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Evaluation of EN 81-20 Requirements with regard to Car Deceleration during Buffering Process of Lifts

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Keywords: Hydraulic buffer, Characteristics, Loading condition, Car deceleration, Limit States, Available stroke, Maximum average deceleration, Maximum jerk requirement, EN 81-20.

Abstract. Buffers in 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. A description of the requirements for buffers according to EN 81-20 is given. Software for detailed simulations of buffer collisions is presented. In the main part of the paper this software is used to calculate and to analyze two cases of buffer collisions at maximum and minimum loading each. The results from of these simulations are presented and discussed in brief.

1 INTRODUCTION

Hydraulic buffers are standard equipment for lifts. In the case of main deceleration equipment failure, they are used as 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 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 smaller mass and/or smaller speed may be relevant. Smaller mass leads to higher decelerations. These decelerations have to meet the requirements of standard EN 81-20. This paper refers to the German implementation EN 81-20:2020 [1].

The paper shows the effects at two certain lift buffer examples based on simulation tests. A comparison of buffer designs under consideration of maximum load and minimum load are reviewed to evaluate the system set up with regard to the standard requirements.

2 HYDRAULIC BUFFER CHARACTERISTICS

Basically, 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 the corresponding buffer force F_b. The buffer force F_b is used to decelerate a lift car mass m of the initial kinetic energy W_{kin} and its driving force F_d, at the shaft stop limit position. 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 such as the total buffer length in relaxed condition (see Fig. 1).

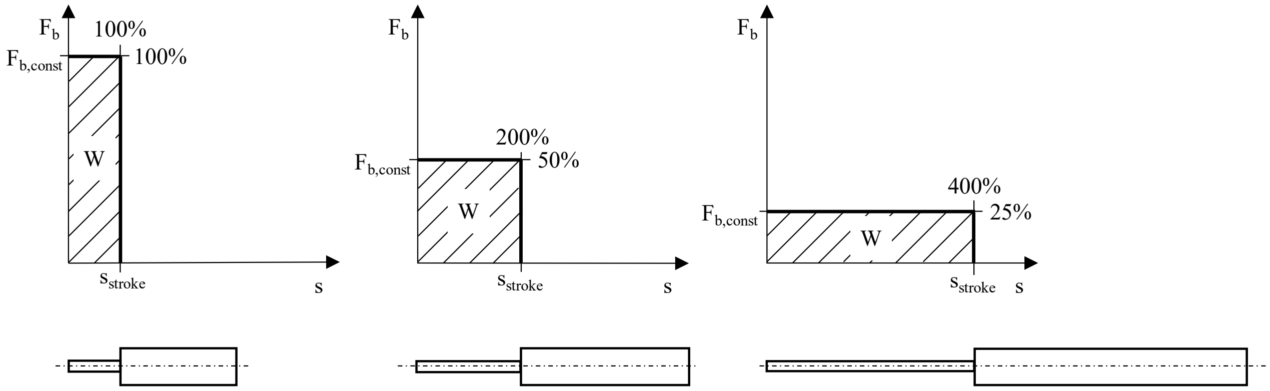


Figure 1 Buffer forces and buffer lengths at constant energy dissipated

As the buffer force is intended to be constant, this results in a constant deceleration of the mass. This constant deceleration leads to a linear decrease of the speed and a quadratic increase of the displacement against time. The speed shows a nonlinear behaviour against, and is a nonlinear function of the position (see Fig. 2).

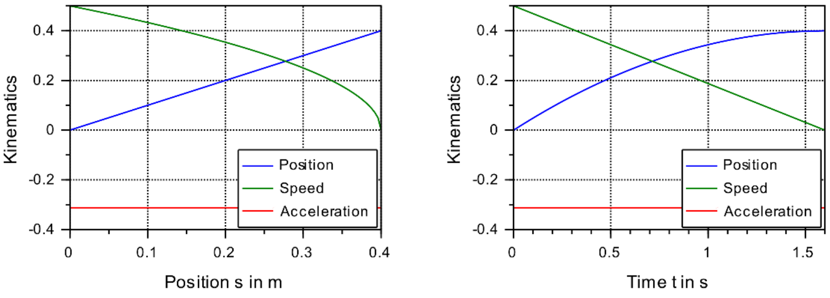


Figure 2 Buffer kinematics against position (left) and against time (right)

Although intended, the buffer curve is not rectangular in practice, as shown (with the dashed line) in Fig. 3. The buffer force F_b is not constant. The slopes of the buffer curve at the beginning and at 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. The parameter k is applied in cranes with the relative buffer energy ξ according to DIN EN 13001-1:2022-10 [2] as $\xi = 1/k$.

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

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

$$k > 1 \qquad (3)$$

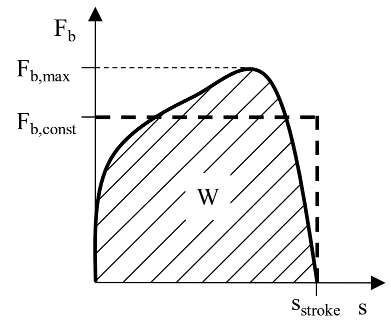


Figure 3 Theoretical vs. practical buffer characteristics

For a range of several simple buffer types, the non-constant buffer force is typical. Metallic springs or cellulose buffers show a parameter k well above one. For 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 absorb the possible maximum energy W. In comparison to other buffer types, hydraulic buffers absorb a 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 result in a non-optimal overshooting behaviour of the system. But this aspect is not taken into onsideration now.

3 REQUIREMENTS ACCORDING TO EN 81-20

Lifts have to meet safety requirements. This includes requirements for buffers in lifts. The main standard for the safety requirements in 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 [1].

Chapter 5 "Safety requirements and/or protective measures", Clause 5.8 "Buffers" lists diverse requirements. Some relevant parts for hydraulic buffers, so called energy-dissipating buffers, following are listed briefly as follows:

- 5.8.1.1: Lifts must have buffers at the bottom limit of travel of the car and counterweight.
- 5.8.1.6: Energy-dissipating buffers may be used in all lifts, regardless of the rated speed.
- 5.8.1.8: On the buffers other than those with linear characteristics there shall be a data plate showing: the name of manufacturer, the type of approval number, the type of buffer, the type of hydraulic fluid in the buffer.

For energy-dissipating buffers more details are given in 5.8.2 "Stroke of car and counterweight buffers", clause 5.8.2.2 "Energy dissipating type buffers":

- 5.8.2.2.1: Available stroke of buffer at least $0.067 \cdot v^2$, so called gravity stopping distance at $115\% \cdot v$, where v is the rated speed of the lift.
- 5.8.2.2.2: Reduced speeds at implemented deceleration monitored by a control circuit. When the slowdown of lift at the ends of its travel is monitored by electric safety devices for rated speeds above 2,50 m/s, the speed at which the car (or the counterweight) comes into contact with the buffers may be used instead of 115 % of the rated speed, when calculating the buffer stroke according to 5.8.2.2.1. However, the stroke shall not be less than 0.42 m.
- 5.8.2.2.3: The average deceleration a_{avrg} shell be $< 1.0 \cdot g$ when hitting the buffer with the mass of the car with its rated load, in case of free fall with a speed of 115 % of the rated

speed or the reduced speed according to 5.8.2.2.2. The maximum time span at deceleration > $2.5\cdot g$ shell be less than 0.04 s. There shall be no remaining deformations after actuation.

- 5.8.2.2.4: The normal operation of the lift shall depend on the return of the buffers to their normal extended position after operation. Returning to the operating position must be monitored by an electric safety device.
- 5.8.2.2.5: Buffers shall be so constructed so that the fluid level can easily be checked.

Requirements for tests before commissioning are given in section 6 "Verification of the safety requirements and/or protective measures", clause 6.3 "Examinations and tests before putting into service", 6.3.7 "Buffers": Energy dissipation type buffers:

The test shall be made in the following manner: the car with its rated load and the counterweight shall be brought into contact with the buffers at the rated speed or at the speed for which the stroke of the buffers has been calculated, in the case of the use of reduced stroke buffers with verification of the retardation (5.8.2.2.2). After the test, it shall be ascertained that no deterioration, which could adversely affect the normal use of the lift has occurred.

The requirements on the available stroke s_{avl} and on the average deceleration a_{avrg} coincide. 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:

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

The requirement concerning the deceleration of more than $a = 2.5\cdot g$ lasting longer than $\Delta t = 0.04$ s is about limiting the jerk applied on car and passengers. To stop the car under these conditions, the car speed, denoted as the minimum car speed v_{min} (see Fig. 4), is determined as:

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

The corresponding minimum distance s_{min} for stopping is then determined as:

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

At higher car speed v the distances s will be at significant 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 provisions for type examinations of safety components", clause 5.1.2 "General provisions", 5.1.2.6(e): recording equipment shall be capable of detecting signals, which vary in time of 0.01 s. This requirement makes the requirement on the jerk stricter, as the limit deceleration can only be exceeded at two measuring points at the minimum measuring frequency.

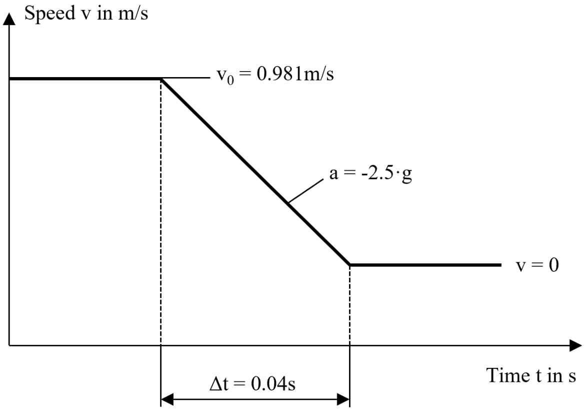


Figure 4 Virtual minimum car speed

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

4 SIMULATION TOOL

The requirements of EN 81-20 consider the time behaviour at buffer impact (shock) in detail. Especially the requirement on the maximum temporary deceleration Δt ($a > 2.5 \cdot g$) < 0.04 s can be proofed by detailed analysis only. Such analysis requires the detailed knowledge of deceleration-time-behaviour at least at 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. To test by simulation, based on [3] and [4] the software tool “BSC - Buffer Selection and Calculation” was developed. The tool describes a certain buffer application via GUI (see Fig. 6), simulates the process of buffer shock in detail and reports the critical process parameters such as the maximum deceleration via GUI and PDF printout. Among others, the simulation includes following physical properties:

- Inertia of impact mass, described by mass m.
- Friction of hydraulic fluid, described by pressure loss coefficient ζ [5].
- 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 [5].

Furthermore, the tool offers options as buffer selection from 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. Last aspect is relevant for consideration of collision in cranes.

5 EXAMPLE OF A BUFFER AT LOWER CAR SPEED

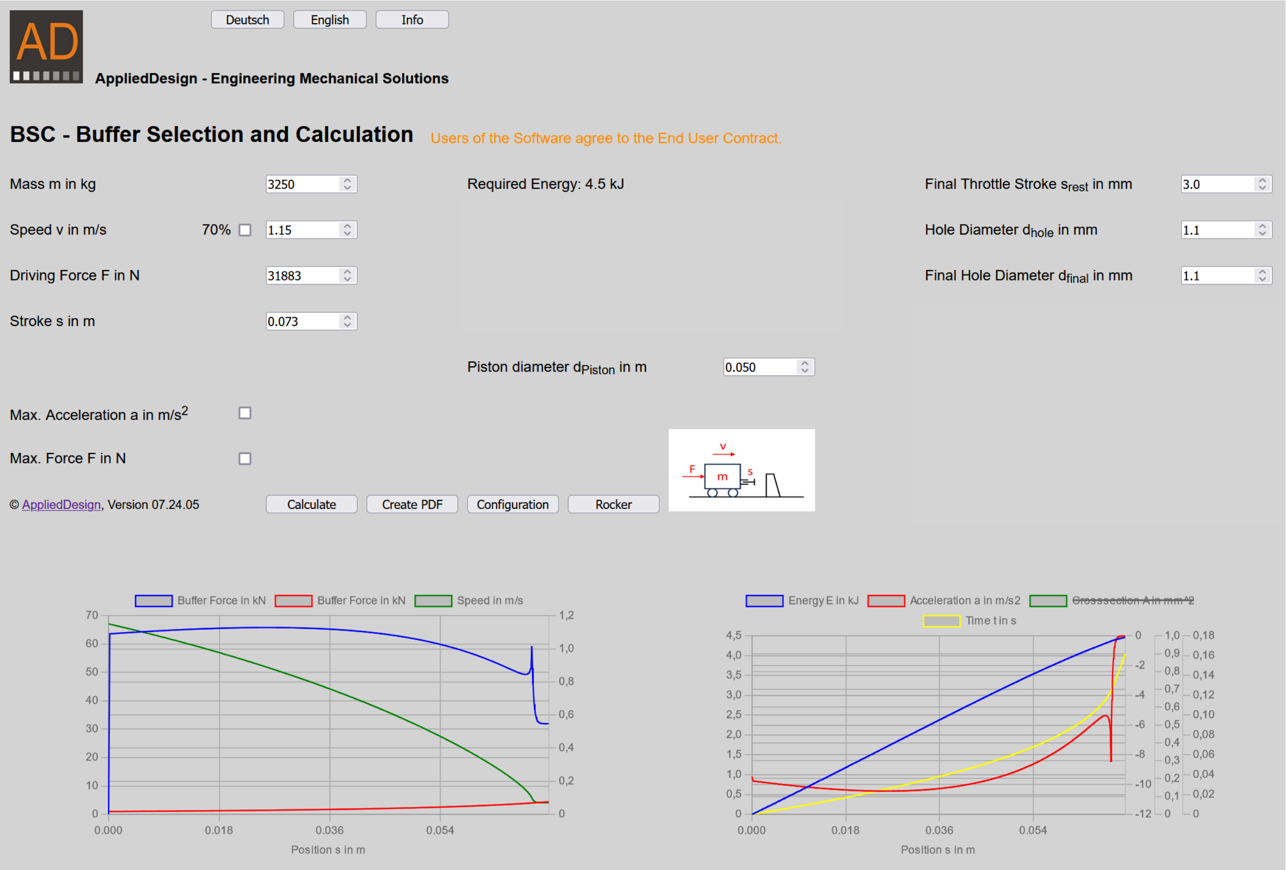
The buffer collision of a lift car is considered as a first example. The car including maximum load with mass m_{max} = 3,250 kg travels at a nominal (rated) speed of v_{nom} = 1.0 m/s. Due to gravitation this leads to a driving force of about F_d = 31,883 N acting on the car. According to the standard the speed at impact to be considered is $v_{115\%}$ = 1.15 m/s. Further data are piston diameter d = 50 mm and stroke s_{stroke} = 73 mm. This stroke satisfies the requirement on the available stroke $s_{avl} = 0.5 \cdot v^2/g$ = 67.4 mm.

$s_{stroke} > s_{avl}$. The data assumed is comparable to typical lift buffers available on the market for nominal speeds of $v_{nom} = 1.0$ m/s as shown in Fig. 5.

Figure 5 Hydraulic buffer for nominal lift speed v_{nom} = 1m/s

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. 6). 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 W_{diss} consists of two parts. The kinetic energy of the car W_{kin} and the potential energy W_{pot} of the car at piston distance zero $s = 0$. The potential energy dissipated W_{pot} grows linear along stroke. The kinetic energy dissipated W_{kin} grows with slightly decreasing slope along stroke, as it depends on the speed v. As the total kinetic energy dissipated E_{kin} and the total potential energy dissipated W_{pot} have about the same amount and occur along the stroke, the energy dissipated W_{diss} shows a slightly decreasing characteristics along stroke (Fig. 6).

Simulation of a buffer shock with this data results in an average deceleration of $a_{avrg} = 9.5$ m/s^2 and a maximum deceleration of $a_{max} = 10.5$ m/s^2 (Fig. 6, Fig. 7). Parameter $k = 1.11$. The requirements are met as the average deceleration $a_{avrg} = 9.5$ m/s$^2 < 1.0 \cdot g$ and the maximum deceleration $a_{max} = 10.5$ m/s$^2 < 2.5 \cdot g$. The jerk requirement is already met, as no higher decelerations occur.



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BSC - Buffer Selection and Calculation

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Mass m in kg: 3250

Speed v in m/s: 1.15 (70% ☐)

Driving Force F in N: 31883

Stroke s in m: 0.073

Required Energy: 4.5 kJ

Piston diameter d_{Piston} in m: 0.050

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

Max. Acceleration a in m/s^2 ☐

Max. Force F in N ☐

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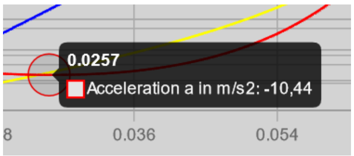
Figure 6 Buffer shock at lower car speed with maximum load



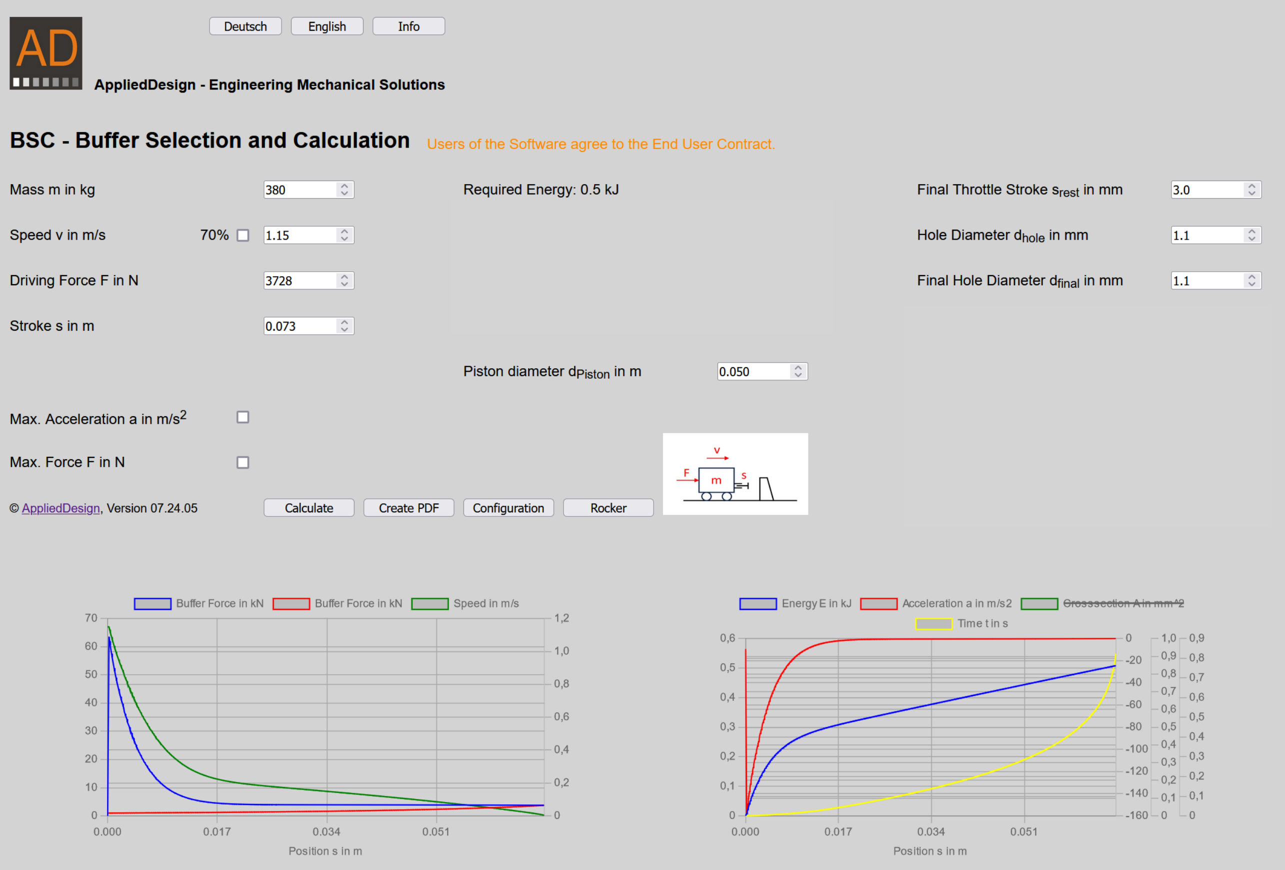
0.0257

Acceleration a in m/s2: -10,44

Figure 7 Maximum deceleration at buffer shock at lower car speed with minimum load

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

Fig. 8 shows the resulting data for 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 maximum load m_{max} and for 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 stroke, at minimum load m_{min} the buffer force F_b decreases immediately after 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 obviously. 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 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 W_{kin} and the total potential energy dissipated W_{pot} have about the same amount. But now the main amount of the kinetic energy W_{kin} is dissipated at the beginning of the stroke. Hence the energy dissipated W_{diss} shows a fast growth at the beginning of the stroke and a moderate increase along the stroke (Fig. 8).



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BSC - Buffer Selection and Calculation

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Mass m in kg: 380

Speed v in m/s: 70% ☐ 1.15

Driving Force F in N: 3728

Stroke s in m: 0.073

Required Energy: 0.5 kJ

Piston diameter d_{Piston} in m: 0.050

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

Max. Acceleration a in m/s^2 ☐

Max. Force F in N ☐

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Figure 8 Buffer shock at lower car speed with minimum load

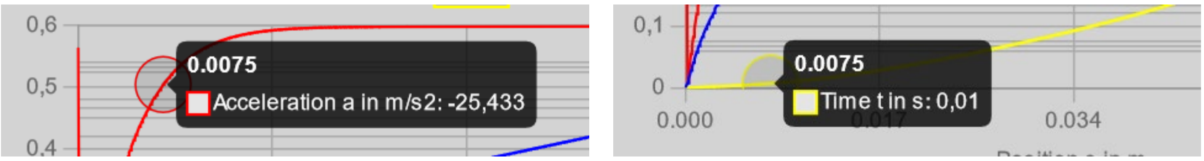


Figure 9 Point of deceleration = 2.5g at buffer shock at lower car speed with minimum load

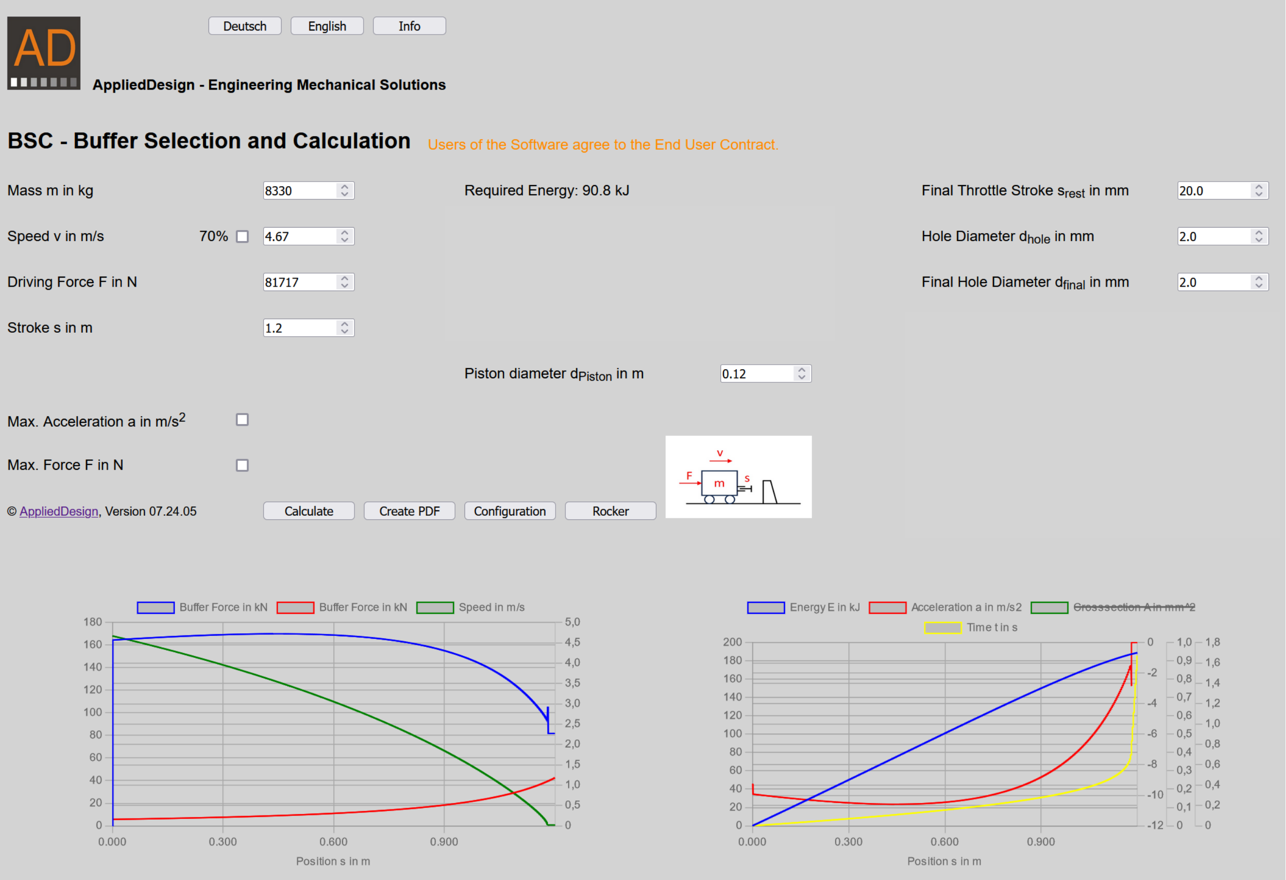
This data results in an average deceleration of $a_{avrg} = 9.5$ m/s^2 and a maximum deceleration of $a_{max} = 157.5$ m/s$^2 = 16.1 \cdot g$ (Fig. 8). Parameter $k = 16.58$. As the impact speed v and the throttle cross section are the same as at high mass m_{max}, the lower mass experiences a quite high deceleration a at the beginning of the buffering process. The requirements are met regarding 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 Δt $(a > 2.5 \cdot g) < 0.04$ s has to be proven. Analysis of the data gained by simulation delivers Δt $(a > 2.5 \cdot g) = 0.011$ s, the requirement is met.

The example simulated comprises a speed of $v_{115\%} = 1.15$ m/s, a speed just a small amount above the minimum speed $v_{min} \approx 1$ m/s necessary to create the limit jerk. This explains the difficulty in this case, not to meet the requirement Δt $(a > 2.5 \cdot g) < 0.04$ s. Quite high decelerations $a_{max} = 157.5$ m/s$^2 = 16.1 \cdot g$ occur, but just over a relatively small period Δt $(a > 2.5 \cdot g) = 0.011$ s (Fig. 9).

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} = 8,330 kg 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 = 81,717 N acting on the car. According to the standard the impact speed is $v_{115\%}$ = 4.67 m/s. Further data are piston diameter d = 120 mm and stroke s_{stroke} = 1,200 mm. This stroke fulfils the requirement on the available stroke $s_{avl} = 0.5 \cdot v^2/g$ = 1,111.6 mm. The assumed data is comparable to typical lift buffers available on the market for nominal speeds of about v_{nom} = 4.0 m/s.

The simulation of a buffer shock with this data results in an average deceleration of a_{avrg} = 9.24 m/s^2 and the maximum deceleration of a_{max} = 10.59 m/s^2 (Fig. 10). Parameter k = 1.15. The requirements are met as the average deceleration a_{avrg} = 9.24 m/s^2 < $1.0 \cdot g$ and the maximum deceleration a_{max} = 10.59 m/s^2 < $2.5 \cdot g$ (Fig. 11). 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

Required Energy: 90.8 kJ

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

Max. Acceleration a in m/s^2 ☐

Max. Force F in N ☐

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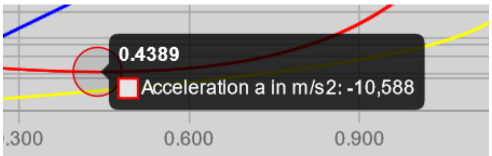
Figure 10 Buffer shock at higher car speed with maximum load



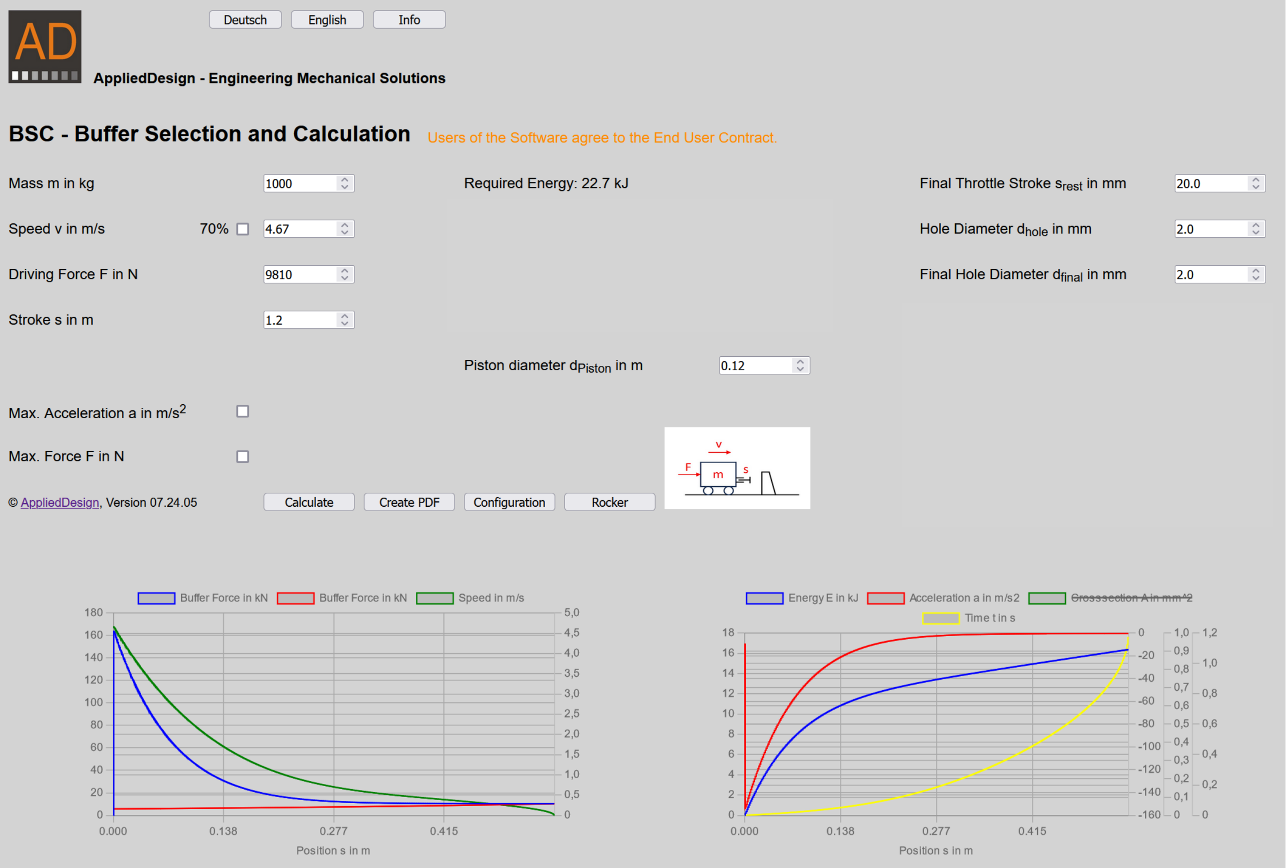
0.4389

🟥 Acceleration a in m/s2: -10,588

Figure 11 Maximum deceleration at buffer shock at higher car speed with maximum load

Now the car including minimum load with mass m_{min} = 1,000 kg travels at the same nominal speed of v_{nom} = 4.06 m/s. This leads to a driving force of F_d = 9,810 N and according to the standard an impact speed of $v_{115\%}$ = 4.67 m/s. This data results in an average deceleration of a_{avrg} = 9.24 m/s^2 and a maximum deceleration of $a_{max} = 154.55$ m/s^2 = 15.8·g (Fig. 12). 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·g. As decelerations $a > 2.5 \cdot g$ occur, the condition Δt ($a > 2.5 \cdot g$) < 0.04 s has to be proved. Analysis of the data gained by simulation delivers Δt ($a > 2.5 \cdot g$) = 0.045 s, 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 Δt ($a > 2.5 \cdot g$) = 0.045 s > 0.040 s (Fig. 13). A modification of the buffer characteristics may be suitable to meet the requirements in this case.



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BSC - Buffer Selection and Calculation

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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

Required Energy: 22.7 kJ

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

Max. Acceleration a in m/s^2 ☐

Max. Force F in N ☐

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Figure 12 Buffer shock at higher car speed with minimum load

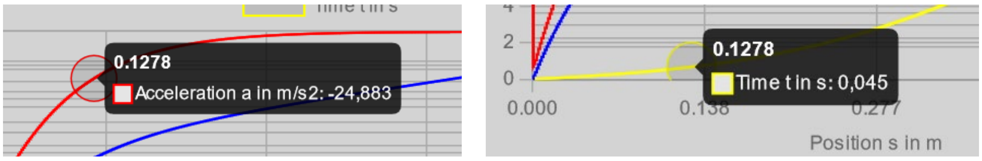
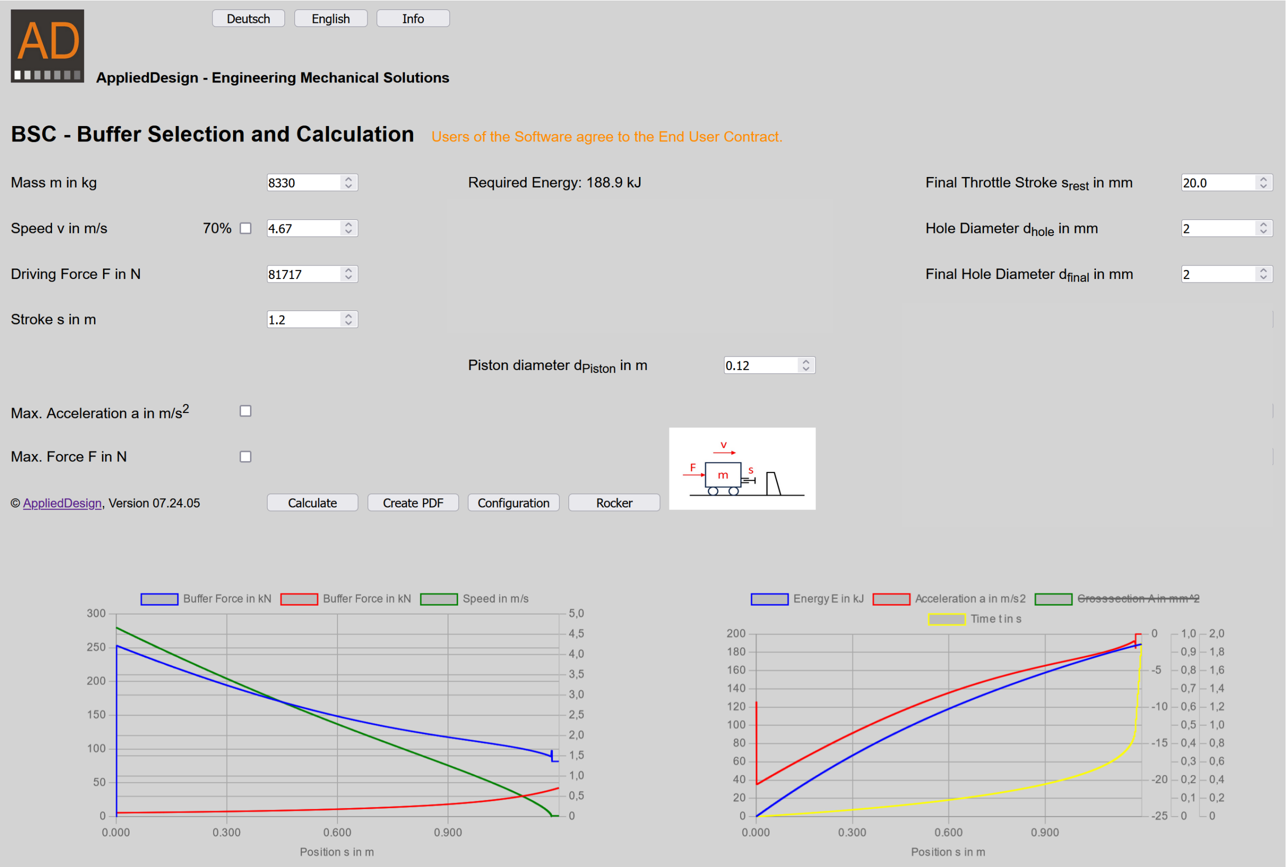


Figure 13 Point of deceleration = 2.5g at buffer shock at higher car speed with minimum load

7 MODIFIED EXAMPLE OF A BUFFER AT HIGHER CAR SPEED

Now a modified buffer is applied to the same lift. The car including maximum load with mass m_{max} = 8,330 kg 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 = 81,717 N acting on the car. According to the standard the impact speed is $v_{115\%}$ = 4.67 m/s. Further data are piston diameter d = 120 mm and stroke s_{troke} = 1,200 mm. This stroke fulfils the requirement on the available stroke $s_{avl} = 0.5 \cdot v^2/g$ = 1,111.6 mm. 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 modified buffer results in an average deceleration of a_{avrg} = 9.24 m/s^2 and a maximum deceleration of a_{max} = 0.64 m/s^2 (Fig. 14, Fig. 15). Parameter k equals k = 1.15. The requirements are met as the average deceleration $a_{avrg} = 9.24$ m/s$^2 < 1.0 \cdot g$ and the maximum deceleration a_{max} = 20.64 m/s$^2 < 2.5 \cdot g$. The jerk requirement is met, as no higher decelerations occur.



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BSC - Buffer Selection and Calculation

Users of the Software agree to the End User Contract.

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

Required Energy: 188.9 kJ

Piston diameter d_{Piston} in m: 0.12

Final Throttle Stroke s_{rest} in mm: 20.0

Hole Diameter d_{hole} in mm: 2

Final Hole Diameter d_{final} in mm: 2

Max. Acceleration a in m/s^2 ☐

Max. Force F in N ☐

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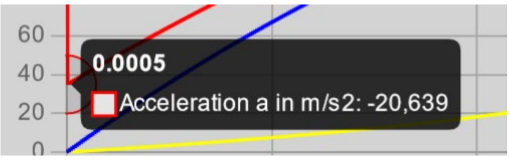
Figure 14 Modified buffer shock at higher car speed with maximum load



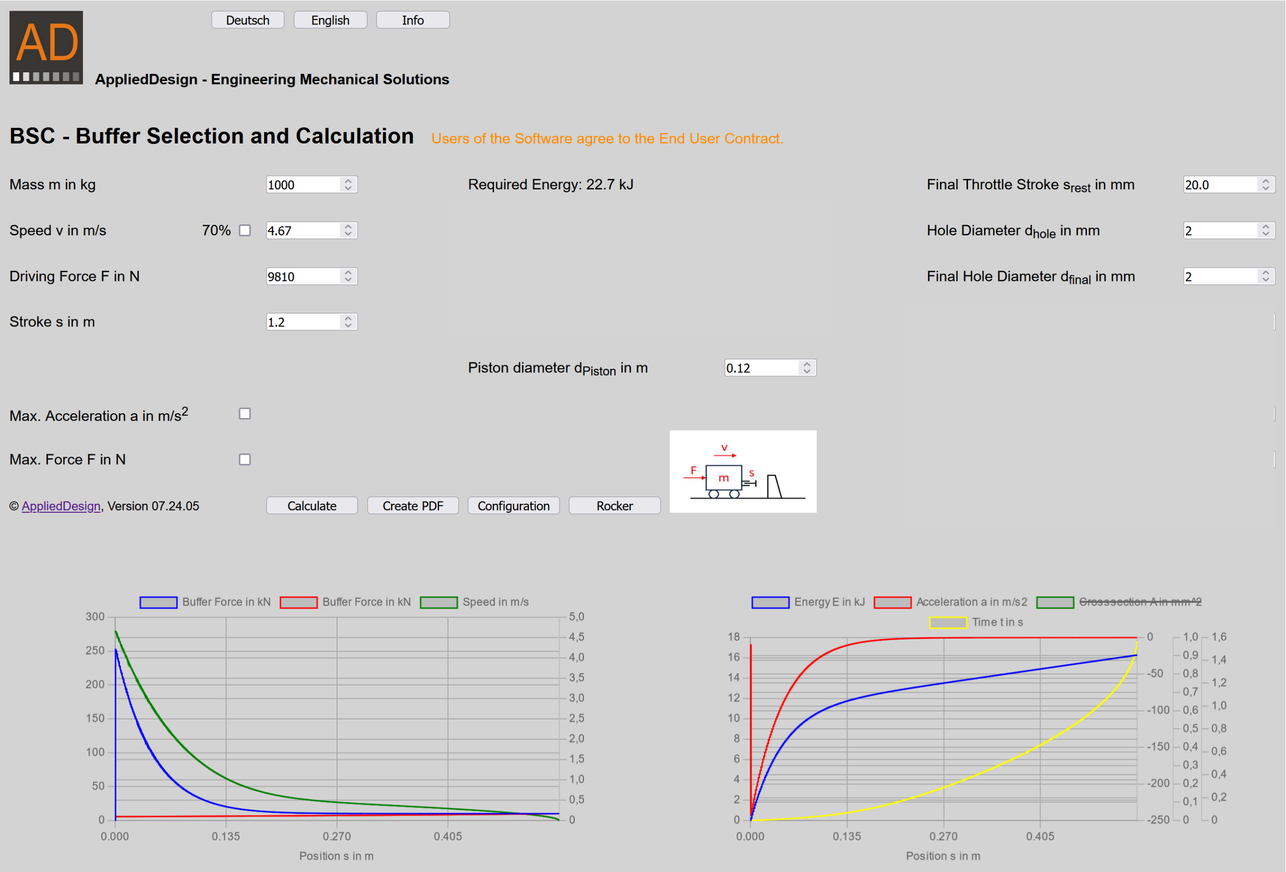
0.0005

🟥 Acceleration a in m/s2: -20,639

Figure 15 Maximum deceleration at modified buffer shock at higher car speed with maximum load

Now the car including minimum load with mass m_{min} = 1,000 kg travels at the same nominal speed of v_{nom} = 4.06 m/s. This leads to a driving force of F_d = 9,810 N and according to the standard an impact speed of $v_{115\%}$ = 4.67 m/s. This data results in an average deceleration of a_{avrg} = 9.24 m/s^2 and a maximum deceleration of a_{max} = 243.83 m/s^2 = 24.9$\cdot g$ (Fig. 16). Parameter k equals k = 26.39. 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 Δt ($a > 2.5 \cdot g$) < 0.04 s has to be proved. Analysis of the data gained by simulation delivers Δt ($a > 2.5 \cdot g$) = 0.040 s, the requirement is at the border to be met. A further modification would be suitable to meet the requirement.

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 is at the limit with $\Delta t\ (a > 2.5 \cdot g) = 0.040$ s. Further modification of the buffer characteristics is suitable to meet the requirements in this case.



BSC - Buffer Selection and Calculation Users of the Software agree to the End User Contract.

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

Required Energy: 22.7 kJ

Piston diameter d_{Piston} in m 0.12

Final Throttle Stroke s_{rest} in mm 20.0

Hole Diameter d_{hole} in mm 2

Final Hole Diameter d_{final} in mm 2

Max. Acceleration a in m/s^2 ☐

Max. Force F in N ☐

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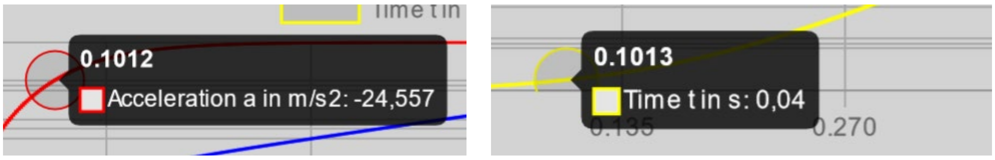
Figure 16 Modified buffer shock at higher car speed with minimum load



0.1012
Acceleration a in m/s2: -24,557

0.1013
Time t in s: 0,04

Figure 17 Point of deceleration = 2.5g at modified buffer shock at higher car speed with minimum load

8 CONCLUSION AND OUTLOOK

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

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, i.e. lower mass of the car including passengers. This induces high decelerations, which might lead to or even beyond the required jerk limits. An appropriate buffer design enables meeting the jerk requirement. This will lead to increasing maximum decelerations. 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 deceleration. It may be a task for further investigations, to analyze the expected maximum decelerations and jerks in practice and to evaluate the resulting impact on passengers.

The maximum time interval at measuring the deceleration according to the standard seems quite high. It strengthens the requirement on the maximum jerk induced indirectly. A lower maximum time interval at measuring the deceleration could be considered.

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