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Risks and Mitigation Actions in Automated Disassembly of Traction Batteries

O. Mannuss

Fraunhofer Institute for Manufacturing Engineering and Automation IPA,
Stuttgart, Germany

Corresponding author's Email: oliver.mannuss@ipa.fraunhofer.de

Author Note: Oliver Mannuß is group manager Quality and Reliability Engineering. He has done more than 100 risk analyses in industrial projects in branches automotive, machinery and medical/pharma. His research fields are besides machinery availability the risk analysis of safety relevant system in product and production process development.

Abstract: Due to the transition of the automotive industry from combustion engines to alternatives, especially towards electric drives with large batteries, it will be inevitable to rethink the end of life of the components used. Especially the batteries, which are one of the main cost drivers, are only used up to approx. 80% SOC (State of charge) of its initial capacity. To handle the expected volumes of traction batteries it will be necessary to establish automated procedures. Due to the high risks of lithium-ion batteries, special precautions must be taken. Risks associated with machinery are addressed in Europe within the machinery directive. For the manufacturer of the machine it is therefore mandatory to identify potential risk of the machinery itself and in combination with the material handled within the machine. Within the paper, we will identify potential risk with a risk analysis according to EN 12100 for the automated disassembly of traction batteries from system to module level. Classical risks as well as risks associated with the lithium-ion batteries are addressed regarding the prevention as well as potential mitigation actions if the risk already occurred.

Keywords: High-Voltage Battery, Disassembly Process, Risk Assessment

1. Introduction

Even if the CO_2 Emissions dropped recently due to the Corona Pandemic (Sikarwar, Reichert, Jeremias, & Manovic, 2021), it is inevitable to enhance efforts to reach the goals of the Paris climate agreement to hold the increase of the global average temperature well below 2 °C (Secretariat UNFCCC, 2015). Embedded in the European green deal by the European commission, Germany sets its limits for CO_2 Emissions with the law of the Climate Change Act in 2019. After the highest court in Germany, the Federal Constitutional Court German, ruled that the “state’s duty of protection arising from Art. 2(2) first sentence of the Basic Law also encompasses the duty to protect life and health against the risks posed by climate” and that the concrete dates and targets set in the law were not sufficient (*Federal Constitutional Court (Germany) - Order of the First Senate of 24 March 2021)* the German parliament adopted the Climate Change Act including a reduction of CO_2 Emissions in 2030 of 65% compared to 1990. Even including the reductions already achieved, the law specifies the reductions necessary by each sector as described in Figure 1.

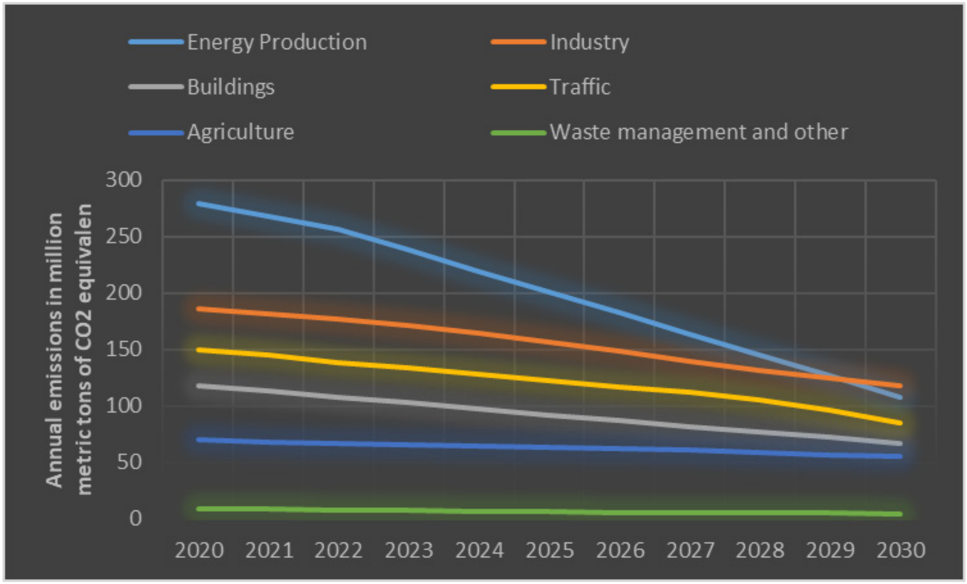

Figure 1. Adopted Climate Change Act (Germany) – annual CO2-equvalent Emissions of sectors up to 2030

To reach the targets for the transport sector a major increase in the usage of electrified cars is necessary, as also addressed with the "Charging infrastructure master plan" of the federal government. Up to one million electric vehicles will be expected on german roads by 2022 with an increase almost tenfold by 2030 as mentioned by forecast of the national electromobility platform (BMWI, 2020). This will lead to an enormous increase in the expected volumes to handle for reuse or recycling, especially due to that Batteries will only be used in electric vehicles until approx. 80% SOC compared to its initial values (Rohr, Wagner, Baumann, Muller, & Lienkamp) and are one of the top valuable elements of the cars with up to 30% of the costs (D'Souza, Patsavellas, & Salonitis, 2020).

Right now only up to 5% of the batteries are recycled or reused and the processes are not meeting the cost efficiency (Melin, 2019). For the disassembly most parts are done manually which will not be possible for the upcoming higher volumes due to qualified labor shortages and, as already mentioned, the costs (Harper et al., 2019) especially in regions with high labor costs. As of today no automated disassembly of Li-Ion is used in industrial setting (Tan, Chin, Garg, & Gao, 2021), but it is seen as an key enabler of circular economy (Glöser-Chahoud et al., 2021).

Besides the technical aspects and the challenges to achieve a partially or fully automate disassembly process, like the flexible handling of highly variable battery designs and small volatile batch sizes (Kwade & Diekmann, 2018), another major issue are the safety risks by handling traction batteries (Tan et al., 2021).

2. Risk in Disassembly

Li-Ion batteries inherit some risk due to handling that can lead to a thermal runaway which can have severe consequences (Williard, He, Hendricks, & Pecht, 2013). Generally, the risk can be classified into four categories: electrical, thermal, chemical and mechanical hazards (Enderlein, Krause, & Spanner-Ulmer, 2012; Gentilini, Mossali, Angius, & Colledani, 2020).. Despite this classification, the various hazards are strongly interrelated (see Figure 3). The mitigation measures for assembled batteries mostly include the logic of the battery management, which can detect and react to critical situations like high current flow or a to high temperature measured with the NTCs inside, but during disassembly those mitigation measures are not available due to an already disassembled/disconnected logic (Zhou, Garg, Zheng, Gao, & Oh, 2021). Potential Standards or Guidelines to address the risk during disassembly are not available (Kong, Li, Jiang, & Pecht, 2018). While some approaches addresses the risks of manual disassembly (Harter, Mcintyre, & White, 2020) an automated disassembly is seen an opportunity to decrease risks for workers (Tan et al., 2021). But even with automated disassembly, risks remain (Blankemeyer, Wiens, Wiese, Raatz, & Kara, 2021) and it is clearly stated that further research regarding risks in automated disassembly is necessary (Bravo Diaz et al., 2020; Zhou et al., 2021). Additional in an automated Process also other risks can emerge due to the machineries used in the process (Gumanova & Sobotova, 2019), especially if a robot is used to address the variability necessary for the disassembly of the various variants.

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2.1 Risk analysis methodology for automated disassembly

For the disassembly process from pack to module level a flexible robot cell is assumed and in focus of the following analysis.

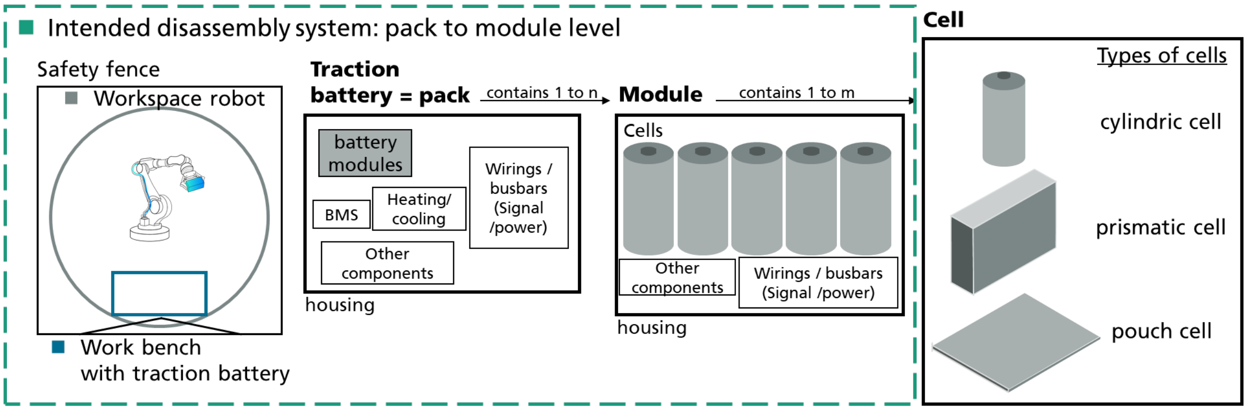

Figure 2. Disassembly process from pack to module level

Within the research project, it is a goal to realize potential risk in such concepts and derive potential mitigation measures on concept level for a future detailed design of such systems. If such a system will be later used in Europe it is necessary to ensure that machinery comply with the machinery directive (Directive 2006/42/EC, 2006). Therefore, an approach using a risk analysis methodology according to EN ISO 12100:2011 has been applied. Based on previous work (Mannuß, Borchardt, Mandel, & Sauer, 2020) the risks derived in the process steps of a manual disassembly had been transferred to the potential automated disassembly. It can be distinguished between risks directly resulting due to the use of a robot and the different types of end effectors and the risks due to the disassembled battery in this setting. The first named, type of classical risks can be easily addressed with a safety fence and standard safety devices (DGUV, 2016). For the later the risk analysis has derived the following main issues, regarding the handling of the batteries (see also Figure 3):

- Mechanical risks: Impact on the modules
  - 1: Mechanical forces due to fall of disassembled components on the module
  - 2: Mechanical forces due to grip the modules
  - 3: Mechanical forces due to fall of the modules

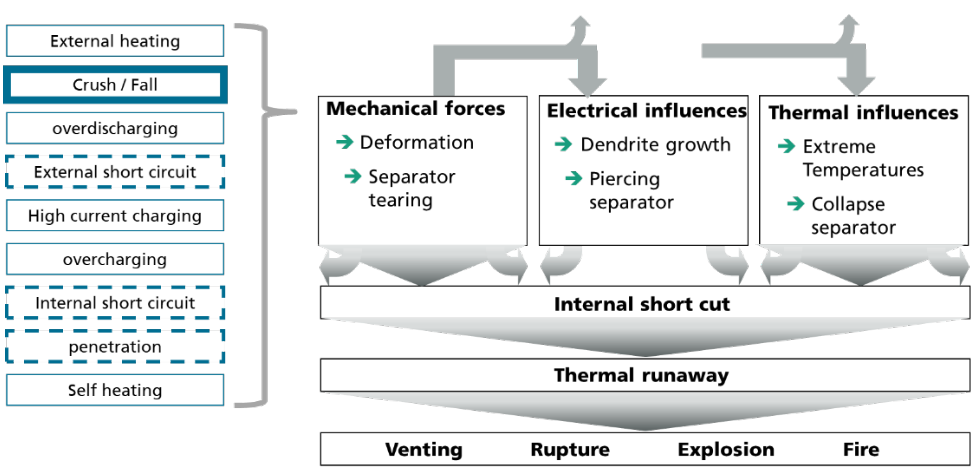

Figure 3. risk and causes of a thermal runaway – in consideration of a disassembly process from pack to module level (figure inspired by (Börger, Mertens, & Wenzl, 2019; Chartouni, He, & Andersson, 2020; Feng et al., 2018; Jindal & Bhattacharya, 2019; Wang, Mao, Stoliarov, & Sun, 2019)

2.2 Risk reducing measures

To generally reduce risks during disassembly of batteries one possible solution is to use only deep discharged batteries and therefore avoid the potential problem for a thermal runaway (Li et al., 2019; Markowski, J., Narra, S., Ay, P., Pempel, H., & Müller, M., 2014). However, batteries treated in this way can only be materially recycled and the intended reuse of one or all cells is not possibly as advised. Therefore, the following requirements and concepts have been derived for the mentioned risks.

2.1.1 preventive and impact-limiting measures

One of the uncertainties for deriving maximum endurable forces on the modules is that the module housing can additionally absorb and dissipate forces. To derive a worst-case limit, the assumption can be to ignore the housing and assume that the forces are directly on the cells. For Risk 2, grip forces on modules, another worst-case assumption is that all forces are concentrated on one cell inside the module. If presumed that the cells used in the modules are commercially available cells they would have to pass standard tests e.g. according to EN IEC 62660-2:2020-07 and EN IEC 62281:2020-08. The tests mandatory according to the standards can be used to derive minimal forces that can be assumed that they would not lead to thermal runaways. For example, EN IEC 62281 apply forces up to 13kN on the cell and if after 6 hours there is no significant warming it has passed this test. The forces in this test are for all kind of batteries identical, but the direction of the load is e.g. for a pouch cell only applied on the flat side of the cell. In contrast to this standard, the standard EN IEC 62660 includes a test with forces that are applied with a defined hemisphere crushing tool and depending on the weight of the cell as well as a defined deformation (max. 15% of the thickness). It was possible to derive an estimation tooling (see Figure 2) that signals if depending on the variables of the cell and the variables on the intended gripping forces necessary for technical reasons (e.g. lifting the modules) the forces are below critical levels.

A similar model was developed for the Risk 1+3. The main differences are that there are not static forces, but forces due to an impact and different standards have to be considered (e.g. EN 50604-1:2017-05; EN 62619:2017-11). Therefore, other variables have to be included in the estimation model, e.g. the number of cells in a module (=total weight of the module/total weight of the component to fall on module). It is possible to derive a maximum height for a noncritical fall of the module.

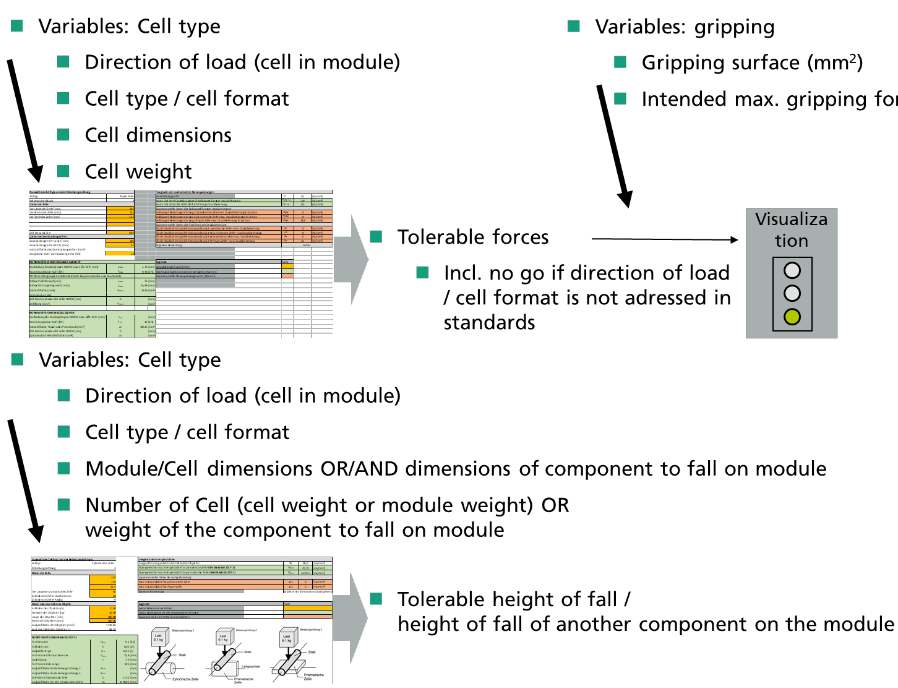

Figure 4. developed estimation models for gripping force and fall of/on modules

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Therefore, the following requirements/concepts for these mechanical induced risks can be derived:

Safety requirement/concept 1 (verification): For each battery variant, the necessary gripping forces have to be compared to the maximum forces of the estimation model. If the forces cannot be matched larger grippers or other grippers have to be used.

Safety requirement/concept 2a (design): to limit the possible height of fall for modules and to minimize the time for possibility to have a fall event the modules have to be placed after the disassembly on an area near to the disassembly bench and not with large differences in height during the movement of the modules.

Safety requirement/concept 2b (verification): For each battery variant, the possible height for fall have to be compared to the maximum height allowed by the estimation model.

Safety requirement/concept 2c (safety related control function): The maximum height for movement should be considered as a safety related control function according to EN 13489-1 as a Safely Limited Position (SLP) with a Performance level (Pld). Additionally, the grip of the module should be ensured as well with a safety related control function according to EN 13489-1.

Safety requirement/concept 3 (robot teaching): Movement of objects over modules should be avoided or, if this is not possible, the weight of the objects should be compared to the results in the estimation tool.

2.1.2 Detection and reaction measures

Even if the above mentioned safety requirements are considered, there is still a possibility for critical events. That leads to the necessity to first: detect a potential thermal runaway and second: to react to them. Some existing approaches note that a thermal detection mechanism is necessary (Gerlitz, Greifenstein, Hofmann, & Fleischer, 2021), e.g. based on thermal cameras. On the other side if a potential thermal runaway is detected, there have to be actions fulfilled in the system to mitigate the risk. One example of such a measure is described in the planning of the disassembly of smartphones, in which in case of detecting a thermal event compartment of the battery is flooded with sand "to snuff out any possible thermal event" (Rujanavech et al., 2016). For the intended disassembly system the two following requirements were derived:

Safety requirement/concept 4 (safety related control function - detection): Thermal runaways should be detected either with devices that have a Performance level (Pld) according to EN ISO 13849-1:2016-06 or with a diverse redundance combination of devices – e.g. one thermal camera and a smoke detector. If the second approach is used both devices should be manufactured according to domain specific standards (Bömer & Schaefer, 2011) and seems to be the more appropriate approach (Wang et al., 2019).

Safety requirement/concept 5 (safety related control function - reaction): If a potential thermal event is detected a fast ejection and transportation of the complete pack inside a safe area should be ensured.

A first design of this concept consist of an ejection cylinder to push the battery from the disassembly bench on a inclined roller conveyor. Further, it is transported by the effect of gravity into a safe box. This box should then be self-sealing and should be filled with suitable materials (e.g. pyrobubbles) that absorb the heat generated and provide additional time for manual removal.

3. Conclusion

The presented approach already achieved promising results for the derivation of additional safety requirements for an automated disassembly unit for traction batteries from pack to module level. Since the concepts for each step of disassembly are in an early design phase a permanent update along the development process for the machinery of the disassembly unit will be carried out. Additionally, it is intended to integrate risk warnings according to selected actions in the graphical user interface that will be developed to support the teaching process of new batteries.

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