LINEAR GUIDES OF LINEAR FLOW SPLIT COMPONENTS — DEVELOPMENT AND INTEGRATION OF POTENTIAL ADDITIONAL FUNCTIONS

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Linear flow splitting is a massive forming process that allows bifurcated profiles to be formed out of sheet metal in integral style. Linear flow split components have specific technology-induced properties (e.g. ultra fine grained microstructures at the surface of the flanges and the splitting ground). That is why they are predestined to be used in linear guides. Additionally linear flow split components enable to integrate supplemental functions (e.g. clamping) in linear guides. These functions need to be developed and implemented by emphasizing the advantages of the new technology. Based on a property-focused examination, different design concepts of linear motion guides of linear flow split components are worked out. Because of the supplemental, integrated functions, these concepts have an additional benefit and should combine good precision with low costs due to the technological advantages.

Keywords: Linear flow splitting, Properties, Multifunctional linear guides.

1. INTRODUCTION

The core element of the Collaborative Research Centre (CRC) 666 is composed of new forming processes called linear flow splitting and linear split bending. Linear flow splitting allows bifurcated profiles to be formed out of sheet metal in integral style.

The results of extensive research show that the linear flow splitting and linear bend splitting technology offer a large quantity of possibilities and advantages that are very interesting for various complex fields of application. Linear guides are very suitable to demonstrate the technologies' potentials. That is why an innovative research concept uses the specific product properties caused by the manufacturing process to design multifunctional linear guides. It has to be clarified what kind of sub-functions generate an additional benefit and can be integrated. For the design process, it is important to identify the properties that have an effect on the fulfillment of the functions and to develop innovative concepts based on these results.

2. PROPERTIES OF TECHNICAL SYSTEMS

According to the theory of properties, technical systems are designed only because certain properties are desired, used and valued. [1] The description of a technical system by its properties always links values to corresponding attributes. So, an attribute (for example "length") and a related value (for example "1.5 meters") form what is called property [2].

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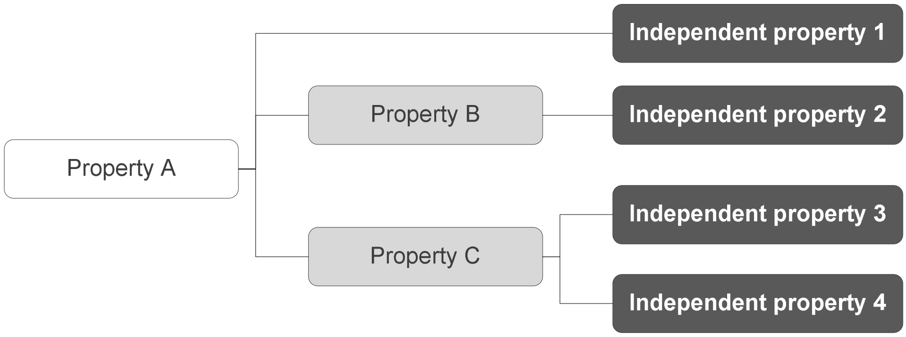

Figure 1. Property-network.

The task of designers is to set the optimum values to the relevant attributes. This is why dealing with product properties is fundamental all over the product development process.

However, not all properties can be set directly. Instead, they depend on other properties, to be exact, on their values. Properties that are set by the designer directly are called "independent properties". By setting these independent properties (mainly geometrical or material properties), the designer indirectly determines a lot of so-called "dependent properties". Dependent means that these properties depend on the arrangement of independent properties [3]. This categorization highlights that the whole product is defined by the determination of the independent properties in the design process. The dependent properties "result" from this determination. It is fundamental to know the relations and dependencies between the independent and the dependent properties very well.

A network-structure, called property-network (Figure 1) is predestined to represent the dependencies [4]. Having knowledge about the dependencies between the properties is a necessary prerequisite to optimize the design.

It is not mandatory that a designer knows which individual parameter influence a dependent property. What he has to know is which "setscrews" and therefore independent properties he can adjust to achieve his desired dependent properties [4].

There are different possibilities to get information about relations or to clarify the relations between properties. The knowledge of properties and their relations is usually found in scientific literature. Properties of very complex or new products are often strongly interlinked and their relations are also complex and not easily perceptible. In these cases, the relevant independent properties have to be identified and their influences on dependent properties have to be analyzed experimentally. The data has to be processed in such a way that they can used as a basis for an optimization.

3. LINEAR FLOW SPLITTING

Linear flow splitting is a massive forming process for the production of bifurcated profiles in integral style. Bifurcated sheet profiles allow implementing desired functions without consuming much space or material. Compared to plane components with the same mass they are much more resilient. In addition, closed cross-sections show heavy torsional stiffness. The bifurcations allow designing multi-chambered profiles. The chambers can be used to integrate different sub-functions, e.g. creation of insulating hollow space, cable ducts, gas conduction, liquids or compressed air. So far, bifurcated sheet metal profiles were mainly produced in differential style, e.g. by gluing, welding or similar procedures. Manufacturing those parts in integral style by linear flow splitting has different advantages. It enables to produce very thin-walled profiles. Due to the lack of or the small number of connecting pieces the profiles have less weak spots. A high accuracy can be achieved through transforming the semi-finished part at ambient temperature. Bifurcated sheet metal profiles are lighter. They have a lower disposition to corrosion and a higher thermal conductivity [5].

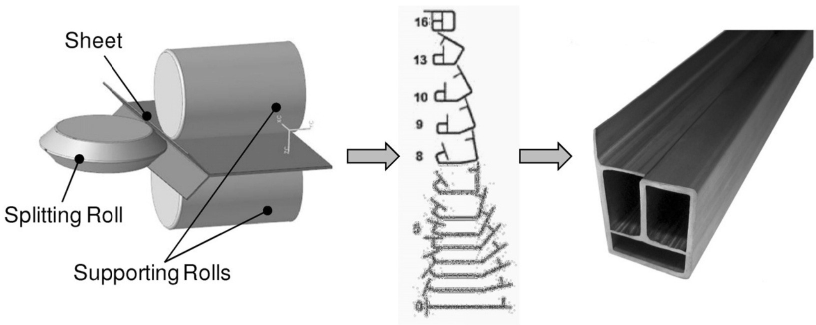

Figure 2. Manufacturing multi-chambered profiles by linear flow splitting and further roll forming and bending procedures [7].

The initial material is a sheet metal plan. It is transformed at ambient temperature by a specific tooling system which consists of obtuse angled splitting rolls and supporting rolls. In discreet steps, the fixed tool system forms the translatory moved work piece to a profile with the final geometry. The further processing of the linear flow split sheet metal by roll forming and bending procedures presents the opportunity to produce multi-chambered profiles with new cross-sections from sheet metal (Figure 2). Numerous new possibilities for chambered profiles to optimize lightweight design arise when anew using linear flow splitting at the end of the flange and forming new flanges [6].

In addition to the described properties and advantages linear flow split profiles feature specific microstructure, surface, hardness and fatigue characteristics [5]. Due to the forming process, the hardness at the splitting ground increases. Hardness measurements parallel to the flange topside reveal a constant hardness over a constant depth in a wide area of the flange and the splitting ground. Figure 3 shows that the hardness in this area is almost twice as high compared to the base material. On the flange edges, the hardness descends strongly with increasing distance from the splitting ground. Hardness measurements perpendicular to the flange topside show a descent of hardness with increasing distance to the flange topside [8].

The extremely high deformation degrees induced by the linear flow splitting process lead to the formation of an ultra fine grained (UFG) microstructure. The ultra fine grained microstructures lead to the described extremely high material strength and hardness in the mentioned areas of the workpiece [5].

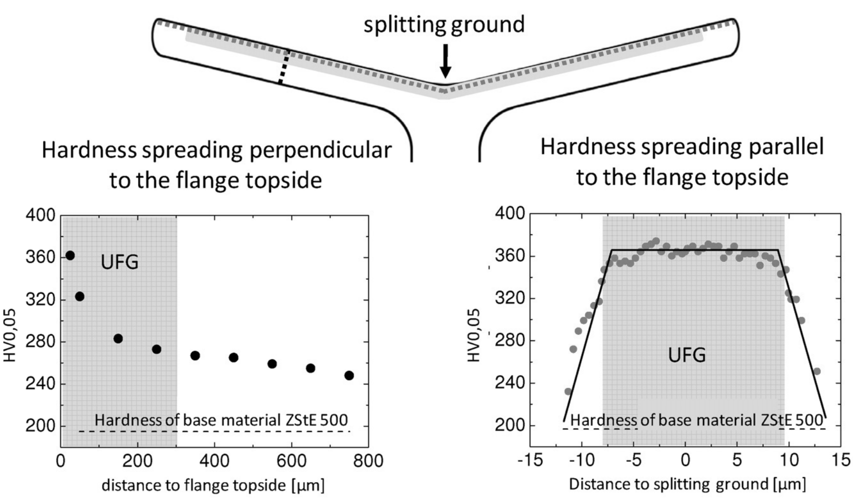

Figure 3. Hardness spreading of split components [8]

4. USING LINEAR FLOW SPLITTING TO DESIGN LINEAR GUIDES

Linear motion guides are frequently used machine elements that find applications in many different scenarios and business sectors. Due to the diverse applications, the requirements for linear guides can differ strongly. Using linear guides to position tools or components in production lines and machine tools, a long life-cycle and high static and dynamic carrying capacity are demanded. In contrast, conventional telescope guides used in drawers have a dominating low cost requirement. Other requirements can be a good running smoothness, resistance to dirt, low weight, resistance to corrosion, in special scenarios resistance to chemicals and more. In medical or food related scenarios additional requirements can occur. Disadvantages of conventional linear guides are mainly an unintentional deflection of the rail and production related imperfections of the running surface.

Conventional linear guides can be classified into three overall designs. These designs are rolling-element linear guides, plain linear guides and magnet linear guides.

Within the CRC 666, linear flow splitting is used to develop innovative linear guides with integrated functions. Therefore, the technological advantages of linear flow split components being used in linear motion guides are presented in the following section.

4.1. Technological advantages of linear flow splitting in regard to innovative linear motion guides

Essential for linear flow split linear guides and basis for the idea to develop linear motion guides with linear flow split components is the running surface. Linear flow split linear guides adapt the concept of conventional rolling guides. The running surface is necessary as contact surface for the rolling element. Requirements towards material to be used as a running surface are high hardness, low surface roughness and high rolling contact fatigue-life. Conventional running surfaces of linear guides are processed with high effort to acquire these properties. This effort is displayed in the production cost of linear guides with a technological complexity. At this point, the linear flow split technology is offering advantages to a manufacturer.

The massive forming process creates linear flow split flanges with changed properties and changed microstructure compared to the base material. In the edge layers of the formed material, an ultra fine grained structure with a high micro hardness and low surface roughness is created. These areas are eligible to be used as running surface for rolling elements. Therefore, the linear flow split flanges do not necessarily need additional effort in regard to surface roughness. Regarding the hardness and rolling contact fatigue-life, the influence of plasma nitration and sand-blasting on these properties is tested.

In comparison to the base material, linear flow split components has a significantly increased hardness and lower surface roughness. The influence of the forming process on the rolling contact fatigue-life still needs to be evaluated. However, preliminary tests regarding the sliding contact fatigue-life indicate an increased resistance to sliding contact fatigue compared to the base material, as it is displayed in Figure 4. The data for this graph was generated on a testing apparatus of the CRC 666. Preliminary tests regarding the rolling contact fatigue-life also indicate increased resistance to rolling contact fatigue.

Summing up, linear flow split flanges are predestined to be used as running surface due to a higher hardness, lower surface roughness and increased fatigue-resistance. High effort in subsequent process is not needed.

In the previous research of the CRC 666, the linear flow splitting process was complemented with accompanying processes such as laser welding and cutting processes. For the development of linear guides with the linear flow splitting technology, roll forming is a necessary accompanying process to create the geometry of a linear flow split linear guide. By combining linear flow splitting and roll forming, bifurcated multi-chambered structures can be created. Using steel to form these chambers is a significant technological advantage of linear flow splitting. Creating chambers by extrusion molding commercially is mainly restricted to aluminum.

Using other attendant processes that are used within the CRC 666, the multi-chambered profiles can be further modified. By laser welding the chamber edges, the chamber can be sealed. Additionally,

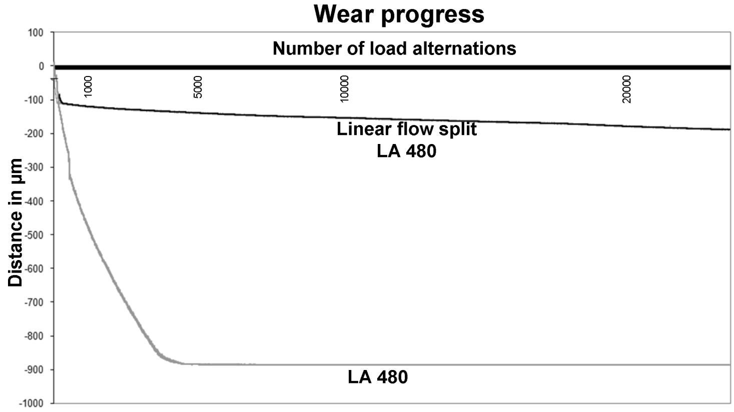

Figure 4. Sliding contact fatigue-life in linear flow split components in comparison to the base material.

grooves and bore holes and other alterations can be conducted. Using all the available technologies within the CRC 666, a variety of design possibilities exists that apply to the geometry of the component as well as to the possibilities of function integration. It needs to be underlined again, that all forming and alternation processes are conducted fully integrated in the production line.

A partial focus of the CRC's research lies on the development and testing of innovative rolling linear guides. An advantage of the new technology regarding the use of linear flow split components in linear guides has already been determined, the running surfaces. Nonetheless, the technology offers other advantages that can be exploited.

In comparison to conventional linear guides made of solid material, using bifurcated sheet metal as a basis for linear guides results in a lower weight. Additionally, the bifurcated structures have big area moment of inertia and therefore, a high stiffness. Thus, linear flow split linear guides have a high potential for light weight design.

Bifurcated multi-chambered profiles offer new possibilities to implement functions into linear guides or to adjust their properties. In previous research, the CRC 666 has already worked on function integration by using chambers in profiles. A cable channel was integrated into the previously designed three chambered profile (see right side of Figure 2) that not only hid the cables leading to the light sources but also protected them.

Bifurcated multi-chambered profiles create options to integrate functions into components and thus, linear guides. The chambers serve as vessels to implement functions as "channel", "transport", "protect", "clamping" or "save".

Linear flow split linear guides can be produced in a continuous process that includes attendant processes, enabling the production of linear guides that are longer than conventional ones. In general, conventional linear guides have a maximum length of approximately four meters. Usually, longer distances are bridged by a head connection of two guides that need extensive mounting effort. Producing in a continuous process is lowering the production time. Additionally, linear flow splitting is a material efficient process.

The completely continuous process chain reduces the post production of components to a minimum. Therefore, linear flow splitting and its attendant technologies present an economic solution to the production of multifunctional linear guides as "bulk stock by meter". The production concept could be described as "full integration".

However, linear flow splitting is a new technology. Today, it is not yet possible to fulfill dimension and form tolerance in the same quality that conventionally produced linear guides achieve. The CRC 666 is progressing in improving the process variables of the massive forming process.

General disadvantages of the process are the calibration effort for splitting and supporting rolls and the high investment costs for the facility. Therefore, big lot sizes are needed to produce linear flow split linear guides economically.

4.2. Implementing functions into linear flow split linear guides

Linear flow split linear guides are eventually not yet able to compete with the precision of extensively machined high precision linear guides that are produced conventionally. These high precision guides are often used to position the tool in industrial machine tools. On the other side, it might not be possible to undercut the cost of mass produced low cost linear guides with a low degree of technology. Taking this into account, linear flow split linear guides should be implemented into an in between market segment. The new linear guides should combine good precision with low costs due to the technological advantage. This market segment should from now on be called "high-tech-low-cost segment".

The success of linear flow split linear guides in the described market segment should be achieved by an additional functional value. Therefore, concepts for function integration of different functions into linear flow split linear guides are presented in this section. Function integration should finally result in concepts that do not need additional processing after production. However, the focus of these concepts is to demonstrate the potentials of the linear flow splitting technology.

The previously mentioned function of "clamping" can be implemented by pressurized chambers. By blowing up the chamber, break forces can be applied to the linear slide. The chamber could be inflated to create a wedge effect on the slide. The pressure of the inflated profile can also take effect on the rolling elements directly. This increases the friction on the elements until they clamp. Another possibility is to create the breaking force by additionally applied by brake pads on slide and rail that are pressed onto each other. Using a lever, that represent an extension of the geometry on one side of a chamber, the inflation of a chamber can result in a bigger movement. The chambers can be sealed by laser welding to transport fluids or gas. Another option is to position another inflatable component into a not welded chamber which could then bend the chamber wall. A concept to fulfill the function "clamping" with pressurized chambers is shown in Figure 5 below. However, unintentional deformation of other chambers remains problematic.

By using a similar approach the function "applying a pre-load" can be implemented. The inflation of a pressurized chamber can thereby create or remove pre-load from the linear guide, depending on the geometry. This design would also enable to vary the pre-load and adapt it to the specific load that is applied to the linear guide. Adaptable pre-load is an innovative function that is not fulfilled by conventional linear guides. Looking back at the function "clamping", it is smart to implement the pressurized chambers into the rail so that the slide will not require a cable drag chain. In contrast, a pressurized chamber can be implemented into the slide's geometry to create and release pre-load at

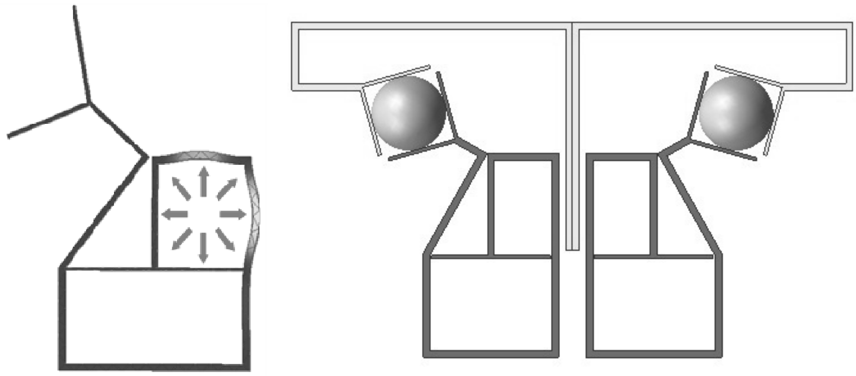

Figure 5. Linear flow split linear guide with function "clamping".

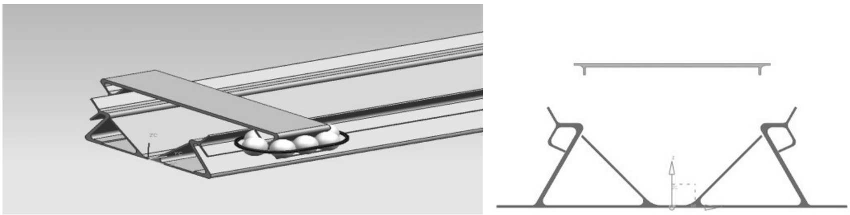

Figure 6. Concept of a linear flow split linear guide with several functions.

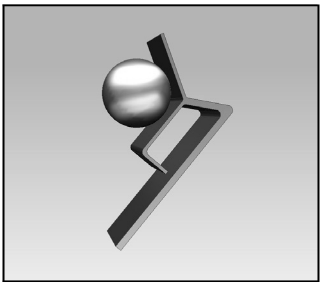

Figure 7. Concept of a linear flow split linear guide with several functions.

certain "docking stations". Another possible solution to apply an adaptable pre-load requires a screw as additional machine element. Depending on the geometry of the linear guide an elastic deformation can easily achieved. Screws could then apply pulling or pushing forces with which the pre-load could be varied depending on the incline of the thread.

A variable pre-load could also be beneficial to the exploitation of the linear flow split bottom of the flange as running surface. With the variable pre-load the contact zone could be controlled to always be at an optimum position. This could be necessary since the forming of the microstructure of the flange and flange bottom does not happen evenly, as shown in Figure 3.

Due to the various options to design the geometry of the linear flow split rail and slide, the geometry could also be used to implement functions. To clarify possible function to implement, a concept is shown in Figure 6 below.

The wedge shape in the centre of the rail concept shown in Figure 6 above can be used to collect dirt, e.g. swarf from chipping processes. Due to the shape, swarf gathers in the centre of the rail and can easily be transported away. At the same time, the geometry can be changed as shown in the right part of Figure 6. By putting on a lid, the function "collect" could no longer be used. The thereby created chamber can be used for different purposes, e.g. to easily run and protect cables.

Another function that is integrated in the rail concept displayed in Figure 6 above is also shown in more detail in Figure 7. The function is to support the linear flow split rolling contact flanges on a bracket of the same component. Therefore, the flange needs to be bent. This can be used to increase the load rating of the linear guide.

5. CONCLUSION AND FURTHER WORK

This contribution explains the particular properties of linear flow split components like the UFG microstructure, high material strength and hardness, the increased contact fatigue-life and the low surface roughness. These properties are the reason why the surfaces of such components are eligible for the use as rolling contact surfaces of linear guides. Linear flow splitting presents the opportunity to manufacture multi-chambered profiles in integral style. Therefore this technology offers great potential to integrate different sub-functions and design multifunctional linear guides.

The research focus for the next years lies in the designing and implementation of the above explained functions as well as the testing and evaluating of their functionality and behavior. Additionally, there is a necessity to develop a housing unit for linear flow split linear guides that enables circulation of the rolling element and therefore enables unlimited traverse paths. New functions could be developed by including new processes as flexible linear bend splitting or using different semi-finished parts as tailored blanks.

To test the designed linear flow split linear guides, a testing apparatus is currently designed at the institute of product development and machine elements. The testing apparatus allows traverse speeds of up to 3 m/s and pneumatically applied loads from different axes of up to 1000 N. The testing scenario allows average speeds and respectable loads in regard to the linear guide scale. The scale of the tested linear guides results from the restrictions of the linear flow splitting facility that allows splitting of sheet metals coils with a width of up to 130 mm [9]. Simultaneously, the linear motion guides are analyzed with finite element simulation with special regard on the rolling contact and the behavior of the linear guide as a complete system.

With the testing apparatus, the relevant independent properties and their influence on the designated functions (and so the desired dependent properties) can be analyzed. Based on the collected data, the very complex relations can be quantified and the determined results can be provided in form of property networks to optimize or redesign innovative multifunctional linear motion guides out of linear flow split components.

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