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A modular design concept for a guide railing system of conveyors for beverage filling and packaging lines

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Abstract

In this paper, a new design concept for a modular guide railing system in a beverage production line is presented that requires no manual labor to adjust the railing, thus drastically reducing the down-time and increasing the flexibility. Starting point of the methodical design process are the requirements that were derived from distributed engineering teams across Europe, North & South America and Asia. Necessary functions of the railing are derived from these requirements and first ideas based on solution principles are drafted. Next, a morphology is used to combine and select the highest ranked concepts. Three of these concepts were designed in 3D-CAD and evaluated by an experienced engineering team. Using a paired comparison, the best ranked concept was then realized as a prototype in stainless steel by applying selective laser melting.

1 Introduction

The modern beverage and food market offers multiple challenges for manufacturers of complete filling and packaging lines. First of all, regarding the manufacturers, the market is characterized by an oligopoly-oriented structure, meaning that only a handful few competitors divide the potential market zones. The established solutions for production lines are very similar nowadays, and unlike in the market of telecommunication, the typical evolution in beverage technology has been linear and not disruptive so far (Foitzik, 2000). Thus, it is very hard to distinguish featurewise between different manufacturers, which leads to intense price competitions and high discounts. Adding to this development is the ongoing organisation of customers in large-scale enterprises, increasing their market power (Kowalik, 2004).

Secondly, the customers constantly demand more flexibility from production lines. In order to distinguish new beverages from competitors and existing products, beverage containers are usually offered in various shapes and sizes, which is a huge challenge for current production lines. Typical for such lines is the usage of conveyors to link different machines, e.g. blow-moulders, filling machines, inspections, labellers and packaging machines (Kallies, 2005). These conveyors transport the containers or packs in an upright configuration on flat mattop chains. Each machine possesses different infeed and outfeed requirements which makes it necessary that the conveyors also manipulate the container and pack formations accordingly. This is usually achieved by a complex guide railing system on the conveyors.

To complicate this manipulation task, modern production lines can incorporate up to 24 different container formats. Since the product appearence is a unique selling point (Bleisch, 2003), these containers need to be handled with great care. In order to offer the needed flexiblity for different containers in the same production line, the guide railing system needs to be adjusted to each format. This can be achieved in multiple ways, e.g. by using „format parts“, which are tailored for specific containers and are exchanged every time the format is changed. Due to the shear areal size of production lines, this leads to high costs and noticeable down-time, which is not acceptable for the customer. Therefore, another possibility is to increase the adjustability of the guide railing itself without the use of format parts. This option represents the chosen approach in this paper, because it offers the advantage of less down-time combined with lower costs and higher versatility.

2 Design task and Focus of the paper

The design task at hand is to create a modular concept for a guide railing system, which is quickly adjustable to different formats at the production line on the installation site of the customer. Furthermore, the concept must fit on every existing container conveyor at KHS and should require no manual labour with regards to cutting, drilling and countersinking of the guide rails, therefore reducing the overall costs.

The following research questions in context to the above design task need to be answered:

1. Is it feasible to adopt a theoretical model of a systematic design approach in a real-world environment for an industrial application?
2. Which initial requirements exist with regards to the design team and what advantages and disadvantages can be deduced from using a methodical approach compared to a pragmatic, straigth-forward design process?

As a basis for the given task, the methodical design approach of the guideline VDI 2221 was chosen, which ensures the drafting and evaluation of different concepts based on identified functions and their active principles (VDI, 1993). These are then combined in a morphology to form complete solutions. After ranking the concepts with the help of criterias derived from the requirements, the best concept is to be realized by rapid prototyping and put under mechanical load equivalents that can be observed in a typical production environment.

3 Requirements for a modular guide railing system

The starting point of any design process is to identify and prioritize the design requirements (Ponn et al., 2011). As straight forward as this sounds, as hard it can be sometimes in an industrial application that has been available for decades. Therefore, it is neccesary to use a structured approach to generate a „complete“ set of requirements. Three steps are considered:

1. Analyse the existing solutions and derive current requirements,
2. complement the requirements by checking the main characteristics (Pahl et al., 2007),
3. incorporate the requirements of all stake-holders of the lifecycle of the product.

Starting with the first step, figure 1 shows the mechanical setup of the current solution for the guide railing system on a straight conveyor. On the right side, a close-up of the guide rail support for one specific installation situation is depicted.

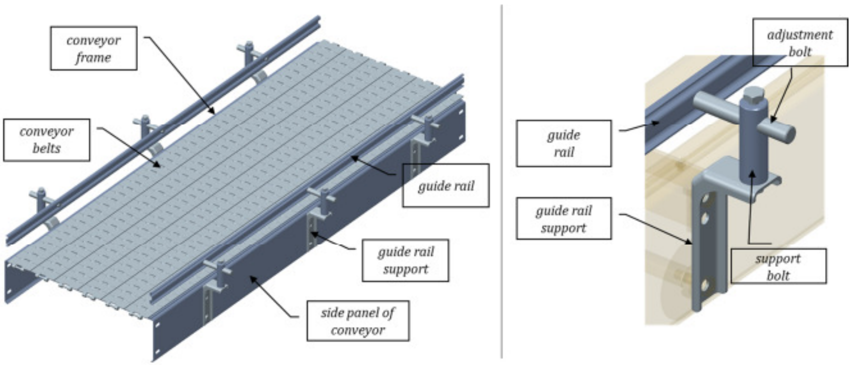


Figure 1. Left side: straight conveyor frame. Ride side: close-up of guide rail support and mount

The current solution consists of a rail support, which is mounted by the help of two screws on the side panel of the conveyor (see figure 1, right side). On top of the support, two bolts are connected, which offer the final mounting point for the guide rail itself. The guide rail is also fixed by the means of screws to the adjustment bolt. For straight conveyors, the rail in the form of an m-profile is pre-perforated and requires no manual drilling. For every other situation, e.g. in curved conveyors or angled setups, it is nowadays necessary to manually drill and countersink the m-profile. This makes a very expensive assembly, if one considers that a typical beverage production line contains on average roughly 200m of guide rails with 2 mounts each 1m. These mounting solutions on different conveyor types were further analysed. Figure 2 presents an excerpt of the conducted analysis.

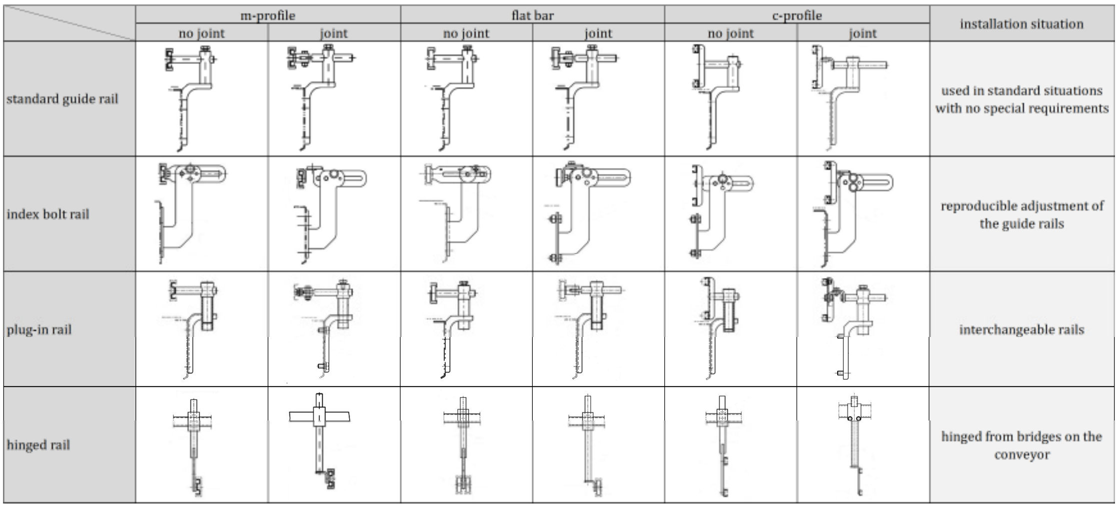


Figure 2. Excerpt of the analysis of installation situations for the guide railing system

The analysis provided the geometric requirements with regards to the preferred installation space, the available mount positions for backwards compatibility, the number of used components and the directions and maxima of the mechanical loads. Due to the lack of empirical data for the acceptable mechanical loads, tests of the current guide rails revealed a maximum load of 800N before plastic deformation occured. Furthermore, corrosion is highly expected in modern production lines, since hygiene is a key factor when producing beverages and therefore very aggressive cleaning and desinfection agents are used. This leads to stainless steel as a material requirement, which is known for its high resistance.

To complement these requirements, steps two and three were executed. By checking the main characteristics according to Pahl & Beitz and including departments like engineering, production planning, production, assembly, quality control, installation and rampup as well as spare parts of the later phases in the life cycle, the subsequent requirements could be derived. Regarding the engineering and manufacturing, the annual usage of roughly 28.000 mounts for the guide rails world-wide is set. This number was validated by contacting the distributed engineering teams across Europe, North & South America and Asia. They also added further important requirements, i.e. material availability world-wide and necessary metric and imperial tools for installation purposes.

The inhouse production department requested a solution which is quick to mount and requires less assembly time than the current solution. Combined with a cost analysis of the existing solution, a target price for each component of the guide railing system could be fixed. During the installation and rampup phases at the customer site, assembly personnel often misuses the fixed bolts to adjust the angle of the guide rails. Therefore, tension forces in direction of the adjustment bolt must be taken into account. In case of a faulty inhouse assembly, the guide rails should be easily adjustable at the customer site, meaning that the connection between the bolts and the rail needs to be easily detachable. Also, it is necessary to allow retrofitting existing solutions with the new, detachable guide rail solution. For this action, no special tools shall be required. To increase the aftersales business, the spare part department suggested a solution that can only be used in KHS production lines and that can be clearly identified as a unique KHS part. Table 1 shows an excerpt of the main requirements list, which was then prioritized in a team meeting, involving all of the above mentioned departments.

Table 1. Requirement specification of the guide railing system (excerpt)

			Requirements specification	**Created by:** **Created at:**	**Changed by:** **Changed at:**
No.	Responsible Eng.	Type of Req.	Detailed requirement	Remark and explanations	
1			**Geometry**		
1.1	SR	F	main dimensions for preferred installation space	width x heigth x depth: maximum: 100x50x50 (mm) minimum: 30x15x30 (mm)	
1.2	SR	F	number of used components	maximum: 7; ideal: 2	
1.3	SR	F	backwards compatibility / retrofitting possible	use standard hole pattern	
2	SR		**Mechanical loads**		
2.1	SR		maximum pressure load orthogonal to conveyor direction	up to 800N	
2.2	SR	F	functional reliability when tension forces are applied	rails must be fixed safely to the guide rail mounting device, connection must withstand tension forces > 200N	
3	SR		**Material properties**		
3.1	SR	F	standard parts made of stainless steel		
3.2	SR	F	anti-corrosion characteristics with cleaning and desinfection agents	cleaning agents accord. to internal company norm K0225	
3.3	SR	F	material shall not creep under load		
4	SR		**Production**		
4.1	SR	F	manufacturing process accord. to annual lot size	annual lot size = 28.000 pcs / yr	
5	SR		**Assembly**		
5.1	SR	F	generelly minimize the effort to assemble the solution		
5.2	SR	F	assembly possible without drilling		
5.3	SR	F	assembly possible without welding		
5.4	SR	F	assembly time	maximum 135 seconds, ideal 30 seconds (calculated)	
5.5		F	bending of rail profile easily possible with current bending machine		
5.6		F	rail profile geometry still intact after bending		
5.7	SR	W	no special tool needed for assembly		
5.8	SR	W	check tool availability for imperial vs. metric markets		
6	SR		**Installation, rampup and spare parts**		
6.1	SR	F	connection must be easily detachable between guide rail and mount without destroying any component		
6.2	SR	F	joint function must be integrated		
6.3	SR	W	can be used in all identified installation scenarios		
6.4	SR	W	unique KHS part which can be identified	e.g. use of logo and spare part number on surface of part	
6.5	SR	W	hygienic design of the connection device		
6.6	SR	W	hygienic design of the rail		
7	SR		**Costs**		
7.1	SR	F	cost of one assembly / mounting area is fixed		
			Type of requirement F - fixed; W - wish / optional;		

4 Design concepts and Morphology

From the analysis of the current solutions of the guide railing system, the following functions are identified: (1) attach solution, (2) adjust railing and (3) contact container (see figure 3). These main functions are decomposed into sub-functions with corresponding physical parts, following the approach of a function-means tree. In addition to the identified functions, the requirement specification (see table 1) is the basis for the start of the synthesis.

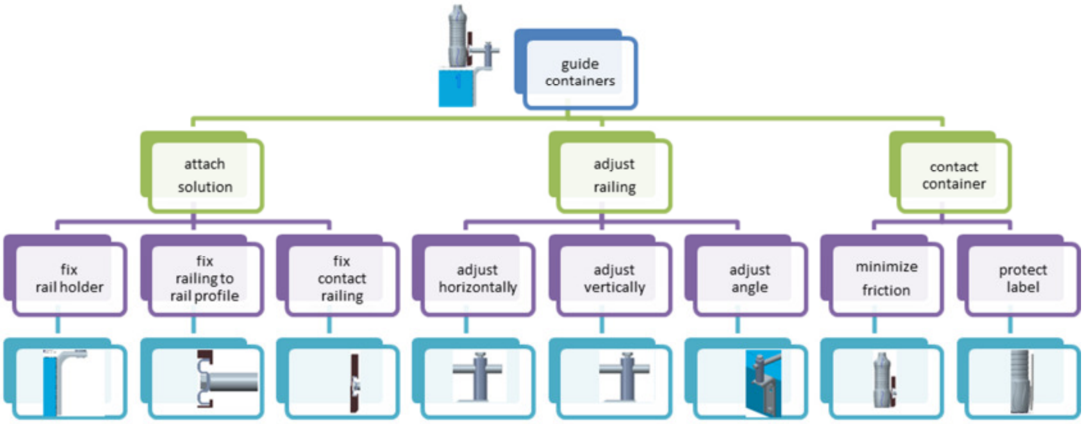
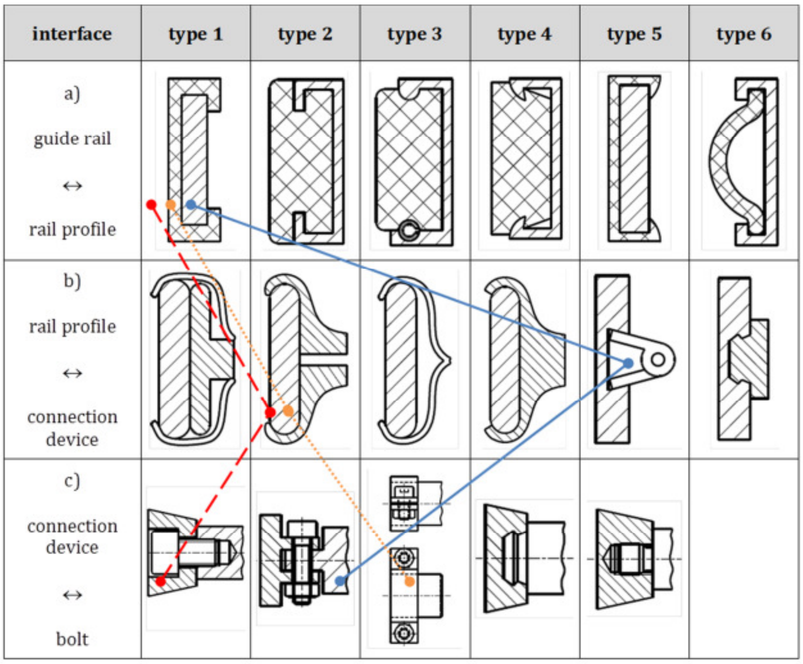


Figure 3. Functional decomposition of the current solution based on function-means-tree logic

The chosen approach of this paper is to generate a solution that does not need format parts, but instead provides high flexibility for the adjustment of the guide railing. In order to systematically create the desired modularity, the concept is divided into three interfaces: a) guide rail profile - rail profile, b) rail profile - connection device and c) connection device - rail holder. A summary of all possible combinations based on a morphology can be found in the following table no. 2 and the combined concepts are marked by coloured lines.

Table 2. Morphology of the new guide railing concept



interface	type 1	type 2	type 3	type 4	type 5	type 6
a) guide rail ↔ rail profile						
b) rail profile ↔ connection device						
c) connection device ↔ bolt						

Starting off with the first interface (guide rail and rail profile), six potential connection methods were identified: (1a) sliding the outside guide rail onto the rail profile, (2a) sliding the guide rail inside the rail profile, (3a) clipping the guide rail in, (4a) crimping the guide rail, (5a) pinching the guide rail or (6a) clamping it by using elastic material properties.

Regarding the second interface (rail profile and connection device), six possibilities were identified: (1b) an elastic bracket as an add-on element, (2b) clamping by external force, (3b) an elastic bracket also acting as the rail profile itself, (4b) pressuring the guide rail, (5b) clamping internally and (6b) clamping it by using elastic material.

The third interface between the connection device and the bolt revealed five potential ideas: (1c) screwing on the front side or (2c) screwing vertically, (3c) clamping with a two-part device, (4c) fixing by partially spreading an elastic material or (5c) directly screwing the bolt into the connection device.

In the next step, the different solutions in the morphology were combined to form overall design concepts. Three main concepts were chosen to be further detailed with the help of CAD (see figure 4). The first concept (1a, 5b, 2c) combines the sliding of the outside guide rail onto the rail profile with an internal clamping of the rail profile to the connection device and a vertical screw mount of the connection device to the bolt. As shown in figure 4 on the left side, the clamp consists of two identical parts, which are bended spherically in order to generate a clamping force inside of the rail profile once the clamp is screwed onto the bolt. The rail profile itself has two trapezoidal grooves which can be used as the counter-surface for clamping.

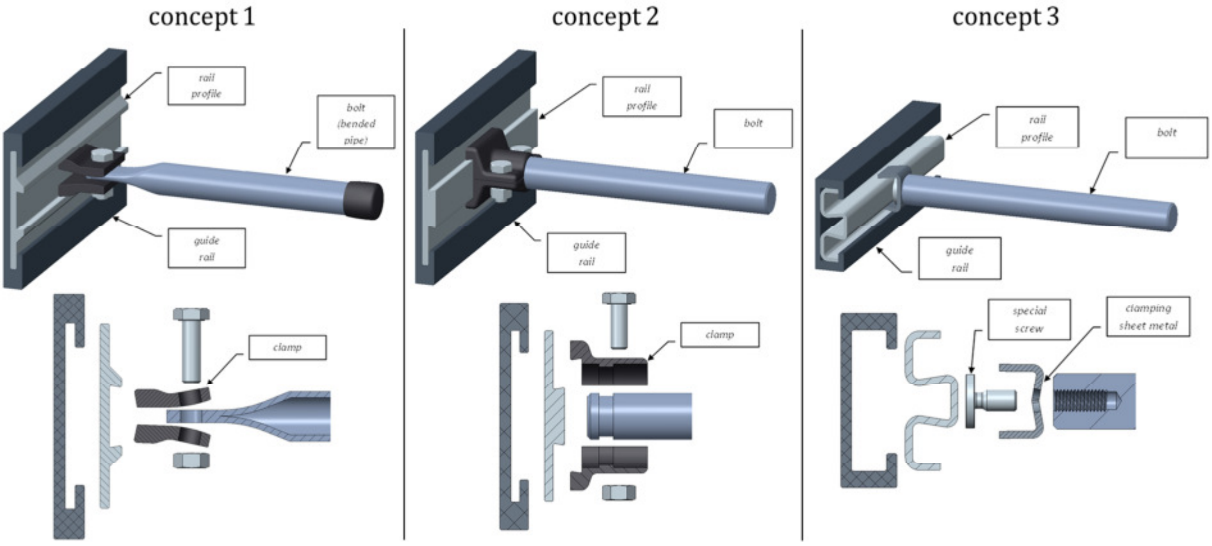


Figure 4. Detailed view of the three chosen concepts

As for the second concept (1a, 2b, 3c), the sliding of the outside guide rail onto the rail profile is used in conjunction with the external clamping and a two-part connection device. The clamp features two screws to deploy the appropriate tension force for the connection to the bolt. The rail profile has an integrated trapezoidal part on the backside which occurs as the negative form at the clamp. Ensuring a proper fit, the bolt can also be secured with regards to torsion without additional parts.

The third concept (6a, 2b, 5c) combines the sliding of the outside guide rail onto the rail profile with the external clamping and screwing on the front side of the bolt. In contrast to the previous solutions, the clamp consists of a bended sheet metal in a W-shape, which flattens once screwed into the bolt. By flattening the sheet metal, it will turn into a V-shape, therefore creating a clamping force on the outer trapezoidal rim of the rail profile, holding it firmly in place.

The detailed concepts are ranked via criteria which reflect the requirements specifications, i.e. hygiene, design to assembly, component cost, assembly cost, number of parts, backwards compatibility, amount of needed guide rail material, reliability and multiple usage of the clamp. In a paired comparison, each member of the design team could weigh these criteria according to the priorities. Following the guideline of the VDI 2225, the comparisons made use of the 0-4 point scale, with 0 = unsatisfying, up to 4 = ideal solution (VDI, 1998). After prioritizing the criteria in the paired comparison, the three concepts were rated in a team meeting by using the European grading system of 1 = very good up to 6 = unsatisfying. This system was chosen because each team member could easily grasp the grade concept without further explanation. Figure 5 shows the ranked concepts with the final scores.

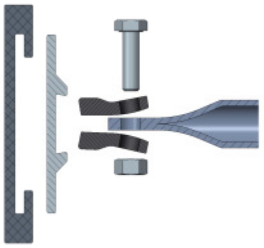
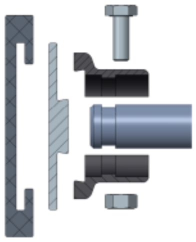
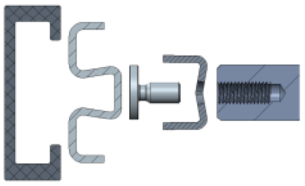
detailed concepts	hygiene	design to assembly	component cost	assembly cost	number of parts	backwards compatibility	amount of needed materials for guide rail	reliability	multiple usage of clamp	sum	**weighted total score**
	1,06	1,93	2,63	2,57	1,26	1,54	2,09	3,30	1,43		
concept 1 	3	4	3	3	4	2	1	4	1	25	
	3,18	7,72	7,89	7,71	5,04	3,08	2,09	13,20	1,43		5,70
concept 2 	4	4	3	3	4	2	1	2	1	24	
	4,24	7,72	7,89	7,71	5,04	3,08	2,09	6,60	1,43		5,09
concept 3 	6	2	3	2	1	2	1	5	3	25	
	6,36	3,86	7,89	5,14	1,26	3,08	2,09	16,50	4,29		5,61

Figure 5. Ranked concepts with weighted criteria

5 Design draft for chosen concept and rapid prototyping

Based on the weighted total score of the concepts in figure 5, the second concept with the score of 5.09 is the highest ranked solution (with the lowest score equalling the best grade) and is therefore chosen to be further detailed. Although the third concept offers a huge advantage when it comes to assembly time and cost, its functional reliability was rated very low after a preliminary test. This is due to the fact that the W-shaped sheet metal part loses its elasticity quickly after one mount/dismount cycle due to strain hardening. Therefore, as it is often observed in real-world industrial design processes, a modular combination of the different concepts was created. This combines the advantages of concept 2 and 3 while trying to minimize the drawbacks of each solution. The advantage of the third concept to directly clamp the m-shaped rail profile is used in conjunction with a more sturdy two-identical parts clamp of concept 2.

The final design draft is shown in figure 6 and offers the possibility to configure the connection clamp to either a straight-line or angled version, depending if either a straight bolt is used or a perpendicular flat profile. In order to quickly create a first test version of this design, rapid prototyping was chosen as the preferred manufacturing method. After a 3D-printed plastic mock-up version of the clamp received a positive team feedback with regards to the overall design, a more realistic version was produced by choosing selective laser melting. This method uses a laser to melt metallic powder and forms the desired part in almost any shape without huge costs regarding tooling or expensive machining. Even stainless steel samples can be produced and unlike in selective laser sintering, the prototype is completely solid. Therefore, typical mechanical loads according to the requirement specification can be tested with this prototype. Figure 6 presents the final design in the upper row and a realized SLM prototype in stainless steel at the bottom.

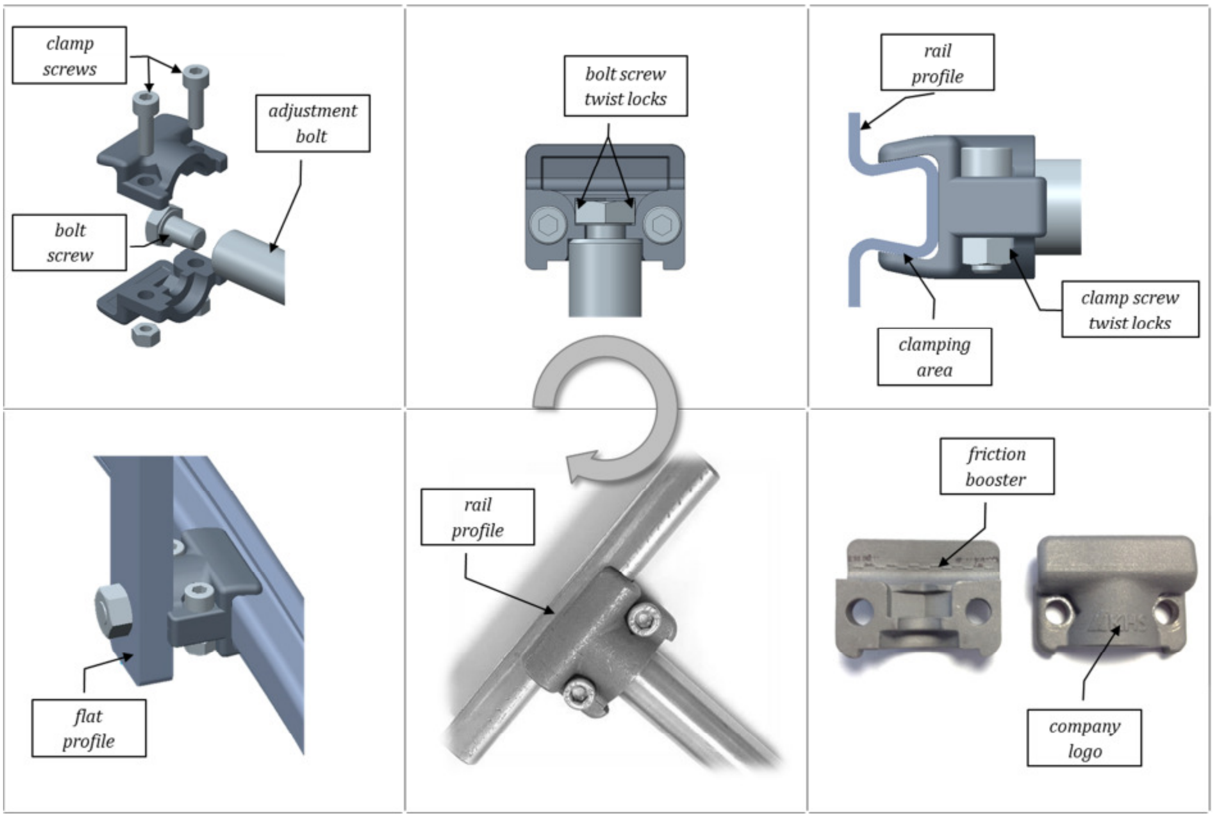


Figure 6. Evolution of the design draft to the SLM prototype

6 Test setup and Discussion

With regards to the necessary testing, three major test cases were examined (see figure 7). In each case, the force was slowly increased and measured by a calibrated load cell. The displacement was checked by using a mechanical dial gauge. Since the clamp was the main test subject, it was decided that parameters like surface roughness, clamping forces and opening angle of the clamp would have major influences and should be controlled closely. Since the clamping force is linear to the torque which is used to tighten the screws, this was set to the maximum for all tests by using a torque wrench.

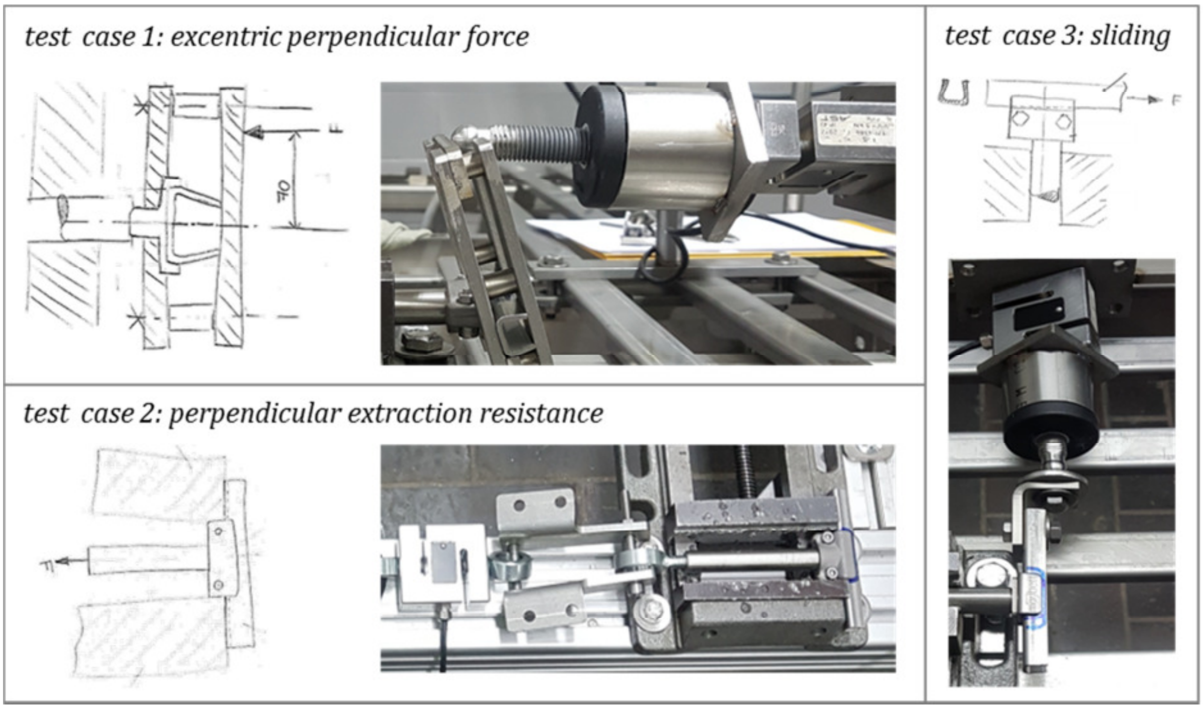


Figure 7. Overview of test cases for the prototype

The first test case applies a perpendicular force to the guide rail with a lever arm of 70mm. This bending test reflects containers on the conveyor which put pressure from the inside to the outside direction and is typical for accumulation situations in a production line. The results showed a huge displacement at approx. 150 N with several millimetres, which is not acceptable. After discussing the setup, it became apparent that the test does not reflect reality, because the test-clamping bracket of the guide rail is far too rigid. The test was then repeated with the original material & brackets for the guide rail and showed very promising results. The previous limit could be increased up to 850 N before the displacement was not acceptable anymore, therefore exceeding the limit of the current solution.

The second test inflicts a perpendicular extraction force onto the clamp, which mimics the assembly personnel trying to modify the guide rails at the customer site by pulling at the connection bolt. The tests indicate a maximum extraction force of more than 2000 N, which by far exceeds the forces manual labour creates. With regards to the third test, the rail profile started sliding around 1000 N, which also by far exceeds the requirements. This test reflects the friction between containers on the conveyor and the induced friction forces at the guide rail. Due to the small contact area of the containers and the guide rail, the reached maximum force before sliding is roughly 5 times higher than it would appear in reality.

7 Conclusion and Outlook

In this paper, a systematic design approach is shown which aims to develop a modular concept for a guide railing system in a beverage production line. The process starts with a structured specification of the requirements and the main functions. Furthermore, the current solutions are analysed and divided into modular parts with set interfaces. Then, three different concepts are created and ranked based on criteria according to the specifications. The best concept is chosen to be detailed in CAD and gets realised in a two-stage process. The first stage consists of a 3D-printed plastic mock-up version, which is then used as the basis for the metal prototype, manufactured by selective laser melting. This prototype is thoroughly examined by predefined test cases in order to assess its mechanical characteristics. These tests showed very promising. Due to the annual lot size of around 28.000 pieces, precision casting was chosen as the desired method as a cost effective manufacturing method suitable for mass production.

With regards to the research questions, the following can be stated:

1. Although the methodical design approach takes more time, especially at the early design phases, it is highly recommended. This is due to two main facts. Firstly, without the help of the systematic check lists, the requirements would have been incomplete and a lot of necessary design goals would have not been specified. Secondly, the different concepts did take some time to be created, but proved to be a great basis for group discussions and evaluations to finalize the design draft. Without these deviating concepts, the best idea would not have been found. The time invested in early phases is easily saved later on by fewer design and test iterations.
2. Before using a methodical approach, the lead designer of the team needs to be trained in using the overall approach as well as the different methods in a non-pressure situation. This reduces the initial resistance and can lead to a deeper understanding why multiple concepts should be created. Also, the experiences can be spread across the whole team by the lead user and will be more easily adopted. The apparent disadvantage compared to a pragmatic approach is the effort needed for training and for generating and ranking the different concepts and solutions.

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