# Geometric thinning for forest bioenergy

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**Abstract:**
*Current Swedish forest management recommendations are intended to maximize production of stem wood and therefore young stands normally are pre-commercially thinned (PCT). If cost-efficient techniques for harvesting small whole trees (≤ 8-10 cm in diam. at breast height (DBH)) could be developed, costly PCT could be turned into an income and more bioenergy would be available. Results from studies of prototype equipment for geometric boom-corridor thinning between strip-roads (approximately 1 m wide and 10 m long corridors) show potential to at least double the productivity, compared to conventional harvesting operations. The goal was to demonstrate a boom tip mounted felling head for continuous felling and accumulation of trees in boom corridors. The accumulation capacity was good enough to handle all trees in most boom corridors. It was thus concluded that the first steps on developing a tailor-made harvesting technique for thinning of biofuel in young dense stands had been taken.*

**Keywords**: Pre-commercial thinning, early thinning, fuel wood

## 1 Introduction

In Sweden, 17.3% (3.9 million ha) of the total productive forested area is young forest, which is dominated by trees at least 1.3 m tall with a diameter at breast height (DBH) below 10 cm over-bark (o-b) (Anon, 2009). Stands dominated by trees with a DBH of up to 14 cm account for 21.9% (ca. 748 million $m^3$ solid o-b) of the total standing volume in Swedish forests (Anon, 2009). When a stand reaches an average height of ca. 3 m, it should be pre-commercially thinned prior to commercial first thinning (FT) when the stems reach an average DBH of ca. 12-14 cm. Pre-commercial thinning (PCT) is costly and therefore often neglected. In general, without PCT stands become dense, heterogeneous in tree size and biomass rich, which can make a FT operation for pulpwood troublesome. If however, the whole trees are harvested for fuel wood, it is not necessary to consider, e.g., tree size.

FT for fuel wood is generally carried out using conventional forest machines and systems, usually a two-machine system comprising a harvester equipped with an accumulating harvesting/felling head together with a forwarder. The productivity of thinning harvesters is affected by the average size of the harvested stems, the stand density, and the intensity of removal (Eliasson, 1999). Compared to pulpwood, harvesting for fuel wood (whole trees) increases biomass removals by 15-50%. In addition, the use of multi-tree handling heads increases productivity by 35- 40% compared to single-tree handling (Björheden et al., 2003; Jylhä & Laitila, 2007). Consequently, the harvesting costs of fuel wood from stump to roadside can be reduced by 20-40% compared to pulpwood extraction (Hakkila, 2003).

The productivity of the felling and bunching operation in young stands has been correlated to factors such as the average size of harvested trees, stand density, density and volume of removal, (Kärhä et al. 2005), frequency of multiple felling (Johansson & Gullberg 2002) and frequency of accumulation (Liss 1999). The productivity of these operations ranges from ca. 1 to 7.5 solid cubic meters of biomass ($m^3$biomass) (~ 0.5 – 3.7 ton DM) per effective hour ($E_0$-hour) across various types of young forests, systems and machinery (Gullberg et al. 1998, Liss 1999, Kärhä et al. 2005). In selective thinning using AFHs trees are normally felled one by one, hence many time-consuming non-linear crane movements around future crop trees are required. For high felling and bunching productivity in stands with relatively small trees the AFH used must have multiple felling ability (Johansson & Gullberg 2002). However, with currently available AFHs multiple felling is limited by the spacing between trees, and it is only practicable in cases where trees are closely grouped. No specialized AFHs for multiple felling of small diameter trees more widely spaced than a few dm apart have been developed and commercialized as yet.

A possibility for the future could be to develop a strip road and corridor system for thinning and bunching at strip road side, instead of PCT, in young stands with high biomass. The narrow corridors between the strip-roads could be created using conventional AFHs or more area-based felling and accumulating felling heads specially designed for corridor thinning, mounted at the boom-tip of a machine with a long crane reach. Such thinning systems are here named boom-corridor thinning systems with focus on the work method, i.e., the intention is not to create corridors in the remaining stand but to take out trees corridor-wise. Up to a certain tree size, harvesting techniques based on area instead of single-tree positioning would probably be more efficient. If techniques and appropriate equipment are developed to fell, cut-to-length, and bundle within almost the same time, regardless of the number of trees in the handled area, the cost reductions should be large. Various geometric boom-corridor patterns could be used, for example a strictly perpendicular pattern or a fan-shaped pattern (Fig. 1)

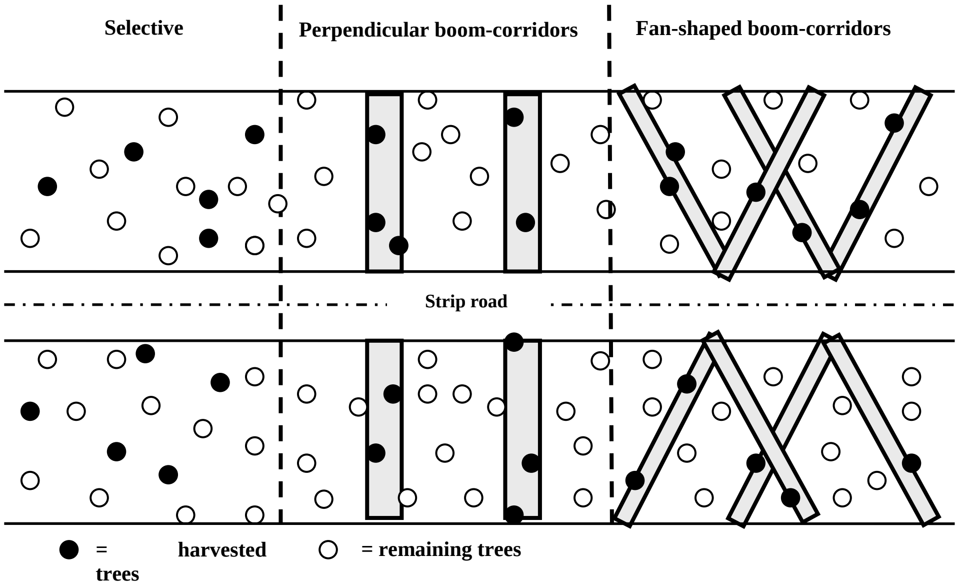


**Figure 1: Sketch of selective thinning and two boom-corridor thinning patterns between strip roads.**

A boom-corridor system for thinning young dense stands using conventional machinery could be designed in which trees between strip roads are harvested in narrow corridors, perhaps perpendicular to the strip-road and ca. 1 m wide, with a length corresponding to the crane reach (ca. 10 m) (Fig. 1). In such systems the time required for re-positioning the AFH in each crane cycle should be reduced since trees hindering its movement would be removed as the corridor is harvested. Liss (1999) found that use of a feller-buncher in early thinnings, in which trees were felled and accumulated solely by linear crane movements, provided no increase in productivity compared to conventional selective thinning. However, the method examined in the cited study involved a combination of geometric and selective thinning, and trees were not exclusively harvested in boom-corridors. Previous studies on geometric thinning have mainly considered strict line/row-thinning systems. In some systems the base machine is driven in the corridors that it produces (cf. Rummer 1993), in other systems cut trees are pulled to the corridor using cables (cf. Bennecke 1985), or rows of trees parallel to the strip-road (at a distance of, for instance, three rows from the strip-road) are harvested (cf. Suadicani & Nordfjell 2003).

If boom-corridor thinning is applied in young dense stands, even with conventional felling techniques, the harvesting efficiency seems to increase. However, if new techniques especially designed for the boom-corridor method are developed and used, productivity and cost-efficiency can be greatly increased. Efforts to develop such techniques could focus on developing/improving conventional AFHs for multiple felling or new techniques for harvesting a whole corridor in one continuous movement. The former approach seems to be appropriate for a FT regime and the latter for a PCT regime.

The goal was to demonstrate a boom tip mounted felling head for continuous felling and accumulation of trees in boom corridors and making bunches of trees at strip-road side.

## 2 Material and Methods

Existing techniques and patents in the area of continuous felling and accumulation of trees were surveyed (Forsberg & Wennberg 2011). A list of technical demands on the boom-corridor felling head was compiled through several brain storms and discussions with a group consisting of staff from the Sveaskog forest company and researchers in the area of forest technology at SLU, approximately 10 persons. The demands were to a large extent based on simulations of boom-corridor thinning in PhD thesis a by Bergström (2009) and on data on unthinned stands from the Swedish national forest inventories and from the Sveaskog forest company.

Based on the compilation of existing techniques by Forsberg & Wennberg (2011) it was concluded that although several solutions for continuous felling were available, techniques for continuous feeding and accumulation of many small trees were missing. It was therefore decided to focus most on the feeding and accumulation part of the problem.

The first part of the study resulted in a master thesis for two mechanical engineering students (Forsberg & Wennberg 2011) at Luleå University of Technology, Sweden. The study continued as a mechanical design project with the two mechanical engineers making a prototype based on earlier findings. The finalized concept was demonstrated at a forest excursion close to Lycksele in northern Sweden 29$^{th}$ of August 2011 with approximately 60 participants consisting of Sveaskog forest company staff, researchers and forest machine manufacturers.

# 3 Results

## 3.1 Technical demands

The technical demands considered the most important on a boom corridor felling head were 1) a felling and accumulating mechanism which can be operated during a continuous boom movement, 2) sufficient capacity for handling of all trees within the boom corridor in a single boom movement and 3) compatibility with existing machines (Table 1). Additional requirements were a head mass below 650 kg, a boom speed of at least 1.0-1.5 m×s$^{-1}$ with a hydraulic pressure below 230 bar and a hydraulic flow to 200 l/min.

**Table 1: Technical demands set on a boom corridor felling head**

| *Demand* | *Specification* |
|---|---|
| Continuous felling, accumulation and handling of all trees in a boom corridor. | Boom corridor dimensions, 1×10 m. Size of the trees, 4-10 cm in breast height diameter (DBH), and a height of 5-10 m. |
| Maximum mass handled by the felling head. | 350 kg. |
| Capacity to handle single larger trees. | Maximum size of a single tree 23 cm in DBH and 14 m high. |
| Simplification of the following extraction work. | Placing the bunch of trees from one boom corridor close to the strip road, and with the but ends towards the strip road. |
| Compatibility with existing machines. | Harvesters, forwarders and excavators with a mass on 15 - 20 metric tons should be suitable base machines for a boom corridor felling head. |

## 3.2 Technical solutions

The chassis on the boom corridor felling head had a rotator at the top and was divided into an upper frame and a lower, tiltable frame. The mechanism for feeding and accumulation was mounted on the upper frame, and circular saws for felling at the bottom of the lower frame (Fig. 2). The purpose of the tilting mechanism between the two chassis parts was to place an accumulated bunch of trees on the ground at the strip-road side.

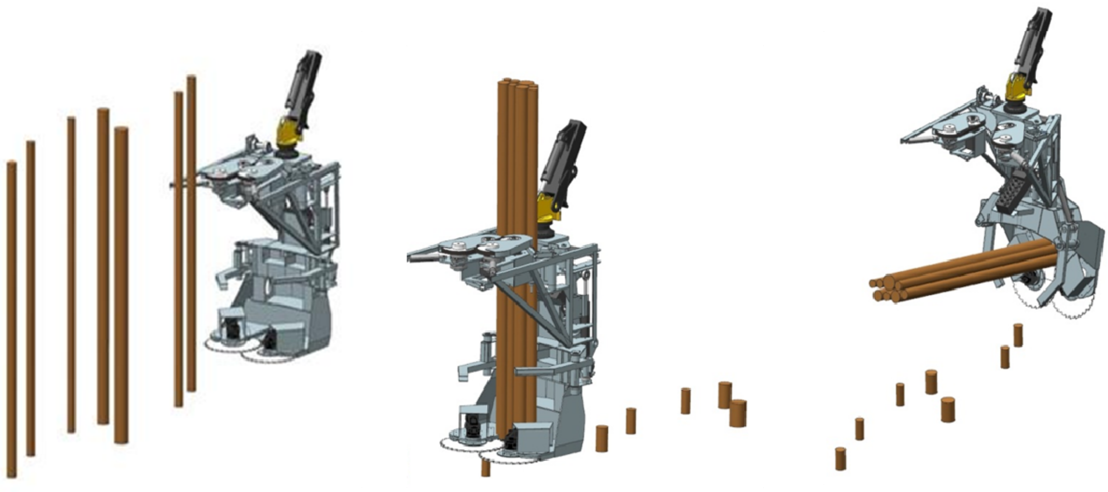

**Figure 2: Principal function on the boom corridor felling head. Left panel: The head in the beginning of a continuous movement to fell and accumulate trees. Middle panel: The head after felling and accumulating standing trees. Right panel: The head in the position to place felled trees beside the strip road.**

The feeding was done with two sharp-toothed chains, each mounted on an arm with a spring suspension bogie function and constantly running during the feeding and accumulation phase. The distance between the arms could be adjusted by a hydraulic piston from 1.0 to 1.5 m (Fig. 3).

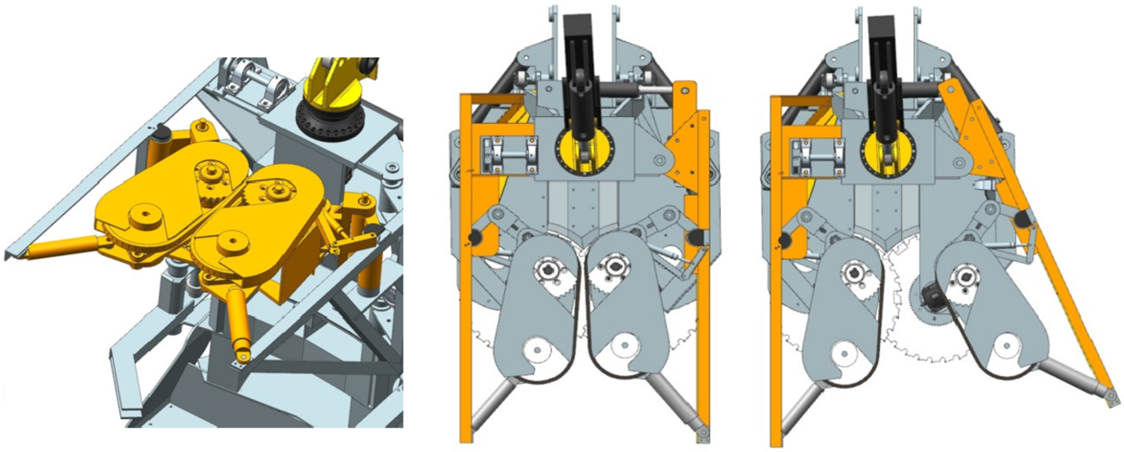

**Figure 3: The feeding mechanism on the boom corridor felling head. Left and middle panel: Close distance between the feeding chains. Right panel: The largest possible distance between the feeding chains, 1.5 m between the two arms.**

The accumulation chamber consisted of two wires on rollers, stretched by a spring at a small and almost constant force. This allowed the space in the accumulation chamber to increase when the wires was pulled from the rollers as more trees was accumulated (Fig. 4).

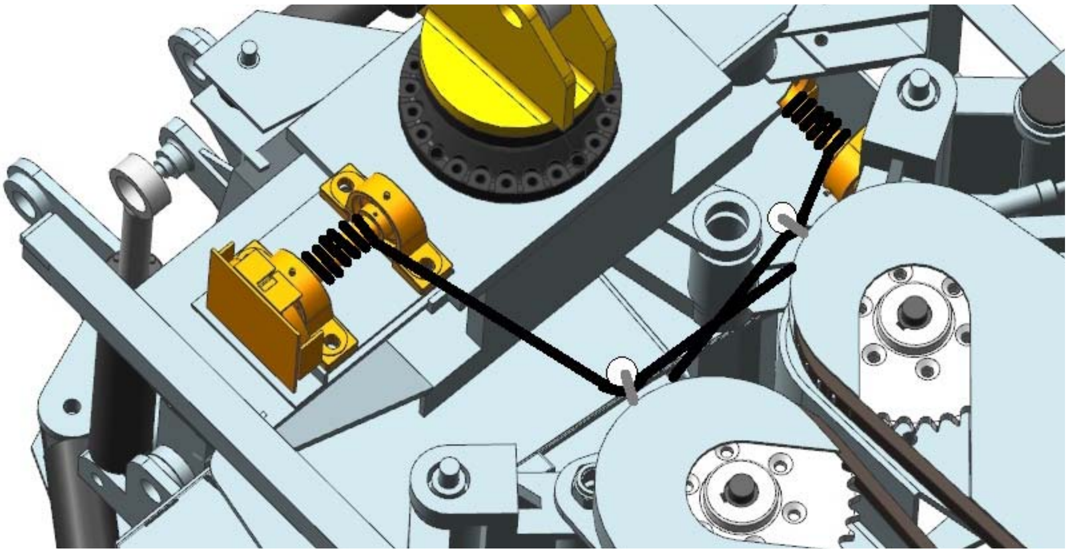

**Figure 4: Wires to keep the accumulated trees together when they have passed the feeding mechanism.**

Two arms to grip the bunch of trees after accumulation were located in the upper part of the lower frame of the head (Fig. 5). Their function was to hold the bunch in a firm grip, together with the above described accumulation part, when the loaded head was positioned for unloading. The arms also had the function to hold the bunch of trees when tilting the lower part of the head for unloading (Fig. 2, right panel). Two circular counter-rotating saw blades with diameters of 60 cm were used to continuously fell the trees, to center them and transport them in to the accumulation chamber (Fig. 5).

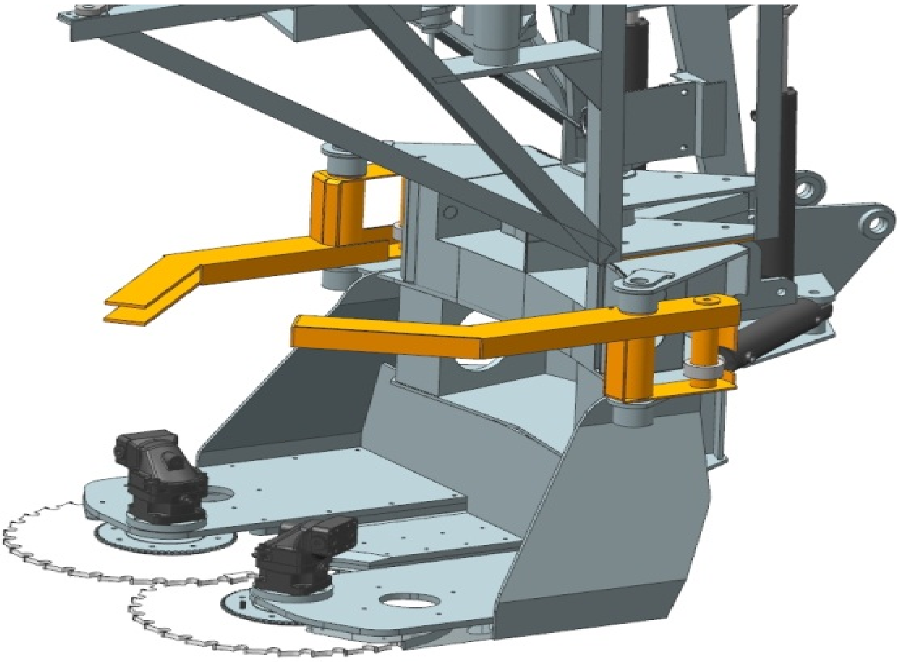

**Figure 5: Arms to hold trees after accumulation in the middle, and circular saw blades for felling of trees at the bottom of the boom corridor felling head.**

### 3.3 The first evaluation of the prototype boom corridor felling head

So far, only an initial evaluation has been made. However, it could be verified that all individual functions (i.e. felling, feeding, accumulation and handling) worked, and that the accumulation capacity was sufficient for handling all trees for in most boom corridors. It was also noticed that not all technical demands specified in table 1 could be fulfilled with this prototype. Trees taller than approximately 8 m was difficult to hold in a firm grip, and the mass of the head was twice as high as desired.

## 4 Discussion and conclusions

All the desired functions had been implemented in the prototype. The technical demands had either been met or appeared feasible to meet. Full tests on manoeuverability in boom corridors remained to be made but it was observed that the capacity to handle trees between 8 and 10 meters in height should be improved. The hydraulic steering was not made fully operational in the prototype and the different functions had to be maneuvered separately by the operator, making the work time consuming. However, at the excursion, the vast majority of researchers, forest company staff and machine manufacturers concluded that the first important steps on a new harvesting technique for bioenergy thinning of young dense stands had now been taken. It was also concluded that forest practice and machine manufacturers as well as researchers will now have to take further steps in the development process if this technique and working method shall be implemented in a large scale.

## 5 Acknowledgments

This study was mainly financed by Sveaskog forest company, The Forest Technology Cluster in northern Sweden and to a minor part by the ‘Botnia-Atlantica (Forest Power)’ research program.

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