Schlussbericht

zu dem IGF-Vorhaben

Entwicklung von höher beanspruchbaren Funktionselementen als Basis für neue Bauweisen mit faserverstärkten Verbundwerkstoffen (FVW) in der Intralogistik

der Forschungsstellen

Karlsruher Institut für Technologie - Institut für Fördertechnik und Logistiksysteme

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Technische Universität Chemnitz- Professur Fördertechnik

Fraunhofer Institut für Chemische Technologie - Funktionsintegrierter Leichtbau (FIL)

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   Institut für Fördertechnik und Logistiksysteme
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Karlsruhe, 26.04.16

Ort, Datum

Name und Unterschrift des Projektleiters der Forschungsstelle 1

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Pfinztal, den 25.04.16

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FVW-Funktionselemente

Vorhaben Nr. 17542/BG

Entwicklung von höher beanspruchbaren Funktionselementen als Basis für neue Bauweisen mit faserverstärkten Verbundwerkstoffen (FVW) in der Intralogistik

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Schlussbericht

Kurzfassung:

Im vorliegenden Schlussbericht wird die Entwicklung von höher beanspruchbaren Funktionselementen für Kontaktpaarungen in intralogistischen Anwendungen beschrieben. Ziel des Forschungsvorhabens ist es, faserverstärkte Verbundwerkstoffe, insbesondere mit einer Kunststoffmatrix, als Materialien für zu bewegende und massereiche Führungsbauteile zugänglich zu machen. Hierdurch soll die Energieeffizienz der Anwendungen erhöht werden.

Beginnend mit einer Recherche und Analyse bisheriger Funktionselemente in relevanten Anwendungen werden die Anforderungen an die Neuentwicklung abgeleitet. Im weiteren Verlauf erfolgt die Konzeption und Untersuchung erster Muster, welche Hinweise für die detaillierte Konstruktion neuer Funktionselemente, insbesondere zu den faserverstärkten Kunststoffen, liefern. Hieraus ergeben sich u. a. auch methodische Erkenntnisse zur Prüfung der Laminate unter Einwirkung von Rollen hinsichtlich der statischen und dynamischen Belastbarkeit mit Hilfe der Ermittlung spezifischer Materialkennwerte. Der Bericht beinhaltet ebenso die Beschreibung der Konzeption und Beschaffung neuer Werkzeuge für die Fertigung der faserverstärkten Kunststoffe mittels dem Pultrusionsverfahren. Zudem wird die Konstruktion und Herstellung eines erforderlichen Prüfstandes zur Simulation praxisnaher Beanspruchungskollektive in Vorbereitung experimenteller Untersuchungen erläutert. Abschließend erfolgen die Darstellung der Versuchsplanung und des Schemas der angestrebten Empfehlungen für die Konstruktion und Dimensionierung neuer Funktionselemente.

Mehrere Zwischenziele des Forschungsvorhabens in Korrelation zum Arbeitsplan konnten erreicht werden. Jedoch stehen die experimentellen Untersuchungen der faserverstärkten Kunststoffe und die Ableitung der Dimensionierungsgrundlagen aus.

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1 Management Report

1.1 Introduction

In many areas of intralogistics selected assemblies or components of a machine have to be moved linearly along an axis in order to transport goods. This axial movement is usually achieved through support rollers and their respective guide rails. Such components are usually made of steel and have a large weight. Obviously, this requires large amounts of energy especially when moving in the vertical direction ('y-axis'). By manufacturing these components with fiber-reinforced composites, especially with a polymer matrix, it is possible to reduce the unnecessary weights significantly and to increase energy efficiency. The main problem of using this kind of materials is the transmission of the high compressive forces from the support rollers into the guide rails. The solution of the problem lies in the development of functional elements with high mechanical resistance, which is the goal of this research project. An example for such element is shown in Figure 1. The structure consists of a guiding zone as base body, which is in contact with an antibody. The guiding zone could be a part of the guideway component or an additional element. The last one has to be joined to the guideway component by a friction-locked, form-locked or adhesive bonded connection.

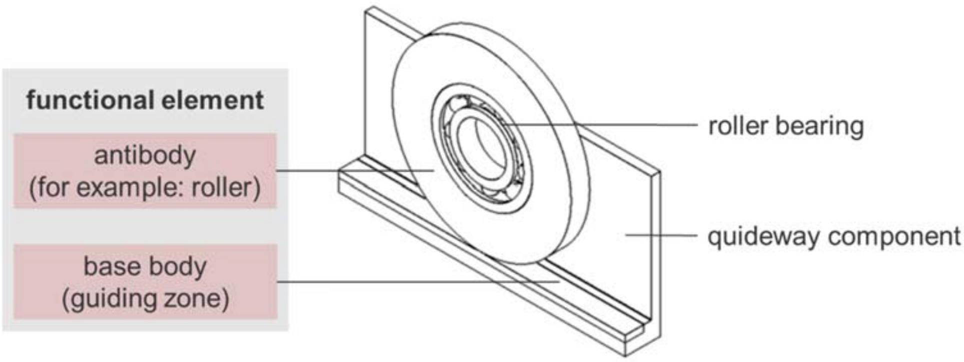

Figure 1: Structure of a functional element

1.2 Proceeding and course of the project

The first goal of the project is to determine the current state of technology and research. This includes in particular the identification of relevant functional elements in intralogistical applications and the analysis of existing load cases. Hence requirements for new functional elements that can sustain higher loads can be derived with a guide member made of fiber-reinforced composite. Due to a predictable diversity of the results, it is appropriate to classify existing functional elements and their respective application, while preparing for the design of new solutions. In order to do this, specific criteria have to be defined. By classifying it is possible obtain class-related concepts, such that an optimal solution for each application can present itself. In the course of individual functional models must be designed and tested. Furthermore individual functional patterns are to be developed and investigated. Using these results appropriate design options can be designed in detail and manufactured. For the experimental study of the designs under load cases with practical relevance, an appropriate test rig is required. The results allow recommendations for the design and dimensioning of functional elements to be derived, based on the previous classification. The project course is defined by the individual work packages as shown in Table 1. It should be noted that the development of the test rig was effort- and cost-neutrally integrated in the original work plan of the project by adaptation of work packages.

Table 1: Work packages of the project

work package (WP)
1. state of the art and research
2. definition and classification of the functional elements of non-continuous conveyors, requirements and functional specifications document
3. design and manufacture of a roller test rig
4. conception of new functional elements and design methodology
5. manufacture and test of prototypes
6. design of the functional elements
7. practical examination and evaluation
8. dimensioning bases
9. documentation

The project began on the 01.11.2012 and ended on the 31.01.2016. This timeline includes an extension period of 15 months. This extension was necessary due to the initial underrating of the time and effort required for the design, procurement of components, assembly and commissioning of the test rig and also due to the move of the pultrusion machine from Fraunhofer-Institute for Chemical Technology in Pfinztal to a new location in Augsburg. This, in turn, also required design and procurement of new, smaller width pultrusion dies. Their length delivery times adding further to the overall project delay.

Through the extension of the project period, the fiber-reinforced composite materials could be manufactured and the remaining components for the new functional elements were procured. However, the test stand was commissioned just shortly after the end of the project, despite all efforts to complete it on schedule. Consequently, no experimental investigations could be carried out and no guidelines for design and dimensioning could be derived. The research institutions involved in the project are eager to continue working on the project on their own and to report the results in a subsequent publication. During the project period the transfer of results was carried out as planned. Furthermore consultation meetings with the project board and several publications took place.

1.3 Results

Most applications with relevant functional elements are among the non-continuous conveyors. An emphasis lies within stacker cranes, industrial trucks and cranes. Important examples of functional elements can be found in the roller-guided lift carriage on the mast of a stacker crane, the roller-guided load carriage or lift frame in the forklift truck and the trolley guide in an overhead crane, gantry crane or a post crane. Only crane types with relatively low roller loads are considered. Such loads can be extremely high for some types of cranes. Certain functional elements of continuous conveyors have a lesser importance, such as skid conveyors or electric monorail systems.

In the group of functional elements which have been investigated, mostly rollers are used as a counter-body. Using simplified calculation models, one can determine contact forces per roller of around 5.3 kN for stacker cranes used in automatic small parts warehouses, to about 55 kN for counterbalanced forklifts with a rated capacity of 9 t. Each application has a variety of designs with a wide range of contact forces. The maximum loads are presented in Figure 2. As part of the development of new functional elements, an upper limit of 30 kN has been set, which in turn covers a sufficiently large number of applications. Another important characteristic is the roller velocity. Lift frames in forklift trucks have a velocity of up to 0.6 m/s at maximum roller load. In some cases cranes can achieve a maximum velocity of up to 120 m/min. However, their speeds are often lower in practice. By contrast stacker cranes have a wide dynamic range. Depending on the load capacity of the crane, maximum speeds of 2.0 to 3.5 m/s can be expected.

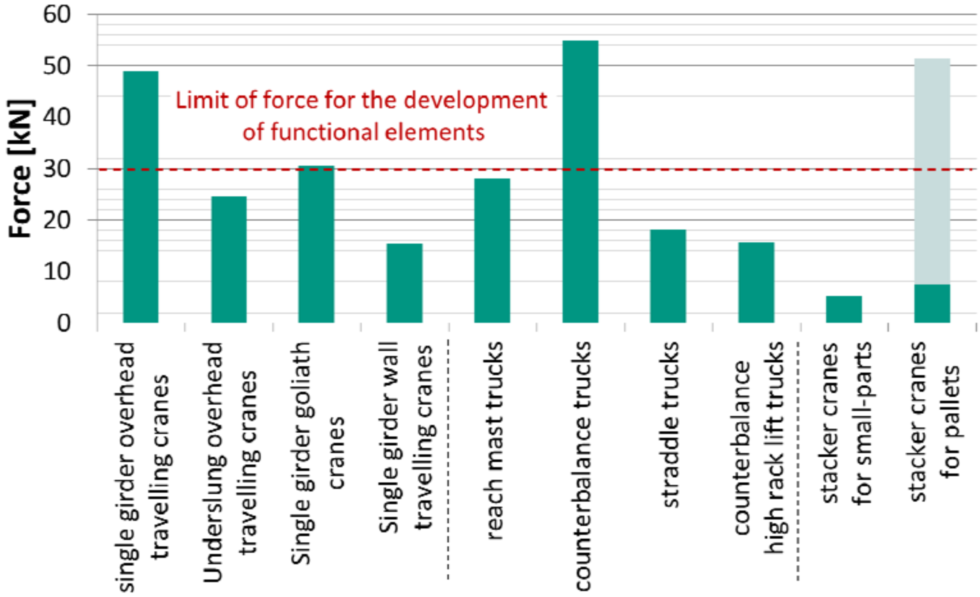

Figure 2: Maximum forces per roller of non-continuous conveyors

When designing new functional elements there are two design options available. First option the guide element is an additional component, e.g. a metal strip, which has to be connected by gluing or another joining technology with the guide member. As a second option the guide portion can be similarly to profile steel beams, integrated in the fiber-reinforced composite. Here, the main body rolls directly onto the material. Through structural design of the fiber-reinforced composite, modifications can be made within the surface area which improve the mechanical and tribological load capacity. There is a limited number of scientific studies, which research this topic, which is why the project will take this direction. The compressive load capacity of the fiber-reinforced composite can be influenced through the layer structure, the type of semi-finished fiber structure and the matrix material. In addition, during the design of the fiber-reinforced composite profiles, manufacturing specific features of the pultrusion process must also be considered.

The conception of first functional element layouts covered different types of laminate-layups. Their static investigation occurred with the aid of a spherical steel roller with an outer diameter of 102.6 mm. Furthermore the dynamic analysis was executed in combination of vulkollan, polyamide and steel rollers with a diameter ranging from 50 to 78 mm. The results show, that the mechanical loading capacity is higher in longitudinal direction of the fibers than in their cross-direction, just as was expected previously.

In comparison to the pure matrix material the strengthening of the fibers produces a maximum increase of the compressive resistance of 35%. Unidirectional laminates possess the highest resistance force as well as the highest difference between the force in longitudinal and cross direction of the fibers. However a possible unsteadiness between the contact surface and the roll like edges can cause a fracture in the matrix. On the other hand using two dimensional semi-finished fibers in a zone near to the surface enable the absorption of shearing forces and avoid a direct fracture of the matrix. Furthermore they produce a better wear resistance. The investigation of unidirectional laminates under a mechanical load of 1 kN showed first fractures of the matrix material in the surface of the laminates already after $2*10^4$ cycles.

Based on the previous investigation and further theoretical considerations regarding the contact geometry the design and production of new functional elements with different laminates were executed and are shown in Figure 3. For this purpose new pultrusion tools for the production of preferred profiles (120 mm width) were designed and purchased. The laminate-layup consist of a combination of glass-fiber mats and glass-fiber rovings and various types of thermoset matrix materials – as shown in Table 2. Furthermore the surface of the profiles can be planar or grooved. Vulkollan and polyamide rollers as well as spherical steel rollers with an outer diameter in a range of 105 to 180 mm with a carrying capacity of 6 till 41.5 kN were used as counter bodies.

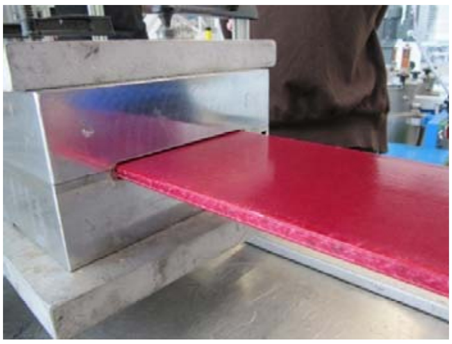

Figure 3: Fiber-reinforced composite exiting from the heated pultrusion die

Table 2: Variation of material parameters from the fiber-reinforced composites

material parameter	parameter value
surface veil	• polyester surface veil 39 g/m² • aramid surface veil 34 g/m² • aramid surface veil 60 g/m² • aramid surface veil 120 g/m²
continuous strand mats and layups	• glass-fiber continuous strand mat 450 g/m² • glass-fiber ‘complex’-layup (586 g/m²)
rovings	• glass-fiber rovings, 4800 tex
matrix material	• epoxy resin (EP) • unsaturated polyester resin (UP) • vinyl ester resin (VE)

With the aid of experimental investigations the influence of the single parameters shall be identified to give basic recommendations for the design and dimensioning of a functional element in a case of practical use. Relevant and characteristic values of anisotropic materials are used to evaluate the stability under load in a long term usage. These values are the interlaminar shear strength, the tensile strength, Young’s modulus and the breaking force. The values are determined by the tensile test and three point flexural tests. They can be used to suggest the remaining load bearing capacity after a defined number of stress cycles. In this connection conclusions regarding the behavior of failure like i.e. delamination or fiber breaks can be found.

In the project a test rig for experimental investigations was designed and built. The test rig enables to apply mechanical loads up to 30 kN at a velocity up to 2 m/s. These conditions are produced by a counter body of the functional element moving in an oscillating run directed to the fixed basic body with the aid of an asynchronous motor and geared belt drive. The contact force of both bodies is provided by a hydraulic cylinder. Furthermore a continuous adjustment of the contact force is enabled.

By the end of the project only some of the initial goals could be achieved. The institutes involved will continue to work on the subject and prepare and release the planned results at a later date. On this account a definitive conclusion regarding suitability and dimensioning of fiber-reinforced composite profiles for the application and their limitations of usage is not yet possible at the current state.