STUDY ON RESISTANCE AND STRUCTURE OPTIMIZATION OF TREE TRUNK INJECTOR'S NEEDLE HEAD
/
注干机针头的进针阻力和结构优化研究

Assoc. Prof. Shang Qingqing[1)], Stud. Jiang Tiantian[1)], Prof. Ph.D. Yin Tongming[2)]
[1)]College of Electronic and Mechanical Engineering, Nanjing Forestry University
[2)] College of Forestry, Nanjing Forestry University
Tel: +8613813990580; Email: qqshnfu@126.com

Abstract: *The paper optimizes the design for the needle head by mechanical analysis, the experiments of the needle head, structural improvements. The purpose is to design the best structure of the needle head, reduce the trunk fibre squeezed by the outer surface of the needle head. Extrusion capacity just is the thickness of the needle head's wall, which decreases splitting of wood fibres, thus ensuring the sealing effect and improving the injection efficiency of the trunk injector. According to the theory and experiments, it is obtained the range of the needle head's best size: the outer diameter is 6-8 mm, the thickness of the wall is 0.5-1mm. There are some relationships between the resistance and sizes of the needle heads. If the head needle's outer diameter is same, the larger the needle head's aperture is, the smaller the resistance of the needle head entering the trunk is. If the thickness of the wall is the same, the larger the needle head's outer diameter is, the larger the needle head's aperture is, the larger the resistance of the needle head entering the trunk is. Comparing the new needle head with the old needle head, the resistance of the needle head has been reduced. It can enhance strength and avoid fracture. It makes the wood core exist in the grooves of both sides without squeezing trunks and has good sealing effect.*

Keywords: *Tree trunk injector; Needle head; Resistance; Structure optimization*

INTRODUCTION

Tree trunk injection is a new method of preventing and controlling fruit tree disease and eliminate pests [1]. It is one of the best ways to control the trees insect. It plays an active role in reducing pollution of the environment [3], maintaining ecological balance, and increasing forest coverage. Now the research of tree trunk injector is becoming more and more widely. And needle head is one of the most critical parts of tree trunk injector, whether the type of manual or mechanical power tree trunk injector is, the performance of needle head directly affecting the efficiency of the injection [4]. So the study of needle head has a vital significance.

This paper main research content includes: first, doing mechanical analysis for the needle head; Second, measuring the resistance of the needle head by the experiment for determining the range of the size of the needle head that has a smaller resistance; Third, optimizing the design of the structure of the needle head [2]; Fourth, doing experimental verification of the needle head. The purpose is to select the optimal size and design the best structure of needle head in order to improve the efficiency of tree trunk injector [5].

摘要：*通过力学分析、进针实验、结构改进，对针头进行优化设计，设计出最优的针头结构形式，减少针头外表面对树干纤维的挤压，挤压量仅为针头壁厚，减小了木材纤维胀裂，从而保证了密封效果，提高注干机注射效率。理论和实验得出最佳针头尺寸大小范围：直径6-8mm,孔的壁厚0.5-1mm。其进针阻力与尺寸的关系为：外径相同时，针头孔径越大，进针阻力越小；当壁厚相同时，针头外径越大，则孔径也越大，进针阻力越大。优化的新针头同旧针头相比，进针阻力有所减小，强度增强，不易断裂。使木芯能够存在两侧槽中，不会挤压树干，密封效果好。*

关键词：*注干机；针头；进针阻力；结构优化*

引言

树木注射施药技术是一种新型的林木果树病虫害防治技术 [1]，其作为防治树木生虫的最佳方法之一，在减少环境污染、保持生态平衡、提高森林覆盖率方面起着积极的作用 [3]。目前，对于注干机的研究也越来越广泛，而针头作为注干机最为关键的部件之一，无论是人力手动型还是机械动力型的注干机，针头的性能都将直接影响注射效率 [4]。因此，对注干机针头进行研究具有重要的意义。

本文主要研究的内容有：一是对针头进行力学分析；二是通过实验测出进退针阻力，确定进针阻力较小的针头尺寸范围；三是对针头结构进行优化设计 [2]；四是进行实验验证。目的是选择最优的针头尺寸大小和合理的结构形式，以提高针头强度和密封效果，提高树干注射机的注射效率[5]。

MATERIALS AND METHOD

Characteristics of A New Type 0f Needle Head

The paper introduces a new type of needle head we studied, as show in Fig.1. Its structure is a hollow cylinder [6]. The forepart of the needle head is ring-shaped knife, a slot is in the middle, the slot is used for medicine and scrape outlet, pontes which connects to the needle head seat is at the back, equipped with O-ring seal, a little wider cylinder lie between the pontes and cylinder-shaped seal. During the progress of entering the trunk, the needle head is pushed by external force, the ring-shaped knife with a hole cuts off the wood fibre and keeps it in the hole and slot(to be pushed out by new wooden meal in the next injection). When the needle head enter the trunk and it forms a good seal with trunk, we stop pressing needle head and start to inject drugs, then the drugs through the medicine hole inflow into the trunk. When injecting drugs is over, the needle head will be pulled out by external forces, then a drug infusion process is over. Due to using this structure of needle head, amount of extrusion is very small, can't result in cracks, it has a good performance of sealing and increase the injection volume [7].

材料和方法

注干施药和针头概况

此次我们研究的注干机针头结构如图 1 所示，其结构为中空圆柱形 [6]。针头的前部为圆环形刀刃，中前部侧面开槽，槽的作用为出药孔和出屑孔，中部结构为圆柱形密封部分，中后部直径较大部分为二次密封的圆柱面，后部为与针头座连接部分，设有 O 形圈密封槽。进退针过程是由外力将针头压入树干，针头在压入树干的过程中，由前面的中孔环形刀刃将木材纤维切断，并保留在中间孔内(由下次注射时新的木芯将其顶出)，当针头中后部直径较大部分挤入树干中与树干形成较好的密封时，停止挤压针头，开始注药，则药液通过出药孔流入树干里。注药结束，由外力将针头往拉出，则一次注药过程结束。由于采用这种结构的针头进针是由针头外表面挤压树干，挤压量为针头壁厚，因此大大地缩小了挤压量，不容易引起木材纤维胀裂，从而保证了密封效果，提高注药量 [7]。

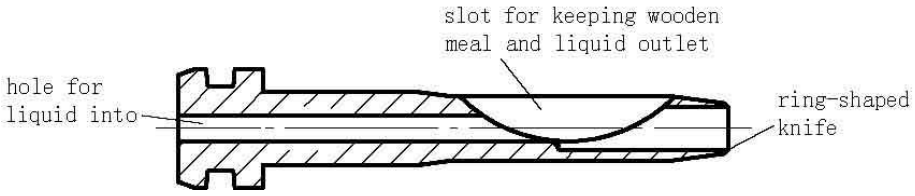


Fig.1 – The needle head of trunk injector

Stress Analysis of the New Type of Needle Head

As show in Fig.2, the force of the needle head can be divided into two parts: the process of the needle head entering the trunk and the needle head exiting from the trunk.

针头受力分析

针头的受力情况可以分为两部分：进针过程和退针过程，如图 2 所示：

(a) (b)

Fig.2 - Stress analysis for the process of the needle head
(a) the needle head entering the trunk (b) the needle head exiting from the trunk

A. The Process of Needle Head into the Trunk

The needle head squeezes the trunk by external forces. Due to the forepart of the needle head which is ring-shaped knife, the needle head is by cutting wood fibre into the trunk and not by brute force. This force by

A.进针过程

针头在外力的作用下开始挤入树干中，由于针头头部为圆形刀刃，因此针头是靠切断木材纤维进入树干而不是

the needle head cutting wood fibre is named extrusion and cutting force, called Fec. The wood fibre will be left in the hole and it will be squeezed out by the new wood fibre next time. At the same time, because the trunk can produces positive pressure to the needle head's surface, and with the needle head sliding constantly, it produces sliding friction force between the needle head and the trunk. The force is called f. This is the first time that the needle head enters the trunk.

The second, third time, the needle head bears the force except for extrusion and cutting force and sliding friction force. Because there is no cleaning the wood fibre remains in the needle head's hole（referred to as wood core）, Then it will produce the extrusion with the new wood core to the old wood core, and it is named extrusion force, expressed in Fe.

B. The Process of Needle Head Exiting from the Trunk

When needle head exits from the trunk by the action of external force the only remaining force is sliding friction force f between the needle head and the trunk. Therefore, the resistance of the needle head exiting from the trunk is only related to sliding friction force.

Above all, the resistance of the needle head entering the trunk and exiting from the trunk should be considered in two different conditions, respectively for the first time the needle head entering the trunk (excluding wood cores) and the second, third…time the needle head entering the trunk (including wood cores). That is to say:

The resistance into the trunk excluding wood cores is: *F1=f+Fec*

The resistance into the trunk including wood cores is: *F2=f+Fec+Fe*

The resistance exiting from the trunk is: *Fr1=Fr2=f*

C .Experiment For Measuring The Resistance

The purpose of this experiment is to measure the resistance data of the needle head entering the trunk and determine the appropriate range of the needle head's size by comparing the data [8]. The specifications of the needle head list in table 1, putting the 8 kinds of size of the needle heads code as 1, 2, 3... 8. Then we connect the experimental equipment and install the needle head in the tree trunk injector. At the same time, we put the tree trunk injector clamping on the poplar and intensify it, process power and begin to do experiments for the needle head entering the trunk.

We take the eight kinds of the needle heads to do experiments for the needle head entering the trunk for four objects, each object performing a group of experiments, being a total of four groups of experiments and each group having eight kinds of the needle heads; each needle head performs experiments for five times. We do image processing for the data collected by using Matlab. In this way, we can intuitively observe the difference between the resistances of two needle heads.

靠蛮力挤压，这种由针头切断木材纤维所需的力称为挤切力，用 Fec 表示。被切断的木材纤维会遗留在针头孔内，由下次进针时新的木芯将其顶出。当针头挤入树干时，因树干会对针头表面产生正压力，并随着针头不断前进产生了针头与木材之间的滑动摩擦力，用 f 表示。这是针头第一次进针。

第二、三…次进针时，针头除了受到挤切力和滑动摩擦力外，由于没有清除遗留在针头孔内的木材纤维（简称木芯），进针产生的新木芯会对旧木芯的挤压，即新木芯将前一个木芯顶出的挤压力，用 Fe 表示。

B.退针过程

针头在退针时，针头在外力的作用下逐渐退出树干，只剩下针头与木材之间的滑动摩擦力 f。因此，退针阻力只与滑动摩擦力 f 有关。

综上所述，针头进退针阻力分两种情况考虑，分别为第一次进退针受力（不含木芯）情况和第二、三…次进退针（含木芯）时受力情况，即：

不含木芯的进针阻力:F1=f+Fec

含木芯的进针阻力 ：F2=f+Fec+Fe

退针阻力 ： Fr1=Fr2=f

C.测进退针头阻力实验

本次实验的目的是测出进针阻力的数值，并通过数据对比确定合适的针头尺寸范围 [8]。针头规格如表 1 所示，将这 8 种规格尺寸的针头，依次编号为 1、2、3…8。

将实验器材进行连接，并将 1 号针头安装在注干机上，同时将注干机装夹在杨树上并加紧,接通电源，则开始进针实验。

将 8 种针头一一进行进针实验，4 个对象，每一个对象进行 1 组实验，我们共进行了 4 组实验，每组 8 种针头，每种针头进行 5 次进退针实验。将实验采集的数据通过用 Matlab 对其进行做图处理，可以直观清楚地观察出两两针头之间进针阻力的差异。

Table 1

The 8 kinds of the needle heads' main dimensions

Code	The outside diameter (mm)	The aperture (mm)	The outside diameter of sealing surface (mm)
1	7.8	6.0	8.6
2	7.8	5.0	8.6
3	7.8	4.0	8.6
4	6.8	4.5	7.6
5	6.8	4.0	7.6
6	6.8	3.0	7.6
7	5.8	3.5	6.6
8	5.8	3.0	6.6

Analyzing and comparing the four groups of experiment graphics, because the conclusions are consistent, now we choose one group to analyze, here the choice being the fourth group.

RESULTS AND ANALYSIS

A. The Comparison For Two States of the Same Needle Heads

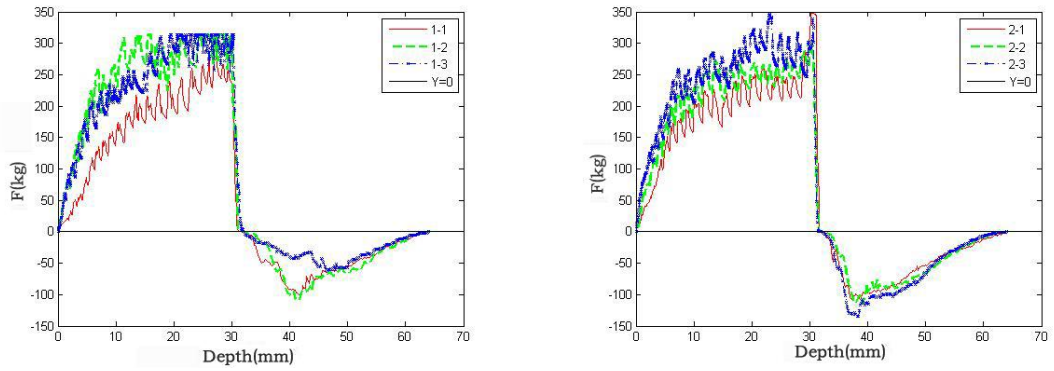
The two states of the same needle heads refer to excluding wood cores and including wood cores. The first time that the needle head enters the trunk it expresses the state of the excluding wood cores and the second, third…time that including wood cores. As shown in figure 3, each graph with A - A expressed, the first number A expresses No. X needle head, the second number A expresses the time the needle head entering the trunk. The curves show the resistance of the first time that the needle head enters the trunk is the least of the three curves. This result is in accordance with the result concluded by theoretical analysis. When X is in the range of 0 to 32 mm, any point on the X axis in the three curves is corresponding to the value of Y which expresses the resistance of the needle head in this depth of the needle head entering the trunk. And the value between the curve of the first time and the second, third…time expresses the extrusion force. In addition, the resistance of the needle head exiting from the trunk is less than the resistance of the needle head entering the trunk, namely below 0 line. It also conforms to the theoretical analysis.

分析比较 4 组实验，由于 4 组实验图形得出的结论基本一致，现选其中一组进行分析说明，这里选择的是第四组实验。

结果和分析

A.同种针头两种状态的比较

同种针头两种状态指的是：不含木芯与含木芯两种状态。第一次进退针表示不含木芯的状态，第二、三次进退针表示含木芯的状态。如图 3 所示，每一个曲线图用 A-A 表示，前一个数字 A 表示 X 号针头，后一个数字 A 表示第几次进退针。曲线图中显示第一次进针阻力是三个曲线中最小的，这个结果是符合理论分析中得出的结论的。X 在 0-32mm 区间时，X 轴上任意一点分别在三条曲线上对应的 Y 值为此进针深度下的进针阻力，且第一次进针曲线分别与第二、三次进针曲线 Y 值差表示就是挤压力 F 挤。另外，0 线以下的退针阻力与进针阻力相比明显较小，这同样符合理论分析的结论。



（a） （b）

Fig. 3- The comparison chart for No.1 and No.2 the needle head of the fourth group of experiments

B. The Comparison For the Resistance of the Different Needle Heads

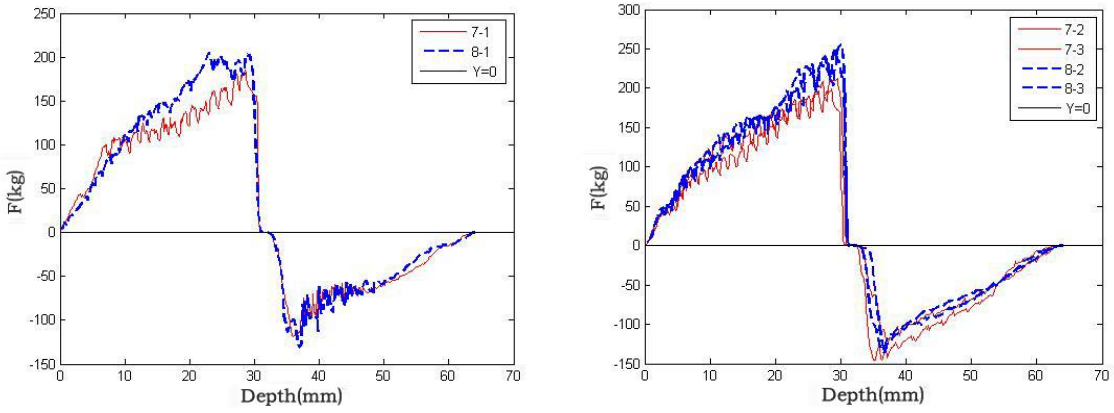
(1) The Comparison of the Same Outer Diameter

There are three groups of the same outer diameter, respectively for outer diameter of No.1, No.2 and No.3 needle heads are 7.8 mm, the outer diameter of No.4, No.5 and No.6 needle heads are 6.8mm, the outer diameter of No.7 and No. 8 needle heads are 5.8mm. As shown in figure 4, comparing the resistance of the three groups of the needle heads respectively, we get the conclusion for *F1<F2<F3, F4<F5<F6, F7<F8* (F1 expresses the resistance of No.1 needle head entering the trunk). Namely when the outer diameter is the same, the larger the aperture is, the thinner the thickness of the wall is, the smaller the resistance of the needle head entering the trunk is. This is because under the condition of remaining the outer diameter unchanged and the aperture get larger, though the friction force remains unchanged, the extrusion force increases, the impact is not obvious. And the extrusion and cutting force decrease with the cross-sectional area decreasing, so the resistance of the needle head entering the trunk is decreasing.

B.不同种针头的进针阻力比较

（1）相同外径比较

相同外径的针头有三组，分别是外径为 7.8mm 的 1、2、3 号针头，外径为 6.8mm 的 4、5、6 号针头，外径为 5.8mm 的 7、8 号针头。如图 4 所示，分别对这三组针头的进针阻力比较，结论为 F1〈F2〈F3，F4〈F5〈F6，F7〈F8（F1 表示 1 号针头的进退针阻力）。即当外径相同时，针头孔径越大，则壁越薄，进针阻力越小。这是因为在针头外径不变、孔径变大的情况下，摩擦力大小不变，挤压力虽然有所增大，但影响不大，而挤切力因针头横截面减小而减小，故进针阻力减小。



（a） （b）

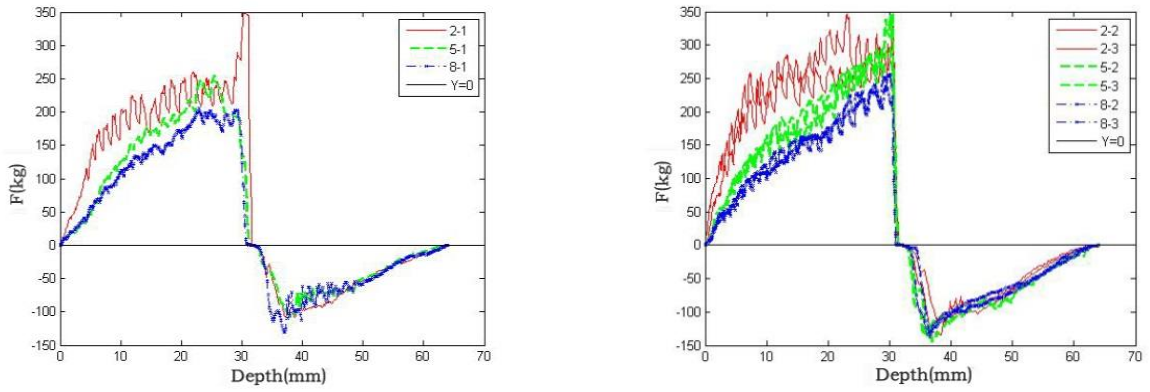
Fig. 4 -The comparison of the same outer diameter

(2)The Comparison of the Same Thickness of the Wall

There are three groups of the same thickness of the needle heads' wall, respectively for the thickness of the wall of No.2, No.5 and No.8 needle heads is 1.4mm, the thickness of the wall of No.3 and No.6 needle heads is 1.9mm, the thickness of the wall of No. 4 and No.7 needle heads is 1.15mm. As shown in figure 5, comparing the resistance of the three groups of the needle heads respectively, we get the conclusion for *F8<F5<F2, F6<F3, F7<F4*. Namely when the thickness of the wall is the same, the larger the outer diameter is, the larger the aperture is, the larger the resistance of the needle head entering the trunk is. Also, the differences of the needle heads' size are greater and the resistance is greater and more obvious.

（2）相同壁厚比较

相同壁厚的针头有三组，分别是壁厚为 1.4mm 的 2、5、8 号针头，壁厚为 1.9mm 的 3、6 号针头，壁厚为 1.15mm 的 4、7 号针头。如图 5 所示，分别对这三组针头的进针阻力比较，结论为 F8〈F5〈F2，F6〈F3，F7〈F4。即当壁厚相同时，针头外径越大，则孔径也越大，进针阻力越大。同样，针头尺寸差异越大，则进针阻力差距越大，越明显。



a) b)

Fig. 5 - The comparison of the same thickness of the wall

(3) The suitable size of needle head

Combined with the experience of the tests and the result of the data analysis, we finally choose the suitable size for:

The outer diameter is 7.8 mm, the aperture is 4.5-5.0 mm.

The outer diameter is 6.8 mm, the aperture is 4.0-4.5 mm.

The outer diameter is 5.8 mm, the aperture is 3.0-3.5 mm.

C. The Optimization Structure of the Needle Head

The purpose of the optimization design for the needle head is to decrease the resistance, guarantee the strength of the needle and improve the efficiency of the injection [9]. Because the tests in the above paragraph have determined the size range of the needle heads, here the design is mainly to optimize the structure of the needle head. The design is shown as figure 6. The new needle head turns the original circular part into the structure that the cross-sectional area of the structure's middle part is an I-shaped sharp edge and both sides are grooves. And it leaves a short length for the structure that is a top and bottom hole, which can easily make the sharp edge cutting the wood core into two pieces and the wood core easy falls off from grooves. This structure can guarantee the strength of the needle, and can improve the extruding way of the wood core. It is as much as possible to reduce the extrusion pressure, improve the effect of sealing and the pesticide penetration.

（3）针头的尺寸范围

结合现场的实验体会和数据分析的结果，最终选择的合适的尺寸规格为：

当外径为 7.8mm 时，孔径为 4.5~5.0mm；

当外径为 6.8mm 时，孔径为 4.0~4.5mm；

当外径为 5.8mm 时，孔径为 3.0~3.5mm。

C．针头优化结果

针头优化设计的目的是为了减小进针阻力，保证针头强度，提高注射效率[9]。由于上述实验已经确定了合理的针头尺寸范围，故此处的优化设计主要是对针头结构进行优化。设计方案如图 6 所示，将针头原来圆弧部分改成中间横截面为工字型的尖刃、两侧为槽的结构，并留一小段长度为上下通孔，方便尖刃将被挤出的木芯切成两块，使之容易从两侧凹槽处掉落。这种结构既能保证针头强度，又能改善木芯的挤出方式，尽可能地减少的挤压力，提高密封和药液渗透效果。

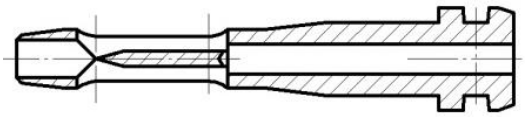


Fig. 6-The structure of the new needle head

Result of Experiment for new structure

The purpose of the experiments is to validate the resistance of the new needle head entering the trunk whether or not reduced. Here we choose two kinds of the new needle heads, specifications for that the outer diameter is 7.8 mm and the aperture is 4.5 mm, the outer diameter is 7.8 mm and the aperture is 5.0 mm. We choose an old needle head, specifications for that the outer diameter is 7.8 mm and the aperture is 5.0 mm. As

新针头实验结果

实验目的是验证新针头进针阻力是否有所减小。这里选择 2 种新针头，规格为外径 7.8mm、孔径 4.5mm，外径 7.8mm、孔径 5.0mm；1 种旧针头，规格为外径 7.8mm、孔径 5.0mm，分别用 1、2、3 表示。如图 7 所示，在不

shown in figure 7, we can know that in the case of excluding wood cores, the relationship between the resistance of the three needle heads is *F2 < F1< F3 (F1, F2, F3* respectively it expresses the resistance of No.1, No.2 and No.3 needle heads).

The formula *F2<F1* verifies that when the outer diameter is the same and the aperture is different, the thickness of the wall is thinner, the resistance of the needle head entering the trunk is smaller. The formula F2 < F3 clarifies that when the structure and the size of the needle heads are the same, the resistance of the new needle head entering the trunk is smaller.

Comparing the new needle head to the old needle head, the resistance of the new needle head is decreasing. But the effect is not obvious, it needs to be improved. However, the handling method of wood core for the new needle head is better. The wood cores cut into two pieces can exist on the grooves of both sides. The wood cores don't squeeze the trunk and have good sealing. What's more, the strength of the new needle head is better.

含木芯的情况下，这 3 种针头的进针阻力大小关系为 F2<F1<F3（F1、F2、F3 分别表示 1、2、3 号针头的进针阻力）。

F2<F1 验证了相同外径，不同孔径，壁越薄，针头进针阻力越小；

F2<F3 说明在针头外形尺寸相同的情况下，新针头进针阻力小。

新针头同旧针头相比，进针阻力有所减小，但是效果不是很明显，说明已达到进针力最低要求，但是它对木芯的处理效果则比较好，切成两段的木芯能够存在两侧槽中，不会挤压树干，密封性好，且新针头的强度也比较好。

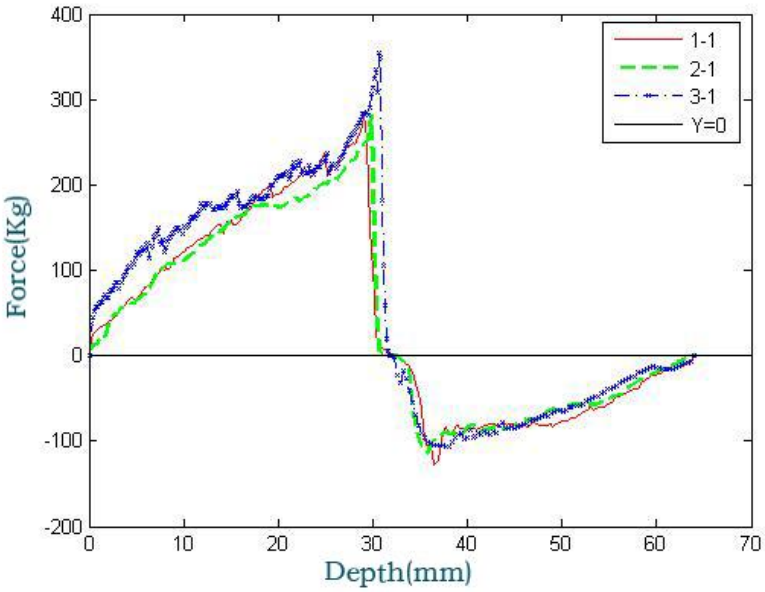


Fig. 7- The comparison of the three needle heads

CONCLUSIONS

The paper optimizes the design for the needle head by mechanical analysis, experiments of the needle head, structural improvements. The purpose is to design the best structure of the needle head. It is obtained the range of the needle head's best size: the outer diameter is 6-8 mm, the thickness of the wall is 0.5-1mm. Comparing the new needle head with the old needle head, the resistance of the needle head has been reduced. But the new structure can enhance strength and avoid fracture. It makes the wood core exist in the grooves of both sides without squeezing trunks. It has good sealing effect and improves the injection efficiency of the trunk injector.

Acknowledgement

The work has been funded by the Special Fund for Forest Scientific Research in the Public Welfare by the state forestry administration (201304102).

结论

本文通过力学分析、进针实验、结构改进，对针头进行优化设计。目的是设计出最优的针头结构形式，并得出最佳针头尺寸大小范围：直径 6-8mm,孔的壁厚 0.5-1mm。优化的新针头同旧针头相比，进针阻力有所减小，但新结构使针头强度增强，不易断裂。使木芯能够存在两侧槽中，不会挤压树干， 密封效果好，提高注干机注射效率。

致谢

本文受到国家林业局林业公益性行业科研专项基金项目(201304102)资助。

REFERENCES

[1]. Caspari HW, Green SR, Edwards WRN, (1993) - *Transpiration of well－watered and water－stressed Asian pear trees as determined by lysimeter, heatpulse and the Penm - a monteith model.* Agri and For Meter, Volume 67, pp.13-27;

[2]. De Filippis Stefano, Košel Vladimír, Dibra Donald, Decker Stefan, Köck Helmut, Irace Andrea, (2011)-*ANSYS based 3D electro-thermal simulations for the evaluation of power MOSFETs robustness.* Microelectronics Reliability, Volume 51, Issue 9-11, pp.1954-1958;

[3]. Guo Shun, Chen Jian, Li Wuyun, Guo Xiaofeng, Gao Guohua, (2011)-*The Progress and Development Trend for the Research of Tree Trunk Injection Machine.* Agricultural Mechanization Research, Volume 9, pp.245-248;

[4]. Liu Jingyuan, He Jinyi, Qi Fei. (2011)- *A Comparative Study of Pesticide Injection Devices Intended for Trees.* Forestry Machinery and Woodworking Equipment, Volume 39, Issue 1, pp.12-15;

[5]. Otho. S, Gary. E., (2010) -*Tree Injector System:* United States Patent 5,355,619 [P] [2010-10-10];

[6]. Shang Qingqing, Zhao Boguang, Zhang Yiquan, (2009)-*Study on a High Pressure and Large Capacity Tree Trunk Injector*.Journal of Nanjing Forestry University, Volume 9, Issue 5, pp. 101-104;

[7]. Shang Qingqing, Liao Kai, Liu Huan, Zhao Boguang, (2011)- *Study on Structure of Needle Head and Seal Mechanism of Tree Trunk Injection*. Proceedings 2011 International Conference on Transportation, Mechanical, and Electrical Engineering, TMEE 2011. December 16-18, Changchun, pp.813-816;

[8]. Zamora M. A. S.,Escobar R.F.(2000)-*Injector size and the time of application affects uptake of tree trunk-injected solutions,* Scientia Horticulturae, Volume 84, Issue 1, pp.163-177;

[9]. Ye Lin,Wei Min Cui,Bi Feng Song.(2012)-*Reliability Optimization Design of Spacecraft Valve Spring.* Advanced Materials Research, pp.851-857.

参考文献

[1]. Caspari HW, Green SR, Edwards WRN, (1993)- *Trans－piration of well－watered and water－stressed Asian pear trees as determined by lysimeter, heatpulse and the Penm - an monteith model*. Agri and For Meter,1993,67:13-27;

[2]. De Filippis Stefano, Košel Vladimír, Dibra Donald, Decker Stefan, Köck Helmut, Irace Andrea, (2011)-*ANSYS based 3D electro-thermal simulations for the evaluation of power MOSFETs robustness.* Microelectronics Reliability, 51(9-11): 1954-1958;

[3]. 郭顺,陈建,李云伍,郭小峰,高国华. (2011)-树干注射施药机械研究进展及发展趋势[J]. 农机化研究,(9):245~248;

[4]. 刘景元,何树川,李瑾义,秦飞. (2011)-树木注射施药装置的比较研究[J].林业机械与木工设备, 39(1):12~15;

[5]. Otho. S, Gary. E. (2010)-*Tree Injector System:* United States Patent 5,355,619[P]. [2010－10－10].

[6]. 商庆清,赵博光,张沂泉.(2009)-高压大容量树木注干机的研制[J].南京林业大学学报,9(5):101~104.

[7]. Shang Qingqing, Liao Kai, Liu Huan, Zhao Boguang, (2011)- *Study on Structure of Needle Head and Seal Mechanism of Tree Trunk Injection.* Proceedings 2011 International Conference on Transportation, Mechanical, and Electrical Engineering, TMEE 2011. December 16-18, Changchun, 813-816;

[8]. Zamora M. A. S., Escobar R.F., (2000)- *Injector size and the time of application affects uptake of tree trunk-injected solutions*, Scientia Horticulturae, 2000,84(1):163~177;

[9]. Ye Lin,Wei Min Cui, Bi Feng Song,(2012)-*Reliability Optimization Design of Spacecraft Valve Spring*. Advanced Materials Research, pp.851~857.