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Automated fastening of the support wire in high trellis of hop

The concept, development and optimisation of a second prototype of a device for fully automated fastening of the support wire will be presented in this paper. The main advantage of the novel device is the minimization of accident risk. Moreover the ergonomic burden of hanging up the support wires can be reduced by this automatization. Furthermore, the device makes it possible to perform the work also under difficult atmospheric conditions.

Keywords
Hop growing, automation in speciality crops, fastening of the support wire, prototype development

Abstract
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The Federal Republic of Germany is the greatest hop producer with a cultivation area of approximately 18 500 ha. The characteristic growing technique in Germany is based on 7-8 m high trellis system which provides support for the hop bines by climbing. The support wires must be replaced every year. In contrast to other hop cultivation regions, where support materials such as coconut, plastic, or paper strings can be used, the 1.2-1.4 mm thick iron wire has proven itself in Germany and is appreciated due to its elasticity and tear resistance [1]. The support wire is still exclusively fastened manually. This work is carried out between October and February. Two to four persons standing on a special hop cultivation platform attached to the front-end loader or on a working platform [2] at a height of approximately 7 m fix the pre-cut wires to the longitudinal cables of the trellises. Manual attaching takes place while the tractor is moving forward at constant speed. The attachment of the support wires involves a considerable danger of accidents. In addition, this work is highly taxing under ergonomic aspects [3] and must often be carried out under unfavourable weather conditions. For this reason, full automation should be striven for. The company Soller GmbH (Geisenfeld) has already been working on this concept for about 10 years. The idea was protected by a patent, and a first prototype was developed. Between 2008 and 2010, the Bavarian State Research Center for Agriculture and the company Soller realised a cooperation project aimed at the development of this technique. During this project, the system was optimized and improved as part of the innovation support program of the German Federal Ministry of Food, Agriculture, and Consumer Protection (BMELV), and a second prototype was developed based on the newly gained insights.

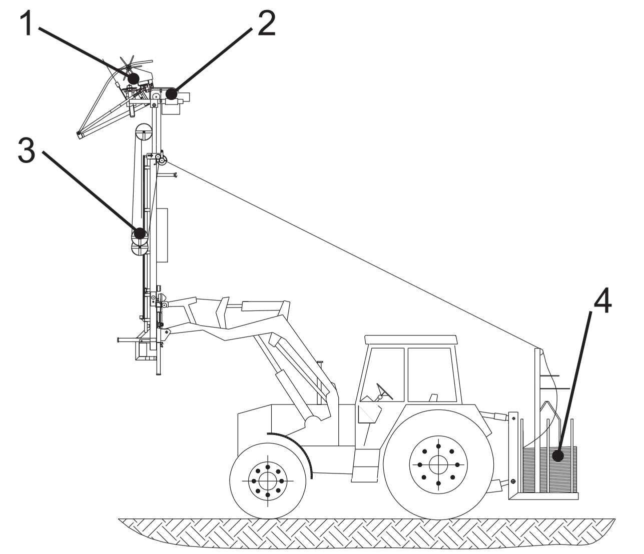
Materials and Methods

In a first phase of the project, the existing technical drawings of the individual parts were revised completely and converted into 3D solids. All newly designed or optimized single parts were generated as 3D solids. As a 3D-CAD-system, the Pro/ENGINEER WF3 was used. This fully parametric 3D-CAD-software allowed to handle the data within the entire process chain from the first draft to the manufacturing of the second prototype. The Design with Pro/ENGINEER enabled as well to model all the parts in detail and their virtual assembly as to perform kinematic analyses with the virtual prototype (VP).

The second phase of the project focused on the observation of hydraulic pressure, flow, and temperature in the main oil hoses of the first prototype during the tying process. The measurements were taken with the aid of a compact modular measuring platform able to acquire analog, digital, and counter signals. For pressure measurement, sensors from the company Danfoss model MBS 3250, series 060 GI 869 were used. Flow was measured using an RE 4 turbine of the manufacturer Hydrotechnik, whose design enabled an additional temperature sensor (Pt 100) for simultaneous oil temperature measurement to be installed. The measurement data were acquired during field trials and stored on the hard disc of a laptop via a standard interface. The software for the data acquisition was developed using the LabVIEW Developer Suite from National Instruments and adapted to the special requirements.

In parallel, the subsystem for intermediate wire storage (**figure 1**) was analysed and optimised under laboratory conditions.

Fig. 1



Device for fully automated fastening of the support wire in high trellis of hop. 1: positioning unit, 2: wire tying unit, 3: intermediate storage of the wire, 4: wire coil

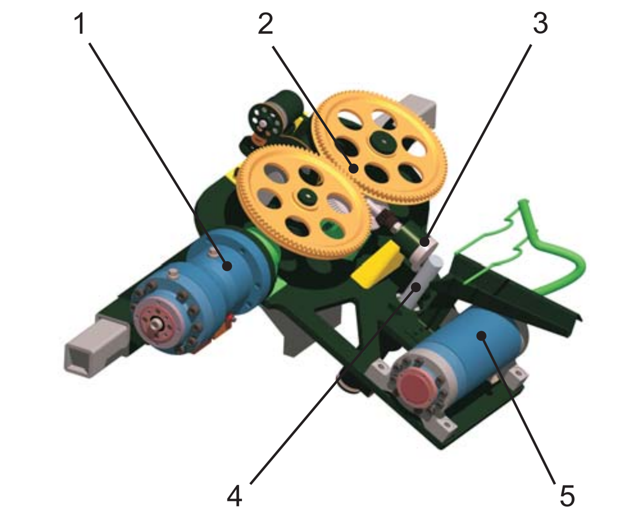
Results

The development of the VP was the basis for the optimisation of the wire tying unit, which is a highly complex subsystem considering its dynamic behaviour. In contrast to the first prototype, two swing motors with integrated damping in both end positions were integrated on the second prototype instead of single-acting cylinders, in order to move the wire tying unit in the upright position and to twist the support wire around the longitudinal cable. The Pro/ENGINEER module mechanism allowed the motion processes of the subsystem to be followed virtually. In addition, it enabled the results to be analyzed and finally the individual parts to be optimized on the basis of these results (**figure 2**).

Thanks to the VP, it was therefore possible to test the functions while the configurations of the swing motors and their activation points in the entire process chain were changing. In addition, collision analyses were able to be carried out during an early phase of the optimization without any need for modification of the existing physical design. Given the technical complexity of the subsystem, analysis based on the VP allowed design errors to be minimized and the development time to be considerably reduced.

In order to determine hydraulic pressure, flow, and temperature in the main oil hoses of the first prototype, the execution times of the four most time-critical processes in a total of 230 wire-attaching sequences were analysed and evaluated, and their deviation from the theoretical nominal value was discussed. The tests provided the following results: The execution times of the wire feeding -vary significantly, and the total duration of the wire feeding oscillates by up to 110 %. The slip between the wire and the feeding mechanism, the limited power of the hydraulic drive of the wire feeding mechanism, and the kind of actuator control were identified as the reasons for

Fig. 2



Virtual prototype of the wire tying subsystem. 1: positioning, 2: wire feeding, 3: twinning, 4: cutting, 5: bending these variations. Similar observations were made with regard to the refilling of the intermediate storage of the wire, whereby the oscillations reached up to 144 %. Increased friction between the wire and the feeding and refilling mechanism reduced the slip. As a consequence, however, power consumption increased and constantly available hydraulic power became necessary. In order to provide this power and to avoid power fluctuations in both mechanisms, the design was modified. For this purpose, the hydraulic system was divided into two independent hydraulic circuits. One circuit supplies power to the positioning system and the refilling mechanism of the intermediate storage of the wire, while the second one provides the hydraulic power required for all operations of wire tying and feeding motion.

The intermediate storage of the wire was optimized. This subsystem is installed between the wire tying unit and the wire coil. It allows the speed of the wire feeding to be increased without the support wire material becoming knotted or entangled while it is being pulled of the coil. The intermediate storage of the wire has the form of a pulley with one fixed and two independent, moving return pulleys. In its mechanism, the spring element which realises the connection between the frame and the moving return pulleys was replaced with a balancer. At the same time, both moving return pulleys were rigidly coupled in order to compensate for the jerky movement of the pulleys. The advantage of the balancer over the spring is that it generates a constant pull-back force over the entire course. The desired pull-back force can be adjusted in a certain working range, which enables optimal conditions to be set. Thus, a balanced pretension force of the wire during the entire working cycle of the intermediate storage of the wire is maintained. In addition, variants were discussed with the goal of reaching a variable refilling speed of the intermediate storage of the wire depending on the driving speed.

In cooperation with the company Mitsubishi Electric Europe, the control of the device for automated fastening of the wire with programmable logic control (PLC) was realized, and programming was optimized. In addition to fully automatic operation, the position of the device can be adjusted using a remote-control unit, and the tying process can be controlled manually.

Conclusions

To enable the optimisation of the device for automated fastening of the support wire, a virtual prototype was developed. This initial step was followed by kinematic and dynamic analysis. The first real prototype was equipped with sensors for the measurement of hydraulic pressure, flow, and temperature. The sensors were connected to the data acquisition system. An appropriate software solution for data acquisition was developed. Furthermore, a test bench for the examination of the prototype under laboratory conditions was modified and extended. Finally, the operating behaviour of the actuators was observed and analyzed, and the reaction times as well as the duration of the operation sequences were measured under field conditions. The optimization process provided new insights, and a second prototype was built. The modifications in particular included the subsystem for wire tying as well as the intermediate storage of the wire and the implementation of external hydraulic power supply. The optimized prototype was successfully tested in hop gardens for several weeks in the winter 2009/2010. The preliminary results clearly prove that the described second prototype provides greater reliability. According to a survey carried out among hop producers, the system will only be introduced in practice if the performance in continuous operation and the total operating costs are comparable with the performance and the costs of the traditional technique with three workers on the hop cultivation platform. This objective is being striven for. After the completion of development and testing, the device is intended to be manufactured by the company Soller.

Literature

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