TECHNICAL PROJECT FOR HOP CUTTING EQUIPMENT IN LOW TRELLIS SYSTEM

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Abstract. Hop pruning is the main spring agrotechnical operation. That is the reason why great emphasis is placed on exact timing of hop pruning operation and on the use of suitable machinery. Double disc mechanical cutter used for high trellis is unsuitable for low trellis system. Development in low trellis has recently been putting pressure on designing a proper cutter. There are two versions of cutters: mechanical cutter and adapted sprinkler for chemical hop pruning. This paper contains construction analysis and agrotechnical requirements for mechanical cutter. Furthermore there is a detailed description of a design for fixed extension arm, mechanical cutter rotor, and telescopic copy wheel used to set up the cut height. The paper also mentions an experimental calculation of FEM analysis of cutting disc and an overall design of mechanical cutter. FEM analysis also contains a graphic interpretation of results which illustrate a deformation caused by critical frequency of cutting disc rotation. The design for mechanical cutter assembly contains also basic visualization of the whole device with distribution of hydraulic hoses to distribute pressure oil. The conclusion deals with a discussion and a suggestion for a consequential research.

Keywords: hop, hop pruning, cutting equipment, low trellis system.

Introduction

For low trellis systems the most suitable proves to be the use of single disc hop cutter with flat cutting disc of 600 mm in diameter [1]. The disc is made of abrasion-resistant steel with cutting edge covered with wolfram-carbide coating 1 mm thick and 20 mm wide. In case that disc is coated only on one side, self-sharpening effect occurs when disc in the soil is self-sharpenned due to a different abrasion-resistancy of the upper and lower part [2]. Flat disc can be also sharpened during pruning by means of grinder which is mechanically pushed to the cutting disc edge. Recommended disc rotation frequency is from 600 up to 750 min^{-1}. Use of only one disc (mechanical cutters for high trellis hop fields are double disc constructions with different sense of rotation) leads to smaller damage when in contact with a hard object (e.g. a stone), for with single disc cutter all the objects are tangentially thrown aside of the disc. Machine crossings over the hopvine interrow should be localized into track rows so that the soil would not be unnecessarily hardened in larger area.

Material and methods

A cutter must meet the following requirements: trim the hop shoots (so called new wood) down to a depth of 50 mm and at the same time cut old hopvines off their root part (rootstock). Cutting mechanism must operate in the space under the low trellis bottom anchoring rope which is stretched about 250 mm about the ground. On this steel cable of 6 mm in diameter there is usually hung a drop irrigation system which must not be damaged by passing of mechanical cutter. Sharpening of cutting disc in the machine operation improves the cutting and above all minimizes the idle time caused by disassembling, sharpening, and reassembling of cutting disc. Automated movement of mechanical cutter arm makes operator's labour easier and above all excludes their mistake which might result in damage of hop field equipment or used machinery. This movement is one of the key parts of mechanical cutter design. Hop rootstocks are planted in the hop row axis under the drop irrigation. Disc movement (deflection of cutting disc from working area and its return) is necessary so that cutting disc edge would not meet the low trellis supporting pole, thus damaging it. This removal must be far enough to avoid the construction damage due to inaccurate drive of tractorist. Furthermore it is advisable to ensure that the cutting disc also deflects from the hop field ground. Thus the hazard of cutting mechanism damage is lowered and cutting disc edge is not uselessly blunted [3].

Placement of mechanical cutter on tractor

There are three possible ways of placing the cutting mechanism to be considered. They are:

1. Front three-point linkage
2. Interaxle tool carrier
3. Rear three-point linkage

Placement of mechanical cutter directly influences the cutting disc drive type. With the front and the rear three-point linkage, tractor's serrated output shaft may be used for the drive. To achieve the required cutting disc rotation frequency it is necessary to use a gear box. Hydraulic drive can be used for cutting disc drive with all of the three ways of cutting mechanism placement owing to an easy transmission of pressure energy by means of hydraulic guide.

Transmission of mechanical energy by means of transmission shaft is more difficult in terms of construction, which is why we incline to the use of hydraulic drive in the first phase of designing.

Cutting mechanism must meet also the requirement of size. The cutting disc axis must be in the hopvine row axis under the drop irrigation which is hung on the bottom steel cable of low trellis 250 mm above the hop field ground.

Results and discussion

Suggested solution

The main task of a carrier is to ensure sufficient movement of cutting disc in a way so that it enables the machine to drive through hop interrows always in the same track lines. That is the reason why the interaxle carrier by Reith company (FRG) appears to be the most suitable and which is therefore used in this mechanical cutter design.

To avoid contact of interaxle carrier with low trellis equipment it is necessary to elongate the arm which the rotor with the cutting disc is fixed to. That is why we used a fixed extension arm of standard profile U 80/B ČSN 42 5570 – 11 373.0 – 42 0135.00. Onto this extension arm is connected a cutter rotor with a shaft and a cutting disc. The cutter rotor contains two single row ball bearings (ČSN 02 4630). The bearings provide the movement of the shaft with a dimension of 35 mm which has a slotted opening to be connected to hydraulic motor at one ending, and a thread M30x1.5 to be connected to cutting disc at the other ending. Axial movement is avoided by means of a notched round nut (ČSN 02 3630) with a lock washer (ČSN 02 3640). The hydraulic motor is connected to the shaft by means of slotted ending of 30 mm in diameter. To avoid dirt getting into the space with bearings there is Gufero sealing (ČSN 02 9401.0). Gear pump is connected to axle box via two through-bolts M10x1.5x30 with hexagon head (ISO 4017 – 8.8). For the cutting disc drive a gear hydraulic motor is used which is produced by DANFOSS company and it is model CG155. The spindle rotation frequency is 1150 min^{-1}.

When the mechanical cutter is in operation, the cutting disc must keep the set cutting plane. To ensure that, there is a copy wheel (Fig. 1) which is connected to the interaxle carrier. The cut height is set up by a rectilinear hydraulic motor placed in the telescopic body of the copy wheel.

In the suggested solution the mechanical cutter rotor (Fig. 2) is connected to the cutting disc carrier by means of the right thread M30x1.5. The diameter of the carrier is 235 mm and on the bottom side of the disc is a 3 mm shoulder of 60 mm in diameter. Into this shoulder is placed a cutting disc which is connected to the carrier by four screws M10x1.5. The used cutting disc is 600 mm in diameter, it is flat without cutting teeth and 3.44 mm thick. The cutting disc edge is sharpened at an angle of 26º.

At a certain rotation frequency the mechanical cutter rotor with cutting disc is subjected to substantial oscillation. This rotation frequency is called critical and we may differentiate about 6 different levels of critical rotation frequency. The most important is the critical rotation frequency of the 1st level. If the cutting disc operated at this rotation frequency it would be damaged. In technical practice it is necessary to avoid this critical rotation frequency and it must be quickly overcome or better not reached at all. That is why we subjected the mechanical cutter rotor and the cutting disc to the FEM (The Finite Element Method) experimental strength calculation with the help of the modal analysis in Autodesk Inventor Professional R11 program. This program contains a working module aimed for technical calculations CAE by the finite element method which was designed by one of the most significant SW companies concerning FEM – ANSYS Inc [4].

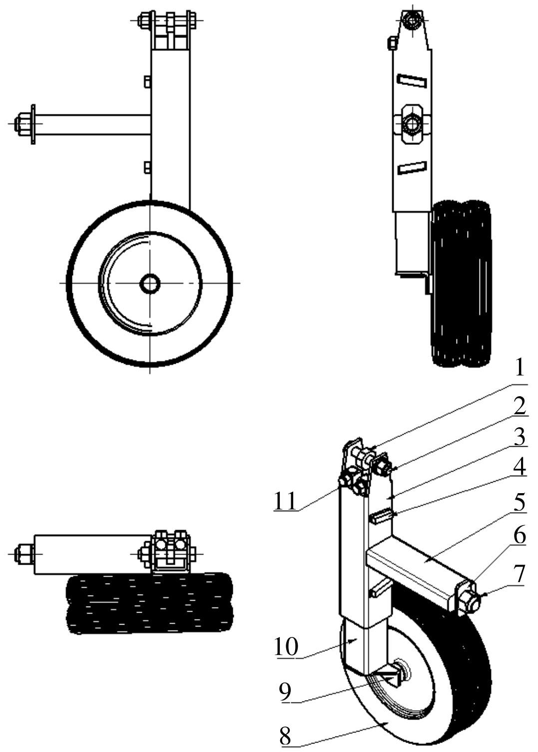

Fig. 1. **Setting of cutting height (copy wheel):**
1 – control hydraulic motor; 2 – hydraulic motor safety screw; 3 – fixed part of copy wheel body; 4 – welded steel part; 5 – connecting profile; 6 – shaped washer; 7 – check nut; 8 -copy double-wheel; 9 – wheel swivel pin; 10 – movable part of copy wheel body; 11 – connectors for pressure hoses of rectilinear hydraulic motor

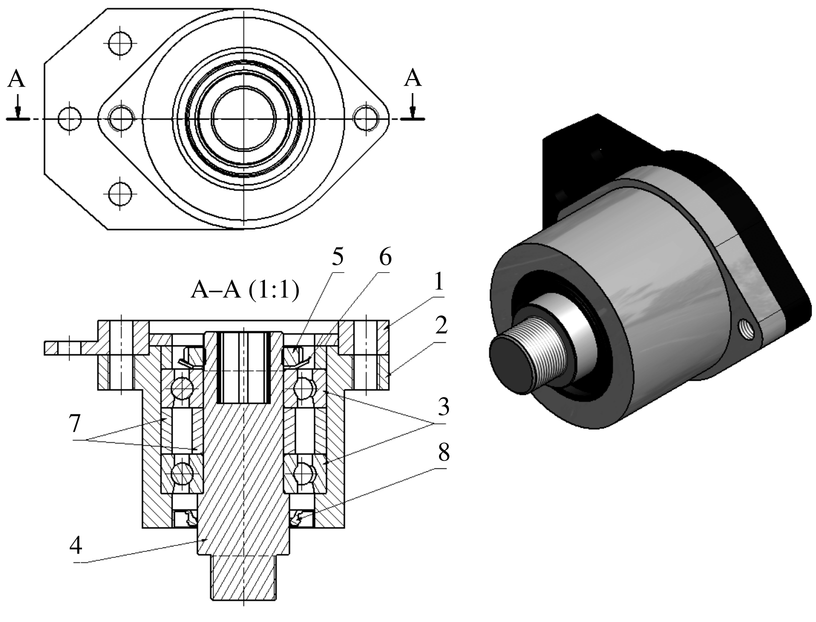

Fig. 2. **Rotor of mechanical cutter:**
1 – linkage of mechanical cutter rotor; 2 – rotor body; 3 – single-row ball bearing; 4 – cutting disc rotor; 5 – round nut; 6 – lock washer; 7 – inserted adapter rings; 8 – sealing Gufero

Strength analysis

The mechanical cutter rotor and the cutting disc were at calculation loaded by gravitational force and considered rotation frequency ranged between 0 Hz – 1000 Hz. Before the launch of the calculation it was necessary to set up suitable marginal conditions of the calculation. First item to set up was the used material with the right density. In this case the selected material is low alloy steel with a high strength (density of 7850 $kg \cdot m^{-3}$). Next step is setting up the bonds. Bonds determine where the individual parts are placed. Besides, bonds eliminate degrees of freedom, thus limiting movement of parts towards themselves. Here the bonds are spots in which shaft is fixed in rotor by means of bearings. Rightly selected bond and its placement is extremely important for the right calculation of FEM analysis. After all the marginal conditions are inserted, the analysis is run and results are displayed.

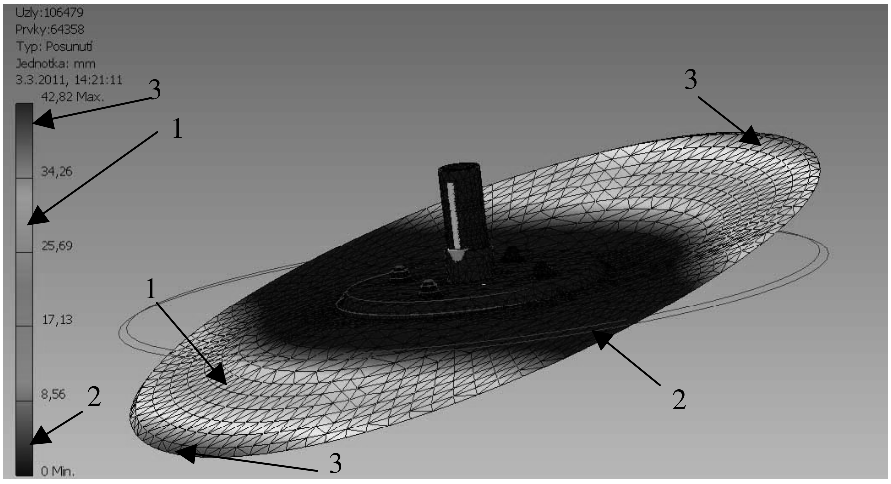

Fig. 3. **Shift of individual elements during FEM analysis (80.23 Hz)**

FEM analysis proceeds in a way that it divides bodies into elements which are then separately burdened. This way it gains an extensive equation system which is consequently solved [5]. The smaller the elements are, the more exact the calculation is, but at the same time it is more demanding. That makes heavy demands on HW computing equipment [4]. Two curves represent the original shape of the cutting disc.

The left scale (Fig. 3, position 1) determines the size of shift of individual points. The normally blue colour (Fig. 3, position 2) represents zero shift, whereas maximum shift is represented by the normally red colour (Fig. 3, position 3). The black net is formed by individual elements of the component. The colouring of individual elements represents the size of shift from their original location at a rotation frequency of 1000 Hz.

As an illustration there is a deformation (Fig. 4) of a cutting disc at a critical rotation frequency of the 6th level. The rotation frequency, at which such a deformation occurs, is 146.44 Hz (146.44 s^{-1}). We may suppose that when approached this rotation frequency, the cutting disc would be damaged.

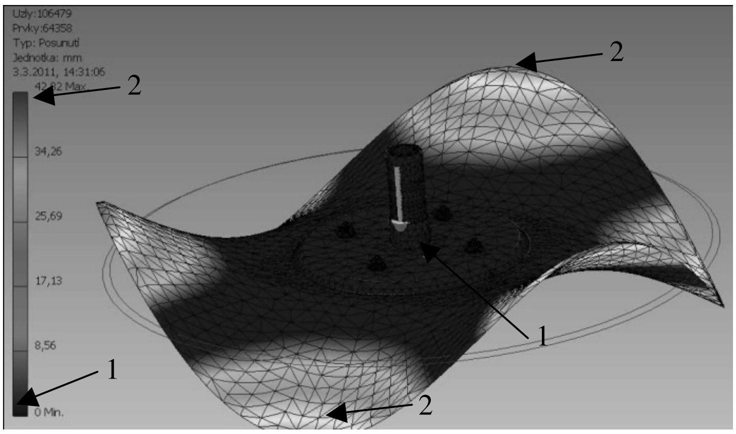

Fig. 4. **Shift of individual elements during FEM analysis (146.44 Hz)**

Overall design of mechanical cutter

The complete assembly of cutting mechanism, interaxle carrier, and copy wheel is depicted in Fig. 5. The cutting mechanism is placed on a fixed extension arm which is fixed by means of linkage base to the Reith interaxle carrier. A telescopic copy wheel which sets the cutting disc height is also fixed to the interaxle carrier.

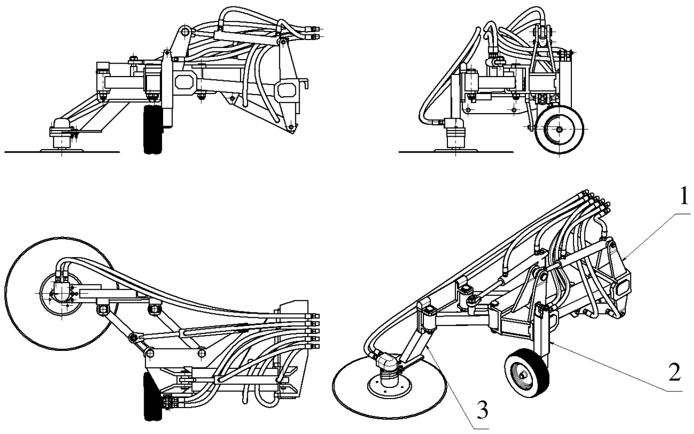

Fig. 5. **Complete assembly of cutting mechanism:**
1 – Reith interaxle carrier, 2 – copy wheel, 3 – cutting mechanism

Conclusion

After analysing the results of FEM strength analysis it was found out that the critical rotation frequency is 80.23 Hz (80.23.s^{-1}). At this rotation frequency a critical cutting disc oscillation occurs (Fig. 3). The real rotation frequency of mechanical cutter disc is 12.5 Hz. This rotation frequency is substantially lower than the critical frequency. The suggested solution thus suits from the point of view of the deformation variant of FEM analysis.

The suggested solution (Fig. 5) is still in the research phase and the way of the cutting mechanism connection has not been tested in practice. The use of interaxle carrier produced in series would make the construction work on mechanical cutter easier. However, it is possible that during the experimental measurement the Reith interaxle carrier turns out to be inappropriate. This fact would lead to a design of a new way of placement. We would consider also a possible use of the rear three-point linkage, but possibly also some other way of cutting disc drive.

After the problems with the interaxle carrier of cutting mechanism have been solved it will be appropriate to complete the whole device with electronic control elements which will make the process of the cutting disc deflection automated.

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References

1. Štranc P., Štranc J., Jurčák. Řez chmele, odrůdy Žatecký poloraný červeňák v podmínkách ČR. Prague: ČZU in Prague, FAPPZ.
2. Štranc P., Štranc J., Jurčák J., Štranc D., Pázler B. Řez chmele. Prague: ČZU in Prague, 2007, pp. 42-50.
3. Hoffmann D., Rybka A. International student scientific conference - Recent advances in agriculture mechanical engineering and waste policy: TECHNICAL PROJECT FOR HOP CUTTING EQUIPMENT IN LOW TRELLIS SYSTEM. 27.4. – 29.4.2010, Nitra, pp. 109-114.
4. Fink M., Řezníček L. FEM/MKP - Základy použití metody konečných prvků pro technické výpočty v programu Autodesk Inventor Professional. Trutnov ČR, 2006, pp. 3-6. [online] [28.02.2011]. Available at: http://www.spstrutnov.cz/o-skole/projekty/technicke-vypocty/skripta-fem-mkp.pdf
5. Rojíček J. Opakování základních znalostí z pržnosti a pevnosti, cvičení 1. Ostrava: VŠB, 2010, pp. 8-15. [online] [28.02.2011]. Available at: http://www.339.vsb.cz/PDF/PPE/1-Opakov%C3%A1n%C3%AD_z%C3%A1kladn%C3%ADch_znalost%C3%AD_z_pru%C5%BEnosti_a_pevnosti.pdf.