Stationary fully automated Hop Picking Machine-Concept, Prototyping and Preliminary Testing

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ABSTRACT

Hop harvesting in Germany takes place in late summer and optimally needs to be carried out within three to four weeks. The harvesting of high trellis hop gardens is carried out sequentially. On the field, together, the hop wines and the supporting wire are pulled or cut from the overhead cables, loaded on to a trailer and transported to a static picking machine on which the harvesting of the cones takes place. Manual placement of each individual vine into a clamp which pulls the vines into the picking machine is a prerequisite on the traditional picking machines. This task is labour-intensive, ergonomically unfavourable fraught with risk of injury. The Bavarian State Research Center for Agriculture and the company Fuß Fahrzeug- und Maschinenbau GmbH & Co. KG started a cooperation project in 2011, with the objective to design and test a novel prototype of a system for automatic picking based on the preliminary work of the company. The manual placement of the vines into the clamps should be replaced with a fully automated feeding of the picking machine. This paper describes the concept and methods used during the development. Furthermore, the results of the preliminary testing are presented and steps of the further development proposed.

Keywords: Automation; Agricultural engineering; Hop; Picking machine; Ergonomics; Hop harvesting

1. INTRODUCTION

The worldwide largest continuous hop-producing area is located in the Hallertau in Bavaria and comprises more than 15000 ha. Typical way of hop growing in Germany is referred to production in hop gardens, in which, a horizontal mesh of longitudinal and transversal cables are fastened on a system of poles composing the main structure of a trellising system. At the start of

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each growing season supporting strings need to be attached to the overhead cables of the main structure to create a 7-8 m high trellis systems. Under optimal conditions and regularly maintained the hop gardens can be effectively used for more than 20 years. Usually 2000 hop rootstocks are planted on one ha with a distance of 1.5m between consecutive rootstocks within a row. The two best developed vines from each rootstock need to be selected in spring and trained to climb and twist around the supporting strings. The most frequently used material for supporting strings in Bavaria is a 1.2 to 1.4 mm thick iron wire. After harvesting has been finished, the preoperational activities for the following season need to be carried out which *inter alia* consider replacement of approximately 4000 supporting wires per ha in the period between October and March and they anchoring to the ground. The harvesting of high trellis hop gardens is sequential, takes place in August and September and optimally needs to be carried out within three to four weeks. The hop vines, which grow together with the supporting strings while climbing, are simultaneously severed from the ground and cut or pulled from the overhead cables using a pull-off implement and in a continuous process loaded on to a trailer. Once the trailer is fully loaded, the hop wines need to be transported to a static picking machine.

The employees of the company Fuß have been actively involved in development and optimization of hop picking machines for 40 years. The idea of completely automated harvesting of hop is not new. Already in early 1970, experts, today employees of the company Fuß Fahrzeug- und Maschinenbau GmbH & Co. KG (Pfeffenhausen, Germany), worked on development of a field harvester, which remained on the evaluation model stage (Fuß, 1976). In the United States the harvesting of hops in high trellis gardens is sequential like in Europe. On the field, however, the hop vines are severed from the overhead cables with other methods and another type of trailers are used. Thus, the separation of single vines from the bulk is not simple and the harvesting on the stationary picking machine is carried out on a different way. In 2004 the idea of automated feeding of the stationary picking machine was patented in the United States (Perrault, 2004). After evaluating this idea, the employees of the company Fuß ascertained that direct adoption of this method will not offer the expected effects on the farms in Germany.

1.1 Problems related to manual feeding of traditional picking machines

Harvesting of optimally matured cones is affected by wetter conditions and limited to a short period in which the involved parties sometimes need to count with 20 working hours per day. The processing implies manual placement of individual vines into clamps, which pull the vines into the traditional picking machines. Placement of hop vines is labour-intensive and monotonous. Hence, this work is fraught with risk of injury due to the cyclical repetition of the task. Considering the ergonomics, especially during the separation of single vines out of the bulk in case they are twisted, the work related to manual feeding of picking machines is associated with increased stress and strain of the muscles. Figure 1 illustrates the stress and body position during the separation of twisted hop vines.

Figure 1. Manual feeding of traditional picking machines

Taking into consideration the different aspects of the stress related to the loading of the picking machine, the number of seasonal workers willing to carry out this task decreased in the past years. The expenditure on manual labour also increased constantly in recent years affecting the hop production in Germany. Hop production is concentrated on relatively small areas and carried out by a modest number of farmers (e.g. the number of involved farms decreased from 8591 to 1294 in the period from 1973 to 2012, while the total area under hop stayed on the same level in this period). Thus, the processing quantities and machine capacities on each farm increased. Hop picking machines are integrated into buildings, are expensive and can be characterised by a high level of complexity, with already identified potentials for optimisation. The most important international and national agricultural machinery manufacturers, however, showed little interest to contribute on the development, because of the small market share and the introduction of new technologies and machines remain on the moderate level.
Analysis of the state of the art and the addressed problems indicate that an automation of the hop picking machine feeding could advance the hop production in future.

2 MATERIAILS AND METHODS

The company Fuß pursued the problem of automation of the manual placement of vines into the clamp or introduction of adequate solution which will improve the feeding of the stationary picking machine and introduced a new idea to solve this problem. The Bavarian State Research

Center for Agriculture and the company Fuß started a joint development project in 2011, with the aim to evaluate this idea through concept and prototype development and testing.

2.1 Concept of the automated Feeding of a Hop picking Machine

The developed concept is based on the implementation of additional mechanisms and processing steps. After unloading from the trailer onto a conveyor, the bulk of hop vines needs to be transported and exactly positioned above the mechanism for cutting. The cutting mechanism moves vertical upwards and cuts the entire bulk through (see figure 2). The cutting length of hop vine pieces can be adjusted and depends on the hop variety and estimated yield quantity. With the pre-picking unit, which is a part of the cutting mechanism, as much cones as possible should be picked already in this preparation phase before the individual hop vines arrive in the picking machine for further processing. After the hop vine pieces have been left the pre-picked unit they are longitudinally spread over the entire width of the second conveyor which transports them into the picking machine providing continuous feeding.

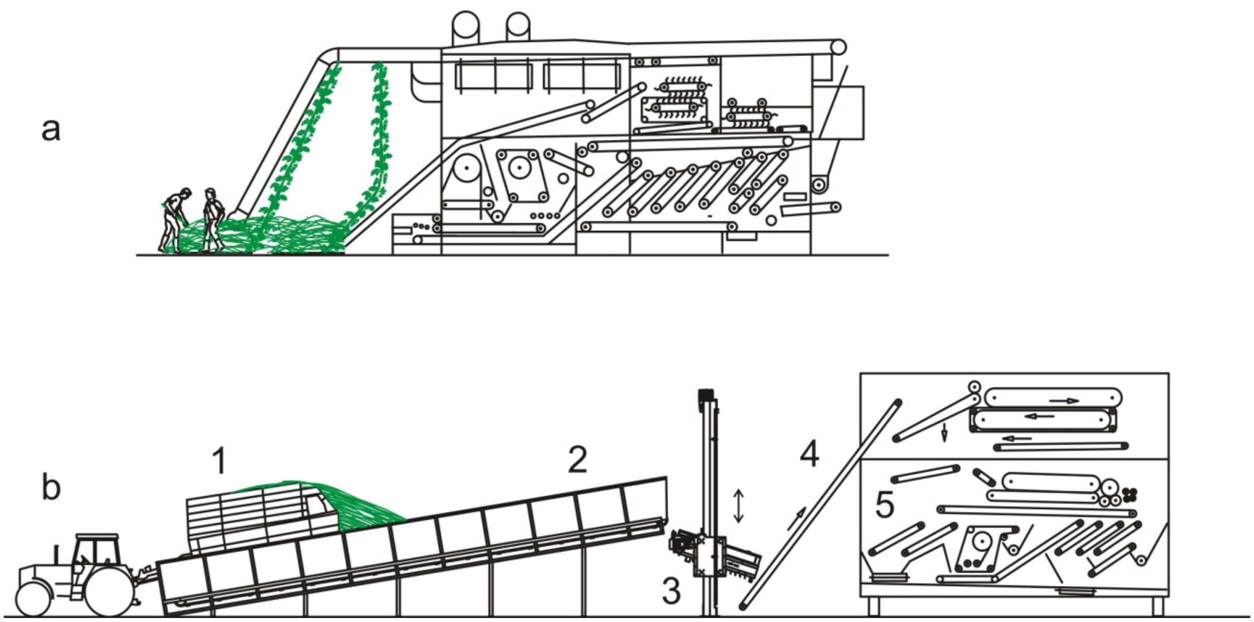

Figure 2. Feeding of the picking machine: a) manual feeding b) concept of the automated feeding (1-trailer; 2-conveyor; 3-cutting mechanism; 4-conveyor; 5-optimised stationary picking machine)

After completing one cut through the entire bulk the cutting mechanism moves automatically into the initial position. Through advancement of the conveyor the bulk is moved to the next cutting position. The above described processing steps are repeated until the remaining length of the bulk become shorter than the adjusted cutting length. To provide continuous utilization of the picking machine, another bulk can be unloaded from the following trailer onto the conveyor.

2.2 Digital Prototyping

The presented concept of the automated feeding of a hop picking machine is a unique approach, which implies the development of a novel system. Similar projects in the past were accompanied with significant number of errors which were able to eliminate by trials involving additional time and causing extra costs. To avoid such a problem a digital prototype of the system was built allowing tests based on simulation. In the first phase the sketches created during the concept development and existing technical drawings were reviewed and converted into 3D solid models. The models of the existing parts for which technical documentation was not available were created using reverse engineering. In order to provide modularity of the system, already during the concept development, lifting systems common in construction, packaging and assembly industry were evaluated. On such a way and using concurrent engineering the digital prototype was built step by step using Product Design Suite 2012 (Autodesk). Additionally, for most important mechanisms, simulation-ready models were created to carry out kinematical simulations, stress and force analysis. A screenshot presenting the digital prototype of the testing facility is shown in the figure 3.

Figure 3. Digital prototype of the automated hop picking machine feeding system

2.3 Physical Prototype of the testing Facility

The prototype of the testing facility consists of a conveyor, a cutting mechanism which includes the pre-picking unit and a second conveyor which transports the pre-picked vines to the further processing.

Like described in chapter 2.1 the trailer driver unloads the bulk of hop vines onto a conveyor (1) which transports the bulk to the first cutting position above the mechanism for cutting (2). The cutter bar (3) and the pre-picking unit (4) are mounted on the same carrier. With the second conveyor (5) the longitudinally arranged and over the entire conveyor width spread hop vine pieces are transported to further processing continuously. The testing facility is controlled by a PLC which is mounted in the electrical cabinet (6). The first prototype of the system is shown in the figure 4.

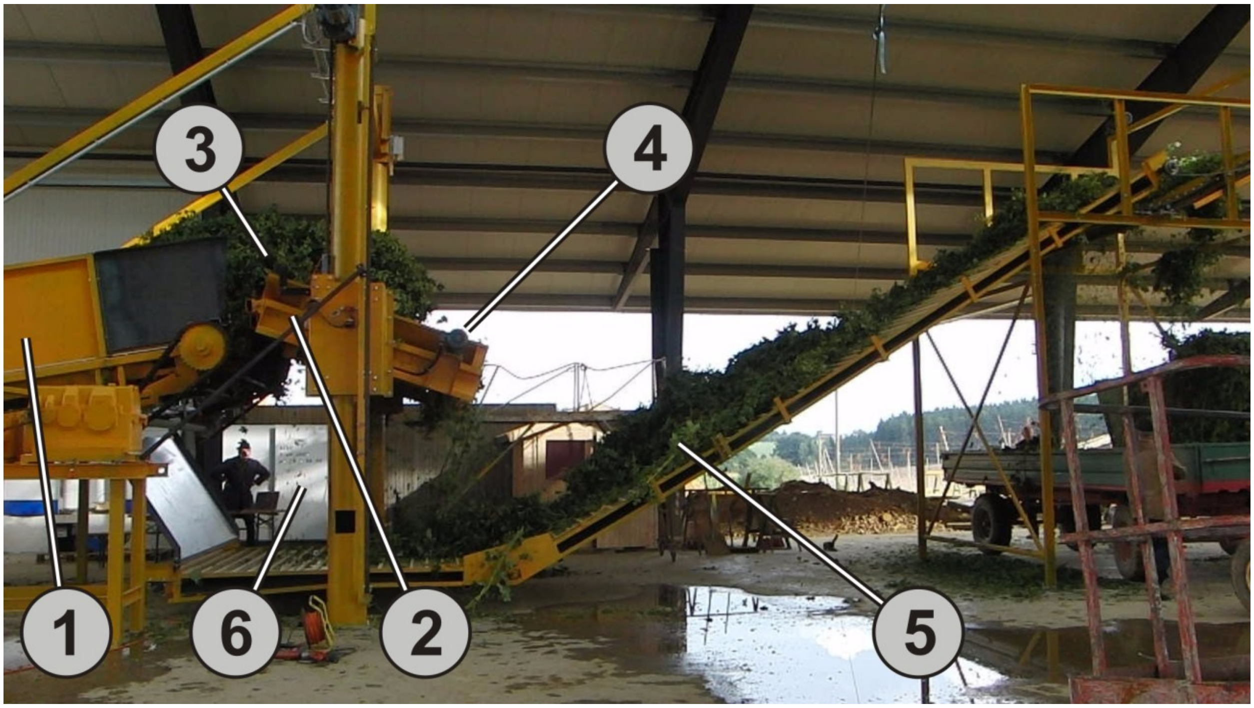

Figure 4. Testing facility of the prototype for automated feeding of the picking machine. Legend: (1) – conveyor; (2) – mechanism for cutting; (3) – cutter bar; (4) – pre-picking unit; (5)– feeding mechanism; (6) – electrical cabinet with the PLC

2.4 Initial Operation of the Prototype

Initial operation of the prototype and the first testing were carried out during the hop harvesting season in 2012, only 3 months after the design was approved. The main objectives during the testing were to prove the quality of the simulation results considering the reliability of sensors, mechanical parts and implemented mechanisms the check the stability and system and to gain new insights. During the testing, videos of the most relevant processing steps and high-speed videos of the cutting bar and pre-picking unit were captured.

3 RESULTS AND DISCUSSION

Based on the digital prototype, the processing of the data from preliminary design to the assembling of the prototype covering the entire process chain became possible. This repeatedly approved design method retained the number of design errors on the minimum level and the time required for achieving the design of the prototype was considerably reduced. The first physical prototype was built and assembled using the documentation and drawings derived from the digital prototype.

The prototype and the facility can operate in three operation modes: off, manual and automatic, whereas adjustment of the parameters, including the speed of both conveyors, can be carried out in the manual mode at the moment. Furthermore, the up and downwards speed of the cutting mechanism, and the speed of the pre-picking unit can be adjusted by the control software, with the aim to induce a maximum pre-picking effect while the damaging of the cones stays on a minimum level. The automatic mode allows iterative repetition of all operation providing processing of a whole hop bulk without manual intervention.

The preliminary tests were carried out under different working conditions. The aim was to test and evaluate different vertical speeds of the cutting mechanism up and downwards, in order to estimate the time necessary to carry out a cut through the entire bulk and providing the preliminary information about the capacities which can be processed with the prototype. During the testing selected parameters of the frequency inverter which controls the electric motor of the lifting system were acquired and analysed in order to see how different speeds affects the energy consumption.

Furthermore, the speed of the pre-picking unit was modified in order to analyse the effects of this parameter to quality and quantity of pre-picked cones. During the testing, the material stream was observed as an important factor which needs to be taken into consideration during the optimisation of the system.

The collected information is currently used for the optimization of the developed prototype and its integration with the stationary picking machine. The improvements regarding to stability, accuracy, reliability and capacity are striven for.

4 CONCLUSIONS AND OUTLOOK

The latest design and analysis tools such as digital prototyping, simulation, capturing of high-speed videos during the testing and real-time acquisition of the selected parameters were used within the join development project for developed of the new prototype of a system for automated feeding of a hop picking machine. Hence, it became possible to carry out the development without high expenditures.

Until the harvesting season in 2013 it is intended to integrate the prototype for automated feeding with an optimised stationary picking machine. An important part of the optimised picking machine will be the picking unit, which is a newly developed product of the private limited company Fuss.

On the final prototype several tests will be carried out considering the yield losses, damaging and quality of the cones during the processing of different hop varieties. The results will be compared with the results during the processing on a conventional picking machine. The system will be optimised toward undisturbed processing of the hop bulk without significant quantity and quality losses. Moreover, the energy consumption and the operational capabilities will be evaluated, in order to detect further improvement possibilities of the entire system.

In the final design the safety aspects will be incorporated and related problems solved according to the new machinery directive 2006/42/EC (Fraser, 2010).

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