Design Project of Row-independent Harvesting Machine for Energetic Plants

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Abstract. This is a description of an all-purpose, row-independent machine prototype for harvesting energetic plants in the form of chips or chaff. Patent claim P 385 536 was submitted to the patent office, regarding two versions of cutting adapters: the feeding unit equipped with elastic fingers, or equipped with worm rolls. The machine has modular structure allowing its easy modification, while a hydraulic drive with electro-hydraulic control enables to select the optimal operation parameters of working elements and units under various field conditions. The machine can cut plants with shoot diameter up to 70 mm at the height up to 100 mm, and break them up into particles of 20–60 mm.

Key words: Energetic plants, harvesting, row-independent machine

INTRODUCTION

Energetic plants can be harvested as whole shoots or in a broken up form. These different harvesting methods especially refer to willow (Salix viminalis). The one-year plants can be cut in bulk and left in the field or can be loaded into a hopper and unloaded periodically into piles. The cut plants can be tied into bundles or formed into bales wrapped in a net after breaking them up by the flail-type chopping unit of a rolling baler (Lavoie et al., 2007); they can also be chopped in a forage harvester equipped with an adapter for harvesting maize for silage. Harvesting of two- or three-year old or older plants calls for the application of a special cutting adapter, since shoot diameter at base can reach 70–100 mm.

Since there was no local product in the Polish market at the moment of starting the project, the work was undertaken in order to design our own all-purpose machine for harvesting energetic plants in a broken up form; this is the main purpose of this elaboration.

MATERIAL AND METHODS

Specially designed machines for harvesting energetic plants as well as modified machines originally designed for harvesting high-stem plants were analyzed in great detail. Conclusions of the analysis and assumptions taken by the authors (Nowakowski et al., 2008) were the grounds for designing our own machine (patent claim P 385 536) (Lisowski et al., 2008). The task was executed with the aid

of computer by application of software SolidEdge. It allowed kinematic spatial analysis of the working elements and units at design stage.

RESULTS AND DISCUSSION

The harvester was designed as a semi-mounted machine (Fig. 1). On the frame part mounted to the tractor the following units were situated: hydraulic oil tank, bevel gear which transfers the tractor PTO drive to the knife drum, and hydraulic pump feeding the hydraulic motors and cylinders via the electro-hydraulic distributor. On the other part of the frame supported by wheels there is the cutting unit, consisting of a knife drum with a counter knife. The cut stems are directed to the hopper of transport mean through the discharge spout. Direction of discharge can be adjusted by rotation of discharge spout with the use of a hydraulic motor, and that of the discharge range by inclination of the spout end.

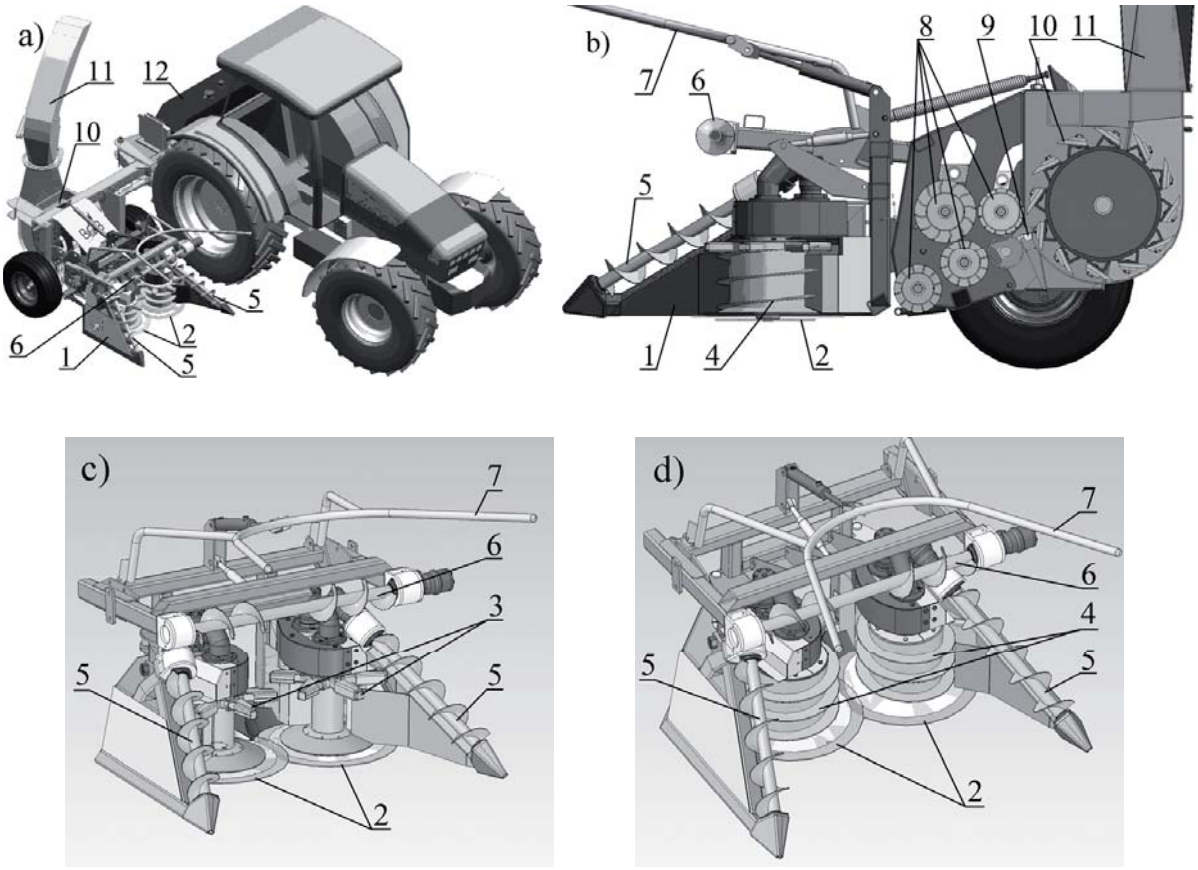

Fig. 1 Cutting machine for harvesting energetic plants: a) working position, b) axial cross section, c) adapter with elastic fingers, d) adapter with worm rolls: 1 – adapter; 2 – circular saws; 3 – elastic finger; 4 – worm rolls, 5 – active dividers; 6 – sloping reel; 7 – sloping element; 8 – toothed pulling-compacting rolls; 9 – counter knife; 10 – drum-type cutting (chopping) unit with knife drum; 11 – discharge spout; 12 – hydraulic oil tank.

Source: Authors' elaboration

The fed material is compacted and held during cutting by the toothed pulling-compacting rolls. The material compaction is obtained due to a pressure of self-aligning top pair of toothed rolls and spiral springs on the lower rolls: Two toothed rolls and one plain roll. The pressing force can be adjusted by changing the initial tension of springs.

The exchangeable cutting adapters are jointed to the body of the roll set. The adapters are unloaded with spiral springs of adjustable initial tension. The cutting height of plants can be adjusted steplessly with the two symmetrical ram-type cylinders.

The key constructional solution of the machine is cutting adapter with driver and lifting-feeding units, designed in two versions. In the first version, the feeding unit is equipped with rotational finger drivers (Fig. 1c), in the second version with vertical worm rolls (Fig. 1d). In both cases, the hydraulic motors are used to drive the circular saws and also the rolls with finger drivers or worms (Fig. 2). The circular saw shafts are driven by the high-speed hydraulic motors of maximal rotational speed about 3800 rev·m^{-1}, enabling to obtain the cutting peripheral speed 100 m s^{-1} with disk diameter 0.5 m. Such high speed is essential to achieve so-called clean cutting of willow stems (Lechasseur & Savoie, 2005). According to these authors, the diameters of circular saws used in machines of that type amount to 450–600 mm.

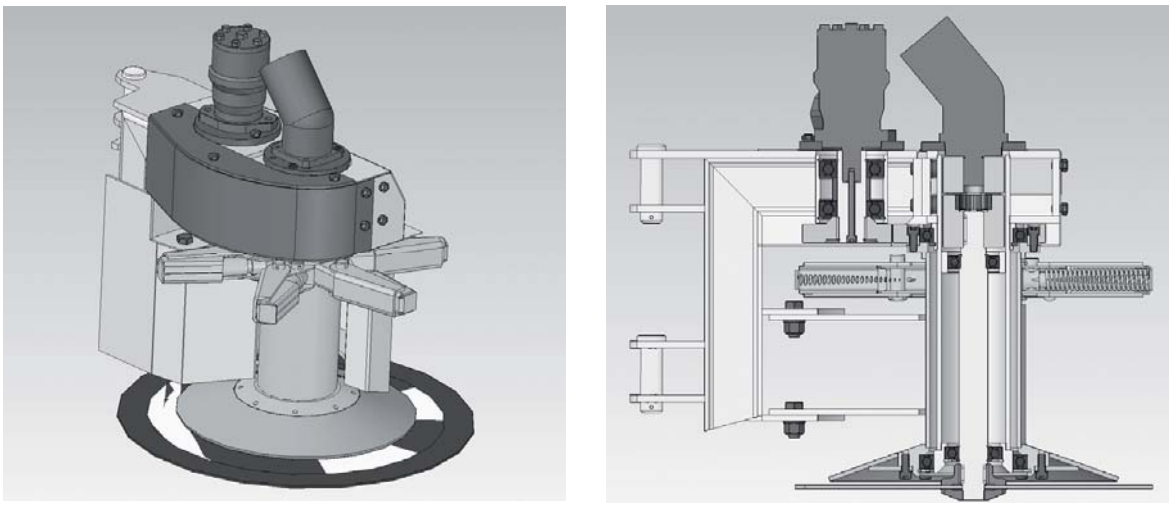

Fig. 2 A cutting-feeding unit with elastic driving fingers.

Source: Authors' elaboration

At cutting speed 100 m s^{-1} the risk of tearing up the fibrous tissue and bark of snag left in the ground is minimal. As a result, the hazard of decay process deteriorating the rate of subsequent growth is decreased. The rolls with driver elements are driven by low-speed hydraulic motor via gear transmission reducing rotational speed to 38 rev m^{-1}. The finger tips reach peripheral speed 1 m s^{-1} at external diameter of drivers equal to 0.5 m. The ratio between peripheral speed of driving material and cutting plants is very high and amounts to 1:100. Such peripheral speed parameters can be obtained at nominal rotational speed of

hydraulic motors. Since the ground speed of tractor-machine outfit can be changed depending on field conditions, the application of hydraulic motor controlled with electro-hydraulic distributor would enable to select the optimal rotational speed, making the peripheral speed higher than tractor ground speed. Excess of this speed in the range of 10–30%, determined by kinematic coefficient, should ensure proper driving of the cut plant shoots.

Application of hydraulically controlled inclining element will allow the cutting of plants by circular saws when plants are bent. The energy accumulated in inclined stem will be used after its cutting to direct the base part of shoot to the subsequent unit of pulling-compacting rolls.

The remaining working units of the machine are similar to units applied in forage harvesters for low-stem and high-stem plants for silage.

At design stage, kinematic and dynamic analysis of working elements and machine units were carried out; this enabled to optimize the machine's constructional structure. Exemplary loading of cutting adapter frame is presented in Fig. 3.

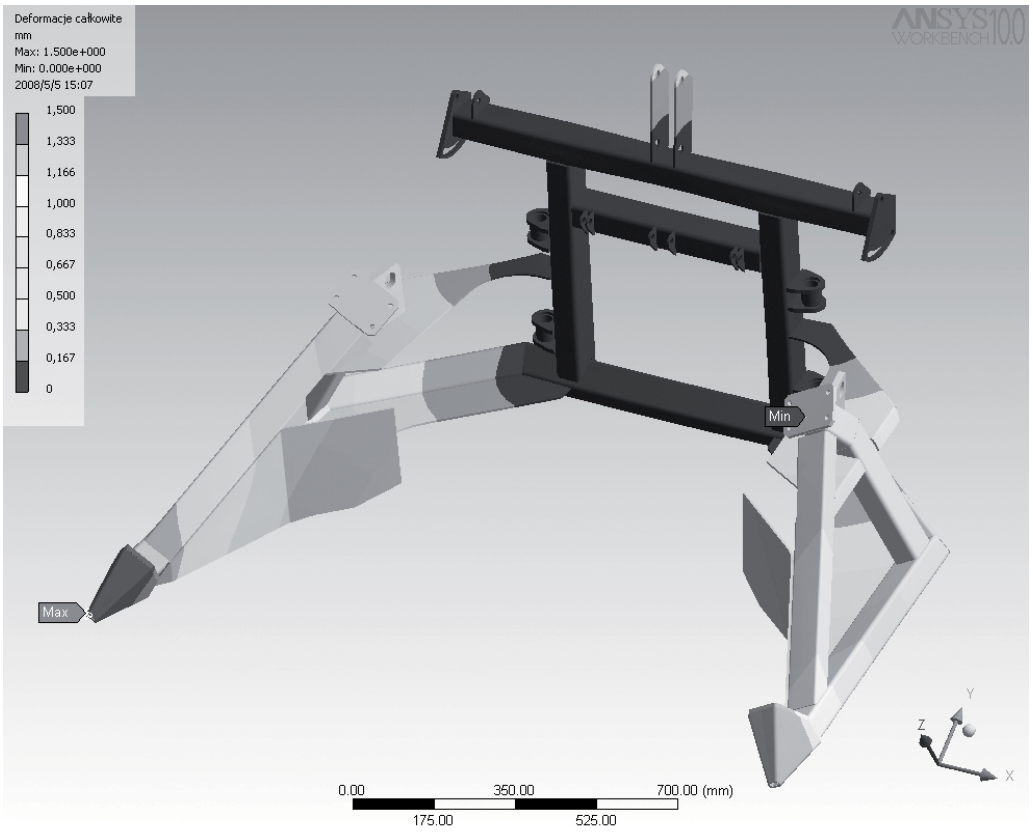

Fig. 3 Total deformation of cutting adapter frame.

Source: Authors' elaboration

Basic technical parameters of the cutting machine prototype are listed in Table 1. It was assumed that the machine will be equipped with row-independent attachment and adjustable dividers, to enable the cutting of separate rows with inter-row distance 0.7-0.8 m (common in Poland, Nowakowski et al., 2008) or twin rows spaced 0.75 m apart.

Table 1. Technical specification of machine for harvesting energetic plants

Item	Parameters
Basic machine:	
Source of power	agricultural tractor 120 kW, class 2 (20 kN)
Number of rows/working width	1-0.75 m
Working speed	up to 8 km·h^{-1}
Coupling with tractor	trailed/semi-mounted
Throughput	30 t·h^{-1}
Ground clearance	300 mm
Chopping unit	drum-type, diameter 600 mm, width 450 mm, rotational speed 700 rev·m^{-1}, number of knives 12
Cutting length	20–60 mm
Cutting adapter:	
Number of cutting disks	2
Cutting height	100 mm
Peripheral speed of disks	75–100 m·s^{-1}
Lifting-feeding unit	finger driver with lifting-feeding roll or worm conveyor
Diameter of harvested shoots	up to 70 mm
Height of cut shoots	up to 9 m
Drives:	
Cutting disks	hydrostatic
Lifting-feeding unit	hydrostatic with reverser
Cutting-discharging unit	mechanical

Source: Authors' elaboration

The ground speed of tractor-machine outfit will depend on field conditions, but the maximal speed will not exceed the recommended 8 km·h^{-1} (Lechasseur & Savoie, 2005). The cutting height of plants 100 mm above the ground corresponds to the range observed in solutions hitherto put forward (50–100 mm, Szczukowski et al., 2006).

The basic machine is equipped with a drum breaking up unit, enabling to cut stems of diameter up to 70 mm into chips of dimensions 20–60 mm (according to PN-91/D-95009 Standard). While harvesting larger diameter stems, especially those exceeding 100 mm, it is recommended to use techniques applied in forestry.

In elaborating the machine design concept it was assumed that it would be of modular structure; its assembly and modifications should result from investigations. Hydraulic drives would facilitate the control of the machine's working units and the selection of the best operational parameters under various field conditions.

CONCLUSIONS

1. Design documentation of the machine prototype equipped with two cutting adapters for harvesting energetic plants was elaborated; the machine meets the assumptions.

2. The design allows the evaluation and measurements of the units' operational parameters at various spatial settings of working elements and machine parameters.

3. The design of the adapter allows the mounting of alternative working elements in order to evaluate their usability under various operational conditions of the device.

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