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DEVELOPMENT OF MECHATRONIC DIBBLING MACHINE FOR IMPROVING THE QUALITY OF FORESTRY SEEDLINGS

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Abstract: A forestry nursery in Tokoroa, New Zealand grows approximately 3 million Radiata pine seedlings per annum of which about 65% (2 million) are of suitable quality for forestry plantations. The high rejection rate of 35% was attributed to poorly trained, seasonal workers and unsophisticated equipment. It was estimated that about 22% of seedling rejection (approximately 220,000 per year) was due to poorly dibbled holes that caused bends in the stems. The bends occurred when planters pinched the stems of the seedlings in an attempt to make them vertical. A research and development project was undertaken to develop a mechatronic dibbling machine that could produce vertical holes of specified depth. The machine also had to produce 120,000 holes per day and be flexible with regard to spacing and size. The completed mechatronic dibbling machine was tested at the Tokoroa nursery and produced 98% of the holes at the required angle and 100% of useable depth. Harvesting, the following season, showed that the unwanted stem bends had been eliminated with a subsequent reduction in rejects. Furthermore, it was found that worker productivity increased by approximately 10% as they did not have to spend time setting seedlings vertically.

Keywords: forestry, dibbling, mechatronic, cuttings, seedlings, machinery

INTRODUCTION

A forestry nursery located in Tokoroa, New Zealand supplies approximately 3 million Radiata Pine seedlings per year to the forestry industry. Once harvested, the seedlings are transported to forestry blocks for planting. The vast majority of seedlings (over 90%) are Radiata Pine as shown in Figure 1, but larger seedlings such as Plug Plus and Douglas fir are also grown. In peak season, up to 120,000 Radiata Pine seedlings per day are planted.



Figure 1 – Bed of Radiata pine seedlings after 1 year growth

This spiked wheel dibbling process, though fast, produced non-circular holes due to the rotation of the spike in the soil. In the forestry nursery this is called ‘tearing’ and the plan shape of a spiked wheel produced hole is represented in Figure 3. Consequently, when juvenile seedlings were planted in the non-circular holes they did not stand vertically as required

Each Radiata Pine seedling requires a vertical hole, ± 3 degrees from vertical, lateral spacing of 80mm (± 2 mm), longitudinal spacing of 125mm (± 2 mm) and hole of 10mm (± 0.5 mm) diameter of depth of 40mm (± 3 mm). These requirements were given by the nursery manager and are based on experience. As approximately 90% of holes are for Radiata Pine, this research focussed on improving the quality of Radiata Pine holes. Once the holes are produced, juvenile seedlings are manually planted in the holes.

The process of producing holes for planting seedlings is called dibbling. To compensate for rejects, the nursery had to plant approximately 5 million seedlings to achieve a yield of 3 million. Poor quality holes, caused by antiquated dibbling methods, was one of the major causes of inconsistent quality. Formerly, dibbling for Radiata Pine was achieved using a spiked wheel towed behind a tractor as shown in Figure 2. The spiked wheel

method could not meet the required hole specification under any conditions.



Figure 2. Radiata Pine dibbling machine

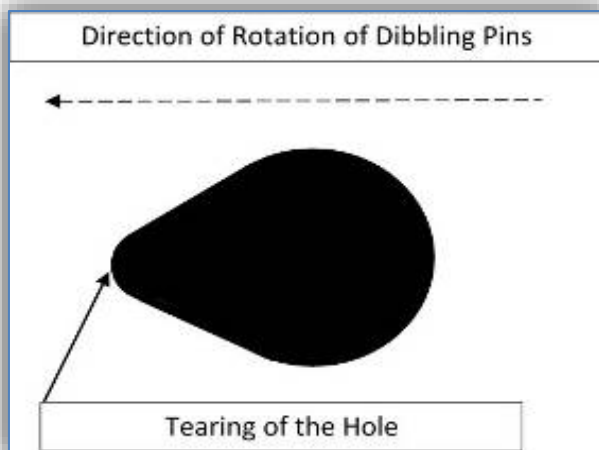


Figure 3. Non-circular holes caused by the spiked wheel dibbling machine 'tearing'

To compensate for this, planters manually set each juvenile seedling visually. They then used their fingers to gather the soil around the stem to fix it in position. It was found that the manual setting caused bends in the stems, accounting for approximately 22% (220,000 per annum) of rejects. Furthermore, the Plus Plug and Douglas Fir seedlings required manual dibbling as the holes were too large to be produced by a spiked wheel. This was labour intensive and therefore costly. To overcome these problems, research was undertaken at the University of Waikato into the feasibility of a mechatronic dibbling machine.

Automated dibbling and seeding has been investigated by a number of researchers. Commonly, spiked wheels are used for dibbling holes, especially for seed planting and are often combined with an integrated seed dropping mechanism [3, 4]. Whereas this is effective for seeds, it is not viable for planting juvenile seedlings due to 'tearing' of the holes by the spike.

Investigations into plunger type dibblers and seeders as alternatives to the commonly used Coulter drill have been undertaken [1,6]. However, the emphasis of that research was on how to make a hole and drop a seed in it rather than producing holes to meet a defined specification for planting seedlings. Furthermore, these dibblers lacked the flexibility and speed required for the forestry nursery.

Lawrence et al [5], developed a dibbler using microprocessor control that offered greater opportunity for varying hole spacing to suit a range of crops. They found that using the new design, 96% of the hole spacing for potatoes and 98% for onions were within the required +/- 10% specification. This flexibility and controllability highlights the advantages of using computer technology compared to purely mechanical systems. However, their system was not suitable for forestry nurseries as the holes have to be deeper and straighter for forestry seedlings and they had no method of achieving this. Consequently, it was found that no dibbling machine existed that met the requirements of the forestry nursery and therefore a new machine had to be developed.

MATERIAL AND METHOD

Firstly, a detailed investigation of dibbling and associated issues was undertaken in close collaboration with the forestry nursery managers. One requirement from the managers was that they wanted drilled holes, not punched. This was because punched holes compress the soil and inhibit root growth. Laboratory experiments were undertaken to determine the best drilling speed, drill types and power for a range of soil conditions. Five seedling trays, each comprising forty eight cells were filled with nursery soil. The soil was then compacted until it resembled the soil consistency in the nursery for a range of conditions from wet to dry. It was very difficult to quantify these conditions so they were based on the experience of the nursery manager. An electric drill was used for the testing and was modified such that its speed could be controlled over a range from approximately 100 to 3000 rev/min. This was achieved using voltage control with a switching DC power supply. The drill speed was measured with an optical tachometer. A scissor mechanism was used to keep the drill vertical during testing. It was found that for Radiata Pine, the optimal drilling speed was approximately 1000 rev/min with a 10mm auger drill. At 1000 rev/min, the drilling left soil at the edge of the hole that planters could use to set the seedling. Furthermore, the centrifugal force on the dirt ensured the drill did not clog with soil. The vertical drill speed was approximately 0.25 m/s. The drilling power consumption was found from the product of the current and voltage and at optimal speed, in dry soil

conditions was approximately 2W. The mechatronic dibbling machine had to be towed by an existing nursery tractor in a continuous process. Also, only the tractor driver was to operate the dibbler and it had to be easily reconfigured to accommodate a range of sizes and hole spacing.

In order to achieve the requirements, the machine had to produce straight vertical cylindrical holes whilst the machine was being towed behind a tractor driving at variable speed. The speed of the nursery tractor when driving with a creeper gearbox was between 0.2 to 0.4 m/s. Even in lowest gear, the speed variation of the tractor would have led to poor quality holes unless there was some sort of closed loop control that linked the dibbling to tractor speed. To achieve closed loop control, a programmable logic controller (PLC) coupled with sensors and precision pneumatics was used. A rotary encoder was mounted in a roller at the front of the dibbler. Therefore, the rotational speed of the roller was directly proportional to the horizontal speed of the tractor. The PLC then calculated the instantaneous speed requirement of a horizontal pneumatic cylinder such that it would match the tractor speed. A control signal was then sent to a Norgren pneumatic speed control valve. A horizontal, speed controlled pneumatic cylinder then moved forward at the speed of the tractor.

As the cylinder moved horizontally, a second pneumatic cylinder, with 16 rotating drill bits, descended to drill the holes. The matching of the horizontal cylinder speed with tractor speed ensured there was zero relative velocity between the vertical drilling cylinder and the planting bed. Once the holes were drilled, the vertical cylinder lifted the drills from the bed and the horizontal cylinder rapidly returned the starting position ready for another cycle. The entire cycle took approximately 1 second.

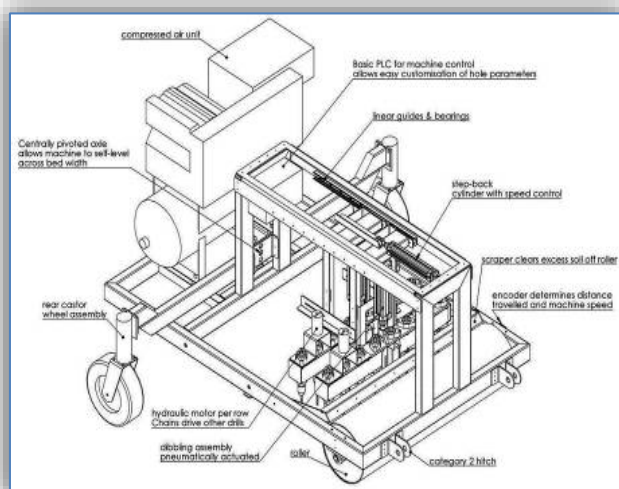


Figure 4 – Arrangement of mechatronic dibbling machine concept

It was found that to achieve the 120,000 holes per day and given the limitations of the pneumatics, that 16 drill bits were required. An arrangement drawing of the mechatronic dibbler is shown in (Figure 4).

Even though this was a research exercise, the nursery wanted to permanently replace the spiked wheel dibbler with the mechatronic dibbler prototype. Therefore, extra design criteria were added to the original mechatronic dibbler requirements as listed below:

- » Must be able to operate in all weather conditions – as dibbling is done in winter, weather conditions include hard frosty ground, severe wind and rain with associated mud.
- » Easy repair and maintenance.
- » Easy and fast transportation from the storage building to the planting beds (up to 1.5km).
- » Easy movement from one bed row to the next.
- » Minimal disturbance to the bed surface, to protect the pesticide layer.

To accommodate these extra requirements the machine used components such as electronics and bearings rated to Ingress Protection (IP 67). This allowed the machine to operate in severe weather conditions and be easily cleaned by waterjet at the end of each day.

For easy maintenance and repair, only high quality, respected brand components were used. Therefore, if a component failed it could be easily sourced and replaced. Non-bought in components were manufactured directly using laser cutting which is fast and readily available in New Zealand.

Rear wheels were added that kept the machine stable when in use but also robust enough for transportation. The machine had hoist attachments so it could be easily connected to a hydraulic tractor hoist for lifting the front for movement from storage to bed and bed to bed.

A front roller provided support and was also used for sensing forward speed without disturbing the pesticide layer.

Once the concept was agreed by the nursery managers, detail design was undertaken using 3D computer aided design (CAD). This was combined with computer aided engineering (CAE) tools to undertake stress calculations using finite element analysis (FEA) to ensure machine robustness. CAE dynamic tools were also used to ensure the machine could achieve the required speed.

The final design was manufactured using Computer Aided Manufacture (CAM), assembled and commissioned by the University of Waikato's AgriEngineering Research Group.

RESULTS

The completed mechatronic dibbler was tested on site at the Tokoroa nursery and achieved the

120,000 required holes per day. The finished dibbler in operation is shown in Figure 5.



Figure 5 – Completed mechatronic dibbling machine during testing

For the mechatronic dibbling machine, a sample of 100 holes was used to determine the consistency of the depth and angle. As the vast majority of holes were for Radiata Pine, they were used in the sampling. A simple measuring system was built that comprised a rod of 10mm diameter, a protractor for measuring hole angle and a rule for measuring hole depth, see figure 6.



Figure 6 – Measuring device for hole depth and angle

The scales of the measuring system could be read to ± 1 mm and ± 0.5 degrees. 100 holes were randomly chosen from a mechatronically dibbled bed. The rod was inserted in the holes and depth and angle ready by eye. The results from the testing are shown in (figure 7).

The basic requirement was that holes for Pine Radiata were 40mm ± 3 mm deep and ± 3 degree angle from the vertical. Due to the lack of

resolution of the measurement method, many of the 100 measurements had the same value.

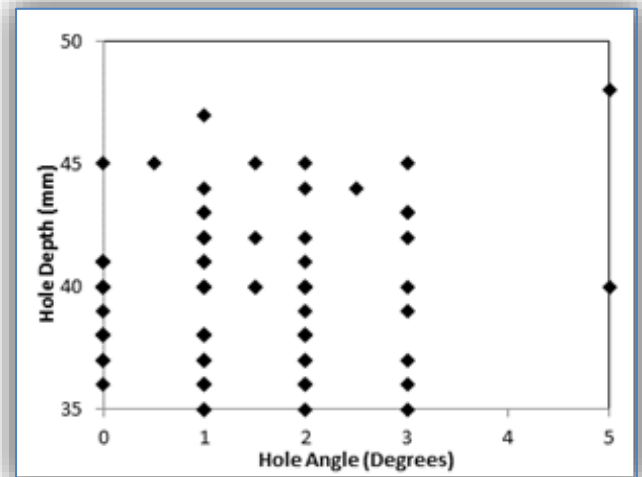


Figure 7 – Hole depth v hole angle for mechatronically dibbled Radiata pine seedlings

It can be seen that the even with the uneven planting bed, the dibbler achieved 76% of holes within the ± 3 mm tolerance. Only 2% of holes are outside the required ± 3 degree angle. The average hole depth was 39.7 mm and angle 1.3 degrees with standard deviations of 3.3mm and 1.1 degrees respectively. With regard to the angle, this is at least an order of magnitude better than the spiked wheel dibbled holes. It was found that all the spiked wheel dibbled holes were outside the requirements. The nursery managers were confident that even the 24 holes outside the depth tolerance would produce saleable seedlings, suggesting that the ± 3 mm tolerance should be increased to ± 5 mm.

It was observed that the uneven surface of the planting bed caused varying hole depth and angle. This was because the machine's depth sensor is located in one place on the bed whereas there are 16 holes, each in different places.

Furthermore, it was also observed that the level of the bed was not even.

Even though the hole data provides useful information on quality, the best indicator is the position of the juvenile seedlings when placed into a mechatronically dibbled hole and spiked wheel hole respectively.

Figure 8 shows 5 juvenile seedlings in holes made by the spiked wheel dibbler. It can be seen that the 'torn' hole causes non vertical seedlings. These then have to be manually set to the vertical position. It can also be seen that the surface of the planting bed is very 'disturbed' due to the tearing effect of the spikes.



Figure 8. Juvenile seedlings in spiked wheel dibbled holes



Figure 9. Juvenile seedlings in mechatronically dibbled holes

Figure 9 shows 5 juvenile seedlings placed in holes made by the mechatronic dibbler. It can be seen that all the seedlings are vertical and of even height. The nursery managers decided that all holes produced by the mechatronic dibbler, including those outside their original specification, were suitable for planting.

It can also be observed that the bed surface is far less disturbed than the spiked wheel bed surface. This highlights the superior quality of the mechatronic dibbling process. An unexpected advantage of the mechatronic dibbler was that planter productivity increased by approximately 10% because they did not have to spend time setting the seedlings vertical. The mechatronic dibbler has now been operating for three seasons and has produced several million holes. The bent stem problem has been eliminated and planter productivity increased.

CONCLUSIONS

A Tokoroa forestry nursery in New Zealand was suffering approximately 220,000 per annum seedling rejects due to poorly dibbled holes. A research and development project was undertaken by the University of Waikato to develop a mechatronic dibbling machine that could produce good quality holes at the required rate and also be flexible with regard to spacing and hole sizes. Furthermore, the nursery wanted the dibbling machine to be towed by a tractor operating at close to a constant speed, to ensure a continuous system. To achieve the requirements, a computer controlled mechatronic dibbler was developed. The dibbler used an encoder on a roller to provide feedback of the tractor speed to a PLC. This then provided a closed loop signal to a horizontal pneumatic cylinder that matched the forward speed of the tractor. The holes were then drilled by a second vertical pneumatic cylinder with 16 drill bits. The relative horizontal velocity between the bed and drill bits was zero. After drilling, the cylinders rapidly returned to the start position to begin the process again.

The completed dibbling machine was tested at the Tokoroa nursery and performed as expected, producing 98% of holes at the required angle and 76% at the required depth. All the holes were considered good quality by the nursery manager suggesting that the current depth tolerances should be increased to ± 5 mm, especially when considering the uneven surface of the planting bed. The machine is now fully commissioned and dibbling holes on a daily basis at the nursery.

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