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DEVELOPMENT OF CODE-MARKING EQUIPMENT FOR LOGS

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Abstract

This paper gives an overview of the product development process applied to development of code-marking equipment for logs. The learning and decision making process during the development is showed. Also the situations when a decision had to be made without having sufficient amount of information are described. The development of a log code-marking equipment for a log sorting station in a sawmill is described retrospectively, but the development of a code-marker for harvester mounting is described as in real time. In the latter case the conditions for code-marking on-board forest machines are discussed and different possible solutions are described and evaluated but the final decision is left open. So it is possible for every reader to make his own decision.
This product development process shows that in a specific case it is not only difficult to generate good concepts, it is also difficult to decide, evaluate and guess whether the concept is viable, would it work in a real environment and is it robust enough? This question appears especially when the product will be created in the field where no solution exists. Finally it is concluded that in this product development process the discovery of new ideas in concept generation is strongly motivated by the need for them, when it is realised that the available concepts/solutions do not work, then there exists much stronger motivation for finding new concepts. This is an iterative process, with several loops.

1 Introduction

The saw milling industry has a big role in the Nordic countries and all kinds of enhancing and rationalisation, which can decrease the production costs, are always welcome. One possible way is to achieve better control of the process and information plays the key role in maintaining control. The traceability technique and communication through a code-mark on logs is one possible tool for monitoring and information transferring. Code-marking can be done in a log sorting station in a sawmill mostly for automatic control of sawmill production equipment or in the forest by a harvester for identity or property marking. The first practical study on code-marking of logs was carried out during the Nordic project "Spårbarhet"

(Uusijärvi R. & Usenius A. 1997). Next study was carried out in the EC project LINESET (Uusijärvi R. 2003) which started in 2000. In both projects the log-marking systems were using electronic log code labels (RFID transponders). A transponder is specially developed for identification but the cost, around 1 EUR per unit, was considered too high. Also the price (for the read-only transponder type) does not depend on the amount of information that will be used. When the transponder technology was chosen, the common idea prevailing at that time was that the transponder would become much cheaper in the near future. Now it is stated that the cost has decreased, but very slowly and they are still too expensive. Also another log code-marking system for a sawmill log sorting station was created in the LINESET project. The system was based on an imprint marking technique and the development of this system is described in the first part of the current paper. Towards the end of the LINESET project an idea appeared to create a cheaper code-marking system for harvesters instead of using transponders. Information and ideas collected during evaluation of log marking problems on the harvester are presented in the second part of this paper.

2 The development of an imprint marker for a log sorting station in a sawmill

2.1 The beginning, the "Trinary marker" and the first ideas here

The default presumption and also the main reason for developing the imprint mark was that the whole marking-reading system must have as low price as possible. The simplest way to reduce the cost was to create a code-mark using only wood material itself. Actually the imprint marking technique has been used already for a long time but not on automatic level. The first idea was "the trinary marker" (Uusijärvi R. 2000); it was like a square matrix including 16 places and every place had three different states (different sizes of holes) thus making possible a trinary code. Their combination is carrying the necessary information. The idea for a trinary code was in fact caused by the fact that it enabled to enter more information into the code than the binary code considering the area under the code-mark. The imprint marking is not sensitive to weather conditions like some paints are, also the wearing risk of the imprint is rather small. The first idea for reading the code-mark was to use some vision system also employing the 3D advantage of imprints without having to deal with the visual variation of log end surfaces. The hypothesis was that a 3D mark had more detecting options than 2D marks when using image processing — again an advantage in comparison with paints. Also, such an imprinted code-mark was considered to be a rather interesting and innovative solution and it was absolutely environment friendly, with no chemicals involved. The first proposed sizes for holes were 4 and 8 mm. Active development work began in January 2001.

2.2 The first study — readability

The first tests were carried out in the field of reading (Forslund M. 2001). The first approach was to test a CCD (Charge Coupled Device) camera and a single light source. After the tests it was concluded that the smallest detectable hole had a diameter of 6 mm; also it was concluded that it was much more difficult to read the marks from harvester cut log ends, the surface roughness of these logs was bigger. Also a 3D profiling system based on laser line triangulation was tested. As the laser moved over the surface it imitated the profile of the surface and the camera recorded the contour projected by the laser from an angle relative to the camera. But this system was as sensitive to the visual variation of log ends as the first system and it was also much more expensive. In conclusion no good solution was found for employing also pure measurement of a surface for employing the 3D feature of the imprints. The imprints also had to be bigger than the natural grooves on the log end, approximately Ø10 mm having the depth of 3.5-5 mm. Also, as the reading system uses shadows from a single light source for illuminating the imprints it was necessary to make the imprints circular for having always the same image of the imprints from whatever illumination (log) angle, thus the name of the code is the Circular Code Mark (CCM).

2.3 How to make these imprints?

The investigations of the imprinting technique (Seidla A. 2002) began just after the first investigation of reading. The considered techniques were compressing, drilling, burning or etching. As compressing seemed to be the simplest then first compressing at the speed of $8.3 \cdot 10^{-3}$ m/s was tested using different stamps and different quality of tree material. These tests showed that wood material could behave rather unexpectedly depending on the quality of wood material in the area of impact. While compressing a log end without knots the average compression strength was 35+/-20% MPa, but during compressing a knot on a log end the compression strength was up to ≈145 Mpa. The strongest alternative to compressing was drilling, but here it was supposed that when cutting with a worn tool the edge of an individual mark (hole/ring) appears diffused which would make reading of the code-mark more complicated. Also the drilling device would be much more complicated. In conclusion, it was decided on fast compressing with a speed up to 10 m/s, considering short marking time and smaller reaction force of logs in comparison with slow compressing. For learning more about the necessary imprinting energy level a spring "cannon" was built. After the tests it was realised that the specific energy was approximately 0.065 J/mm^3. For decreasing the reaction of the log to the marking impact the movable mass of the stamping device had to be as small as possible and the impact speed as high as possible. In spite of this philosophy the mass can not be decreased lower than to a certain limit and the same holds for speed. Probably unwanted displacement for lighter logs will appear with worse imprint as result. However the behaviour of small logs was uncertain and a risk was taken here, but it was expected that the problem with small logs and knots is not too critical.

As the imprinting time was very limited it seemed wise to make all the imprints simultaneously. But how should the compressing operation be carried out, should all the stamps be energetically connected or should each stamp be energised separately? It seems that it is simpler to energise each stamp separately because then it is possible to energise and control the stamps with one operation. However, afterwards it was decided to energise all the stamps simultaneously having them mechanically locked in a marker head during imprinting. This principle was found to be more flexible: the final size and layout of the code-marks were not known, also this choice would imply a longer longitudinal variation of the log position. Finally there was one more reason, considering the fact that the compression strength was much higher at knots, the imprinting into a knot needs more energy. It was not possible to add this additional energy to each stamp separately but it is possible to add total energy to all stamps. But how to share it "equally"? Here was the biggest advantage of imprinting with the whole marking head and having the stamps mechanically connected. If one stamp had to make an imprint into a knot then it could take the additionally needed energy from the other stamps that had to imprint softer material. Mechanical locking automatically equalised the imprinting depth of all the stamps regardless of material hardness at different stamps.

A binary system was chosen as code base and the code elements chosen were rings with diameters Ø10/6 mm as "1" and nothing as "0" because it was much simpler both to mark and read this code element (Figure 1). The code-mark had eleven elements for the carrying of information making it possible to have 2048 different combinations. It was considered that the code base could be upgraded in the future to trinary code but not at the first prototype.

As the stamps were locked into the marking head it was possible to separate the marking and the code changing operation. There was a philosophy to make the marking part as robust and light as possible because of the risk of failure due to vibrations and shocks. Also in this way it was possible to decrease the movable mass of the marking head. The actual vibrations and amplitudes were not known, or how much they would affect the device. A lower risk was taken and the separation idea was employed. Finally, the system had two main parts, the marking head and the code-changing unit. For code-changing it was necessary that the marker head approached the code-changing part and the stamps in the marker head were moved by hydraulically driven pushers. For the marking movement a reciprocating movement was chosen, it could manage a much longer longitudinal variation of the log in comparison to a the rotary movement using a pendulum. For energising the marker head a pneumatic cylinder was chosen which accelerated the marker head up to 8 m/s and the final movable mass of the marking device was ≈13 kg making it possible to reach 416 J of kinetic energy for imprinting.

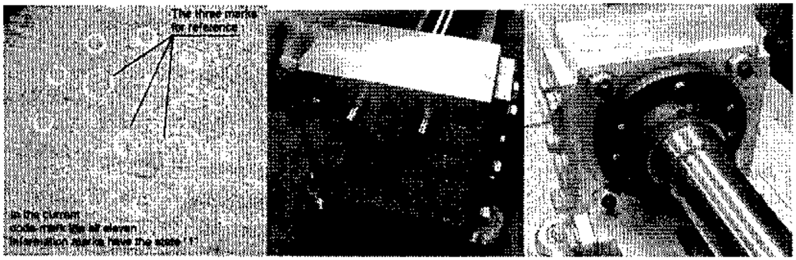

Figure 1 — The code-mark, the marker head and the marker head with the locking plate.

2.4 Where must the marking device be installed in the log sorting station in a sawmill?

Here it must be considered that the marking function is somehow an additional function which must be added to the existing log sorting station. As the latter is designed without considering the marking process then the marking technique had to be chosen more or less according to the constraints in log sorting station and no production delay was allowed.
The marking device had to be installed in the log sorting station of the sawmill in Mönsterås (in Sweden), built by the company Interlog AB. The maximum speed of the log sorting station is one log per 1.4 seconds, it means that the longest possible time for a marking cycle is 1.4 seconds if all logs are marked having a single marking device. The first idea was to install this marker at the end of a longitudinal conveyer and to mark the log while it is longitudinally moving. This idea seemed to be feasible because the position of the log was definable and could be used for marking. While talking to the people who had practical experience they did not agree with this idea. The reason was that it was very dangerous to mark logs moving at 2.5 m/s, and afterwards to get the marker out from the log. If something would happen the marking device would be damaged. This was really interesting because while developing the marker one did not realise that in the log sorting station the situation is so chaotic, something can always happen there. A better choice was a place before lifting the log onto the second longitudinal conveyer (Figure 2). The log stands still for just a short moment and also the disadvantage was that the longitudinal position of the log varied very much. For solving the variation the marker must have a stroke long enough or logs must be propelled to the necessary marking place; timing was considered a non-solvable issue on the first prototype.

2.5 Testing and Discussion

During testing up to 400 logs were marked and the first problem appeared when reading the code-marks. The reference elements needed to be twice as big as the elements chosen during the first approach. In conclusion it was not believed that the visual variation of log ends would vary much in practice, but there were a lot of places where the system could find an "alias-imprint". Also it was concluded that for this first prototype some 10% of the marked logs could not be read in this configuration and this was considered to be the "price" of having no cost for the marking material of CCM code-mark. The problems with knots were

not so big, for example when 100 logs were marked in the log sorting station it was noticed that on 2 logs the imprint mark occurred to be on the same place as a knot.
The second problem was that the marking device could not perform within the available time cycle and this fact strongly influenced the testing process. Actually the problem is more on the prototype level, also it can be considered that separating the marking and the code-changing part was not a very good idea. First, the shock and vibration were not so hard, and secondly, such separated code-changing took a lot of time. In other words the non-existing risk was avoided and the problem was created because the environment was not familiar enough.

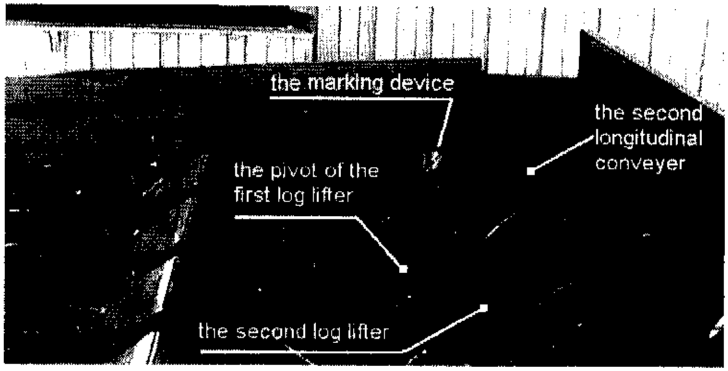

Figure 2 — the set up of the marking device in the log sorting station.

Before getting to the third shortage an accident is described. Namely, on one occasion the second log lifter started to lift the log before the marking head had come out from the log and this damaged the marking device. Such accidents could be avoided if the marking device would be attached to the lifter and move together with it as well as with a log. Such a design would solve even the last problem with timing because then the marking device would have more time for the marking operation. This attachment should not be rigid, it must enable small movements between the log and marker, but the platform of the marking device must have the same pivot as the log lifter (the lifter rotates). In general, the construction of the whole marking device must be much stronger, it must be so strong that it can carry at least the biggest log. The philosophy that the marker can have weak construction if the process is absolutely controlled would not work in practice because anything can happen to this marker and the construction of the marker must be so strong that it survives the "chaos". On the other hand stronger construction means bigger movable mass of the marker and light logs will be displaced. The problem of displacement of light logs must be solved purely mechanically, an extra weight should be attached that helps to hold small logs in place. As the result of these tests it can be concluded that the construction has to be much stronger and fine-tuning of marking technique (mass versus speed) is not so important. Locking all the stamps into the marker head and energising them all worked pretty well, also the amount of necessary energy was determined correctly. Certainly the readability could also be enhanced.
If one tries to create some method based on this work - it would be as follows: point out what is the situation at the moment and what is the goal, then generate concepts and map decisions according to the different choices in the concepts. By evaluating the decision map, the decisions that are most critical or "soft" must be considered first. The most critical can mean something that influences the entire system, or that none has done/tested it before or something that is very tricky or challenging and these must have the highest priority in the product development process — these must be tested and evaluated, first. In the current work

the most important restriction was the decision of using imprints which was based on the investigation of code readability, next important restriction was to achieve a reliable marking operation without any production delay.

3 Code-Marking at the harvester

For creating a traceability chain or for monitoring the wood flow from forest to sawmill code-marking of logs must be performed in the forest on the forest machine. The single-grip harvester has reinforced its position as the dominant machine for final felling in both Sweden and other countries (Thor M. 2001). A cost-effective log code-marking system for single-grip harvesters, providing every log with a unique code-mark does not exist today. In the LINESET project a transponder marking system for the single grip harvester was developed, but, as was considered, the transponders are too inflexible and costly. The other method that is used today for marking the logs by a harvester, is painting the logs automatically using different colours (Bohult Maskin AB). This system is placed into the limbing knife and when the log is cross cut and while it is falling spraying from the nozzles in the limbing knife takes place (Figure 3). This system is used by many harvester operators and mostly for sorting logs in the forest. Today this system cannot be used for marking logs on an individual level. The amount of information necessary for identity marking is too big for the paint-system to carry and no automatic reading system for painted marks exists.

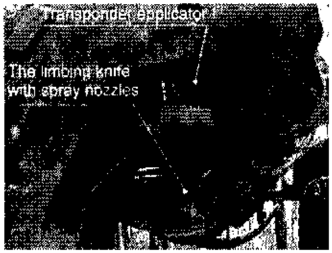

Figure 3 — Timberjack's 762 harvester head with the installations from Bohult Maskin AB.

From an overall perspective the harvesting process today is more or less a continuous process and in the best case the marking operation must take place in parallel with some already existing harvesting operation. However, every lost second of harvesting means additional cost for the code-mark per log. In general the biggest problem when adding any kind of additional device onto the harvester aggregate is connected with room deficiency. Also the conditions where the harvester head works are very hard, all that is mounted onto the harvester head must be well covered and protected.

3.1 Where should the code-mark be placed on a log?

It is possible to apply the code-mark onto the mantle of a log rather easily, but such code-mark will wear out before reaching the debarking machine in the sawmill and can not be read while the logs are in a pile. According to the reading possibilities of a code-mark in a log-sorting station in the sawmill, logs as marking objects, and harvesting process, the code-mark should be located on the log end; in best case at the top end (Möller J. 2000; Sondell J. 2002). The main reason for this is connected with coupling log data with its code-mark. During harvesting a log moves longitudinally from root end to top. At the moment when the root end is available for marking there is no information about the log length and diameter. A potential solution for this problem is to use a database and to mark just a reference number onto the log end and data about a log would be added afterwards into the database. Anyway, this idea means more constraints for the marking system and the top end of logs must be preferred. Secondly, the root end of the first log in a stem has rather often a "zigzag" edge, it is not always round. This fact makes placing of the code-mark to the log end difficult. Also, it always happens in practice that some trees have bigger root diameter than that harvester can take into its grip. For that reason the work of a harvester is organised in co-operation with a workman, who fells trees using a manual chain-saw and the harvester just supports these trees during felling and afterwards harvests too. In that case the root end of the first log (bole) will never pass through the harvester aggregate and it is not available for marking. This is mainly caused by the conical shape of a bole and by the need to have as low stumps as possible in forest.

3.2 How to mark the top end of a log?

Looking at the harvesting process it can be seen that the log end is undergoing operations (is "busy") during the entire harvesting process, it is moving longitudinally or the guide bar of a saw is cutting and covering the log end. For executing a marking operation and applying a code-mark onto the top end of a log the marking operation must happen during sawing or at the moment when a log starts to fall down immediately after sawing and its movement is still predictable. Probably the simplest way is to use the guide bar for marking. As it was considered that the price of a code-mark must be as low as possible, there appeared an idea to make an imprint code-mark onto the top end of the log — to scratch it in somehow with the guide bar. Probably this is not a very realistic idea to build some marking mechanism into an existing guide bar which uses imprint technique, but in case when a code-mark would be painted, a "simple" pipe system must be added into a guide bar. Now we return to the moment in the development process when the paint marking was under the consideration (see the chapter 2.1).

While building the imprint code-marker at the log sorting station, colour marking with paints was under consideration and here is the most interesting part of the current product development! The biggest supposed problem that caused skipping paints was reading. As the visual image of log ends varies considerably then reading paints was claimed to be too complicated. Also marking is difficult when the log ends are covered with something, even after heavy rain marking wet logs with paint is questionable; the paints seemed to be too risky. But on the harvester the log end is just cut and it is fresh, so marking with paints is not problematic. How to solve the reading problem? If the paints with a "glowing in the dark" feature will be used, fluorescent paint should be very well discernible from log ends. This moment in the current product development shows clearly how the concept generation worked because these paints were actually not under consideration during the development of the sawmill marking equipment at all! When the idea of marking on a harvester created the need for using paints again, then necessary paints were found also. Surely, the paint marking technique must be proved in a log sorting station in a sawmill too. Paint marking is much easier because there is no physical contact between a marker and a log, but the sensitivity of marking to weather conditions is still under testing. Also reading paints is easier than reading imprints, only resin and knots emit blue light under ultraviolet (UV) light that disappears under sunshine during couple of days or it can be filtered out by using non-blue colour.

3.3 What are the possible solutions for paint marking?

In general, paint must be somehow attached to the log end surface during paint marking. Again there exist different options, first, it is possible to give big enough kinetic energy to the paint drop and secondly, it is possible to use some "soft" mechanical contact, like a brush or a wheel, but the last solution needs more room.

Also marking can take place at once or in sequence corresponding to the log falling or to the movement of the guide bar. It seems that marking at once is more reliable because the code-mark does not depend on the movement of a log or guide bar, but it needs more paint hoses/canals for example in the guide bar.

For giving the necessary volume of paint the classical "drop-on-demand" technique seems not to be feasible at a harvester; there is no room for building a small dropping device. So the size of a paint drop must be prepared in a place where there is sufficient room and then the demanded volume must be transported to the top end of log. In that case the flow of information and marking material — paint are the same.

3.3.1 Pipe system in the guide bar

The first option, which is already patented (WO9007870, inventor Keller L. 1990; WO9814312, inventor: Leini A. 1996), is to build some pipes into the guide bar and to transport paint onto the log end through these pipes. In the best case the pipes are pressurised and some passive valve or nozzle is located at the end of a pipe in the guide bar. As the guide bar is the second most often exchanged part after the chain, then it cannot be too expensive and as a guide bar edge wears during operation, it must be reversible without too big complications. Hopefully the chain of the saw won't destroy the code-mark. There was a test with a manual chain saw, into the guide bar was installed a plastic hose and a commercially available spray bottle was connected with this hose. In Figure 4 are shown the engine saw and also the paint rows under visible light and under UV illumination. It is seen that the chain has scattered the paint up to 2 cm but still the rows are discernible and the paint is not scattered totally onto the log end. At the harvester the conditions are not the same, the surface of the log has bigger roughness, thus the paint should have the option to penetrate into the wood material. Also the speed of the chain is much higher at the harvester (up to 40 m/s) [12/Hallonborg U. & Granlund P. 2002; 16/ Lycken A. 1991]. The less paint is sprayed from the guide bar onto the log end the less it will be scattered. However, a field test with a harvester (using the similar simple testing equipment) is needed.

Figure 4 — The chain saw, the painted test samples under the illumination of "visible" light and under the UV illumination.

3.3.2 Pipes and nozzles as a separate system after the saw

If the pipe system is a separate plate with nozzles placed after the saw chain, it can follow into the rift made by a saw during cutting. This is much simpler to build and also the construction of guide bars won't change. The problem is that the guide bar with a chain is approximately 130 mm wide, so small logs would be cut through already before the nozzle-plate reaches the log end. Looking at the picture in Figure 5 it is clearly seen that after cross-cutting the stem of the guide bar has come out from the log and the log has just started to fall and during this very moment it is possible to mark it. It means that marking must take place at once and the nozzles of the pipes must be arranged according to the code-layout. The problem with this solution is that the saw bar bends a lot and such a system will be damaged, but still this idea should be considered further.

Figure 5 — Free-falling process of a log.

3.3.3 Pipe system on the side of the guide bar

As the guide bar is thinner (6 mm) than the chain (≈ 9 mm), then perhaps it is possible to build miniature pipes onto its side using the existing guide bar and integrating the pipes into an assembly as a plate that is 1.5 mm thick. On the prototype level the assembly can be built using some clue; the system with valves and other components would stay out of the guide bar. The pipe assembly would be attached to the saw bar using screws enabling fast exchange of the whole pipe assembly. Would such pipe assembly disturb the movement of a saw bar due to the extra friction force? Theoretically it should not, but this question can be answered only after a real field test, perhaps it is necessary to have a plate of the same thickness on the other side of the guide bar as well for avoiding extra forces from only one side. The next question is, would the paint dry or freeze in these small pipes? Probably it will. The solution here is to use some transport fluid medium for paint drops (which is not visible under the UV), it can be some solvent that also holds the pipe clean and dry. Perhaps then it is possible to transport even small drops through the pipes onto the log end (length of 500 mm). Probably the best option is to make the whole code-mark to the log end at once and to place the pipe nozzles according to the code-mark layout as for the previous solution.

3.3.4 The existing system on the limbing knife

The system in Figure 3 can be easily adapted for automatic marking-reading if an automated reading program existed. The number of different combinations would certainly be more limited than in the case of a guide bar, but such a system already exists and, having up to 4 different combinations, it is very viable for marking just some properties of a log. The biggest challenge here is the question how much does the code-mark change due to the fact that the limbing knife has different positions for different diameter of logs. Also the saw bar is covering the log end for a while (Figure 5) and small logs would not fall down directly, instead they are pushed down by the saw.

3.4 Discussion

Finally, comparing marking on the limbing knife and marking through a saw bar, it is certain that painting with the limbing knife needs more paint. On the other hand, this system already exists and it is adapted for such a mature assembly like the harvester aggregate. The biggest presumable problem with this system is the limited number of combinations, probably it is difficult to upgrade it for marking logs on individual level. When comparing these two systems from the point of view of reading then it is clear that the code-mark varies more in the case of a limbing knife. Actually even with the saw bar it is not possible to predict exactly what the code-mark will be like in reality, the field test is strongly needed.

Surely, paint marking technique that uses the guide bar of the saw seems to enable more combinations for the code-mark. On the other hand the marking system should not affect the manufacturing price of guide bars, if possible it should be a separate and/or fast attachable piece. The guide bar on the harvester is one of the most often exchanged parts and embedding something into it makes the price of the guide bar to increase. Also it is rather difficult to connect the pipes in the guide bar and the paint feeding system mounted in the harvester head. Some harvester operators also use the guide bars for spraying fresh stumps with urea against root rot (Thor M. & Frohm S. 1993). In some of the spraying mechanisms a pipe system is built into the guide bars (Iggesund AB) but there also exists another system in which urea is sprayed from the aggregate.

4 Final discussion

If a technique or a method is going to be used in some device then firstly, the economical aspects must be considered. For example, using paint marking on the limbing knife is more sensitive to the price of the paint, but still the price is so low that it is would be possible (8.4

EUR/litre). Comparing the development of the marking-reading system for a log sorting station (chapter 2) with the harvester then for the latter case there are much bigger constraints on the marking operation and the reading system needs to be developed according to the possible code-mark given by a harvester. Although a fluorescent paint mark is much easily discernible from the log end, the study for readability has the highest priority because is assumed that in the current case the shape and layout of the code-mark will vary. Equally important is the question whether the top end of logs can be marked without any production delay?

When starting with the development of a new idea there is always some uncertainty, afterwards uncertainty will be reduced, according to collected information, executed tests and simulations/calculations — it is like endless learning and it takes time. And with each learned information bit all the decisions made earlier must be examined again. Looking back to the concept finding process it seems that it was not the most difficult task, for example it was not a big discovery to know that paints can glow in the dark. The important aspect was realising that this feature was needed for marking logs at the forest machine. It is important to know exactly what happens when the imprint mark is used and what happens if the paint mark is used. And when it is realised that neither of them is good enough, then perhaps an even better option could be found.

In the current development process a lot of information was collected using function prototypes. Building the prototype was vital because there was no information available for calculations. Here it can even be concluded that when the time is available, ideas can be tested by building some cheap prototypes then it certainly must be done. A good example is the question what happens if the chain runs over the paint-mark— very difficult to calculate. But using this simple and cheap guide bar prototype a lot of important information was collected.

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