International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:10, No:1, 2016

Design Approach for the Development of Format-Flexible Packaging Machines

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***Abstract*—**The rising demand for format-flexible packaging machines is caused by current market changes. Increasing the format-flexibility is a new goal for the packaging machine manufacturers' product development process. There are no methodical or design-orientated tools for a comprehensive consideration of this target. This paper defines the term format-flexibility in the context of packaging machines and shows the state-of-the-art for improving the changeover of production machines. The requirements for a new approach and the concept itself will be introduced, and the method elements will be explained. Finally, the use of the concept and the result of the development of a format-flexible packaging machine will be shown.

***Keywords*—**Packaging machine, format-flexibility, changeover, design method.

I. Introduction

THE increasing individualisation of products is nowadays one of the biggest market trends [1]. This is the reaction of the manufacturing industry to changing customer wishes and demands, as well as to market saturation. As a result of this development, the diversity of variants will increase in the future [2]. New groups of customers are to be reached with these new products. It takes only a few seconds for the consumers to decide at the point-of-sale (POS), which product of daily life they will purchase. For companies of the FMCG-industry (fast-moving-consuming-goods), this quick decision has to be used for commercial success. Along with the packaging as one very important aspect of a product [3], the rising range of variants is increasingly affecting the packaging. In fact, from 1997 to 2012, the number of variants in the fast-moving-consuming-goods industry (FMCG) increased by 62%, while the product life time decreased by 46% [4].

The users of packaging machinery have to handle these market trends by increasing flexibility [5]. In the production and packaging process, the results of the increasing range of variants are the reduction of the batch sizes, the rising number of format-changing processes and, finally, a growing demand for format-flexibility [6], [7]. Product changeover is perceived as a loss of time and money [8].

There are manufacturing concepts, like lean or mass customisation principles, for efficient production [9]. These principles require a high level of manufacturing and machine flexibility, as well as a rapid changeover capability as an enabling tool for that [10]. To sum up, production will be more and more defined by flexible production systems with a minimal changeover time for individualised manufacturing [11].

The manufacturers of packaging machines have to offer format-flexible systems for addressing the challenge of their customers. For manufacturers of packaging machines and plants, it is a new requirement to offer economical solutions for more flexible systems [12]. In the past, these kinds of machines were designed and developed for mass-production and, because of this; the changeover process was not a focused phase in a life-cycle-analysis [6]. Nowadays, the impact of life-cycle engineering, which also addresses non-production phases like recycling, will also increase. Furthermore, the suppliers of packaging machines have to realise a shorter time-to-market [1]. An efficient development process is necessary for realising this short time-to-market [13]. A new approach will be introduced and explained which combines increased format-flexibility with efficient development processes.

II. Definitions

Many research activities consider the ability to handle changing boundary conditions in the field of production engineering. Different strategies and terms do, therefore, exist, e.g. changeability and flexibility [14].

The focus of changeability is the complete production system and the three subsystems: the management system, the operation system and the information system [15]. There is a need for planning and controlling activities involving a significant expenditure of time and money to realise a change in the context of changeability. Changeability has a more strategic focus compared to flexibility. The reduction of batch sizes, and the changing from one format to another, is a more operative task. From this point of view, flexibility is the fitting concept for the described challenge (see section I).

Flexibility has been a frequently and manifold defined term in the last two decades [16], [17]. Especially in the research field of production engineering, flexibility is defined in many diverse ways because of different views on impacts, effects and enablers. For a better understanding, and a clear differentiation, a definition of format-flexibility will be introduced.

Reference [18] defines the flexibility of a production

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International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:10, No:1, 2016

process as the ability to adapt production resources with less expenditure of time and money under the effect of environmental impacts. The expenditure of time and money is summarised as friction, because a clear differentiation between these two definitions is not useful [19]. Each dimension of flexibility, e.g. quantity, has a range with reachable states within it, and the border of the range is the flexibility corridor [15]. Fig. 1 shows the difference between two machines in the context of flexibility. The friction of machine 2 is bigger than the friction of machine 1. In this case, machine 1 is more flexible than machine 2.

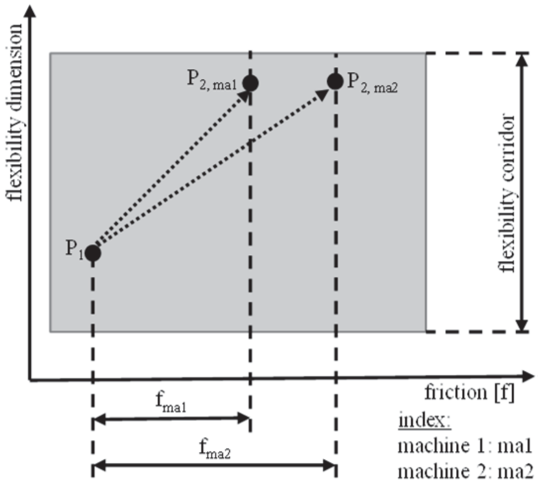

Fig. 1 Flexibility corridor and friction, according to [15]

The term format is used in packaging technology as an expression of the size, shape, or assembly of a packaging good, packaging material or auxiliary packaging means [20]. To sum-up, format-flexibility is defined as the ability of a packaging machine or a packaging line to be adapted to the production of another package with less expenditure of time and money. In addition to this theoretical definition, a classification is introduced which focuses on the enabler of format-flexibility. Typical changeover processes for packaging machines, e.g. thermoforming machines, were analysed. On this basis, the different changeover tasks, manual and automatic, were divided into three classes (Fig. 2). For each of these three classes, different enablers for the increasing of format-flexibility were collated.

The ‘parametric flexibility’ class is defined by the little effort needed for changing the format-specific parameters, e.g. temperature, pressure. These parameters are mostly a scalar. Main enabler is the PLC-technology, combined with sensors and actors at the field level. Without the use of PLC-technology, a worker had to manipulate each parameter manually. With a PLC, it is only necessary to select another program at the HMI (Human-Machine-Interface) of the machine. For the realisation of a parametric flexible packaging machine, it is necessary to know the flexible corridor, which is defined by the manufactured packaging. The changeover process between different states inside the flexible corridor is very easy to realise automatically.

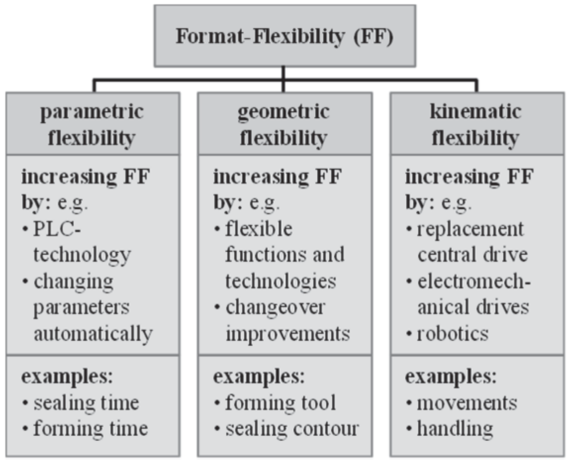

Fig. 2 Classification of enabler for increasing format-flexibility

In packaging machines, many movements of the machine parts have to be realised to fulfil the packaging process, e.g. handling, lifting unit for sealing, or cutting. For processing different formats, ‘kinematic flexibility’ is necessary. In the past, the movement has been realised by a central drive, an upright shaft, and many other mechanical elements. Nowadays, more and more electromechanical drives are in use and are replacing mechanical systems. Furthermore, the number of packaging machines using robotics is on the increase. In the context of format-flexibility, the main advantage of these systems is that no replacement of any mechanical system is necessary. The next position of a robot or a drive is a parameter and so it becomes an example of ‘parametric flexibility’.

The next class is ‘geometric flexibility’. This class of flexibility is necessary if the differences between the producing packaging are geometrically based, as in size or shape. Especially during the different packaging processes, there are ‘geometric flexibility’ requirements, e.g. forming, filling, and cutting. For example, a thermoforming process needs a forming tool, which has to be changed when another packaging shape has to be produced. There are different ways of realising ‘geometric flexibility’. By using more flexible technology, the quantity of format-individual working tools will be reduced and it will become a kind of ‘parametric flexibility’. Furthermore, the application of changeover improving methods is a way to increase the ‘geometric flexibility’ (see Section III).

III. State-of-the-Art

A summary of relevant research works will be represented. Here, the improvement of the changeover process is typically seen as the best way for realising a flexible machine.

Nearly all the papers on increasing the flexibility of production machines during the usage phase are based on Shingo 1985 [21]. The acronym of this approach, SMED, stands for single-minute-exchange-of-dies. SMED has four conceptual steps to reach the goal of a product change in less than ten minutes. The core of SMED is the separation of necessary tasks during the changeover in internal and external tasks, as well as the reduction of these activities. For the changeover improvement, a three-stage method and different improvement techniques are introduced. In the preliminary step, there is no differentiation of internal and external activities. These internal and external set-up activities will be separated during the first step. The use of checklists, function checks and the improved transport of parts and tools are therefore recommended. The content of step two is to convert the internal activities to external ones with the help of the following techniques: advance preparation of operating conditions, function standardisation and intermediary jigs. Then, the third and last step is to streamline all the aspects of set-up operations. For the shortening of the external time, the improvement in the storage and management of parts and tools is proposed. The parallelisation of operations, functional clamps, elimination of adjustments and mechanisation are the techniques introduced to reduce the internal time. In addition, many different examples of successful changeover improvement projects, with the focus on forming machines in the automotive industry, are explained in [21]. In [21], it is shown that, in the main, organisational actions are very constructive from an economical point of view. However, nearly 64% of the improvements of SMED in [21] are based on technical, and not on organisational improvements [22]. Retrospective changes during the usage phase are much more time and cost intensive compared to the development phase [23]. The focus of the manufacturers of packaging machines is on the technical functionality of the machines, and not the organisational processes of their customers.

The enhancement of SMED's objective is 'Zero Changeover', which is introduced by [24]. The basis of this approach is the detection and elimination of waste during the changeover process. Three kinds of waste are distinguished: set-up, replacement and adjustment. As a practical tool, nine instructions are explained, e.g. eliminating the need to remove and fasten bolts. Similar to [25], the focus is on forming machines in the automotive industry. A further approach for improving the changeover process is the 'Reduction-In' strategy [20]. This approach also tries to reduce waste. In [20], waste is seen as excess. The following four 'Reduction-In' categories are distinguished: on-line activity, adjustment, variety and effort. For each category, there are design rules and case studies. For the practical use, an iterative approach is introduced which consists of three steps. The first step is a screening of changeover tasks which should be improved. During the second step, and with the help of the 'Reduction-In' strategy, the difficulty with the changeover task should be identified. Step three contains the creation of appropriate solutions. The 'Reduction-In' strategy focuses on retrospective improvements during the usage phase. It is explained that this strategy could also be used during the development process, but the special characteristics are not considered. Another approach uses design rules for the improvement of existing machines or the development of new machines [25], [26]. Reference [25] introduces 27 design rules in six different categories. These design rules were added and adapted by [26]. In both works, these design rules are based on the experience from the changeover projects of existing machines and are retrospective improvements. The use and integration during the development process are not shown.

The method, 'Design for Changeover' (DFC) [27]-[29], referring to the 'Design of Assembly', stands for a more detailed consideration during the design phase. This is a metric-driven approach and is based on different method steps. Five merit indexes are introduced for the step-by-step improvement. If the objective of a merit index is not achieved, there are different design rules which act as an aid. In total, there are 15 design rules. DFC is introduced as a standalone approach and there is no integration in a development process, which also has other goals, such as costs, and time-to-market.

The relevant responsibility for the format-flexibility of packaging machines has to be assumed by the development team but, nowadays, there is no comprehensive consideration of this objective during the engineering process of packaging machines.

IV. Requirements of the Concept of a Design-Led Approach

The definition of requirements is an essential task for the development processes of a product, as well as a method. The following requirements regarding the concept for an efficient design process to increase the format-flexibility of packaging machines are decisive for the introduced concept.

- **Adaptability:** The approach for an efficient design of format-flexible packaging machines has to be flexible. The characteristics of the different users, like a development department or an individual designer, should be considered, as well as differences in the designed packaging machine and the degree of innovation.
- **Integrability:** As format-flexibility is one of many other design targets, e.g. costs, time-to-market, the approach should not be a stand-alone concept. The approach should be able to be integrated into different design methods and procedures.
- **Practicability:** An adequate cost-benefit ratio should be reached, e.g. with the aid of simply usable tools. No expensive and complicated software should be necessary.
- **Traceability and reproducibility:** A key requirement is to have a clear structure and proceeding so that different people get the same result and can understand other results.
- **Extensibility:** The approach should ensure that later changes or new developments in different ways, e.g. new technologies or methods, can be easily integrated.

V. Concept of a Design-led Approach for Increasing Format-Flexibility

The concept is based on a detailed consideration of all aspects of format-flexibility in the product design and development process. Every development process of a technical system could principally be divided into four different phases [30]. These phases are: requirements specification, conceptual design, embodiment design and form design. These four phases could be found in many different common design approaches for technical systems. These four phases were analysed with regard to their contribution to the format-flexibility of the development object packaging machine. One result is that, in each phase, there are potentials for improving the format-flexibility. For every phase, a design module is introduced for supporting the development process in the context of format-flexibility. These design modules contain a method or a detailed information basis. Thus, these are recommendations for a developer to increase efficiency during the developing phase [31]. Fig. 3 shows the integration of these design modules in the four development phases. These four design modules are the scenario-based flexibility requirements, the modelling of the format-flexibility demand, the function pool and the design pool. Every design module will be briefly introduced and explained.

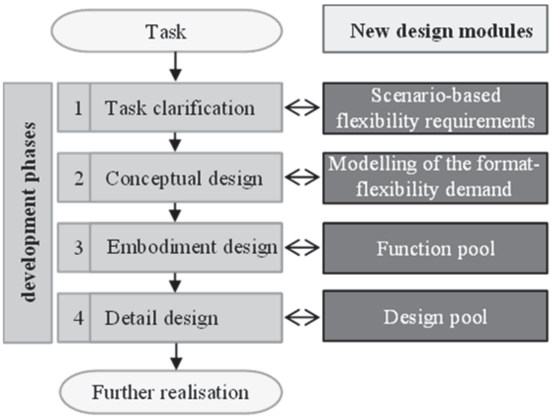

Fig. 3 Concept of a design-led approach

Scenario-Based Flexibility Requirements

The realisation of adaptable systems is connected to additional financial expenses [32]. From an economical point of view, it is important to find the proper degree of format-flexibility. It is valuable to have a consolidated data base for the next design steps, which is the result of the requirements identification. Packaging machines are mostly custom-made products because of the great diversity of packaging styles and the very individual requirements of the customers. The concept of life-cycle engineering addresses all phases of a machine. In this context, it is very important to collect all the necessary information about format-flexibility and changeover. For this task, scenario-based planning is an interesting method. Scenario-based planning is an established technique for plant and strategic planning [33], [34]. The necessary scenarios have to include all the information which is connected to the changeover, e.g. packaging designs, batch sizes, education of the worker, and availability of technical equipment. A scenario combines retrospective with future information. The scenario-based planning of a design object consists of five steps [33]. These are the scenario-preparation, the scenario-field-analysis, scenario-forecasting, the scenario-development, and the scenario-transfer. For a better development of format-flexible packaging machines, the second and last steps are of particular importance. During the scenario-field-analysis, the key factors, which have an influence on the design object, are investigated, e.g. market changes or new product trends. The scenario-transfer includes an analysis of effects on the design object. For the design of more format-flexible packaging machines, the existing methods and tools have to be adapted. These scenarios could be used during design process for the assessment of different created alternative solutions, thus making it easier to achieve the design objective, which is called [35] ‘customised flexibility’.

Modelling of the Format-Flexibility Demand

The objectives of this design module are a methodical, documented and transparent identification of the necessary format-flexibility and to prognosticate the impact on the design object-packaging machine. Every parameter, which causes a demand for format-flexibility, is part of this model. It is important to identify the necessary flexibility corridor. The focus of the modelling process is the generation of geometric information, e.g. width, length. Packaging machines are highly integrated und complex machines, which fulfil packaging based on main and auxiliary processes. Main processes are, for example, the forming of the packaging material, filling the packaging and closure. Examples for auxiliary processes are the preparation of the packaging material and labelling. During a format change, different functions and elements of the packaging machine have to be switched. The degree of changes depends on the granularity of the differences between each format, e.g. another label, compared to the complete change of all parts of the package and the format design.

The model to generate the format-flexibility demand will be generated in six steps (Fig. 4). Basis of the modelling approach is the product structure of the packaging and the structure of the packaging machine. In step one, the format-dependent attributes of a packaging will be derived with the help of the product structure. This packaging is input from the method of the ‘scenario-based flexibility requirements’. During step two, the attributes of this packaging will be filled into the matrix-based structure. The packaging machine will then be abstracted (step three). It depends on the newness of the machine whether the function structure or the product structure of the machine will be applied. In the case of a new development, the function structure will be used, the product structure in case of a change development. A matching of the results of steps two and three will be executed to generate the information, which influences a packaging attribute in the context of format-flexibility on the packaging machine (step four). Finally, in step five, the demand of format-flexibility could be described. An optional step is step six, where the machine model will be specified and steps four and five have to be repeated. Step six could also be executed during the next phases of the development in order to get a detailed view of the format-flexibility of this machine.

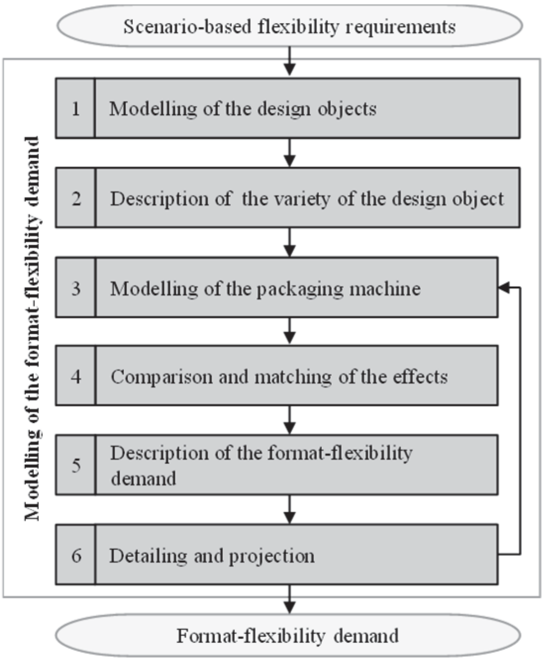

Fig. 4 Method of getting the format-flexibility demand

For the practical application, a type of structured matrix has been developed (Fig. 5). This structured matrix fulfils the method requirements of practicability, traceability and adaptability very well. This matrix-based structure has similarities to modelling approaches based on the Design-Structure-Matrix (DSM), or approaches by [27], [28], and [32].

The format-flexibility demand could be generated very comprehensibly with the help of this tool. The matrix-based structure could be adapted to different developing objects and aims. In addition, it could be advanced during the following development process to be a tool for the complete process.

Function Pool

One task of the third development phase is the search for solution principles and their structure. The main and auxiliary processes of a packaging machine could be realised by different technologies, which have an individual degree of inherent flexibility.

Today, during the development of packaging machines, the comparison of these different flexible technologies is considered to be insufficient. Therefore, it is unclear if there is potential for realising more format-flexible packaging machines by the use of technologies with a higher degree of inherent flexibility. If there are differences between technologies, the proper choice reduces the effort in the following development steps, because a lack of inherent format-flexibility has to be eliminated by a more expensive design process. If there are no differences between technologies, then there is no potential at the level of solution principles for realising a more flexible system. Therefore, the most potential for increasing the format-flexibility is during the detail design.

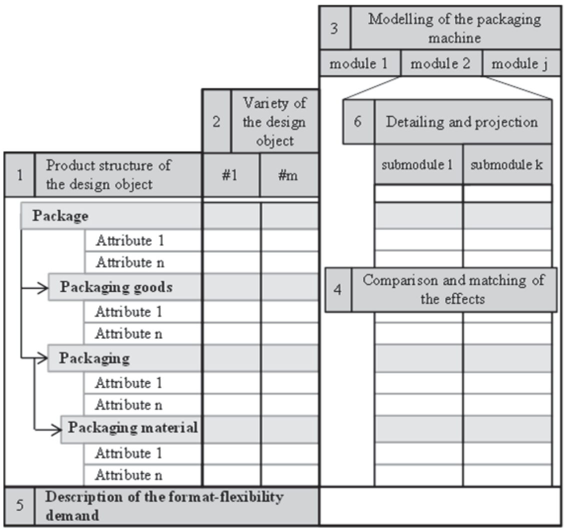

Fig. 5 Matrix-based structure of the tool to generate the format-flexibility demand

To get a practical tool for the developing process, possible technologies for realising the main or auxiliary processes have to be collected. This collection is called the function pool. There are many ways to fill a function pool for a specific packaging process, e.g. literature and patent review, the consideration of other industries, creative and structuring technics. In total, these are all methods of information generation and methods of technology screening.

The inherent flexibility of the elements of this collection has to be assessed and, in this way, the potential for raising the format-flexibility of a packaging machine is investigated. A measurement of the inherent flexibility of a technology is very theoretical. A more practical way is the use of the introduced three classes of flexibility (Fig. 2). The need for a geometric-dependent working tool is a signal of a low degree of inherent flexibility. If the change between two packages could be realised by ‘kinematic flexibility’ or even by ‘parametric flexibility’, this solution principle has a higher degree of inherent flexibility. Of course, all the interesting technologies have to fulfil the basic processing requirements, e.g. processing speed and quality. This assessment could be realised by theoretical analyses or practical studies. Finally, the result is a function pool, which could be very easily extended with new technologies or innovative ideas. The focus of this work is format-flexibility, but this assessment could also be expanded to other categories, like costs, robustness or degree of innovation. In Section V, a function pool for the typical main process of ‘case erection’ will be shown. Another example is a function pool for the processing step of sealing for a thermoforming packaging machine. The common technology is permanent heating contact sealing with a geometric-dependent working tool. This has a low inherent flexibilisation potential. There are technologies, like laser-beam sealing or impulse heating contact sealing by a multi-contour working tool with a higher degree. The theoretical assessment is finished and experimental studies are currently in progress.

Design Pool

The design pool should help the developer during the fourth phase of form design. The choice of a flexible function and technology is not enough to get a format-flexible packaging machine. The design pool is orientated on the common design rules. These design rules support the developer with fulfilling the various development objectives, e.g. suitable for manufacturing or assembly [36]. The advantages of these design rules are well-known because of the good acceptance in industrial application. There are many different design rules, see Section III. These rules are a good basis for categorising and extension, by giving design advice to create a better tool for the industry. Examples for added design advice are discretisation, function integration, function enlargement, a proper degree of automation, as well as format independence. These are theoretical ideas which could be transferred to the present design situation.

VI. Exemplary Creation of a Function Pool for Case Erection

The volume of sales by e-commerce is rising. For transport and logistics, a cheap, light-weight and stable type of packaging is needed. Boxes of corrugated paperboard are becoming more and more important, because this packaging type fulfils these requirements very well. One main challenge in e-commerce is to construct different sizes of cartons to optimise the volume of each customised transport unit.

The standardised box format, FEFCO-0201 (Fig. 6), is very common in e-commerce, as well as in many other industries. It is also a packaging style, which could be fulfilled very well by the top-loading method. This is very flexible compared to other filling methods, e.g. wrap-around, because there is no need for staple stacking. For this reason, the focus of this function pool is the erection of FEFCO-0201 boxes from corrugated paperboard. The result of the function pool for realising the carton erection process is a kind of morphology. This is a typical type of creative method during the design process and documented alternatives and is very common in visualisation. It is intuitive for developers for creating new ideas and could be extended very easily, thus many requirements of the approach could be fulfilled. Furthermore, it has to be analysed if there are functions, which require a higher degree of inherent flexibility or if there is no difference between the alternatives.

First, for the ‘case erection’ function pool, the current process will be reduced to the basic function. The input for a case erection process is a flat, non-folded carton and all the inner angles of the folding edges are 0° or 180° respectively. At the end of the process, all the inner angles are 90° (Fig. 6). For reaching this output state, a torque has to be introduced in the four folding edges and can be induced by force. In the present case, the necessary force could have different directions and positions. On this basis, four fundamental ways of realising this function are derived and are the basis for creating alternatives (Fig. 7).

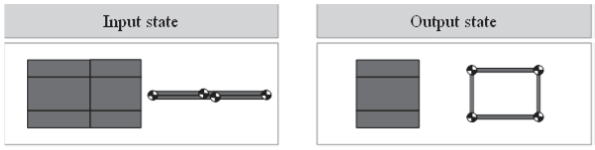

Fig. 6 Input state and output state of a carton erection process

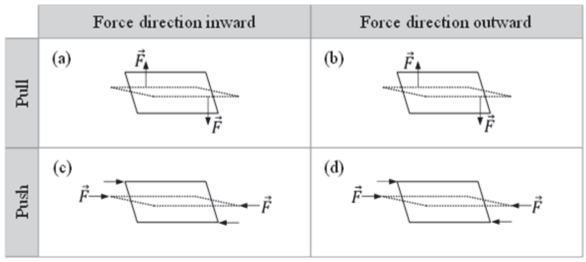

Fig. 7 Matrix of four fundamental ways to erect a carton

An assessment of the degree of inherent flexibility potential is not useful at this abstraction level of principle solutions. For this assessment, a concretisation is necessary which also connects the principle idea with the necessary working tool and the kinematic. Fig. 8 shows, at the first level, four exemplary principle solutions. The next step is to analyse what effect another carton size has on the principal solution. This assessment can be made with the help of two questions. Is a geometric-dependent working tool necessary and could the function be realised by the use of a kinematic, are the two questions. For example, the first two alternatives need a geometric-dependent working tool, thus these alternatives show a lower degree of inherent flexibility potential. The other alternatives are more or less equal with regard to inherent flexibility potential. These two alternatives, with a higher inherent flexibility, could then be made more detailed, combined with working tools and extended with a kinematic. Fig. 8 shows five examples of principle solutions, which are based on erecting by push or pull. These alternatives could also be analysed as to what effect a new carton size has. The result of this analysis is that different principle solutions have the same inherent flexibility. Therefore, it depends on the following design process to create a format-flexible machine. The interfaces to the process steps before and after the case erection also have a big influence. During the form design step, the assessment could be extended by other criteria, like costs, complexity, robustness, or degree of innovation. If there are new ideas or function principles for erecting a case, the morphology box could be extended and the analysis of inherent flexibility repeated. As there is no difference in the inherent format-flexibility, the following form design process has no restrictions in the context of format-flexibility.

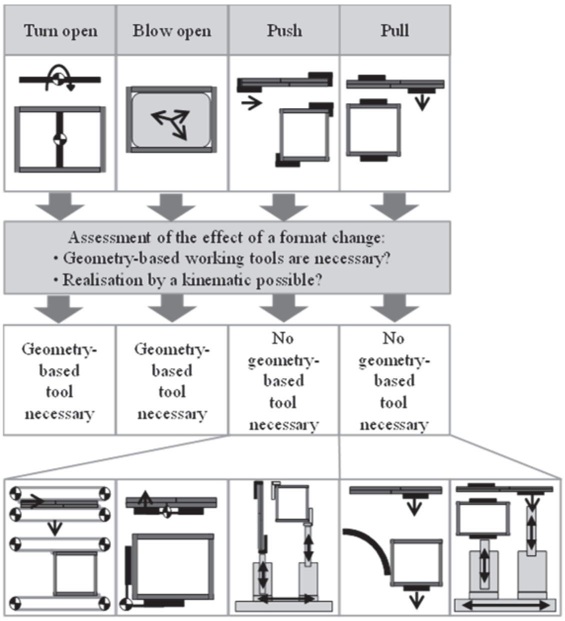

Fig. 8 Exemplary principle solutions for case erection and assessment of inherent flexibility

VII. Design and Validation of a Format-Flexible Case Erecting, Filling and Closing Machine

With the help of the introduced concept and the 'case erection' function pool, a format-flexible case erecting, filling and closing packaging machine has been developed.

Firstly, the concept (Fig. 3) had to be adapted to the used process model. The majority of German companies in the packaging machinery manufacturing industry are small or medium-sized enterprises (SMEs). Here, the standardised engineering processes, such as VDI-2221 [37], have a high distribution. The introduced design modules could be integrated with less effort into the VDI-2221 (Fig. 9). The integration of these design modules in an existing and industrially-established method, like VDI-2221, ensure a more conformable allowance of format-flexibility compared to a new, stand-alone method without any connection to the applied design and development process.

The addressed use case is a packaging department of a mail-order business. Every order, and thus every arrangement of filling goods, is customised. The collection of products, which the costumers can buy, is also changing all the time. To reduce the non-filled and empty volume of the packaging, different case sizes could be selected. Nowadays, the boxes are produced in a batch, because the format-flexibility is too small and the changeover time too long. The box format is FEFCO-0201. The machine should be the result of a completely new development with a high degree of innovation.

The usage of the introduced concept is kept short because the focus of the following section is the description of the technical aspects of the designed packaging machine.

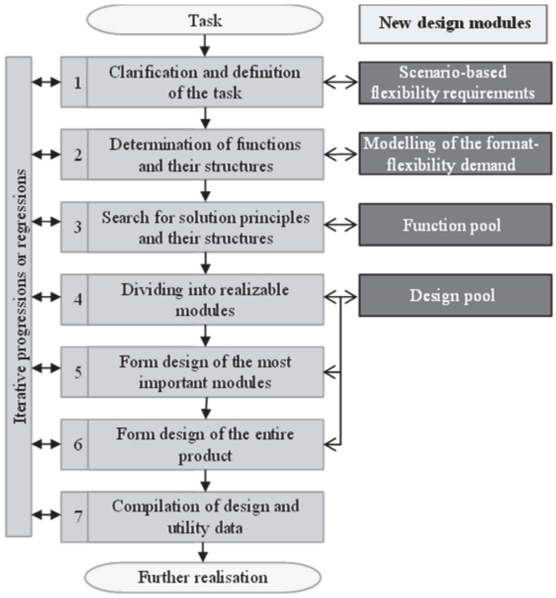

Fig. 9 Design-led approach integrated in the VDI-2221

The definition of the scenario-based flexibility requirements is uncomplicated due to the addressed use case. The main requirements are: economic changeover for batch size 1, need for full automation, box format is FEFCO-0201 with various dimensions and an incalculable amount of different filling goods.

The necessary flexibility corridor of each packaging process step becomes obvious with the help of the modelling of the format-flexibility demand. During the further design steps, this model could be extended to get a more detailed model.

The usage of the function pool of section VI shows that there are different solution principles for the erecting of a box with the same inherent flexibility. Therefore, the choice depends on other criteria, e.g. costs, degree of innovation. The other processing steps, like closing or filling, could be handled in the same way. It is very important that the overall concept is assessed to get an economic and format-flexible concept.

With the design advice from the design pool, different functions of the packaging machine could be made more flexible. These aspects will be shown during discussion of the realisation of the research demonstrator. A focus was necessary to reduce the financial expenditure for the realisation of the research demonstrator.

The demonstrator starts with the erection of the case. The storage of the unfolded cartons is not inside the chosen system boundary. Due to the flexibility and the function integration, as well as the erection and transport in one step, the differential belt system was the selected alternative. This combination is based on the 'function integration' design advice. This solution principle also has a high degree of innovation, but there is a lack of practical experience. One objective is the investigation of the differential belt system for the case erection. In detail, the differential belt system will be used in two different phases (Fig. 10). During the erection phase, the two belts move with different velocities until all the angles are 90°. In the transportation phase, the two belts move at the same speed. It is cost effective to integrate the erection as for the transport of different case sizes, a movement of the two belts is necessary anyway; therefore, no additional effort is generated. For the erection of a new or another format inside the flexible corridor, only the start position needs to be adapted – this is an example of 'parametric flexibility'.

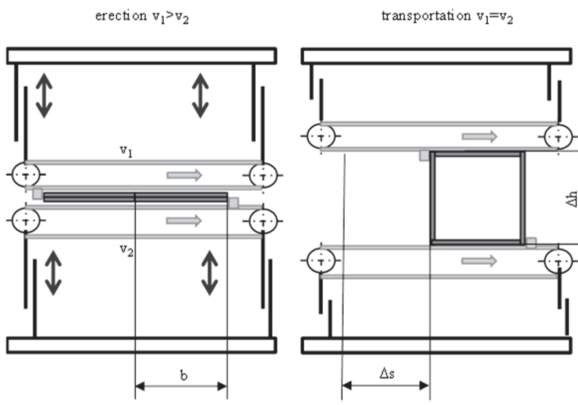

Fig. 10 Case erection and transportation phase of the differential belt system

The width movement is coupled to the movement of the two differential belts. A mathematical description could be derived (1). This is also the basis for the programming of the PLC control and the servo drives. The term Δh stands for the distance between the two differential belts (Fig. 10). The movement of the mechanical stop between the start position and the current position describes Δs. The length of the case is b.

$$\Delta h = \sqrt{b^2 - (b - \Delta s)^2} \quad (1)$$

During the start-up, the solution principle could be evaluated. The ability to solve the packaging function case erection could be shown, as well as the function integration and the continuous working. A stochastically dysfunction could be recognised. During the erection phase, the unfolded carton sometimes bends in the wrong direction (Fig. 11). This happened frequently in the case of longer and wider case dimensions. As the result of an analysis, this situation could be compared to buckling by 'Euler'. Furthermore, the variation of process parameters, like speed or the shape of the mechanical stops, could not avoid this behaviour. The 'push open' solution principle, realised by a differential belt, has to be extended to increase the robustness. The mechanical stop of the differential belt 2 was replaced by suction pads to avoid the buckling (Fig. 12). This is now a combination of the 'push open' and 'pull open' solution principles, because one half of the case will be erected by 'push open' and the other half by 'pull open'. Due to this measure, the robustness of the erection process could be guaranteed. The function pool needs to be extended to include this information.

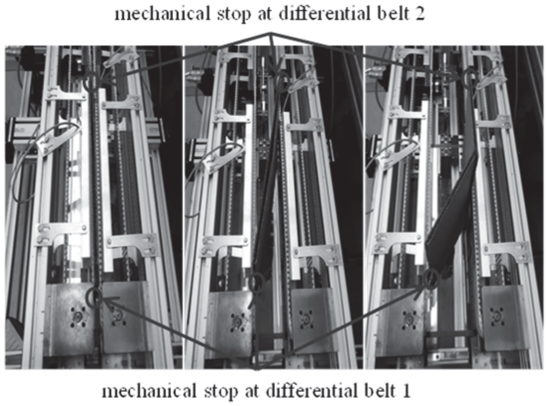

Fig. 11 Malfunction during case erection

After the erection, the underside of the case is closed to get a fillable packaging. Fig. 13 shows the different states for reaching this. Firstly, the front and the back flap have to be folded. Special working tools have been designed for this, which could be used for the whole flexibility demand corridor, thus avoiding changeover activities. This is a good example of the 'format independence' design advice. Secondly, both of the side flaps are folded. During the folding process, the front and back flap have to be held in the folded position to get a finally closed case. Finally, the flaps are permanently fixed by taping. The working tools for folding the side flaps are also designed to have no demand for changeover.

After taping, the cases are ready for filling. For realising a robust filling process by the top loading method, it is useful to get a defined position of the flaps of the top side of the case. Fig. 14 shows the result of the design process. With a turning working tool, the front flap is folded into the fixing frame. This fixing frame brings all four flaps into a defined position for filling the box by a robotic kinematic.

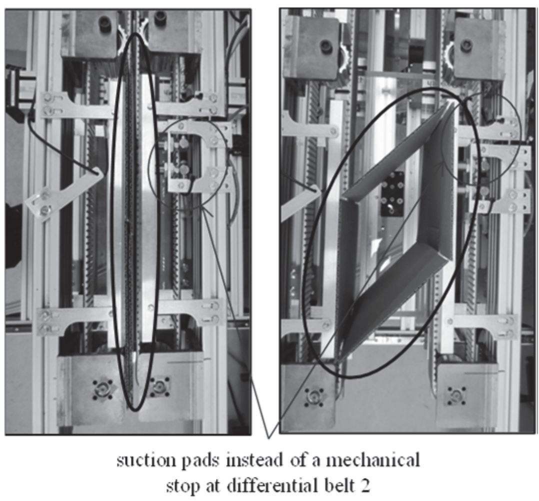

Fig. 12 Replacement of a mechanical stop by a suction pad for increasing the robustness

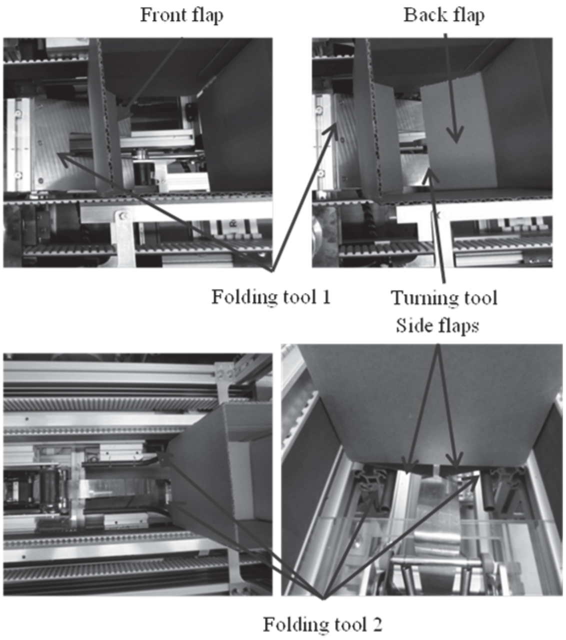

Fig. 13 Folding process of the front and back flap, as well as both of the side flaps

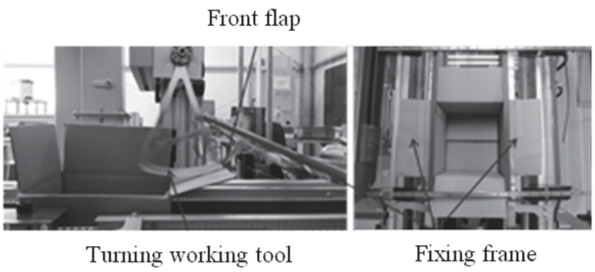

Fig. 14 Turning working tool and fixing frame to enable a robust top loading filling

The next process step is filling the box. For realising the product flexibility of the robotic kinematic and the gripper system, an automatic gripper change system is used. Each product group was able to be handled very flexibly without any manual changeover.

The closing of the top side of the case is not inside the system boundaries of the demonstrator, because it is only a repetition of the realised system for the underside. Fig. 15 shows the realised demonstrator.

VIII. Conclusion and Outlook

The demand for format-flexible packaging machines will increase in the future because of various market changes. The increase in format-flexibility is a new development goal for the packaging machine manufacturers. This is the reason for the demand of an approach for the efficient design of format-flexible machines. The approach and the different design modules have been introduced and explained. As one example, the creation of a function pool for the 'case erection' packaging process was shown. Finally, the use and especially the design of a format-flexible packaging machine were demonstrated.

In the future, function pools will be created for other packaging process, e.g. sealing and cutting. Furthermore, the design pool will be constantly expanded.

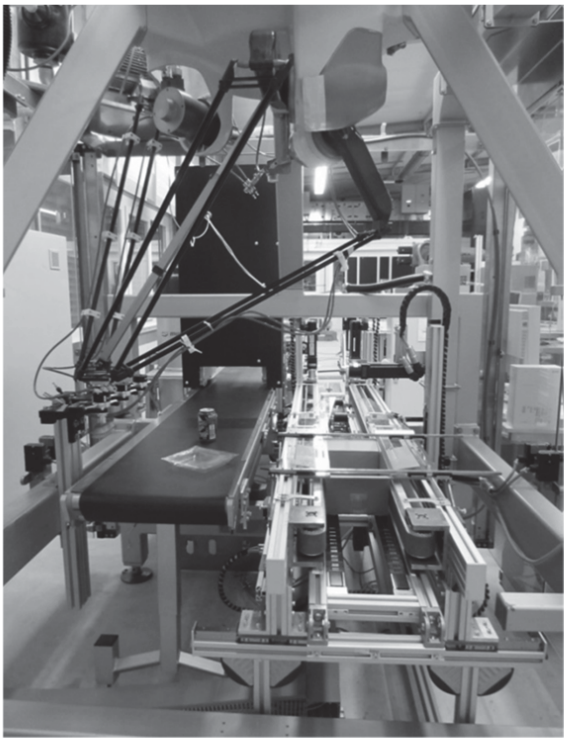

Fig. 15 Demonstrator of a format-flexible case erecting, filling and closing packaging machine

Acknowledgment

The project 'FORFood' was funded by the Bavarian Research Foundation.

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