop and upright frame.
In all these cases the velocity of the load handling device is in general of that magnitude that the kinetic energy action has to be considered, apart from hitting the front of a UL in 1st deep position