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ORIGINAL PAPER

Avoiding structural redundancies between the vehicle body and the battery housing based on a functional integration approach

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Abstract
In this paper, the approach for a functionally integrated battery housing is presented, to avoid structural redundancies towards the vehicle body. The goal is to reduce the overall structural weight while simultaneously increasing the package space for battery modules. The typically existing boundary conditions for the battery system are taken into account. Especially, the detachability of the battery as a closed unit is in focus, to ensure the leak tightness of this system and to enable replacement. Based on the available space in a research vehicle, such a functionally integrated concept is developed. In particular, the vehicle floor and the vehicle rocker are identified as suitable components for integration. The verification of the concept with regard to the crash performance is carried out on component and on full vehicle level. On both levels, the side pole impact is used as load case and the deformation behavior is investigated.

Keywords Functional integration · Battery housing · Battery electric vehicles · Crash simulation

1 Introduction

Increasing environmental awareness and strict legal restrictions regarding CO_2 emissions in the automotive sector have facilitated the adoption of new propulsion technologies. Highly efficient electric drive train systems which are powered by sustainable energy sources and especially battery electric vehicles (BEVs) are supported by policy makers and introduced by the automotive industry [1]. Due to this shift in the automotive industry, the high voltage battery as an energy storage system is gaining importance.

Since the energy density of today's battery systems is significantly lower compared to a conventional fuel tank, a large and heavy battery storage unit is needed to meet the same vehicle range target [2, 3]. On this account, the designated mounting position of the high voltage battery for purpose-design BEVs is beneath the vehicle floor panel and between the axles [4]. The available package space in this comparatively safe space regarding vehicle crash has formed the shape of modern high voltage batteries as a relatively flat and rectangular structure [5]. Among the numerous national and international automotive manufacturers, which have chosen this geometry and positioning for the battery system are for example Audi e-tron [6], Volkswagen ID.3 [7], Daimler EQC [8], Tesla Model 3 [9], Chevrolet Bolt [10] and Mazda MX-30 [11].

Due to the low placement and the high weight of the battery assembly, a low vehicle center of gravity is achieved, which is beneficial for vehicle dynamics [3, 12]. However, a high vehicle mass is adverse for the energy requirement of the vehicle and shortens its range [13]. To improve the range of battery electric vehicles, it is therefore necessary to integrate the battery into the vehicle in both a space-efficient and weight-optimized way.

However, the vehicle integration of this key component poses numerous challenges. Regarding the development process, the battery has to meet a wide range of requirements [14], which typically result in a conflict of interests [15]. In particular, these include the vehicle package towards maximizing the stored energy and crash safety of the battery cells or the accessibility for repair as well as the leak tightness of the battery housing [15]. Regarding safety aspects, certain regulations and standards exist towards the battery on a system level such as UN ECE R100, GB/T 31467.3, ISO 12405-3. In these, the battery is subjected to a series of tests in which the structural integrity, the behavior under thermal load, and the tightness of the battery system is tested [16].

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At the same time, there are also regulations and standards on a full vehicle level, which must be met. In this context, the side pole impact is considered to be the most challenging for battery electric vehicles, which is why numerous publications by automotive manufacturers and vehicle suppliers foresee this load case regarding the design of the battery system such as [7, 11, 17–21].

The state of the art therefore requires a battery housing, which serves as a protective structure for the battery cells and other internal electric components from environmental influences and mechanical loads [3]. Especially in the scenario of a vehicle crash, the integrity of the battery housing is crucial. Due to the low mechanical load capacity of the battery cells, any cell damage is to be avoided [22]. Otherwise, thermal runaway of the battery cells can occur, which would lead to severe consequences including vehicle fire [23]. To ensure the safety of internal components, the battery housing is typically made predominantly of aluminum or steel [24, 25]. In some cases composite material is utilized for the battery lid [24]. The battery housing is designed either profile intensive or sheet metal intensive to the aforementioned rectangular shape [15]. Especially for a profile intensive design, scalability of the battery housing can be achieved [15].

Nevertheless, on a full vehicle level, both the battery housing and the vehicle body act as protective structures to prevent the battery cells from damage in an event of a crash [6, 19]. Therefore, structural redundancies between the vehicle body and the battery housing occur. This leads potentially to a higher structural weight on a full vehicle level and in a smaller package space for battery cells.

2 Scope and requirements

The goal of this paper is to present a novel concept for a functionally integrated battery housing, in which the aspects of lightweight design and improving space-efficiency on full vehicle level are pursued by reducing structural redundancies between the vehicle body and the battery housing. To achieve this goal, the method of functional integration is applied, while taking into account, that both the battery housing and the vehicle body can each be assembled without any major interferences. At the same time, typical requirements currently stipulated towards the battery system and especially on a full vehicle level regarding the side pole impact shall be met.

To comply with the current standards, it is essential that the chosen direction of functional integration is targeted form the vehicle body towards the battery housing and not vice versa. As such, the battery can be designed as a sealed system and the leak tightness of the battery can be ensured. The testing regarding leak tightness can be conducted on component level [26]. A vehicle supplier can therefore provide the whole battery as a sealed system in contrast to having the battery parts assembled and integrated into the vehicle on site. If the direction of functional integration was reversed, structures of the battery housing would be missing and the housing would no longer be a closed system once it is removed from the vehicle. Having the battery designed as a detachable and sealed system also enables the battery to be replaced as a whole unit. This can be advantageous for example in the event of maintenance or when employing a battery-swapping concept, where a discharged battery can be replaced by a charged one in a short period of time [27, 28].

To derive variants of the battery system with comparatively little effort, the housing is to be designed scalable in various directions. A profile intensive design is therefore most suitable [29]. The desired suitability for high volume production is met by the use of a purely metallic design and the use of established joining techniques.

As a research vehicle, the full vehicle model developed in the EU-funded project ALIVE is used as a baseline [30], since it fulfills the requirements of a compact class vehicle designed for high volume production. The vehicle model was modified in preparation for the simulations to be carried out. The two-part battery, which was located under the vehicle seats was removed, resulting in the design space for the functionally integrated battery system. The surrounding vehicle components, such as the vehicle rockers and the longitudinal members were simultaneously redesigned to fit the new structure. The modified model of the vehicle body and the available package space for a rectangular battery housing can be seen in Fig. 1.

3 Functional integration approach

The general idea of the functional integration approach can be seen in Fig. 2. Based on the position in the vehicle underbody and the general shape of the battery housing according to the state of the art [7, 15, 17, 19, 20, 31, 32], suitable components for integration can be identified. The side frame of such a battery housing is typically "L"-shaped and is utilized for mounting the battery to the vehicle body [25]. For this purpose, bolts are used to attach the side frame to the underside of the vehicle rocker [7, 17, 19].

The structural redundancies especially occur between the vehicle floor panel and the battery housing lid as well as between the vehicle rocker and the battery side frame. By functionally integrating the vehicle floor panel and the vehicle rocker into the battery housing, the overall shape is not altered, since these components are parallel to the battery system. Furthermore, functionally integrating these components into the battery housing does not interfere with the detachability of the battery system. Therefore, these

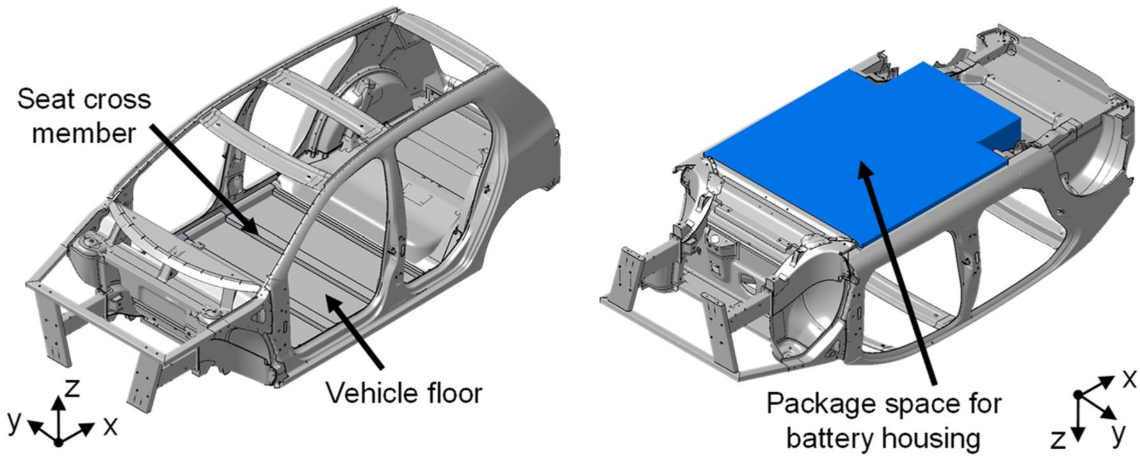


Fig. 1 Body of the ALIVE-Vehicle model with the design space for the battery housing

components in particular are to be considered for functional integration.

Since the housing lid and vehicle floor are usually made of sheet metal, these two components show structural compatibility for functional integration. To integrate the vehicle floor panel into the lid of the battery housing, the battery must be enlarged to match the layout of the vehicle floor panel. To achieve a weight reduction, a full integration of the floor panel is to be pursued. The passenger compartment is thus closed by the battery housing, whereas the sealing can be provided either directly in the division plane of the rocker or circumferential between the vehicle rocker and the lid of the battery housing. However, due to the required detachability of the battery housing from the vehicle body, such a seal cannot be provided by seam welding. Therefore the usage of sealing adhesive or compression seals or both is more suitable in this scenario.

By contrast, a full integration of the vehicle rocker into the side frame of the battery system is not beneficial. Several components of the floor assembly are attached to the vehicle rocker, for instance the A-pillar, B-pillar and seat cross members. Considerable interferences regarding body assembly are to be expected by a full integration of the vehicle rocker into the battery side frame. A more desirable approach is to divide the vehicle rocker into a vehicle sided part and a battery sided part. The vehicle sided part of the rocker would remain in the vehicle body and ensure the aforementioned attachments. The battery sided part of the rocker is suitable for functional integration into the battery housing, where the corresponding counterpart is the battery side frame. Here, the battery side frame needs to be enlarged to match the length of the vehicle rocker. Similar to state of the art, the use of bolts in the rocker division plane is intended to ensure the detachability of the battery from the vehicle.

In the process of dividing the vehicle rocker, the body sided attachment points and the detachability of the battery housing must be taken into account. Hence, a top–bottom division is appropriate, since the attachment points of the floor assembly are located on the top half of the rocker and the battery housing can only be detached along the vertical vehicle axis. This concept is shown in Fig. 3, where the before mentioned division is indicated as "General division plane".

Based upon these boundary conditions, different variants of the division plane can be derived. Suitable versions towards manufacturing and ensuring the detachability of the battery are presented in Fig. 3. Whereas the notch-design has a high assembly complexity since low tolerances are required, the horizontal division plane is the simplest variant to manufacture and to assemble. However, the horizontal division plane offers the fewest adjustment options, as the vertical height of the parting line is directly determined by the height of the battery housing. In addition, the bolt connection is on the same surface as the connection of the housing lid. This poses the risk of the bolt connection negatively affecting the tightness of the battery system. The same situation can also be identified for the angled version. However, in comparison to the horizontal version, the usable surface area for the bolt connection is even smaller and the risk of compromising the leak tightness of the housing lid increases. As with the horizontal and angled versions, long tools are required regarding assembly for the bolt connection. In addition, the profile is weakened by the insertion of holes over the height of the profile. From a design perspective the most suitable variant is the z-division plane and therefore chosen for further investigation. In contrast to the other variants, the positioning of the bolting connection can be optimally adjusted. Due to the given degrees of freedom, the same

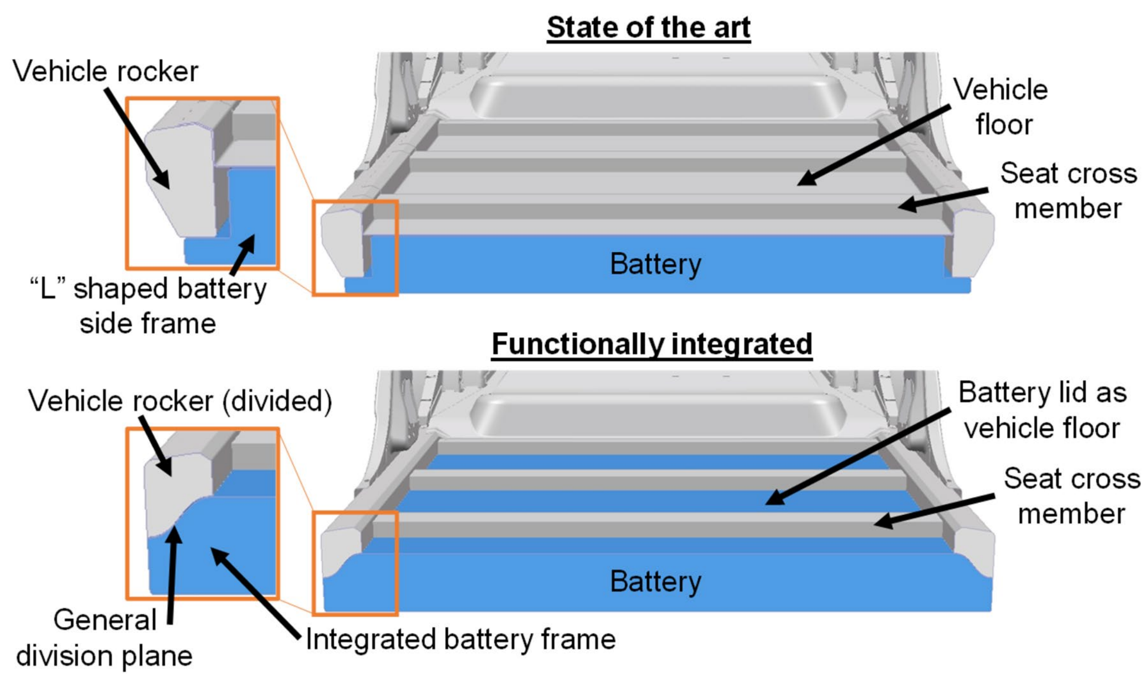


Fig. 2 Functional integration approach

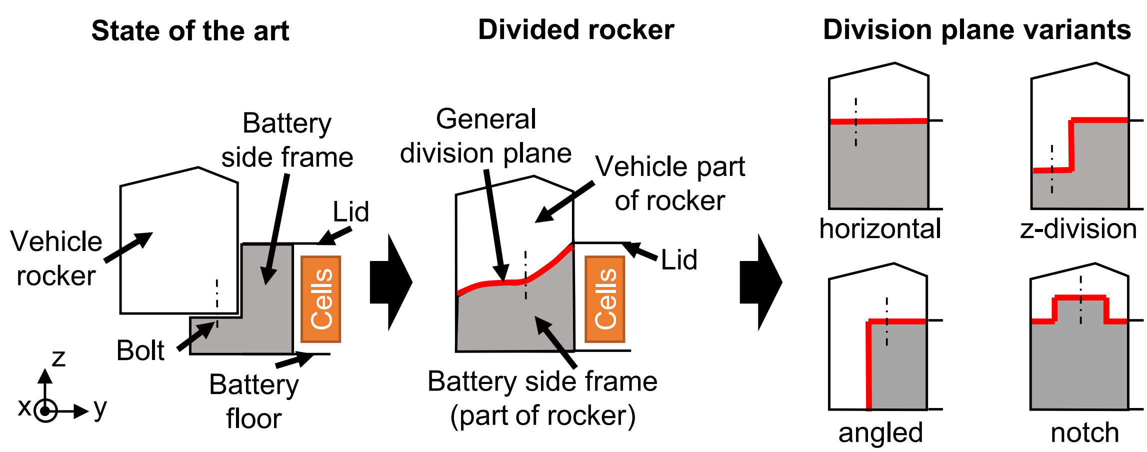


Fig. 3 Division of the vehicle rocker

applies to the load distribution between the battery housing and the vehicle body.

4 Battery concept

At the core, the battery housing consists of a frame structure, to which all internal components are attached. The frame structure is formed using extruded aluminum profiles, which are welded together. This profile intensive design enables the scalability of the battery system. From a lightweight perspective, the use of inner longitudinal members or a truss structure is avoided. Instead, only cross members are intended in this concept, which support the side frame of the battery housing especially in the event of a lateral crash. The impacting load is therefore transferred and distributed among the cross members. The concept of the battery system with the approximate dimensions can be seen in Fig. 4. For visualization purposes, the battery lid is shown transparent in the left picture.

The design of the battery housing is symmetrical, with the external connections positioned in the center. Therefore, the coolant supply and the high voltage wiring are also arranged centrally and threaded continuously through the

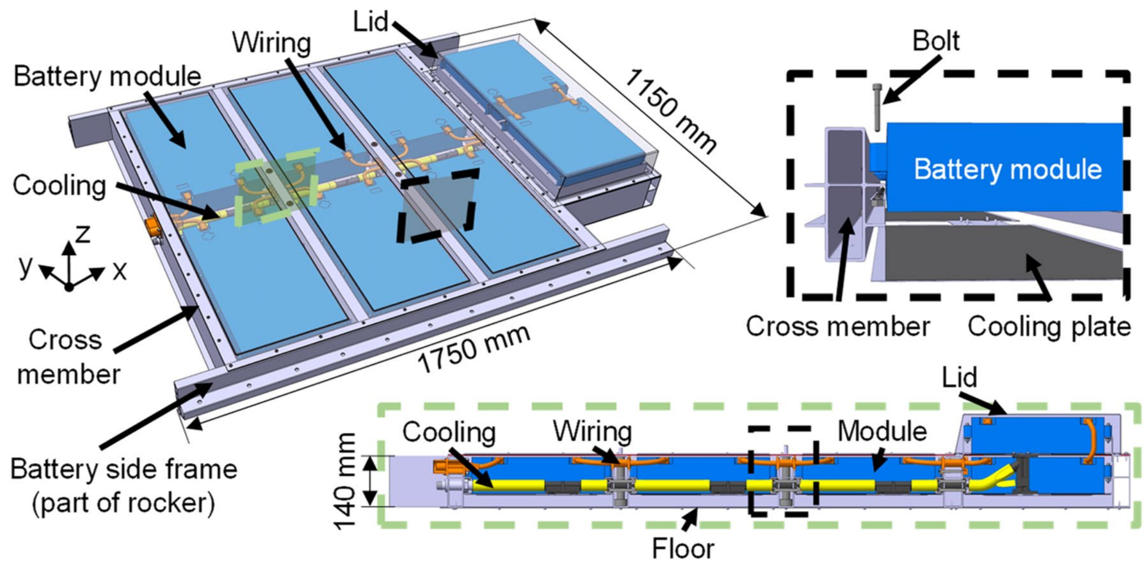


Fig. 4 Concept of the integrated battery system

cross members. In the main area of the battery housing, six large modules are positioned between the cross members. In the rear area, four smaller modules are arranged on two levels. The corresponding cooling plates are located under the battery modules. The cooling plates and modules are mounted to the cross beams with flanges provided for this purpose. Hereby, the cooling plates are directly welded to the flanges. To ensure the detachability in case of maintenance, the modules are bolted to the frame structure using metric bolts.

Both the battery housing lid and the battery housing floor consist of aluminum sheet metal and are adhesively bonded to the frame structure. Additionally, these components are attached to the frame structure using flow drill screws. While the battery housing floor sheet is bonded to the frame using structural adhesive, the battery housing lid is bonded using sealing adhesive [33]. This allows for detachability of the lid and access to the battery modules.

Similar to the state of the arte, the battery system is connected to the vehicle body using bolts and nuts [7]. In addition to the connections in the division plane of the rocker, central bolt attachments are also provided to connect the battery cross members to the seat cross members. This prevents the battery structure from bending. Regarding the attachment, blind rivet nuts are embedded into the seat cross members and the vehicle rockers. Therefore, during assembly and disassembly of the battery system along the vehicle's vertical axis, only one sided accessibility to the bolt connection is needed and is given in this scenario form below the battery housing. While the vehicle seats stay constantly attached towards the seat cross members, the vehicle carpets would be bonded to the top surface of the battery housing lid and would be removed together with the battery housing in case of disassembly.

The main supporting structures are therefore the vehicle frame, consisting of the vehicle sided parts of the rocker and the seat cross members, as well as the battery housing consisting of the battery frame, the housing floor and the housing lid. Both frames seamlessly interlock resulting in a divided frame structure, which can be seen in Fig. 5.

In the event of a side crash, the impacting force is distributed onto the two rocker parts. The force is then transferred over the seat cross members and the battery cross members to the other rocker.

5 Structural simulation

The crash performance of the functionally integrated approach is investigated by the means of finite element simulation. The battery system and the vehicle model are set up for the LS-DYNA solver code. Regarding standard crash tests, the side pole impact is particularly critical for the vehicle structure, since the load is applied in a concentrated manner and accordingly high intrusions can occur [34]. Due to the positioning of the battery in the underbody and the short deformation length in lateral vehicle direction, the side pole impact is a critical test for the battery system. Therefore, the battery side frame is tested on a component and on a full vehicle level and analyzed regarding the structural behavior for this impact scenario. Several iteration loops are run accordingly to optimize the side structure.

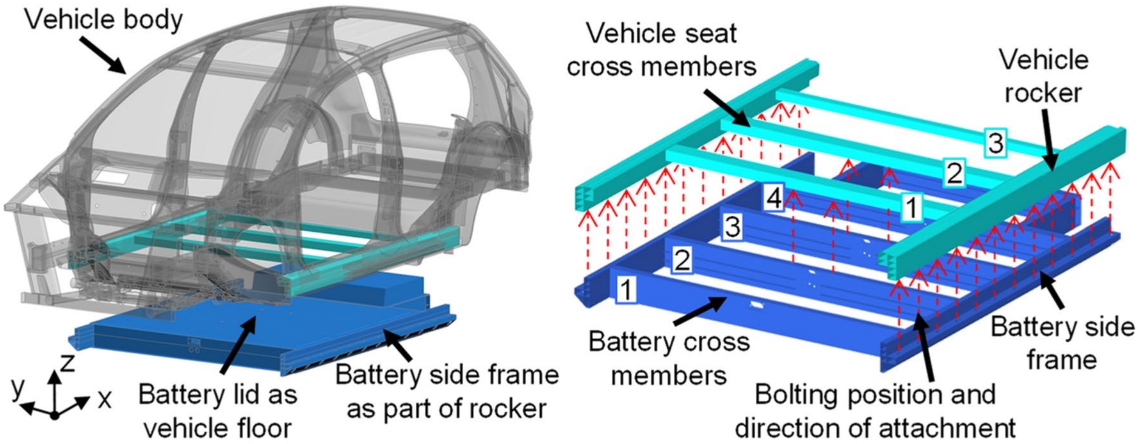


Fig. 5 Battery and vehicle divided frame structure

5.1 Test on component level

The aim of the component level test, regarding the side frame of the battery housing, is to investigate the influence of individual parameters on its crash performance. For instance, while the profile width for the vehicle rocker is predefined for the research vehicle based on the A- and B-pillar attachment points, a suitable width of the battery side frame is to be determined. Since the deformation behavior on component level cannot fully reproduce the behavior of a full vehicle test, due to the lack of vehicle structures and the missing vehicle rotation, the final design is to be determined on a full vehicle level. However, individual parametric influences on the crash performance can be investigated within limits on component level.

The test on component level is carried out using finite element simulation and is set up according to the procedure for the Euro NCAP side pole test, in which the structure collides with a rigid pole at a velocity of 32 km/h and an angle of 75° [35]. For this purpose, the battery side frame is clamped into a constraining system, which consists of a central longitudinal beam and several cross beams. The positions of the cross beams are equivalent to those shown in Fig. 4. The deformation behavior of the side profile was investigated beforehand, with additional mass applied to the structure. The resulting deformation was examined as a function of the added mass. The total structural deformation approximately represents the deformation of the full vehicle model, if the total mass of the constraining system is set to 200 kg.

Therefore, mass is added and distributed evenly across the constraining system. The individual components are meshed with 5-mm element size, with shell elements used for the profiles and solid elements used for representing the weld seams. The profiles are connected to each other via the weld seams using a tied contact definition. For the individual profiles and parts, an according aluminum material card was assigned, which was varied during the investigation. By varying individual parameters, the effect of these on the deformation behavior of the battery side frame can be investigated. For this purpose, the test described above is simulated several times. The deformation of the profile is measured as well as the remaining distance to a reference plane (remaining gap that needs to be maintained). Thus, the potential intrusion into the battery modules can be quantified. The described setup on component level and the different parametric variations can be seen in Fig. 6.

For the tested geometry variants, lower deformation occur with increasing alloy strength (see Fig. 7a). Stiffening the structure with inner ribs as done in geometry "H" and "D" contrary to geometry "E", also has a positive effect and reduces the deformation values consistently. For complex chamber geometries however, the manufacturing process of extrusion profiles is more complicated using higher-strength alloys. Therefore, compromises must be found. In this scenario, the aluminum alloy of a strength class C28 was chosen for the other variations.

From a lightweight and design perspective, thinner and narrower structures are to be favored against wider profiles. While maintaining the same material thickness, thinner profiles weigh less and need less package space. As shown in Fig. 7b), an optimum for the remaining gap can be identified for each geometry variant shown in Fig. 6 with regard to the inner chamber width. For geometries with inner ribs such as geometry "H" and "D" the deformation as such increases for narrower structures, but the initial gap to the reference plane is also increased. This nonlinear behavior results in an optimum regarding the chamber width. The described observation is partially valid for the geometry "E" without additional inner ribs, where the structure deforms more significantly when thinned. The optimum for the structure without stiffening ribs falls therefore within the region of wider chamber structures.

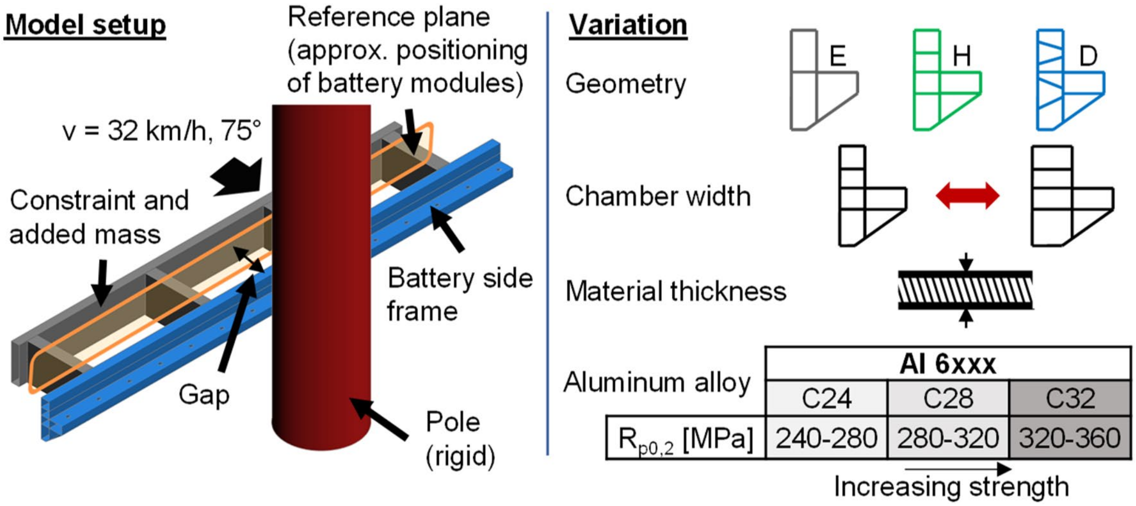


Fig. 6 Setup on component level and performed variations, aluminum strength as in [25]

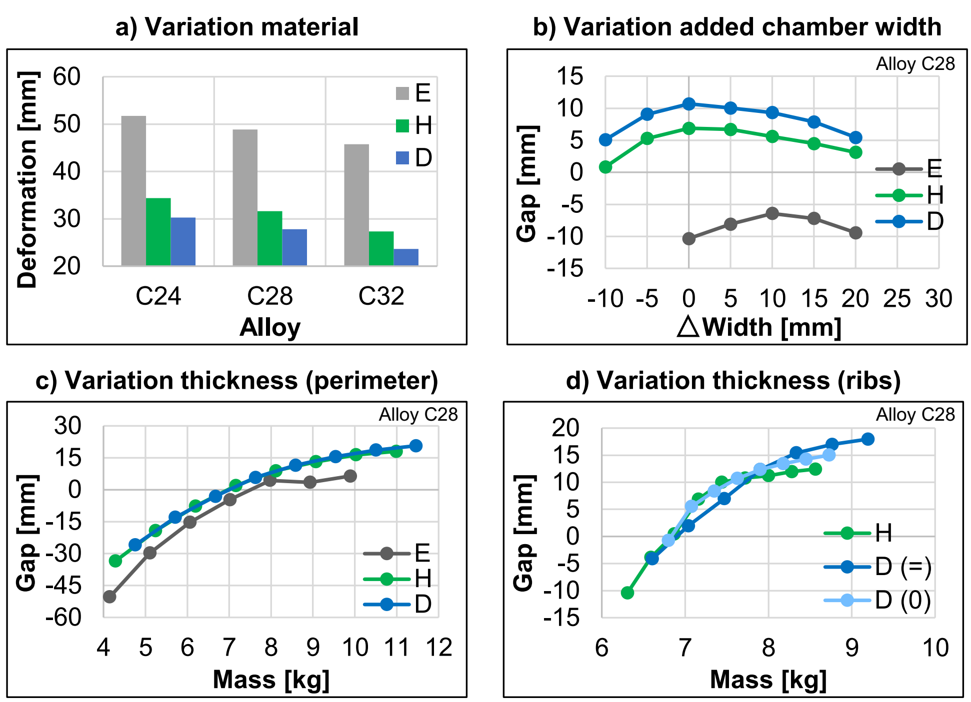


Fig. 7 Results of the variation on component level

When varying the aluminum alloy, as can be seen in Fig. 7a), stiffening with diagonal ribs geometry "D" initially shows better deformation values than stiffening with horizontal ribs as in geometry "H". However, this representation does not take the corresponding mass of the structure into account, as more ribs are used in the diagonal variant "D". The variation of the thickness of the outer perimeter while keeping the thickness of the inner ribs constant on the other hand shows, that the curves of these two geometric variants "H" and "D" are almost congruent. In this scenario, described in Fig. 7c), the chosen design of the inner ribs is less important, as long as ribs are used within the inner chamber, as can be seen by comparison with the geometry variant "E".

Allocating the mass of the structure differently by only varying the thickness of the ribs and keeping the outside perimeter constant, shows slightly different results, which is described in Fig. 7d). As the geometry variant "E" does not have any stiffening ribs, two variations of geometry "D" were investigated. With "D (=)" the horizontal and diagonal ribs were kept the same, while with "D (0)" the horizontal ribs were kept constant and only the diagonal ribs were varied. Comparing these with the horizontal geometry “H”, the version “D (0)” and the horizontal geometry variant show quite similar tendencies with lower thicknesses. However, variant “D (=)” shows better performance with higher inner ribs thicknesses.

Based on these results however, only tendencies can be determined. An investigation of the same load case on full vehicle level, in which the deformation behavior of the surrounding body structure is also taken into account, is therefore necessary.

5.2 Test on full vehicle level

Similar to the test on component level, the general simulative procedure for the side pole impact is based on the Euro NCAP protocol [35]. Two different impact points of the pole were investigated. The first impact point is the original position based on the Euro NCAP protocol. The second position is shifted in vehicle longitudinal direction approximately 110 mm towards the A-Pillar, so that the pole impacts in the middle between the battery cross members “2” and “3” (see Fig. 5). This point is the most critical in terms of deformation, due to the small area of load distribution generated by the rigid pole and the lack of direct support through the cross members. The simulation setup on full vehicle level is shown in Fig. 8

The design of the wall thicknesses of the profiles and the choice of geometry and material alloy have been carried out in iteration loops for these two impact position. Thus, no contact with the battery modules was allowed to occur during the simulation. The comparison for the horizontal and diagonal geometry versions for different aluminum alloys can be seen in Fig. 9. The assessment of manufacturability

	Material	Lightweight design	Manufacturability	Cost**
Horizontal	C32	++	Ø*	Ø*
	C28	0	0	160%
	C24	--	+	110%
Diagonal	C32	Complex to manufacture		
	C28	+	Ø*	Ø*
	C24	-	--	> 200%

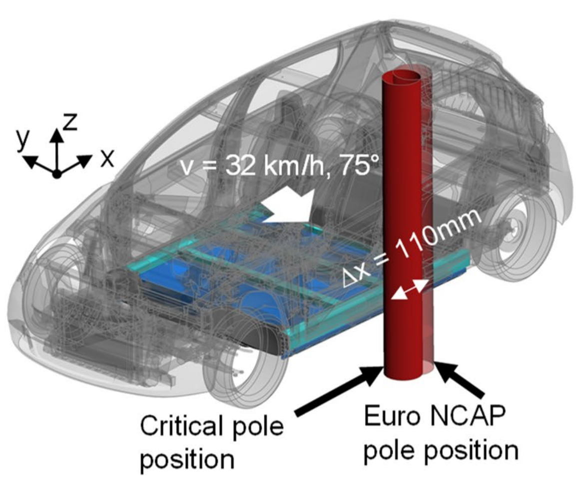
++ very high + high 0 neutral - low -- very low
Ø no evaluation possible

* Profile variants have to be tested more thoroughly, no evaluation possible
** Costs estimated in relation to the base price of EN AW 6060 = 100%

Fig. 9 Comparison of different profile geometries with varying aluminum alloys

and cost has been carried out in consultation with a leading manufacturer of aluminum extrusion profiles.

Similar tendencies compared to the test on component level can be identified. The profiles with higher strength aluminum alloys and complex chambers designs show better intrusion behavior. For a given maximum deformation value, based on the positioning of the battery modules and the resulting initial gap to the battery side frame, the profiles with higher strength alloys can be designed lighter than profiles with lower strength alloys. However, for profiles with such higher strength alloys, the manufacturability and the resulting costs are more critical, especially in combination with complex profile geometries. The high strength variants with diagonal ribs and the required wall thicknesses are difficult to manufacture. In this scenario the most suitable compromise between lightweight design, manufacturability and cost is the horizontal variant with the aluminum alloy



Vehicle information	Compact class
Length (x) * width (y) * height (z)	4,20 m x 1,74 m x 1,48 m
Tested weight of vehicle	1589 kg
Test scenario	**Euro NCAP Side Pole**
Barrier diameter	254 mm
Impact speed and angle	32 km/h, 75°
Simulation duration	0,06 s
Time step	$8{,}43 \cdot 10^{-7}$ s

Fig. 8 Setup on full vehicle level and vehicle information

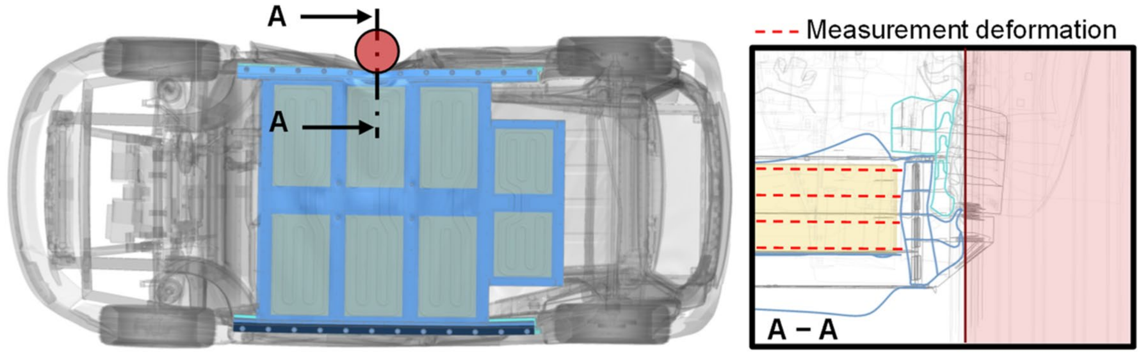


Fig. 10 Rocker deformation during the side pole impact (critical impact position)

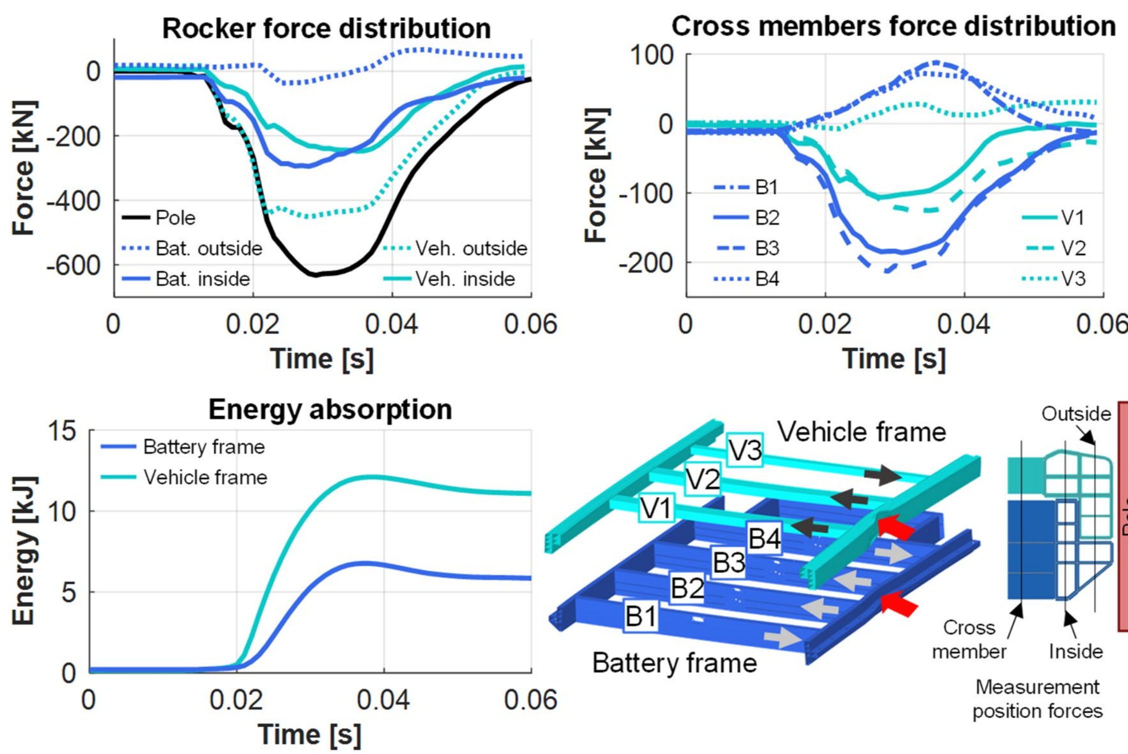


Fig. 11 Load distribution between battery frame and vehicle frame (critical impact position)

of a strength class C28. This combination will therefore be further investigated in the following.

The simulation results for the most critical impact position regarding deformation can be seen in Fig. 10. For evaluation purposes, the deformation of the battery side frame is measured over the height of the battery cells at various points. The remaining gap between the battery modules and the battery frame can be determined and thus contact can be excluded. The inner chambers of the divided rocker are designed to be very stiff. They therefore provide the necessary support for the outside chambers facing the rigid pole, so that these can deform in a controlled manner. The outer chambers absorb energy through buckling deformation.

In the process, the load behavior within the divided rocker and the subsequent load distribution between the vehicle body and the battery housing can be investigated. The corresponding results are shown in Fig. 11. Positive values for forces act in direction of the initial vehicle motion and negative values act in opposite direction. The total of forces are displayed over the respective cross section for each component.

Due to vehicle sided structures facing the pole and the vehicle rotation around the longitudinal axis during impact, the vehicle rocker encounters a more significant part of the load compared to the battery side frame. However, the chosen z-shaped division plane distributes the load relatively

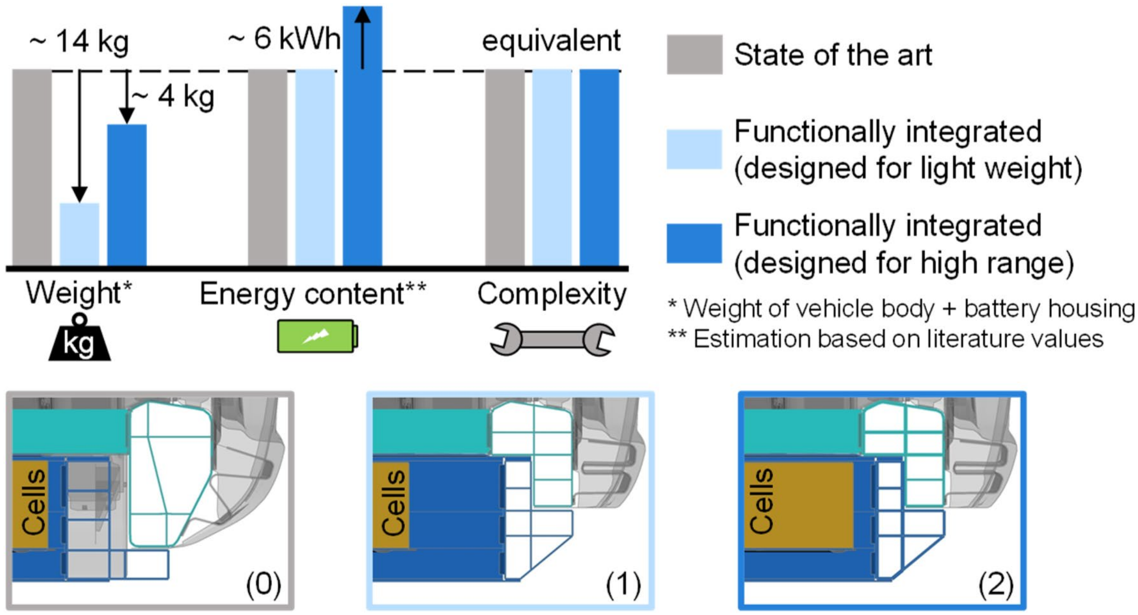


Fig. 12 Comparison between the functionally integrated battery and the state of the art

evenly between the battery side frame and the vehicle part of the rocker structure on the inside of the divided vehicle rocker. The subsequent cross members transfer the applied forces to the opposite rocker. The cross members close to the point of impact experience higher forces in terms of magnitude and act in the initial direction of vehicle motion. The outer cross members are subject to significantly less load and act in opposite direction due to the bending of the frame structure around the pole.

The investigation of the energy absorbed shows that the vehicle part of the rocker absorbs significantly more energy compared to the battery side frame. This can be primarily accounted to the intentional deformation of the outer chamber structure of the vehicle part of the rocker. The outer ribs can deform under relatively high force influences, which leads to energy absorption. The battery sided part of the rocker on the other hand is designed stiffer to protect the battery modules. Therefore, less deformation occurs.

6 Results of the functionally integrated approach

Based on a comparison with a reference structure designed according to the state of the art, the advantages achieved through the functional integration approach can be identified. The reference structure uses the same vehicle body, while the rocker is taken from the original research vehicle. The lower side of the rocker was slightly modified so that a battery housing can be mounted to it. In addition, a vehicle floor panel was added. The side frame structure of the battery housing is designed according to the state of the art in an “L”-shaped contour (see Fig. 2) and is therefore attached to the underside of the vehicle rocker. However, the internal structure of the battery housing is identical to the integrated variant to merely assess the functional integration approach. The comparison between the state of the art (0) and two versions of the functionally integrated concepts (1) and (2) are shown in Fig. 12.

The functional integration approach eliminates structural redundancies and therefore increases the available package space in lateral vehicle direction. For the research vehicle the additional package space is about 70–80 mm. While maintaining the same vehicle width, it is therefore possible to increase the air gap between the side structures and the battery modules (1) or include larger battery modules (2). Whereas the first approach increases the vehicle safety in the event of a side impact due to a larger deformation zone, the second variant increases the storable energy content and therefore leads to a higher vehicle driving range. However, the use of larger battery modules directly affects the structural design of the divided rocker. Due to the smaller deformation space in the event of a side impact, the structures of variant (2) must be designed stiffer and thus require higher wall thicknesses, leading to an increased overall weight compared to variant (1). Nevertheless, a reduction of weight compared to the reference structure (0) can be identified for both variants (see Fig. 12). The shown variants (1) and (2) represent in both cases the extreme. Technically, a compromise between both variants can be found and might be worth investigating in the future.

7 Summary

In this paper, a concept for a functionally integrated battery housing was described. Taking into account various constraints, for example scalability of the battery and the option to detach the battery from the rest of the vehicle, structural redundancies between the vehicle body and the battery housing were avoided. For this purpose, a functionally integrated approach was chosen, in which the direction of integration is targeted from the body to the housing. The vehicle floor was fully integrated into the battery housing lid. Accordingly, the vehicle no longer requires a separate floor. With regard to the vehicle rocker, this component was divided and partially functionally integrated into the battery side frame. The simulative investigation of the battery side frame structure was carried out abstractly on component level and on full vehicle level. In both cases, the side pole impact according to the Euro NCAP protocol was used as the main load case. On both simulation levels, several design criteria were varied and a crash-optimized divided vehicle rocker was successively developed.

The comparison with a reference structure finally showed the benefits that can be realized with the functionally integrated approach. Especially by fully integrating the vehicle floor and partially integrating the vehicle rocker into the battery housing, a weight reduction and an increase of available package space was achieved. The described concept for a functionally integrated battery housing therefore presents a new approach for the optimization of battery electric vehicles.

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Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

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