HYDRAULIC CIRCUIT OF MECHANICAL PRUNER DRIVE FOR HOPS ON LOW TRELLISES*

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A mechanical pruner serves for pruning new hopvine shoots in spring. The later yield depends on the right timing and quality of pruning. That is why hop pruning is one of the most important agrotechnical procedures. A double-disc mechanical pruner used on high trellises cannot be used on low trellises due to its large size. Abroad, for pruning hops on low trellises a specially adapted sprinkler is used (chemical pruning). With regard to the effort to minimize the chemical environmental burden, we opted for the design of the mechanical pruner. Firstly, the low trellis, mechanical pruner, and also elements used in the design of hydraulic circuit are described. Next part of the paper is devoted to the input requirements for both the hydraulic circuit and the mechanical pruner designs. Then a description of an adapted inter-axle carrier used for the experimental model of the hop mechanical pruner and of the effected field measurement follows, along with interpretation of the measured data. These data are depicted in clearly arranged graphs showing the dependency of pressure and hydraulic oil flow on the cutting disc rotational frequency.

hops; mechanical pruner; low trellis

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INTRODUCTION

Hop growing in the low trellis system has brought about new agro problems. The technology of growing Czech hops are currently offering three ways to perform this task. The first option is to inhibit sprouting of new shoots or to remove them through a chemical desiccant (chemical cut) (Ebersold, 2004; Srečes et al., 2013). The second option is the manual hop cut, which is laborious and costly. The third method is to use a mechanical pruner, however its production has currently been limited (Křivánek et al., 2008; Křivánek, Ježek, 2010; Krofta, Ježek, 2010; McAdam et al., 2013).

The mechanical pruner serves for spring pruning of new hop shoots. On its proper timing and quality depends later yield, which is why hop pruning is one of the most important agrotechnical operations (Tomlan, 1992; Kopecký, Ježek, 2008).

For low trellis systems, using the single-disc hop pruner with the flat cutting disc of 600 mm in diameter proved to be the most effective (Štranc, 2007).

The mechanical pruner must be designed with respect to the basic requirements for its functioning. The mechanical pruner with the cutting disc could be carried on a tractor. Three possible ways of placing the cutting mechanism can be considered: front three-point linkage, inter-axle tool carrier, or rear three-point linkage. In the presented design, the mechanical pruner is placed on the inter-axle tool carrier produced in series (Wallner Company s.r.o., Chlumčany, Czech Republic).

At first, the model of the mechanical pruner was tested in the laboratory of the Czech University of Life Sciences Prague, Department of Agricultural Machines. The rear transmission with the hydromotor was fixed by means of four eye screws with a loop onto a clamping plate on the special laboratory holder. The designed and installed hydraulic circuit did not enable a fluent stopping of the cutting disc and it was the reason a one-way valve was added.

For field testing, a hydraulic circuit extended by several sensors was designed. During installation of the model on the tractor, a copying wheel was also connected. The copying wheel is composed of hol-

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low steel profiles of square cross-section into which a rectilinear hydromotor operated from the driver's cabin is placed. The depth of the cut is adjusted by moving of the rectilinear hydromotor.

The measurement itself was carried out on a 10 m long low-trellis section where the tractor with the connected mechanical pruner moved at a speed of 1 km.h^{-1}. The cutting disc in no-load conditions rotated at a maximum speed of 12.4 rps and the hydraulic oil temperature was kept at the value of 40 ± 2°C.

During the first drive of the tractor the cut height was set at 0. During the second drive through the same measured section, the cut depth was set at 50 mm (i.e. at maximum recess).

All the measured data are presented in the Results chapter, however, the research is still under way.

MATERIAL AND METHODS

Basic requirements for a mechanical pruner

The basic requirement is trimming the hopvine shoots (the so-called new wood) down to a depth of 50 mm below the terrain level. Thus the old hopvines are cut off their root part (rootstock) (Hoerner, Rabak, 1940; Royston et al., 1958). The cutting mechanism operates in the space under the low trellis anchoring rope, which is stretched at the maximum height of 250 mm above the terrain. Such height, however, is not the same for all low trellises due to which this limiting value cannot be relied upon. Generally we may say that the lesser the construction height of the rear transmission with cutting disc (Fig. 1) is, the more universal the mechanical pruner will be. On the anchoring rope of 6 mm in diameter there is usually hung a drop irrigation system which must not be damaged by the passing mechanical pruner. Some low trellises have the drop irrigation placed right on the ground in the axis under a plastic net. This type of low trellis excludes the usage of a mechanical pruner, where it is necessary to apply chemical pruning through a specially adapted sprinkler.

Sharpening of the cutting disc when the machine is in operation improves the cutting and above all minimizes the idle time caused by disassembling, sharpening, and reassembling of the cutting disc. Without quality sharpening the cut would fray rendering the rootstock more prone to mildew and pest.

The drive is the designed axial piston hydromotor (model A2FM – size 62; Bosch Rexroth, Stuttgart, Germany) with a diagonal block. The hydromotor includes a splined shaft 1 3/8 21T 16/32 DP (ANSI B92.1a- 1976) (Bosch Rexroth, Stuttgart, Germany), angle 30°, 5th tolerance class. Nominal pressure Pn = 40 MPa, torque M_t = 141 Nm, weight = 19.5 kg.

Mechanical pruner carrier

The mechanical pruner motion is one of the key parts of the mechanical pruner design. Hop rootstocks are planted in the hop row axis under the drop irrigation. In the particular axis there are also low trellis supporting poles. The mechanical pruner rotor motion (deflection of the cutting disc from the operating position and its return) is necessary so that the cutting disc edge would not meet the low trellis supporting pole, thus causing its damage.

There are three possible ways of placing the cutting mechanism to be considered: front three-point linkage, inter-axle tool carrier, and rear three-point linkage. The presented design uses the placement of the mechanical pruner on an inter-axle tool carrier produced

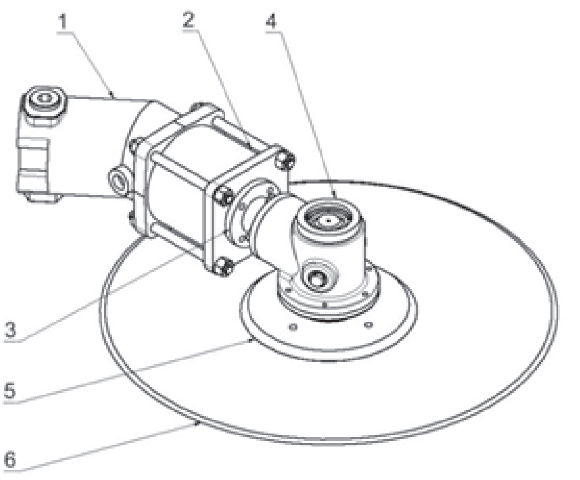


Fig. 1. Rear transmission with hydromotor
1 = axial piston hydromotor, 2 = coupler, 3 = extension, 4 = angular gear, 5 = carrier, 6 = cutting disc

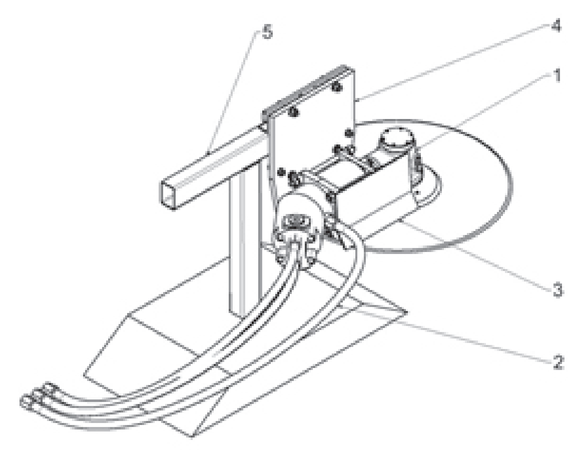


Fig. 2. Laboratory set of mechanical pruner design
1 = rear transmission with axial piston hydromotor, 2 = hydraulic lines, 3 = little plough blade, 4 = clamping plate, 5 = frame for laboratory measurement

in series (interaxle carrier made by Wallner Company s.r.o.) because in this case the tractor operator can see the pruning device from the cab and can manipulate the carrier arm motion directly. Another advantage of using the inter-axle carrier that is produced in series is the lower financial costs at acquiring a mechanical pruner. An interaxle carrier is a universal device enabling attachment of various working tools.

The model of the mechanical pruner will be connected to the inter-axle carrier with a clamping plate, which will be subsequently designed and manufactured.

Hydraulic circuit

The rear transmission with the hydromotor is fixed by means of four eye screws with a loop onto a clamping plate (Fig. 2, position 4). By these screws we can set any cutting angle of the cutting disc we need. The clamping plate secures the connection between the rear transmission with the hydromotor and the inter-axle carrier. A little plough blade (Fig. 2, position 3) serves to wipe the soil carried by the cutting disc off the body of axial hydromotor. This prevents stuffing the soil in the space between the cutting disc and the hydromotor block during hop pruning.

The mechanical pruner laboratory set is depicted in Fig. 3.

The designed and installed hydraulic circuit did not enable a fluent stopping of the cutting disc. After the hydraulic drive had been turned off, influenced by the cutting disc kinetic energy, impacts against clamping plate (Fig. 2, position 4) occurred. For this reason the hydraulic circuit was supplemented with a one-way valve with a spring. When the drive is stopped due to the negative pressure, the one-way valve switches the hydraulic oil flow from waste branch into pressure branch. Thus, when the drive is switched off, the cutting disc gradually stops.

The hydraulic circuit (Fig. 4) contains 2 flowmeters (positions 2 and 3), 2 nanometers (positions 4 and 5), a thermometer (position 6), and a revolution counter (position 8). The flowmeters measure the flow of hydraulic oil. They are placed on the pressure and waste branches. To measure the rotational frequency we used a Photo/contact speedometer (model DT-2268; Lutron Electronic Enterprise Co. Ltd., Taipei, Taiwan) in the mode of non-contact measurement. A reflective mark was placed on the cutting disc. The measurement was carried out this way – the revolution counter laser beam was set on the spot where the reflective mark was moving. After stabilization the actual rpm value (min^{-1}) could be read on the counter display.

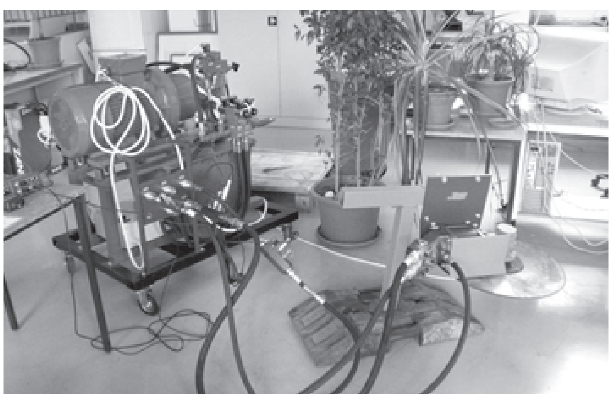


Fig. 3. Laboratory set of mechanical pruner

Axial piston hydromotor laboratory measurement

When measuring the flow depending on rotational frequency of the cutting disc of the mechanical hop pruner hydraulic circuit (HC), the hydraulic oil tem-

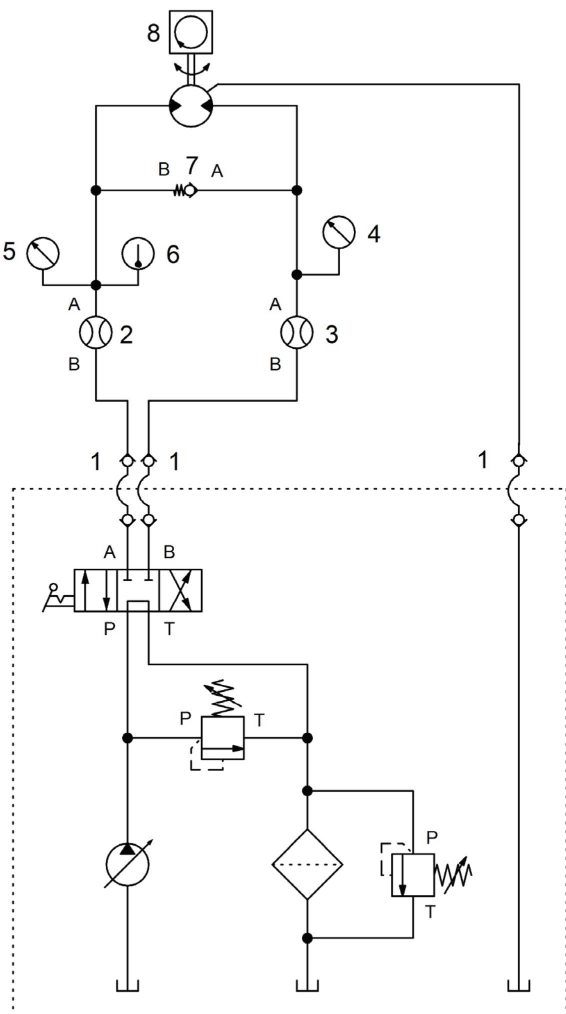


Fig. 4. Designed hydraulic circuit
1 = quick couplers, 2 = flowmeter on pressure branch, 3 = flowmeter on waste branch, 4 = manometer on waste branch, 5 = manometer on pressure branch, 6 = thermometer, 7 = one-way valve with spring, 8 = optical revolution counter of cutting disc

perature was kept at 35°C. The same temperature of hydraulic oil was kept by K u č e r a , R o u s e k (2005), H u j o et al. (2013), and M á c h a l et al. (2013). The measurement was carried out by Multi System 5060 measuring equipment (Hydrotechnik Co., Limburg an der Lahn, Germany). The mechanical pruner was measured without load.

Rotational frequency changed every 10 rpm, when after each change the actual values measured on the flowmeters were recorded. The difference between both flows can show the flow of the leakage fluid.

RESULTS

Field measurement

Field measurements were carried out in close cooperation with Chmelařství, cooperative Žatec, Mechanizace department, in the low trellises.

After having verified the correct functioning of the experimental model of mechanical pruner and of the designed hydraulic circuit in laboratory conditions, it was installed on the inter-axle carrier placed on the tractor. The mechanical pruner model was connected to the source of pressure energy on the tractor represented by a hydraulic aggregate placed on the rear three-point linkage and driven from the rear outlet shaft of the tractor. The last step before the field measurement was to ensure a precise automatic copying of the hop-field surface. That was achieved by adding a copying wheel and removing one rectilinear hydromotor of the inter-axle carrier which enables vertical motion of the carrier. The whole set is depicted in Fig. 5. Owing to this adjustment the copying wheel was then fully loaded, thus the copying effect was ensured. The copying wheel is composed of hollow steel profiles of square cross-section into which a rectilinear hydromotor operated from the driver's cabin is placed. By moving of this rectilinear hydromotor the depth of the cut is adjusted.

Fig. 5. Experimental model of mechanical pruner

The measurement itself was carried out on a 10 m long low-trellis section where the tractor with connected mechanical pruner moved at a speed of 1 $km.h^{-1}$. The cutting disc in no-load conditions rotated at a maximum speed of 12.4 s^{-1} and the hydraulic oil temperature was kept at the value of 40 ± 2°C. D r a b a n t et al. (2005) and C v í č e l a et al. (2008) measured the same temperature in a hydraulic circuit. The hydraulic circuit tested in the laboratory conditions was also supplemented with two sensors of pressure placed next to the sensors of flow (i.e. on pressure and waste branch).

During the first drive of the tractor the cut height was set at 0, i.e. the cutting disc was moving on the surface level of the hop field. This way the hop-field surface was levelled. During the second drive through the same measured section, the cut depth was set at 50 mm (i.e. at maximum recess – see the agrotechnical requirements for mechanical pruner).

During the measurement first of all the cutting disc was placed into the required depth, then the tractor pulled away at the required speed, and subsequently the measurement itself in the selected section began. Values taken by sensors of pressure, flow, and temperature were recorded only from the moment when the cutting disc reached the required depth and rotational frequency.

Data measured during the first drive through the measured section are given in Fig. 6. The upper black curve shows the course of pressure in the pressure branch of the hydraulic circuit, while the red curve represents pressure in the waste branch. The graph clearly shows a drop in pressure and its immediate considerable rise in the interval between 6.6 and 9.5. This deviation was caused by the terrain unevenness of the hop-field surface (hollow). Subsequently a repeated gradual recess of the cutting disc occurred until the pressure in the pressure branch stabilized at a mean value of 2.2 MPa.

The data measured at the cut at a depth of 50 mm are shown in Fig. 7. In the graph, the upper black curve depicts the course of pressure in the pressure branch of the hydraulic circuit, while the red lower curve shows pressure in the waste branch. At such a big recess the cutting disc began to stop working due to the friction force. One part of the hydraulic aggregate was a safety pressure valve with a set value of 22 MPa. After the set pressure had been achieved, the safety pressure valve started letting the hydraulic oil flow back into the tank. In spite of that the rotation of the cutting disc did not cease, owing to the effect of friction forces. Due to the unevenness of the hop-field surface, the rotation of the cutting disc almost stopped two times in the measured section. Decrease in the friction force led to a repeated rotation of the cutting disc in the 11^{th} second of the measured section. This was caused by lifting the cutting disc up slightly. From the 23.5 s the cutting disc rotation ceased again

Fig. 6. Pressure at the input and output depending on time of the cut on the hop-field surface
black upper curve – pressure in the pressure branch, black lower curve – pressure in the waste branch

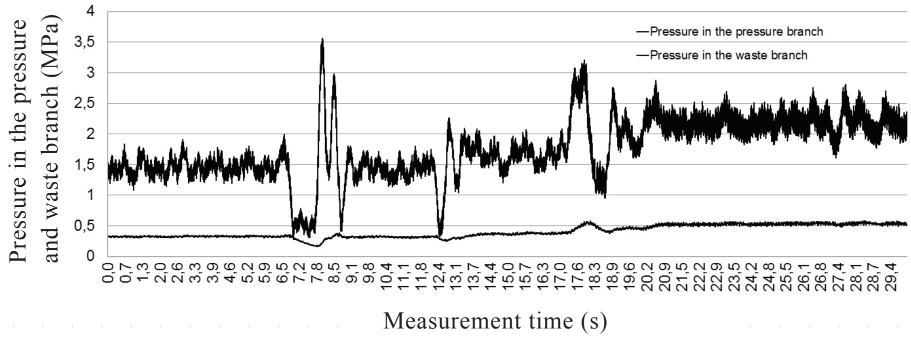


Fig. 7. Pressure at the input and output depending on time of 50 mm recess
black upper curve – pressure in the pressure branch, black lower curve – pressure in the waste branch

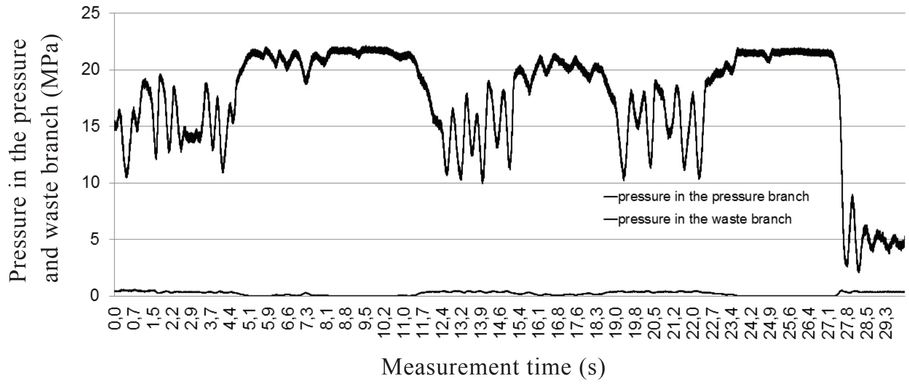
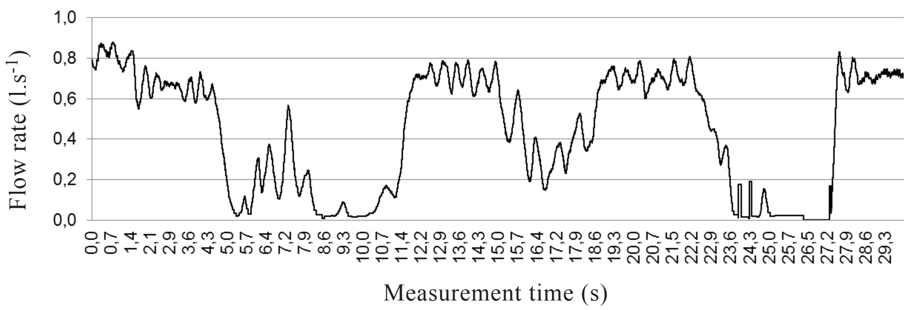


Fig. 8. Flow in the pressure branch depending on the time of measurement



until the time when the cutting disc was dug out just below the hop-field surface. The hydraulic oil pressure in the pressure branch subsequently levelled off at the value of 5 MPa. The flow curve in the pressure branch, recorded in the course of the measurement (Fig. 8), also corresponds to this development.

CONCLUSION

During the field measurement we repeated the measurement and setting of various depths (from 0 up to 50 mm) at which the cut was performed.

Fluctuating oil pressure in the hydraulic circuit is caused by unevenness of the hop-field surface.

The repeated measurements clearly show that a precise setting of the cut depth with a difference of 10 mm is practically impossible. The best results from the viewpoint of the hydraulic circuit power parameters (p, Q) were achieved by the experimental model of mechanical pruner at the cut on the surface and at the recess of a flat cutting disc at the maximum of 40 mm below the hop-field surface. A bigger recess of the cutting disc led to a decrease in or even cease of the cutting disc rotation due to friction forces.

The cutting disc in no-load conditions (during field testing) rotated at a maximum speed of 12.4 s^{-1} and the hydraulic oil temperature was kept at the value of 40 ± 2°C.

One part of the hydraulic aggregate was a safety pressure valve with a set value of 22 MPa. After the set pressure had been achieved, the safety pressure valve started letting the hydraulic oil flow back into the tank.

For the purpose of a following measurement the model will be supplemented with a saw blade commonly used for mechanical hop pruning in low trellises.

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