TAMPEREEN AMMATTIKORKEAKOULU

ERGONOMICS EVALUATION OF CUT-TO-LENGTH FOREST HARVESTERS

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Master's thesis
June 2017
Management and Economy in the International Forest Sector

TIIVISTELMÄ

Tampereen ammattikorkeakoulu
Management and Economy in the International Forest Sector

LAHTINEN MATTI:
Ergonomian arviointi tavaralajimenetelmän harvestereissa

Opinnäytetyö 44 sivua, joista liitteitä 1 sivu
Kesäkuu 2017

Koneellisessa puunkorjuussa ergonomia on yksi työhyvinvoinnin tärkeimmistä osa-alueista. Viime aikoina metsäkoneiden ergonomiaan on kiinnitetty huomiota enenevissä määrin. Tämän työn tarkoituksena on arvioida ja vertailla kahden erityyppisen harvesterin ergonomiaa. Tässä ergonomiatutkimuksessa oli mukana kolme osapuolta: Lahtinen Forest Oy (puunkorjuuyritys), Ponsse Oyj (metsäkonevalmistaja) ja Työterveyslaitos (tutkimuslaitos). Lahtinen Forest Oy vastasi testileimikon järjestelyistä ja puunkorjuutyöstä, jossa mittaukset suoritettiin. Mittaukset suoritettiin käyttämällä PONSSE harvestereita todellisessa puunkorjuutyössä. Työterveyslaitos suoritti mittaukset ja analysoi mittausten tulokset. Ergonomiamittausten osa-alueisiin kuuluivat: Kehotärinä, ohjaamomelu, niska/ hartia/ selkä alueiden lihasjännitys, sykevariaatio ja kognitiivinen ergonomia. Tavaralajimenetelmän historia ja kehityskulku käydään työssä läpi lyhyesti ja myös ergonomian kehitykseen vaikuttava lainsäädäntö ja standardit esitellään pääpiirteittäin. Mitatut harvesterit, mittausmenetelmät ja maasto olosuhteet esitellään myös.

Tuloksia ei esitetä kokonaisuudessaan salassapitosopimuksen takia. Siksi tulokset on esitetty vertailemalla harvestereita keskenään. Mittaustuloksista selvisi, että mitatuilla harvestereilla on eroavaisuuksia ergonomian eri osa-alueilla. Tulokset osoittavat pääpiirteissään, että PONSSE ScorpionKing harvesteri olisi ergonomisilta ominaisuuksiltaan parempi harvesteri kuin PONSSE Fox.

Työvuorot joissa ergonomiamittaukset suoritettiin, olivat lyhyempiä kuin normaali työvuoro. Mittauksista saadut tulokset olisi voineet olla erilaisia, mikäli mittausaika olisi ollut normaalin työvuoron mittainen. Maastomittausten järjestäminen puunkorjuutyössä on hankalaa, koska maaperä muuttuu joka kerta kun siitä ajetaan ja jokainen puu on erilainen, joten on lähes mahdotonta löytää identtiset olosuhteet useammalle eri mittaukselle. Siten näiden mittausten toistaminen on mahdotonta identtisissä olosuhteissa. Työn tilaaja Ponsse Oyj on pystynyt hyödyntämään mittauksista saatua tietoa tuotekehityksessään.

Asiasanat: ergonomia, harvesteri, tavaralajimenetelmä

ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
Management and Economy in the International Forest Sector

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Ergonomics evaluation of Cut-To-Length forest harvesters

Master's thesis 44 pages, appendices 1 page
June 2017

Ergonomics in mechanised harvesting is one of the most important sectors when it comes to work wellbeing. Recently, more attention has been paid to the level of ergonomics in forest machinery. The purpose of this thesis is to evaluate the level of ergonomics in two different types of forest harvesters and compare the harvesters with each other. This ergonomics project had three participants: Lahtinen Forest Ltd (wood harvesting company), Ponsse Plc (forest machine manufacturer) and Finnish Institute of Occupational Health (health and safety research institute). Lahtinen Forest Oy was the inventor of this project and was responsible for organising the harvesting area and the actual harvesting work where the measurements were taken. The measurements were carried out by using PONSSE forest harvesters in actual forestry work. Finnish Institute of Occupational Health designed the measurement program, performed the measurements and analysed the results. The analysed parameters in this project were: Seat vibration, cabin noise, neck/shoulder/back area muscle tension, heart rate variability and cognitive ergonomics. History and development of ergonomics in CTL method harvesting are introduced shortly. Also, the legislation and standards that have influence in harvester ergonomics are represented. Measured harvesters, measurement planning and terrain features are also introduced.

Complete results are not published because of the confidentiality agreement. Therefore, results are conveyed by comparing harvesters with each other. Measurement results indicated that there are differences in level of ergonomics between studied harvesters. Results show that PONSSE ScorpionKing has better level of ergonomics than PONSSE Fox.

Measurement time was shorter than normal work shift. Therefore, it is possible the results may have been different if the measurement time had been as long as the normal work shift. Field measurements are difficult to arrange because there are so many changing variables. It is almost impossible to arrange identical conditions to several measurement sessions. Project`s client Ponsse Plc has managed to utilise the information that the measurements provided in their research and development.

Key words: ergonomics, harvester, ctl (cut-to-length)

CONTENT

ABBREVIATIONS AND TERMS

CTL	Cut-To-Length
ECG	Electrocardiography
EMG	Electromyography
FIOH	Finnish Institute of Occupational Health
FOPS	Falling-Object Protection Systems
HMI	Human Machine Interface
HRV	Heart Rate Variability
ISO	International Standardization Organization
OPS	Operator Protective Structure
PIMEX	Picture Mix Exposure
R&D	Research and Development
RMS	Root mean square
ROPS	Roll-Over Protection Systems
TAMK	Tampere University of Applied Sciences

1 INTRODUCTION

Forest machine manufacturer Ponsse Plc introduced new kind of machine layout in summer 2013. The harvester was named PONSSE Scorpion. The general feedback from harvesting entrepreneurs was that the Scorpion harvester had better level of ergonomics than traditional harvester but it had not been measured scientifically by a neutral party. The purpose of this project was to get information about the level of ergonomics of studied harvesters and analyse the differences between studied harvesters.

Author of this thesis contacted Ponsse Plc in summer 2014 that has there been made measurements about ergonomics comparison between PONSSE Scorpion and a traditional harvester. Ponsse Plc was interested from subject and that is how project got started. The third independent and neutral party was needed to perform the measurements and that how FIOH that had earlier experience of similar measurements came along in the project.

Harvester operator`s job is mainly sitting work which causes great burden to musculoskeletal system. Earlier researches of mechanized harvesting and statistics about work diseases have been utilized when this project was in planning phase. Also, the measured methods were chosen by the criteria that would indicate how the harvester operator is exposed to different kind of stresses during each work phase.

Forest machine operators' typical illnesses are caused by noise and different kind of stresses caused by repeat during work tasks according to statistics made by FIOH.

Measured methods in this project were:

- Seat vibration
- Cabin noise
- Neck, shoulder and back area muscle tension
- Heart rate variability
- Cognitive ergonomics

The level of ergonomics is important matter also to harvesting entrepreneur because he must provide working environment to his employees that doesn`t exceed the values that are given in law. High level of ergonomics has also major influence to working environment so the employees can stay healthy and productive. Especially productivity during long working shifts is difficult to keep on satisfactory level without high level of ergonomics.

If the operator gets injured because poor level of ergonomics it causes significant costs to harvesting entrepreneur. So, the level of ergonomics influences greatly to profitability of harvesting as much as to operator`s work wellbeing. Results give information how much the operator is exposed to different kind of stresses. Analysing the results give information that can be used to improve the ergonomics of machines in future as well.

The level of ergonomics is evaluated by comparing two different types of forest harvesters. The traditional harvester PONSSE Fox and new generation harvester PONSSE ScorpionKing. At the end, the results are analysed and conclusions of the project are represented.

2 BACKGROUND

Harvesting performed by saw and axe was the major technique at the beginning. The manual harvesting work with primitive equipment in cold temperature was very rough for loggers. These circumstances were the main reasons why logger`s back illnesses were the main symptoms in that day`s working life.

In 1960`s the chainsaw replaced saw and axe as a major harvesting technique and different kind of symptoms started to occur. The white finger syndrome caused by vibration of chainsaw was discovered after logger`s had used a chainsaw for few years. (Metsäteho review 8/1969)

First single grip harvesters came in the market at 1970`s but it was the beginning of 1990`s when the harvesters replaced the chainsaw as a major harvesting technique in Finland and Scandinavia. The changes of harvesting techniques can be seen in Figure 1.

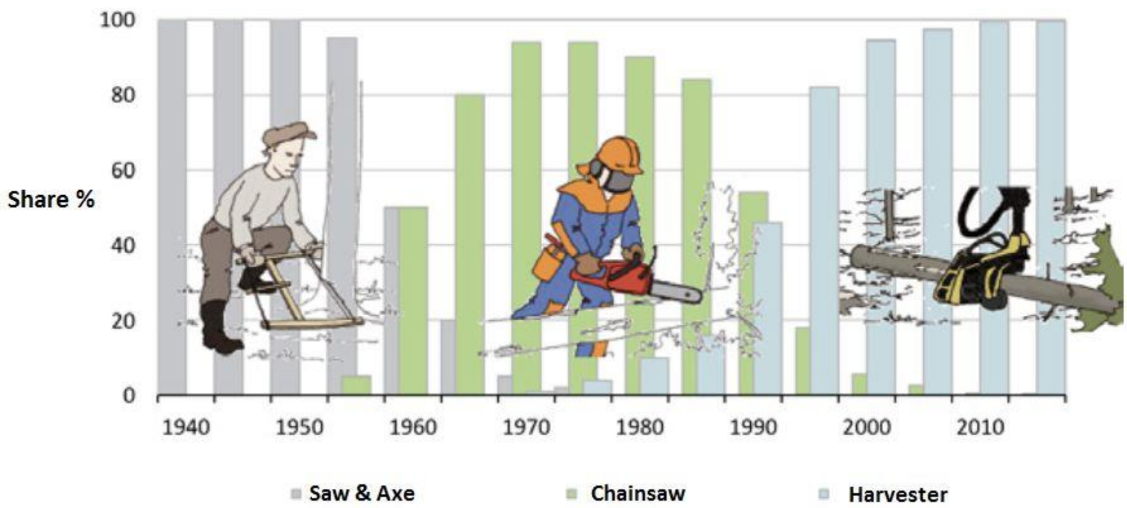


FIGURE 1. Harvesting techniques in Finland 1940-2015 (Kariniemi)

Significant researches have been made in past years considering ergonomics in forest harvesting. One of the widest research project was called Ergowood. It was funded by European Union and had participants from France, Germany, Norway, Poland, Sweden and United Kingdom as well as a reference group from Finland. Its purpose was to develop guidelines on ergonomic matters for European users, buyers and manufacturers of forest machines. It promotes the development of safe and efficient forest machines, which are easy to use and maintain, as well as improving the sustainability in human resources. Its purpose is also to make easier to understand the benefits of ergonomic investments. (Gellerstedt, Almqvist, Attebrant, Myhrman, Wikström & Winkel 1999, 5)

Vibration and cabin noise of forest machinery have also been researched by FIOH in 2004. Research was performed in various kinds of terrain and consisted of 22 forest machines and 8 of the researched machines were harvesters. Results told that 5 out of 8 harvesters exceeded the vibration limit value. (Rytkönen, Sorainen, Vähänikkilä & Pasanen 2004, 6)

Forest machine operators' typical illnesses are caused by noise and different kind of stresses that are caused by repeating work tasks according to statistics made by FIOH in 2013. The total work disease frequency of mechanized harvesting workers is 11,3 cases per 10 000 workers. (Oksa, Palo, Saalo, Aalto-Korte, Pesonen, Mäkinen & Tuomivaara 2015, 80)

3 DEVELOPMENT OF ERGONOMICS IN MECHANIZED CTL METHOD HARVESTING

Considerable development has happened in CTL forestry machines during decades. Harvesters and forwarders have become more stable with more wheels and active chassis systems, information systems have become easily understandable, cabin noise have been reduced, heating and cooling systems have improved, working lights are brighter, cabin rotation with levelling systems have become available. The development of harvester features can be seen in Pictures 1 and 2.

PICTURE 1. First PONSSE harvester that was modified from forwarder to harvester introduced in 1985. (Ponsse Plc)

PICTURE 2. New kind of harvester called PONSSE Scorpion was introduced in summer 2013. (Ponsse Plc)

The information systems have developed over time and five years ago, more easily understandable touch screen monitors became available. The user interface is more user friendly also because of symbols that makes machine`s information easier to understand. The forest machine manufacturer must consider that in some developing countries, operators are not so educated and may even have difficulty to read.

The development of harvester handles to increase the level of ergonomics can be seen in Pictures 3, 4 and 5. Forest machine manufacturers have studied the muscular stresses of operators and developed control handles to the way that the stress would be minimal and the buttons/switches are in optimal position. Especially harvester application sets high requirements to the HMI as the number of functions to control.

PICTURE 3. Gessmann harvester handle introduced in 1980`s (Ponsse Oyj)

PICTURE 4. Ball harvester handle introduced in late 1990`s (Ponsse Oyj)

PICTURE 5. PONSSE Comfort harvester handle introduced in 2010. (Ponsse Oyj)

4 DEMANDS FOR ERGONOMICS AND SAFETY

Forest harvesting entrepreneur is responsible to arrange working conditions that meet the requirements that are represented in law. In mechanized forestry, this means that the machine must meet or exceed the essential safety requirements of Machinery Directive 2006/42/EC. For self-propelled forest machinery, a C type standard ISO 11850 exists and can be used as general safety standard, typically a safety cabin certified to meet ISO 8082 (ROPS), ISO 8083 (FOPS) and ISO 8084 (OPS) must be used all-purpose built forest machines.

4.1 Directives

A directive is a legal act of the European Union which requires member states to achieve a particular result without dictating the means of achieving that result. It can be distinguished from regulations which are self-executing and do not require any implementing measures. Directives normally leave member states with a certain amount of leeway as to the exact rules to be adopted. (European Agency for Safety and Health at work)

4.1.1 Vibration directive

The exposure limit values and action values are given in the degree of Finnish Government 48/2005 which is based on the Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical vibrations. (Vibration directive)

The assessment of the level of exposure to vibration is based on the calculation of daily exposure A(8) expressed as equivalent continuous acceleration over an eight-hour period, calculated as the highest (RMS) value, of the frequency-weighted accelerations, determined on three orthogonal axes ($1{,}4a_{wx}$, $1{,}4a_{wy}$, a_{wz}) in accordance with ISO standard 2631-1(1997).

Exposure limit values and action values for whole-body vibration:

- Daily exposure limit value standardized to an eight-hour reference period shall be 1,15 m/s^2
- Daily exposure action value standardized to an eight-hour reference period shall be 0,5 m/s^2

(Vibration directive)

4.1.2 Noise directive

The exposure limit values and action values are given in the degree of Finnish Government 85/2006 which is based on the Directive 2003/10/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from noises. Noise exposure is also regulated by standards in forestry machine work. (Noise directive)

The exposure limit values and exposure action values in respect of the daily noise exposure levels and peak sound pressure are fixed at:

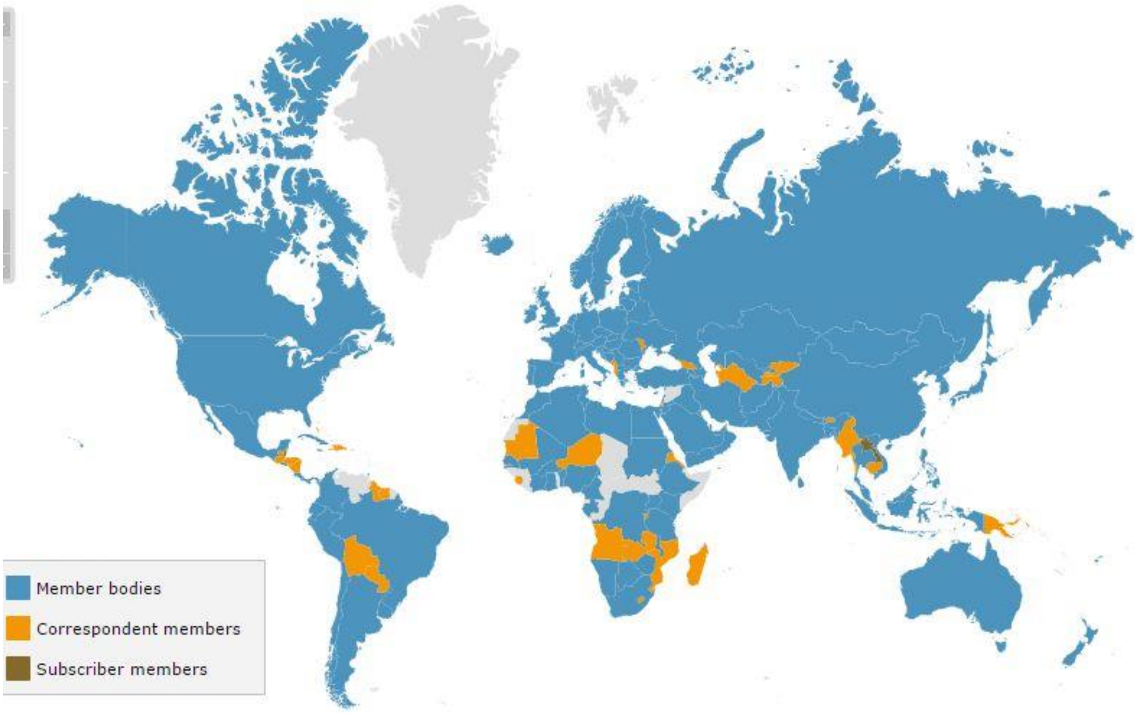
- exposure limit values for the mean pressure of sound for eight hours is 87 dB and for the peak 140 dB.
- upper exposure action values for the mean pressure of sound for eight hours is 85 dB and for the peak 137 dB.
- lower exposure action values for the mean pressure of sound for eight hours is 80 dB and for the peak 135 dB.

When applying the exposure limit values, the determination of the worker's effective exposure shall take into account of the attenuation provided by the individual hearing protectors worn by the worker. The exposure action values shall not take into account of the effect of any such protectors.

(Noise directive)

4.2 ISO-standards

A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose. Basically, every developed country is member of International Organization for Standardization which can be seen in Picture 2. (International organization for Standardization)



PICTURE 6. ISO members (ISO)

ISO International Standards ensure that products and services are safe, reliable and of good quality. For business, they are strategic tools that reduce costs by minimizing waste and errors, harmonize technical specifications of products and services making industry more efficient and breaking down barriers to international trade and increasing productivity. They help companies to access new markets, level the playing field for developing countries and facilitate free and fair global trade. (International Organization for Standardization)

There are almost 100 standards that are related to forest machinery as normative or informative standards. Few of the normative safety & ergonomics related ones are introduced shortly below:

ISO 11850 specifies general safety requirements for self-propelled forestry machines and machines configured as forestry machines. It deals with all significant hazards, hazardous situations and events common to forest machinery. A number of other standards are referred in ISO 11850 as normative references, example safety cabin structure standards below. (ISO 11850)

ISO 8082 establishes a consistent, reproducible means of evaluating the force–deflection characteristics of ROPS on self-propelled forestry machines under static loading, and prescribes performance requirements for a representative specimen under such loading. (ISO 8082)

ISO 8083 establishes a consistent, reproducible means of evaluating characteristics of FOPS under loading, and prescribes performance requirements for a representative specimen under such loading. (ISO 8083)

ISO 8084 establishes a laboratory test method and performance requirements for OPS on self-propelled forestry machines. The OPS are designed to provide reasonable protection from objects otherwise able to pierce, such as saplings, branches, broken winch lines and poking hazards in forestry work, but not from small, thrown objects such as chain teeth. Those OPS meeting the performance criteria will not provide complete operator protection under all conceivable circumstances, but are expected to minimize the possibility of operator injury in normal operational situations. (ISO 8084)

5 MEASURED HARVESTERS

5.1 PONSSE Fox

PONSSE Fox is traditional 8-wheeled harvester. The frame of machine consists of two parts and the crane is located close to cabin which is presented in Picture 7. Machine consists of two parts, cabin is rigidly fixed onto the other frame and crane is attached in the other. The stabilization of the operator is solved by Sit Right mechanism that stabilizes the seat sideways. (Ponsse Fox)

PICTURE 7. PONSSE Fox harvester (Matti Lahtinen)

5.2 PONSSE ScorpionKing

PONSSE ScorpionKing is new generation harvester. The frame of machine consists of three main frame parts which can be seen in Picture 8.

PICTURE 8. PONSSE ScorpionKing`s triple frame structure (Ponsse Plc)

The cabin is in the middle frame, which is kept hydraulically balanced, while the front and rear frames tilt according to the terrain. Moreover, the driver is positioned in the middle of the cabin’s rotation axis: when the cabin turns, the driver does not feel like being on a carousel. In other words, during slewing function, only rotation movement exists, no translation. The Y-boom crane solution which is attached to cabins pedestal offers non-blocked visibility to all needed directions which can be seen in Picture 9. (Ponsse ScorpionKing)

PICTURE 9. Operator`s view inside PONSSE ScorpionKing (Ponsse Plc)

The stabilisation system is based on detecting the direction and position of the crane, and then pressing the rear frame in the direction of work. Pressing the rear wheels against the ground and the weight of the rear frame improve the machine's stability when working on one side, even when the harvester is moving. These features are designed to improve operator`s comfort and well-being at work. (Ponsse ScorpionKing)

5.3 Comparison of harvesters features

Harvesters are from different size classes, but they can be compared in the field of ergonomics, because both have same tire size, number of tires and similar control handles. Also, both harvesters have same kind of tracks and chains. The harvesters' technical details can be compared by using TABLE 1.

TABLE 1. Harvesters technical details

	PONSSE Fox	**PONSSE Scorpion King**
Weight on full equipment and tanks full (kg), Service weight	23 000	24 700
Engine power/ torque	197 hp, 705 Nm	286 hp, 1150 Nm
Hydraulic system	Working pump: 190 cm^3	Harvester head: 190 cm^3 Crane: 145 cm^3
Crane model/ reach	C22/ 10,3 m	C50/ 11 m
Crane lifting moment (gross)	190 kNm	252 kNm
Harvester head	H6	H6
Information system	Opti4G/Opti6	Opti4G/Opti6
Control handles	PONSSE Comfort	PONSSE Comfort
Tire size	710/45-26.5“	710/45-26.5“
Equipment	1 pair tracks 1 pair chains liquid filled tires	1 pair tracks 1 pair chains
Special features	Crane located close to cabin, Sit Right seat stabilisation	Cabin levelling system, stabilisation system, triple frame structure, Y- boom crane structure

PONSSE Ergo 8w would have been the perfect comparison to PONSSE ScorpionKing in terms of productivity because it is the same size class and similar power system, but there wasn`t practically available a harvester of that type at the time of field measurements.

6 PLANNING OF THE MEASUREMENTS

First actual meeting was held in winter 2015 at FIOH research facility, Kuopio. The timetable and content of project was decided. Field measurements were performed at 2^{nd}-4^{th} of June in Kannonkoski, Finland. The data from measurements was analyzed in fall 2015 and the measurement results were presented in December 2015 at workshop at Ponsse factory and headquarters, Vieremä. The total length of the project from start to finish was two years.

6.1 Harvesting area

The demand for harvesting area was that it needed to be challenging so that the differences between harvesters could be noticed. The field measurements were performed in summer time at Central Finland and the land is owned by UPM Kymmene. Harvesting type was clear cutting and density of forest was 200 m^3 per hectare. Average size of stem was 535 litres and forest type was dry boreal forest by Finnish forest classification method. The main tree species was pine. In PICTURES 10 and 11 you can see the harvesting area before and after harvesting. Photos were taken at the spot of storage point 002 which can be seen in PICTURE 12. Most of the harvesting work was done at a rocky steep slope (even 15 degrees) which can be seen in PICTURES 10, 11 and 12.

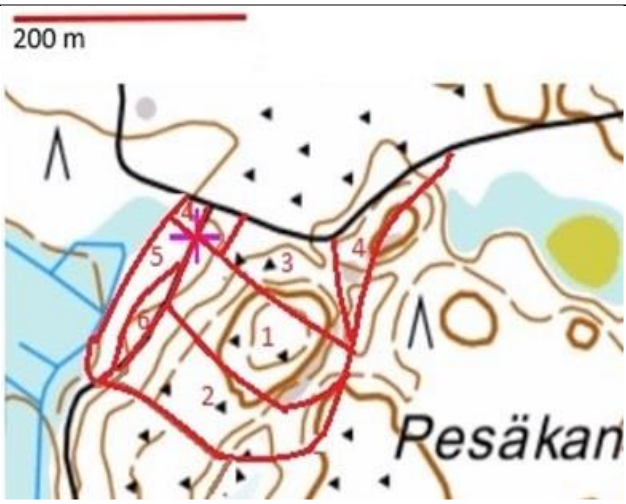
PICTURE 10. Harvesting area before harvesting (Matti Lahtinen)

PICTURE 11. Harvesting area after harvesting (Matti Lahtinen)

PICTURE 12. Map of harvesting area captured from harvester`s information system (Matti Lahtinen)

Harvesting area was divided to six sections so that each operator had similar working environment with both harvesters which can be seen in TABLE 2.

TABLE 2. Working areas and dates

	Area no.	Date	Machine	Operator
	1	2.6.2015	Scorpion King	A
	2	2.6.2015	Scorpion King	B
	3	3.6.2015	Fox	A
	4	3.6.2015	Fox	B
	5	4.6.2015	Scorpion King	C
	6	4.6.2015	Fox	C

6.2 Operator profiles

There were three operators who worked one shift each with both harvesters. The duration of work shift was two hours. It was important to have different kind of operators because every operator uses harvester differently. Operator`s experience in mechanized harvesting are represented in TABLE 2. Operator A has mainly worked as forwarder operator and has been a substitute operator for harvester. Operator B has a long career in mechanized harvesting and has experience as harvester operator for 8 years. Operator C works at Ponsse Plc as operator trainer, so he is expert in handling and adjusting forest machines.

TABLE 3. Harvester operator information

Operator	Experience years harvester + forwarder	Experience years harvester
A	10	substitute
B	30	8
C	30	Ponsse operator trainer

6.3 Measurement crew

Personnel of FIOH were responsible for designing the measurement program and analyzing the results of measurements. Lahtinen Forest Oy was responsible for organizing the field measurements and doing the actual harvesting work.

6.4 Seat vibration

The vibration was measured in intervals of four minutes, and during this interval the weighted vibration mean value was recorded. Seat vibration was visualized using PIMEX-method. With this method, the vibration data was sent from the cabin to laptop and simultaneously the movements of the machine were recorded with video cameras from inside of cabin and outside the harvester within a safe distance. Inside cabin, the

GOPRO video camera was fastened to back window behind the operator. The schematic diagram of the method is presented in Figure 2. (Rytkönen)

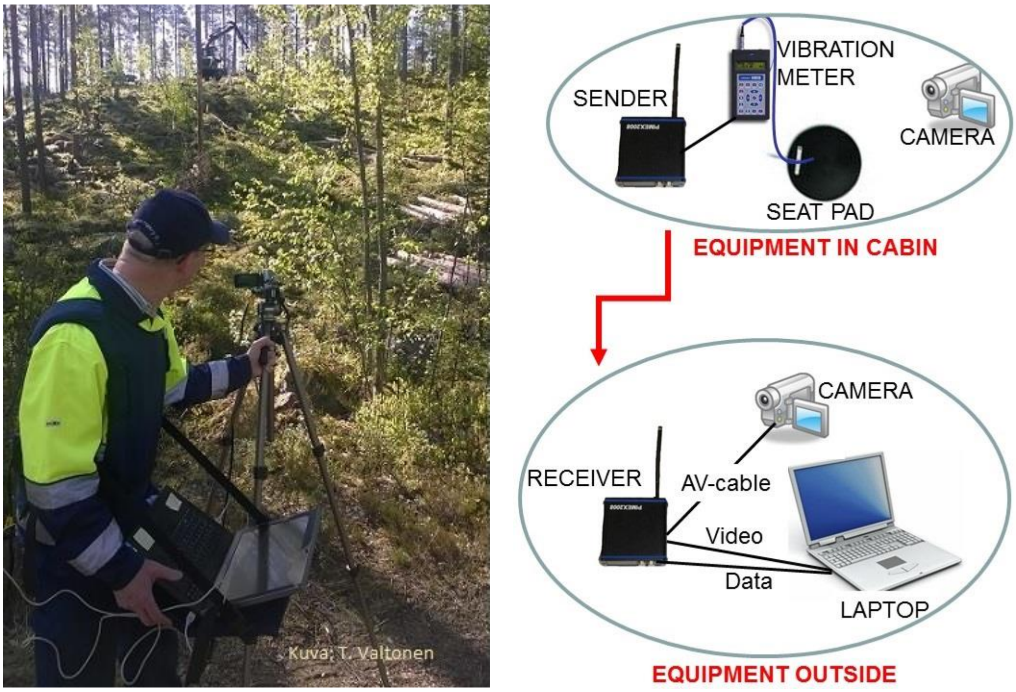


FIGURE 2. Picture and schematic diagram of the PIMEX method. (FIOH)

6.5 Cabin noise

Noise exposure was measured with noise dose meter which was calibrated. The microphone of the meter was fastened close to the ear of the operator. The noise was measured in intervals of one minute, and during this interval the A-weighted equivalent level and the C-weighted peak level were recorded. In addition, the value of the whole measuring period was calculated. (Rytkönen)

During measurement, the radio was turned off and all the operators worked on same engine RPM. Also, the climate control`s fan was at the same level with each operator.

6.6 Neck, shoulder and back area muscle tension

6.6.1 EMG

The EMG signal is a biomedical signal that measures electrical currents generated in muscles during contractions representing neuromuscular activities. Average EMG (aEMG) can be used to quantify muscle activity over time. In the case of comparisons (pre-post test) the question type addresses a qualitative answer and the aEMG amplitudes are probably the most important and practical way of analyzing research subjects' data. A muscle is inactive when the amplitude of the EMG is effectively 0, and active when its amplitude is greater than 0. By analyzing groups of muscles in this way, it is possible to establish muscle timing patterns for dynamic movements. This gives insight into how muscles are strained during specific work tasks. (Konrad)

Operator`s EMG activity of neck extensor (*m. splenius capitis*), trapezius (*m. trapezius*), shoulder (*m. deltoideus*), and back (*m. latissimus dorsi*) muscles (left and right) was recorded during harvesting work. (Mänttäri & Rissanen)

The pre-gelled bipolar surface electrodes were placed over the belly of the muscle, and the distance between recording contacts was 2 cm. The ground electrode was attached above inactive tissue. The EMG signals from the skin above the working muscles were acquired at a sampling rate of 1000 Hz. The measured signal was amplified 2000 times and the signal band between 20-500 Hz was full-wave rectified and averaged with a 0,1-s time constant. Muscular activity was determined using a portable eight-channel EMG device. The EMG setup is presented in PICTURE 13. (Mänttäri & Rissanen)

PICTURE 13. EMG setup (FIOH)

6.6.2 Myotonometer

Musculoskeletal discomfort and pain in the neck and shoulder area has been associated with different kind of occupations and types of work. Spasticity and hypertonia (ie, increased stiffness and tone) are common impairments observed in connection with different work-related tasks. Myometer is a reliable device for measuring skeletal muscle tone, elasticity and viscoelastic stiffness. (Bizzini)

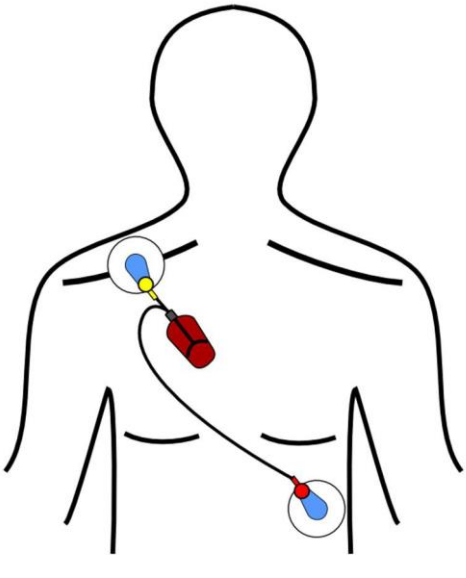
Muscle tone, elasticity and stiffness of neck extensor (*m. splenius capitis*), trapezius (*m. trapezius*), shoulder (*m. deltoideus*), and back (*m. latissimus dorsi*) muscles (left and right) were measured with myometer before and after the harvesting period with either PONSSE Fox harvester or PONSSE ScorpionKing harvester. Myometer measuring device can be seen in PICTURE 14. (Mänttäri & Rissanen)

PICTURE 14. Myometer measuring device (FIOH)

6.7 Heart rate variability

HRV quantifies the variability in the rhythm of the heart. The basis for HRV analysis is the determination of the so-called interbeat intervals (IBIs), representing the time between two consecutive heart beats. It can be used to monitor the body stress and recovery. (Task Force 1996, 354)

The heart rate variability was measured using eMotion Faros 360° ECG measurement device. The measurement was conducted with two channels and 500 Hz sampling rate. The measurement setup is presented in PICTURE 15. (Valtonen)



PICTURE 15. The ECG measurement setup (FIOH)

6.8 Cognitive ergonomics

Cognitive ergonomics elicits the characteristics of work that are important from the perspective of mental processes, such as know-how and learning, perception and vigilance, and thinking and decision making. The report bases on observation of the real work tasks, interviews of the operators and questionnaires such as NASA Task Load Index which can be found from appendix 1. (Valtonen)

The aim of the research is to find out if using the harvesters is significantly different from the perspective of human cognition. The report does not claim to give an exhaustive answer but rather an informed opinion on the cognitive requirements of harvesting and the differences between two harvesters relative to the information processing of operator. (Valtonen)

7 RESULTS

The complete measurement reports are not published here because confidentiality agreement. It would also be impossible to arrange exactly similar conditions, so that is why these results cannot be reliably compared to possible results measured in future.

Results are told by comparing the traditional harvester (PONSSE Fox) and new kind harvester (PONSSE ScorpionKing) which has been the main purpose of this project all along.

7.1 Seat vibration

Vibration directions are demonstrated in Picture 16. The results are presented and compared in Figures 3, 4 and 5. The daily exposure action value is indicated in figures by horizontal line. It is important to remember that these measurements were performed in rocky and steep conditions performing actual harvesting work.

PICTURE 16. Vibration directions (FIOH)

Measuring results of seat vibration of both machines exceeded slightly the daily exposure action value in y-direction by some of the operators. The vibration was smallest in z-direction. The vibration profiles show that the variation of vibration is big. The PIMEX method shows clearly, that during driving the vibration is biggest, and the quality of the ground surface and obstacles effects strongly on the vibration. (Rytkönen)

Transverse vibration is presented in Figure 3. Operator A´s vibration measurement with Fox was failed because technical problems of measuring equipment. The measuring device didn`t save the data that was recorded from seat pad. Operator B had 15% less vibration working with ScorpionKing than working with Fox. Operator C had 31% less vibration working with ScorpionKing than working with Fox. On average level ScorpionKing had 24% less vibration than Fox in direction y (sideways).

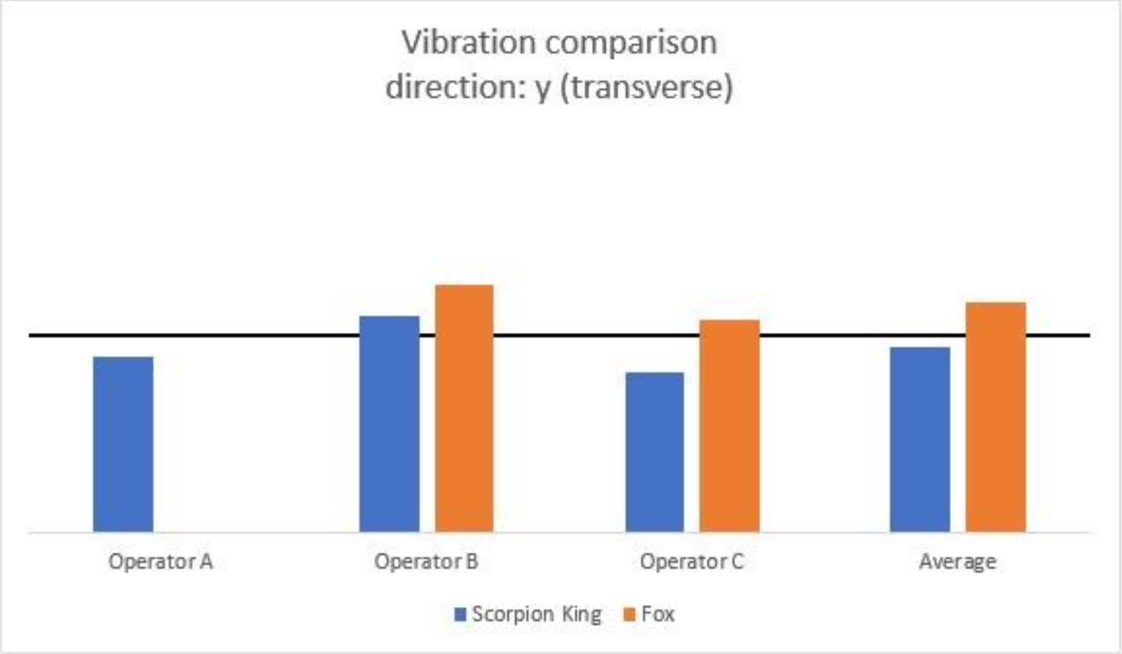


FIGURE 3. Vibration direction y

Longitudinal vibration is presented in Figure 4. Operator B had 5% less vibration working with ScorpionKing than working with Fox. Operator C had 18% less vibration working with ScorpionKing than working with Fox. On average level ScorpionKing had 14% less vibration than Fox in direction x (front/back).

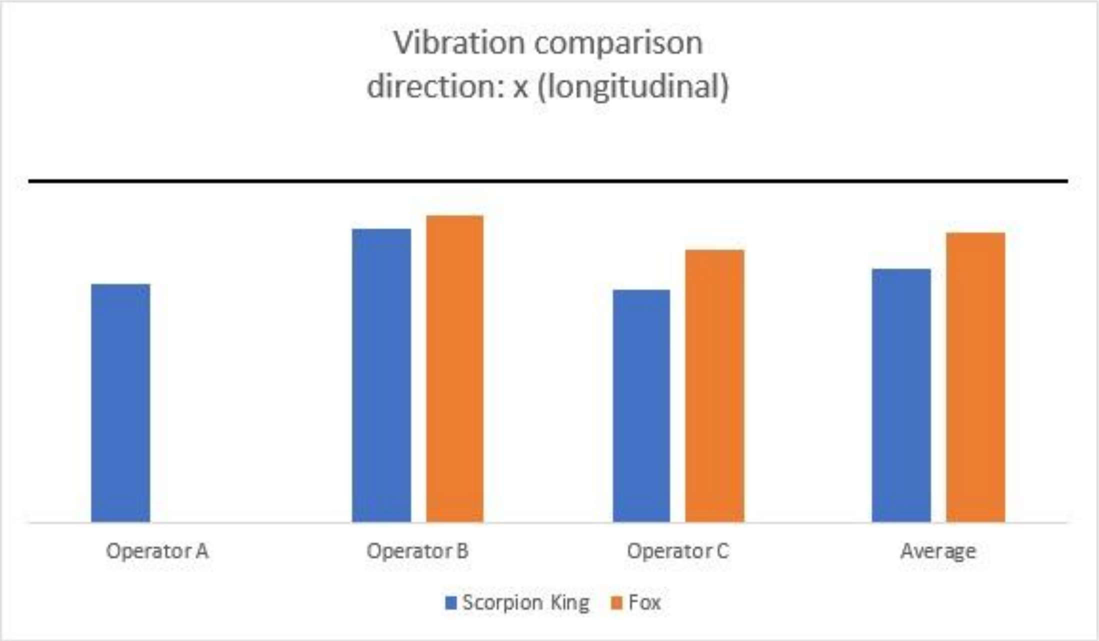


FIGURE 4. Vibration direction x

Vertical vibration is presented in Figure 5. Operator B had 9% more vibration working with ScorpionKing than working with Fox. Operator C had 4% more vibration working with ScorpionKing than working with Fox. On average level ScorpionKing had 6% more vibration than Fox in direction z (up/down).

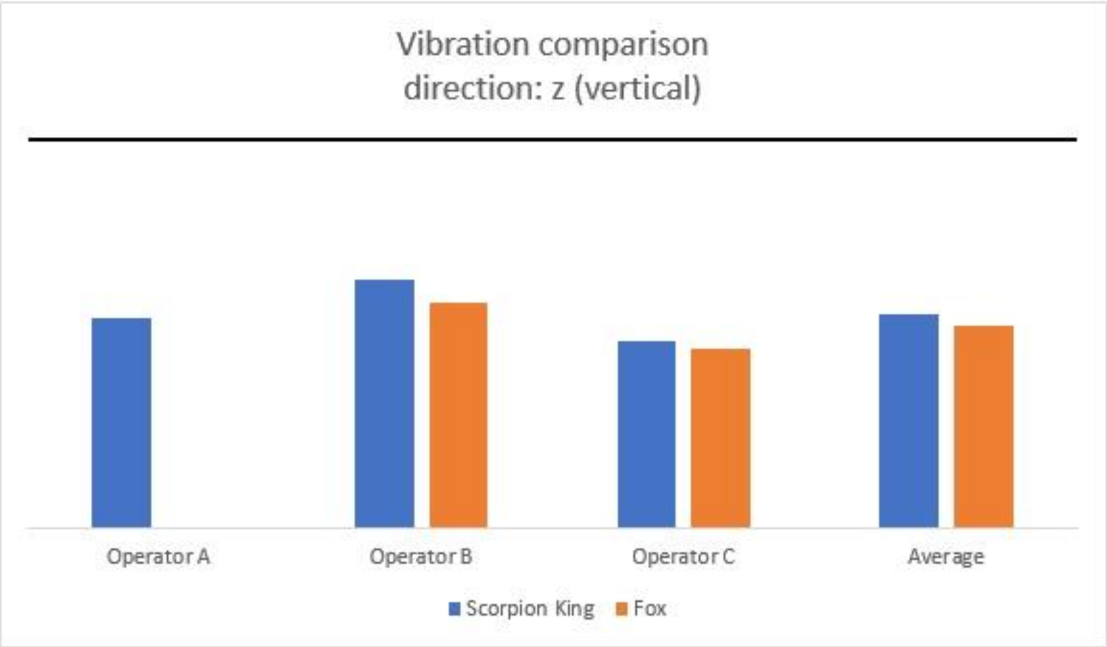


FIGURE 5. Vibration direction z

7.2 Cabin noise

The results are told and compared in Figure 6. Lower exposure action value is indicated with horizontal line in Figure 6.

The measured A-weighted equivalent level and C-weighted peak level values were below the lower exposure action values in both harvesters. During normal work, the variation of noise is small. Comparing the noise profiles shows that operators A and C had lower noise values working with ScorpionKing, but Operator B had lower noise value working with Fox. There are a lot of factors that have effect to the amount of noise, such as working technique. The biggest peak in noise profiles was when the operators closed the door of the cabin before they started their work shift. (Rytkönen)

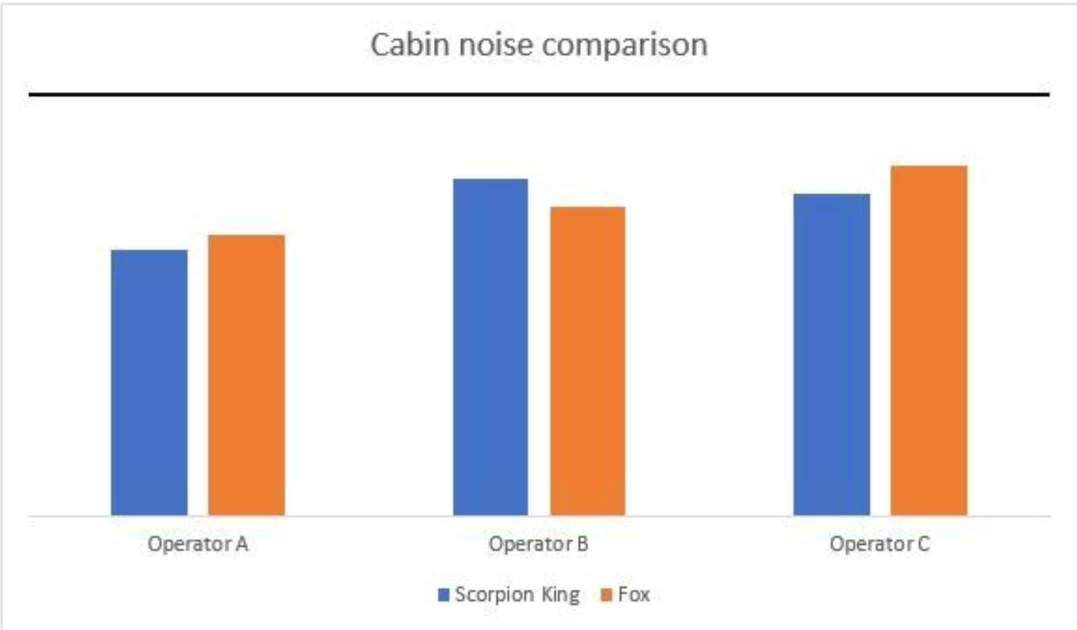


FIGURE 6. Cabin noise comparison

7.3 Neck, shoulder and back muscle tension

7.3.1 EMG

The muscle activity level was lower in neck muscles, as well as in trapezius muscles, in all subjects while working with ScorpionKing harvester when compared to Fox harvester. There were no differences in the activity of shoulder muscles between the harvesters. (Mänttäri & Rissanen)

Based on the present results the activity level of back muscles (*latissimus dorsi*) was higher in ScorpionKing harvester compared to Fox. This might indicate that in ScorpionKing harvester the working position and/or right hand manual performance are different from the one in Fox, and thus induce more muscle strain. (Mänttäri & Rissanen)

7.3.2 Myotonometer

In general, the tone of the muscles increased similarly while working in Fox or ScorpionKing harvester. In elasticity, no differences were observed before and after working in both harvesters. The stiffness of the muscles was slightly increased after working. Only minor difference between the harvesters was observed in back muscle; stiffness increased more while working in ScorpionKing harvester compared to Fox, which is in line with the observed higher level of average EMG. (Mänttäri & Rissanen)

More specifically, in one case the tone and stiffness of neck muscle (left side) was considerably increased after working with Fox harvester. No considerable changes were observed in muscle tone, elasticity or stiffness while working in either harvester. (Mänttäri & Rissanen)

7.4 Heart rate variability

Based on the measurements, it seems that the type of harvester might influence the variability of the heart rate. The standard deviation is smaller for ScorpionKing compared to Fox, on all subjects. The ratio of powers in low and high frequency ranges is also smaller for ScorpionKing compared to Fox, on all subjects. (Valtonen)

Smaller standard deviation and smaller Low frequency/ High frequency imply that, within these subjects and the studied work tasks, mental stress may have been smaller while operating ScorpionKing compared to operating Fox harvester. (Valtonen)

7.5 Cognitive ergonomics

Both Fox and ScorpionKing harvesters have the same kind of control handles, information system as well as a rather similarly functioning parallel crane and harvester head. The differences motoric requirements are related mainly to maintaining a decent posture on a rugged terrain. (Valtonen)

The active cabin levelling system of the ScorpionKing keeps the cabin straight while moving, almost regardless of the terrain. This makes it easier for the operator to concentrate on other functions than just correcting posture. In addition, the more ergonomic working environment of the ScorpionKing may help the operator to stay more efficient during the whole work shift. Especially in the long-run, compared to the Fox, the ScorpionKing may inflict less repeated stress to the body of the operator. (Valtonen)

Due to the novel structure, handling the trees takes place always in the middle of the field of vision in ScorpionKing. Neither the crane nor the frame of the harvester block the view to the terrain. Compared to the Fox, it is easier for the ScorpionKing operator to observe and detect the form of the terrain as well as obstacles, like rocks. Determining the category of the trunk is also easier with the ScorpionKing since the operator can see almost always the whole tree. (Valtonen)

Like working under the requirements of attention, the novel structure of the ScorpionKing helps also three-dimensional perception. Since the active working area is always in front of the operator, he/she may be better able to perceive the locations of the standing trees, the form of the terrain and the rocks on the ground. Also, when the visibility to the stump of tree when sawing the first time to make the tree fall down, operator don`t saw to the soil or rocks so often. That makes less changing the sawchains and the operator don`t feel frustration so often. (Valtonen)

The requirements of thinking and decision-making are similar in both machines. However, there may be differences in performance due to, for example, different working posture. In Fox, the working area can be to the side of the operator and the operator must keep his/her head strongly turned, which may hinder perception and thinking, or, for example, busy decision-making. (Valtonen)

7.6 Analysis of results

The video footage from inside and outside cabin was linked to the data that measurement devices recorded during harvesting and it was analysed by professionals of FIOH with collaboration of harvesting entrepreneur which is presented in Figure 7.

FIGURE 7. Example of look of PIMEX video, recorded simultaneously from cabin and outside. (FIOH)

The observed working time was shorter than usual work shift and therefore the possible longer-term effects of working, like fatigue towards the end of a typical 8 hour work shift might not appear so clearly in the measurements. The vibration directions which are represented in PICTURE 16. could have been mixed in ScorpionKing because of its turning cabin/crane combination and frame layout.

Measurement device backpack was attached in ScorpionKing so that it may have caused more recorded noise & sound than in Fox. This was noticed when video footage from inside the cabin was analysed.

ScorpionKing travelled and harvested a longer stretch of harvesting strip road in same time than Fox which can be seen in Table 2. so, it is likely that the driving speed has been higher even though the driving speed wasn`t monitored. That could have effect higher vibration values to measuring results. In other words, the operators typically exploit the capabilities of the new machines offering them higher ergonomics and productivity level – a fact that makes measurements harder to compare. For respective measurements in the future, the driving speed should be monitored and recorded. The vibration was most powerful in y-direction (transverse) which is similar result as in research made in 2004 by Rytkönen, E., Sorainen, E., Vähänikkilä, A. & Pasanen, T.

The results compared to directives show that the ergonomic profiles are on high level in both harvesters. The daily exposure action value that is given in Directive 2002/44/EC – vibration wasn`t exceeded in longitudinal or vertical direction in any measurement. In transverse direction, the daily exposure action value was slightly exceeded by Fox with two operators and ScorpionKing by one operator. It is important to remember that the measurements were performed in rocky and steep terrain conditions while performing actual harvesting work. All the cabin noise measurements were below lower exposure action value that is given in Directive 2003/10/EC - noise.

It is obvious that harvesting is cognitively very demanding work. It requires learning both abstract information and concrete, high-precision skills. The operator must be vigilant and able to perceive three-dimensional structures and locations. He/ she must constantly think about the current state of the work and make decisions on the next steps. The modern harvesters are highly effective and can produce an incomprehensible amount of ready assorted and stacked timber. The harvester carries centuries worth of knowledge of an effective harvesting process. Improving the process and making a leap in the efficiency is extremely difficult. The novel structure of ScorpionKing helps the operator to keep more of his/her activities in front of him/her. This seems to help attention, perception, thinking and decision-making.

8 CONCLUSIONS

Harvesting techniques in CTL method have developed in half century significantly. The evolution of ergonomics from saw and axe to modern harvester is incredible. In the beginning the primitive equipment and techniques demanded a lot of lifting and that how muscle power. Today, harvesting is mainly sitting work which includes a lot of thinking and quick decision making which causes different kind of stresses to operator. Work shifts extend from typical eight hours to even more and requirements for ergonomics are set high.

The planning phase of the project is very demanding and there are a lot of details that must be considered. This project gave answers to many questions, but inspired new questions to future projects as well. In future, it would be interesting to research vibrations with more advanced methods and instrumentation as gyroscope as an example. Results are valid and comparable within operator and harvester's ergonomic profiles can be compared by that how.

The harvester with improved ergonomics level tends to cost more than traditional harvester but entrepreneur should think it as an investment to better work wellbeing and increased productivity. Improved visibility and ergonomics leads to better work quality as well, on a thinning sites this could mean better thinning quality and less damage of remaining trees – on a clearcutting site, good ergonomics and visibility leads to ease of work and high-quality bucking of the stems respectively. The recruitment of professional operators is also easier if the entrepreneur has high level ergonomics harvester(s) in his/her company.

As we can see from the results of measurements, the level of ergonomics has effect to the operator. The benefits of better ergonomics in working environment effect to operator`s daily life and reflect to his/her whole career. Operator can focus on harvesting more precisely and longer period not get tired because body muscle activity is lower. Also, the days of sick leave could be decreasing because of better ergonomics.

Fulfilling the directives and standards are just the minimum requirements to forest machine manufacturers. R&D is in key position when the aim is to upgrade the level of ergonomics. High level ergonomics is important matter to all sides. To forest machine manufacturer, it`s a selling point. To harvesting entrepreneur, it`s productiveness of the machine and operator, and to operator it is increased level of work well being. The final conclusion of this thesis is that ScorpionKing has better level of ergonomics than Fox.

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Appendix 1. NASA Task Load Index

Name: ________________ Date: __________ Time: ___________

NASA TASK LOAD INDEX

INSTRUCTIONS:

Mark a spot to every line which represents your load best

1. Was the task easy and simple or hard and complicated? How much the task needed decision making, thinking, remembering, calculating etc.?

MENTAL REQUIREMENT LEVEL

LITTLE -- A LOT

2. How much the task demanded physical activity example carrying, pushing buttons etc.?

PHYSICAL REQUIREMENT LEVEL

LITTLE -- A LOT

3. Was the tempo of task slow, convenient or fast?

TEMPORAL REQUIREMENT LEVEL

SLOW --- FAST

4. How well did you accomplish the task?

PERFORMANCE

WELL -- POORLY

5. How much you had to make effort mentally and physically during task?

MAKING EFFORT

LITTLE --- A LOT

6. Were you stressed and frustrated or relaxed and satisfied during task?

FRUSTRATION

LITTLE-- A LOT