AN OMNI-DIRECTIONAL ELECTRIC PRUNING SAW FOR FOREST TENDING
/
全方位电动打枝锯研究

Qingqing Shang*, Bin Wang, Jiawei Yang, Yizhi Lu, Tongming Yin [1]
Nanjing Forestry University, Nanjing 210037, China
Tel: +8613813990580; E-mail: qqshang@njfu.edu.cn

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ABSTRACT
This paper attempts to design a universal, easy-to-use pruning tool suitable for taller branches. For this purpose, the author proposed an omni-directional electric pruning saw. The saw has a 360° rotatable head, which can prune branches in all directions. Under the saw blade, a V-shaped groove was added so that the branches can be introduced, cut and released stably. A telescopic rod was included in the design to prune branches at different heights. To facilitate the retraction and release of wire, a winding reel was provided to make the wire change with the length of the rod. In addition, there is a deadlock device at the handle, which prevents the manmade safety hazards. The proposed pruning saw was tested through an experiment. The results show that the saw could be used for various branches and was 4 times more efficient than the traditional hand saw.

摘要
本文研究一种全方位电动打枝锯，其旋转锯头实现了 360 度全方位打枝作业；锯片下方设计的 V 型槽，方便了枝条的导入，保证了锯切打枝的稳定性；伸缩杆满足了高度不同树种打枝的需求；绕线盘使导线在伸缩杆的收缩和拉伸的过程中，随杆长变化而变化，解决了导线收放不便的问题；手柄处设计的锁死装置，有效避免了由于人为操作误失而造成的安全隐患。实验结果证明：该打枝据可应用于多种枝条，相比普通手工锯，效率提高了 4 倍。

INTRODUCTION

China has made great progress on land afforestation. In 2017, China planted 7.362 million hectares of trees and tended 8.302 million hectares of forest, making a great contribution to the ecological protection in the country *(Li and Wang, 2006)*. One of the main measures for forest tending lies in tree pruning. Rational pruning keeps the trees straight, tough and bending-resistant and facilitates the upper photosynthesis; it is very important for the growth of trees *(Cheng, 1981; Ji, 1990; Liu, 1975)*. Traditional pruning tools like saw and machete are relatively backward. These tools require high labour intensity and only apply to lower branches, failing to achieve desirable pruning effect. China is located in East Asia, in the north of the distribution centre of bamboo plants in the world. There are more than 30 genera of bamboos, accounting for about 45% of the world's bamboos. The total area of bamboo forest is about 3.4 million hectares, the total volume is about 71.2234 million tons, and the total annual cutting volume of commercial bamboo is about 5 million tons. In the paper (*Yu, 2019*), a cluster bamboo selective cutting machine featuring operation in a small space, small size, light weight and a reciprocating saw-based cutting mode was designed. The preliminary test shows that the surface cut by the reciprocating saw is very relatively smooth, with no serious tearing phenomenon of bamboo outer skin, able to meet the basic requirements for selective cutting of cluster bamboo, the saw was 4-6 times more efficient than the traditional hand saw. Bosch GSA18V compact reciprocating saw (*Jeremy, 2018*) did everything the operator wanted to do. Cordless, portability and convenience with high electrical storage capacity of 6.3 Ah, makes the instrument more competitive on the market. One V-type bamboo cutting program with double cylindrical helical cutter was proposed in his paper (*Wang, 2016*). Two experiments about the efficiency of cutting bamboo and impact resistance capacity show that the cylindrical cutter can be used for cutting bamboo, and its cross section is similar to conical surface which is formed by the chopper. Considering the huge demand for forest pruning in China and the poor capacity of traditional pruning tools *(Chen, 2018; Deng, 2017; Shen, 2010)*, this paper attempts to design a universal, easy-to-use pruning tool suitable for taller branches.

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[1] *Qingqing Shang, M.S.; Bin Wang, B.S.; Jiawei Yang, M.S.; Yizhi Lu, M.S.; Tongming Yin, Ph.D.*

MATERIALS AND METHODS

Determination of pruning saw working mode

At present, most of pruning saws at home and abroad are circular saw, chain saw and hand saw. The circular saw has simple operation and high rotational speed, but its feeding is difficult and the safety is poor. The cutting thickness of the chain saw is large and the maintenance can sometimes be difficult. The hand saw needs pure manpower for operation with high labour intensity, low work efficiency and high risk, which is not suitable for large-area pruning operation (*Wang et al., 2017; Tang, 2015; Lin, 1985*).

In the omni-directional electric pruning saw, a high-power charged lithium battery is taken as power supply, a worm gear reducer is provided, and a small teeth space saw blade is used for reciprocating cutting, ensuring sufficient power and increasing working stability. Charged machine is light, environmental and energy-saving. By increasing the extension length of the equipment and the rotation degree of the saw head, it can be well adapted to the change of the height and orientation of tree branches, highlighting its strong application value (*Michael and Jin, 2014*).

Overall design and parameters of pruning saw

The pruning saw consists of a locking device, a telescopic device, a rotating device, a cutting device, and an introduction device, as shown in Fig.1. The winding device is composed of a winding reel, a winding reel and electric wire. The wire can be retracted or released according to actual requirements to avoid enwinding of the electric wire (*Liu et al., 2018*).

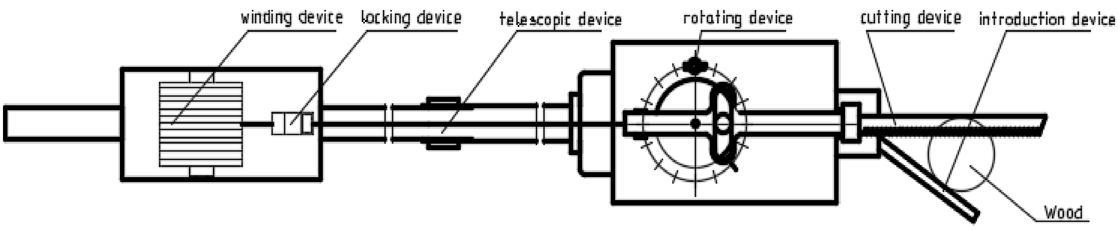

Fig. 1 - Schematic diagram of omni-directional pruning saw

The locking device is composed of a power dead lock button and a power switch button. The telescopic device is composed of n (n>=3) one-meter-long steel pipes and n-1 connection heads. The telescopic device can be adjusted over two meters in length, and the connection heads are used to fix the position of the steel pipes.

The rotating device consists of a shell, a bayonet lock and an annular support which can rotate within 360 degree, and the bayonet lock is responsible for fixing its position.

The cutting device is mainly composed of a slider-crank mechanism, which converts the rotary motion of the motor into the reciprocating linear motion of the saw blade.

The introduction device is mainly a V-shaped groove structure composed of a saw blade and a frame, which is convenient for locking the branches and stabilizing the sawing operations.

Operation force analysis of pruning saw

The force analysis of V-shaped groove structure is shown in Fig.2. $\vec{V}$ is the moving direction of the saw blade, $\overrightarrow{F1}$ is the force of the frame to the wood, $\overrightarrow{F2}$ is the vertical force of the knife saw to the wood, $\overrightarrow{F3}$ is the horizontal force of the cutter to the wood. Therefore, the resultant force received by the wood is $\vec{F}$, so the wood will move in the direction of $\vec{F}$ in the process of being cut, which is conducive to fixing the cut branches.

As shown in Fig.3, $\vec{V}$ is the moving direction of the saw blade, $\overrightarrow{F1}$ is the force of the frame to the wood, $\overrightarrow{F3}$ is the horizontal force of the cutter to the wood, and $\overrightarrow{F2}$ is the vertical force of the knife saw to the wood. The resultant force received by the wood is $\overrightarrow{F2}$, so the wood will move downward and leave the saw blade in the process of being cut, which is not favourable for the operator to perform the pruning operation.

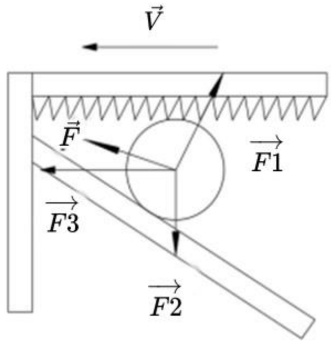

Fig. 2 - Force analysis 1

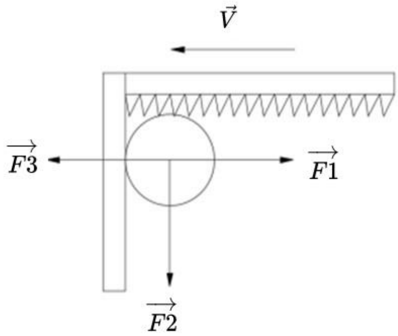

Fig. 3 - Force analysis 2

The following symbols are used in this paper:

$\vec{V}$ =The moving direction of the saw blade;

$\vec{F}$ =The resultant force received by the wood;

$\overrightarrow{F1}$=The force of the frame to the wood;

$\overrightarrow{F2}$=The vertical force of the knife saw to the wood;

$\overrightarrow{F3}$=The horizontal force of the cutter to the wood

Pruning saw parameters

For the users of electric power tools, efficiency and running time are the most important to evaluate whether a pruning saw is excellent or not besides the comfortable holding and exquisite design, so it is important to set the parameters of the pruning saw correctly.

Worm gear reducer. When using tools for wood sawing, one of the basic characteristics of cutting machine under load is power. The correct selection of worm gear reducer determines the cutting force of pruning saw. Specific parameters include the structure type of the motor, output speed, power, voltage, and diameter specifications. Technical parameter range and selection parameters of small worm gear reducer are as follows:

Table 1

Technical parameter range and selection parameters of small worm gear reducer

Parameters	Range	Selection parameters
Voltage (V)	3-24	18
Power (W)	0.5-50	24
Reduction	1:17, 1:31, 1:50	1:31
Output	5-1,000	260
Gear	Metal and plastics	Metal
Motor	Motor, DC, Step-by-	DC motor

Lithium battery. The battery pack with high mA hour rating can maintain the reciprocating saw for a longer time than the battery pack with low mA hour rating. According to the number of branches cut by the saw after one charge, the voltage of the worm gear reducer and the weight of the whole machine, the pruning saw is equipped with 2 to 3 lithium batteries with a voltage of 18 (V) and battery capacity of 3.0 (Ah) for one day's work (*Zhang et al., 2018; Katuril and Gorantla, 2018*).

Saw blade. In daily life and industrial production, there are numerous examples of interchangeability, and saw blades are produced and sold according to the requirements of interchangeability. Therefore, the selection of the saw blade in this study is based on the parameters existing on the market, and can be replaced with each other in the same specification. (1) Choice of materials. According to the processing object, using strength and processing precision, the cutting object of the pruning saw is wood, the strength requirement is lower than in the case of metal, and the precision requirement is lower. At present, there are duplex metal saw blades (*Jia et al., 2017*), high-speed steel saw blades and carbon steel saw blades. Carbon steel saw blades are low in cost and hardness, so they are more generally used. (2) Selection of dimensions. The maximum cutting width of the saw blade is equal to the total length (mm) of the saw blade minus 70 (mm). The thicker the material is, the larger the teeth spacing is. In accordance with the load capacity of the battery and the power analysis provided by the worm gear reducer, the larger the teeth spacing is, the larger the saw feed amount is, the larger the battery power consumed by the sawing process is. When the electric quantity is small, the saw blade is easy to be blocked (*Li, 2017*). A saw blade with length of 150 (mm) and teeth spacing of 2.6 (mm) is selected in combination with market research and experiment.

EXPERIMENTAL TEST OF PRUNING

Experimental test of pruning is carried out on three kinds of common trees, poplar, plane tree and pine in Fig.4. The hand saw with teeth spacing of 6 mm and omni-directional pruning saw with teeth spacing of 4.3 mm, 2.6 mm and 1.4 mm are used to conduct pruning on the trees with different diameters and their time is counted. Each experiment group is carried out for three times. Finally, the average value is taken. The results are shown in Table 2.

Table 2

Statistical table of data

Type of tree	Poplar			Plane tree			Pine		
Branch diameter (mm)	**25**	**30**	**35**	**25**	**30**	**35**	**25**	**30**	**35**
Pruning time with teeth spacing of 6 mm (s)	28.3	39.1	69.7	15.6	51.6	98.1	22.6	29.6	49.3
Pruning time with teeth spacing of 4.3 mm (s)	7.8	18.5	20.3	6.3	15.0	22.2	6.0	11.7	17.6
Pruning time with teeth spacing of 2.6 mm (s)	5.3	9.2	14.9	3.5	10.4	12.5	6.9	9.4	12.1
Pruning time with teeth spacing of 1.4 mm (s)	10.8	15.5	36.8	5.9	15.6	19.6	11.2	13.7	20.5

Experimental analysis: as a whole (take Fig.5 as an example), the larger the diameter is, the longer the pruning time of different cutters is. Under the condition of the same tree diameter, the pruning time of omni-directional pruning saw is obviously shorter than that of the hand saw. In the case of the same tree diameter, the pruning time of saw blade of 2.6 teeth spacing is significantly shorter than that of the other two kinds of teeth spacing. And we also cut the bamboo with this experimental equipment and saw blade. In this case, compared with the time taken for hand saw, the omni-directional pruning saw of 2.6 saw blade is approximately 1/4 of the time, that is, its efficiency is approximately 4 times that of the hand saw.

Fig. 4 - Experimental test of pruning

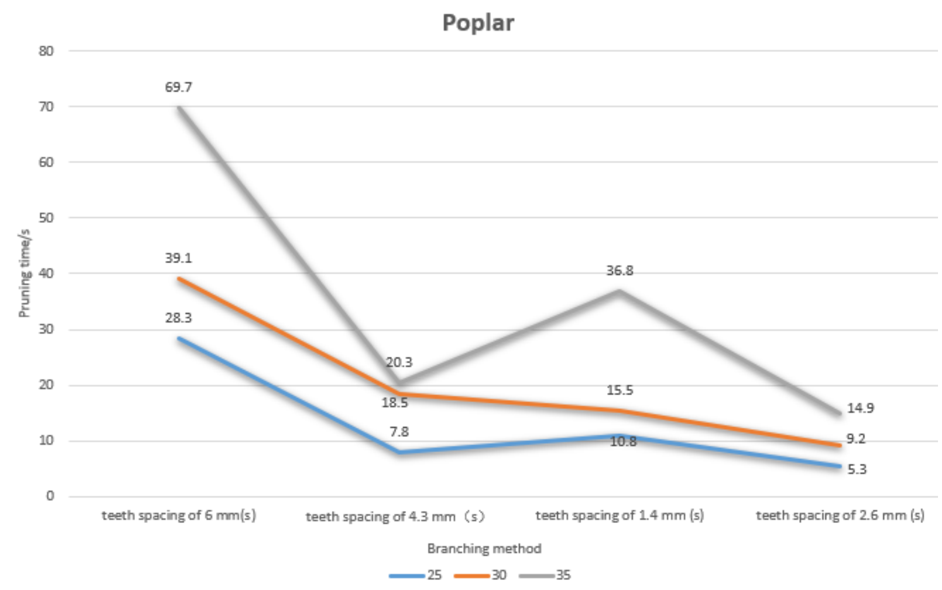

Fig. 5 - Line chart of poplar

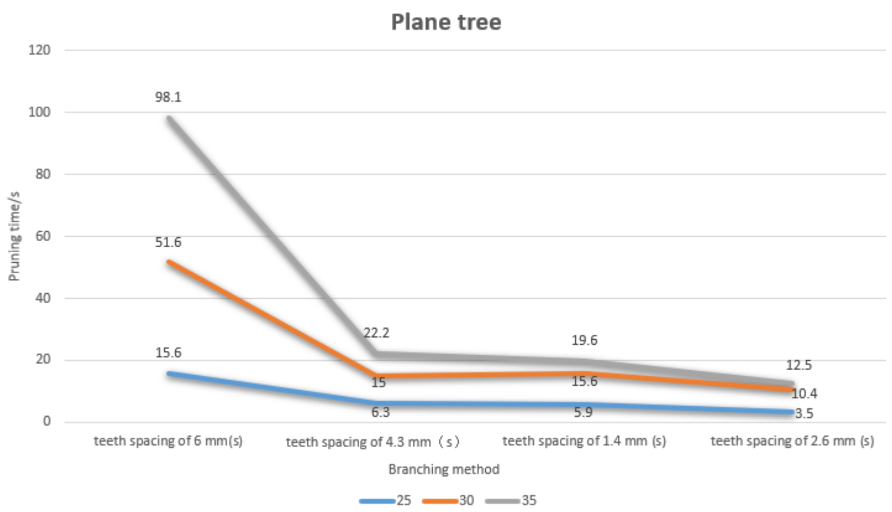

Fig. 6 - Line chart of plane tree

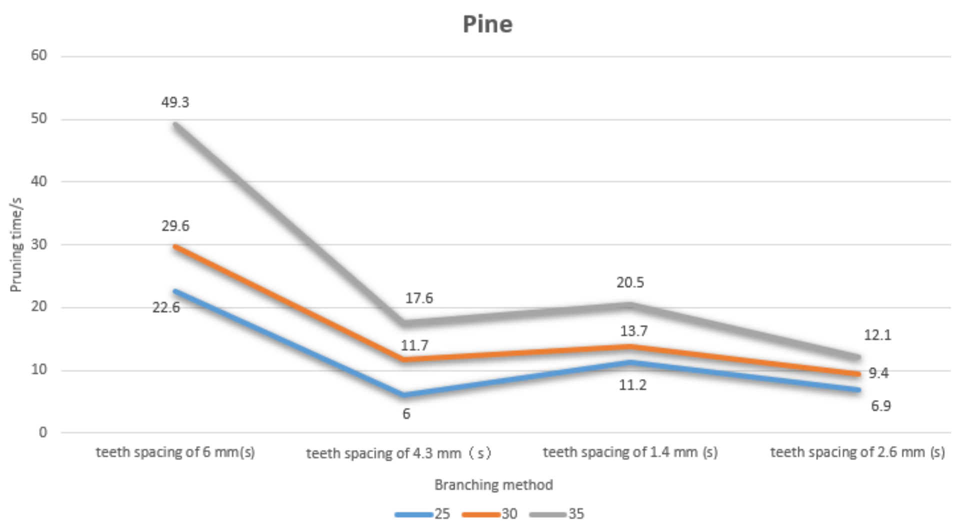

Fig. 7 - Line chart of pine

CONCLUSIONS

The study researches a type of omni-directional electric pruning saw with 360-degree rotary saw head, V-shaped groove under saw blade, telescopic rod, winding reel and head lock device at the handle. The experiment shows that the saw can be used for various branches; compared with ordinary hand saw, the efficiency is improved four times and the present manual labour mode is completely replaced, reducing the field labour intensity and the risk of high-altitude operation and improving the overall work efficiency of the existing high-altitude operation. In addition, the pruning operation cost is reduced and the pruning economic benefit is improved.

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