Car Deceleration During Buffering Process of Lifts

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Abstract. Buffers at lifts comprise a certain design. This design and the resulting buffer properties have to cover the different modes of operation. For lift buffers this means the coverage of varying car masses at the specified speed. The paper shows the basic characteristics of hydraulic buffers. Following this, a sketch of the requirements for buffers according to EN 81-20 is given. A software for the detailed simulation of buffer collisions is presented. In the main part of the paper, this software is used to calculate and analyze two cases of buffer collisions at maximum and minimum loading each. The results of these simulations are shown and discussed in brief.

1 INTRODUCTION

Hydraulic buffers seem to be standard equipment for lifts. In case of main deceleration equipment failure, they are used as a final means for the limitation of car decelerations and the restriction of impact loads on structures and passengers during processes of kinetic energy reduction at the end stop. This is realized by a certain buffer force acting along the stroke of the buffer. The product of buffer force and stroke results in the energy being dissipated during a buffering process.

The controlled and restricted buffer force is a result of the load mass, the load speed and the buffer stroke chosen. In order to gain a suitable buffer capacity, the maximum values of mass and speed are considered first. Nevertheless, the consideration of less mass and/or less speed may be relevant. Less mass leads to higher decelerations especially. These decelerations have to meet the requirements of standard EN 81-20; this paper refers to the German implementation of EN 81-20:2020 [1].

The paper shows the effects of two certain lift buffer examples on the basis of tests by simulation. The buffer designs under consideration of maximum load and minimum load are viewed in comparison to evaluate the system set-up with regard to the standard requirements.

2 HYDRAULIC BUFFER CHARACTERISTICS

Hydraulic buffers work according to a simple principle. A moving piston presses hydraulic fluid through a throttle. The pressure drop at the throttle $\Delta p_{Throttle}$ contributes to fluid pressure p and an according buffer force F_b. The buffer force F_b is used to decelerate a mass m with its initial kinetic energy W_{kin} and its driving force F_d. A lift car mass at the shaft limit stop e.g. For a first approach the buffer force F_b may be assumed to be constant against the piston rod position s. As the product of constant buffer force $F_{b,const}$ and stroke s_{stroke} in this case equals the energy dissipated W_{diss}, there are different design options for the buffer. A higher buffer force F_b in combination with a smaller stroke s_{stroke} may give the same energy dissipated W_{diss} as a lower buffer F_b force in combination with a larger stroke s_{stroke}. The choice of combination has a significant impact on the buffer force F_b, the buffer stroke s_{stroke} and the buffer geometric properties as total buffer length in relaxed conditions (Fig. 1).

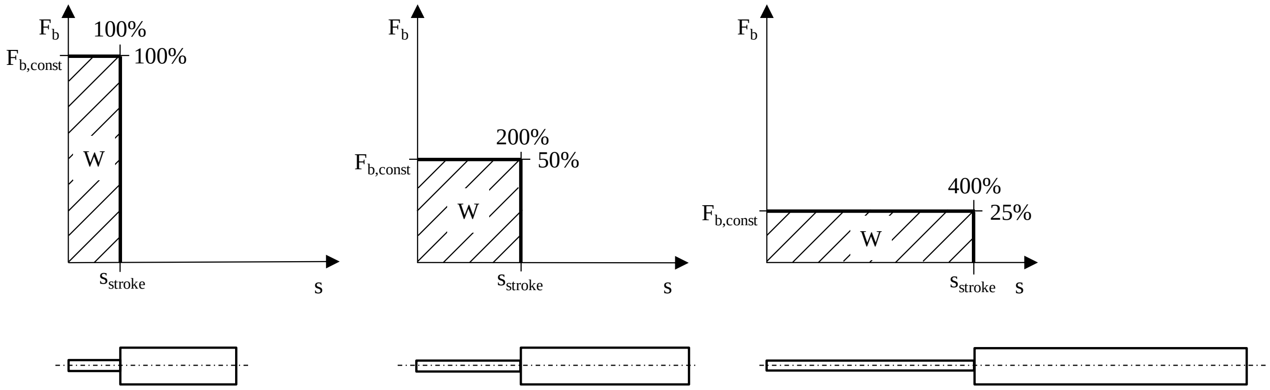


Figure 1 Buffer forces and buffer lengths at constant energy dissipated

Although intended, the buffer curve is not rectangular in practice, as shown with the dashed line (Fig. 2). The buffer force F_b is not constant. The slopes of the buffer curve at the beginning and the end of the buffer curve are not infinite. As the dissipated energy W_{diss} has to be covered and the stroke s_{stroke} is a constant, this results in a maximum buffer force $F_{b,max}$ well above the constant buffer force $F_{b,const}$. $F_{b,max} > F_{b,const}$. The relation of the maximum buffer force $F_{b,max}$ to the constant buffer force $F_{b,const}$ is indicated by parameter k. Parameter k corresponds at cranes with the relative buffer energy ξ according to DIN EN 13001-1:2022-10 [2] as $\xi = 1/k$.

$$W = \int_0^{s_{stroke}} F\,ds = F_{b,const} \cdot s_{stroke} \tag{1}$$

$$F_{b,max} = k\frac{W}{s_{stroke}} = k \cdot F_{b,const} \tag{2}$$

with

$$k > 1 \tag{3}$$

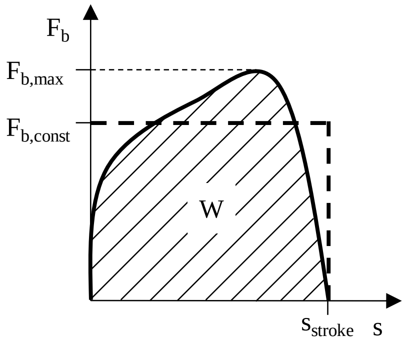


Figure 2 Theoretical vs. practical buffer characteristics

For several simple buffer types, a non-constant buffer force is typical. Metallic springs or cellulose buffers show a parameter k well above one. At cranes DIN EN 13001-1:2022-10 shows values of $\xi = 0.5$ which corresponds to $k = 2.0$. This leads to a high maximum buffer force $F_{b,max}$. Hydraulic buffers are designed to reach a parameter k just slightly above one. For a certain stroke s_{stroke} and a certain maximum buffer force $F_{b,max}$ they are close to absorbing the maximum energy E possible. In comparison to other buffer types, hydraulic buffers absorb certain energy at a minimum buffer force. This leads to a positive impact on static and cyclic system requirements. On the other hand, due to their characteristics, hydraulic buffers induce a non-optimal overshooting behaviour of the system. But this aspect is not in focus now.

3 REQUIREMENTS ACCORDING TO EN 81-20

Lifts have to meet safety requirements. This includes requirements on buffers in lifts. The main standard on requirements for lifts is EN 81-20: “Safety rules for the construction and installation of lifts - Lifts for the transport of persons and goods, Part 20: Passenger and goods passenger lifts”; German version EN 81-20:2020.

Chapter 5 “Safety requirements and/or protective measures”, 5.8 “Buffers” lists diverse requirements. Some relevant parts for hydraulic buffers, so-called energy-dissipating buffers, are listed in brief form:

- 5.8.1.1: Lifts must have buffers at the bottom end of the car and counterweight tracks.
- 5.8.1.6: Energy-dissipating buffers may be used in all lifts, regardless of the rated speed.
- 5.8.1.8: Indication of the manufacturer, type approval number, type of buffer, and type of hydraulic fluid at the buffer.

For energy-dissipating buffers, more details are given in 5.8.2 “Stroke of buffers at car and counterweight”, 5.8.2.2 “Energy-dissipating buffers”:

- 5.8.2.2.1: Available stroke of buffer at least $0.067 \cdot v^2$, so called gravity stopping distance at $115\% \cdot v$.
- 5.8.2.2.2: Reduced speeds at implemented deceleration control circuit.
- 5.8.2.2.3: Average deceleration $a_{avrg} < 1.0 \cdot g$ at $115\% \cdot v$, Maximum time span at higher deceleration Δt $(a > 2.5 \cdot g) < 0.04s$. No remaining deformations.
- 5.8.2.2.4: Returning to the operating position must be monitored by a safety device.
- 5.8.2.2.5: Oil level check possible easily.

Requirements on tests before commissioning are given in 6 “Proof of compliance with requirements and/or protective measures”, 6.3 “Tests before initial commissioning”, 6.3.7 “Buffers”: Energy-dissipating buffers: No damages at buffer at test with nominal load at nominal speed.

The requirements on the available stroke s_{avl} and the average deceleration a_{avrg} coincide more or less. At the stopping process, the constant deceleration equals $a = g = const.$ As the deceleration is constant, the average deceleration $a_{avrg} = g$ in this case is just at the required limit $a_{avrg} < 1.0 \cdot g$. The gravity stopping distance s_{jh} equals:

$$s_{jh} = \frac{(115\% \cdot v)^2}{2 \cdot g} = 0.067 \cdot (115\% \cdot v)^2 \tag{4}$$

The requirement concerning the retardation of more than $a = 2.5 \cdot g$ lasting longer than $\Delta t = 0.04s$ is about limiting the jerk applied to the car and passengers. To make this jerk possible, a minimum car speed v_{min} must exist (Fig. 3):

$$v_{min} = 2.5 \cdot \mathrm{g} \cdot \Delta\mathrm{t} = 0.981\, m/s \approx 1 m/s \tag{5}$$

At this minimum car speed v_{min}, action of the jerk requires a minimum distance s_{min} for braking down:

$$s_{min} = (v_{min} - 1.25 \cdot \mathrm{g} \cdot \Delta\mathrm{t})\Delta\mathrm{t} = 19.6 mm \tag{6}$$

At higher car speed v, the distances s will be at a significantly higher level.

Requirements on test equipment given in EN 81-50: “Safety rules for the construction and installation of lifts - Examinations and tests”, Part 50: “Design rules, calculations, examinations and tests of lift components”; German version EN 81-50:2020, 5 “Design rules, calculations and tests”, 5.1 “General regulations for type approval of safety parts”, 5.1.2 “General regulations”, 5.1.2.6: Measuring devices must recognize processes changing within a time span of 0.01s. This rather weak requirement in fact makes the requirement on the jerk stricter, as the limit deceleration can only be exceeded at two measuring points at the minimum measuring frequency.

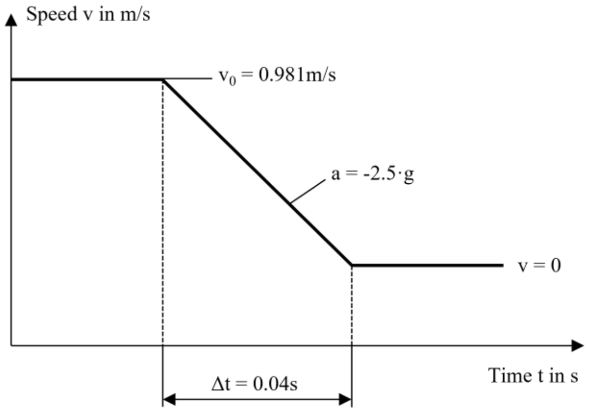


Figure 3 Virtual minimum car speed

Requirements on type approval tests are given in 5 “Design rules, calculations and tests”, 5.5 “Type approval for buffers”, 5.5.3 “Testing”, 5.5.3.1 “Energy-dissipating buffers”, 5.5.3.1.6 “Tests”, 5.5.3.1.6.1 “Test of deceleration”: At tests with minimum mass and maximum mass the decelerations must meet the requirements of EN 81-20, 5.8.2.2.3 (see above).

4 SIMULATION TOOL

The requirements of EN 81-20 consider the time behaviour at buffer shock in detail. Especially the requirement on the maximum temporary deceleration $\Delta t\ (a > 2.5 \cdot g) < 0.04s$ can be proofed by detailed analysis only. Such analysis requires detailed knowledge of deceleration-time-behaviour at the millisecond-level, and better sub-millisecond-level during engineering design and testing. To reduce hardware optimization cycles during product development it seems target leading to apply suitable virtual analysis methods during engineering design already. For conducting tests by simulation, the software “BSC - Buffer Selection and Calculation” was developed. The tool describes a certain buffer application via GUI (Fig. 4), simulates the process of buffer shock in detail and reports the critical process parameters as the maximum deceleration e.g. via GUI and pdf-printout. Among others, the simulation includes the following physical effects:

- Inertia of impact mass, described by mass m.
- Friction of hydraulic fluid, described by pressure loss coefficient ζ.
- Friction of sealings, described by an overall efficiency η of the buffer.
- Elasticity of compressive spring, described by stiffness c.
- Elasticity of compressive gas, described by the polytropic exponent n.

Furthermore, the tool offers options such as buffer selection from a catalogue, restriction of buffer force, restriction of deceleration, modification of characteristics, consideration of various discrete throttle characteristics and collision of two cars including two buffers. The last aspect is relevant for consideration of the collision of cranes.

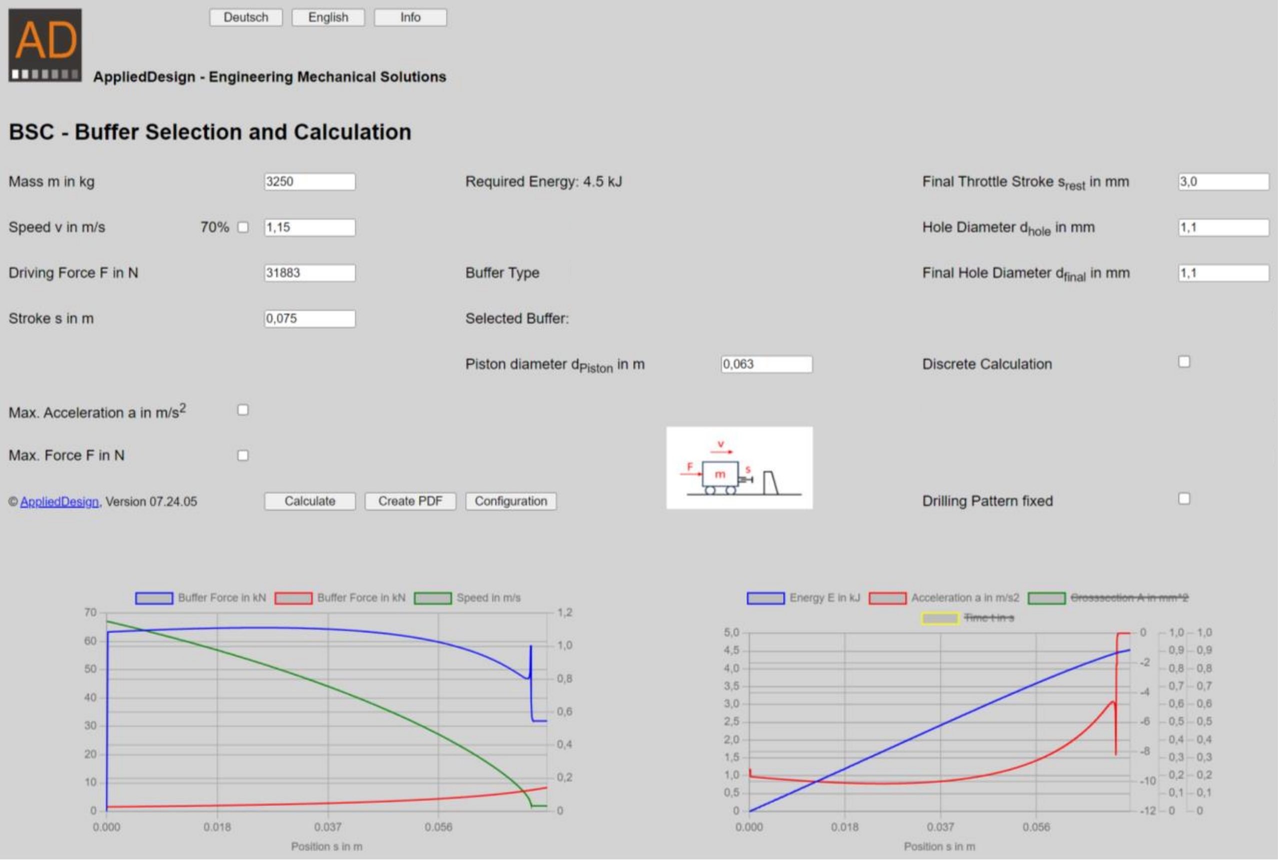
5 EXAMPLE OF A BUFFER AT LOWER CAR SPEED

The buffer collision of a lift car is considered as a first example. The car including maximum load with mass m_{max} = 3,250kg travels at a nominal speed of v_{nom} = 1.0 m/s. Due to gravitation, this leads to a driving force of about F_d = 31,883N acting onto the car. According to the standard, the impact speed to be considered equals $v_{115\%}$ = 1.15m/s. Further data are piston diameter d = 63mm and stroke s_{stroke} = 75mm. This stroke fulfils the requirement on the available stroke $s_{avl} = 0.5 \cdot v^2/g$ = 67.4mm.

$s_{stroke} > s_{avl}$. The data assumed is comparable to typical lift buffers available on the market for nominal speeds of $v_{nom} = 1.0$ m/s.

The target of the buffer design is a constant buffer force F_b leading to a constant deceleration a and a linear decrease of speed v over time t. The forecast due to simulation shows a slightly different behaviour (Fig. 4). The buffer force F_b shows a slight hump and gets constant at a lower level at the end of the stroke. The hump is caused by the fact that the designed throttle does not fit to the throttle required in theory perfectly. The constant buffer force F_b at the end of the stroke is caused by the final throttle A_{final}. The final throttle A_{final} is a constant throttle cross-section active until the very end of the stroke. The final throttle A_{final} in combination with the very low speed v results in a constant buffer force F_b, about equal to the external driving force F_d. Due to the driving force F_d the piston is driven across almost the complete stroke s_{stroke}. The buffer force peak at transfer to the final throttle may be removed by detailed buffer design. As the buffer force F_b is not perfectly constant, the deceleration a is not as well. The deceleration a depends on the buffer force F_b and shows similar characteristics. This slight non-constant behaviour of deceleration a cannot be seen in the speed v. Mathematically, speed v is the integral of deceleration a which leads to a smoothening effect. The speed v decreases as intended and adopts the final constant level at the final throttle A_{final}. The energy dissipated E_{diss} consists of two parts. The kinetic energy of the car E_{kin} and the potential energy E_{pot} of the car at piston distance zero s = 0. The potential energy dissipated E_{pot} grows linearly along the stroke. The kinetic energy dissipated E_{kin} grows with a slightly decreasing slope along the stroke, as it depends on the speed v. As the total kinetic energy dissipated E_{kin} and the total potential energy dissipated E_{pot} have about the same amount and occur along the stroke, the energy dissipated E_{diss} shows slightly decreasing characteristics along the stroke (Fig. 4).

Simulation of a buffer shock with this data results in an average deceleration of $a_{avrg} = 9.5\text{m/s}^2$ and a maximum deceleration of $a_{max} = 10.5\text{m/s}^2$ (Fig. 4). Parameter k equals k = 1.11. The requirements are met as the average deceleration $a_{avrg} = 9.5\text{m/s}^2 < 1.0 \cdot g$ and the maximum deceleration $a_{max} = 10.5\text{m/s}^2 < 2.5 \cdot g$. The jerk requirement is already met, as no higher decelerations occur.



BSC - Buffer Selection and Calculation

Mass m in kg: 3250
Speed v in m/s: 70% ☐ 1,15
Driving Force F in N: 31883
Stroke s in m: 0,075
Max. Acceleration a in m/s^2 ☐
Max. Force F in N ☐
Required Energy: 4.5 kJ
Buffer Type
Selected Buffer:
Piston diameter d_{Piston} in m: 0,063
Final Throttle Stroke s_{rest} in mm: 3,0
Hole Diameter d_{hole} in mm: 1,1
Final Hole Diameter d_{final} in mm: 1,1
Discrete Calculation ☐
Drilling Pattern fixed ☐

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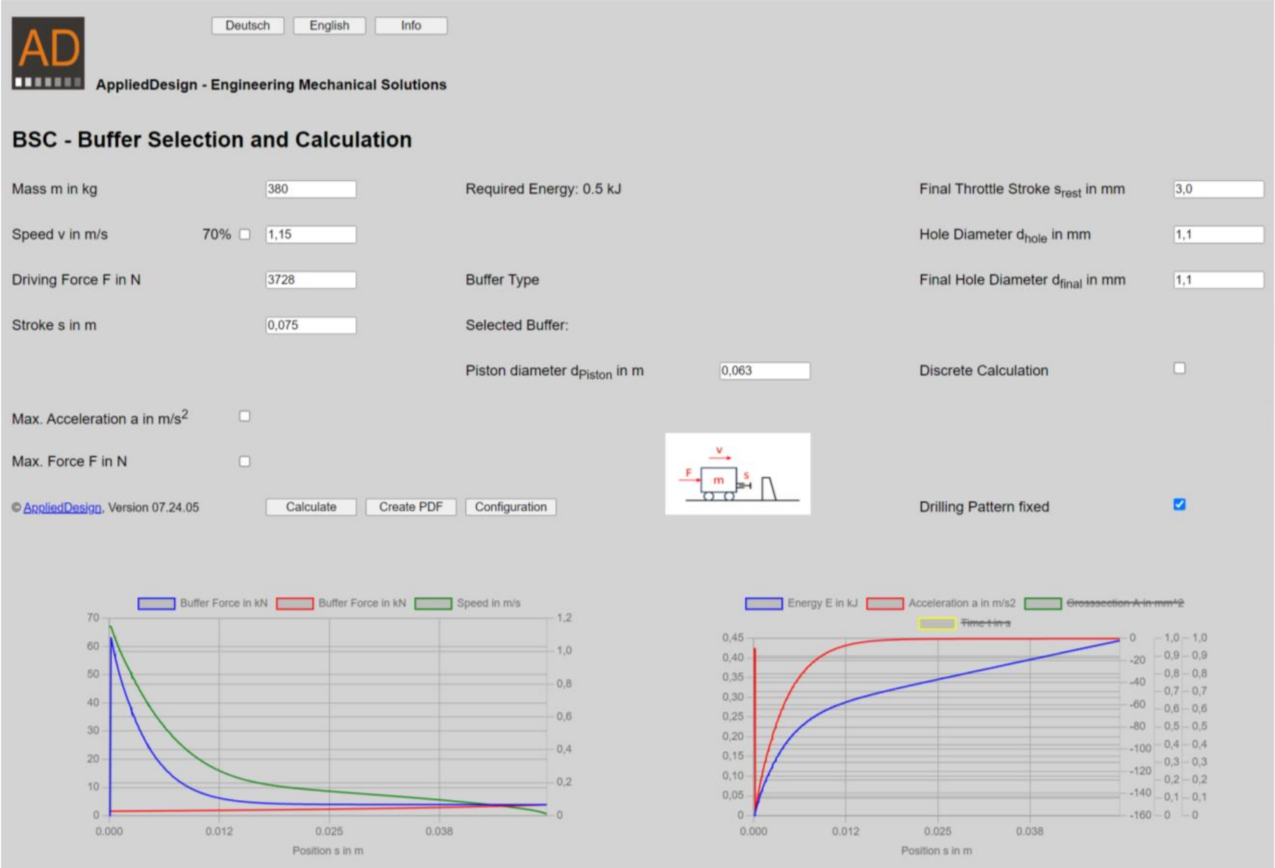
Figure 4 Buffer shock at lower car speed with maximum load

The car including minimum load with mass m_{min} = 380kg travels at the same nominal speed of v_{nom} = 1.0m/s. This leads to a driving force of about F_d = 3,728N and according to the standard an impact speed of $v_{115\%}$ = 1.15m/s.

Fig. 5 shows the resulting data for the simulation of this case. The initial buffer force F_b just depends on the buffer design itself and the impact speed v. These data are the same as in the maximum load case considered. The initial buffer force F_b is the same for the maximum load m_{max} and the minimum load m_{min}. No effect of deceleration a occurred so far. At maximum load m_{max} the buffer force F_b stays more or less constant along the stroke, and at minimum load m_{min} the buffer force F_b decreases immediately after the first impact. This happens according to the high deceleration a of the small load m_{min}. At smaller loads, the whole buffering process will take more time. At the minimum load m_{min} the initial buffer force F_b equals the maximum buffer force $F_{b,max}$. At maximum load m_{max} the maximum buffer force $F_{b,max}$ is somewhat higher than the initial buffer force F_b. This is a result of the specific buffer characteristics. In a first approach, the maximum buffer force $F_{b,max}$ may be considered of the same height as the initial buffer force anyway. At minimum load m_{min} the initial buffer force F_b equals the maximum buffer force $F_{b,max}$ exactly. The total kinetic energy dissipated E_{kin} and the total potential energy dissipated E_{pot} are about the same amount. But now the main amount of the kinetic energy E_{kin} is dissipated at the beginning of the stroke. Hence the energy dissipated E_{diss} shows fast growth at the beginning of the stroke and a moderate increase along the stroke (Fig. 5).



BSC - Buffer Selection and Calculation

Mass m in kg 380

Speed v in m/s 70% ☐ 1,15

Driving Force F in N 3728

Stroke s in m 0,075

Required Energy: 0.5 kJ

Buffer Type

Selected Buffer:

Piston diameter d_{Piston} in m 0,063

Max. Acceleration a in m/s² ☐

Max. Force F in N ☐

Final Throttle Stroke s_{rest} in mm 3,0

Hole Diameter d_{hole} in mm 1,1

Final Hole Diameter d_{final} in mm 1,1

Discrete Calculation ☐

Drilling Pattern fixed ☑

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Figure 5 Buffer shock at lower car speed with minimum load

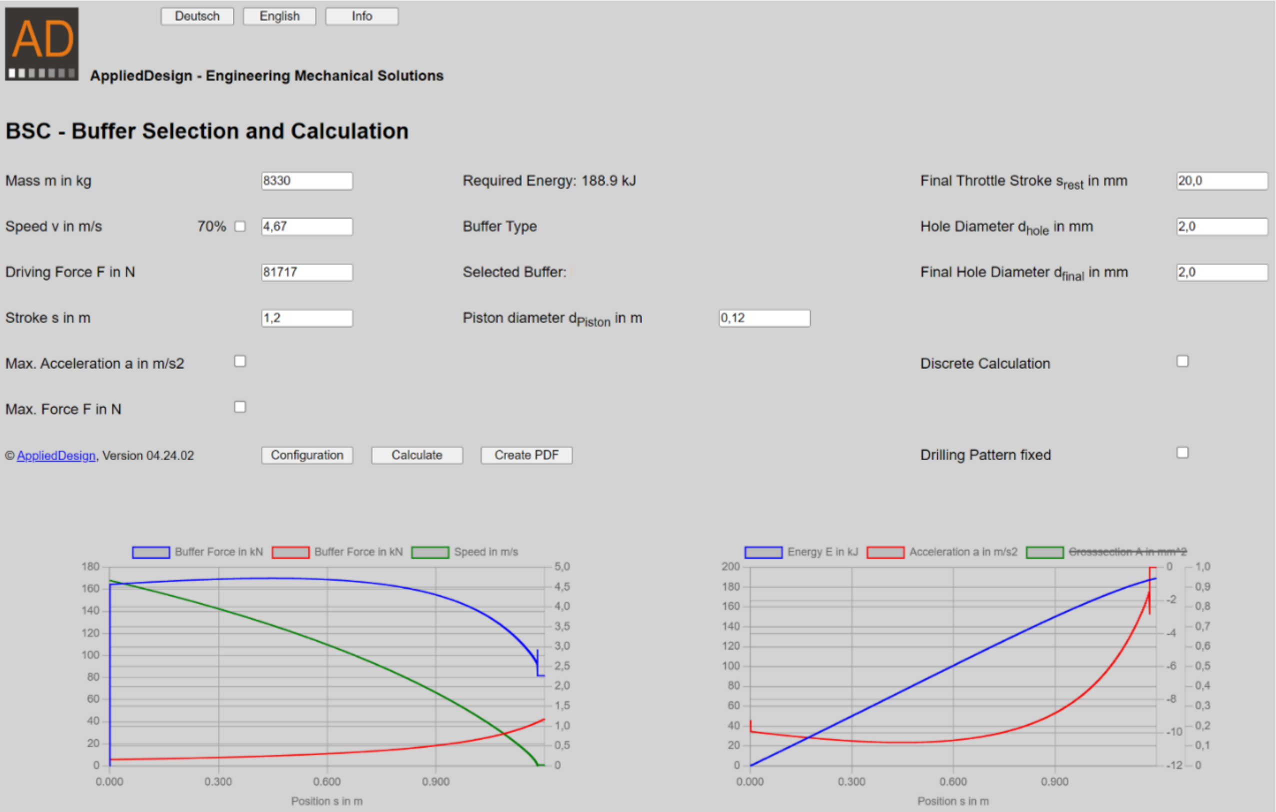
This data results in an average deceleration of a_{avrg} = 9.5m/s^2 and a maximum deceleration of a_{max} = 157.5m/s^2 = 16.1·g (Fig. 5). Parameter k equals k = 16.58. As the impact speed v and the throttle cross section are the same as at high mass m_{max}, the lower mass experiences a quite high deceleration a at the beginning of the buffering process. The requirements are met with regard to the average deceleration $a_{avrg} = 9.5 m/s^2 < 1.0 \cdot g$. The average deceleration a_{avrg} is at a low level, as after a short phase of high deceleration a long phase of low deceleration occurs. As decelerations $a > 2.5 \cdot g$ occur, the condition $\Delta t\ (a > 2.5 \cdot g) < 0.04s$ has to be proven. Analysis of the data gained by simulation delivers $\Delta t\ (a > 2.5 \cdot g) = 0.011s$, so the requirement is met.

The example simulated comprises a speed of $v_{115\%} = 1.15m/s$, a speed just a small amount above the minimum speed $v_{min} \approx 1m/s$ necessary to create the limit jerk. This explains the difficulty in this case, not meeting the requirement $\Delta t\ (a > 2.5 \cdot g) < 0.04s$. Quite high decelerations $a_{max} = 157.5m/s^2 = 16.1 \cdot g$ occur, but over a relatively small period $\Delta t\ (a > 2.5 \cdot g) = 0.011s$.

6 EXAMPLE OF A BUFFER AT HIGHER CAR SPEED

Now a second buffer collision of another lift car is considered. The car including maximum load with mass $m_{max} = 8{,}330kg$ travels at a nominal speed of $v_{nom} = 4.06$ m/s. Due to gravitation, this leads to a driving force of about $F_d = 81{,}717N$ acting onto the car. According to the standard, the impact speed equals $v_{115\%} = 4.67m/s$. Further data are piston diameter $d = 120mm$ and stroke $s_{troke} = 1{,}200mm$. This stroke fulfils the requirement on the available stroke $s_{avl} = 0.5 \cdot v^2/g = 1{,}111.6mm$. The assumed data is comparable to typical lift buffers available on the market for nominal speeds of about $v_{nom} = 4.0$ m/s.

Simulation of a buffer shock with this data results in an average deceleration of $a_{avrg} = 9.24m/s^2$ and a maximum deceleration of $a_{max} = 10.59m/s^2$ (Fig. 6). Parameter k equals $k = 1.15$. The requirements are met as the average deceleration $a_{avrg} = 9.24m/s^2 < 1.0 \cdot g$ and the maximum deceleration $a_{max} = 10.59m/s^2 < 2.5 \cdot g$. The jerk requirement is met, as no higher decelerations occur.



BSC - Buffer Selection and Calculation

Mass m in kg: 8330
Speed v in m/s: 70% ☐ 4,67
Driving Force F in N: 81717
Stroke s in m: 1,2
Max. Acceleration a in m/s2 ☐
Max. Force F in N ☐
Required Energy: 188.9 kJ
Buffer Type
Selected Buffer:
Piston diameter d_{Piston} in m: 0,12
Final Throttle Stroke s_{rest} in mm: 20,0
Hole Diameter d_{hole} in mm: 2,0
Final Hole Diameter d_{final} in mm: 2,0
Discrete Calculation ☐
Drilling Pattern fixed ☐

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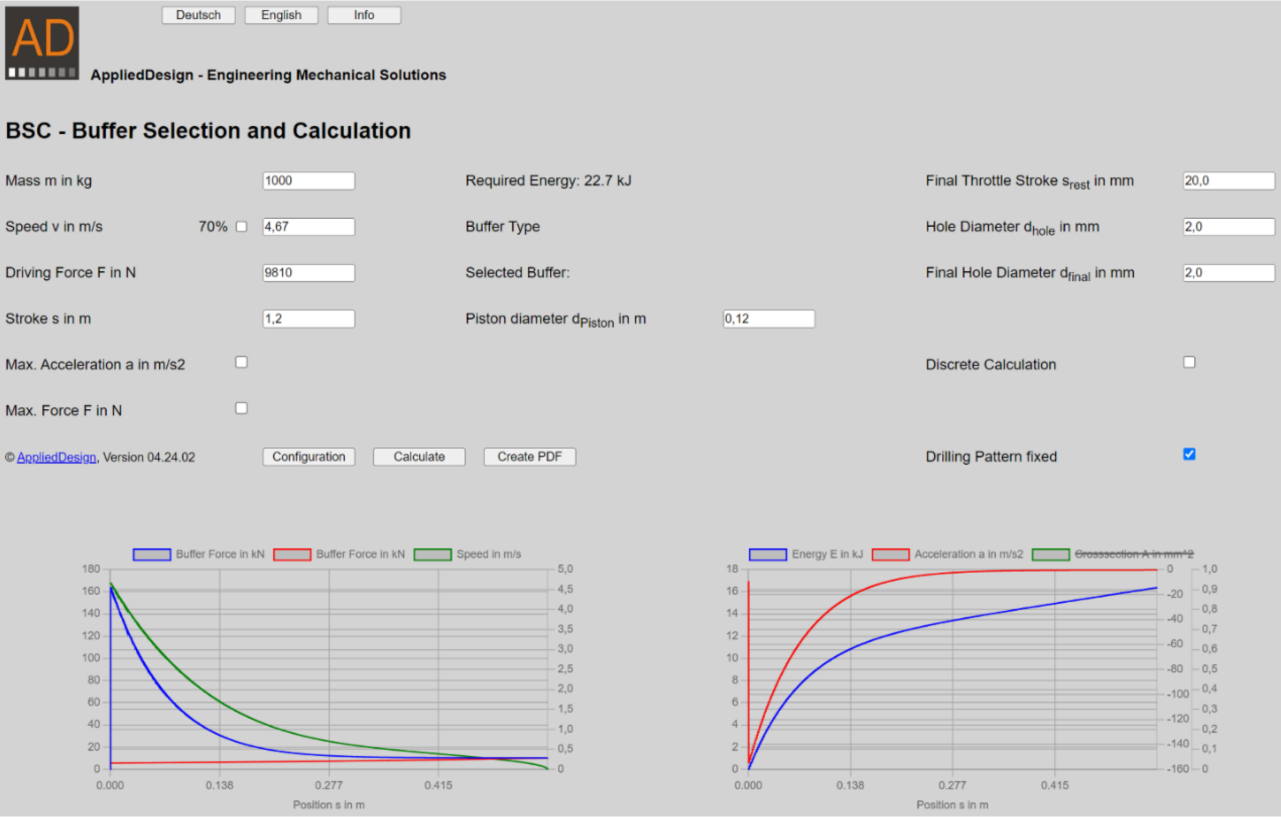
Figure 6 Buffer shock at higher car speed with maximum load

Now the car including minimum load with mass $m_{min} = 1{,}000kg$ travels at the same nominal speed of $v_{nom} = 4.06m/s$. This leads to a driving force of $F_d = 9{,}810N$ and, according to the standard, an impact speed of $v_{115\%} = 4.67m/s$. This data results in an average deceleration of $a_{avrg} = 9.24m/s^2$ and a maximum deceleration of $a_{max} = 154.55 m/s^2 = 15.8 \cdot g$ (Fig. 7). Parameter k equals k = 16.73. The requirements are met with regard to the average deceleration $a_{avrg} = 9.24 m/s^2 < 1.0 \cdot g$. As decelerations $a > 2.5 \cdot g$ occur, the condition $\Delta t\ (a > 2.5 \cdot g) < 0.04s$ has to be proved. Analysis of the data gained by simulation delivers $\Delta t\ (a > 2.5 \cdot g) = 0.045s$, so the requirement is not met.

The example shows the effect of low mass: the deceleration growths to a level $a > 2.5 \cdot g$. Now it is just a question of duration whether the requirements are met or not. In this case, the duration of the jerk overshoots the limit with $\Delta t\ (a > 2.5 \cdot g) = 0.045s > 0.040s$. A slight modification of the buffer characteristics is suitable to meet the requirements in this case.



BSC - Buffer Selection and Calculation

Mass m in kg: 1000
Speed v in m/s 70% ☐: 4,67
Driving Force F in N: 9810
Stroke s in m: 1,2
Max. Acceleration a in m/s2 ☐
Max. Force F in N ☐
Required Energy: 22.7 kJ
Buffer Type
Selected Buffer:
Piston diameter d_{Piston} in m: 0,12
Final Throttle Stroke s_{rest} in mm: 20,0
Hole Diameter d_{hole} in mm: 2,0
Final Hole Diameter d_{final} in mm: 2,0
Discrete Calculation ☐
Drilling Pattern fixed ☑

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Figure 7 Buffer shock at higher car speed with minimum load

7 CONCLUSION AND OUTLOOK

The deceleration of cars influences the safety and comfort of lifts. EN 81-20 sets requirements on the maximum deceleration at buffer shock accordingly. Limit states are given for the average deceleration and the jerk applied to the car.

Hydraulic buffers are designed to cover the maximum load at maximum mass combined with maximum speed. The resulting initial buffer force also acts in situations of lower load, esp. the lower mass of the car including passengers. This induces high decelerations, which might lead to or even beyond the jerk limit defined in EN 81-20. Meeting the average deceleration requirement does not imply meeting the jerk requirement automatically. For a compliant setup, this has to be in focus during buffer design and type testing.

However, the maximum car deceleration at buffer collision is not restricted by EN 81-20. Buffers meeting the standard requirements may show different maximum car decelerations. It may be a task for science to analyze the awaited maximum decelerations and jerks in practice and to evaluate the resulting impact on passengers.

The maximum time interval for measuring the deceleration seems quite high. It strengthens the requirement on the maximum jerk induced indirectly. A lower maximum time interval for measuring the deceleration should be considered.

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