New delimbing tool for hardwood trees: feedback on new ribbed knives after one year experience

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Challenges and context

- **2 main challenges:**
  - To harvest +12 Mm$^3$/year by 2025 (80% of available resources = broadleaved species)
  - To counteract the decrease of manual workforce: - 400 lumberjacks/year during the last decade

- **Hardwood mechanization in France to date:**
  - 10% of volume felled and processed with CTL harvesters (80% for softwood), 54 full time equivalent harvesters
  - Average annual productivity: 14,000 m$^3$/CTL harvester/year
  - Expectations from harvester operators:
    - Harvesters are now more powerful but need yet to be adapted to hardwood’s typical characteristics (branchiness, crookedness…), which still hinder productivity
    - Less selection of stands that can be mechanized (straight trees, small branches…) would enhance utilization rate of harvesters and facilitate global organization
ECOMEF project and methodology

- ECOMEF: Eco-design of a mechanized tool for hardwood harvesting
- Objective: to develop a hardwood-dedicated harvesting head
- Methodology:
  - Mains problems listed and ranked:
    1. Delimbing
    2. Feeding process
    3. Grabbing trees in clumps
  - Brainstorming to imagine new concepts
  - Design and tests in laboratory
  - Real field tests
  - Preparation for industrialization

Example for new delimbing knives
Design and test of ribbed blades in laboratory
Design of ribbed knives

• Contradiction:
  – The blade should be thin to minimize deliming force...
  – and thick to avoid destruction due to extreme bending

• How to decrease cross-section area while increasing quadratic moment?

⇒ Solution: Additional ribs used as stiffeners are spaced regularly

• Make use of wood anisotropy:
  – The blade’s edge cuts wood fibers
  – The stiffeners cross between the fibers with minor increase of deliming force
Tests of various ribbed knives with delimbing test benches (1/2)

- Different dimensional parameters influence cutting force and blade resistance:
  - $\beta$, sharpness angle
  - $th_b$, blade thickness
  - $l_r$, rib depth
  - $th_k$, knife thickness
  - $d_r$, distance between ribs
  - $th_r$, rib thickness

- 1st step: finite element simulations to determine the 9 best performing configurations
- 2nd step: test of these 9 best configurations with benches (ex. right)
Main results:

- 30° sharpness angle ($\beta$) seems to be a good compromise between cutting forces and blade resistance
- The thinner the blade, the lower the max. cutting forces
- Thickness $th_b = 3\text{mm}$ is not rigid enough
- + 1 - 2 mm thickening of ribs increases cutting forces
- Little influence from height of the ribs

<table>
<thead>
<tr>
<th>Knife name $th_k$ - $th_b$ - $th_r$</th>
<th>Knife thickness $th_k$ (mm)</th>
<th>Blade thickness $th_b$ (mm)</th>
<th>Rib thickness $th_r$ (mm)</th>
<th>Maximal cutting force (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Smooth 8 mm</td>
<td>8</td>
<td>/</td>
<td>/</td>
<td>30</td>
</tr>
<tr>
<td>2. Ribbed 8-3-2</td>
<td>8</td>
<td>3</td>
<td>2</td>
<td>26.9</td>
</tr>
<tr>
<td>3. Smooth 10</td>
<td>10</td>
<td>/</td>
<td>/</td>
<td>32.9</td>
</tr>
<tr>
<td>4. Ribbed 10-3-1</td>
<td>10</td>
<td>3</td>
<td>1</td>
<td>26.3</td>
</tr>
<tr>
<td>5. Ribbed 10-3-2</td>
<td>10</td>
<td>3</td>
<td>2</td>
<td>25.6</td>
</tr>
<tr>
<td>6. Ribbed 10-5-2</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>27.4</td>
</tr>
<tr>
<td>7. Smooth 12</td>
<td>12</td>
<td>/</td>
<td>/</td>
<td>32.4</td>
</tr>
<tr>
<td>8. Ribbed 12-5-2</td>
<td>12</td>
<td>5</td>
<td>2</td>
<td>25.9</td>
</tr>
<tr>
<td>9. Ribbed 12-7-2</td>
<td>12</td>
<td>7</td>
<td>2</td>
<td>30.2</td>
</tr>
</tbody>
</table>

Branch diameter 80mm, $\beta = 30^\circ$, $l_r = 40\text{mm}$, $d_r = 16\text{mm}$
First short field tests

- **Methods and material:**
  - CASE CX210 + harvesting head Kesla 25 RH II
  - Only on the first upper mobile knife
  - Ribbed blade fixed on a supporting knife
  - Time studies (PMH5) for 50 trees per configuration, and comparison with the original knife

- **Five ribbed knives configurations:**

<table>
<thead>
<tr>
<th>Knife type th_k-th_b-th_r-l_r</th>
<th>12-5-2-43</th>
<th>10-3-2-43</th>
<th>12-7-2-43</th>
<th>12-5-2-94</th>
<th>12-7-2-94</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity gain</td>
<td>8%</td>
<td>23%</td>
<td>40%</td>
<td>32%</td>
<td>32%</td>
</tr>
</tbody>
</table>

=> Results to be confirmed by additional experiments
Tests of ribbed knives in real productive conditions
Material and method

- 2 harvesters working in hardwood stands (oak, chestnut...):
  - CASE CX210 + harvesting head Kesla 25 RH II
  - John Deere 1170E + harvesting head H752

- 1 year practice:
  - Comparison with the original knives
  - Different versions of the ribbed knives (NB: only 1 fix + 1 mobile ribbed knives for JD H752)
  - Time studies (PMH5) for 768 trees (characterized by species and shape rating)
  - Qualitative feedback from operators
Positive feedback from drivers

- Correct and close to trunk branch delimming
- Processed logs in accordance with specifications
- Good robustness
- Good resistance of sharpening (≥ original knives)
A gain on global productivity but not statistically significant

- Whatever their shape, knives can only influence delimbing
- Many other parameters weight on harvesters’ productivity in broadleaved stands
Statistically significant results on sub-process productivity

- **Comparison between original and ribbed knives for the 2 harvesters** (based on sub-samples with trees having the same average volume, statistically significant difference, ANOVA-test):

<table>
<thead>
<tr>
<th></th>
<th>Case CX 210 + harvesting head Kesla 25 RH II</th>
<th>John Deere 1170E + harvesting head H752</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original knives</td>
<td>Ribbed knives</td>
</tr>
<tr>
<td>Average stem volume (m$^3$)</td>
<td>0.151</td>
<td>0.150</td>
</tr>
<tr>
<td>Number of monitored trees</td>
<td>50</td>
<td>225</td>
</tr>
<tr>
<td>Productivity during tree process (m$^3$/PMH)</td>
<td>Min 11.0</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>Max 54.2</td>
<td>69.4</td>
</tr>
<tr>
<td></td>
<td>Moy 27.2</td>
<td>32.9</td>
</tr>
<tr>
<td>Gain on productivity</td>
<td>+21%</td>
<td></td>
</tr>
</tbody>
</table>

- **Tree processing**
  - = delimming + cross-cutting
  - ≈ 50% of productive machine hour (PMH) in broadleaved stands
Influence of shape and species on sub-process productivity

Shape grade: from 0.5 (easy) to 3.5 (many difficulties, big branches)

- +37% gains thanks to ribbed knives for trees shape-graded from 0.5 to 1.5 (statistically significant, ANOVA-test)

- No significant difference over 1.75 shape grade (but few monitored trees)

- Better results with chestnut, birch and aspen than oak

=> Because delimming is shock-driven, larger and harder branches remain too tough to stomach for ribbed blades, although the upper limit of their capacity is higher than conventional knives’
Conclusion
Conclusion, discussion

- Real productivity gains are reachable with ribbed knives for delimbing, despite the fact that for one harvester the delimbing ring was not totally ribbed

- Still on-going improvement and monitoring: new global shape for the knives, fully ribbed delimbing system, choice of the steel…

- Patented knives which can fit in any harvesting heads
Thank you for your attention!
Questions?

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