**ESTONIAN UNIVERSITY OF LIFE SCIENCES**
**Institute of Technology**

# XI MASTER STUDENTS CONFERENCE HUMAN AND ENGINEERING

# PROCEEDINGS

**Tartu 2017**

## PROGRAMME

| | |
|---|---|
| 9.45 | Registration and coffee (room A202) |
| 10.15 | Plenary session (room A204) |
| 12.15 | Break |
| 13.00 | Special sessions |
| 14.45 | Discussion and coffee (room A202) |

## PLENARY SESSION

**Thursday 20. april at 10.15**
Fr. R. Kreutzwaldi 56/1, room A204

Chair: **Alo Allik, PhD**

**Presentation lenghts** 12 minutes

## ENERGY ENGINEERING

**Thursday 20. april at 13.00**
Fr. R. Kreutzwaldi 56/1, room A204

Chair: PhD student **Erkki Jõgi**

**Presentation lenghts** 10 minutes



## PRODUCTION ENGINEERING

**Thursday 20. april at 13.00**
Fr. R. Kreutzwaldi 56/1, room B136

Chair: PhD student **Vahur Rooni**

**Presentation lenghts** 10 minutes

## ERGONOMICS

**Thursday 20. april at 13.00**
Fr. R. Kreutzwaldi 56/1, room A220

Chair: PhD student **Märt Reinvee**

**Presentation lenghts** 10 minutes

# Plant Surface Temperature Measurement with Infrared Camera

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**Abstract.** Plant surface temperature measurement was carried out at the strawberry field in late autumn at a specific natural climatic situation in night frost conditions. 640×480 pixel thermal and visual colour images of strawberry leaves were obtained with thermal camera FLIR P660 with thermal sensitivity 30mK and accuracy ±1 K at ten-minute interval. Taken images were analysed with FLIR ResearchIR Max software. Air temperature, dew point, relative humidity, wind speed and solar radiation were measured with Davis Vintage Pro2 weather station. During the measurements, difference between air and leaf temperature, especially in absence of solar radiation, was established. The study showed that plants might be endangered in night frost conditions. Even when the air temperature was above 0ºC strawberry plant lost energy by long wave radiation to the sky.

**Key words:** surface temperature, thermal imaging, strawberry leaf, night frost conditions

## INTRODUCTION

As the climate changes, plants growth conditions need more attention. To do that it is extremely important to understand the correlation of plants and the surrounding environment. That knowledge will help to adapt and prepare for the changes. The objective of this research is to observe strawberry leaf in night frost conditions and find out how air temperature and environment affect plants' surface temperature using the measurement possibilities of IR thermography.

Researches have shown that plants' surface temperature could be higher than air temperature during the day and lower than air temperature during the night. In the night, the heat from plants will radiate to space and plants' temperature will drop significantly and it might frost the plants [1].

## MATERIALS AND METHODS

The measurement of leaves and ground surface temperature in current study was carried out using FLIR P660 thermal camera with thermal sensitivity 30 mK and accuracy ±1 K. FLIR P660 camera sensor is based on 640×480 pixel Focal Plane Array uncooled microbolometer. The camera temperature range is from –40.0°C to +120.0°C and sensors perceiving thermal radiation wavelength is 7.5–13 μm (IR) [2]. The images were taken at ten-minute interval from 0.5 m distance. The net radiant flux to camera sensor is found with equation [3]

$$E_{tot}=E_l+E_{refl}+E_{atm}, \quad (1)$$

where $E_l$ – radiant flux from leaf to the sensor depending on the leaf surface temperature;
$E_{refl}$ – radiant flux reflected to the sensor from the leaf surface;
$E_{atm}$ – radiant flux emitted to the sensor by the atmosphere.

In current study, the distance between camera and leaf is 0.5 meters, so the transmissivity of the atmosphere $\tau_{atm}$=1 which means that $E_{atm}$=0. The net radiant flux to camera sensor be shown as [3]

$$E_{tot}=E_l+E_{refl}. \quad (2)$$

Radiant flux from leaf to the sensor in Equation 2 is found with equation [3]

$$E_l=\varepsilon_l\cdot\sigma\cdot T_l^4, \quad (3)$$

where $\varepsilon_l$ – leaf surface emissivity;
$T_l$ – temperature of leaf;
$\sigma$ – Stefan-Boltzmann constant.

Radiant flux emitted to the sensor by the atmosphere is found with equation [3]

$$E_{refl}=(1-\varepsilon_l)\cdot\sigma\cdot T_{refl}^4 \quad (4)$$

where $T_{refl}$ – temperature corresponding to reflected radiant flux.

Equations 2, 3 and 4 are illustrated in Figure 1.

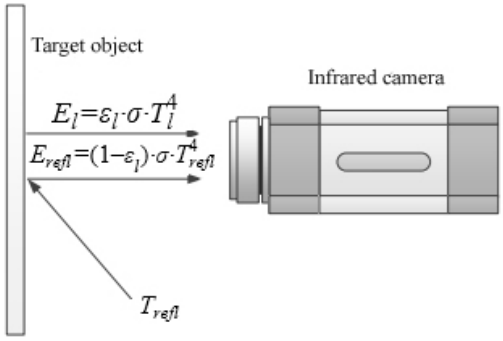


**Figure 1.** Net radiant flux to camera sensor [3]

Inserting Equations 3 and 4 into Equation 2, we get more complex equation for the amount of radiation caught by infrared camera:

$$E_{tot}=\varepsilon_l \cdot \sigma \cdot T_l^4 + (1-\varepsilon_l) \cdot \sigma \cdot T_{refl}^4. \quad (5)$$

Deriving $T_l$ from Equation 5 gives us equation

$$T_l = \sqrt[4]{\frac{E_{tot} - (1-\varepsilon_l) \cdot \sigma \cdot T_{refl}^4}{\varepsilon_l \cdot \sigma}}. \quad (6)$$

As the net radiant flux to camera sensor is

$$E_{tot}=\sigma \cdot T_{tot}^4, \quad (7)$$

the Equation 5 could be written as

$$T_l = \sqrt[4]{\frac{T_{tot}^4 - (1-\varepsilon_l) \cdot T_{refl}^4}{\varepsilon_l}}. \quad (8)$$

Taken images were analysed with FLIR ResearchIR Max software (version 4.30.3.76). Strawberry leaves thermal image and selected areas in ResearchIR software is shown in Figure 2. Air temperature, dew point, relative humidity, wind speed and solar radiation were measured with Davis Vintage Pro2 weather station at 2 m above the ground. During calibration the emissivity of strawberry leave found to be 0.96.

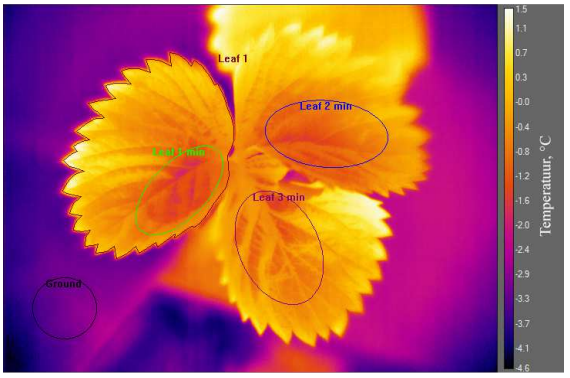


**Figure 2.** Strawberry leaves thermal image and selected areas in ResearchIR software

The measurements were carried out at strawberry field on three consecutive days in late autumn night frost conditions. The air temperature was around +7°C in daytime down to

-5.0°C at night and wind speed was from 0.0 m/s to 2 m/s. Thermal camera was controlled remotely to avoid effects of additional radiation sources. The camera was placed on a stand from distance of 0.5m from leaf surface at 30 degrees angle.

## RESULTS AND DISCUSSION

The most essential period of the results of statistical analysis of thermogram from 15:10 to 19:30 on October 18, 2016 for ROI Leaf 1 is brought out in Table 1. This is the measurement period when solar radiation reaches 0 W/m$^2$ and leaf surface temperature $T_{leaf}$ starts to decrease rapidly.

**Table 1.** Thermal images statistical analysis results for ROI Leaf 1 surface temperatures from 15:10 to 19:30

| Time | Air temp. °C | Ground surface mean temperature °C | Leaf surface temperature, °C | | | | Solar radiation W/m$^2$ |
|---|---|---|---|---|---|---|---|
| | | | Mini-mum | Maxi-mum | Mean | Standard deviation | |
| 15:10 | 6,9 | 13,6 | 4,2 | 10,3 | 7,7 | 1,8 | 275 |
| 15:20 | 7 | 15,8 | 4,3 | 10,4 | 7,9 | 1,9 | 261 |
| 15:30 | 7 | 15,7 | 4,4 | 10,4 | 7,8 | 1,8 | 246 |
| 15:40 | 7,2 | 15,7 | 4,3 | 10,9 | 7,9 | 1,9 | 228 |
| 15:50 | 7,2 | 15,2 | 4,4 | 11,8 | 8,1 | 2,0 | 207 |
| 16:00 | 7,1 | 13,3 | 3,1 | 9,9 | 6,9 | 2,0 | 186 |
| 16:10 | 7,1 | 13,4 | 3,9 | 11,4 | 8,1 | 2,3 | 165 |
| 16:20 | 7 | 12,3 | 3,1 | 9,1 | 6,4 | 1,8 | 143 |
| 16:30 | 6,9 | 11,2 | 2,7 | 9,1 | 6,2 | 2,0 | 121 |
| 16:40 | 6,8 | 8,0 | 2,3 | 8,8 | 5,8 | 1,9 | 100 |
| 16:50 | 6,8 | 8,1 | 1,1 | 7,9 | 4,8 | 2,1 | 80 |
| 17:00 | 6,6 | 3,3 | 0,3 | 7,2 | 4,0 | 2,1 | 61 |
| 17:10 | 6,2 | –0,7 | –1,0 | 3,7 | 1,6 | 1,3 | 41 |
| 17:20 | 5,8 | –2,9 | –3,1 | 0,5 | –1,3 | 0,7 | 23 |
| 17:30 | 5,3 | –4,6 | –4,0 | –0,9 | –2,5 | 0,6 | 17 |
| 17:40 | 4,9 | –5,5 | –4,2 | –1,3 | –2,7 | 0,5 | 14 |
| 17:50 | 4,6 | –6,0 | –4,5 | –1,4 | –3,1 | 0,5 | 11 |
| 18:00 | 4,2 | –6,4 | –4,7 | –1,9 | –3,5 | 0,5 | 6 |
| 18:10 | 3,9 | –7,3 | –5,2 | –2,4 | –4,0 | 0,4 | 0 |
| 18:20 | 3,7 | –6,8 | –4,7 | –2,3 | –3,6 | 0,4 | 0 |
| 18:30 | 3,3 | –8,1 | –6,6 | –3,2 | –4,8 | 0,5 | 0 |
| 18:40 | 2,9 | –8,1 | –6,8 | –3,1 | –4,7 | 0,5 | 0 |
| 18:50 | 2,6 | –9,0 | –7,9 | –4,5 | –6,0 | 0,5 | 0 |
| 19:00 | 2,3 | –9,3 | –7,9 | –4,4 | –5,9 | 0,5 | 0 |
| 19:10 | 1,8 | –9,7 | –8,6 | –5,7 | –7,0 | 0,5 | 0 |
| 19:20 | 1,4 | –9,7 | –5,6 | –4,0 | –4,8 | 0,2 | 0 |
| 19:30 | 1,3 | –10,2 | –7,4 | –5,1 | –6,5 | 0,4 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 19:40 | 0,9 | –10,4 | –7,9 | –5,3 | –6,5 | 0,5 | 0 |
| 19:50 | 0,8 | –10,6 | –8,2 | –5,3 | –6,9 | 0,5 | 0 |
| 20:00 | 0,6 | –11,1 | –8,6 | –5,8 | –7,3 | 0,5 | 0 |
| 20:10 | 0,2 | –11,3 | –8,6 | –6,4 | –7,5 | 0,5 | 0 |
| 20:20 | –0,1 | –11,2 | –8,8 | –6,3 | –7,6 | 0,5 | 0 |

The measurement series of leaf's surface temperatures along with weather station data from 15:10 to 23:50 in October 18, 2016 are presented Figure 3. We can see that leaf surface mean temperature ($T_{l\ mean}$) stays close to air temperature until 16:20 and then starts to decrease quickly because of diminishing of solar radiation and reaches 0°C at 17:10…17:20. At that moment, the air temperature is 5.8…6.2°C, staying positive till 20:10 when $T_{l\ mean}$ is already -7.5°C.

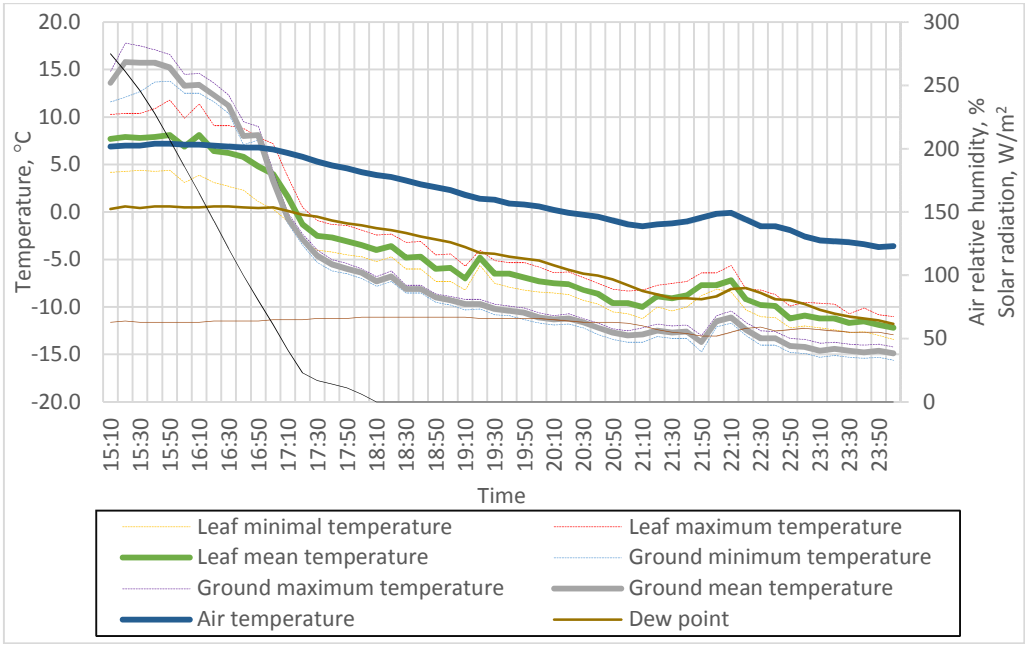


**Figure 3.** Strawberry leaf's temperature variations in night frost conditions

Around 19:10…19:20 there is unexpected rise of $T_{l\ mean}$ from –7.0°C to –4.8°C. This effect could not be caused by air temperature because it remains decreasing. Given situation might be the process of supercooling that cause short-time rise of leaf surface temperature. After 19:20, the change of plant temperature is highly correlated to air and ground temperature.

## CONCLUSIONS

In current study it was found out that the temperature of strawberry leaf surface in night frost climatic conditions is considerably lower than surrounding air temperature. This confirms that plants surface temperature should be investigated with thermal radiation measurement equipment simultaneously with air temperature measurements. This method helps to get more exact timing of night frost prevention measurements for plants.

## REFERENCES

[1] Perry, K. 1994. Frost/freeze protection for horticultural crops. Horticulture Information Leaflets. North Carolina A&T State University, 9 p.

[2] FLIR P660. The High Performance infrared inspection system. FLIR P Series. 2009. http://www.metaf.com/Content/Site-Products/Document/229_Flir_P660%20_01.pdf

[3] Usamentiaga, R. 2014. Infrared Thermography for Temperature Measurement and Non–Destructive Testing

# RGB LED driving

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**Abstract.** LED lighting has become very popular in these years. Different light fixtures have become cheaper and due to that available to almost everyone. Also, different lighting solutions for changing objects or rooms according to user's mood have become easier. Cheap controllers are great way to solve everyday household mood lighting. How these controllers actually work, is examined in this project.

**Key words:** RGB LED, remote control, driver, infrared, LED strip.

## INTRODUCTION

LED technology has made a big breakthrough in last years, being almost perfect and reasonable replacement to older lighting fixtures. Today, we can find LEDs in home lighting, on streets, banners, factories and so on. Mostly, they are used to supply us with regular white light for daily living, but more and more are different solutions used to make rooms cozier and comfortable to be in. Not maybe so much in standard flats or houses, but for example hotels are using the opportunity to offer their clients the chance to shape the hotel room as they want by changing light colours. Earlier, controlling RGB LEDs was more expensive and not reasonable for daily use. But as the technology keeps developing, producing different devices becomes cheaper. As a result, LED controllers are basically affordable to everyone.

## MATERIALS AND METHODS

A light-emitting diode (LED) is a two-lead semiconductor light source. It is a p–n junction diode, which emits light when activated [1]. When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the colour of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor. LEDs are typically small (less than 1 $mm^2$) and integrated optical components may be

used to shape the radiation pattern [2]. Also, LEDs are very energy efficient light source. In table 1 is the comparison of different types of regular bulbs.

**Table 1.** Comparisons between Traditional Incandescent, Halogen incandescent, CFLs, and LEDs. [3]

| | **60W Traditional Incandescent** | **43W Energy-Saving Incandescent** | **15W CFL** | | **12 W LED** | |
|---|---|---|---|---|---|---|
| | | | 60 W | 43 W | 60 W | 43 W |
| **Energy saved** | - | ~25 % | ~75 % | ~65 % | ~75-80 % | ~72 % |
| **Annual energy cost** | $4.80 | $4.80 | $4.80 | $4.80 | $4.80 | $4.80 |
| **Bulb life** | 1000 hours | 1000 to 3000 hours | 10,000 hours | 25,000 hours | 1000 hours | 1000 to 3000 hours |

Table 1 comparison is based on 2 hours per day of usage, an electricity rate of 11 cents per kilowatt-hour, shown in U.S. dollars. But what about other ways of using LEDs in every home?

To begin with, in this article, the cheaper LED controllers are taken under research. These are the kind of drivers everybody basically can buy from local electronics or DIY store. Based on Estonian DIY electronics shop, named Oomipood, 72 W output power LED controller costs 7 € (based on price on 23rd of March 2017) [4]. Power consumption of a controlled LED strip depends on its length and diodes being used in construction. Usually, LED strips are made to run on 12 V power supply.


**Figure 1.** RGB controller and remote control. [4]

To see, how the controller changes patterns and colours, a segment of 3528 RGB LED strip was attached to the controller. To read signals, Peaktech 1255 was connected to wires soldiered on the circuit board of the controller.

## RESULTS AND DISCUSSION

So what can be done with this little cheap controller? It allows switching lights on and off, changing the colour of light, intensity of light and even using different light patterns. The device has 16 predefined light colours as extra to basic colours (red, green, and blue) and white. Also, for creating the colour by the user, buttons for changing intensity of every basic colour are available. Light intensity of every colour can be changed in 8 steps.

Controller uses pulse-width modulation to light LED up darker or brighter.

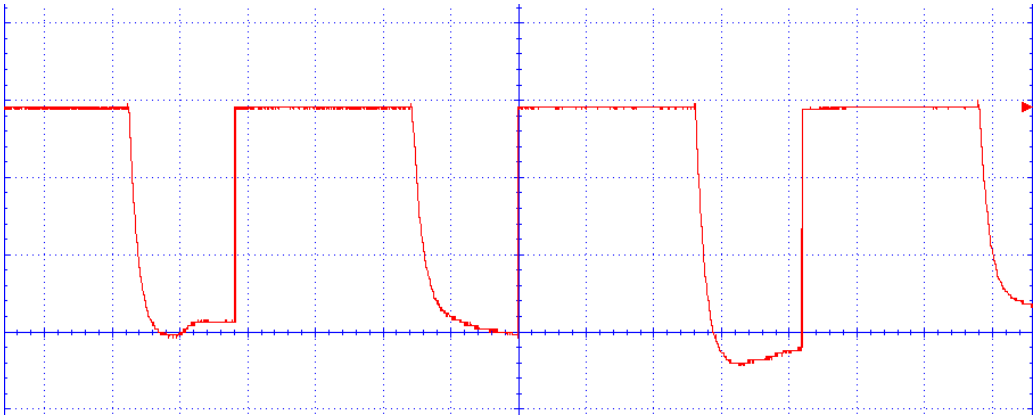

**Figure 2.** RGB LED strip controller output signal on dimmed light intensity

In the figure 2 is shown the controllers PWM to turn lights darker than full output voltage and current. To understand better, how it all works, we should take a look at the controller itself. Inside the box is quite simple electronics circuit. It contains several resistors, capacitors, zener diode, three transistors and two integrated circuits.

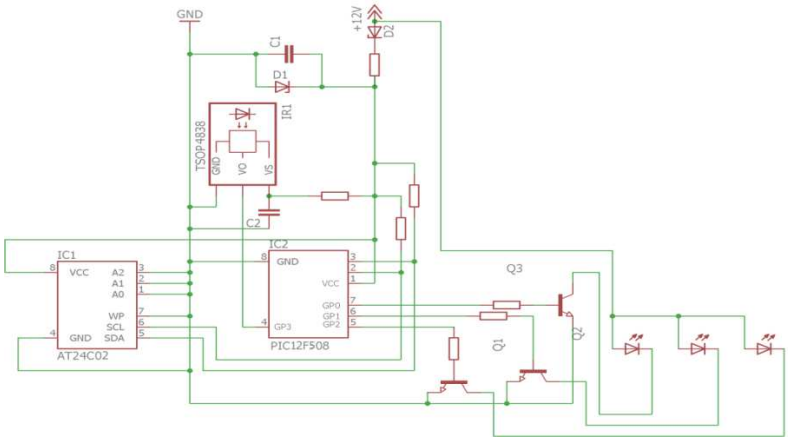


**Figure 3.** RGB LED controller circuit schematic.

Circuit in figure 3 shows the basic components of cheap infrared controlled controller. Components and accomplishment can vary in different manufacturers' controllers. Unfortunately, there is no data about the company, which composed that certain controller being used in this research. The circuit's supply voltage is 12 V, which is rectified to 5V using 1 kΩ resistor and 4.7 V zener diode to stabilize voltage on different load. For smoothing the voltage changes, 10 µF capacitor is used in the IR-receiver circuit. On the PCB are located two SIOC8 packages, one is marked to be Atmel 21B 24C02 SU18, which is EEPROM. To simplify the coding and controlling, all address pins are grounded, which means that all Second IC does not have any markings on it, but it shoud be PIC12 series controller. It has power and ground on pins 1 and 8, consistent with a lot of 8 pin PIC microcontrollers. It probably doesn't need much program space or RAM, especially based on the external EEPROM. The best guess it is probably a PIC12F508 because of the low cost. [5] For receiving signal from remote control, TSOP4838 receiver is used, which runs on 38 kHz frequency.

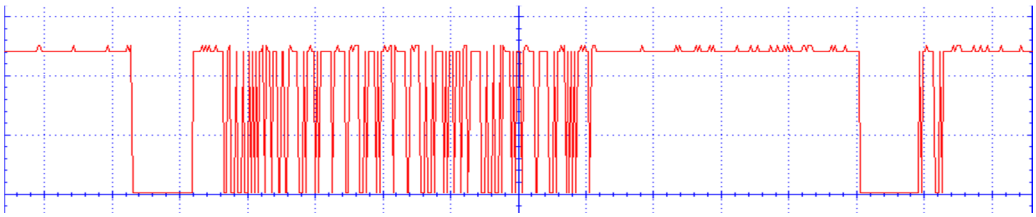

**Figure 4.** Infrared receiver received and defined code from remote control.

For the data transfer, NEC-protocol is used. The NEC code starts the transmission using a so called leader code, a burst with a length of 9 ms, followed by a pause of 4.5 ms and then the data word. The original purpose of this leader code was to let the internal control loops in the receiver modules settle. After transmitting

the data word, only the leader code and a single bit are transmitted repeatedly for as long as a key is pressed. A special property of this code is a constant word length in combination with pulse distance modulation. Both the address and the data bits are transmitted twice, first as a normal byte followed by an inverted byte. The half period burst portion of each bit contains 22 pulses, each with a width of 8.77 μs and a period of 26.3 μs. A “0” is represented by a pulse distance of 1.125 ms and a “1” by a pulse distance of 2.25 ms.

Eight address bits are used to identify the device to be controlled. A further eight bits are used for the transmission of the command data. As mentioned above, the words are always followed, without a pause, by the inverted words. E.g., the transmission of the address word “00110111” and the command data word “00011010” is performed by sending the bits:
“00110111'11001000'00011010'11100101”. [6]

Because of the address not being used, the controller can react on other home electronics remotes, e.g. TV or radio.

## CONCLUSIONS

Led strips are very compact and simple solution to create cosy feeling in home. Cheap controllers offer a good chance to change appearance of a room with just a push of a button. The only drawbacks of these controllers are combined with infrared data transfer. Many remote controlled household appliances use also infrared transmitters and receivers which can use the same frequency and codes for communication. Also, because the transmitter is not very powerful, in even couple of meters the angle between transmitter and receiver is very important. From the positive side, even on the lowest light intensity, the light is not flickering or unstable.

## REFERENCES

[1] Houghton Mifflin Company, "LED", The American heritage science dictionary. Available: http://www.dictionary.com/browse/led. [Accessed 24.03.2017].

[2] Moreno, I.; Sun, C. C Modeling the radiation pattern of LEDs, OSA Publishing, vol. 16, no. 3, p. 16, 2008.

[3] How Energy-Efficient Light Bulbs Compare with Traditional Incandescents, U.S. Department of Energy. Available: https://energy.gov/energysaver/how-

energy-efficient-light-bulbs-compare-traditional-incandescents. [Accessed 24.03.2017].
[4] Wireless IR 44 button RGB LED controller, Oomipood. Available: https://www.oomipood.ee/product/ee_11_302_juhtmeta_ir_44_nupuga_juht plokk_rgb_led_toodetele_12v_3_1a?q=RGB%20IR. [Accessed 24.03.2017].
[5] Reverse engineering an RCG LED controller, University of Waterloo Electrical Engineering department. Available: http://www.leeszuba.com/2014/11/26/led_controller_1.html [Accessed 27.03.2017].
[6] IR Receiver Modules for Remote Control Systems, Vishay Semiconductors. Available: http://www.vishay.com/docs/82459/tsop48.pdf [Accessed 28.03.2017].

# Stroke parameters measurement in rowing and sculling

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**Abstract.** Rowing and sculling have long history in Estonia. In order to get better results at those sports, getting steady stroke rate is one the very important parts. Elite rowers can row about 36 strokes per minute, but good rower also have to know how to control his rowing rate and it has to be trained. In order to achieve constant rate there are different methods that can be used for measurement. With every stroke, rower creates force that makes boat moving. Movements can be measured with sensors, feedback returned to trainers to analyse performance and effectiveness. Sensors like gyroscope can be used, but problem is that boat actually never moves on one axis. With every stroke boat moves a little bit on a different axes. So there should be also another sensor in order to get correct or adjusted data. Measuring velocity can be used in order to detect strokes.

**Key words:** rowing, sculling, sensors, speed, stroke rate

## INTRODUCTION

Since ancient times people have admired rowers and scullers for their good physical shape and look. [1] Nowadays it is also possible to train indoor, because in 1981 brothers Dick and Peter Dreissigacker invented rowing machine called Concept 2. It has become so popular that non-athletes use it also to train. Rowing machines advantage is that it can be used by everyone and does not matter if the person is young or old. Rowing will train all the muscles at the same time and does not give much stress to joints. Nowadays rowing machines are usually found in almost every gym, because it is easy way to train durability. It is also used by police, rescue service, defence forces and by professional athletes. For example, British army have 3000 Concept 2 rowing machines, Subaru Rally Team and Formula 1 pilots use same training machines. First rowing machines arrived to Estonia in 1986. Using extra sensors can measure heart rate or by connecting it with computer, it is also possible to participate in the world virtual rowing competitions via internet. Indoor rowing has become sport itself. Indoor rowing World Championships have been held since 1982. In Estonia International rowing competitions called ‘Alfa’ have been organized since 1993.

In order to getter better results, rowers and scullers must hold required stroke rate and strokes should be analysed. In this article, there are some sensor types tested, that could be used to measure rowers and scullers strokes. There are some metronomes in market, but usually they do not have feedback option or feedback tempo meters that usually use only accelerometer. In order to gain better understanding, why some sensors are preferred over other, series tests has been made in order to find out different measurements from different sensors.

## MATERIALS AND METHODS

Research object is rower at Concept 2 rowing machine. Test was held in Tamme Staadion Gym at Tartu, Estonia. The aim was to measure same object movement with different sensors. For measuring it was used Samsung Galaxy S2 Plus mobile phone, that includes following sensors: MPU-6K Accelerometer (Invensense Ver: 1), MPU-6K Gyroscope (Invensense Ver: 1), YAS532 Magnetic Sensor (Yamaha Corporation Ver:1), Gravity Sensor (Google Inc. Ver 3), Linear Acceleration Sensor (Google Inc. Ver:3) and Rotation Vector Sensor (Google Inc. Ver: 3). Smartphone was attached to rower's right hand. Testing distance was 500 m and damper setting 7,5. The aim was to keep 30 strokes per minute. Professional rowers row around 36 strokes per minute. Concept 2 is also able to show stroke rate and this function was used to keep correct stroke rate. All sensor readings were measured from same test. Test length was 139 seconds, first 30 seconds are shown on graphs in order to give more precise information via graphs. When starting to row, it is difficult at first to find right stroke rate. Displayed figures are picked by relevant information. Figure 1 shows acceleration sensor readings. First stroke is slowest because Concept 2 is using flywheel and first pull is hardest. On figure 1, there are some reading errors for example pull number 8 and 10. Strokes and releases are drawn out. Also periods are easily readable.

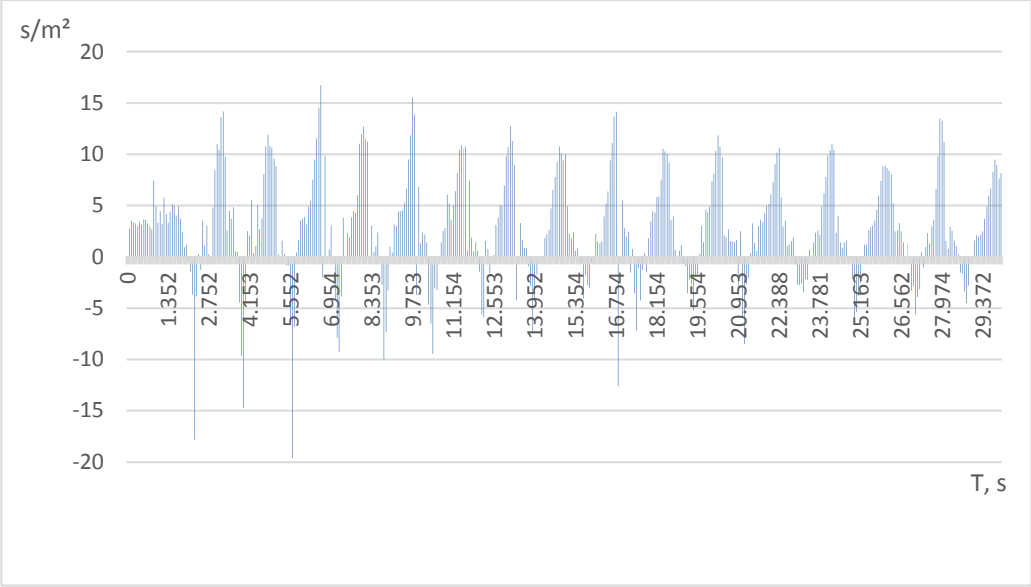


**Figure 1.** Acceleration reading first 30 seconds in 500 m rowing test on Concept 2.

On figure 2 there is a gyroscope sensor x-axis reading. Gyroscope readings were different from other sensors as it gave reading from 2. axis, that could be used for measuring strokes. The main difference from figure 1 is that readings are more like pulses and it is possible only to detect strokes.

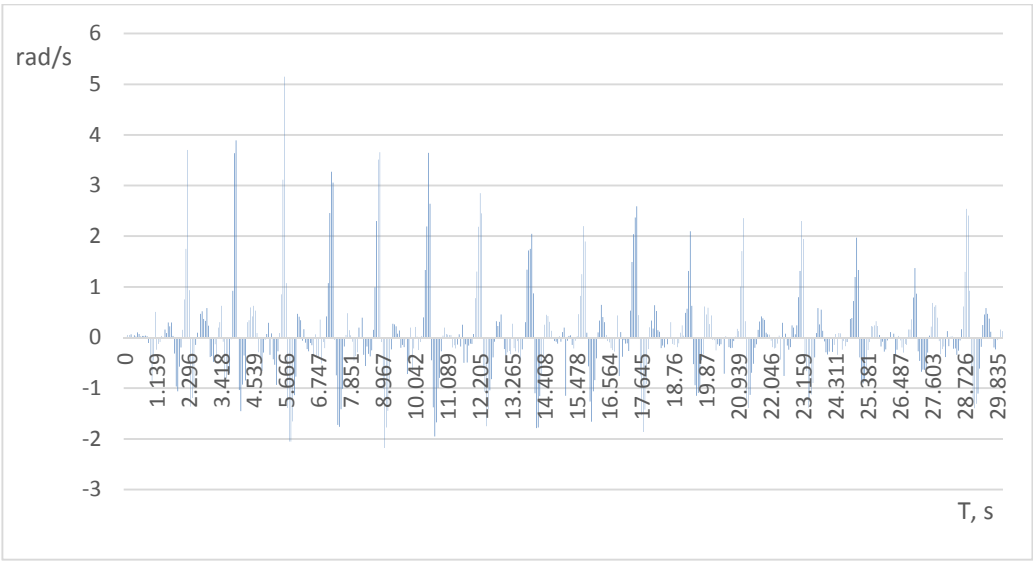


**Figure 2.** Gyroscope sensor on x-axis reading first 30 seconds in 500 m rowing test.

Reading from gyroscope, sensor z-axis figure 3 is better than x-axis although there is more noise with figure 1 sensor.

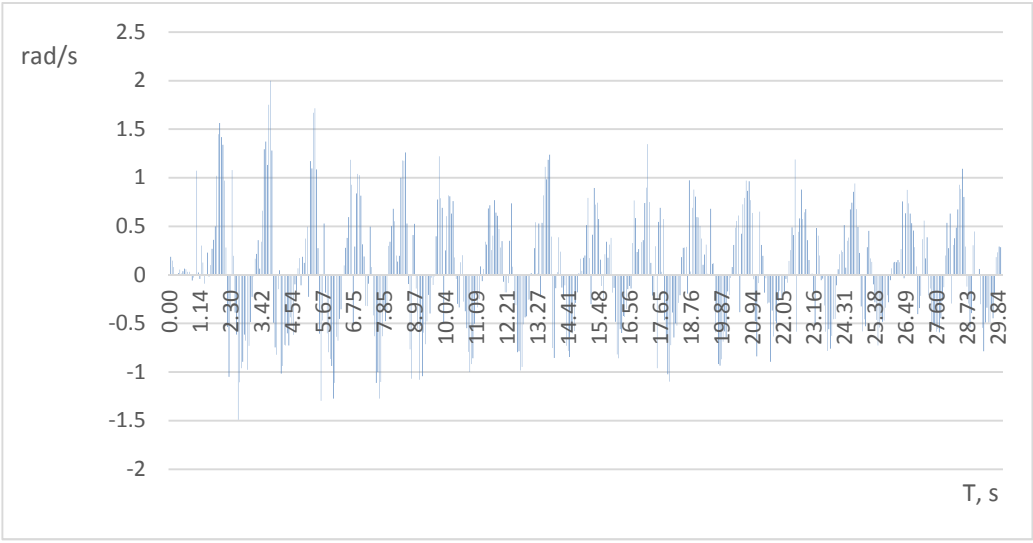


**Figure 3.** Gyroscope sensor on z-axis reading first 30 seconds in 500 m rowing test.

On figure 4 there is magnetic sensor used for stroke measurement. As Concept 2 is made of metal, it is possible to detect magnetic field changes. Strokes are possible to read, but pauses between strokes are difficult to read.

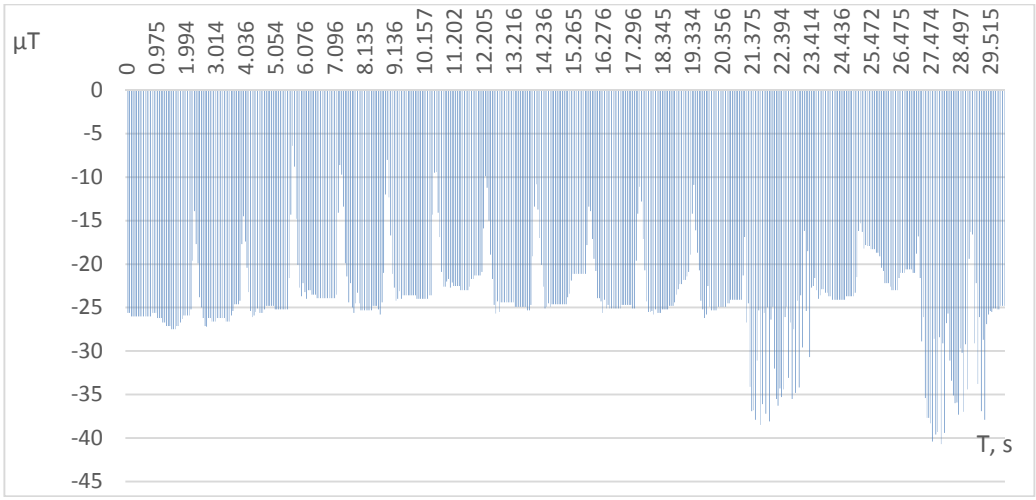


**Figure 4.** Magnetic sensor on z-axis reading first 30 seconds in 500 m rowing test.

On figure 5, there is gravity sensor reading. Gravity sensor consist of readings from accelerometer, magnetic sensor and gyroscope sensor. Pulses are readable.

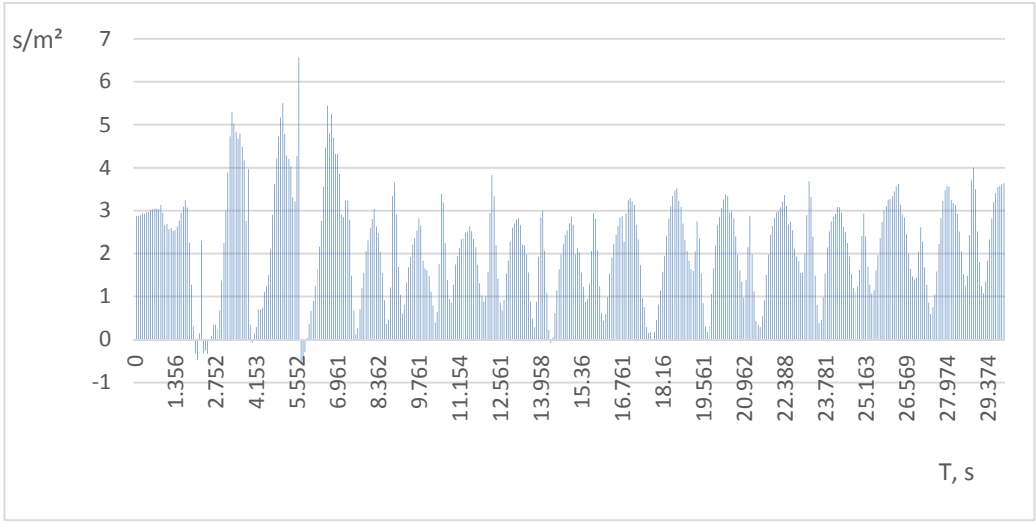


**Figure 5.** Sensor on y-axis reading first 30 seconds in 500 m rowing

On figure 6 it could be seen that linear acceleration sensor readings are similar to acceleration sensor. Strokes and releases are drawn out. Periods are easily readable. Test actually lasted 139 seconds, but the graph depicts first 30 seconds. On all 139 seconds, there were no direction misreadings from stroke to release. Linear acceleration uses info from acceleration sensor, magnetic sensor and gyroscope.

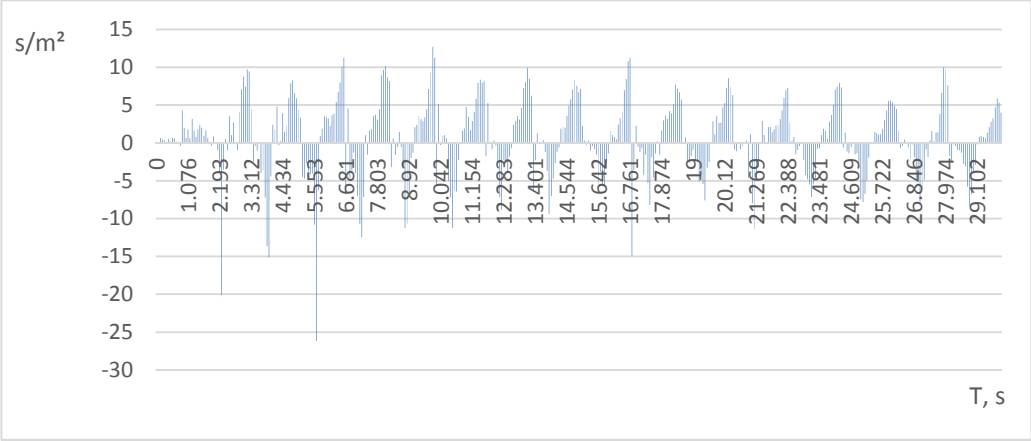


**Figure 6.** Linear acceleration sensor on y-axis reading first 30 seconds in 500 m rowing test.

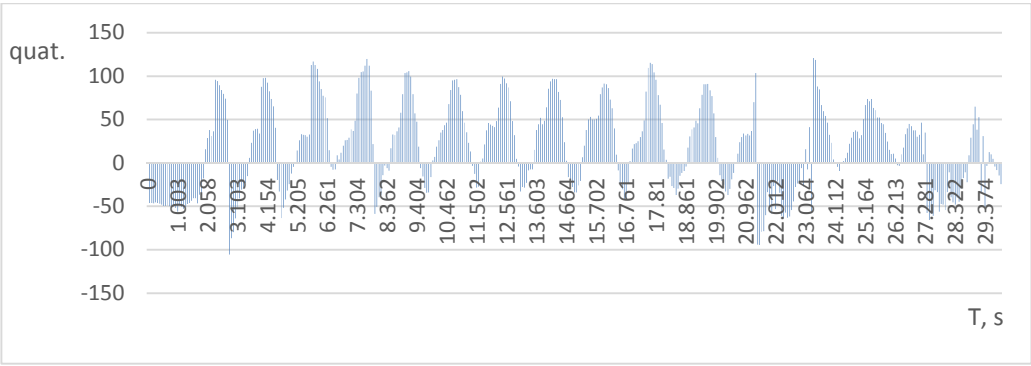


**Figure 7. R**otation sensor on z-axis reading first 30 seconds in 500 m rowing test.

As all tests were held indoor and out of water, it was not possible to test GPS sensor. By literature, GPS enabled smartphones have accuracy 4.9 m. [2] With high-end dual-frequency receivers it is possible to achieve accuracy up to few centimetres. Getting so accurate readings takes up to 20 - 60 minutes. Therefore, using GPS for stroke measurement preparation would take a lot of time, it can be influenced by surrounding and it is not best sensor for measuring strokes.

Since acceleration sensor reading is not based on other sensors information, stroke rate, period and max acceleration is calculated by that sensor.

$$f = \frac{strokes}{period} \times time = \frac{17\ \mathbf{st}}{30\ \mathbf{s}} \times 60\ \mathbf{s} = 34\ \mathbf{st/min} \quad (1)$$

where $f$ is stroke rate;

$strokes$ – strokes during viewed period, st;

$period$ – measured time, s;

$time$ – period 1 minute, 60 s;

Table 1 depicts data collected from test.

**Table 1**. Data collected from test

| | |
|---|---|
| Release acceleration max | -19,6 s/m² |
| Pull acceleration max | 16,73 s/m² |
| First pull period length | 1,98 seconds |
| Other pulls length during 30 seconds | 0,8 – 1,4 seconds |
| Average strokes per minute | 34 st (Concept 2 reading varied 30 to 34 st) |

## RESULTS AND DISCUSSION

Test show that the best sensor for measuring stroke rates is accelerometer. In addition to stroke rates, acceleration is understandable and the period is quite easily measureable, that gives more information to athlete and to coach. Average stroke rate was first 30 seconds 34 strokes per minute. Measuring one axis only could give good enough results for stroke rate measurement. That means less information to process.

## CONCLUSIONS

Research shows that the best sensor for measuring strokes is accelerometer as it gives more information than other sensors. In addition, this test shows that for measuring strokes, many different sensors could be used.

## REFERENCES

[1] “Sõudeliit,” [Online]. Available: http://www.soudeliit.ee/sisesoudmine/. [Accessed 2 April 2017].

[2] “Official U.S. government information about the Global Positioning System (GPS) and related topics,” [Online]. Available: http://www.gps.gov/systems/gps/performance/accuracy/. [Accessed 2 April 2017].

# MEASURING THE TEMPERATURE OF RUNNING WATER IN PIPELINES

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**Abstract.** To evaluate the efficiency of the central heating system the temperature should be monitored in different parts of the system. During the measurement, the pipelines should not be damaged. The static electricity interferes the accurate measurement and is generated by the running fluids in pipelines. Pipelines, in which flows the flammable liquid, the problem of static electricity is very high. [1] This presentation will cover different measuring methods and tools that can be used to measure the temperature of a pipeline with running water in.

**Key words:** flowrate, thermocouple, analog temperature sensor, digital temperature sensor.

## INTRODUCTION

Under the current Energy Action Plan 'Energy Roadmap 2050'. [2] According to the plan, the pan-European trend is reducing the energy consumption. To obtain the aim of this plan a range of energy efficiency measures in the buildings has facilitated. To find effectiveness of heating system of a centrally heated building it is required to measure the central heating piping temperature every part of the building and compare it with the water temperature. From the captured data, it is possible to draw conclusions about the condition of the heating system. Since the efficiency of heating depends largely on the pipeline inner condition which by external observation, it is difficult to estimate, it is necessary to carry out measurements. In addition to the assessment of the condition of the heating system, the renovation of the heating system or maintenance can be planned. To measure pipes and water temperature and record the data a variety of sensors and data acquisition equipment can be used.

The tasks of the research is to comparative analysis of the different measuring devices and finding the best measurement solution.

## MATERIALS AND METHODS

### Heat transfer

The heat transfer i.e. the heat exchange is the transfer of energy from one body to another. The body of lower temperature gains the energy from the body

of higher temperature. In this case, from the liquid inside the pipeline to the pipeline and from the pipeline to the temperature sensor. The heat transfer always takes time to equalize the temperatures. [3]

There are three types of heat transfer: conductive, convective and radiative heat transfer. Heat transfer types can combine with each other. The thermal conductivity is present in gaseous, solid and in a liquid medium. Good heat conductors are metals; gases are poor conductors of heat.

Radiative heat transfer takes place because of the characteristics of the physical bodies to radiate electromagnetic waves when the body's temperature is higher than 0°K. In addition, bodies absorb electromagnetic waves. Therefore, the radiative heat transfer do not require direct contact between the bodies. The ability to radiate the heat depends on the temperature of the body. [3]

**T-type thermocouple**

Thermocouples are electromotive generators. The electrical conductivity of different materials generates the electromotive force when junctions are kept at different temperatures. Fig. 1 shows a possible interconnection of thermocouple. There are different types of thermocouples, since the liquid temperature in the pipeline is between 0 to 100°C, the T-type thermocouple is the most suitable. Thermocouple standards are set out in DIN IEC 584. T-type thermocouple material is Cu-CuNi, the optimal operating temperature range is -40..350°C, the maximum error of 0.5°C.[5] T-type thermocouples are corrosion resistant, and can therefore be used in humid environments.

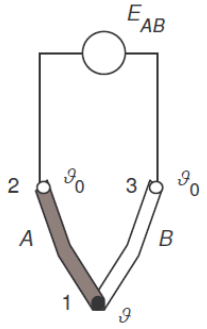


**Figure 1** Thermocouple possible interconnection [4].

**Temperature Sensor DS18B20**

Temperature Sensor DS18B20 is a digital temperature sensor. Each DS18B20 has a unique 64-bit serial code, which allows multiple DS18B20s to function on the same 1-Wire bus. Measuring range of the temperature sensor is -5..125°C and the measurement accuracy is 0.5°C oat the temperature -10..85°C. The sensor has three pins, as seen in Fig. 2. [6]

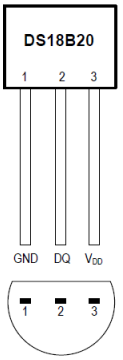


**Figure 2** Temperature sensor DS18B20. GND - ground, DQ - Data Input / Output, $V_{DD}$ – Power.

**Temperature sensor LM35**

LM35 temperature sensor is an analog sensor. Analog signal must be converted into a digital signal when the sensor is used with a digital storage medium. The sensor has three pins, as shown in Fig. 3. Measurement range is -55°C to 150ºC. For each 1°C of the output signal becomes 10.0 mV. Accuracy of measurement at + 25ºC is 0.5ºC. [7]

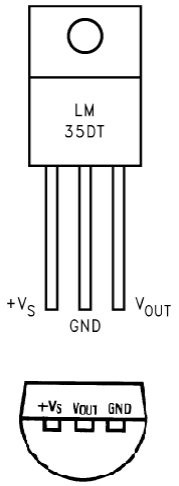


**Figure 1.3.** The temperature sensor LM35. + VS - power supply, GND - Ground, $V_{out}$ - output voltage.

**Temperature measurement**

To mount the temperature sensor on the heating pipes so that the pipes are not damaged, but the measurements are accurate, and the results are fast enough to react to the changes in the tube, is a specific task. The temperature

measurement sensor and the pipe is fixed geometrical shape. For the temperature sensor to transmit the correct pipe temperature, the temperature of the sensor and the pipe must be equalized. Since the contact surface of a round pipe and the plane of the temperature sensor (or a thermocouple) is low, then the heat transfer from the tube to a temperature sensor takes place in two different ways: heat conduction and radiation. Even the surfaces of the contact points is not good conduction heat transfer because of surfaces occurs the bumps and fills asperities gas, which is the thermal resistance. Therefore, it is difficult to balance the sensor and the tube temperature. Thus, the heat transfer from the tube to the temperature sensor has a number of thermal resistance. Fig. 4 shows the temperature drop in the two different surface upon completion. That the temperature sensor would transmit the temperature changes as quickly as the temperature changes in the heating system, reducing the thermal barrier is necessary and the measuring area must be isolated from the surrounding environment.

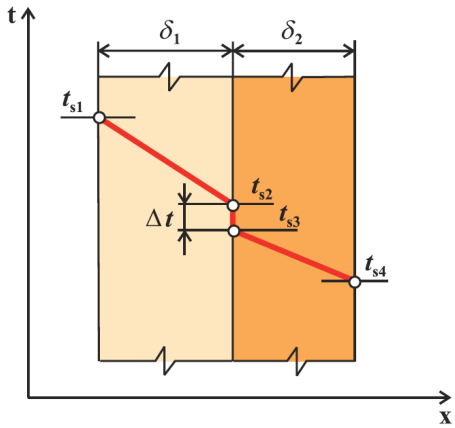


**Figure 1.4**, the temperature drop between the surfaces. $t_{s1}$ - the initial temperature, $t_{s2}$ - the temperature of the first surface, $t_{s3}$ – the temperature of the second surface at the beginning, $t_{s4}$ - temperature onto another surface. Δt - temperature difference between the surface exposure level, $\delta_1$ and $\delta_1$ is the thickness of the various surfaces. [3]

**Thermal Grease**

In order to reduce the temperature to fall from between the surfaces and to accelerate the transmission of the temperature to the sensor, it is expedient to use the additional material that will take the shape of both bodies and removes the gaseous medium between the bodies. For this purpose fit the thermal grease, used in the computer technology. It is used between the processor and radiator to increase the cooling effect. The thermal grease is manufactured in a variety of species, and their thermal conductivity is in large range (ca. 1.5 to >8.5 W·(m·K)

$^{1}$). Since the aim is to measure as accurately as possible the temperature change happening in the pipe then it is suitable to use thermal grease with thermal conductivity of at least 8.5 $W \cdot (m \cdot K)^{-1}$, which is suitable for the MX-4. [8]

**Static electricity**

Static electricity usually occurs by friction materials. Static electricity in piping is caused by the flow rate, liquid velocity, pipe diameter and pipe length. The static electric current can reach up to 40 kV. [9] Thermocouples generate electromotive force, which is low, beginning from 50..55 $\mu V \cdot {}^{o}C^{-1}$. Thus, static electricity affects the results and using the thermocouple may be impossible.

## RESULTS AND DISCUSSION

Measurement the temperature with electronic devices, which have physical contact with the heating bodies, is complicated since it has to take into account the time required for the heat transfer, the potential static electricity and to heat transfer obstacles. More accurate measurement results can be taken if the contact surface is increased and the gaseous medium is reduced. Static electricity is dangerous to any electronic equipment. The inaccuracy caused by the static electricity to the measurement can be reduce by grounding the object and the measuring device first to equalize their potential.

## CONCLUSIONS

The heat transfer from movable water inside the tubes to the room is a multi-step: the liquid is moving inside a tube different speeds, the sludge accumulated in the inner surface of the tube prevents heat flow, on the surface of the outer tube heat exchange takes place as well as radiative and conductive, but only if there is a contact surface. Comparing the relative change in time of temperature of the pipes and the water, the decisions about the condition of the pipes and the analysis of the water heater can be made.

AKNOWLEGEMENT. The author wishes to thank Märt Reinvee and Mart Hovi for consultations and the time spent.

## REFERENCES

[1] Stewart R. Browne Manufacturing. Grounding and Bonding Applications for Control of Static Electricity. http://www.srbrowne.com/booklet/ (30.03.2017).

[2] European Economic and Social Committee, Resolutions, recommendations and opinions http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:C:2012 :229: FULL&from=EN (30.03.2017).
[3] Ots, A. (2011). Thermal Engineering Basic Course. TTÜ kirjastus. Tallinn. 816 lk. (in Estonian).
[4] Lehtla, T. (1996). Sensors. TTÜ Robotitehnika õppetool, Tallinn 125 lk. (in Estonian)
[5] R. Hörnemann GmbH DIN-Toleranzen für Thermopaare und Thermoleitungen, http://www.hoernemann-rh.de/technik_details.asp?technikid=3 (30.03.2017). (in German)
[6] Maxim Integrated. DS18B20 datasheet. https://datasheets.maximintegrated. com/en/ds/DS18B20.pdf (30.03.2017)
[7] National Semiconductor Corporation. DS005516 datasheet. https://www.engineers garage.com/sites/default/files/LM35.PDF (30.03.2017)
[8] ARCTIC Switzerland. MX-4 datasheet. https://www.arctic.ac/eu_en/mx-4.html (30.03.2017)
[9] ’Static electricity - friend or an enemy?’ Keskkonnatehnika 5. 1999

# Types of wind turbines

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**Abstract.** The location of the wind turbine is important because obstacles can lower the wind speed and also make turbulence. Before installing wind turbine to certain point it is wise to measure wind speed in that point for a year. For this purpose there have made 3 measurements in 3 different locations and has been calculated theoretical productivity in those locations with different types of wind turbines. Results revealed that 100 m tall horizontal axis wind turbines output of a 3 MW annual productivity can reach up to 30% in coast area as in farther onshore it is only 7%. Output of a 5 kW lower wind turbines with 10 m towers and vertical axis can produce also 30% in coast and 7% in onshore but 10 m horizontal axis wind turbine can only 9% on coast and 2% onshore. According to results it is wise to use bigger 3 MW turbines in coast and smaller 5 kW farther onshore.

**Key words:** Wind turbine, productivity, wind speed,

## INTRODUCTION

Global population is growing and as of that also the need for electricity. The main fuels to provide electricity are oil, coal and natural gas. These fuel combustions provide greenhouse gas that gets into the atmosphere and can cause Global warming. To lower these gas emissions there have been made protocols which make tougher environmental requirements and due to that we are looking to produce cleaner energy such as wind energy.

The use of wind as a mechanical energy is believed to originate from the ancient Babylonian era 17 centuries before Christ and it was used to pump water to moisten the grain fields. This was done using vertical axes windmills. In Europe windmills were used more widely in the 13th century, when the British and French used it for grain milling. Unlike Babylonians Europeans used horizontal axis mills, where it has the basic foundation and were built in such way that they could be turned, if necessary, to the wind direction.

Wind electricity generators era began in the 19th century when the first modern wind generator was built in 1890 in Denmark. At the beginning of the 20th century gearbox was added to increase the speed of the generator and begun the development of the blade aerodynamic[1].

Wind turbines must be built to the areas where the nature and man-made objects won´t lower wind speed and don't make turbulence to get maximum out of wind power. Also, before building the turbine it is wise to measure the wind speed at least a year, to make sure the location is reasonable.

In this article author has gathered one year wind speed measuring in three different areas in Estonia. The results have been analysed and the author calculated

theoretical productivity of different types of turbines and found out witch would suit the best for specific area.

## MATERIALS AND METHODS

In this research there has been measured wind speed in one year at location A and B, and the Tartu-Tõravere meteorological station. Locations A and B are near the cost as far as 3.4 and 1 km, and the Tartu-Tõravere further onshore.

Wind speed has been measured using an ultrasonic anemometer, that is attached to wind turbine at height 100 m from the ground, and regular anemometer at height from the ground 10 m. In locations A and B recording frequency is in every 10 minutes, and in the Tartu-Tõravere meteorological station in every hour. The recorded results are calculated to daily mean wind speed. For better comparison of the results there has been used a wind speed calculator [2] so that the Tartu-Tõravere (Table lane C) measurements would be converted at height 100 m altitude measurements and the locations A and B would be in 10 m height.

To calculate wind speed in certain altitude it has been used the following formula [2]:

$$v = v_{ref} \ln(z/z_0) / \ln(z_{ref}/z_0), \quad (1)$$

where $v$ - wind speed at height z above ground leve, m/s;
$v_{ref}$ - reference speed, i.e. a wind speed we already know at height z, m/s;
$ln$ - logarithm function;
$z$ - height above ground level for the desired velocity, m;
$z_0$ - oughness length in the current wind direction;
$z_{ref}$ - reference height, i.e. the height where we know the exact wind speed, m.

The results are listed in Table 1 and daily average wind speed is divided into frequency ranges. Column a is indicated in the days when the wind speed was within the range and in column b indicated in percentage (%), which covered a part in that year.

**Table 1.** Wind speed in location A, B and Tartu-Tõravere (C) meteorological station.

| **Wind speed, m/s** | **Location** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **A** | | **B** | | **C** | | **A** | | **B** | | **C** | |
| | **Altitude 100 m** | | | | | | **Altitude 10 m** | | | | | |
| | **1** | | **2** | | **3** | | **4** | | **5** | | **6** | |
| **Range** | **a** | **b** | **a** | **b** | **a** | **b** | **a** | **b** | **a** | **b** | **a** | **b** |
| **0-1** | - | - | - | - | 1 | 0,3 | - | - | 2 | 0,5 | 13 | 3,6 |
| **1-2** | - | - | - | - | 25 | 6,8 | 14 | 3,8 | 24 | 6,6 | 108 | 29,6 |
| **2-3** | 7 | 1,9 | 15 | 4,1 | 66 | 18,1 | 70 | 19,2 | 65 | 17,8 | 137 | 37,5 |
| **3-4** | 15 | 4,1 | 31 | 8,5 | 82 | 22,5 | 104 | 28,5 | 102 | 27,9 | 79 | 21,6 |

**Tabel 1.** continued

| Wind speed, m/s | Location | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | | B | | C | | A | | B | | C | |
| | Altitude 100 m | | | | | | Altitude 10 m | | | | | |
| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | |
| **Range** | **a** | **b** | **a** | **b** | **a** | **b** | **a** | **b** | **a** | **b** | **a** | **b** |
| **4-5** | 53 | 14,5 | 41 | 11,2 | 77 | 21,1 | 88 | 24,1 | 74 | 20,3 | 22 | 6,0 |
| **5-6** | 66 | 18,1 | 59 | 16,2 | 55 | 15,1 | 55 | 15,1 | 43 | 11,8 | 3 | 0,8 |
| **6-7** | 54 | 14,8 | 61 | 16,7 | 37 | 10,1 | 24 | 6,6 | 21 | 5,8 | 3 | 0,8 |
| **7-8** | 50 | 13,7 | 46 | 12,6 | 11 | 3,0 | 8 | 2,2 | 14 | 3,8 | - | - |
| **8-9** | 54 | 14,8 | 34 | 9,3 | 5 | 1,4 | 2 | 0,5 | 14 | 3,8 | - | - |
| **9-10** | 27 | 7,4 | 25 | 6,8 | 2 | 0,5 | - | - | 5 | 1,4 | - | - |
| **10-11** | 17 | 4,7 | 18 | 4,9 | 1 | 0,3 | - | - | 1 | 0,3 | - | - |
| **11-12** | 11 | 3,0 | 7 | 2,2 | 3 | 0,8 | - | - | - | - | - | - |
| **12-13** | 5 | 1,4 | 7 | 1,9 | - | - | - | - | - | - | - | - |
| **13-14** | 5 | 1,4 | 8 | 2,2 | - | - | - | - | - | - | - | - |
| **14-15** | 1 | 0,3 | 9 | 2,5 | - | - | - | - | - | - | - | - |
| **15-16** | - | - | 1 | 0,3 | - | - | - | - | - | - | - | - |
| **16-17** | - | - | 1 | 0,3 | - | - | - | - | - | - | - | - |
| **17-18** | - | - | 1 | 0,3 | - | - | - | - | - | - | - | - |

Table 1 shows that, at the same location at different heights wind speed changes significantly which affects wind turbines year productivity.

Based on these results it is possible to calculate the annual wind turbine production. To compare the productivity measured in different locations in the real and calculated wind speeds, it has selected one horizontal axis wind turbine at a height of 100 m and at height 10 m two different types of wind turbines, one with horizontal and the other with vertical axis. For 100 meters height turbine, has been selected WinWind WWD-3-100 3 MW wind turbine. At 10 m height has been selected 5 kW horizontal axis turbine NE-5k, and 5 kW turbine VAWT with vertical axis. Table 2 shows parameters of the power production of the wind turbines in certain wind speeds according to the drawings of power curves [3, 4, 5].

**Table 2.** Wind turbine WinWind, NE-5k and VAWT power in certain wind speed

| WinWind WWD-3-100 | | NE-5k | | 5 kW VAWT | |
|---|---|---|---|---|---|
| **P, MW** | **v, m/s** | **P, kW** | **v, m/s** | **P, kW** | **v, m/s** |
| 0,25 | 5 | 0,5 | 4,5 | 0,5 | 3,5 |
| 0,5 | 6,2 | 1 | 5,8 | 1 | 4 |
| 0,75 | 7 | 1,5 | 6,5 | 1,5 | 4,6 |
| 1 | 7,6 | 2 | 7 | 2 | 5 |

| | | | | | |
|---|---|---|---|---|---|
| 1,25 | 8,3 | 2,5 | 7,5 | 2,5 | 5,3 |
| 1,5 | 8,8 | 3 | 8 | 3 | 5,5 |

**Tabel 2.** continued

| **WinWind WWD-3-100** | | **NE-5k** | | **5 kW VAWT** | |
|---|---|---|---|---|---|
| **P, MW** | **v, m/s** | **P, kW** | **v, m/s** | **P, kW** | **v, m/s** |
| 1,75 | 9,2 | 3,5 | 8,5 | 3,5 | 5,7 |
| 2 | 9,8 | 4 | 9 | 4 | 5,9 |
| 2,25 | 10,4 | 4,5 | 9,5 | 4,5 | 6,4 |
| 2,5 | 11 | 5 | 10 | 5 | 7 |
| 2,75 | 11,7 | - | - | - | - |
| 3 | 12,6 | - | - | - | - |

According to table 1 and table 2, it is possible to calculate a theoretical annual output of the wind turbine with the following formula:

$$P_a = \frac{\sum(t*n*P)}{t_a*P_{max}*100}, \quad (2)$$

kus $P_a$ on annual production, %;
$\sum$ annual production of energy, kWt;
$t$ one day, h;
$n$ frequency range of wind speed in a year;
$P$ production of turbine in certain wind speed, kW;
$t_a$ lenght of a year, h;
$P_{max}$ maximum production of electricity in a year, kWt.

The results are listed in table 3.

## RESULTS AND DISCUSSION

In table 3 are the maximum amount of energy that turbine can produce in a year how much turbine has produced and productivity.

**Table 3.** Wind turbine one year production in locations A, B and Tartu-Tõravere meteorological station.(C)

| **Turbine** | **WinWind WWD-3-100** | | | **NE-5k** | **5 kW VAWT** | **NE-5k** | **5 kW VAWT** | **NE-5k** | **5 kW VAWT** |
|---|---|---|---|---|---|---|---|---|---|
| **Location** | **A** | **B** | **C** | **A** | | **B** | | **C** | |
| **$P_{max}$, MWt** | 2628 | 26280 | 26280 | 43800 | 43,8 | 43,8 | 43,8 | 43,8 | 43,8 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **∑, MWt** | 7935,6 | 8133,6 | 1915,2 | 4,02 | 13,08 | 5,54 | 14,18 | 0,87 | 3,01 |
| **$P_a$, %** | 30 | 31 | 7 | 9 | 30 | 13 | 32 | 2 | 7 |

Table 3 shows that the coastal areas´ of wind turbines theoretical productivity is higher than inland´s area in Tartu Tõravere. Large wind farms use wind turbines, such as WWD WinWind-3-100 and can achieve 30% of productivity [6] as well to confirm the calculations. Locations A and B have been carefully chosen areas where annual wind guarantees the desired result, but if the wind turbine were built in Tartu Tõravere, it could result in an annual production of 7%, which is below the expected results.

Small wind turbines as it is seen that the vertical axis of the turbine 5 kW VAWT by the calculations the theoretical productivity is as well as 30% which is a very good result but the horizontal axis of the NE-5k productivity is approximately three times lower. It also must been taken into account that large companies do not build smaller turbines in that location and more individuals are using their own household consumption, which are located in areas where the nature or man-made objects are surrounded. Onshore is more suitable for vertical axis wind turbine than a horizontal axis, as shown in Table 3, it is seen that there are also about three times the output gap.

## CONCLUSIONS

Coastal areas are affecting the wind and direction of objects less than inland, so it would be reasonable to build in those areas a horizontal axis wind turbines with heights of 100 m. In the 1970s and 1980s in Canada and in the United States was developed a 4.2 MW vertical axis wind turbine, which was abandoned as the blades broke off because of the aerodynamic characteristics of the blades. [7] However, the vertical axis wind turbine structure is simpler, more durable, and less expensive. Today, such a type of

wind turbines with such capacity are more developed to the sea rather than on the land.

Calculations show that the inland does not make sense to install a large wind turbine height of 100 meters, because an annual productivity would be 7%. Although Tartu Tõravere meteorological station location is not the best area to measure wind speed, it is recommended to explore the area on land where there is less around obstructions like forest and buildings. When looking at the small 5 kW wind turbines in the productivity of a vertical axis turbine in same location is 7% and 2% in the horizontal axis. However, smaller wind turbines cost less and the payback period is shorter. Thus, the inland would be more appropriate to use a small 5 kW vertical axis wind turbine.

If we consider the fact that the land has less wind, you should carefully choose the location. Often it happens that a person sets up its own wind turbine using the area where he thinks there is enough wind, but when turbine is built and after a year the results something else. There should always be determined the location of the wind measuring at least a year.

## REFERENCES

[1] Mathew, S. (2006)“Wind energy fundamentals, resource analysis and economics”, Berlin: Springer-Verlag. 246 lk.

[2] Wind speed calculator. Danis wind industry association [Online]. Available: http://xn--drmstrre-64ad.dk/wp-content/wind/miller/windpower%20web/en/tour/wres/ calculat.htm [ Accessed 27.03.2017].

[3] WinWind WWD-3-100 power curve drawing. The wind power [Online]. Available: http://www.thewindpower.net/turbine_en_65_winwind_wwd-3-100.php [ Accessed 29.03.2017].

[4] NE-5k power curve drawing. Alibaba [Online]. Available: https://naier.en.alibaba.com/product/60454673467-804189659/ 5KW_Wind_Turbine_ Generator_for_Wind_and_Solar_Power_for_Houses_eolic_generator.html [Accessed 29.03.2017].

[5] 5 kW VAWT power curve drawing. Usa solar [Online]. Available: http://www.usasolarwind.com/(VAWT)%20Vertical%20Axis%20Wind%20Turbines/5kw-VAWT.jpg [ Accessed 29.03.2017].

[6] Kasonen, T. (2012). “Väiketuulikud toovad elektritootmise inimestele lähedale“ Elektriala 5/2012 [Online]. [Available] http://www.tuuleenergia.ee/wp-content/uploads/ EA5-2012lk16-18KasonenVaiketuulikud.pdf [Accessed 30.03.2017]

[7] Ragheb, M. (2015). “Vertical axis wind turbines“ University of Illinois at Urbana-Campaign [Online]. [Available]: http://mragheb.com/NPRE%20475%20Wind%20Power%20Systems/Vertical%20Axis%20Wind%20Turbines.pdf[Accessed 30.03.2017].

# Efficiency and Energy

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**Abstract.** An energy efficiency is considered one the most important aspects of energy production. Energy efficiency is calculated through input and output energies. Actual efficiency is much less if considered is energy that was used to produce the fuel (for example wood). If these aspects are considered, calculation of different energy efficiencies could be performed and give feedback which energy type is most reasonable to produce.

**Key words:** Energy, Efficiency, Energy consumption, Energy production.

## INTRODUCTION

Nowadays energy efficiency is one of the most crucial aspects of energy consumption and production. Energy efficiency is calculated from inputs and outputs relations. Therefore it is possible to calculate efficiencies of any type of energies that are used.

Efficiency is ability to bypass wasting materials, efforts, energy and so on. In energy it is referred as energy conversion. Energy conversion efficiency depends on the usefulness of the energy output. There are many different energy types where efficiency can be calculated.

The main reason of calculations is to lower energy wasting and to find which is the most reliable source of energy that could be produced.

## MATERIALS AND METHODS

Research purpose is to find different efficiencies of energy types which could be applied to production of different energy types. Research is performed through measurements and calculations. For example the inputs of field labour and output of field labour is taken. Field operations of straw energy are next, ploughing, cultivating, levelling of field, seeding and fertilizing. [1]

These processes consume energy and is considered input energy.

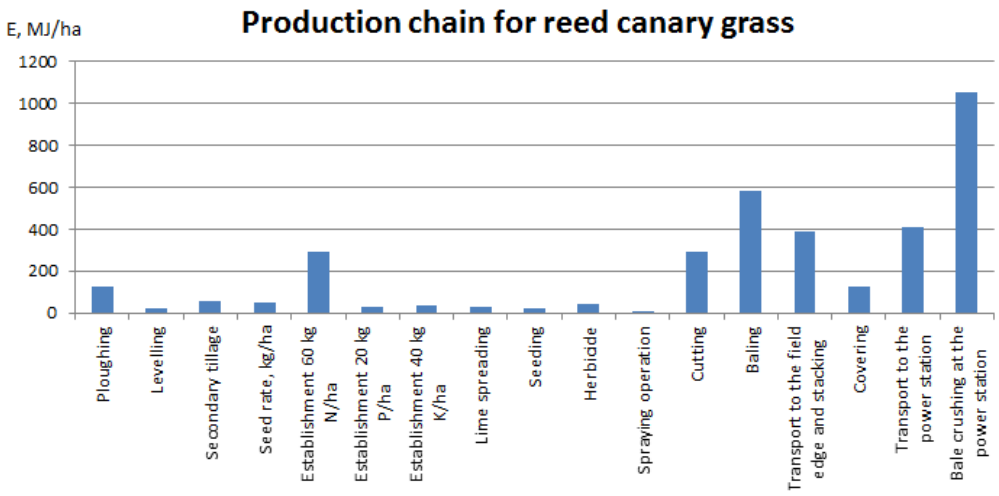


**Figure 1.** Production chain for reed canary grass[1]

The most energy consuming processes are bale crushing at power station, transport to the power station. Cultivating and harvesting processes total energy consumption for one cycle of reed canary grass makes up 10,212 MJ/ha. And production of energy for the same process yields 94,714 MJ of energy per hectar. Amount of energy is calculated via the mass of the reed canary grass with 25% loss of the production and moisture that is in reed canary grass. [1]

**Tabel 1.** Reed canary grass specifications[2]

| Material | Ash, % | Hemicellulose, % | Cellulose, % | Energy content, MJ/kg |
|---|---|---|---|---|
| Reed canary grass | 0.52 | 29.60 | 35.86 | 17.6 |

Reed canary grass is easily maintained and could be used to produce heat energy due to its low ash consistency it could be used as alternative fuel in boiler houses which work on other similar fuel types.

Input and output energy ratios are also calculated with next formula: [1] [2]

$$EER = \frac{E_{Output}}{E_{input}} = \frac{94,714}{10,212} = 9.27 \quad (1.1)$$

Where $EER$ - Effective Energy Ratio
$E_{output}$ - Output energy
$E_{input}$ - Input energy

Effective energy ratio between outputs and inputs are 9,27 which means that input energies are 9,27 times lower than output energies.

Efficiency of the process can also be calculated from total energies used and the useful energy that could be produced by making energy of compressed reed canary grass. Efficiency is calculated using next formula. [1]

$$\eta = \frac{E_{usful}}{E_{total}} = \frac{94,714}{104,926} \approx 0.903 \quad (1.2)$$

Where $\eta$ - is Efficiency

$E_{usful}$ - is useful energy, MJ

$E_{total}$ - is total energy used in process, MJ

Efficiency of whole process is 90,3 % and it can be said that process is efficient. This whole process is explained with next figure.

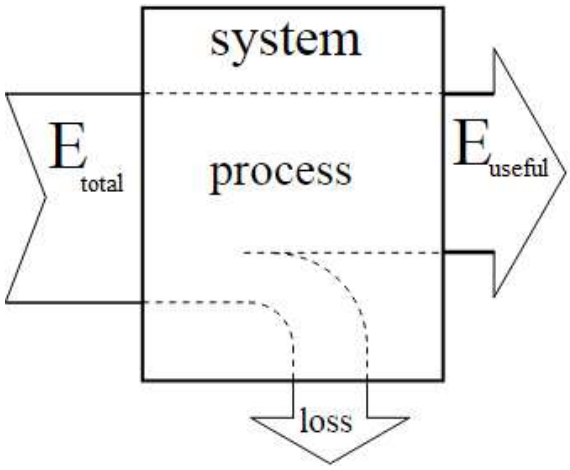


**Figure 2.** Energy and useful energy.

Useful energy can newer exceed total energies on figure 2 it is shown that in any kind of process where energy is used there are energy losses that are lost in process or in transformation of one energy type to another. If heat energy is converted to electrical energy useful energy is even lower.

## RESULTS AND DISCUSSION

By producing reed canary grass the most energy consuming processes are bailing, bale crushing and transportation to the power plant, also the production of annual fertilizers is energy consuming. Energy inputs for growing reed canary

grass is 9,27 times less than the energy that is got in return therefore it can be said that growing reed canary grass for energy production purposes could be considered.

Energy efficiency is calculated by dividing useful energy and total energy and it shouldn't exceed 100%. In any given processes there are considerate amount of energy losses. For reed canary grass example the production of heat energy had closer to 9.7% of energy loss whereas the losses of boiler house has not been taken into account. Although there are more energy losses in that processes it is still considerate amount of energy that could be used to produce hot water or electricity.

## CONCLUSIONS

In conclusion it could be said that energy could be produced in many different ways. Nowadays people are prospering green and efficient ways that are sustainable for any energy use need whether it is electricity, heat or some other type of energy.

## REFERENCES

[1] H. Mikkola, *Reed Canary Grass*, 2008.

[2] "ScienceDirect," march 2014. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0960852414000807. [Accessed 2 April 2017].

# Synthetic generator for simulation of renewable energy sources

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**Abstract.** The aim of this research paper is to introduce synthetic generator which is based on the Institute of Technology, Estonian University of Life Sciences, Kreutzwaldi 56, EE51014 Tartu, Estonia. The synthetic generator is used for digital electronics laboratory to imitate electrical energy source in order to research and develop renewable energy-control technics, grid reliability and storage management on and off the grid. It is possible for the synthetic generator to imitate small hydro station, distant wind turbine etc. by using their production data. The researched device consist of sine filter, frequency drive, rectifier, isolation transformer, grid-direct inverter. Synthetic generator's output is in sync with PV-system, wind turbine, supercapacitor, battery pack, monitoring devices and also load appliances to imitate consumption in the laboratory. The research concluded that the synthetic generator a useful device for research work, but the power control of the system needs improvement.

**Key words:** energy management, research laboratory, renewable energy sources, programmable controllers, scene simulation

## INTRODUCTION

Renewable energy solutions have become more obtainable and expedient due to the development of technology and competitiveness of manufactures. The renewable energy systems will become more feasible in the future [1]. At the moment the construction of these systems are evaluated by the term pay-back period, which represents the time when or whether the built system repays its construction, maintenance and failure costs. It can also be measured as the period when the system starts collecting profit. Pay-back period is mainly influenced by the exploited technology efficiency, environmental- and renewable energy taxes and cost of the fuel [2].

In the field of solar- and wind energy the price of the fuel is assessed by the electricity charge value of the stock market. The shortening of the pay-back period is feasible in the circumstance when the production by the renewable energy source is reasonable not to sell, but to use on site. These are the circumstances when value of the stock market is high. Otherwise, when the price at the market is low, it is reasonable to become the provider and sell the produced energy to the market.

With the renewable energies off-grid solutions the pay-back period in compared to the construction of the grid and maintenance costs. In many cases it is economically rational to offer a client an off-grid solution, because in aggregate the off-grid solution is with the lower cost to sustain.

Usually the off-grid system is the combination of the diesel generator, battery pack and the renewable energy resource, but other methods can be integrated. To analyse

the cooperation of the different components of the system it is legitimate to test the solution by using modelling. The similar experiments can also be taken with the on-grid solutions to assess the system error possibilities and improve energy management.

The current research paper introduces the possibility of the Institute of Technology, Estonian University of Life Sciences, to simulate renewable energy resources and its opportunities for experiments and testing.

## MATERIALS AND METHODS

Digital laboratory of the Institute of Technology ,University of Life Sciences is equipped with solar panels (2.5 kW), a small wind turbine (3.5 kW), battery pack (fully loaded 20 kWh), power analysers, monitoring system, supercapacitor (165 F), resistive loads, weather station and the synthetic generator.

The aim of the synthetic generator is to imitate any given renewable energy source's characteristics. By using the modelling software (LabView, Mathcad etc.) the load curve of the energy source is imported to the program or the needed scenery for running the synthetic generator is created in the software itself [3]. The main components of the synthetic generator are next:

- frequency drive *VFD-EL* (U7);
- sinefilter *FUSS-EMV 3AFS400* (L1);
- isolation transformer (T1);
- rectifier (U8);
- SMA inverter Windy Boy 3600TL – P= 3,6 kW (U9).

The principle scheme of the synthetic generator is shown in the Figure 1.

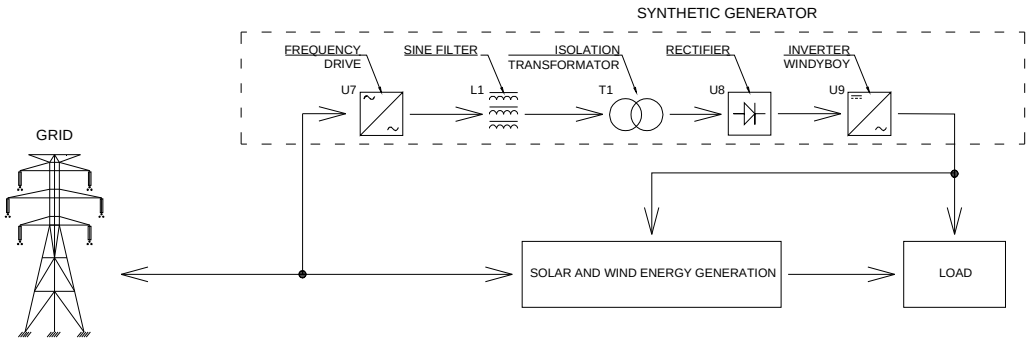


**Figure 1.** Principle scheme of synthetic generator and its connection with rest of the system. The arrows mark the energy flow direction.

For synthetic generator simulating of renewable energy source's production the following requirements need to be met [4]:

-local area network is energized and voltage parameters according to standard EVS-EN 50438:2013;

-served power is chosen manual or automatic on the screen;

-served power is defined on the screen or imported from database.

The synthetic generator is guided from the screen manually or the load curve is imported to the system automatically. Manual control is achieved by regulating the output voltage by adjusting frequency of the frequency drive.

The automatic synthetic generator management is achieved by importing the program with the file extension .RCP or .CSV to the local server. The data is usually time-dependent output values of power represented stationary or unfixed, which is transmitted through the main guide screen (HMI) to the programmable logic controller (PLC). The program can be created according to calculations with the software, a random data or output production (or scenery) values of some distant renewable energy source. The logic controller then feeds the values to the frequency drive (U7). The output voltage of the frequency drive imitates the output production of the renewable energy source and is then lead to the inverter Windy Boy 3600TL, which is set to rely on the output voltage of the frequency drive [4,5]. The data transmission from data input to the inverter Windy Boy 3600TL is described in the figure 2.

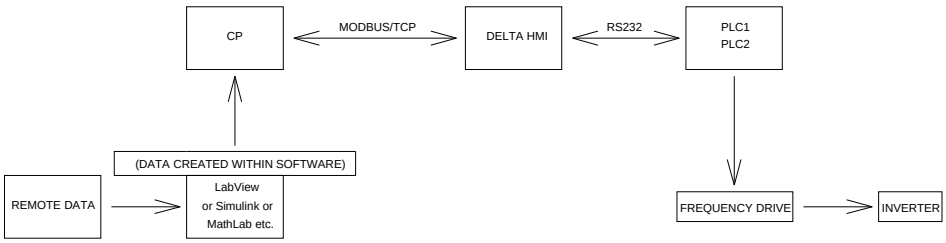


**Figure 2.** Data transmission of the synthetic generator.

## RESULTS AND DISCUSSION

The synthetic generator obtains its power form the main grid. Grid is also used for powering existing renewable energy sources and for feeding the produced energy to the main grid. The first component of the synthetic generator is the frequency drive. Its purpose is to set alternating voltage values just as chosen manually or automatically. Then the voltage is lead to sine filter, where smoothing the waveform of the frequency drive output is taken place. The polishing is needed because the output voltage might contain higher harmonic frequencies that may cause problems for other electronical components of the system. Filtered voltage then travel through isolation transformer for safety reason, which purpose is to separate power source from the electrical device in order to maintain power flow in one direction only. The ensuing segment is rectifier, which symbolises the common component of the renewable energy source whereas alternating current is converted into direct current. The last component, the power inverter, is again a typical unit of renewable electricity system. The power is then converted back to alternating current which working parameters are suitable for national grid standards.

The power output of the synthetic generator's inverter is figuratively the amount of energy produced by imitated renewable energy source which is firstly guided to the nearest consumer and secondly back to the main grid. The production of the current generator can be analysed in the next circumstances:

-production on-grid;
-production off-grid;
-production alongside with PV- production;
-production alongside with wind turbine.
-production alongside with the combination of the before mentioned situation.

By cooperating the entire system it is possible to do research and work out more efficient energy management technics, storage opportunities and the reliability of the renewable energy resources [6].

Also a test was executed and the input and output values of the synthetic generator were analysed. Result of the test are presented on figure 3.

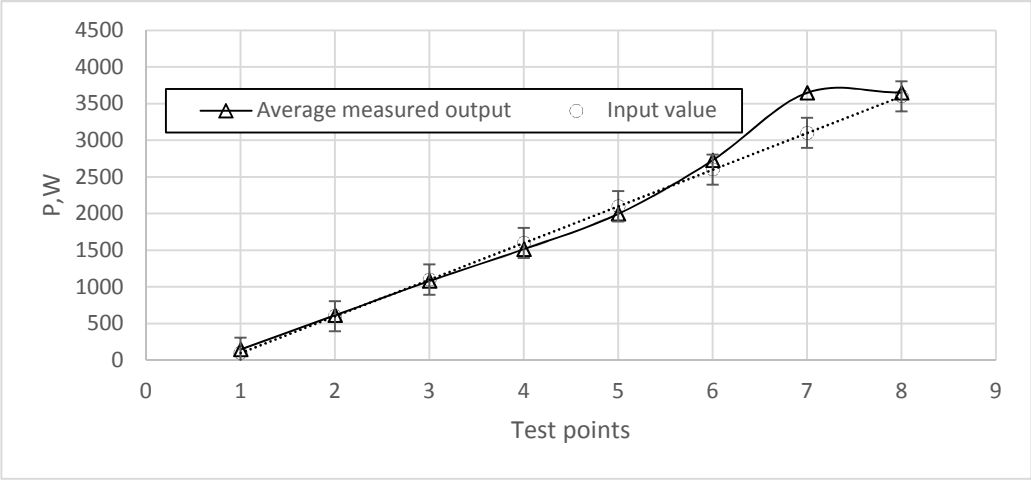


**Figure 3.** Synthetic generator's input and output test result graphically.

The input values were set on the HMI manually with the 500 W climb starting form 100 W up to 3600 W (inverter maximum) and the output value from the inverter screen was saved manually. The test was executed two times, and the results were averaged.

## CONCLUSIONS

The test concluded that among the 3 lower test point (up to 1100 W) input values the output power is always slightly higher than setpoint. From test points 4 to 5 (1600-2100 W) the measured output values were somewhat lower. The results of the 3 last test point output values differed significantly as the output values are marked higher. The main contract is seen with the penultimate test point, whereas the input value differ as

much as 500 W and is equal to the maximum value, which indicates the mismanagement on the higher portion of power values. Also the root mean square error was calculated with the Excel software and is shown on the figure 3. The calculated root mean square value is approximately 206 W, which also indicated the error with the penultimate test point.

For more accurate output readings the test results should be saved automatically. During the manual saving, the output readings varied randomly and the measured value is quite approximate. Although the experiment still managed to show that the control over synthetic generator's output power needs improving.

Still the principle and the compound of the synthetic generator represents itself as a great opportunity for researching and testing for different renewable energy systems.

## REFERENCES

[1] **Taastuvenergeetika koda.** (2014) Taastuvenergeetika aastaraamat 2014. Tallinn.

[2] **Elering.** (2016). Elektrituru käsiraamat. Tallinn.

[3] Web page of the Estonian University of Life Sciences' digital electronics laboratory. [WWW] http://energia.emu.ee/ (14.03.2017)

[4] **Energiatehnika OÜ.** (2014). EMÜ digitaalelektroonika labori energiasüsteem-kasutusjuhend versioon C. Retained in Tartu, Kreutzwaldi 56, room 501 electricity shield EK1 [CD-ROM].

[5] Lisa 4.5. Delta DOP eServer program kasutusjuhend. Retained in Tartu, Kreutzwaldi 56, room 501 electricity shield EK1 [CD-ROM].

[6] **Märss, M., Annuk, A., Allik, A., & Uiga, J.** (2014). AC-link based new microgrid system for research of local power flow management. Agronomy Research, 12(2), 553-562.

# SMA SUNNY SOLAR BOX IRRADIANCE SENSOR

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**Abstract.**
Solar panels have been used increasingly within recent years for converting solar energy into electrical energy. To maximize the production of solar energy into electrical energy, the best conditions must be applied. Since solar irradiance is quite variable depending on the location on land, it is advisable to first perform testing measurements to find out the given location solar irradiance potential. Solar irradiance sensors are used for evaluating the most effective tilt degree and position for future solar plants establishments. An overview and testing of a solar sensor is examined in this project.

**Key words:** SMA, Sunny Solar Box, Sunny Webbox, Sunny Portal, solar sensor, solar irradiance

## INTRODUCTION

PV systems generate electricity by absorbing solar energy. In 2013, photovoltaics was one of the most installed source to electricity in EU countries. The same year solar power formed a part of 3% of the whole electricity demand in EU countries and 6% of peak electricity demand [1]. Because PV systems will be most probably getting more and more cheaper and the efficiency will be getting higher, more PV plants will be built. To find out a suitable position for a PV plant, control measurements can be held. The best way to temprarily measure an areas solar irradiation values temporary is by a irradiance sensor. With these measurements it is easy to decide whether the location is suitable for the PV plant or not. Solar sensors make it easy to detect any deviations in measured data such as dust and shadows.

## MATERIALS AND METHODS

The Sunny Sensorbox is a device which can be installed directly onto the solar modules structure. Sensorbox measures the suns radiation, ambient temperature and module temperature. Sensorbox is supported with a PV monitoring portal Sunny Portal. In Sunny Portal it is possible to access measurement data anytime, anywhere. Values can be analyzed, visualized and compared to detect any

deviations. Many bigger solar inverter producers have their own solar irradiance sensors. In table 1 is a brief comparison of different producers solar sensors.

**Table 1.** Comparisons between different solar sensors

| | Sensor type | Accuracy | Online data interface | Module temperature sensor[1] | Ambient temperature | Max. data cable length[2] |
|---|---|---|---|---|---|---|
| SMA Sensorbox [2] | aSi | ± 8% | Solar Portal | Yes | -25°C ...+70°C | 1200 m |
| Solaredge SE1000-SEN-IRR-S1[3] | No data | ± 5% | SolarEdge monitoring portal | Yes | -40°C ...+85°C | No data |
| Fronius Irradiation Sensor [4] | Mono-Si | ± 5% | Fronius DATCOM | No | -40°C ...+85°C | 30 m |
| Steca TA ES1 [5] | Mono-Si | ± 5% | Stecagrid Portal | Yes | No data | 33 m |

[1] Module temperature sensor connection compatibility in device
[2] Max cable length from sensor to data collector

As it is seen in Table 1, different solar sensors have their advantages and disadvantages. SMA Sensorbox has the longest maximum communication range of 1200 m which makes it really useful for measuring values away from any buildings or electrical boxes. The most durable to ambient temperature are Fronius Irradiation Sensor and Solaredge SE1000-SEN-IRR-S1 which are operable within the temperature range of -40°C to +85°C.

In this article, the SMA Solarbox is taken under research. Solarbox was mounted on the solar panels on the roof of Estonian University of Life Sciences Techical Institute building. Solarbox was mounted in the same tilt angle and position as the existing solar panels to maximize the accuracy of the measurement data as shown in figure 1.

**Figure 1.** Sunny Sensorbox mounted on the solar panels structure

Measured values will be compared to the solar panel values on which the Solarbox is mounted. Block scheme of the connections is shown in figure 2.

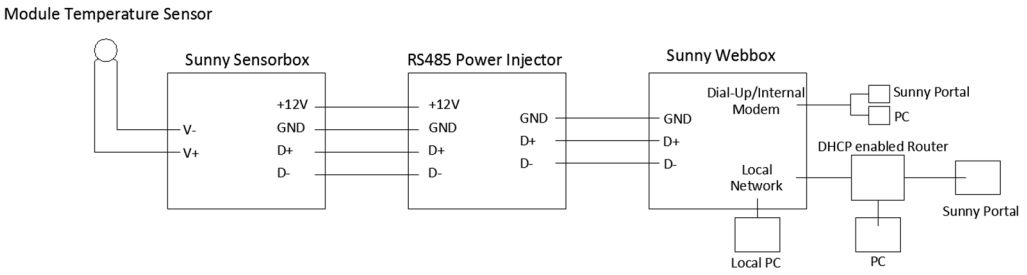


**Figure 2.** Sunny Sensorbox connection scheme

As shown in figure 2, the connection scheme consists of several different elements. Module Temperature Sensor is to measure the temperature on the Solarbox solar sensor. RS485 Power Injector is required for the communication between Sunny Sensorbox and Sunny Webbox. Sunny Webbox is a device which acts as a central communication interface connecting the solar sensor and its operator. Sunny Webbox collects and documents measured data of the connected devices in real time. Data stored by Sunny Webbox can be accessed through local network with a personal PC. If the Sunny Webbox is connected to Sunny Portal, all the data will be automatically uploaded to the PV monitoring portal. It is also possible to install a Dial-Up/Internal Modem to go online.

## RESULTS AND DISCUSSION

Sunny Sensorbox measured solar data in the period of 24 hours every 15 minutes. In total 194 values were recorded.

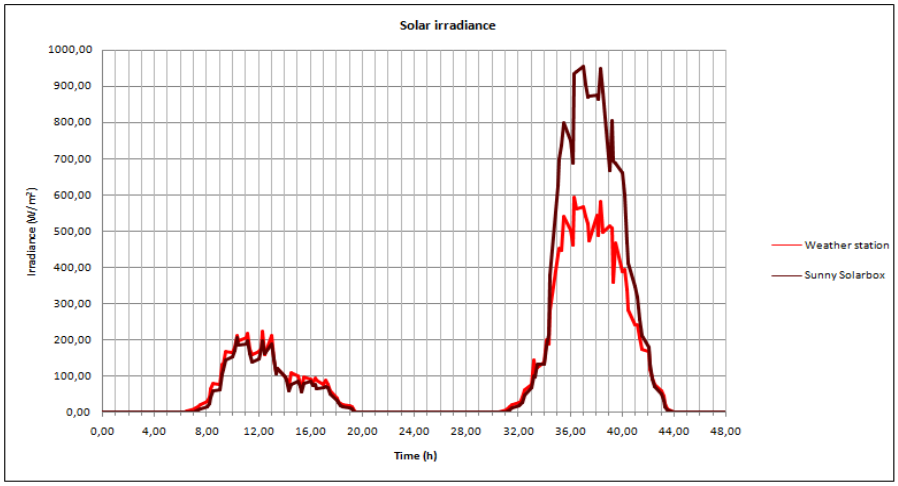


**Figure 3.** Measured solar irradiance

In the figure 3 is shown the irradiation values for the time period of 48 hours. Average sunshine time for each day was around 7 am to 8 pm totaling 13 hours per day. The first day was cloudy. Maximum amount of irradiation on the first cloudy day was 207 W/m$^2$ measured by weather station. Maximum amount measured by Sunny Sensorbox was 198,44 W/m$^2$. Values difference fit mostly in the Sunny Sensorboxes accuracy range of $\pm$8%.

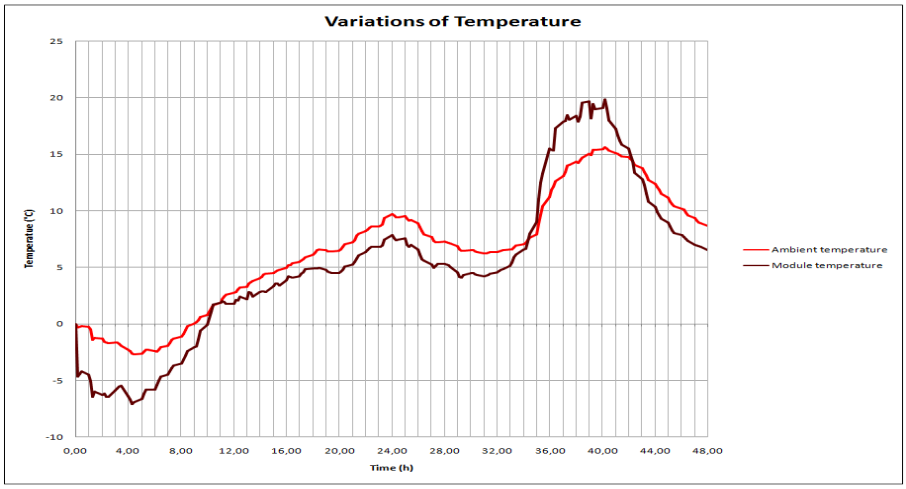


**Figure 4.** Variations of temperatures

In the figure 4 is shown the temperature variation values for the time period of 48 hours. Average temperature on the sunshine period of the first day measured by Sunny Sensorbox module temperature was 1,79°C and the average ambient temperature was 3,12 °C. Average temperature on the sunshine period of the seconth day measured by Sunny Sensorbox module temperature was 12,95°C and the average ambient temperature was 11,60 °C. In figure 5 the variations of temperatures and irradiation are displayed on one graph. With so few measurements, it is not possible to explain the connection between temperature and irradiance levels.

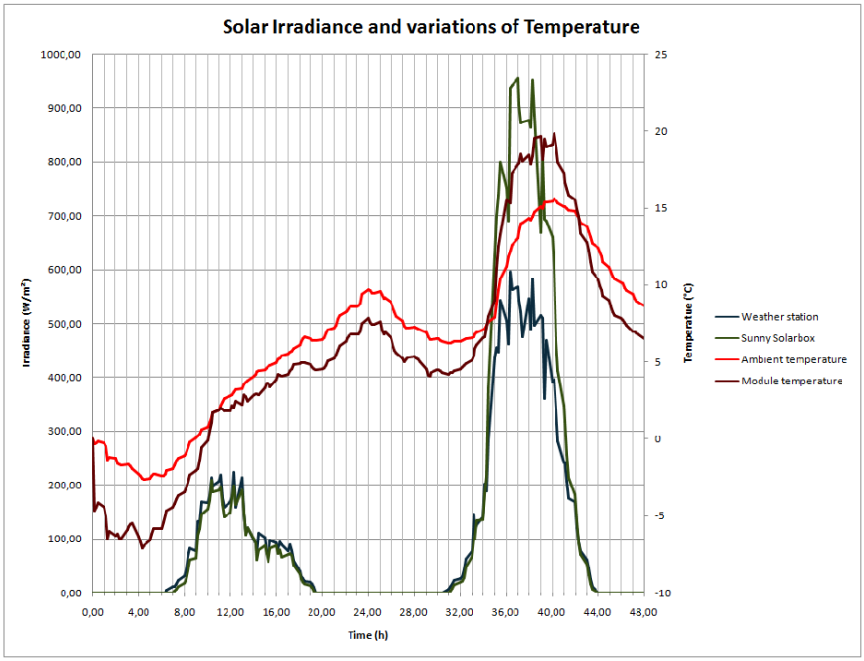


**Figure 5.** Solar irradiance and variations of temperature

## CONCLUSIONS

Sunny Sensorbox is a compact and simple solution to measuring solar irradiance. Many other alternatives are offered on the market, but with the communication range of 1200 m, Sensorbox is clearly the most flexible. Since Sensorbox has a accuracy of $\pm$ 8%, the differences of the measured values of the weather station and Solarbox are easily detectable. Solarbox combined with Webbox and Sunny portal creates easily operatable overview of the solar devices and solar plant.

**REFERENCES**

[1] Global Market Outlook for Photovoltaics 2014-2018, EPIA - European Photovoltaic Industy Association [Online]. http://resources.solarbusinesshub.com/solar-industry-reports/item/global-market-outlook-for-photovoltaics-2014-2018 [Accessed 01.04.2017].

[2] SMA Solar Technology, Installation guide [Online]. Available: https://www.wholesalesolar.com/cms/sma-sunny-sensor-box-installation-manual-3182707407.pdf. [Accessed 01.04.2017].

[3] Solaris Technology Industry, Product description [Online]. Available: https://www.solaris-shop.com/solaredge-se1000-sen-irr-s1-irradiance-sensor/ [Accessed 01.04.2017].

[4] Fronius International GmbH, Sensors [Online]. Available: http://www.fronius.com/cps/rde/xchg/SID-D1E59E03-0BC84213/fronius_international/hs.xsl/83_16139_ENG_HTML.htm [Accessed 01.04.2017].

[5] Steca GmbH, TA ES1 datasheet [Online]. Available: http://www.steca.com/index.php?Steca-TA-ES1-en [Accessed 01.04.2017].

# Analysis for integrating PV panels

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**Abstact.** Electricity consumption through times has been rising around the world, even though new developments in technology are designed to use less energy than they used before. People tend to buy new appliances to replace old ones but the production and distribution volumes are getting bigger to fulfill the needs of the market. The purpose of this article is to give information about reducing energy consumption through renewable energy. It will give information about history of solar panels, different types with new developments and breakthroughs in production. Also it will give information about efficiency and affordability.
**Key words:** electricity consumption, renewable energy, PV panels, efficiency

## INTRODUCTION

Energy consumption has been on the rise for decades. The need for energy has been solved with using more and more non-renewable energy resources. Due to the different regulations and taxes on polluting air with burning mineral resources, new green energy producing technologies are being developed, such as solar-, wind- and wave energy.

Since the discovery of photoelectrical effect in 1839, scientists have been searching ways to make more efficient solar panels to help to preserve the nature. Since the last decade the prices for the photovoltaic (PV) panel system has started to lower which makes them affordable for private users as well, who can give their contribution to a greener world.

There are mainly 3 types of solar panels: Mono,- Polycrystalline and thin film. They're purpose is the same, but their efficiency and prices are different. Mono(mc-Si)- and polycrystalline(p-Si) panels are mostly used in solar parks. They are heavier and rigid. Most preferred panel type is p-Si due to his higher efficiency. Finished p-Si panel costs more but the €/W ratio is better. Thin film panels on the other hand are with lower efficiency but almost with the same price. They are flexible and lower in weight which makes installing them easier to almost everywhere.[1, 2]

PV panel park needs only few elementary things - first of all, sun radiation to produce energy. Secondly, a lot of space. Since the PV panels are quite large, they need quite a room to make sure that any part of the panel is not shaded on any circumstance because it will effect energy production.

This article will give information how much more solar panels should and can be used to help to reduce energy production from non-renewable sources.

## MATERIALS AND METHODS

Research object is global energy consumption and production market. Figure 1 gives an overview of world energy consumption from 1971 to 2014 by region (Mtoe).

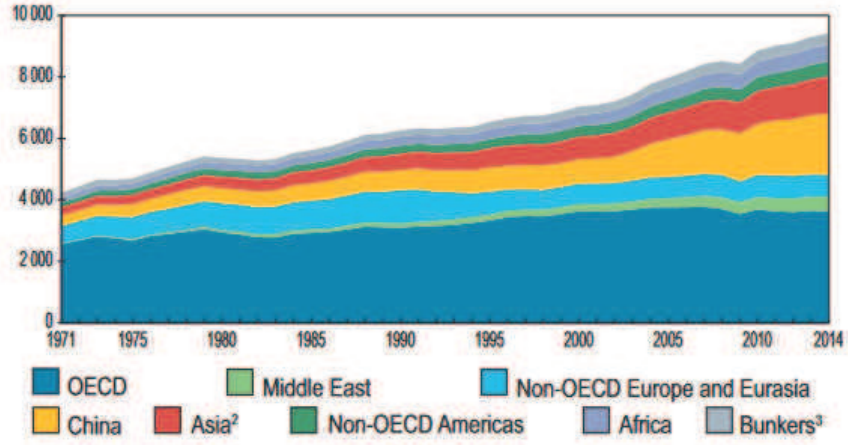


**Figure 1.** World total energy consumption. [3]

Figure 1 shows that worlds energy consumption has been rising through the years. In 2014 it was about 9000Mtoe (104670000GWh, ~11949GW) of energy. In 1980, there was 4.4 billion persons on earth who used about 5500Mtoe of energy. On 2015, there was 7.4 billion humans. Figuratively, 3 billion persons has used almost double the amount of energy than it was used in 1980. It is estimated that in 2100 there will be 11.2 billion persons on earth. [3, 4] Figure 2 shows how many GW of energy was produced with solar panels in 2015 globally.

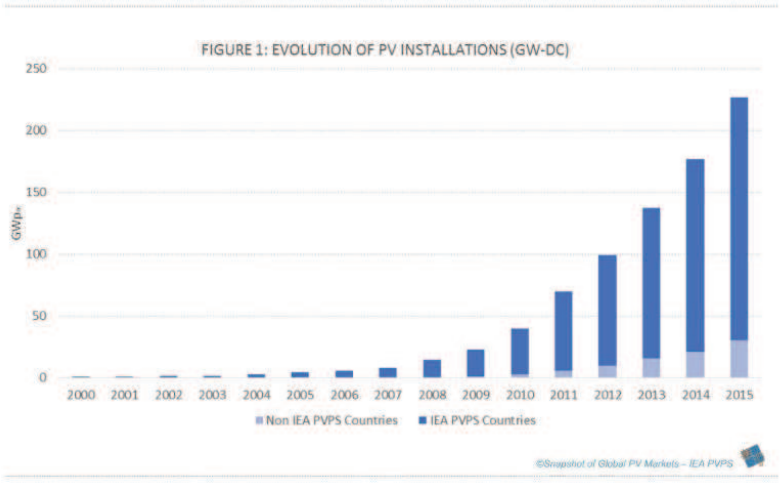


**Figure 2.** Energy produced with solar panels. [5]

Figure shows that at least 227,1GW of energy was produced globally. The figure is not complete since it doesn't show off-grid installations and it doesn't show data from the countries where there is no exact regulations about PV panels. The numbers show, that solar panels production is a fraction of the total energy, which is needed globally in each year. [5]

Most of the solar energy is produced by 10 countries, which is seen on figure 3. If countries with high solar radiation and large areas for installing PV panels, such as Africa, South-America, Australia and India, could contribute more to producing solar energy, it would be a step to the future to more greener environment.


**Figure 3.** Countries with biggest installed PV capacity in 2015 [5]

Figure 3 shows countries which have contributed to solar energy most. Due to the fact that most of the countries haven't started to invest in greener energy, hypothetical energy production can significantly increase.

## RESULTS AND DISCUSSIONS

PV panels are under constant development and their efficiency percentage is getting better with every year. Perovskite technology is still in early stage with his high price and efficiency achieved about 20% in laboratory conditions but the author believes that in the near future it would be one option for producing solar energy in masses. [6]
Figure 4 shows how much scientist have improved the technology throughout the years on conventional panel types.

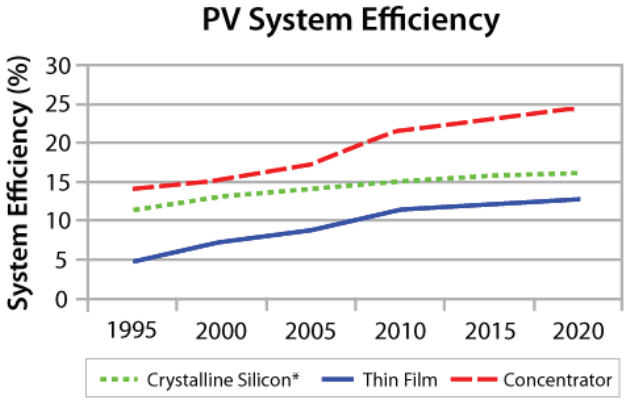


**Figure 4.** PV System efficiency through years. [1]

To help to spread the idea of greener energy and greener nature, local governments should encourage private persons, factories and cities to invest in solar energy. Depending on their contribution on installed power, there should be a tax exemption to compensate initial cost on

system. Figure 5 shows how much has the prices fallen on PV systems on 3 biggest countries who have been spokesman's on green energy.

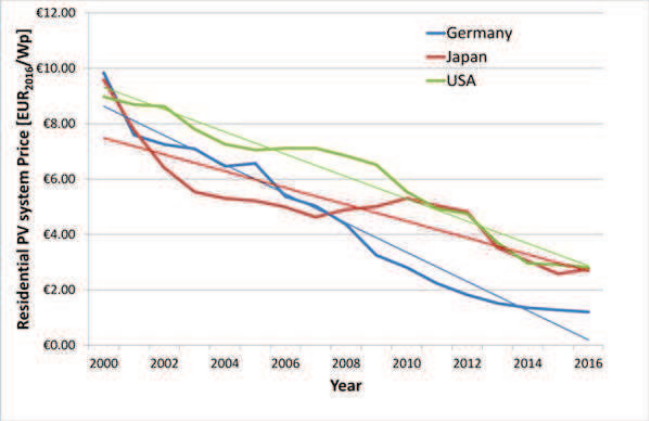


**Figure 5.** PV panel system prices on different markets. [7]

Figure shows that from 2000 to 2016 the prices has fallen around 7-8€/W on different markets which has made them more and more affordable. Keeping in mind, that the energy consumption and -prices are increasing year by year, it is a smart way where to invest. For example, Germany is in the second place on installed capacity even though they're total area is a lot smaller than China.

## CONCLUSIONS

Our nature is fragile and ruing it with behavior that someone in the future will take care of it is wrong. Humankind needs to make investments for better future now.

Solar energy has gained his position on the market on recent decade, where the system prices has fallen. Many countries have invested already on green energy but many still hasn't. There is a lot to do before we can be independent. Bringing energy closer to people, will improve many people's lives.

## REFERENCES

**Han, A.** Efficiency of solar PV, then, now and future

1. Han, A. "Efficiency of solar PV, then, now and future" [Online] Available: https://sites.lafayette.edu/egrs352-sp14-pv/technology/history-of-pv-technology/ [Accessed 27.03.2017].
2. Dobrotkova, Z., Goodrich, A. Mackay, M., Philibert, C., Simbolotti, G, Wenhua, X., "Renewable energy technologies: Cost Analysis Series" Volume 1: Power Sector, Issue 4/5 [Online] Available: https://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-SOLAR_PV.pdf [Accessed 27.03.2017].

3. International Energy Agency, "Key world energy statistics" [Online] Available: http://www.iea.org/publications/freepublications/publication/KeyWorld2016.pdf [Accessed 28.03.2017].
4. Roser, M., Ortiz-Ospina, E., "World Population Growth" [Online] Available: https://ourworldindata.org/world-population-growth/ [Accessed 1.04.2017]
5. IEA International Energy Agency, "2015 Snapshot of Global Photovoltaic Markets", [Online] Available: http://www.iea-pvps.org/fileadmin/dam/public/report/PICS/IEA-PVPS_-__A_Snapshot_of_Global_PV_-_1992-2015_-_Final_2_02.pdf [Accessed: 1.04.2017]
6. Perosvkite-Info, "Perosvkite info" [Online] Available: http://www.perovskite-info.com/ [Accessed 1.04.2017]
7. Jäger-Waldau, A., "Costs and Econimics of Electricity From Residential PV Systems in Europe" [Online] Available: http://www.europeanenergyinnovation.eu/Articles/Winter-2016/Costs-and-Economics-of-Electricity-from-Residential-PV-Systems-in-Europe [Accessed 1.04.2017]

# Finding the optimal flow of the flue gas to insure the maximum carbon dioxide uptake by a microalgae in a photobioreactor

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**Abstract.** Flue gas mitigation by using microalgae is an attractive strategy to reduce carbon dioxide amount in emission gases. Microalgae is cultivated in open ponds and in photobioreactors. In this research microalgae cultivated in a photobioreactor is considered. The aim of this research is to calculate the optimal bubbling flow for the photobioreactor, which was constructed in 2016 in the Institute of Technology of Estonian University of Life Sciences. Optimal bubbling rate is important to insure that carbon dioxide would be fully consumed by the microalgae and no carbon dioxide would exit the photobioreactor. To insure maximum uptake of carbon dioxide, gas bubbles have to have enough contact area and time with a liquid phase. As our photobioreactor has defined gas opening of 0.15 millimetres, the bubble size can be calculated. Calculations start from defining parameters of a gas bubble (it is determined that the bubble is spherical) in a photobioreactor, finding the speed of the bubble and how fast the microalgae consumes carbon dioxide diffusing from the bubble (the speed doesn't change even after total depletion of carbon dioxide), considering that flue gas contains 15% carbon dioxide. After that, absorption of the gas into the water is calculated and then a differential equation on both mass exchanges is constructed (absorption and consumption of microalgae). Finally, the gas flow can be calculated for a situation where all the carbon dioxide would be absorbed into the water and consumed by the microalgae, depending on the density of microalgal biomass in the water. Calculations showed that the optimal flow of the flue gas into the photobioreactor (which is saturated by microalgae) is 0.014 $m^3 \cdot h^{-1}$.

**Key words:** Photobioreactor, microalgae, flue gas exchange, bubbles.

## INTRODUCTION

Microalgae has been regarded as a potential resource to replace fossil fuels. To grow microalgae it is important that it gets sufficient light, nutrients and carbon dioxide. One possible way of carbon dioxide sequestration by microalgae is to drive a flue gas through a bioreactor, thus offering an attractive strategy to reduce carbon dioxide amount in such emission gas. Flue gas contains around 12...15% carbon dioxide, which is acceptable for microalgae and is not toxic [1].

The aim of the study was to find an optimal bubbling rate for a photobioreactor, which was constructed in 2016 in the Institute of Technology of Estonian University of Life Sciences. There are two sides of the equation, where one side shows how fast can water absorb carbon dioxide into the reactor and how fast can microalgae consume the carbon dioxide in specific photobioreactor.

## MATERIALS AND METHODS

In this work we have a photobioreactor, which is used as an example for the purpose of calculations.

There are some assumptions to be made. First, the liquid phase in the photobioreactor is assumed to have mass equilibrium except for carbon dioxide and oxygen. Carbon dioxide moves from a gas bubble to a liquid phase, while oxygen moves from liquid phase to gas phase. Since this study concentrates only on carbon dioxide movement and oxygen movement is independent of the gas bubble movement, we can calculate only based on carbon dioxide movement.

As the photobioreactor has gas openings with defined diameter of 0.15 millimetres, the bubble size can be calculated. In this work we assume that gas contains 15% of carbon dioxide, which has replaced oxygen in the air. Thus, the average molecular mass of the gas mixture is 30.76 $g \cdot mol^{-1}$. Thus, density of the gas is 1.28 kilograms per cubic metre. Thus, we can calculate the size of the bubble in the reactor [2]:

$$V = \frac{2 \cdot \pi \cdot R \cdot \sigma}{g \cdot (\rho_v - \rho_g)} = 34.67 mm^3 \quad (1)$$

, where R is the gas opening radius (0.0075),

σ is surface tension (72 $dynes \cdot cm^{-1}$),

g is gravitational constant (980.7 $cm \cdot sec^{-1}$),

$\rho_v$ is density of the water (0.998 $g \cdot cm^{-1}$),

$\rho_g$ is density of the gas (0.0001205 $g \cdot cm^{-1}$).

We can also calculate the radius of the bubble:

$$a = \left( \frac{3 \cdot R \cdot \sigma}{2 \cdot (\rho_v - \rho_g) \cdot g} \right)^{1/3} = 2.02 mm \quad (2)$$

We know that the area of the surface of a sphere is [3]

$$A = \pi \cdot (2 \cdot a)^2 = 11.104 mm^2 \quad (3)$$

Next we can calculate the velocity of the bubble [4]:

$$v = \sqrt{\frac{4 \cdot g \cdot d \cdot (\rho_v - \rho_g)}{3 \cdot C_d \cdot \rho_g}} = 26.2 cm \cdot s^{-1} \quad (4)$$

, where $C_d$ is drag coefficient (0.45).

To know how fast can carbon dioxide absorb into the water, we need to calculate how many grams of carbon dioxide is in one bubble.

$$m_{gas} = \frac{44.01 \cdot 34.67 \cdot 0.15}{24 \cdot 10^6} = 9.536 \cdot 10^{-6} g \quad (5)$$

Next we determine how much carbon dioxide is lost from one bubble per second. The assumption is that the liquid part does not have any carbon dioxide. Firstly, we determine the mass density of carbon dioxide in the water at the interface, which is identical to the solubility of the carbon dioxide in the water: 1.7 $g \cdot kg^{-1}$, which is 1.7 $kg \cdot m^{-3}$. Thus, we can calculate how much carbon dioxide is absorbed into the water: [5]

$$m_{diff} = \frac{D_{ab} \cdot A \cdot \rho_{co2}}{L} = 1.11 \cdot 10^{-8} kg \cdot s^{-1} \quad (6)$$

, where $D_{ab}$ is binary diffusion coefficient in water. ($1.6 \cdot 10^{-5}$ $m^2 \cdot s^{-1}$),

$A$ is area surface of the bubble. (11.104 $mm^2$),

$\rho$ is mass density of carbon dioxide in the water,

$L$ is mean diameter of carbon dioxide transfer depth (0.126 m).

Thus, we can calculate how many seconds gas bubble has to be in the water so all of carbon dioxide can diffuse into the water

$$\frac{9.536 \cdot 10^{-6}}{(1.11 \cdot 10^{-5})} = 0.862s \quad (7)$$

From this, we can determine the required height of the water column for full carbon dioxide transfer into the water phase

$$0.862 \cdot 26.2 = 22.59cm \quad (8)$$

Thus, in ideal situation the photobioreactor can absorb carbon dioxide fully when the water column is more than 22.59 cm high.

This depth is only valid when there isn't any carbon dioxide in water. If for example water was 50% saturated with carbon dioxide, the required depth for full sequestration would have been 45.2 cm, which is not enough for this particular reactor design. This means microalgae have to consume all of the carbon dioxide diffusing into the liquid phase of the photobioreactor. In addition, bubbling is not done by one bubble at a time, as there are 90 gas openings. Thus, the mean diameter of carbon dioxide transfer depth reduces approximately tenfold, to 0.008 m, but in the meantime the carbon dioxide from different bubbles overlap, thus decreasing absorption rate. When we account for this, we get carbon dioxide absorption rate of 0.00017533 $g \cdot s^{-1}$, which is 15.85 times lower than in ideal case.

On the other hand, the rate at which microalgae can consume carbon dioxide per second is dependent on microalgal culture. Chiu et al. [6] give carbon dioxide reduction by chlorella 3.441 $g \cdot h^{-1}$ per 4.8 litres of saturated culture. In SI units it is 0.00019913 $kg \cdot m^{-3}s^{-1}$. That means in ideal situation the photobioreactor of 100 L could sequestrate 0.019913 grams per second. Thus, we can calculate how many bubbles can be put through the reactor for ideal absorption of carbon dioxide per second

$$\frac{0.019913}{(1.11 \cdot 10^{-5})} = 1800 \quad (9)$$

Considering the difference in absorption rates, in real situation the optimal bubble number would be 114.

The final optimal gas throughput (in ideal situation) can be calculated

$$Q = V \cdot 1800 = 0.0624l \cdot s^{-1} = 0.225m^3 \cdot h^{-1} \quad (10)$$

, where $Q$is gas throughput.

In the real situation, the optimal gas throughput should not be higher than 0.014 $m^3 \cdot h^{-1}$ in order to guarantee that any carbon dioxide would not exit the photobioreactor.

## RESULTS AND DISCUSSION

The final optimal bubbling rate is about 50 times less than what has been used in this photobioreactor. This implies that the photobioreactor should be redesigned so that the optimal bubbling rate could be improved. Mixing effect of carbon dioxide

diffusion has been excluded in those calculations, thus the real optimal throughput could be bigger by about 20-30%. The next step would be to design such reactor, which would sequestrate carbon dioxide more efficiently – probably by increasing the depth of the reactor. Another factor, which plays the role of the optimal bubbling rate, is gas opening radius, but this plays less role than the depth of the reactor.

These calculations don't include the scenario where microalgae is partially unsaturated in the photobioreactor. We can assume that in this scenario the optimal bubbling rate would be even less.

## CONCLUSIONS

In this work we have calculated the diffusion rate of the carbon dioxide of the bubble and how much throughput can photobioreactor provide so that none of the carbon dioxide would escape the reactor. As has been concluded, the optimal bubbling rate is too low for this particular photobioreactor, which is 0.014 $m^3$.

## REFERENCES

1. Baltic Sea microalgae transform cement flue gas into valuable biomass. M. Olofsson, E. Lindehoff, B. Frick, F. Svensson, C. Legrand.
2. Motion of Bubbles and bubble characteristics. http://www.seas.ucla.edu/stenstro/Bubble.pdf (02.04.2017)
3. Mehaanikainseneri käsiraamat. **Ulrich Fischer, Roland Gomeringer, Max Heinzler jt. 2015.**
4. Terminal velocity. https://en.wikipedia.org/wiki/Terminal_velocity (03.03.2017)
5. Heat and Mass Transfer: Fundamentals and Applications 5th Edition. Yunus Cengel and Afshin Ghajar. 2015
6. Reduction of CO2 by a high density culture of Chlorella species in a semicontinuous photobioreactor. Sheng-Yi Chiu. 2007

# Development of drone logistics

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**Abstract.** Nowadays communitys pace of life is very fast and people are getting more and more comfortable. Most important about todays consumer society is time management and handling it, because time is money and it almost always withdraws to money. Because of the modern mans appreciation of three basic things in life (money, time, convenience), therefore it leads us to a topic where all three are represented - merchandise ordering and delivering. This article gives a small overview about the logistics of drone transportation at the campus of Estonian University of Life Sciences and how could this system improve existing mail management. The research is based on qualitative method, which consists of data collection, text analysis and making conclusions. Problem lies in current post system which is time-consuming and not very economical. In this article the use of a drone is proposed for faster and more comfortable mail management and transportation.

**Keywords:** logistics, drone, post system, management, deliver, convenience

## INTRODUCTION

Todays people are very fond of merchandise ordering especially through internet and this means that the delivering system has very big attention. This article concentrates on the mail management and logistics at the campus of Estonian University of Life Sciences and how to improve current post system. This leads to the problem - present mail delivery takes a lot of time, is not very economical and could be more convenient. Solution for all this could be a self-managing unmanned aerial vehicle (UAV), commonly known as a drone. The use of a drone can reduce significantly the traffic-based doubtfulness of the shipping process, which means a more reliable and faster service [1]. Drones have very comprehensive field of applications, e.g. military; research and development; civil and commercial and logistics. Although many usage areas are nowadays already widely spread and more advanced, greatly due to drones different abilities like replacing vehicles, reducing labor and avoiding difficult terrains , the logistical side is still at an early stage [2].

## MATERIALS AND METHODS

This research is based on qualitative method, which consists of the set goal, data collection, text analysis and making conclusions. This is used to gain an understanding of underlying reasons, opinion and motivations. In qualitative method the focus is on depth analysis and the content is examined thoroughly. This kind of method provides

insights into the problem or helps to develop ideas. After obtained data analysis author forms his opinion and vision about the problem and then offers a solution [3].

One of the most important part of drones transportation is logistics. Logistics involves management, storage, flight route, payload capacity, flight time, package weight and supervision of the transport of goods. The better the logistics, the higher the satisfaction of the customers and more efficient the delivery [4].The selection of different drone build types (fixed-wing, tilt-wing, unmanned helicopter, multicopter) gives us a various usage areas for drones. For logistics department, the focus is on multicopters because of their low weight, they are easy to launch and have vertical take-off. Also, they don't cost as much as other drones. Disadvantages for this build type are limited payloads and sensitivity to wind [5].

To ensure maximum economy and efficiency for delivering post by drone the two essential aspects are flight route and time. Drone has to be programmed in such way that it flies along the most direct path and there is no "empty flights" [6]. This way the flying time and expenditure decreases. The following description about the flight routes of post delivery at the campus of Estonian University of Life Sciences are made up by the author and are not intended as an exact solutions, but they are one of the possible ways.

Flight route number one is based on the drone flying back and forth between all the buildings at the campus, but the returning point remains the same on each delivery round and changes when the round is over. For example the drone delivers packages from the main building, which is the returning point, to other facilities and if needed, brings back what is sent to the main building (Fig. 1). The next round the returning point will be different building etc.

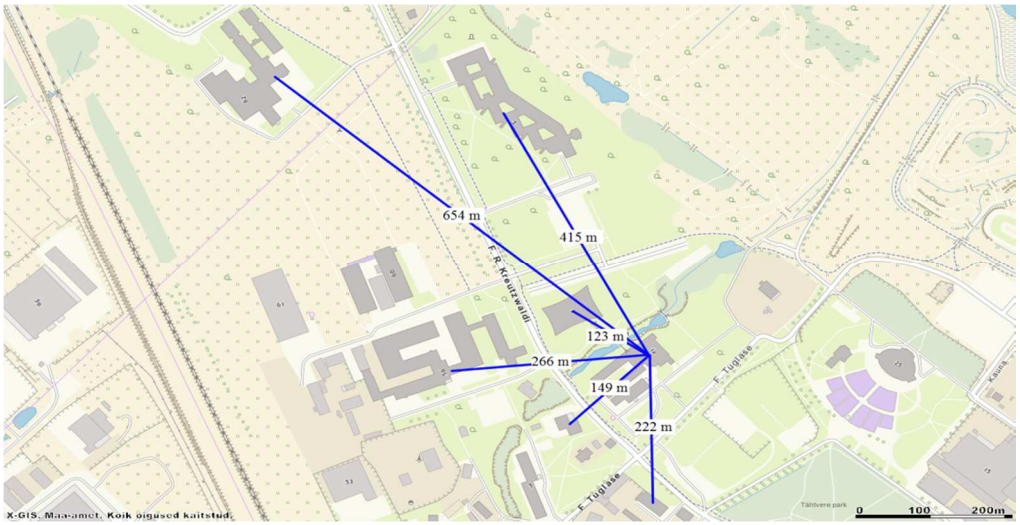


**Figure 1.** Drone flight path approximate lengths of the main building [5]

Flight route number two is based on the drone flying in a circle between all the buildings at the campus and each time drone takes a box with separated compartments for all the facilities. For example when the drone starts its delivery round at the main building, it delivers all the mail from there to other structures in a circle (Fig. 2) and when the round is finished the drone will start its new delivery round at the next building etc.

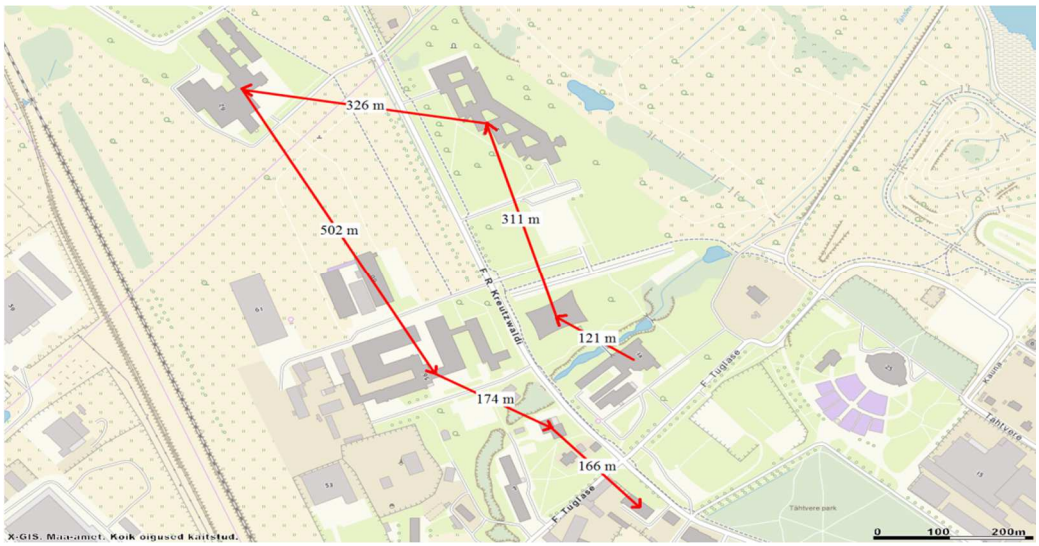


**Figure 2.** Drone flight path approximate lengths starting at the main building [5]

It is very important to calculate the approximate flight time of the drone, because that way we can analyse the results and conclude which route is the fastest and most economical. To find the most optimal delivery route the author uses drone flight path lengths, the flight altitude that is possibly safe, max. flight speed of the drone and the max. ascent and descent speeds. In calculation, for the flight, ascent and descent speed, the author uses a drone model called DJI Phantom, that is widely used. Drones specifications are shown in table 1. Calculations include drones pure flying time, but the time for charging and parcel delivery (dropping/taking) are not considered.

**Table 1.** DJI Phantom specifications [7]

| Drone | Weight, g | Diagonal size, mm | Max. ascent speed, m $s^{-1}$ | Max. descent speed, m $s^{-1}$ | Max. speed, m $s^{-1}$ | Max. flight time, min |
|---|---|---|---|---|---|---|
| DJI Phantom 4 | 1380 | 350 | 6 | 4 | 20 | ~28 |

The flight time of the drone can be calculated by the following formula (Formula 1):

$$v = \frac{s}{t} \rightarrow t = \frac{s}{v} \ , \qquad (1)$$

where v – flight speed, m $s^{-1}$;
s – route length, m;
t - flight time, s.

Drones max. flight speed, max. ascent and descent speed, the length of the flight path, flight altitude and flight time for both routes are shown in following table (Table 2).

**Table 2.** Drones speeds, flight distance, altitude and time

| Route | Max. speed, m $s^{-1}$ | Max. ascent speed, m $s^{-1}$ | Max. descent speed, m $s^{-1}$ | Flight distance, m | Flight altitude, m | Flight time, s |
|---|---|---|---|---|---|---|
| Route 1 | 20 | 6 | 4 | 10,877 | 10 | 643.85 |
| Route 2 | 20 | 6 | 4 | 7,407 | 10 | 482.85 |

As it appears from the table, the faster and more economical route is Route 2. The flight time for the second route is ~483 seconds or ~8.05 minutes which is about 161 seconds less than it would take on the first route. But this does not mean that it is the most optimal, because when the drone is using the second route, it uses a box with separated departments to carry the post and this means that it has less load capacity for packages, in other words the limit could be exceeded. If the drone travels along Route 1 it takes more time, but it is capable to carry an extra package besides to daily mail. The loss of time is only about 2.68 minutes, but if someone wants to send heavier and larger package, drone does not have to make an extra flight.

Other important aspects in drone transportation logistics are the package weight and drones payload capacity. Drone has to be able to carry a load of approximately 3 kg. Nowadays average drone can carry less than 1 kg, but there are many more powerful drones available on the market. Only bad sides about these flying machines are the cost and measurements. Payload capacity is influenced by many different factors such as battery type and capacity, motor power, propeller size, number of propellers and frame weight. The biggest limitation of them all is battery capacity, because it regulates the amount of power available to generate the propeller thrust required to fight the force of gravity. For stable flight there is a rule, according to which the required propeller thrust equals 2x the amount of total weight of the drone. For example, if the total weight (drone + payload) is 5 kg, then it requires sufficient power to lift 10 kg. This means, the bigger the load, the bigger the lift requirement. The bigger the lift requirement, the bigger the battery. The bigger the battery, the bigger the total payload etc. It all depends on the balancing [8]. The propeller thrust can be calculated by following formula (Formula 2) [9]:

$$F = A \cdot \Delta p, \quad (2)$$

where $F$ – thrust;
$A$ – the propeller disk area;
$\Delta p$ – the pressure jump.

## RESULTS AND DISCUSSION

As an result of this research it can be said that from the logistic side, it is beneficial to use a drone for post delivery. With a drone the mail and package management could take much less time and be more economical compared to the current delivery system. Calculation results show that faster and more economical route was route 2, but the first one was more optimal. Also this kind of delivery system would be very convenient and a good advertisement for Estonian University of Life Sciences.

## CONCLUSIONS

1. Most suitable UAV build type for post delivery at the campus of Estonian University of Life Sciences is multicopter, commonly known as a drone.
2. Post management by drone can improve the delivery speed, keep the environment cleaner and make the system more economical.
3. The more the drone can carry, the larger it is and the more it costs.
4. Drones pure flying time for route 1 is 643.85 seconds and for route 2 it is 482.85 seconds.
5. Route 1 is more optimal for post delivery by a drone, because it can carry packages with different parameters.
6. Route 2 is faster and more economical.

## REFERENCES

[1] M. Tavana, Khalili-Damghani, F. J. Santos-Arteaga, M. H. Zandi, "Drone shipping versus truck delivery in a cross-docking system with multiple fleets and products", 2016.
[2] L. A. Haidari, S. T. Brown, M. Ferguson, E. Bancroft, M. Spiker, A. Wilcox, R. Ambikapathi, V. Sampath, D. L. Connor, B. Y. Lee, "The economic and operational value of using drones to transport vaccines",United States, 2016, vol. 34.
[3] S. E. Wyse. (2011) What is the Difference between Qualitative Research and Quantitative Research? [Online]. Available: https://www.snapsurveys.com/blog/what-is-the-difference-between-qualitative-research-and-quantitative-research
[4] Multirotor. Logistics and Transport. (2017) [Online]. Available: https://www.service-drone.com/en/applications/logistics-and-transport
[5] Maa-amet. Kaardiserver. Maa-ameti kaart. (2016) [Online]. Available: https://xgis.maaamet.ee/maps/XGis?app_id=UU82A&user_id=at&LANG=1&WIDTH=1620&HEIGHT=974&zlevel=0,552500,6505000
[6] A. Goodchild, J. Toy, "Delivery by drone: An evaluation of unmanned aerial vehicle technology in reducing CO2 emissions in the delivery service industry", Univ. of Washington, Seattle, Dept. of Civil and Environmental Eng. United States. 2016.
[7] DJI. Drones. Phantom 4. Phantom 4 Specs. (2017) [Online]. Available: https://www.dji.com/phantom-4/info
[8] R. Aitken. (2015) How much weight can delivery drones carry? [Online]. Available: http://unmannedcargo.org/how-much-weight-can-delivery-drones-carry
[9] National Aeronautics and Space Administration. Propeller Thrust. (2015) [Online]. Available: https://www.grc.nasa.gov/www/k-12/airplane/propth.html

# Alternative gear set production methods for planetary gearbox

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**Abstract.** This article is about innovative planetary gearbox production methods which is used in a pneumatic vehicle (pneumobile – T1) as a transmission. The pneumatic vehicle is built to compete in "International Aventics Pneumobil competition". The purpose of alternative production methods is to produce gears in a materially more effective manner as well as more time efficiently. The production method for manufacturing gear sets is different to the conventional milling or shaping procedure due to usage of abrasive water jet cutting for prototype construction. The prototype gear sets are tested on a prototype competition vehicle in the course of several weeks. The gear sets are visually inspected after the competition and prior to reassembly for second run time to check how the system responded to competition loads.
The article focuses on positive and negative aspect of traditional and experimental gear manufacturing processes. For applications similar to pneumobile vehicle the water jet cut gears were sufficient enough to be used in the transmission system.

**Key words:** Pneumobile, Planetary gearbox, Abrasive water jet.

## INTRODUCTION

Prototyping by using mass production methods is very expensive, therefore alternative ways of prototyping seem like a logical solution. Alternative production capabilities will reduce the cost of prototype drastically through reduced machining time and universal tools. The benefits however may come at the price of low durability and quality.
Price (averaged offered price) for gear sets when hobbing (tools + manufacturing time) – 420€
Price (averaged offered price) for gear sets when cut with abrasive water jet – 250€
As a student project prototype, the limiting funds and workshop capabilities quickly became a problem which needed an alternative solution. Manufacturing

module 1 gear sets for planetary gearbox in machining manner meant the need for special workbenches and tools, therefore an alternative method was needed. The solution for the prototype problem was an abrasive water jet cutter. The article focuses on positive and negative aspects of manufacturing gear sets with abrasive water jet with the example of prototype planetary gearbox.

## MATERIALS AND METHODS

The purpose of the research was to find an alternative way to manufacture small module gear sets.

The process of gear manufacturing starts from model of the gear. When designing a gear to be cut with abrasive water jet method, several aspects have to be considered:

1. Thickness – the thicker the material gets, the rougher and bent the surface finish gets in the bottom layers, even with nozzle head active compensation (Fig 1) [1][2].

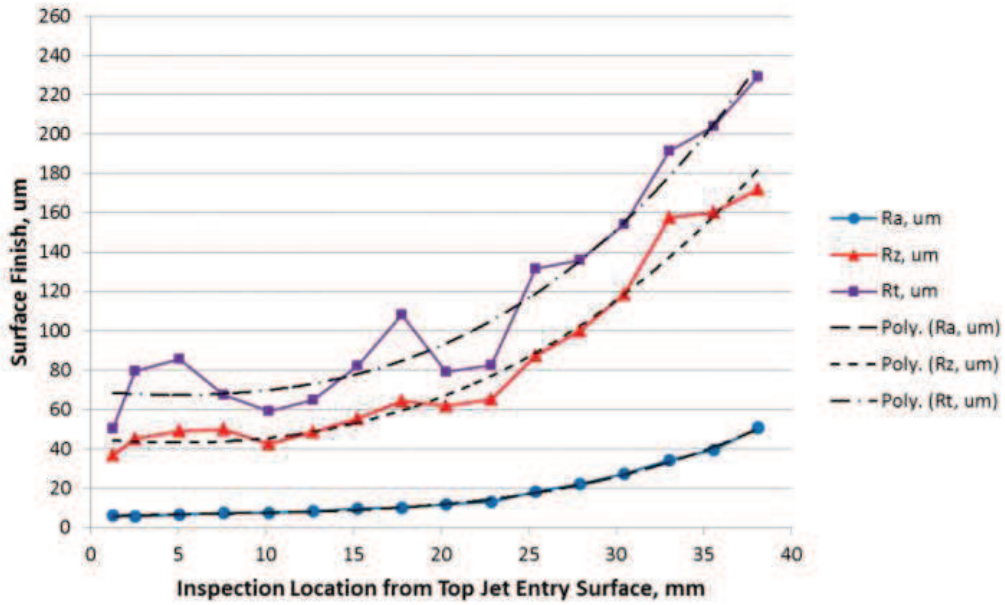


**Figure 1.** Surface finish measurements in 50 mm thick aluminium. Source [1]

2. Module – The module of the gear in this context means the detail level of the part. With smaller modules the problem with jet stream diameter comes into effect (Fig 2). For prototype gears, abrasive water jet workbench "Flow Mach 4–4020c" [3] was used. The stream diameter was provided by the cutting company.

There are several solutions to overcome this problem however they come in the form of altering the original design of the part:
a) Using greater module for the gears
b) Changing the gear tooth height
c) Cutting into the gear tooth bottom to gain the contour by sacrificing the sides of the gear tooth.

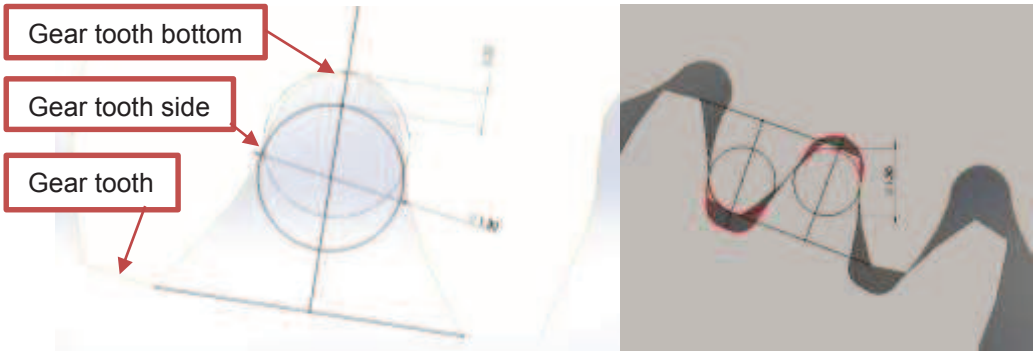


**Figure 2.** Jet stream diameter is larger than the bottom of the gear tooth and affecting the contact of module 1 gear sets

3. Bore – If the gear is used on a shaft where a specific fit is necessary, machining room needs to be added to the work piece.

If the gear has no 3D contours, usually a 2D drawing in the file format of dwg or dxf is enough for abrasive water jet cutting (Fig 3).

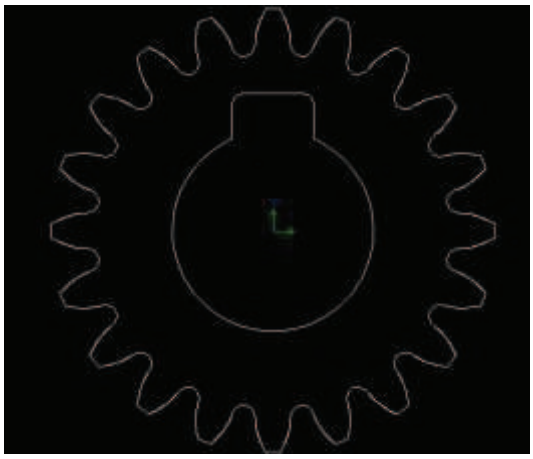

**Figure 3.** DXF file content visualization for abrasive water jet manufacturing

## RESULTS AND DISCUSSION

For research purposes and to test previously mentioned theories, a gear set consisting of six gears was cut (Fig 4). After first visual inspection, bottom 5 mm layer had distinct tapered grooves on smooth curve surfaces. The teeth quality was satisfactory, however the tapered pattern was also present – gear set could only be assembled when all gears faced the way they were cut on the plate. On further assembly it came clear that the jet stream diameter turned into a problem – teeth bottoms were too high and for assembly purposes 0.3 mm of teeth tips per radius had to be removed.

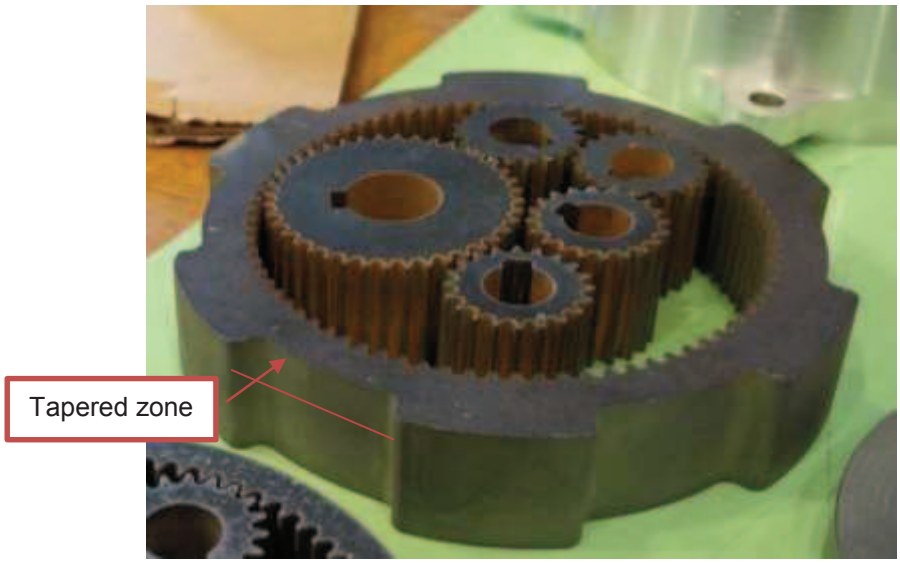


**Figure 4.** Module 1 gears after abrasive water jet manufacturing

After fitting the gear sets to works, a prototype planetary gearbox (Fig 5) was assembled and used as transmission for a pneumatic vehicle which competed in a race competition. For next generation vehicle design process, after around 30 hours of under load working time, the gearbox was disassembled and gear sets visually inspected. No mechanical flaws, that would jeopardize the reassembly of the gearbox, were found.

**Figure 5.** Prototype planetary gearbox

## CONCLUSIONS

In conclusion several new tests should be made with taking in account the features that abrasive water jet manufacturing demands. For now the gears sets cut will be sufficient enough for the prototype gearbox however for other applications, some changes are recommended.

## REFERENCES

[1] P. Miles, A. Henning, Rz: A better measurement of abrasive waterjet cut surface finishes [Online]. Available: https://www.wjta.org/images/wjta/Proceedings/Papers/2013/C2%20-%20PM%20Rz%20-%20A%20Better.pdf [Accessed 28 03 2017].

[2] V. Babashov, G. Mammadova, S. Devadula, A. Rashid, An Investigation on the Suitability of Abrasive Waterjet Cutting for Hybrid Manufacturing of Gears in Automotive Industry [Online]. Available: http://www.diva-portal.se/smash/get/diva2:907532/FULLTEXT01.pdf [Accessed 28 03 2017].

[3] Flow Waterjet, Mach 4 C, [Online]. Available: http://www.flowwaterjet.pl/getattachment/Machines/Mach-4c/Mach-4c-Series.pdf.aspx [Accessed 28 03 2017].

# 3D printing of thermoplastic polyurethane

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**Abstract.** The feeder design of 3D printer Ultimaker 2 which uses fused filament fabrication technology for printing is not ideal for printing thermoplastic polyurethane due the great elasticity of filament. The purpose of this research is to reverse engineer and upgrade original Ultimaker 2 3D printer feeder for printing thermoplastic polyurethane. To fulfil the purpose of this research, the original Ultimaker 2 feeder had to be scanned by using laser scanner. After scanning the measuring points of feeder parts, the received data was then converted into mesh data. Mesh data was later converted into 3D model, which allowed different 3D modelling software's to remodel the feeder system. After the alternations, the new feeder parts were printed out with Ultimaker 2, by using material ABS. The new feeder for Ultimaker 2, works normally without problems. Also the filament didn't jam in feeder during tests. The tests results conclude that the upgraded feeder allows pushing the filament made of thermoplastic polyurethane with greater and even force compare to original feeder, when the filament was covered with glycerol. Presumably this provides stable material flow from extruder and better quality of printing.

**Key words:** Ultimaker, Feeding system, reverse engineering, fused filament fabrication,

## INTRODUCTION

The first 3D printer was invented by Charles Hull in 1984 while working in the 3D systems Corp. He was mostly known by designing process known stereolithographic, which means solid imaging. In 3D printing the layers are successfully printed by on top of each other. There are a vast variety of uses in 3D printing, from plastic to metal and even human body parts. [12].

Ultimaker types of printers are using fused filament fabrication technology or FFF for printing. The technology can be described as a technology where the molten material is forced through printer head's nozzle and deposited on a growing workpiece. The printing tolerance with FFF technology is from 0.05mm to 0.5mm [3].

Thermoplastic polyurethane or TPU was invented in 2013 and in 2016 NinjaTek launched two new industrial grade TPU materials. They were called Cheetah and Armadillo. TPUs are class of elastomers, which are quite unique with their tuneable properties. The soft segment of TPU is based on ester or ester based polyol, this gives TPU its flexibility [10].

NinjaFlex is a filament that is combined with thermoplastic and rubber, which gives the filament quite extraordinary properties in terms of flexibility, mechanical strain and printability. Its flexibility and manufacturing could improve the antennas and conformal components, yet the electrical parameters are still quite unknown. The study published in " IIEE ANTENNAS AND WIRELESS PROPAGATION LETTERS "

called "Infill-Dependent 3-D-Printed Material Based on NinjaFlex Filament for Antenna Applications" shows that NinjaFlex substrate can be used for manufacturing flexible antennas with similar characteristics used now [11].

The feeding system design of 3D printer Ultimaker 2 which uses FFF technology for printing is not suitable to print thermoplastic polyurethane due the great elasticity of filament. The mechanical properties of ABS and two different thermoplastic polyurethanes that are used for 3D printing are given in Table 1.

**Table 1**. The properties of used thermoplastic filaments.

| Filament | Tensile Strength, Yield | Tensile Strength, Ultimate | Elongation at Yield | Elongation at Break | Hardness |
|---|---|---|---|---|---|
| ABS [4] | 35 Mpa | 35 Mpa | 8% | 8% | 70 Shore D |
| TPU 95A [5] | 8.6 MPa | 39 MPa | 55 % | 580 % | 95 Shore A |
| NinjaFlex [3] | 4 Mpa | 12 Mpa | 65% | 660% | 85 Shore A |

The purpose of this research is to reverse engineer and upgrade original Ultimaker 2 3D printer feeding system, for printing thermoplastic polyurethane. To fulfil the aim of this research, some of the task had to be done:

1. Scanning the original feeder parts, in order to receive mesh data;
2. The reversed engineering of received 3D model;
3. Printing of the new feeder parts with Ultimaker 2;
4. Testing of the new feeder.

## MATERIALS AND METHODS

### Scanning of the feeder system

The existing feeding system was scanned using Nikon MCAx20/MMDx50 laser scanner. The measurement accuracy of the scanner is 50 μm [6]. After scanning the feeder parts, the received mesh data was converted into 3D model using SpaceClaim program.

### The reverse engineering of the recieved 3D model

The converted 3D model was then opened with AutoDesk ReMake. The program allows the user to edit the surfaces, deleting and adding surfaces if needed, also fixing holes which came due the scanning- the scanned detail was too small for the scanner head to scan form everywhere. After merging and deleting extra surfaces, fixing holes, the remained surfaces were decreased so it wouldn't change the outcome of detail. This is best shown in Fig.1.

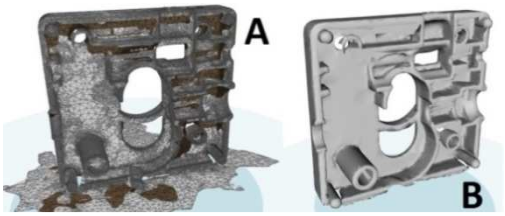


**Figure 1.** In the picture is before using AutoDesk ReMake (A) and after using AutoDesk ReMake (B).

The modelling and chances were made in the program AutoDesk Fusion 360. The unnecessary parts of feeder were deleted the openings for the material movement were made wider. Material tube which leads to printing nozzle can be inserted deeper. After the changes were done, the reverse engineered feeder was printed out with Ultimaker 2, while using the material ABS. For knowing if the alternations had any affect, the compressive stress tests were done.

## Printing of the feeder parts

The printing of the feeder was done with Ultimaker 2, using the filament called ABS with diameter of 3mm. The printing parameters are shown in Table 2.

**Table 2.** Important parameters for printing the new feeder.

| **Parameter** | **Value** |
|---|---|
| Printing speed | 40 mm/s |
| Retraction | 4.49 mm |
| Filament flow | 105% |
| Printing speed | 100% |
| Temp of printing nozzle | 230ºC |
| Infill | 20% |
| Infill pattern | Lines |

## Testing of the new feeder

For calculating the force, the used mass was found with the scale while the filament pushed to the scale. The diameter of the filament was also know, it was 3mm. All the parameters used while testing compressive stress are shown in Table 3. The used materials and their properties can be found in Table 1.

**Table 3.** The compressive stress test conditions.

| **Feeding speed** | **Retraction** | **Filament flow** | **Printing speed** | **Temp of nozzle** | **Infill** | **Infill pattern** |
|---|---|---|---|---|---|---|
| According to normal printing | 0 mm | 105% | 80 mm/s | 191ºC | 100% | Concentric |

The material tube was connected with scale which allowed seeing the mass with what the filament was pushed on the scale. The tests were done five times per each filament and the mass obtain there was read when the filament was jammed, shown in Fig. 2, or the filament started to slip. Slip was when the feeder started to feed but the filament didn't move. The measurements were done by using a kitchen scale Soehnle 66100 [13].

**Figure 3.** Filament is jammed between feeder roller and feeding parts.

The compressive stress was found when the filament is pushed through material tube. The filament pushes to the scale, which allowed the author to estimate the effecting stress to the heating nozzle.

Standard deviation $s(x_{ij})$ of mass measured with scale was calculated with Equation 1 [7,8].

$$s(x_{ij}) = \sqrt{\frac{1}{n_i - 1}\sum_{j=1}^{n_i}(x_{ij} - \bar{x})^2} \quad (1)$$

Where $x_i$ is value of measurement;
$\bar{x}$ is the arithmetic mean;
n is the number of measurements.

Experimental standard deviation in the mean $s(\bar{x}_i)$ was calculated with equation 2 [9].

$$s(\bar{x}_i) = \frac{s(\bar{x}_{ij})}{\sqrt{n}} \quad (2)$$

The experimental standard deviation in the mean $s(\bar{x}_i)$ can be taken as being equal to the type A evaluation of uncertainty $u_{A(x)}$. The uncertainty of measurement device $u_B$.

$$u_B = \frac{\Delta x}{\sqrt{3}} \quad (3)$$

Where $\Delta x$ is absolute error of measurement device.

Cumulative uncertainty $u_C$ was calculated by using equation 4.

$$u_c = \sqrt{u_A^2 + u_B^2} \quad (4)$$

## RESULTS AND DISCUSSION

Modelled feeder parts were printed out by using 3D printer Ultimaker 2, material ABS was used while printing these parts. Some minor alternations were made in SolidWorks 2013. The modelled and printed feeder parts can be found in Fig. 4.

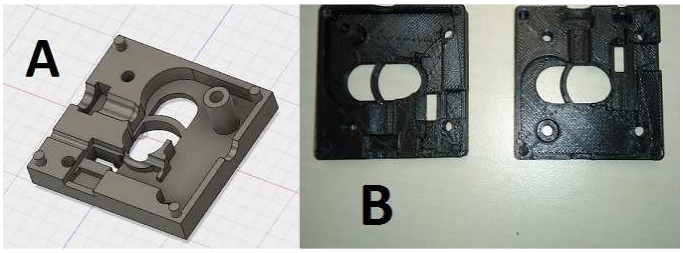


**Figure 4.** In the figure there is feeder part modelled in (A) and a printed feeder parts (B)

To see if the new feeder had any affect, the compressive stress tests were made, by using different materials. The results of the tests are shown in Table 4.

**Table 4.** The compressive stress tests result.

| **Material** | **Arithmetical mean of measured values [kg]** | | **Standard deviation** | | **Compressive stress [N/mm$^2$]** | |
|---|---|---|---|---|---|---|
| | Original | New | Original | New | Original | New |
| Ninjaflex | 0.277 | 0.251 | 49.95 | 21.013 | $0.384 \pm 0.086_{95\%}$ | $0.348 \pm 0.036_{95\%}$ |
| TPU 95A | 1.154 | 1.292 | 277.18 | 23.607 | $1.600 \pm 0.478_{95\%}$ | $1.79 \pm 0.040_{95\%}$ |
| ABS | 2.596 | 3.036 | 648.714 | 158 | $3.602 \pm 1.12_{95\%}$ | $4.212 \pm 0.272_{95\%}$ |
| NinjaFlex + glycerol | 0.337 | 0.424 | 71.48 | 15.166 | $0.468 \pm 0.123_{95\%}$ | $0.588 \pm 0.026_{95\%}$ |

## CONCLUSIONS

The new parts for Ultimaker's feeder allow the material tube, which connects the feeder and printer head, to go deeper inside feeder. The results show that original feeder's compressive stress was a bigger compare to new feeder. After adding glycerol to the filament, the compressive stress with new feeder was bigger compare to original. Adding the glycerol should be done after the feeder, so the material tube would be more

lubricated, this also avoids the feeder roller to be lubricated. The standard deviation between original and new feeder, while using NinjaFlex covered with glycerol, has around 4,7 times difference. This can conclude, that using NinjaFlex covered with glycerol in new feeder could improve printing qualities. New feeder using ABS filament had around 12 times bigger compressive stress than NinjaFlex. While using NinjaFlex with the new feeder the filament doesn't jam so often, mostly because of the small gap between feeder roller and material tube. The compressive tests show that the material ABS has the biggest compressive stress with new feeder. Tests show that adding glycerol on the filament helps for the compressive stress. The standard deviation between NinjaFlex and TPU 95A is quite small, when it was tested with new feeder parts. Overall the tests conclude that the new feeder works better with ABS and TPU 95A. If glycerol is added on the filament, then the filament NinjaFlex also prints better with new feeder.

## REFERENCES


[1] Ultimaker Materials. https://ultimaker.com/en/products/materials (20.03.17)

[2] 3D Printers - How Do They Work? - *3D Printing for Beginners* http://3dprintingforbeginners.com/wp-content/uploads/2014/04/3D-Printing-Technology_Download.pdf (03.02.2017)

[3] Flexible Polyurethane Material for FDM Printers.- *NinjaFlex® 3D Printing Filament* https://ninjatek.com/wp-content/uploads/2016/05/NinjaFlex-TDS.pdf (12.03.2017)

[4] Rigid Styrene Material for FDM Printers. - *NinjaTek™ ABS 3D Printing Filament* https://ninjatek.com/wp-content/uploads/2016/05/ABS-TDS.pdf (15.03.2017)

[5] Technical data sheet TPU 95A. (19.10.2016). - *Ultimaker It's in the making.* https://s3-eu-west-1.amazonaws.com/prod.ultimaker.com/download/materials/Ultimaker-TPU95A-(TDS).pdf (20.03.2017)

[6] ModelMaker MMDx. – *Nikon*. http://www.nikonmetrology.com/en_EU/Products/Laser-Scanning/Handheld-scanning/ModelMaker-MMDx/(specifications) (27.03.2017)

[7] Aruvee, E., Engstrand, E., Olsson, U. (2000) - Matemaatiline statistika. Tartu 111 lk.

[8] Laaneots, R., Mathiesen, O.(2011) An instruction to metrology. Tallinn, TUT Press

[9] Ficher U., Heinzler, M., Näher, F., Paetzold, H., Gomeringer, R., Kilgus, R., Oesterle, S., Stephan, A.,(2008) Mechanical and Metal Trades Handbook, (2nd English edition). Verlag Europa Lehrmittel, Germany, 428pp (in English)

[10] McDonough, J., K., (01.10.2016). Thermoplastic polyurethanes for 3D printing – *Rubber World.* Lk 40-42. http://web.b.ebscohost.com/ehost/pdfviewer/pdfviewer?sid=2500ea22-dee8-4573-85c7-f8bdb6fca79a%40sessionmgr101&vid=3&hid=125 (29.03.2017)

[11] Moscato, S., Bahr, R., Le, T., Pasian, M., Bozzi, M., Fellow, L., P., Tentzeris, M., M. Infill Dependent 3-D-Printed Material Based on NinjaFlex Filament for Antenna Applications. (29.03.2017) https://pdfs.semanticscholar.org/b302/a0cc608b61f300cc64e4aff0546c62837df7.pdf?_ga=1.112873997.803393932.1490799101 (29.03.2017)

[12] Bhandari, S., Regina, B., 3D Printing and Its Applications. - *International Journal of Computer Science and Information Technology Research Vol. 2, Issue 2, pp.* Aprill-Juuni 2014. lk. 378-380

[13] Page White. – *Soehlne.* https://www.soehnle.de/en/kitchen-scales/digital- kitchen-scales/details/page-white.html (30.03.2017)

# Maintenance mechanism for army cable

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**Abstract.** The aim of this article is to give an overview of Estonian Defence Forces method of maintaining an army cable and to design a maintenance mechanism for semi-automatic army cable winder. The cable has to be constantly maintained to prolong its useful lifespan. The problem with today's cable lies in their maintenance method. The method requires a great amount of resources and labor to maintain one spool of cable. A new design solution is required to optimize resources, requiring only one person to operate the device. Another solution would be to increase simplicity of the device so it can be used by anyone. With the knowledge of the Estonian Defence Forces inventory, it will be more attainable to simplify the design of this devices and use it for their advantages. For the purpose of this article a prototype was developed to test the devices efficiency and user-friendliness.

**Key words**: military, army cable, wire, cleaning, mechanism.

## INTRODUCTION

Estonian Defence Forces uses three different methods for communication: radio-, cable- and alternative communication [1]:

1) Radio communication – transmission of information via radio waves. Radio communication works by using a radio transmitter and one or more radio receivers [2];
2) Cable communication - transmission of information via electric wiring [3];
3) Alternative communication – subdivides into three methods: signal communication, civil communication and usage of a courier [1]. Alternative communication is mostly based on creativity. Used when there is no radio- or cable communications.

All three communication types are very important for Estonian Defence Forces. This means that all communication equipment for these three methods require continuous development and modernization.

This article will establish the Estonian Defence Forces cable communication method. Maintenance mechanism for an army cable is a part of a project called semi-automatic winder and maintenance mechanism for army cable.

Cable communication is used by winding the cable onto the terrain between point A and point B. Telephones are connected to each end of the cable to exchange information. The period of time for using cable communication can vary from couple of hours to couple of days. Afterwards they respool the mismanaged cable and change position.

The protocol that the Estonian Defence Forces use today, needs at least four people to maintain a spool of army cable. The first person holds the cable harness that has a spool filled with mismanaged cable. The second person cleans the cable by holding the cable with a oiled cleaning cloth or a rag. The third person also cleans the cable but the individual holds the cable with a less oiled cleaning cloth or a rag, thus removing excess oil and directing the cable onto the spool evenly. The fourth person uses the hand crank to wind the empty spool where the cleaned cable will be directed. This method needs a lot of workforce and there has to be a maintenance mechanism that is able to do most of the processes independently, in order to decrease the labor resources required.

Every household uses sponges for cleaning surfaces or dishes, this does not exclude the Estonian Defence Forces either. As a result, it is known, that they order sponges in large quantities so everyone can easily access the sponges. It is possible to use sponges to maintain the army cables. The device should also ensure the opportunity to use a cleaning cloth or a rag to maintain the cable. For this reason, it is necessary to assemble a sponge holder and a cleaning cloth fixer to lower the workforce necessary for maintaining a cable.

## MATERIALS AND METHODS

Maintenance mechanism will be made of sheet metal and bended according to the assembly. Ermaksan Fibermak Momentum Gen-3 laser cutting bench will be used for cutting the sheet metal and Trumpf Trubend 5130 for bending the metal.

Even though the maintenance mechanism will not be used under heavy loads it has to be resistant and reliable for military purposes. In that assumption 2 mm thick sheet will be used for the maintenance mechanism. The chosen material will be Domex 355MC.

**Table 1.** Domex 355MC mechanical properties [4].

| Material | Thickness | Yield strength (min. Mpa) | Tensile strength (Mpa) | Elongation (min. %) | Min. inner bend radius for a 90° bend |
|---|---|---|---|---|---|
| DOMEX 355MC | 1.80-3 | 355 | 430-550 | 23 | $0.2xt^{1)}$ |

1) *t* is material thickness

Domex 355MC grade is produced under rigorous quality control. A well-balanced analysis with a fine grain structure produced through thermomehanical rolling creates a steel with first-class mechanical and cold-forming properties. With the steel's high

purity, these properites make a outstanding repeatability, excellent bending and cutting characteristics and a steel that can be welded using all standard methods [4].

Domex 355MC does not need much adjustment on the Trumpf Trubend 5130 bending bench. The corrections usually vary from the angle of a bend and the length of the sides.

Two sponges were used with the measurements of 85x88x27 mm. For the sponges to be tight, it is necessary that the sponges are maximally compressed. To get this result one sponge was put on another and then pressured together. The result thickness was 17 mm. When the sponges were pressured the width did not change, that means the width stayed 85 mm. It is known that most sponges are in a different shape and size but there are not many smaller sponges than the ones used in this mechanism. In addition, if the sponges are with larger dimensions, it is easy to cut them into neccesary shape. It is important that the maintenance mechanism is easily understandable and operated for everyone without any special training.

Figure 1. illustrates the exploded view of the maintenance mechanism. The device has to ensure that no extra wear or any other kind of damage would be inflicted on the cable. For that reason, two rollers were added inside of the assembly to ensure less friction on the sides. The cable height does not change, while going to the next mechanism that directs the cable on the spool. However that mechanism itself moves left and right distributing the cable evenly on the spool. In that assumption the rollers are only needed on the sides of the maintenance mechanism. Washers will be used to fix the rollers in the right position.

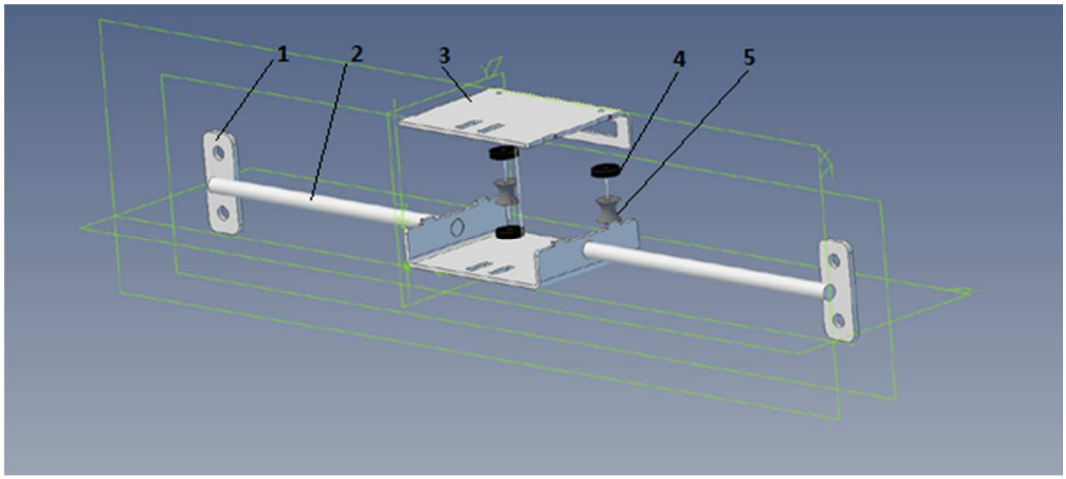


**Figure 1.** Assembly of maintenance mechanism, where 1-mounting plate, 2- 8mm round bar, 3- assembly for holding sponges or a cleaning cloth, 4- washer, 5- roller.

The semi-automatic winding and maintenance mechanism project specifies that the maintenance mechanism has to be removable. In order to accomplish that, there will be 8 mm round bars welded on both sides of the assembly to make sure that the maintenance mechanism is centered and in the end of the round bars will be a 3 mm thick sheet metal plates with suitable holes for M8 bolts. On the frame of the project there will be matching plates to fix the maintenance mechanism with bolts.

## RESULT AND DISCUSSION

Most of the Estonian Defence Forces cables are from the sixties and they are still being used regularly. Most of the cables used in civilisation are not used as often. Those cables are laid between point A and point B and left there until it reaches the point of replacement. However, the Estonian Defence Forces use the same cable over and over. After every use, maintenance for the the cables are necessary to preserve them for numerous decades. In conclusion the cables used in civilisation do not need this kinda of a maintenance as military cables and for the same reason there has not been a cable maintenance mechanism created.

A prototype of the maintenance mechanism was constructed to test out following:

1) How well the sponges fit in the mechanism and are the sponges fixed well enough;
2) How easy is it to use the maintenance mechanism;
3) Can the cable move freely between the sponges;
4) Are the rollers correctly positioned;
5) Is it possible to use cleaning cloth or a rag in the maintenance mechanism.

Figure 2. illustrates an assembled maintenance mechanism with two sponges in the assembly. The sponges fit perfectly inside of the maintenance mechanism. Sponges were pressured together enough that they would not fall out. It was a bit hard to get them out of the mechanism when the sponges were pushed in equally and lined with the side of the mechanism. To resolve this problem a cap was added on the both sides of the assembly, where the sponges could be grabbed and pulled out more easily.

**Figure 2.** Assembly of maintenance mechanism with sponges

Figure 3. illustrates the maintenance mechanism, which has both sponges in it and a cable going through. A spool filled with cable on a harness that helps the spool turn can be seen it the background of Figure 3. Testing showed that cable could move freely between the sponges and the rollers where in the right position to protect the cable from additional wear. The preparation for maintaining the cable in the maintenance mechanism works as following: firstly the cable has to be put through the mechanism and then the sponges are added. If the sponges are put in the mechanism first then there will not be any room to pull the cable through.

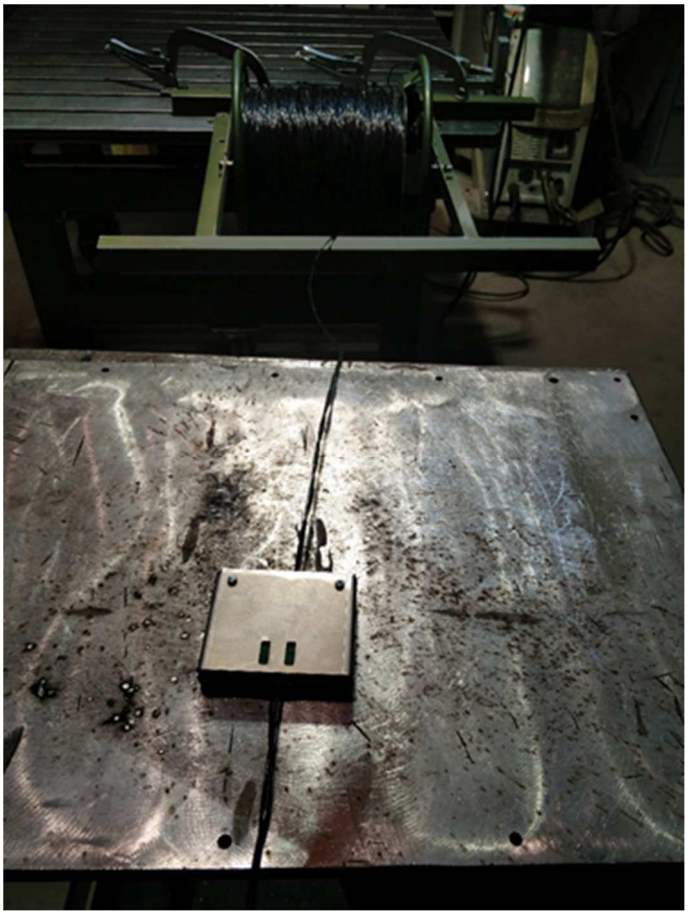

**Figure 3.** Assembly of maintenance mechanism cleaning a cable with sponges

Figure 4. illustrates the maintenance mechanism were a piece of rag is used for cleaning the cable. Should be approached creatively and try different methods when using a cleaning cloth or a rag for maintaining the cable. The holes were a bit small for attaching the rag therefore the holes were made 2 times longer.

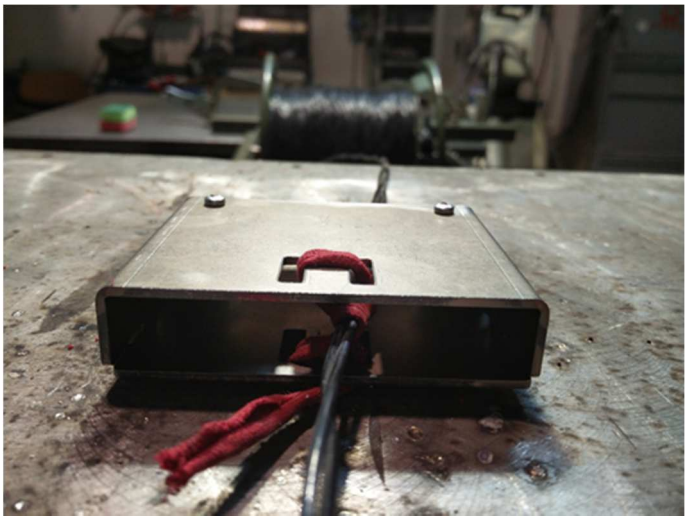

**Figure 4.** Assembly of maintenance mechanism cleaning a cable with a piece of rag

## CONCLUSIONS

The maintenance mechanism maintained the cable as Estonian Defence Forces requires. By making the prototype, it was clearer what needed modification and how would the modification increase efficiency. The mechanism is easy to use with sponges or with a cleaning cloth. However it is necessary to try different methods when using a cleaning cloth or a rag to get the best result.

## REFERENCES

[1] Estonian Defence Forces soldier manual for trainees, p. 157-159, 2008, [Online] Available: http://www.mil.ee/UserFiles/sisu/dok/Soduriopik.pdf [Accessed: 20.03.2017]
[2] Radio communication, [Online] https://et.wikipedia.org/wiki/Raadioside [Accessed: 20.03.2017]
[3] Cable communication, [Online] https://et.wikipedia.org/wiki/Traatside [Accessed: 20.03.2017]
[4] SSAB DOMEX 355MC, [Online] https://www.ssab.com/products/brands/ssab-domex-structural-steel/products/ssab-domex-355mc [Accessed: 20.03.2017]

# The effect of unsprung mass on the driving quality on the basis of an electric motorcycle

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**Abstract.** Due to recent years progress in electric vehicle industry more in-wheel based electric motors are being used in electric vehicles for generating torque. That kind of design enables to cut energy loss in transmission and gearbox. But on the other hand using in-wheel based engines increases vehicle's unsprung mass. This article presents the effects of increased unsprung mass in various suspension configurations on the basis of an electric motorcycle. Kinematic models and simulations were carried out using SolidWorks Motion software. The results indicated that depending on suspension's characteristics increasing unsprung mass may have a positive effect on electric motorcycle's driving quality.

**Key words:** Unsprung mass, in-wheel motor, electric motorcycle, suspension.

## INTRODUCTION

The subject of the research is an electric motorcycle which is currently being developed in Tartu Science Park. Electric motorcycle is based on a model BMW f650gs and uses two EnerTrac MH602 liquid cooled dual hub motor. Both motors can generate up to 60 kW of peak power and 40 kW power constantly. EnerTrac in-wheel motor is brushless direct current motor which makes this motor efficient and easy to control [1].

Altough in-wheel motors enable engineers to eliminate conventional gearbox and transmission and therefore cut energy losses in those mechanisms, in-wheel motors makes motorcycle's swingarm heavier. This causes an effect known as increased unsprung mass. It is a largely debated subject if unsprung mass has positive or negative effect on vehicle's dynamics.

The objective of this article is to determine the change in motorcycle's dynamics when increasing unsprung mass by simulating motorcycle's reaction to a road bump. During the simulations motorcycle rear suspension's characteristics were changed to see how unsprung mass effects the vertical acceleration of motorcycle frame. Received data were compared with the same simulations but with less unsprung mass, then analysed and suggestions on motorcycles rear suspension's characteristics were made.

## MATERIALS AND METHODS

Motorcycle's rear suspension system can be described as a two degree-of-freedom model (Fig. 1). This model determines motorcycle's parts which take part in softening road imperfections. These components are rear suspension and rear tire.

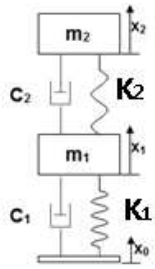


**Figure 1**. Abstract model of motorcycle's rear suspension system. Source: [2]

These components, suspension and rear tire, have their own characteristics. In Figure 1, $C_1$ and $K_1$ represents tire damping coefficient and tire stiffness. $C_2$ and $K_2$ are respectively suspension's damping coefficient and spring stiffness. $M_1$ is unsprung mass and $m_2$ is a mass of a motorcycle's body.

Taking account model described in Figure 1 and electric motorcycle's 3D model, kinematic scheme of rear part of a motorcycle were created by using SolidWorks (Fig 2). In this kinematic scheme motorcycle main body was restricted to move only vertically. Kinematic scheme constructed in software environment allows us to use SolidWorks Motion software to conduct motion study.

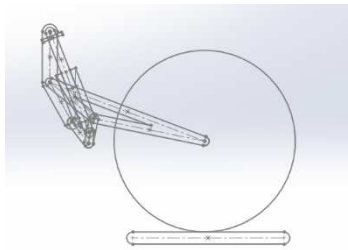

**Figure 2.** Kinematic scheme of a rear section of a motorcycle.

Based on motorcycle's rear part kinematic scheme simulations were carried out. In each simulation driving over 50 mm round obstacle with the speed of 30 km/h were imitated and vertical acceleration of a motorcycle's body was then registered (Fig. 3). Vertical acceleration of a main body implies force which the driver receives when driving over an obstacle. According to Newton's Second Law, the greater the acceleration, the more force driver will receive from driving over a bump.

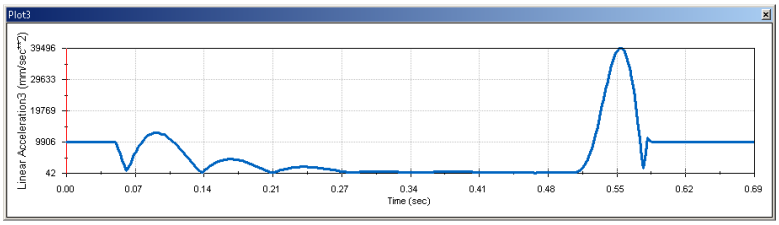

**Figure 3**. Example of a vertical acceleration graph of a motorcycle's body.

For simplification, it was assumed that half of the motorcycles mass, 130 kg, will be loaded on a rear wheel. Unsprung mass of a swingarm were chosen 40 kg with in-wheel motors and 15 kg without them. Stiffness and damping factor on a tyre were chosen $K_1$=300 kN/m and $C_1$=0,00035 N*s/mm [3]. Although motorcycle's tire characteristics could be described as non-linear, for this simulations it was assumed that they were linear. Rear suspension's damping factors chosen for simulations were 5, 25, 50, 100, 150, 200 and 250 N*s/mm. Spring constants of 50, 100, 150, 200, 250, 300, 400 and 500 kN/m were used during simulations.

## RESULTS AND DISCUSSION

### Simulations with unsprung mass of 40 kg

First set of simulations were carried out with unsprung mass of 40 kg. Total of 48 simulations were carried out on different suspension parameters. The results are seen in Table 1. From this table we can see that suspension with damping factor of 25 N*s/mm and with spring constant 500 kN/m had the least impact on motorcycle's frame and therefore for driver's body. This can be explained as most of the shock coming from road bump is absorbed in motorcycles spring. For practical reasons it is recommended to use small damping coefficients because suspension tends to oscillate (Figure 4).

**Table 1**. Registered accelerations with unsprung mass of 40 kg, m/s^2.

| Spring constant, kN/m \ Damping factor, N*s/mm | 25 | 50 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|---|
| 50 | 27,983 | 28,209 | 32,378 | 35,329 | 37,438 | 39,054 |
| 100 | 22,191 | 26,955 | 32,144 | 35,270 | 37,412 | 39,057 |
| 150 | 19,663 | 26,075 | 31,943 | 35,205 | 37,399 | 39,058 |
| 200 | 18,156 | 25,431 | 31,775 | 35,145 | 37,387 | 39,045 |
| 250 | 17,244 | 24,972 | 31,631 | 35,102 | 37,367 | 39,038 |
| 300 | 16,785 | 24,654 | 31,510 | 35,065 | 37,346 | 39,031 |
| 400 | 16,815 | 24,360 | 31,346 | 34,991 | 37,317 | 39,021 |
| 500 | 14,838 | 22,015 | 29,978 | 34,463 | 37,393 | 39,372 |

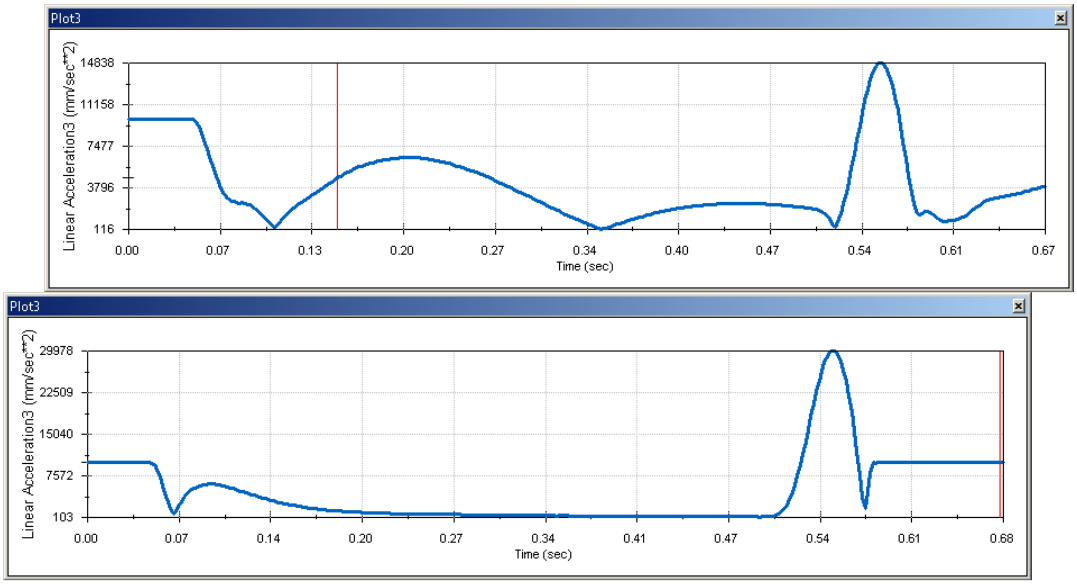


**Figure 4**. Example of oscillation. Upper picture represents suspension with parameters C=25 N*s/mm and K=500 N/m. Lower picture represents parameters C=100 N*S/mm and K=500 N/m.

From the Figure 5 it is seen that spring constant do not have so much impact on vertical acceleration when using higher damping coefficients. This can be explained by the fact that suspension with higher damping coefficients cannot absorb rapid shock coming from rear wheel and therefore shock impact will be transferred directly to motorcycle's body.

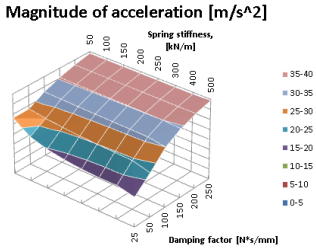


**Figure 5.** Magnitude of acceleration with unsprung mass of 40 kg.

**Simulations with unsprung mass of 15 kg**

To see the difference between heavier and lighter swingarm, simulations with unsprung mass of 15 kg were carried out. Simulations showed a slight difference in the results. The results can be seen in Table 2. Overall the results looked similar to the simulations which were carried out with heavier swingarm.

**Table 2**. Registered accelerations with unsprung mass of 15 kg, m/s^2.

| Spring constant, kN/m \ Damping factor, N*s/mm | 25 | 50 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|---|
| 50 | 25,458 | 26,417 | 31,453 | 35,085 | 37,682 | 39,623 |
| 100 | 19,860 | 25,031 | 31,164 | 34,989 | 37,636 | 39,612 |
| 150 | 17,328 | 24,067 | 30,914 | 34,889 | 37,589 | 39,600 |
| 200 | 16,798 | 23,357 | 30,700 | 34,812 | 37,554 | 39,687 |
| 250 | 14,828 | 22,832 | 30,518 | 34,740 | 37,528 | 39,554 |
| 300 | 14,269 | 22,456 | 30,357 | 34,664 | 37,500 | 39,534 |
| 400 | 14,081 | 22,058 | 30,122 | 34,543 | 37,434 | 39,508 |
| 500 | 14,838 | 22,016 | 29,978 | 34,463 | 37,393 | 39,493 |

3D graph of simulations with lighter swingarm can be seen on Figure 6. The shape of a graph looks similar with Figure 4. The smallest acceleration registered were with suspension parameters C=25 N*s/mm and K=500 kN/m.

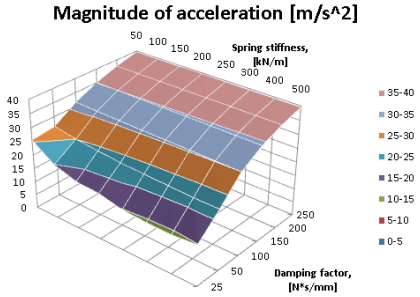


**Figure 6**. Magnitude of acceleration with unsprung mass of 15 kg.

To compare these two results, new table was formed where data from Table 2 was subtracted from data in Table 1. This way differences in accelerations with different suspension parameters can be seen. Results of this subtraction is shown in Table 3. From this table we can see, that relation with acceleration and unsprung mass is not linear. Results with higher damping coefficients shows a slight improvement in absorbing road bumps while driving. This can be explained that most of the shock is absorbed in tyre while motorcycle's swingarm is heavier and suspension is more 'rigid'.

What is interesting is that simulations showed that spring stiffness of 500 kN/m had no or very little impact on motorcycle's dynamics while having different unsprung mass.

**Table 3**. Acceleration differences, m/s^2

| Spring constant, kN/m \ Damping coefficient, N*s/mm | 25 | 50 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|---|
| 50 | 2,525 | 1,792 | 0,925 | 0,244 | -0,244 | -0,569 |
| 100 | 2,331 | 1,924 | 0,980 | 0,281 | -0,224 | -0,555 |
| 150 | 2,335 | 2,008 | 1,029 | 0,316 | -0,190 | -0,542 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **200** | 1,358 | 2,074 | 1,075 | 0,333 | -0,167 | -0,642 |
| **250** | 2,416 | 2,140 | 1,113 | 0,362 | -0,161 | -0,516 |
| **300** | 2,516 | 2,198 | 1,153 | 0,401 | -0,154 | -0,503 |
| **400** | 2,734 | 2,302 | 1,224 | 0,448 | -0,117 | -0,487 |
| **500** | 0 | -1 | 0 | 0 | 0 | -121 |

Figure 6 visualizes the effects of increased unsprung mass. The blue area indicates that using those particular suspension characteristics (higher damping coefficients) the motorcycle's performance improves while using heavier swingarm and vice versa. Lighter swingarm will perform better with lower damping coefficients.

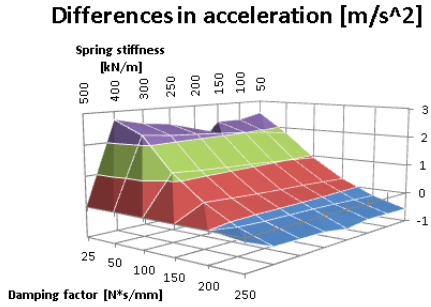


**Figure 7.** Acceleration differences of simulations.

## CONCLUSIONS

Although simulations indicate that changing unsprung mass motorcycle's dynamics while driving on a bumpy road changes also no solid statements could be made if this effect is positive or negative. It all depends on what kind of suspension is used in what configuration. But nevertheless, Figure 4 indicates that when possible suspensions with smaller damping coefficients should be considered to use while using in-wheel motors.

When it comes suspensions with higher damping factors Figure 6 shows that the effect may be opposite. Adding unsprung mass in those configurations to swingarm reduces motorcyle's frame vertical acceleration and therefore reaction to a road bump.

This research showed, that SolidWorks Motion software is capable of solving dynamic problems and helps to choose optimal suspension parameters.

## REFERENCES

[1] EnerTrac motors, Datasheet of EnerTrac MH602 motor [ONLINE]. Available: http://www.enertrac.net/product.php [Accessed 23.03.2017]

[2] Anderson, M., Harty, D., Unsprung Mass with In-Wheel Motors – Myths and Realities. [ONLINE]. Available: http://www.proteanelectric.com/wp-content/uploads/2013/07/protean-Services3.pdf [Accessed 24.03.2017]

[3] Apicella, M., Ride Model Analysis – The Development of Motorcycle Suspension Damping to Optimise Vehicle Grip Through Vehicle Dynamics Fundamental Model Formulations, 2015. [ONLINE] Available: https://core.ac.uk/download/pdf/30617928.pdf [Accessed 25.03.2017]

# Modeling of shear pin for an industrial robot end effector

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**Abstract:** Mechanical overload conditions must be avoided on robot arms. One possible solution is to use shear pins that break on overload. A way to dimension shear pins is use FEM modeling. For this purpose Solid Edge CAD system was used. The chosen material was ABS and the fixture conditions with loading conditions were chosen to suite mechanical design of the planned end effector. From the simulations the best solution from the selection can be chosen. The chosen pin can be further tested in real life to validate the simulation results.

**Keywords:** FEM, plastic, shear pin, simulation.

## INTRODUCTION

Because robotics is increasing in importance in the economy, then the development of the field is increasing. Estonian University of Life Sciences has a Mitsubishi Electric robotic arm RV-4FL that is used as a teaching object. The robotic arm has lifting capability of 4 kg[1]. To increase the functionality of the robot different end effectors are needed. One possible gripper design is a universal jamming gripper that can pick up unfamiliar objects of widely varying shape and surface properties[2,3]. Therefore a prototype jamming gripper for RV4-FL is being built. To lessen the change

of significant damage to the robot arm from overloading shear pins were introduced to the design of the prototype gripper, that must break at the 4 kg lifting capability.

## MATERIALS AND METHODS

Utilising Solid Edge in build FEM capabilities four different designs were analysed. A solid cylinder, throw hole cylinder, V-cut body and V-cut body with throw hole. The pin material was chosen ABS plastic that has yield strength of 31 MPa. As the gripper design has 4 pins in the design, making the safety threshold to be cut down to 1 kgf= 9.81 N. Pin base form is a cylinder with a diameter of three and length of five mm. Throw hole sized one mm in diameter was placed on the axis of the cylinder. The V cut with a sharp 90 deg tip, depth of cut 0.5 mm was placed 1.92 mm from the reference plane of the cylinder. Normal shear pins are subjected to pure shear loadings[4]. The pin is fixed on both ends to the other parts, the dimensions can be seen on figure 1.

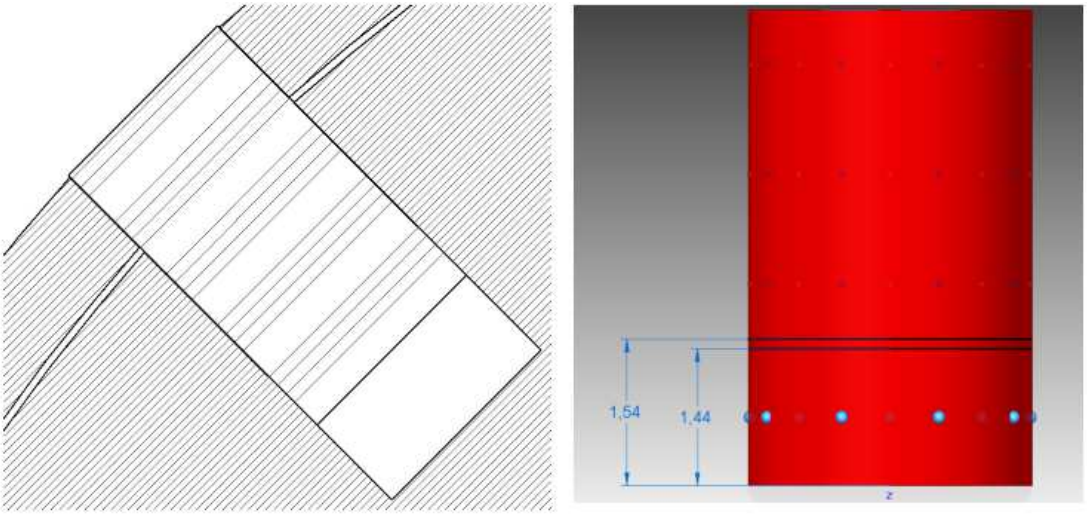


**Figure 1.** Shear pin fixture dimensions (right), cut throw section of the gripper assembly showing pin location(left).

Fixed and force applied (9.81 N) surfaces are shown on figure 2 for the simulation along with the generated mesh with element size 0.11mm.

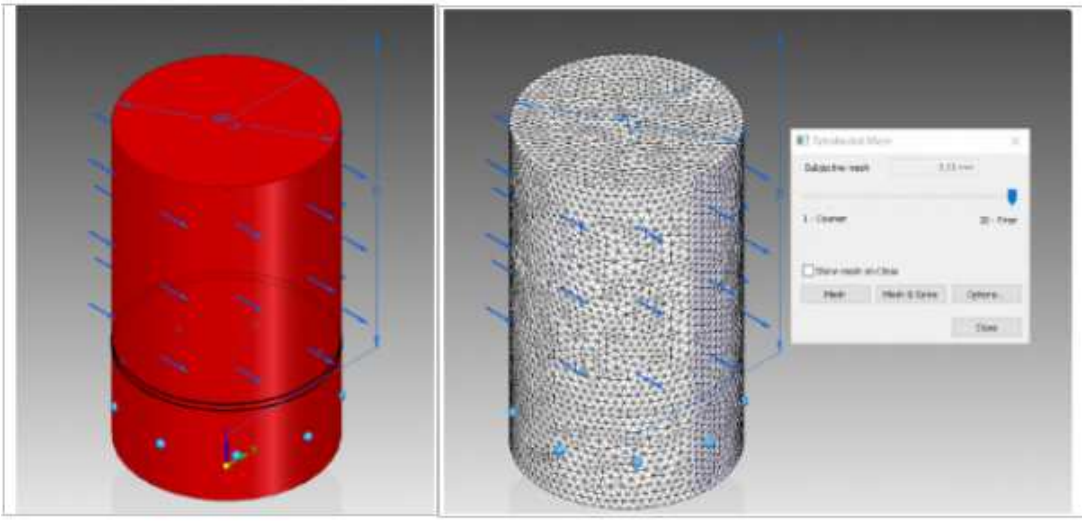

**Figure 2.** Simulation model fixed (dots) and force applied (arrows) surfaces, generated mesh (left)

## RESULTS AND DISCUSSION

Solid cylinder simulation had largest von Mises stress value of 20.3 MPa remaining under the material yield strength(figure 3). As the largest stress concentration is located only in a few nodes, the results have to be taken as a guidance only.

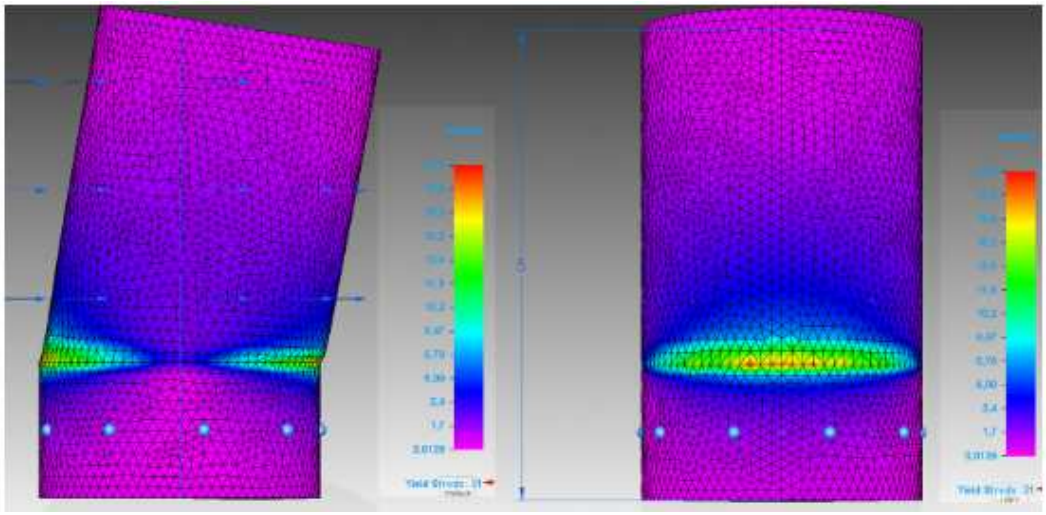

**Figure 3.** Solid cylinder FEM results.

Throw hole cylinder simulation had largest von Mises stress value of 37.2 MPa going over the material yield strength(figure 4). As the largest stress concentration is located only in a few nodes, the results have to be taken as a guidance only.

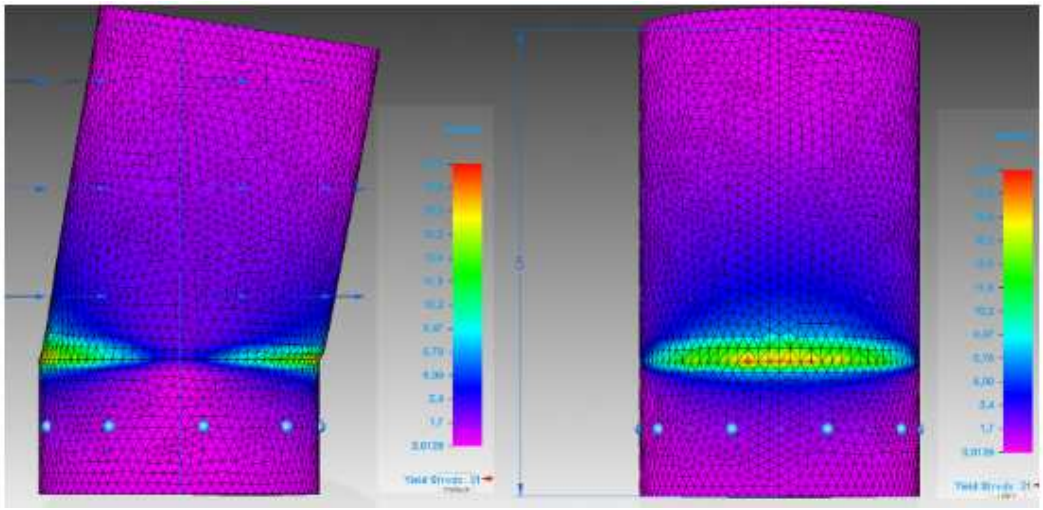

**Figure 4.** Throw hole cylinder FEM results.

V-cut body simulation had largest von Mises stress value of 37.1 MPa going over the material yield strength(figure 5). As the largest stress concentration is located only in a few nodes, the results have to be taken as a guidance only.

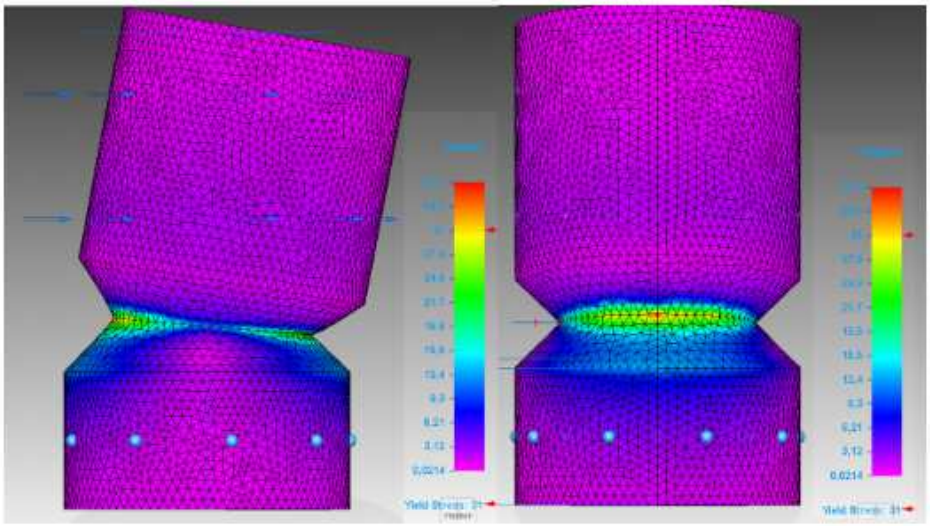

**Figure 5.** V-cut body FEM results.

V-cut body with throw hole simulation had largest von Mises stress value of 36.7 MPa going over the material yield strength(figure 6). As the largest stress concentration is located only in a few nodes, the results have to be taken as a guidance only.

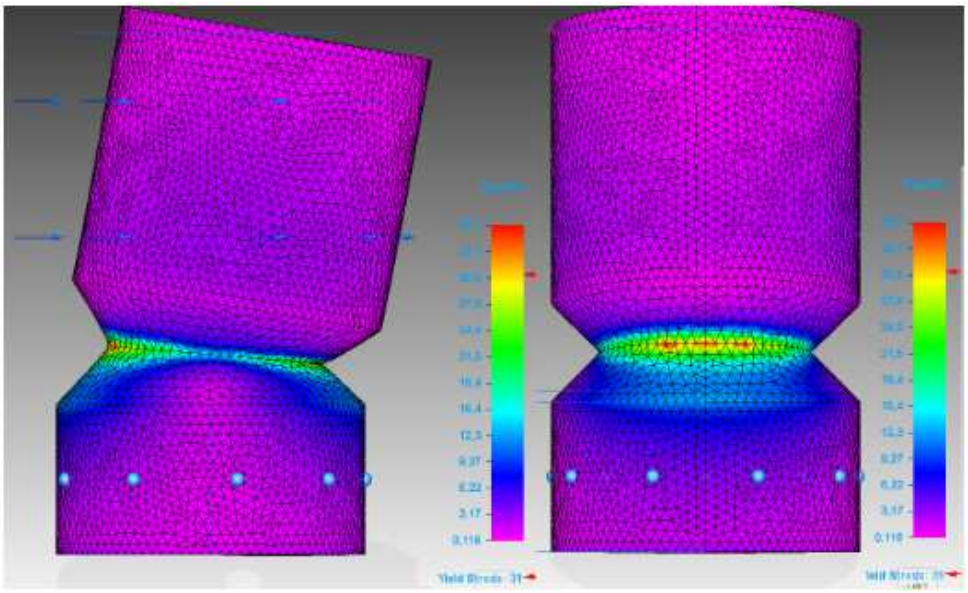

**Figure 6.** V-cut body with throw hole FEM results.

All the modified bodies simulation results from the base cylinder exited the yield strength value. As for the limited number of nodes at the possible breakage line experimental fallow up should be performed[5].

## CONCLUSIONS

The FEM analysis results using Solid Edge for a shear pin sized diameter of three and length of five mm for the prototype gripper needs to be put to the test with real test pieces. The results show that modifying the base shape yield in higher stress values under load. All the modified shapes seem to have better chance to work as a shear pin under the specification compared to the base shape.

## REFERENCES

[1]Mitsubishi Electric ,Mitsubishi Industrial Robot F Series. [Online]. http://mitsubishirobotics.com/pdf/F-Series_Robot_Brochure.pdf. [Accessed 31.03.2017].

[2]Brown, E.,Rodenberg, N.,Amend, J., Universal robotic gripper based on the jamming of granular material, Proc. Nat. Acad. Sci., vol. 107, Nov., p. 18809–18814, 2010.

[3]Amend, J., Brown, E., Rodenberg, N., A Positive Pressure Universal Gripper Based on the

Jamming of Granular Material, IEEE TRANSACTIONS ON ROBOTICS, VOL. 28, NO. 2, p. 341-350, 2012.

[4]Sankara, S., Natarajb, M., Prabhu Raja, V., Failure analysis of shear pins in wind turbine generator, Engineering Failure Analysis, vol. 18, no. 1, p. 325–339, 2011.

[5] D'Urso, G.; Giardini, C.,Thermo-Mechanical Characterization of Friction Stir Spot Welded AA7050 Sheets by Means of Experimental and FEM Analyses. Materials 2016, vol. 9, nr. 8, 689, 2016.

# Tractor´s wheel slip on meadow

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**Abstract.** Wheel slip is a significant factor that influences tractor´s working productivity and fuel economy. Wheel slip depends on the tyre pressure and contact area between the tyre and the ground. The lower the tyre pressure the larger the contact area. According to this, larger contact area reduces wheel slip. In this article, tractor´s wheel slip is researched on meadow. The aim of this article is to find optimal tyre parameters in order to achieve minimal wheel slip on a slope. Tests were performed on uphill driving on different soil conditions. One test was performed on snowy and frozen ground, the other without snow in melted conditions. The method used for determining wheel slip in tractor user manual has problems with achieving the required accuracy. In this article, there is used more precise method. The results showed that because of the lower tyre pressure the distance of ten wheel revolutions is longer. It also means less wheel slip.
**Key words:** uphill driving, soil, drawbar pull, fuel economy.

## INTRODUCTION

Tractor´s wheel slip has been researched on the different terrains, but wheel slip on slope has not been studied so much. Cost-effective manufacturing, optimization costs per unit of production is more and more important. Due the increased rivalry only stronger entreprenurs will survive.

Farmers want to control the wheel slip, because it's negative effect to the crop production. It influences the soil structure and reduces the water infiltration into the soil [1].

Tractors are not only used in agriculture, but also in public utility, in forestry and other fields. Wheel slip depends on terrain conditions (soil structure, moisture etc), tyre pressure, wheel properties and other factors. In this research is focused on determining wheel slip on meadow. The opimal and recommended wheel slip for 2WD tractors is between the 8 and 15% [2,3].

Uphills and downhills are common in southern Estonia. Farming in that area is more complicated than in north and middele Estonia. So that is one reason why tests are taken in the hills. Due to hilly relief the rolling resistance increases. This article is different from others, beacuse attempts and measurements are taken on uphill conditions. The angle of ascent is 3.3 degrees.

According to research there are three types of losses that influence work on agricultural soil: transmission loss, losses due to motion resistance and losses due to slippage [4]. In this research is mainly focused on losses due to slippage.

## MATERIALS AND METHODS

For testing is used wheeled tractor John Deere 6920 S (Fig. 1) [5]. For load is used a lorry Volvo FL 614 (Fig. 1).

**Figure 1.** Machines used for testing.

Other option for load was to use a semitrailer, but it applies part of it´s mass to the tractors rear axle. Thus, it was not suitable. The full trailer was not available, so the final choice was to use the lorry. It´s mass is 8,110 kg. To estimate needed tractive force to move it is used a dynamometer ДПУ–5–2. This also gives a opportunity to achieve similar load levels in different conditions, so the tests results are comparable.

Tests were taken using the rear–wheel drive only.

The existing method for determining is described in tractor´s user manual. This method is inaccurate, so completed and more precise method is developed. The method that is used for getting accurate results of measurement is following: the distance of ten wheel revolutions is measured. The distance is measured in unloaded and loaded conditions. The wheel slip is calculated according to test results.

For simplifiying counting tire revolutions, there is made sign with chalk to the side of the tire.

To avoid casual errors, same attempts are repeated four times. Then the average result is calculated. Four different tire pressures are used, accordingly 50 kPa, 100 kPa, 150 kPa and 200 kPa.

## RESULTS AND DISCUSSION

The relationship between the tyre contact area and soil is shown in table 1. The results show the lower the tyre pressure the bigger contact area. If tyre pressure changes from 200 kPa to 150 kPa, the contact area increases 7.31%. Change from 150 kPa to 100 kPa increases contact area 7.88%. And last, the change from 100 kPa to 50 kPa increases the contact area 29.05%. According to these results it can be seen that change in lower tyre pressures is more than three times bigger than other changes. Problably the static radius of the tyre changes the most and this causes rapid increase in contact area.

**Tabel 1.** Rear tyre contact area using different tyre pressures

| Tyre pressure, kPa | 50 kPa | 100 kPa | 150 kPa | 200 kPa |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Contact area, $mm^2$ | 35,570 | 25,238 | 23,250 | 21,550 |

In table 2 is described the test results of snowy meadow (Fig. 2). It can be seen the rule that the distance of the ten wheel rotations in unloaded situation rises if the tyre pressure is bigger. One explanation to this is that the static radius of the tyre influences the results. Other one is that beacuse the attempts were taken four times in each pressure, so the same terrain were used twice in some attempts.

**Table 2.** Test results on snowy meadow using different tyre pressures

| Attempt number | Tyre pressure, kPa | Distance without load, m | Distance with load, m | Dynamometer value, kgf |
|---|---|---|---|---|
| 1 | 50 | 52.85 | 44.15 | 0.650 |
| 2 | 100 | 53.61 | 43.36 | 0.625 |
| 3 | 150 | 53.82 | 40.04 | 0.675 |
| 4 | 200 | 54.05 | 38.27 | 0.60 |

Table 3 describes the test results of melted meadow (Fig. 3). On meadow the dynamometer scale value is bigger than on snowy meadow

**Table 3.** Test results on meadow using different tyre pressures

| Attempt number | Tyre pressure, kPa | Distance without load, m | Distance with load, m | Dynamometer value, kgf |
|---|---|---|---|---|
| 1 | 50 | 52.65 | 51.20 | 0.800 |
| 2 | 100 | 53.00 | 50.46 | 0.900 |
| 3 | 150 | 52.55 | 49.90 | 0.750 |
| 4 | 200 | 52.61 | 47.77 | 0.950 |

But more important is the ratio comparision between the unloaded and loaded situation. This aim is achieved thanks to equation 1, which allows to calculate the wheel slip. Wheel slip results can be seen in table 4.

**Table 4.** Test results on meadow using different tyre pressures

| Tyre pressure, kPa | 50 kPa | 100 kPa | 150 kPa | 200 kPa |
|---|---|---|---|---|
| Wheel slip on snowy meadow, % | 16.16 | 19.12 | 25.60 | 29.20 |
| Wheel slip on meadow, % | 2.75 | 4.79 | 5.04 | 9.20 |

As it can be seen, the wheel slip significally depends on tyre pressure. The hypothesis in abstract is correct, the wheel slip can be reduced by lowering the tyre pressure.

The test results between the frozen, snowy meadow and the melted meadow show the rule the lower the tyre pressure the lower the wheel slip. The pattern of the tyre is not ensuring efficient adhesion In frozen soil. The opposite situation is in melted conditions, the pattern of the tyre works more effectively.

**Figure 2.** Snowy meadow

The wheel slip is calculated using the following equation

$$S_r = \left(\frac{l_k - l_l}{l_k}\right) \cdot 100, \quad (1)$$

where $Sr$ – wheel slip, %;
$l_l$ – distance with load, m;
$l_k$ – distance without load, m.

**Figure 3.** Melted meadow

## CONCLUSIONS

The more precise method was used to get accurate results. The method based on measuring the distance of ten wheel revolutions.

The tire contact area changes the most in the range of 100 kPa to 50 kPa. The change is 29.05%.

The wheel slip on snowy meadow is more than three times bigger than in melted soil. The most suitable choice is to use 100 kPa. Although the best test results are achieved at lower (50 kPa) tyre pressure, it is not suitable, because it may harm the tire´s structure. The test results show that despite the soil, the lower pressure reduces the wheel slip in any kind of situation.

## REFERENCES

[1] Shahgholi, G., Abuali, M., Measuring soil compaction and soil behaviour under the tractor tire using strain transducer. Journal of Terramechanics vol 59, p. 19–25, 2015.

[2] Raheman, H., Jha, S.K., Wheel slip measurement in 2 WD tractor, Journal of Terramechanics vol 44, p. 89–94, 2007.

[3] NSW Farmers, Monitoring wheel slip to achieve fuel efficiency. [Online]. Available: https://www.nswfarmers.org.au/__data/assets/pdf_file/0011/35849/Efficient-Farm-Vehicles-Monitoring-wheel-slip-to-achieve-fuel-efficiency.pdf [Accessed 30 03 2017].

[4] Botta, G.F., Tolon-Becerra, A., Tourn, M., Lastra-Bravo, X., Rivero, D., Agricultural traffic: Motion resistance and soil copaction in relation to tractor design and different soil conditions. Soil and Tillage Research 120p. 92–98, 2012.

[5] John Deere user manual. Tractors 6520, 6620, 6820, 6920 and 6920S. In Estonian. p. 60–2.

# Test method of planer tool wear

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**Abstract.** This article describes the test method of planer tool wear. The aim of these experiments is to evaluate the cutting geometry influence to the planer tool wearing and on the wooden material surface quality. There are planned several experiments with different parameters of cutting edge and planing materials for measuring durability. Sharpening angle is changed after every 2,5 ° between 20...27,5 °. Planer tool wear will be examined after planing the solid wood of pine. The material of planer tool is cemented tungsten carbide. Cutting edge wears while planing and this affects the quality of detail surface. The quality of wood surface is measured with roughness tester. The deprecation of cutting edge is measured in the measurement laboratory with microscope.

**Key words:** planer tool, experiment, wear, cemented tungsten carbide, pine, sharpness angle.

## INTRODUCTION

Planed materials have high quality of surface finish requirements. Planed material should be smooth to touch, it means that there should be no tears, rough wood structure and wood structure resurrection. Precision planer is used to achieve best surface quality. Planer one important component is planer tool. Cemented tungsten carbide tool is tested, to get information of planer tool wear. Cemented tungsten carbide tool is designed to cut laminated wood and hard wood, because they have longer service life compared to conventional high-speed steel. Cemented tungsten carbide tool wear has been researched by *Sheikh-Ahmad, J.Y. Bailey*, who established that the worn takes place mostly on the front cutting face [1]. *Ramasamy, G. Ja Ratnasingam, J.* described cemented tungsten carbide tool wear, which is the mechanical wear and micro-cracks [2]. This article examines a cemented tungsten carbide tool wear on front cutting edge. The aim of this work is to operate in the methology, which allows to detect cemented tungsten carbide tool wear features.

## MATERIALS AND METHODS

Planer tool endurance test methods can be roughly divided into three stages. In first stage pine wood will be planed with different sharpening angles. In the second step, the processed wood surface roughness is perpetuated visually, after removal of the worn tool. In the third stage the extent of wear cemented tungsten carbide tool is measured and image is captured. Worn tool measurements are taken in the Estonian University of Life Sciences Institute of Technology. The test bodies are cemented tungsten carbide tool, with thickness of 3 mm. The tool is suitable for cutting dry soft and hard wood, laminated wood, medium-density fibreboard, thermoplastics and composite materials for wood-plastic [3]. Cemented tungsten carbide tool overview is shown in figure 1.

**Figure 1.** Cemented tungsten carbide tool overview

Different sharpening angles are used in planing. Sharpening angle is changed with bench setup, however the condition $\alpha + \beta + \gamma = 90^{\circ}$must be valid. Sharpening angle will be changed pitch $\Delta = 2{,}5^{\circ}$ a range of $\alpha = 20...27{,}5^{\circ}$. Planer tool sharpening angle is illustrated in figure 2 below.

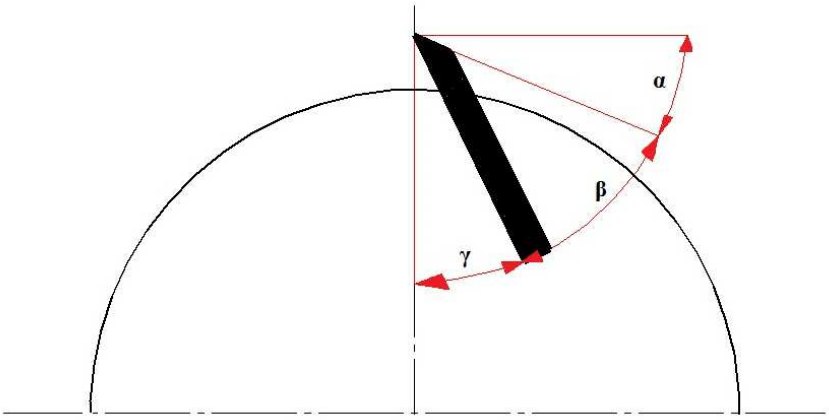


**Figure 2.** Planer tool sharpness angle sharpening angle $\alpha \neq const$ ; wedge angle $\beta \neq const$ ; cutting angle $\gamma = const$,

Sharpening angle should practically affect wood surface quality in planing. According larger sharpening angle wood surface quality is better, but planer tool wears faster. With smaller sharpening angle the cutting edge is less sharper, surface quality is not so good, but planer tool should last longer. Planed material is pine. Material is mostly knot-free, which facilitates planing. Planing material relative humidity is in range of 10...17 %. Quality of the material surface should be smooth, with no tears, should not be too rough or have structure resurrections. Material is planed with same processing

parameters: blank movement velocity v = 10 ± 2 m/s, cutting depth 0,5 mm, spindle rotational speed n = 6000 $min^{-1}$. Quality planed feed rate, as a work cutting meters is a changing parameter, which will be measured. Test will be repeated 4-6 times, in order to obtain reliable results. Testing will start with a sharpened tool planing pine wood. In the beginning of the cutting wood, surface roughness will be measured and average measurement is written down. Surface roughness refers to the structure of the timber rising. Wood is planed as long as surface quality is not acceptable and then the worn tool is replaced. If tool is worn, surface quality will be measured again. Cutting meters will be written down. Worn tools are measured and photographed at the Estonian University of Life Sciences Institute of Technology in measuring laboratory. Worn tools are photographed with Zeiss V12 Discovery stereomicroscope, which can make x64 zoomed picture. Stereomicroscope image is shown below in figure 3.

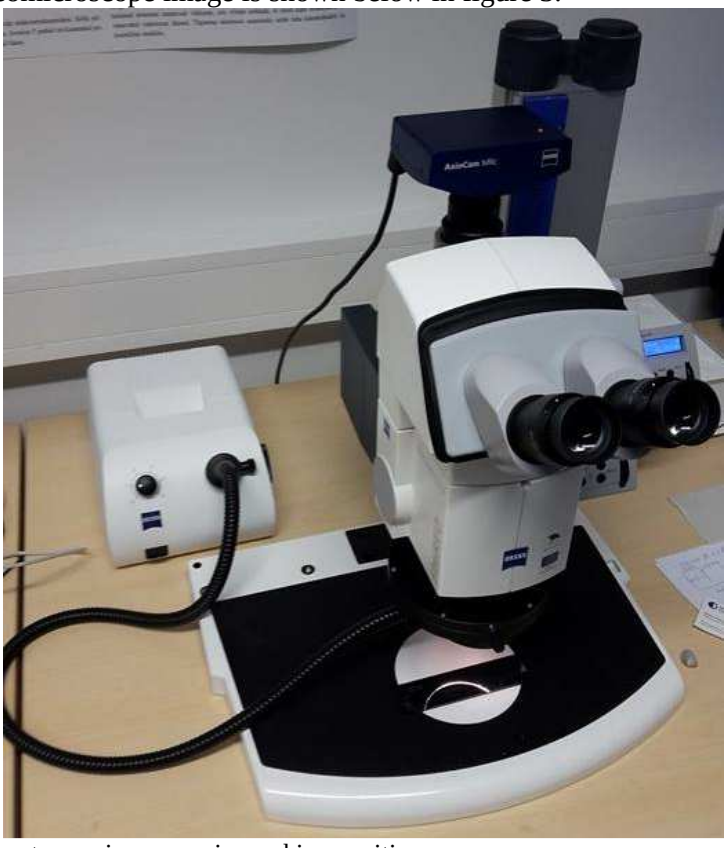

**Figure 3.** Zeiss stereomicroscope in working position

In addition, wear of the tool is measured at the cutting edge. Worn is visible on cutting edge and cutting face. When the cutting face worns white, then the cutting edge becomes blunt. Measurement of worn cutting edge is shown in figure 4.

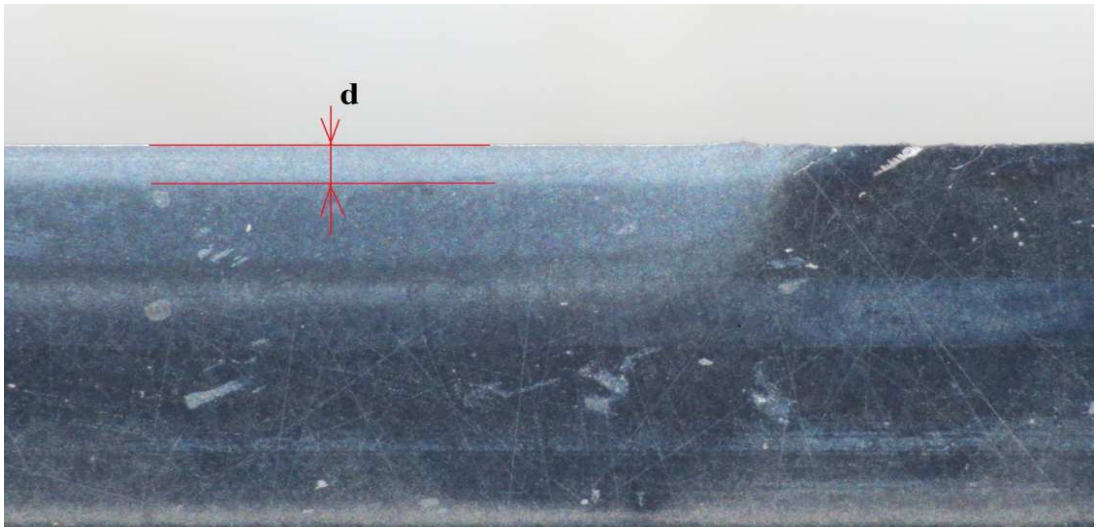


**Figure 4.** Measuring worn cutting edge: d – worn cutting edge width

A worn cutting edge width is measured with a computer programme, which is connected to the stereomicroscope. Worn tool surface are compared before and after planing. Planed surface roughness is measured and cutting meters are taken into account .

## RESULTS AND DISCUSSION

Planing tests with different sharpening tools provide information about how long optimally it lasts and what quality of surface it makes. The method provides an overview of pine planing with different sharpening angle. Worn width is measured on cutting edge. Worn tool edge, planed blanks surface roughness and planed meters are compared. Below in Figure 5 is shown worn tool with zoom x64, after cutting 1644 m pine.

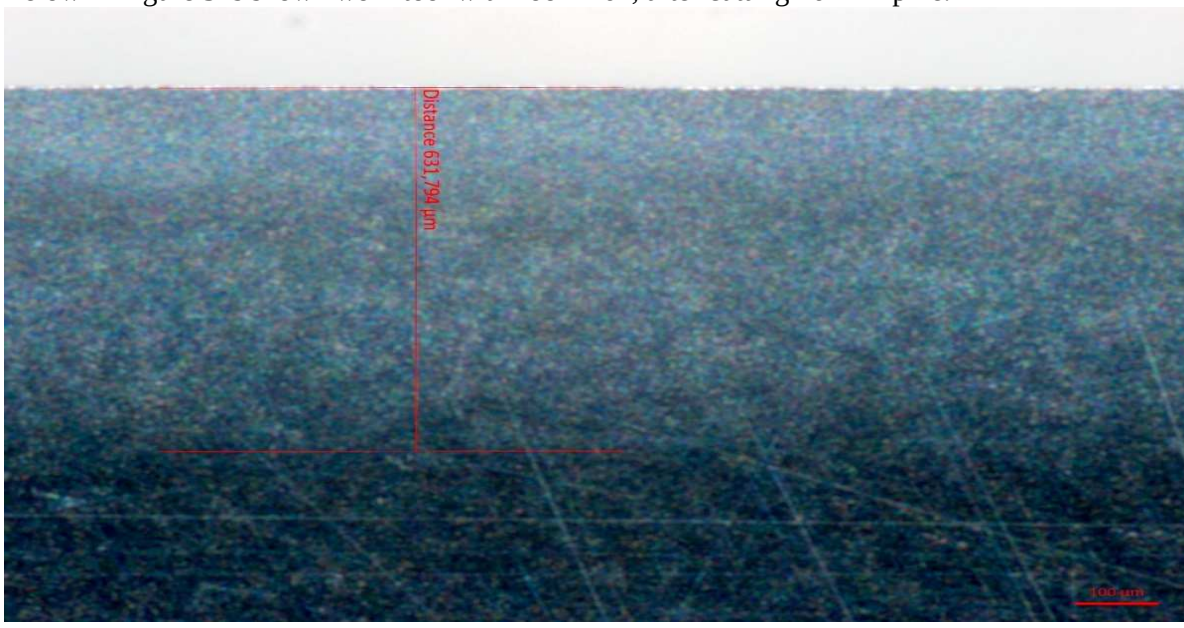

**Figure 5.** Worn-out planer tool zoom x64, after cutting 1644 m pine

Planer tool takes a rounded cutting edge and cutting face worns white. After planing 1644 m pine wood, the wood surface was full of tears and streaks. Pine wood surface quality after 1644 m planing is shown in the figure 6.

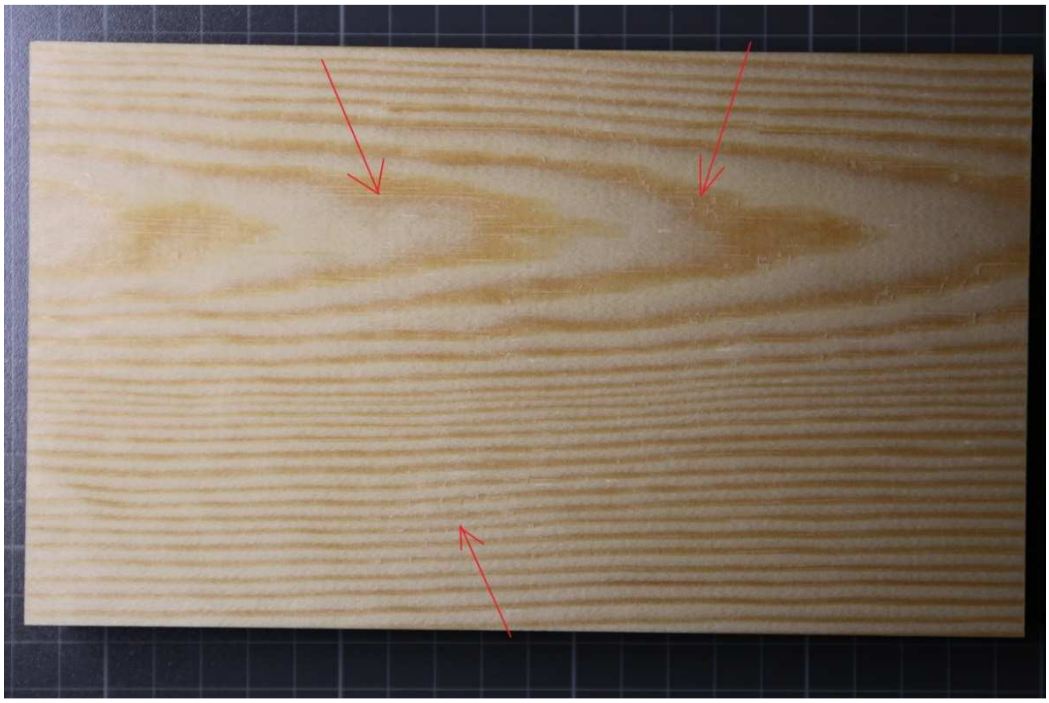

**Figure 6.** Pine surface quality after cutting 1644 meters pine wood

## CONCLUSIONS

This method will provide an opportunity to evaluate the effect of sharpening angle $\alpha$ to a material surface quality and cemented tungsten carbide tool durability.

## REFERENCES

[1] Sheikh-Ahmad, J.Y. Bailey, J.A. The wear characteristics of some cemented tungsten carbides in machining particleboard, 1999.

[2] Ramasamy, G. Ja Ratnasingam, J. A Review of Cemented Tungsten Carbide tool wear during Wood Cutting Processes, 2010.

[3] Leitz. The condensed Leitz-Lexicon, http://www.leitztooling.com/downloads/leitz-condensed-catalog-v51.pdf

# Development of tire pressure monitoring system

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**Abstract.** The aim of this article is to find and describe properties to improve measurement of car weight and its load. The problem emerged with inconveniences in the use of tire pressure sensors. Since November 1st 2014, tire pressure sensors are compulsory on all cars sold on EU territory, however they don't indicate the weight of the load. There are some ideas and patents for determining weight and its load of the vehicle. Most of them are based only on measuring the weight of an empty vehicle and then cargo load by measuring tire pressure and temperature. With properties and experiments described in this article, tire pressure monitoring sensors could be more accurate and easier to use.

**Key words:** TPMS, cargo load, vehicle weight, pressure sensor

## INTRODUCTION

Product development is a process, which begins with coming up with an idea and results in launch of the product. In my thesis, I mostly focus on research, which is the groundwork.
Research includes:

1. Market research – prognosis of demand and analysis of the need for development
2. Patent research – evaluation of innovation, competitiveness and new levels of engineering
3. Research and development – compilation of new technical functions that are necessary to the new product

According to the EU directive, all 2014 and newer cars must have tire pressure monitoring system (TPMS) installed. The main reason for using TMPS is road safety. EU studies show that around 500 people die and 8000 get injured in a traffic accidents caused by tire defects. *Sécurité Routière* (French Road Safety Institution) estimates that 9% of road deaths are either caused or contributed by low tire pressure. Tires can lose up to 0.65 bar per year and the majority of people deal with tires only when it is time to have them replaced. What is more, incorrect tire pressure significantly affects the car's handling, braking distances, tire wear, car tractability and fuel consumption. So there TPMS is needful, but it is not perfect system yet.[1]

## MATERIALS AND METHODS

There are two different systems, the most popular one has sensors in each tire. That TPMS configuration in the world is represented by a micro-machined pressure sensor, a

micro controller for processing, a radiofrequency transmitter to transmit the data to a central receiving unit and a battery as power source. Information is displayed either as an error message or as detailed information in car display. For motion detection - to decide whether the car is parking or driving, an additional acceleration sensing device may be used. It is said that tire pressure monitoring system can not be replaced nor programmed yourself. So if a car is taken to service, experienced hands take tires off your wheels, assemble detectors and program them. [2]

There is also a system that estimates tire pressure without TPMS. It combines GPS with on board wheel speed sensors. They estimate tire's rolling radius with GPS and detect tire pressure changes. Algorithm uses GPS and wheel speed signals to estimate the effective radius of the tires, is discussed and validated in simulation and experiment, but there are other factors that change tire pressure. [3]

There are 3 main factors that can change tire pressure:

1. Temperature
2. Uneven ground
3. Elevation

There is a patent WO 01/86239 A1 - *Vehicle weight and cargo load determination using tire pressure* [4]. Its main idea is to measure tire pressure and outside temperature and calculate cargo load. Although, results are not accurate enough, because outside temperature may not be the same as temperature in the tire.

Another patent US5081443 [5] describes a special tire pressure and temperature sensor – a system where tire pressure and temperature can be viewed inside and outside the vehicle, but measured tire pressure and outside temperature are used in non-correlated equations. The temperature based function is calculated at first and then it is used to calculate cargo load. So there is need for tire pressure measuring device to find relations between temperature in tire and weight.

Therefore, the aim is to improve the measurement of car weight and its load. To improve measurement accurateness of car weight and its load, basic formula needs to be known.

There is a magnetic inductive sensor used against uneven ground. Also, it is important to find temperature on standardized *atmospheric* pressure on each vehicle. After that, cargo load can be calculated with equation 1 [4]:

$$W = C_f \times P_{sT} \ , \tag{1}$$

where $W$ – total weight of vehicle;
$P_{sT}$ – total sum of pressures;
$C_f$ – change of weight.

Cargo load $W_C$ can be found with equation 2 [4]:

$$W_C = W - W_v \ , \tag{2}$$

where $W_C$ – cargo load;
W – total weight of vehicle;
$W_v$ – vehicle weight.

Tire pressure monitoring system and cargo load weight system can be used to measure a car and its load weight together. It does not matter how many wheels the vehicle has, so it can also be used on trucks with more than 4 wheels. Total weight of car splits between 4 wheels. Each load on tire is marked with symbol: W1, W2, W3 and W4. Total weight affects tire pressure and ground. Too big sag is usually caused by lack of pressure in tire, not overloaded vehicle.

Another reason to measure tires separately is that weight is not divided equally on each tire, mostly because engine and transmission are in front. That is why front tires have higher pressure – to withstand more weight. However, loaded vehicle can have more weight in back. Following equation 3 considers previous:

$$W = W_1 + W_2 + W_3 + W_4 \ , \tag{3}$$

where W – total weight of vehicle;
$W_1$ – weight of first tire;
$W_2$ – weight of second tire;
$W_3$ – weight of third tire;
$W_4$ – weight of fourth tire.

If each tire's pressure is known, car and its cargo weight can be calculated with equation 3. This is different from previous formula because total weight affects air in tire and the detector gets wrong results if ground is uneven.

If accurate change of tire pressures is added, then total weight of vehicle can be calculated. Another option is to measure vehicle and set weight into system, but it is not

that accurate.

It is important to measure tire pressure accurately. Detectors have to be accurate and measure millivolts, because there may be very little difference in tire pressures.

## RESULTS AND DISCUSSION

Pressures measured by a magnetic inductive sensors are converted to standardised temperature pressure in a program with special software. Tires have different pressure and they also change while driving. System calculates results using empty car weight and full weight. When cargo is taken off, result changes in real-time. All results can be read in car salon. They update automatically.

## CONCLUSIONS

Since many accidents happen because of tires, quality of tires is undervalued, hopefully this article will encourage people and developers to find better systems. There are suggestions to calculate vehicle and its cargo load to decrease road accidents. Suggestions include improving accuracy and ease of use.

## REFERENCES

[1] TPMS – Rehvirõhu jälgimise süsteem. Available: http://www.akustika.ee/?article &article_id=56 . [Accessed 1 12 2015].

[2] Lange,T., Löhndorf, M., Intelligent Low-Power Management and Concepts for Battery-less Direct Tire Pressure Monitoring Systems (TPMS), Advanced Microsystems for Automotive Applications 2007, p. 237-249, 2007.

[3] Ryan, J., Bevly, D., Tire Radius Determination and Pressure Loss Detection Using GPS and Vehicle Stability Control Sensors, in 8th IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes 2012.

[4] Breit,C., Device for protecting the systems and load of motor vehicle [Online]. Available: https://worldwide.espacenet.com/publicationDetails/biblio?II=0&ND=3&adjacent=true&locale=en_EP&FT=D&date=19920114&CC=US&NR=5081443A&KC=A . [Accessed 25 02 2017].

[5] Chaklader, A. C. D., Vehicle weight and cargo load determination using tire pressure [Online]. Available: https://worldwide.espacenet.com/publicationDetails/biblio?FT=D&date=20011115&DB=&locale=en_EP&CC=WO&NR=0186239A1&KC=A1&ND=4 [Accessed 25 02 2017].

# Experiment planning methodology of determining force needed for plastic film retrieval from soil.

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**Abstract.** Plastic film mulch is used for many different crops. As there is sufficient technology for laying plastic film to soil, there has not been sufficient technology for removing it, especially for smaller tractors. The purpose of this article is to develop reliable methodology for determining force needed for plastic film removal from soil and also to find settings configuration of lowest force. As the plastic is pulled from different angles the force needed should vary. Also force should vary after changing the depth of soil lifter and the height of soil lifting. Data received from experiments can later be used for strength calculations of transmission and frame of the plastic film retrieving device and later on it also can be used for calculating precise propulsion.

## INTRODUCTION

Plastic mulch is used for growing different crops. Growing vegetables and other plants while using plastic mulch, the WUE (water use efficiency) is 17,0%-21,6% higher than without it. Because of that it helps plants to overcome water deficiency caused by drought that can occur during summer in our climate. In addition to that it can raise the average temperature of soil by 1-3 °C and therefore extends growth period 5,9-10,7 days [1]. Combining plastic mulch with agricultural fleece allows growing cultures that usually would not be suitable in our climate. Even though mounting plastic film is relatively easy, retrieving it is not. While being in soil for long periods of time, plant roots and soil form thick rind over and around the plastic film below ground level edges. Cutout of a three years old strawberry field mulch bed is shown on Figure 1.

**Figure 1.** Cutout of strawberry fields mulch bed.

Throughout of years there have been many different methods for retrieving plastic mulch. One of the worst methods is plowing the field and breaking plastic film into smaller pieces, later on making extraction process even more time consuming and difficult. Another solution is using glyphosate-containing herbicides. By using it on the rind, it exterminates all plants and their roots. It will ease extracting the plastic film considerably. However this method can`t be used in organic farming where using plastic mulch is most beneficial. In addition to previously stated benefits, the darkly colored plastic effectively prevents weeds from growing. Therefore, by using it, it is possible to reduce any costs related to mechanically destroying weeds.

In the beginning of this decade, there have been several apparatus patents on retrieving residue plastic mulch. Usually those devices are quite big and only can be operated with bigger tractors. Also operating with them requires two people- tractor operator and device operator. In addition to that, in can be speculated that those devices are not designed for retrieving plastic mulch that have been in use for several years. For designing a device that could be used with smaller tractors and could retrieve plastic after for example 5 years of use all processes must be optimized to the level where all operations are carried out correctly but without excessive energy waste. Those processes are: 1) preceding elevation of soil, 2) plastic film extracting, 3) extracted plastic film cleaning, 4) winding plastic film on a roll, also called collecting. Current article focuses on optimizing the process of extracting the plastic from soil. For that there will be experiments held while changing different parameters that affect the process of extraction

## MATERIALS AND METHODS

Determining the necessary input and output variables for experiment the “black box” method was used. It can also be seen in Figure 2 [2]. Input parameters are divided into controllable, difficult to control and uncontrollable variables. Output parameter is the force needed for extraction. During the experiment, the focus is on controllable variables and combining different pre-set values so that most optimal combination is found. It means the combination of different input values where targeted output is lowest possible force. Controllable variables are the angle of plastic extraction, soil lifter depth and elevation of soil. In addition, depth of plastic in soil and plastic film edge coverage by soil can also be listed, but it would have expected many years of planning and had to be considered already while mounting plastic film. Therefore, changing these variables is impossible and the corresponding values of test field will be used. Logically it can be concluded that the deeper is plastic in soil and the bigger is the coverage of plastic by soil, the greater is force needed for extraction. Because of that throughout experiments, there is no immediate need to change these variables for reliable results.

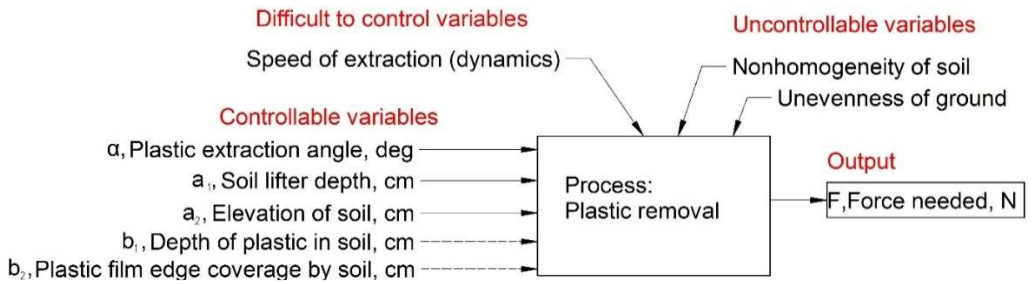


**Figure 1.** Schematic presentation of plastic removal process.

Before starting the experiments, tensile strength of the narrowest known plastic film mulch is found. Even though the test fields' film width is 1000 mm but smallest known width of plastic film is 600 mm and tensile strength of it will be considered while designing apparatus. Minimal thickness of plastic film mulch is 0,04-0,05 mm and is made of low density polyethylene (LDPE) [3]. Tensile strength of plastic film made out of LDPE is 11-37,9 MPa, in calculations smallest values are used, that means, thickness of 0,04mm and tensile strength of 11 MPa is used [4]. Using pre-said data, the calculated tensile strength of 600 mm wide plastic film is 264 N. Before starting the experiments, some of the data is still to be found. The source of values $b_1$ and $b_2$ can be seen in Figure 3.

**Figure 2.** Depth of plastic mulch ($b_1$=7,5 cm) and soil coverage ($b_2$=26 cm) measured values.

The experiment is carried out by using full factorial method. The accuracy of output is defined by accuracy of densitometry gauge, meaning ±10 gr and stability levels are defined by the medium accuracy , meaning ±5%. The factor is measured during the test experiment, the size of which has a certain value at a certain time.

The controlled parameters sweeps etc. range is as follows:

1) plastic film extraction angle α=45...135˚;
2) lifter depth $a_1$=8...12 cm;
3) elevation of soil $a_2$=2...12 cm.

As an experimental test-object has been previously studied in some respects, it is contemplated the present application, these parameters, if the sizes determined from empirically.

Variables for α ($\alpha_1$, $\alpha_2$, $\alpha_3$), $a_1$ ($a_{11}$, $a_{12}$, $a_{13}$) and $a_2$ ($a_{21}$, $a_{22}$, $a_{23}$) are chosen by relying on data received from cut-out.

Now Table 1 is composed where in first row there are changeable variables and in first column, there are experiment numbers

**Tabel 1.** Experiment variable measurement results.

| **Experiment nr.** | **Plastic film extraction angle, deg** | **Lifter depth, cm** | **Elevation of soil, cm** | **Plastic film depth, cm** | **Plastic film coverage by soil, cm** | **Force, N** |
|---|---|---|---|---|---|---|
| **1** | 45˚ | 8 | 2 | 7,5 | 26 | |
| **2** | 45˚ | 10 | 2 | | | |
| **3** | 45˚ | 12 | 2 | | | |
| **4** | 45˚ | 8 | 6 | | | |
| **5** | 45˚ | 10 | 6 | | | |
| **6** | 45˚ | 12 | 6 | | | |
| **7** | 45˚ | 8 | 10 | | | |
| **8** | 45˚ | 10 | 10 | | | |
| **9** | 45˚ | 12 | 10 | | | |
| **10** | 90˚ | 8 | 2 | | | |
| **11** | 90˚ | 10 | 2 | | | |
| **12** | 90˚ | 12 | 2 | | | |
| **13** | 90˚ | 8 | 6 | | | |
| **14** | 90˚ | 10 | 6 | | | |
| **15** | 90˚ | 12 | 6 | | | |
| **16** | 90˚ | 8 | 10 | | | |
| **17** | 90˚ | 10 | 10 | 7,5 | 26 | |
| **18** | 90˚ | 12 | 10 | | | |
| **19** | 135˚ | 8 | 2 | | | |
| **20** | 135˚ | 10 | 2 | | | |
| **21** | 135˚ | 12 | 2 | | | |
| **22** | 135˚ | 8 | 6 | | | |

| Experiment nr. | Plastic film extraction angle, deg | Lifter depth, cm | Elevation of soil, cm | Plastic film depth, cm | Plastic film coverage by soil, cm | Force, N |
|---|---|---|---|---|---|---|
| **23** | 135˚ | 10 | 6 | | | |
| **24** | 135˚ | 12 | 6 | | | |
| **25** | 135˚ | 8 | 10 | | | |
| **26** | 135˚ | 10 | 10 | | | |
| **27** | 135˚ | 12 | 10 | | | |

Experiment is conducted by using:
1) specially constructed device frame which principal scheme is shown on Figure 4;
2) newton-meter;
3) tractor for towing the test device;
4) ground lifter (cultivator equipped with 2 pairs of cutters in special settings);

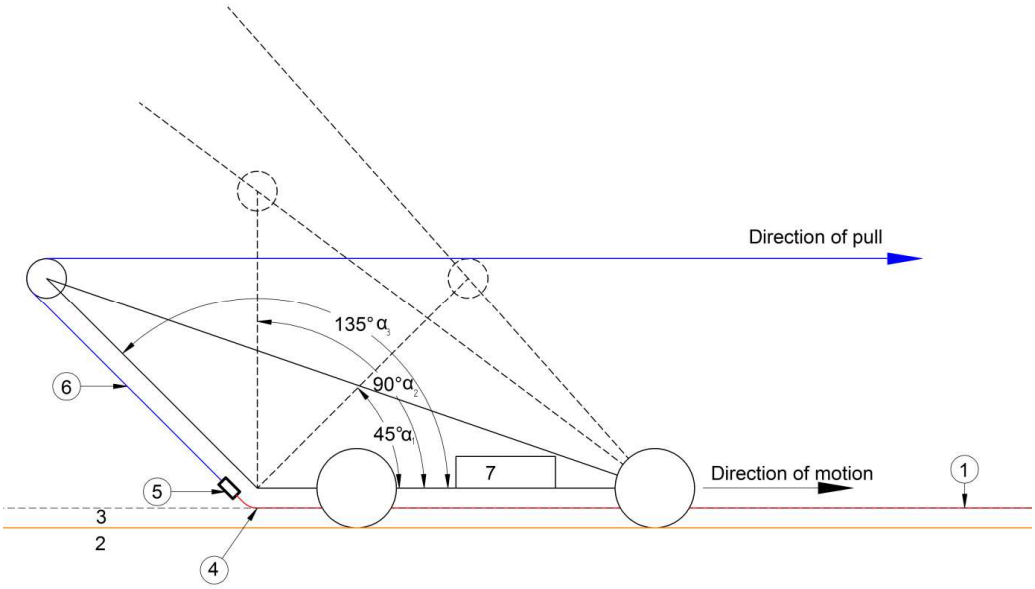


**Figure 4.** Scheme of conducting an experiment: 1) plastic mulch film, 2) ground, 3) plastic mulch bed, 4) point of plastic film extraction from soil, 5) newton-meter, 6) cable, 7) ballast.

Firstly, the force of pulling the device without pulling the plastic film is determined, then the plastic mulch is attached to newton-meter and rerun takes

place and force is measured. Afterwards idle run force is subtracted from whole force and plastic extraction force is found.

## RESULTS AND DISCUSSION

Since the experiments have not yet been carried out we can only assume the results. It is quite difficult to know the perfect balance between moving the soil enough and not too much or too little. Overdoing it is going to pointlessly waste energy and when soil is not moved or lifted enough, the plastic film extraction force gets too great. Furthermore, there are going to be experiments on how much force one working part of soil lifter cutter consumes and after doing that, perfect settings of retrieving device can be ascertained. With current experiment only the force of extracting film from soil is determined, but for finding out force needed for winding plastic film on a roll calculations on friction and other losses of energy have to be done. After determining the force of collecting plastic the data can be used in choosing operation drive and in overall propulsion calculations.

## CONCLUSIONS

Since the experiments are yet to be held there can´t be any conclusive statements. While conducting the experiment it can be expected that the greater the elevation and lower the angle of extraction, the lower is the output force.

## REFERENCES

[1] Effects of plastic mulch on soil moisture and temperature and limiting factors to yield increase for dryland spring maize in the North China, [Online]. Available: https://www.ncbi.nlm.nih.gov/pubmed/25898617 [Accessed 30 03 2017]

[2] Petersen, I, Katsete planeerimine, Valgus, p. 11, 1966.

[3] Kilekaubandus OÜ, Must kile, [Online]. Available: http://www.kilekaubandus.ee/kataloog/must-kile/ [Accessed 30 03 2017]

[4] Abdel-Bary, E, Handbook of Plastic Films, iSmithers Rapra Publishing, p. 33, 2003.

# Work ability dynamics depending on type of work cycle and gender of workers in a glass industry

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**Abstract.** Work ability (WA) is a good indicator of health impact of working hours' length and cycle type among the employees. The aim of present study was to compare physiological parameters and the dynamics of work ability among the glass industry workers in two work cycles with different duration – the first with length of four days and second nine days. Based on the aim the purpose was to complete the research on WA factor above 100 the measurements to detect WA for every participant in the start and end of work shift. The results showed the tendency that as shorter the work cycle the higher WA, when to compare the results of the longer cycle. Gender differences have observed in the physiological parameters - hand strength and memory test. The males had remarkable higher parameters of hands' strength but recorded worse memory tests as to compare the females ($p<0,05$). That to measure statistically significant changes in work ability dynamics the larger groups should be selected for the further studies.

**Keywords:** work ability, work cycle, physiological parameters, gender

## INTRODUCTION

Every work assignment needs a time to be completed. In spite work time regulations, many people are harmed because of long working hours, shift work and night work. One work cycle is completed by the amount of working and resting days in which the employees in total have no more than 36 hours of continuous rest time between the work shifts. In Europe and Estonia 7% of workers are working at night shifts more than 48 h per week and about one fifth of employees are working in night shifts. Despite the working hours are limited to 13 hours per day by the law, long working hours per shift often in use in the industries. The European Foundation for the Improvement of Living and Working Conditions' survey (n=44 000) on perceived working conditions (2010) showed that a double more the night shift workers than day shift workers (40% vs 20%) reported that health and safety at risk because of work [1,2]

Work ability is a good indicator of health impact of working hours' length among the workers. Work ability is a capability to perform the assigned work related tasks not making harm on the physiological systems of the body. WA is greatly related to the human personal traits and habits. The indicators of physical and mental state and cardiovascular parameters could be sensitive biological markers reflecting WA. The influence of different work cycles on biological parameters has observed in the earlier studies. For example, already Ladou (1983) and Harrington (2001) described the effects of shift work on health of workers, impairing circadian rhythm, causing sleep disorders like insomnia, hypersomnia, sleep apnea etc. Also, Boggild and Knutsson (1999) have analyzed the relations between shift work and cardiovascular diseases. They concluded that shift work increased 40% risk of cardiovascular diseases. [3…5] These earlier studies clearly demonstrated bad health impact of shift work and long working hours, but there are no any studies on comparing different work cycle dynamics through work ability and it's depending factors.

The aim of present study was to compare physiological parameters and the dynamics of work ability among workers in two work cycles with different length of four and nine days' dynamics [6,7].

## METHODOLOGY

In the participating company, there is two types of work cycles: type A (long) work cycle has three night shifts with rest days, which leads to three sequential day shifts. Type B (short) work cycle has four successive work days (two day shifts and two day shifts) which leads to four rest days. The difference of type A and B work shifts is displayed in table 1.

**Table 1.** The difference of the companies work cycles with the work ability measuring times, where: N – night shift, F – rest/free day, D – day shift.

| **Title** | **Type A** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shift | N | F | N | F | N | F | D | D | D | F | F | F |
| Before working | X | – | X | – | X | – | X | X | X | – | – | – |
| After working | X | – | X | – | X | – | X | X | X | – | – | – |

| **Type B** | | | | | | | |
|---|---|---|---|---|---|---|---|
| D | D | N | N | F | F | F | F |
| X | X | X | X | – | – | – | – |
| X | X | X | X | – | – | – | – |

The measurement of the WA took place relative to the difference of the work shifts which are displayed in the table 2. Time lapse was important to give the measurements an exact 12-hour gap.

**Table 2.** The measurement times in relations of the day and night shifts

| **Shift (measurement time)** | **Start of the work day** | | **End of the work day** | |
|---|---|---|---|---|
| | **Beginning** | **End** | **Beginning** | **End** |
| Day shift (07:00 – 19:00) | 06:30 | 07:00 | 19:00 | 19:30 |
| Night shift (19:00 – 07:00) | 18:30 | 19:00 | 07:00 | 07:30 |

Work ability itself is complex phenomenon reflecting the worker's capability to perform the assignments was given to him. But the assignment process is difficult because every person is unique by response to body loads. Work ability is affected greatly by employee's personal characteristics, such as: health, skills, motivation etc. [8]. To measure WA the respondent was sitting on a comfy chair to measure blood pressure, pulse, palmar strength, reaction speed to a light signal and memory. The pulse and blood pressure were measured with blood pressure apparatus and palmar strength by *Lafayette* dynamometer. To measure memory the author used a white paper with 16 different numbers in the interval of 1...100. During every single measurement, the numbers' combination was changed. The respondent had 60 seconds to memorize the numbers as much as possible. Then they had to write down the memorized numbers in the next 60 seconds. Reaction time was measured with the tablet program *Asus Google Nexus 7* (2013) which was installed with an application called "*GreenButton"*. The aim of this program was to show randomly a green light to what the respondent needed to

react. The only requirement was that the worker needed to hold its' arm next to tablet on the table.

The determination of WA it was needed to calculate the averages of every before mentioned physiological factor. The parameter's change is showed in percentages in comparison with the work cycle's first reading. The work cycle's first reading is always taken as the 100% because the employee should be the most rested at that time moment. WA is projected as the average formula of blood pressure and pulse, palmar strength, reaction time and memory with [9]:

$$R_i = 0{,}20 * \{\left[100 + \left(100 - \frac{m_{1i}}{m_1}\right)\right] + \left[100 + \left(100 - \frac{m_{2i}}{m_2}\right)\right] + \left[100 + \left(100 - \frac{m_{3i}}{m_3}\right)\right] + [(\frac{m_{4i}}{m_4} * 100) + (\frac{m_{5i}}{m_5} * 100)] \quad (1)$$

where $M_{1i}$, $M_{2i}$, $M_{3i}$, $M_{4i}$, $M_{5i}$ - according to average heart pulse (l/min), reaction time (s), blood pressure (mmHg), palmar strength (N) and memory (tk) determined by i measurement;
$M_1$, $M_2$,$M_3$,$M_4$,$M_5$ – same parameters measured in the first work cycle measurement.

The physiological parameters as cardiovascular (pulse, blood pressure), physical (palmar strength) and mental (reaction time and memory) indicators are depicted by the type of work cycle in the table 3.

The Statistical Package for Social Sciences (SPSS.24.0) was used for data analysis. The descriptive statistics and t-test for measuring group differences have used.

## RESULTS AND DISCUSSION

In the measurements participated 11 people, and from them five persons (3 men and 2 females) were from type A and six (3 men and 3 females) from type B. The average age of the groups allocated as such: type A 38±14 and type B 40±10 years. During the recognition of the results the physiological parameters has compared between shift types A and B (table 4). The average WA dynamics throughout the work cycles (graph 5) and sex has been analyzed (table 6 and graph 7).

**Table 3.** The physiological indicators of the study groups by the work cycles type A and B

| Shift type | Pulse | Reaction time | Blood pressure | Palmar strength | Memory | WA |
|---|---|---|---|---|---|---|
| | b/min | s | mm/Hg | N | piece | % |
| **Type A** | 82 | 0,51 | 134 | 28,0 | 9,0 | 104 |
| **SD** | 10,8 | 0,08 | 8,33 | 9,72 | 2,3 | 9,15 |
| **Type B** | 72 | 0,52 | 128 | 31,0 | 7,0 | 106 |
| **SD** | 8,3 | 0,08 | 9,76 | 20,51 | 1,6 | 10,13 |

From the table 1 we can see an impact of work cycle Type A to the workers' blood pressure (mm/Hg) and pulse (beats per minute, b/min). Also, the average palmar

strength (N) had tendency to be lower among employees of the work cycle A than cycle B. The reaction time (seconds, s) seems to be quite same in the two groups. All the differences reflect the WA only by 2% in favor of type B workers with an average result of 106%. No any statistically significant differences observed between the groups.

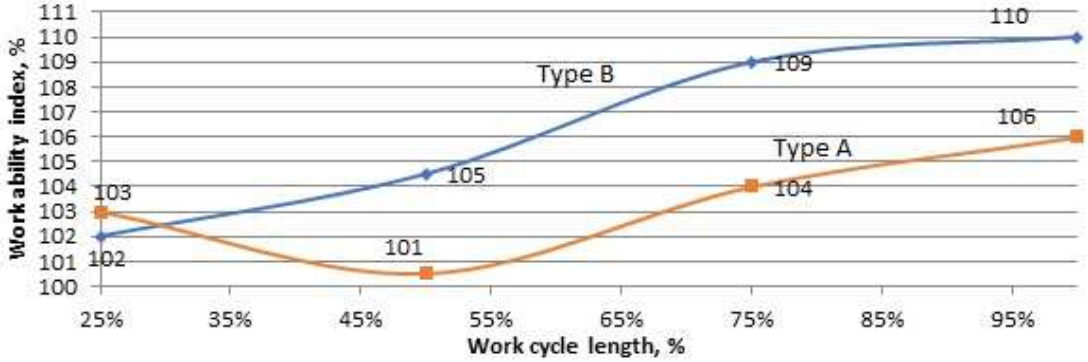


**Figure 5.** Dynamics of WA averages by the work cycle A and B

The average WA throughout the work cycle B showed 4% difference, except in the starting phase of work cycle. In the both cycles the work assignments contain very similar lifting jobs for 12 hours a shift. That leads the author to make a conclusion that the work cycle differences make the 4…5% change during one cycle. The good note is that on average WA stays constantly over 100%, which means that the rest times are well planned.

**Table 5.** The physiological indicators of the study groups by the gender

| Gender | Pulse | Reaction time | Blood pressure | Palmar strength | Memory | WA |
|---|---|---|---|---|---|---|
| | b/min | s | mm/Hg | N | tk | % |
| **Female** | 80 | 0,52 | 125 | 16,3 | 8,9 | 102 |
| **SD** | 6,86 | 0,08 | 8,23 | 4,65 | 2,1 | 5,65 |
| **Male** | 74 | 0,51 | 135 | 41 | 8,0 | 107 |
| **SD** | 10,4 | 0,07 | 6,58 | 11,14 | 1,7 | 11,79 |

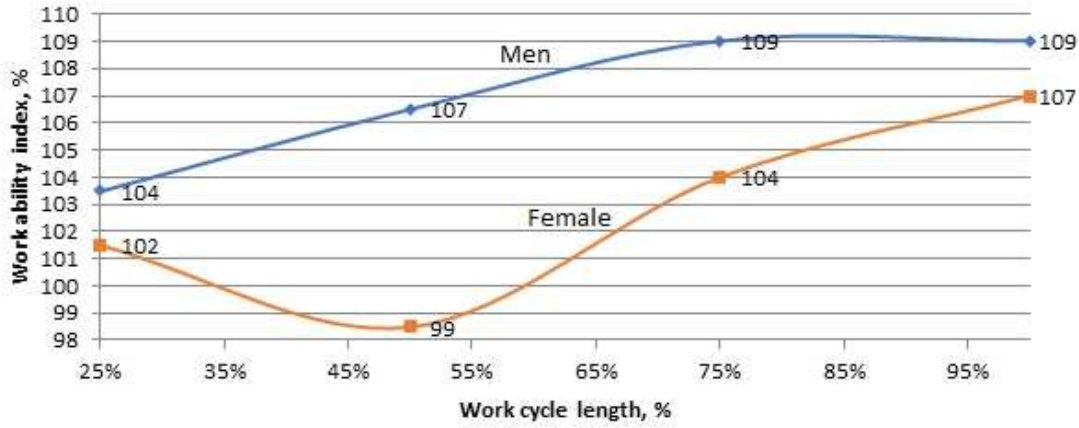


**Figure 7.** Gender differences of WA averages' dynamics by the work cycle A and B

We see a remarkable sex difference in favor of the male workers (*p=0.05*). In average the male respondents had 2…8% better work ability than females. The smallest difference was in the beginning of the work cycle, where the males showed 2% better WA. The largest gap at the 50% point of the cycle was observed among females, where the average WA of 99% was the lowest at all.

Palmar strength showed statistically significant difference between the study groups of work cycle type A and B (*p= 0,0013*).

## CONCLUSIONS

The author carried out a research with the aim to map out the WA difference during two different work cycles and compare physiological parameters between these groups. The study consisted of 11 participants: 6 males and 5 females whom attended over 100 observations. From the observations, the work ability was calculated with the formula 1.1 and the statistical analysis was carried out. Based on the study results we summarize the next below:

- When comparing the different work cycle types the workers of the cycle type B could perform at a 2% better rate than the workers of the cycle type A over the whole work cycle period;
- The workers of the work cycle Type A demonstrated better scores in the beginning of the studies where they were 4…5% better than the workers of the work cycle type B;
- When comparing the results by gender, the male workers were at average 2…8% better by average WA than females. The smallest gap was at the beginning (25% marker point) and at the end (100% cycle point). The largest difference between

WA averages was observed in the work cycle points where the cycle has changed from night to day cycle and *vice versa*;

- Gender differences have observed in the palmar strength.

The further research is needed on WA dynamics by work cycle and larger study groups to see the confidential results.

## REFERENCES

1. Estonian Ministry of Social Affairs. Estonian worklife study 2015 [Online]. Available: https://www.sm.ee/sites/default/files/content-editors/Ministeerium_kontaktid/Uuringu_ja_analuusid/eesti_tooelu_uuring_2015.pdf [Accessed 01.03:2017].
2. European Working Conditions Surveys (EWCS). Eurofound [Online]. Available: https://www.eurofound.europa.eu/surveys/european-working-conditions-surveys [Accessed 01.03.17].
3. Ladou, J. (1983). Health Effects of shift work. The Western Journal of Medicine.
4. Harrington, J.M. (2001). Health effets of shift workd and extended hours of work. Occupational environment.
5. Boggild, H. Knutsson, A. (1999). Shift work, risk factors and cardiovascular disease. Scandinavian Journal of Work Environment & Health. 14 pp.
6. Töötervishoiu ja tööohutuse seadus (vastu võetud 16.06.1999, viimati jõustunud 01.07.2016). - *Riigi Teataja [Online]*. Available: https://www.riigiteataja.ee/akt/110022012005?leiaKehtiv [Accessed 12.12.16].
7. Halliday, David. (2011). Füüsika põhikursus: õpik kõrgkoolile. (1.köide). Tallinn: Printon. 600 pp.
8. Karwowski, W. (2006). International Encyclopedia of Ergonomics and Human Factors. (vol I). Boca Raton: CRC Press. 3606 pp.
9. Šott, N. (2016). Piimatööstusettevõtte tootmistöötaja töökeskkond ning töövõime. (Magistritöö). Eesti Maaülikooli tehnikainstituut. Tartu.

# Prevalence of musculoskeletal disorders among the workers in hospital rehabilitation department

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**Abstract.** The aim of this study was to measure musculoskeletal parameters and evaluate prevalance of work related musculoskeletal disorders (MSDs) among workers in a hospital rehabilitation department.
**Method.** The anonymous questionnaire about work related risk factors and health was carried out in December 2016 and the measurements of functional state of musculoskeletal system was performed in January 2017. The study group consisted of 12 physiotherapists, 1 occupational therapist and 2 masseuse filled the questionnaire and sent back to the researcher. Ten of them agreed with measurements on functional state musculoskeletal system. Myotonometry and cervical range of motion (CROM) measurements were carried out at the beginning and end of the workday and in both sides of the body. Frequency, stiffness and decrement were measured on *m. flexor carpi radialis, m rectus femoris, m. biceps brachii, m. trapezius superior, m. erector spinae, m. biceps femoris caput longum* and *m. gastrocnemius medialis.*
**Results.** All 10 participants (1 male and 9 female) reported pain in the neck, shoulders and low back in the past 12 month. The mean age of study group was 34.4 ± 8.9 years and average service length 7.2 ± 6.1 years. The myotonometric measurements showed that frequency (muscle tone) increased in the right leg *m. biceps femoris caput longum* ($p = 0.03$) at the end of the workday. Significant differences between left and right side musculosketeal parameters have observed. In the beginning of the workday the decrement in the left hand *m. biceps brachii* ($p = 0.003$) was signifigantly lower than right side. At the end of the workday the muscle tone in the left leg *m. gastrocnemius medialis* ($p = 0.005$) was higher when to compare with the right side and decrement in the right leg *m. biceps femoris caput longum* ($p = 0.03$) was higher when to compare with left side. No any differences in *m. trapezius superior* and *m. erctor spinae* observed among physiotherapists. At the end of the workday CROM showed tendency to decrease of in the flexion and rotation to the right.
**Conclusions.** The physiotherapists are subjected to intensive physical work, causing fatigue in observed muscle groups of upper and lower limb during the workday, whereas the muscles' functional state deteriorated rather in right than left side.
**Key words:** rehabilitation workers, musculoskeletal disorders, myotonometry, goniometry

## INTRODUCTION

Musculoskeletal disorders are one of the most common work-related health problem, that affect millions of workers and cost employers a lot of money [1]. Research, which was published in 2011 showed that nearly 60% of the active population suffer from musculoskeletal symptoms, which grealty reduce the working capacity [2]. Musculoskeletal disorders are

serious problem among rehabilitation workers and are often caused by manually lifting and moving patients. In previous studies, it has been found that the risk factors most frequently perceived by health professionals are working in the same posture for long periods, bending or twisting, reaching and working away from your body, carrying, lifting or moving heavy materials or equipment, unanticipated sudden movements or fall by patient, performing the same task repeatedly and treating large numbers of patients in one day [3]. Several studies have shown that musculoskeletal disorders of the neck, shoulder, low back, wrist and hand are most often identified by rehabilitation workers [3–5]. Musculoskeletal disorders are found not only in elderly, but also in younger employees. The survey carried out in Canada revealed that pain in the lower back and neck has detected mostly among younger workers who have short work experience [5].

The aim of this study was to measure musculoskeletal parameters, evaluate prevalence of work related musculoskeletal disorders among workers in a hospital rehabilitation department and compare the results between the right and left side of the body and at the beginning and the end of the work day.

## MATERIALS AND METHODS

The study was carried out in a department of the rehabilitation hospital. There are working a little more than 40 employees in the department of rehabilitation including physiotherapists, occupational therapists and masseuse. The department offers a variety of outpatient and inpatient rehabilitation services for adults and children. The outpatient treatment options for example are doctor appointment, physiotherapy, occutaional therapy, hydrotherapy, heat therapy, manual therapy, manual lymphatic drainage massage, salt chamber, speech therapy, music therapy, psycological counseling and so on.

The study group consisted of 12 physiotherapists, 1 occupational therapist and 2 masseuse. All participants uses a variety of physical techniques and therapies in the treatment. Depending on the work participants occurs different working postures, standing and sitting while working. All 10 participants reported pain in the neck, shoulders and low back in the past month.

The study group ($n$ = 15) filled the questionnaire and sent back to the researcher. The questionnaire consisted of the following components: demographic information, working environment, therapy equipment and tools, work load, prevalence of musculoskeletal morbidity, safety and health

behavior awareness. At the end of the questionnaire was able to give consent to measure musculoskeletal parameters.

Employees' functional status was measured by myometry, cervical range of motion (CROM) and musculoskeletal strain scale. The measurements were carried out at the beginning (10:00–10:30) and end (16:00–16:30) of the workday and in both sides of the body to evaluate musculoskeletal status changes during the work day. Myometry *Myoton-3* created in Estonia have been developed for assessing the functional status of the human musculoskeletal [6]. It is possible to evaluate the muscle tone (frequency), stiffness and decrement. Myotonometric measuring of muscles were performed in the relaxed state: *m. flexor carpi radialis, m rectus femoris, m. biceps brachii, m. trapezius superior, m. erector spinae, m. biceps femoris caput longum* and *m. gastrocnemius medialis.* The CROM is a system of inclinometers with gravitational reference capable of measuring the mobility of the neck by flexion, extension, lateral flexion and rotation (degrees) []. Flexion and extension were recorded first (figure 1).

**Figure 1.** Neck (cervical) range of motion (CROM), flexion, extension

Data were analyzed using descriptive statistics (frequency and mean ± SD). Group differences were evaluated with $\chi^2$-test. The comparsion of data points (at the beginning and end of the work day, on the right and left side of body) were evaluate by using a Paired T-test and compairing the groups of variance (One-Way ANOVA). The statistical significance level was $p < 0.05$. SPSS 24.0 was used to analyze the data of measurement results.

## RESULTS AND DISCUSSION

All the participants ($n = 15$) signed an inform consent and completed the questionnaires. The response rate was 83%. The research involved 12

physiotherapists, 1 occupational therapist and 2 masseuse specialists. The average age of the entire group was 37.53 ± 10.54 years, the youngest 29 and oldest 61 years. Considering the age, younger workers (< 45 years) percentage was higher than older workers (> 45 years). Whereas, there were 53% younger workers in the study group. Based on body mass index (BMI) 66.7% was normal weight, 6.7% was overweight and 26.7% was obesity. The backround factors are shown in Table 1.

**Table 1.** Comparsion of backround and professional characteristics of physiotherapists ($n$ = 12), occupational therapist ($n$ = 1) and masseuse ($n$ = 2) in a rehabilitation hospital.

| **Characteristic** | **Physiotherapists** | | **Occupational therapist** | | **Masseuse** | |
|---|---|---|---|---|---|---|
| | ***M*** | ***SD*** | ***M*** | ***SD*** | ***M*** | ***SD*** |
| Age (years) | 36.67 | 9.72 | 29.00 | - | 51.00 | 14.14 |
| BMI (kg/m$^2$) | 25.08 | 5.21 | 19.00 | - | 27.00 | 7.07 |
| Years of practice | 8.35 | 6.62 | 1.00 | - | 20.00 | 0.00 |

**Table 1.** Continued.

| **Characteristic** | **Physiotherapists** | | **Occupational therapist** | | **Masseuse** | |
|---|---|---|---|---|---|---|
| | ***M*** | ***SD*** | ***M*** | ***SD*** | ***M*** | ***SD*** |
| Hours worked per day | 7.25 | 1.08 | 7.50 | - | 7.50 | 0.71 |
| Hours worked per day with computer | 1.42 | 0.42 | 2.00 | - | 0.50 | 0.71 |
| Number of patients per day | 8.00 | 1.17 | 8.00 | - | 11.00 | 0.00 |
| Regular physical activity per week | 2.00 | 2.02 | 1.00 | - | 0.00 | 0.00 |

The masseuse specialists were older, had a higher BMI, higher number of patients per day and longer years of practice.

The musculoskeletal measurement study group involved 10 workers with chronic pain in the neck, both side of the shoulder and low back in the past 12 month (Figure 2). All of them agreed to take part in the myotonometry and cervical range of motion (CROM) measurements.

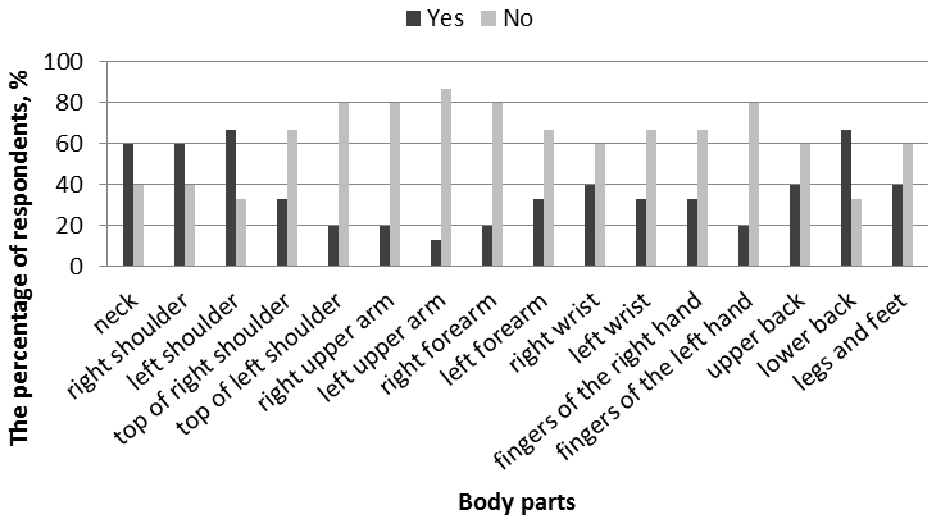


**Figure 2**. Prevalence of musculoskeletal disorders by different regions of the body.

The myotonometric measurements showed that frequency increased in the right leg *m. biceps femoris caput longum* ($p$ = 0.03) at the end of the workday (Table 2).

**Table 2.** Comparison of musculoskeletal parameters in the beginning and end of the workday depending on the body side ($p$, statistically significant difference between the parameters in the beginning and at the end of workday).

| Muscle | Parameter | Mean ± SD | | $p$ |
|---|---|---|---|---|
| | | Beginning of the workday | End of the workday | |
| **Right side of the body** | | | | |
| *M. biceps femoris caput longum* | frequency (Hz) | 14.27 ± 2.11 | 16.19 ± 2.43 | 0.03 |
| **Left side of the body** | | | | |
| *M. biceps femoris caput longum* | frequency (Hz) | 14,70 (±2,53) | 15,06 (±3,07) | - |

Significant differences between left and right side musculosketeal parameters have observed (Table 3). In the beginning of the workday the decrement in the left hand *m. biceps brachii* ($p$ = 0.003) was signifigantly lower than right side. Decrement in the right leg *m. biceps femoris caput longum* ($p$ = 0.03) was higher when to compare with left side. At the end of

the workday the muscle tone in the left leg *m. gastrocnemius medialis* ($p$ = 0.005) was higher when to compare with the right side.

**Table 3.** Comparison of musculoskeletal parameters of the left and right side of the body depending on the measurement time ($p$, statistically significant difference between the body sides).

| **Muscle** | **Parameter** | **Mean ± SD** | | ***p*** |
|---|---|---|---|---|
| | | **Left side of the body** | **Right side of the body** | |
| **Beginning of the workday** | | | | |
| *M. biceps brachii* | decrement | 1.53 ± 0.23 | 1.74 ± 0.27 | 0.003 |
| **End of the workday** | | | | |
| *M. biceps femoris caput longum* | decrement | 1.46 ± 0.26 | 1.67 ± 0.25 | 0.03 |
| *M. gastrocnemius medialis* | frequency (Hz) | 15.30 ± 2.79 | 13.74 ± 2.45 | 0.005 |

The data of goniometric measurements have revealed in the Table 4.

**Table 4.** Cervical range of motion (mean±SD) depending on gender and measurement time.

| **Parameter** | | **Mean±SD** | | **Range of motion (degrees) 5…95 precentile [7]** |
|---|---|---|---|---|
| | | **Beginning of the workday** | **End of the workday** | |
| **Male** | | | | |
| Cervical range of motion | flexion (˚) | 77.0 | 79.0 | 34.5…71.0 |
| | extension (˚) | 59.0 | 60.0 | 65.4…103.0 |
| | lateralflexion left (˚) | 59.0 | 60.0 | 35.5…63.5 |
| | lateralflexion right (˚) | 54.5 | 55.0 | 34.9…63.5 |
| | rotation left (˚) | 63.0 | 66.0 | 74.3…99.1 |
| | rotation right (˚) | 72.5 | 71.0 | 73.3…99.6 |

**Table 4.** Continued.

| **Parameter** | **Beginning of the workday** | **End of the workday** | **Range of motion (degrees) 5…95 precentile [7]** |
|---|---|---|---|
| | **Mean±SD** | | |
| **Female** | | | |

| | | | | |
|---|---|---|---|---|
| Cervical range of motion | flexion (˚) | 61,3 (±12,1) | 58,8 (±17,2) | 46.0…84.0 |
| | extension (˚) | 62,9 (±14,1) | 63,1 (±14,7) | 64.9…103.9 |
| | lateralflexion left (˚) | 37,8 (±12,0) | 37,9 (±10,8) | 29.1…77.2 |
| | lateralflexion right (˚) | 36,3 (±10,2) | 38,4 (±10,3) | 37.0…63.2 |
| | rotation left (˚) | 66,6 (±14,2) | 67,8 (±11,0) | 72.2…109.0 |
| | rotation right (˚) | 69,4 (±8,9) | 67,1 (±14,2) | 74.9…108.8 |

The measurements showed that mobility of the neck at the beginning of the workday among both male and female were lower. At the end of the workday CROM showed tendency to decrease in the flexion and lateral rotation to the right. Compared to the NASA study cervical spinae extension and rotation were lower among male and female.

## CONCLUSIONS

The Labor Inspectiorate 2016 annual report revealed that uncomfortable work postures and repetitive movements are still the most often occupational risk factors that causes occupational diseases. Unfortunately workers themselves do not recognize that the repetitive movements, manual handling of loads or wrong working position are bad for health [7]. All the research participants are subjected to intensive work in compulsory work positions for long period, repeated activities and patient transfer. All these positions and activities have impact on fatigue of various muscle groups. Compulsory work positions, especially among masseurs, promotes muscular tiredness. The body does not receive oxygen enough as heart function and breathing are restricted which may cause chronic headache or backache [8].

All 10 participants reported musculoskeletal disorders in the past 12 month. The neck, shoulders and low back are the most painful body regions for physiotherapists. It was observed that age influenced the prevalence of pain. The employees who complained more pain have higher BMI and 30% of them are in age range 40–59.

back pain.Myotonometric measurement results did not showed any differences in *m. trapezius superior* and *m. erctor spinae* among study group. Significant differences were found in *m. biceps femoris caput longum, m. biceps brachii, m. gastrocnemius medalis* and *m. biceps femoris caput longum.* At the end of the workday decrement in the right leg *m. biceps*

*femoris caput longum,* decrement in the right hand *m. biceps brachii* and muscle tone in the left leg *m. gastrocnemius medialis* was higher.

All the CROM parameters despite gender increased at the end of the workday, except for rotation to the right, which showed tendency to decrease.

It is important to make regular reaks and exercises, eat healthy and implement ergonomics techniques to prevent MSDs among physiotherapists. More attention should be paid to the distribution of the workload, time planning, working environment and working postures [9].

ACKNOWLEDGEMENTS. The authors would like to thank all the respondents who took the time to complete the survey and the hospital rehabilitation department management.

## REFERENCES

[1] Europan Agency for Safety and Health at Work, Musculoskeletal disorders. Available: https://osha.europa.eu/en/themes/musculoskeletal-disorders. [Accessed 9 02 2017].

[2] Zheltoukhova, K., Bevan, S., Musculoskeletal Disorders and the Estonian Labour Market. Available: http://www.fitforworkeurope.eu/estonia_english1.pdf. [Accessed 9 02 2017].

[3] Passier, L., McPhail, S., Work related musculoskeletal disorders amongst therapists in physically demanding roles: qualitative analysis of risk factors and strategies for prevention. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3038991/. [Accessed 9 02 2017].

[4] Darragh, R. A., Huddleston, W., King P., Work-Related Musculoskeletal Injuries and Disorders Among Occupational and Physical Therapists. Available: http://ajot.aota.org/article.aspx?articleid=1865848 [Accessed 16 02 2017].

[5] Albert, W. J., Currie-Jackson, N., R.M.T., Duncan, C. A., A survey of musculoskeletal injuries amongst Canadian massage therapists. Available: https://www.ncbi.nlm.nih.gov/pubmed/19083660. [Accessed 17 02 2017].

[6] Vain, A., Myotonometria. Biomechanical diagnostics of the functional state of the skeletal muscles, University of Tartu, 2002.

[7] Joint Movement Ranges for Males and Females, Anthropometry and Biomechanics, National aeronautics and space administration. Available:

https://msis.jsc.nasa.gov/sections/section03.htm#Figure 3.3.2.3.1-1. [Accessed 23 03 2017].
[8] The Labor Inspectiorate. 2016 year annual report. Available: http://ti.ee/fileadmin/user_upload/tookeskkond_2016.pdf [Accessed 15 03 2017].
[9] Roja, Z., Kalkis, H., Roja, I., Measuring muscle fatigue in relation to the workload of health care workers. 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015. Available: http://www.sciencedirect.com/science/article/pii/S2351978915003959 [Accessed 22 03 2017].
[10] Metsma, T., The relationship with workload, -environment, working posture and work-related musculoskeletal disorders in massage therapists, University of Tartu, 2015.

# Occupational hazards and musculoskeletal disorders among rotary parlor operators

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**Abstract:** In Estonia more than 67% of dairy cows of local dairy barns live in herds larger than 300. For the recent 10 years a considerable number of new dairy barns have been built, equipped with modern milking technology and rotary milking parlors (carousels). New milking routines have lead to new work requirements for milking operators, including the requirements for work safety, hazards and risks. So far few special research has been conducted on work environments for the operators at rotary parlors.
The aim of the present paper is to study the work environment and work conditions of operators working at large rotary parlors, as well as clear out possible musculoskeletal disorders (MSD) connected with routine work (repetitive movements, awkward position, lifting loads). The anonymos survey among the operators of three rotary parlors was carried out, including questions about occupational hazards and MSD prevalence during the recent month, based on CUPID-questionnaire *(Cultural and Psychosocial Influences on Disability).*
Preliminary findings of the current study indicate that despite of the modern milking technology the operators still feel and describe their work at the parlor as „hard". The main occupational hazards mentioned were continuous standing position and repetitive routine movements at work. In summer the working area is too hot and in winter it can be cold, so that the „fingers in latex gloves are freezing". 94% of the respondents declared MSD in the course of the recent month. In average the operators indicated three to five points of pain on the body related to their work.
***Key words*:** rotary milking parlor, milking operator, work environment, repetitive movements, standing position, musculoskeletal disorders

## INTRODUCTION

As reported by the Estonian Livestock Performance Recording Ltd. of 01.01.2017, 82 279 cows are in performance testing with the average milk production of 9 294 kg in 2016. 54 556 cows making up more than 67% of dairy cows of local dairy barns, live in herds larger than 300 head [1].
Becoming a full member of the European Union, direct grants and investment subsidies have provided the opportunities to invest in improving the competitiveness of dairy companies by building modern barns and buying dairy technology. Over the past ten years a number of large dairy farms have been built.

The greater the number of dairy cows in barn, the larger the milking parlor, and the more milking cows are serviced by one place in a milking station [2].
The rotary milking parlor (carousel) has greater efficiency than parallel or herringbone stations and justifies its technical specifications in milking particularly large herds. The carousel station operates as a slowly swirling platform and milking cows reach it in a continuous stream. The carousel parlor is serviced by 2-4 milkers, who stand at predetermined position and perform only one type of working task, as on a conveyor. The task can be either cleaning the udder, pre-milking, attaching the cluster, or treating the teats with disinfectant. The rotation of the carousel determines the pace of performance for milking operators.
The work tasks of milking operators have changed, resembling those at a conveyor line of a factory where certain fixed subtasks are performed. Repetitive movement rate has increased dramatically. Instead of lifting heavy items which used to be the risk for operator`s work environment, it is now repetitive movements and caused exhaustion postures during work time which might in turn lead to health consequences. The urgent need for dealing with musculoskeletal overload and ergonomic design of work is indicated by increasing work-related musculoskeletal disorders (MSD).
In Sweden dairy workers in large-scale farms over 300 cows were surveyed. A study based on questionnaires showed that 86% of the dairy workers reported some kind of MSD during a period of 12 months [3].
Scientific research shows that the milking operators of modern large-herd dairy parlors intensly work with wrists, arms and shoulders at a high speed and high rate of repetitive movements, having too little muscle rest during the work period [4]. Working wiht the rotary system one has high pressure on wrists and hands when work is performed continually without any pauses [5].
In Germany a study was carried out to obtain material for complex health prevention of milking operators. Interviews with physiotherapists, milking operators and farm managers were conducted. The following risk factors were mentioned: cold temperature, high humidity, repetitive movements, long working hours, work on shifts, stress, low social and managerial support [6].
In Estonia there are no similar studies. To raise awareness of the problem, the present research aims at finding out what are the occupational hazards and health complaints of milking operators working in rotary parlor of large-scale dairy farms of more than 500 cows.

## MATERIALS AND METHODS

To collect the data a survey was carried out among volunteer respondents in three large-scale dairy farms of more than 500 cows. Two farms had parallel rotary systems serviced outside, in one farm there was a herringbone station

serviced inside. In three farms there 33 milking operators, of whom 18 anonymously completed the questionnaire. Thus, 55% of the operators were voluntary respondents. Of them there were 16 women and two men with the average age of 39 ±11 years, the mean length of 166 ±6 cm, average weight 70 ±18 kg, average work experience with rotary systems 1.8 ±1.2 years, and overall work experience with dairy cattle 9.6 ± 9 years.

The questionnaire consisted of two parts:

I Questions about work environment to identify the risk factors and toucing upon microclimate; physical, physiological and psychological risk factors. To assess the frequency of the factors the following scale was given as option for answers: never / sometimes / often / always / I do not know.

II Questions about musculoskeletal disorders based on the international questionnaire CUPID (Cultural and Psychosocial Influences on Disability), part III asking about pains experienced in the past month. To determine the location of pain drawings of body areas were added to the questionnaire. Some of the questions were yes / no questions. Some asked about the length or sharpness of pain describing the perceptions on three levels, as 1-6 days/ 1-2 weeks / more than 2 weeks; mixed / sharp / intolerable.

In addition to the questionnaire the dairy farm managers were interviewed to outline general work conditions and on site observation sessions were performed in milking stations during work time in July 2016 and February 2017.

The data were analyzed in *MS Office Excel* program.

## RESULTS AND DISCUSSION

Milking system should combine the cows, technology and people into one working system. Hundreds of animals in the waiting area and on the carousel have different thermocomfort requirements than a few milking operators working with them. Different farms have contributed to the thermal comfort of operators in different ways.

In Estonia the four seasons and changing weather can not guarantee permanently comfortable temperature in the milking area. To cool down the summer heat, the windows and doors are opened and the fans switched on which, in turn, creates the draft zone. In winter the waiting area is cold and using the heaters causes greater circulation. In winter and summer the temperature differences are due throughout the working shifts when groups of cows leave and arrive to the waiting area.

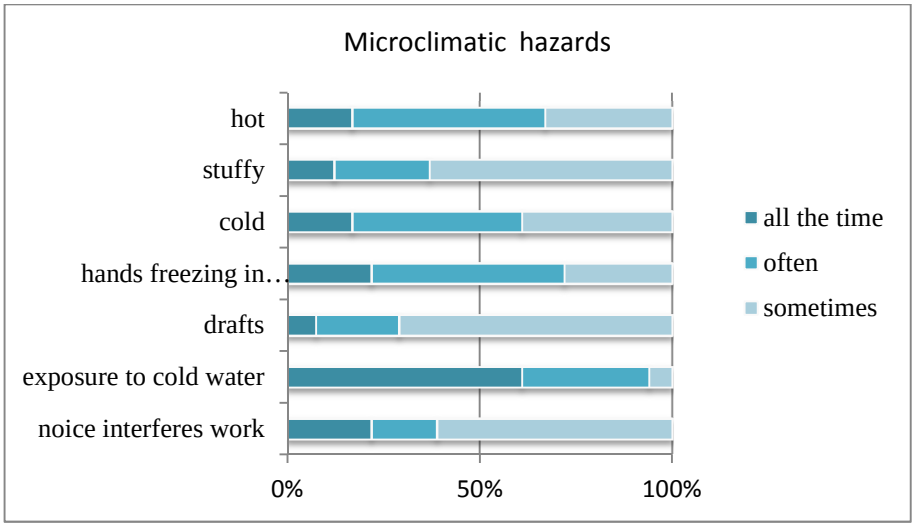


**Figure 1.** The questionnaire responses by exposure to the share of microclimatic hazards.

During active physical work it is important to keep the heat balance also in excess heat conditions. In summer high temperature and humidity prevent body from cooling, as does the waterproof clothing (rubber sleeves, long aprons, rubber boots). 50% of the operators responding the questionnaire indicated that heat often disturbs them.

One micro-climatic hazard unanimously noted by the respondents is constant exposure to cold water (Figure 1). When hands get wet by using even hot water but the air temperature is low, it produces body cooling. 72% of operators responding to the questionnaire noted that „fingers in latex gloves are freezing“ all the time or often. To prevent feeling cold some operators wrap paper or cloth around their wrists, under the cuffs. Putting cotton gloves under latex gloves hinders the grip and smooth movement of fingers during milking procedure.

The main physiological hazards are working in standing position and repetitive movements (Figure 2), the occurrence of which was indicated "all the time" by 100% of the operators. Beyond repetitive hand or arm movements, body or neck bending to check the teats or reach the udder is also a significant hazard, as it was noted „all the time“ by 67% or „often“ by 28% of operators. Cows do not like quick movements, so the risk of getting kicked by the animals is also a hazard. After active physical work milking operators feel overall fatigue by the end of the work day.


**Figure 2**. Different farms rated the unanimous exposure to the physical, physiological and psychological risk factors

In the questionnaire it was also asked about sufficient sleeping time. 67% of operators responded that they would like to get more sleep. However, waking up early morning was usually not a problem, rather the feeling of tiredness was sensed on evening shifts. In two of the three dairy farms the cows were milked three times a day which meant the late shift from 20:00 to 03:00 which, in fact, should be considered working at night.

The level of difficulty of the current milking operator`s job was rated as „very hard“ by 17%, „hard“ by 61%, „moderately hard“ by 17% and „light“ by 5% of respondents. Milking operators think that compared to some other jobs, their job is more difficult because of the permanent standing, strain and high pace, risk of injuries from animals, irregular sleep. Operators with longer experience, including tethering or loose-house parlor experience, found their work in rotary parlor system physically tiring.

Musculoskeletal pain survey revealed that during the past month 94% of the operators had felt pains in different body areas. 72% of the respondents had felt pain in 3 to 7 locations, for example, both of the shoulders, both wrists, neck, back.

Shoulder pain caused the most inconveniences as it was noted by 67% of operators (Figure 3), and for 50% of the respondents it lasted over two weeks in total during the recent month. Shoulder pain interfered with dressing for 67% and household chores for 58% of the respondents. 92% of respondents associated shoulder pain with work. However, the operators continued going to work and only one person (6%) had been absent from work due to the pain.

At the next place was the wrist pain, which was felt by 67% of the milking operators. For 58% of the operators the pain lasted up to 6 days, for 25% - more

than two weeks. Wrist pain disrupted writing for 67% and household chores for 25% of the respondents. 83% of the respondents associated wrist pain with their work.

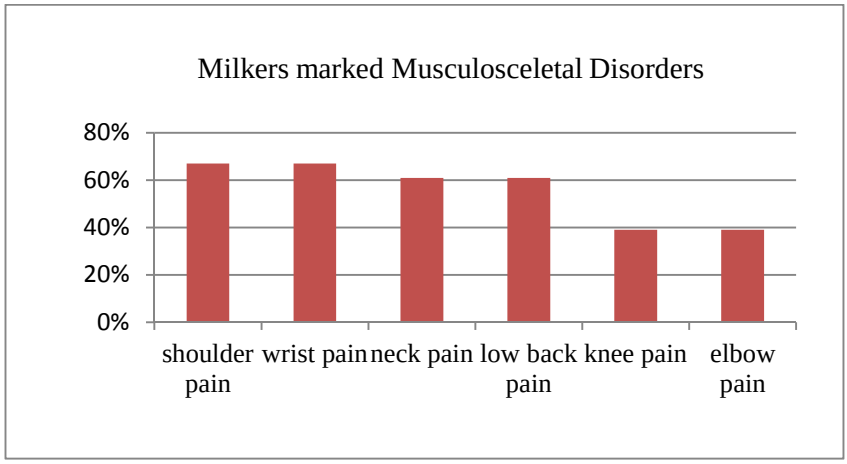


**Figure 3**. The presence of rotary operators discomfort during the past month.

Low back pain was felt by 61% of the milking operators during the last month, and 64% of them duration of pain lasted for up to 6 days. 45% of the respondents stated that back pain hindered dressing, and 64% said that doing household chores was difficult. 82% of back pain sufferers complained that it radiated to the foot (sciatica). People with back pain also continued working, only one person was absent from work less than 5 days due to back pain. 91% of the respondents associated low back pain with work.

Neck pain was felt by 61% of milking operators, of whom 45% suffered from pain up to 6 days and and 27% over two weeks. Neck pain hindered dressing for 55% of the respondents and had also interfered with household chores. Due to neck pain only one person (6%) was absent from work and pain was associated with work by 82% of the respondents.

Knee pain bothered 39% of the milking operators over the recent month, lasting up to 6 days in 71% of cases and more than two weeks in 14% of cases. Knee pain was not the cause to be absent from work. 71% of the respondents associated knee pain with work.

Pain was felt in elbow(s) by 39% of operators, and it lasted up to 6 days for 57% of the cases, and over two weeks for 43% of cases. This pain interfered with dressing for 43% of these respondents and it also hindered household chores. 71% of the respondents associated elbow pain with work.

During the previous year 61% of the milking operators had been on sick leave. 72% of them associated their illnesses with work (musculoskeletal disorders, colds and other work conditions), and 28% of the respondents – partly with work. No respondent used the questionnaire option „do not associate it with work“.

At the end of the questionnaire the milking operators were asked to assess their work ability on a 10-point scale and the result was 7 points, on average. Only 7 persons out of the total 18 respondents were of opinion that in two years they would be able to continue their present work, being a milking operator at the carousel system. 10 operators were not sure about it, regarding their present health condition. One operator excluded the option totally.

## CONCLUSIONS

Scientific studies show that milking operators in modern high performing dairy farms experience intense wrist, arm and shoulder work, also high pace and constant repetition of movements, and too little muscle rest during the work operations [4,5]. This is related to milking technology with increasing pressure to raise the capacity of the cows milked – to cope with milking of large herds. Intense work without adequate recovery breaks causes muscle tension and musculosceletal diseases.

The present study suggests that the micro-climatic conditions for milking operator`s active physical work are not always appropriate. Questionnaires revealed that in winter milking operators feel cold all the time or often (61%), and in summer they feel too hot all the time or often (67%), their hands in latex gloves are freezing (72%), and sometimes they suffer from of the drafts (56%). Coming and going of groups of cows changes the air temperature during the work shift and from the waiting area chilly air reaches the parlor. Those unfavourable work conditions cause musculoskeletal disorders (pains, inflammations).

Responses to questionnaires revealed that during the past month 94% of the milking operators have felt musculoskeletal disorders (MSD) at least in one location of the body. Most of them noted disorders in multiple (up to 7) locations. Most of all shoulders cause the feeling of discomfort, and for 50% of the respondents the pain lasted for over two weeks in total, hindering dressing and doing household chores. Wrist area, lower back and neck are the next critical locations. Milking operators accociate different pains with work as much as for 71-92%. However, the operators continue going to work despite pain, being absent from work only in a few cases.

Farm manager should be aware and careful of the statements by the respondents that only 39% of them are sure that they would be healthy and able to continue the operator`s job in two years.

Ergonomic assessments of repetitive movements and causing exhaustion postures of rotary parlor operators are highly recommendable, to determine the risk level of physiological hazards. The micro-climatic parameters should also be measured. Collecting further data about work environment enables one to make proposals for optimizing the work load of milking operators and improving the work environment in milking parlors.

## REFERENCES

[1] Estonian Livestock Performance Recording Ltd homepage [WWW] https://www.jkkeskus.ee/ (08.01.2017)
[2] Luik, H., & Viira, A. H. (2016). Feeding, milking and manure systems in Estonian dairy barns. *Agraarteadus*, *27*(2), 92-107.
[3] Kolstrup, C., Stål, M., Pinzke, S., & Lundqvist, P. (2006). Ache, pain, and discomfort: the reward for working with many cows and sows?. *Journal of agromedicine*, *11*(2), 45-55.
[4] Douphrate, D. I., Fethke, N. B., Nonnenmann, M. W., Rosecrance, J. C., & Reynolds, S. J. (2012). Full shift arm inclinometry among dairy parlor workers: A feasibility study in a challenging work environment. *Applied ergonomics*, *43*(3), 604-613.
[5] Stal, M., Pinzke, S., Hansson, G. A., & Kolstrup, C. (2003). Highly repetitive work operations in a modern milking system. A case study of wrist positions and movements in a rotary system. *Annals of agricultural and environmental medicine*, *10*(1), 67-72.
[6] Jakob, M. C., & Thinius, M. (2015). A strategy for workplace health promotion on German dairy farms. *Agricultural Engineering International: CIGR Journal*, *17*(1).

# Artificial lighting's influence on the working efficiency of office workers and teachers in educational-research buildings and offices.

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**Abstract:** All office workers and teachers spend their eight hour workdays inside buildings where artificial light is mostly used. This has affect on workers mood, work efficiency and on their physical health. The aim of this study was to evaluate the influence of artificial light on the working efficiency of office workers and teachers. In this study participated 199 employees, where 66.8% (n=133) were office workers and 32.7 % (n=65) were educational employees. The workers average age (mean ± SD) was 45.9 ± 12.0 years and average working experience 11.6 ± 10.4. The basic duration of working hours per week on average is 38.0 ± 7.5. Based on the electronic survey most of the respondents thought the workplace lightning to be sufficient enough and 2/3 of the answerers said there were no disturbing shadows or contrasts. Almost every workroom has windows. 172 people work with a computer for half of their working time or even more. Always and often 53.7 % of participants reported eyestrain, 37.2 % experienced eye dryness and 33 % reported sore eyes and vision loss.

**Key words:** office workers, teachers, artificial lighting, health

## INTRODUCTION

Working with a screen is increasing fast and therefore it is important to pay more attention to health risks and lighting conditions. Physiological risk factors cause the most health problems which are directly related to artificial lightning. There are different types of artificial lights which is why their light indicators affect workers health and productivity differently. Also natural light affects workers' productivity and comfort. Based on the survey that was carried out in 2010 in Sweden natural light has a direct impact on performance and attention. The participants preferred a lighting with different kinds of light source to a more neutral lightning and gave it higher ratings for well-being [1]. Correlated colour temperatures of light play an important role in human psychological and physiological need. Results reveals that cool white and daylight lights were more beneficial in office setting for computer-based tasks [2]. Recent research has indicated that lighting may have an impact on biological and psychological processes [3].

## MATERIALS AND METHODS

Purpose of this study was to investigate office workers and educational institutions in South-Estonia. The survey was electronic and sent to be answered by 18 South-Estonian establishments. The conditions for forming the group were working with a screen and at least one year of working experience.

In this study was used self-administrated questionnaire, which is based on international qualified questionnaires (*COPSOQ - Copenhagen Psychosocial Questionnaire, CUPID – Cultural and Psychosocial Influences on Disability* and *WAI – Work Ability Index*). Questionnaires should be found out working environmental risk factors about lighting conditions, work characteristics and workers health [4-6].

Questions on the survey sheet were divided based on the subject into eight sub-groups:

1. Demographic information
2. Psychosocial and psychological risk factors
3. Artificial light (ceiling lamps)
4. Natural light (sunlight)
5. Physical risk factors
6. Working with a computer
7. Health and productivity
8. WAI – performance index

The electronic survey was put together in *Google Forms* and the results were recorded straight to *MS Excel* spreadsheet. The average time to complete the questionnaire was 10 minutes.

**Table 1.** Sample characteristics

| | |
|---|---|
| Number of participants | 199 |
| Gender | Female: 75.9 % |
| | Male: 24.1 % |
| Age | Mean ± SD 45.9 ± 12.0 |
| | Range 21-68 years old |
| Work experience in the company | Mean ± SD: 11.6 ± 10.4 |
| Working hours per week | Mean ± SD: 38.0 ± 7.5 |
| Computer usage ≥ 50 % work day | 86.4 % |

The statistical analysis was performed with *SPSS.24.0 (Statistical Package for the Social Sciences).* Descriptive Statistics, $\chi^2$ – test and Spearman Correlation Analysis was carried out to find group differences between gender and occupation.

## RESULTS AND DISCUSSION

The survey was answered by 210 employees, but by the imposed conditions 199 results were taken into account. In this study participated 66.8% (n=133) office workers

and 32.7 % (n=65) education workers. Based by occupation, 42.2 % were specialists, 25.6 % teachers, 24.6 % advisors or consultants and 7.5 % leaders. The workers average age was 45.9 ± 12.0 years and the average working experience 11.6 ± 10.4. The basic duration of working hours per week is 38.0 ± 7.5.

The results of assessment of lighting conditions among the respondents are shown in the Fig.1.

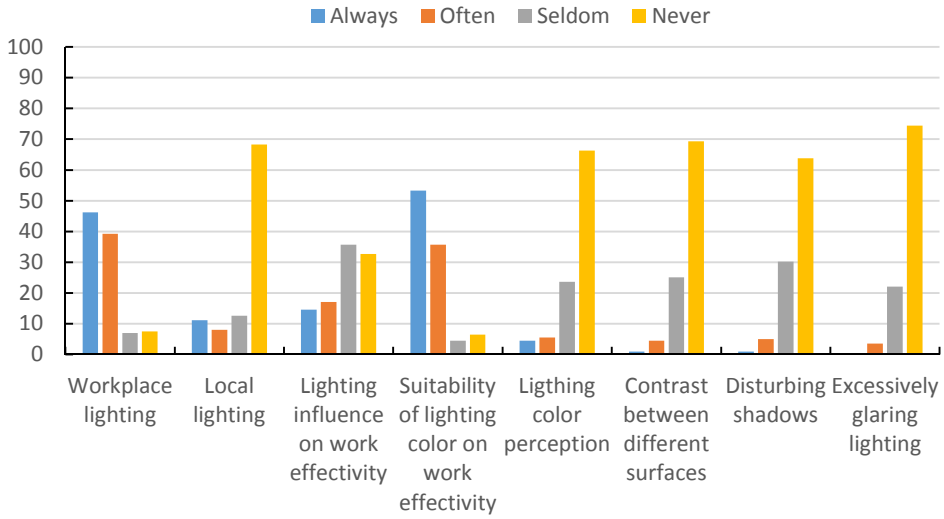


**Figure 1.** Artificial lighting conditions on the workplaces (n=199)

85.4 % of the participants were satisfied with their workplace lightning. In despite the lack of local light source about 2/3 of respondents claimed that there were no disturbing shadows, contrast and excessive glaring lighting doesn´t influence work effectiveness. About 50 % of the study group confirmed that workplace lighting conditions and lighting colour were often and always adequate. The light source colour was 51.3 % white, 31.2 % yellowish and 5.0 % bluish. Reflections from working surfaces were very or moderately disturbing to 72 employees, and 64 workers thought that computer screen reflections were upsetting.

99 % of the offices have windows and for 87.4 % of the respondents the windows were clean. Most of employees can have regulate natural lighting, because 81.9% of rooms have curtains on the windows and 12.6% have partly curtains. Almost half of the workers (47.2%) answered that natural lighting is very important and this affects their work ability. Bright natural light irritates workers few times in months (45.7%), and few times in week (7.5%). All participants were daily computer users, where over 75% of workday uses computer 118 workers, 50% - 75% of workday uses computer 54 workers and less than 50% of workday 27 workers. Laptops are used by 38.7% of the respondents. 89.9% of participants can change their screen position, and rotate it. 93.9% noted that their computer screen is clean and bright.

The results of health condition and vision problems among computer workers are shown in the Fig.2.

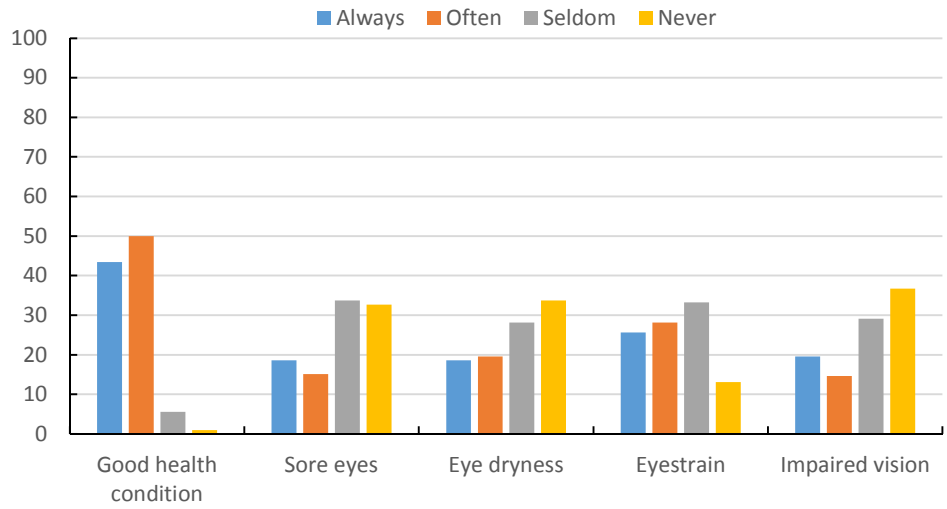


**Figure 2.** Health condition and vision problems among computer workers (n=199)

93.4 % of the people who answered, said their health was generally good. Always and often 53.7% of participants reported eyestrain, 37.2 % experienced eye dryness and 33 % reported sore eyes and impaired vision.

Spearman´s correlations analysis showed relationships between demographic parameters, workplace lighting condition and health complaints. Negative correlation between age and headache and tiredness has observed ($r$ = - 0.153, $p$ = 0.032; $r$ = - 0.176, $p$ = 0.013). Insufficient lighting was related to eye dryness ($r$ = - 0.206, $p$ = 0.003), eyestrain ($r$ = - 0.212, $p$ = 0.003) and sore eyes ($r$ = - 0.179, $p$ = 0.012). Working hours of computer use was positively related to eyestrain ($r$ = 0.171, $p$ = 0.016) and sore eyes ($r$ = 0.150, $p$ = 0.035). Screen reflection and flickering were positively related to sore eyes, eye dryness and eyestrain ($r \leq 0.156$, $p \leq 0.011$)

## CONCLUSIONS

From 199 of the office and educational workers 172 of them use a computer for more than half of their working time to complete their working tasks. There are windows and curtains in all the working rooms. Almost half of the workers found that natural light affects their work performance. The lighting in the workplace is mostly sufficient for the respondents and 89% of the workers believe the light colour to be suitable for their performance of duties. Work effectiveness was influenced by lighting reflections from work desks and computer screen. Working with a screen caused for more than half of the respondents eyestrain and 1/3 experienced eye dryness, sore eyes and impaired vision. Insufficient lighting, screen reflection and flickering related positively to eye

dryness, sore eyes and eyestrain. The younger employees detected more often headache and tiredness. To avoid eye vision problems is needed to measure workplace lighting and evaluate risk factors.

ACKNOWLEDGEMENTS. The authors would like to thank all who answered the survey and for finding the time to respond.

## REFERENCES

[1] Kronqvist, A., The influence of the lighting environment on performance and well-being in offices, Colour and Light in Architecture_First International Conference, 2010.
[2] Sivaji, A., Shopian, S., Bahri, S., Lighting does matter: Preliminary assessment on Office workers, Social and Behavioral Sciences 97, 2013.
[3] Kort, Y., Smolders, K. Effects of dynamic lighting on office workers: First results of a field study with monthly alternating settings, Lighting Res. Technol, p. 345–360, 2010.
[4] COPSOQ II. The contruction of the scale in COPSOQ II [Online]. Available: http://www.arbejdsmiljoforskning.dk/~/media/Spoergeskemaer/copsoq/uk/construction-of-the-scales-of-copsoq-ii-22-6.pdf#. [Accessed 27 03 2017].
[5] Coggon, D., The CUPID (Cultural and Psychosocial Influence on Disability) Study: Methods of Data Collection and Characteristics of Study Sample, 2012.
[6] Tuomi, K., Ilmarinen, J., Jahkola, A., Katajarinne, L., Tulkki, A., Work Ability Index, Institute of Occupational Health, 1994.

# Methodological considerations when studying the effect of lighting on human performance

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**Abstract.** This paper is about research methods, which allow understanding of how lighting conditions affect human performance. The purpose of this overview is to compare methods for measuring the effect of lighting conditions on human performance, in order to screen out methods which require the least of time and monetary resources. Typically lighting research is contacted in the laboratory or real workplace and human performance is evaluated if real or standard tasks. The appropriate environment and task depend on the researcher goal. Laboratory fits best for theory intended research, while real workplace is most suitable for directly applicable results.

**Keywords:** Illuminance, human productivity, visual performance

## INTRODUCTION

There are three key concepts, which characterise workplace ergonomics: system integration, ergonomic design and human performance [1]. In fact, all these concepts work together and form a human-machine-environment system. System integration is a process of bringing subsystems together into one system in this way, that subsystems work together to fulfil a common goal [2]. Generally, systems can't function without input. Every process starts from the inputs which come from sources outside the system (e.g. material, information, energy, etc.) and ends with the outputs transformed by the system (e.g. products). This process can run only if all subsystems work together.

Ergonomic design means making the jobs, workplaces, equipment, and environment compatible with the substantial majority [3]. As the name of the human-machine system implies the human and the machine have a reciprocal relationship with each other [4].

Performing tasks in accordance with the agreed standards of accuracy, completeness and effectiveness is called human performance. Human performance may be defined as including cognitive, physical, psychosocial, environmental, organisational and system factors [1].

Working environments are sources of many forms of stress (physical, chemical, biological, physiological and psychological factors) [5, 6], but if we talk about stressors, which imply financial expenditure, then air temperature, air velocity (ventilation) and lighting are the ones, which requires some type of energy (electricity) to be controlled. In the case of lighting, the effect of many variables (circadian system, SPD etc.) is currently unknown.

The idea of most electrical lighting research is to find lighting conditions, what will contribute to the achievement of best costs and benefits ratio through reducing energy

consumption and increasing human performance. Environmental Protection Agency (EPA) claims, if all businesses would utilise lighting technologies with high power consumption then 11% of the used electricity would be saved (total costs in the year 2007 would be over $18.6 billion) [7].

Lighting conditions may affect human performance by several mechanisms: visual performance, visual comfort, visual ambience, interpersonal relationship, biological clock, stimulation, job satisfaction, problem-solving, the halo effect and the change process [8].

The purpose of this overview is to analyse different methods for measuring the effect of lighting conditions on human performance in order to screen out methods which require the least of time and monetary resources.

## METHODOLOGICAL CONSIDERATIONS WHEN STUDYING THE EFFECT OF LIGHTING ON HUMAN PERFORMANCE

For understanding relationships between lighting and work, there is a need to identify the routes by which lighting affect human work productivity. There are three main routes: through the perceptual system, the circadian system and visual system. Perceptual system affects human work productivity in the case of inadequate lighting conditions that produce eyestrain. Eyestrain is the stress felt when the visual system has difficulties with achieving the aim of the task [9]. The circadian system can affect work productivity through shifting and acute effects. Shifting effect means that a phase of the circadian rhythm may be shifted earlier or later by changing illuminance. In the case of acute effect, it's proved that alertness at night may be increased by bright light [10]. The only route where lighting directly affects vision and visual performance is through the visual system. It is self-evident that in complete darkness it’s impossible to complete a visual task.

Different types of mechanisms maps are developed to explain the relationship of lighting with health, well-being and human performance. A model proposed by Boyce et al [11] proposes, that changing lighting conditions in an office directly affects workers in three ways: changes visual capability, visual comfort and perception of the conditions. Through these changes worker’s mood, motivation, well-being and task performance may be affected. In contrast, a simplified conceptual model proposed by Juslen and Tenner [8] where human performance is directly linked to profitability of the industry and is affected through three main routes: visual, photobiological and through process change. The most sophisticated model is proposed by Boyce [10] which describes the links between lighting conditions and visual performance, visual performance and human performance, but also different effect modifiers.

The preferred model for conducting lighting research is the model proposed by the Boyce [10]. The reason is that this model gives the best review about what factors can affect human performance both in a positive and negative way. If these variables are known, it is more clear what method for measuring human performance is needed to investigate the effect of a specific factor on human performance.

Another important issue is the understanding of the difference between visual performance and task performance. Task performance is the sum of visual, motor and

cognitive performance. Visual performance includes only the visual component of the task. Cognitive performance deals with decision making and motor performance is responsible for carrying out the action. None of these is specific to the impact of lighting conditions. Therefore, the importance of cognitive and motor performance should be limited in lighting research. The best solution is to design a standard task, where cognitive and motor components are controlled and their impact minimalised. This is usually achieved with reaction time testing [12] or some sort of visual acuity test [13, 14]. However standard task gives only limited information about overall task performance. As the importance of cognitive, motor and visual components is not equal and depends on the specific jobs, the changes in visual performance might not have the same effect on the overall performance. If one's interest in productivity is connected with actual productivity units (parts per minute) then the performance of the real task should be measured.

In addition to the task, the venue or environment of the experiment must be considered. Lighting research is usually conducted either in a range of existing conditions [15] or in the laboratory [16] and participants are required to perform either a real task [15] or a standard task [17]. Such options may be combined (table 1), however, the applicability of the results does vary.

**Table 1.** The continuum of methods that can be used to measure the effect of lighting conditions on task performance. Summarised from [18]

| Environment | Task | Pros | Cons |
|---|---|---|---|
| Real world | Real | Clear understanding of performance. Results are directly applied in practice | Hard to control confounding variable. Limited generalisability |
| Real world | Standard | – | No useful information |
| Laboratory | Real | Confounding variables are controlled. Results are directly applied in practice | Limited generalisability |
| Laboratory | Standard | Generalisability. Confounding variables are controlled | Results are hard to apply in practice |

Real task in real world study is very specific meant to improve existing conditions or workplaces. If researcher's objective is to demonstrate the effect of an independent variable (illumination and contrast) on the dependent variable (comfort and performance), the best solution would be a standard task in the laboratory.

## CONCLUSIONS

There are a total of four methods to conduct a lighting research and the approach depends on the information one is interested in. If researcher's interest in productivity related to actual productivity units then a real task in real world method should be used. In this case, directly applicable results will be gathered. A standard task in laboratory methods is most suitable for studies where the goal is to study the general effect of the lighting conditions.

## REFERENCES

[1] W. Karwowski, International Encyclopedia of Ergonomics and Human Factors, 2nd ed., Kentucky: Taylor and Francis, 2006, p. 3606.

[2] H. T. Gilkey, "New Air Heating Methods", New methods of heating buildings: a research correlation conference conducted by the Building Research Institute, Division of Engineering and Industrial Research, as one of the programs of the BRI fall conferences,November 1959., Washington: National Research Council (U.S.), 1960.

[3] EASTMAN KODAK COMPANY, INC. Kodak's Ergonomic Design for People at Work, Second Edition, Hoboken: WILEY, 2004.

[4] Kroemer K. H. E., Grandjean E., Fitting the task to the human. Fifth Edition. A Textbook of Occupational Ergonomics, London: Taylor & Francis Ltd, 2003.

[5] S. J. Guastello, Human factors engineering and ergonomics. A systems Approach. 2nd edition., Boca Raton: CRC Press, 2014.

[6] Estonian Parliament, "Occupational Health and Safety Act," Riigi Teataja, Tallinn, 2016.

[7] Deborah, S. K, Ergonomics Made Easy. Second Edition. A Checklist Approach, Lanham, Maryland: The Scarecrow Press, 2008.

[8] Juslén, H., Tenner, A., "Mechanisms involved in enhancing human performance by changing the lighting in the industrial workplace," *Industrial Ergonomics*, vol. 35, no. 9, pp. 843-855, 2005.

[9] Peter R. Boyce, Human Factors in Lighting. Third Edition, Boca Raton: CRC Press, 2014.

[10] Peter R. Boyce, Human Factors in Lighting. Second edition, London: Taylor & Francis, 2003.

[11] Boyce, P. R., Veitch, J. a, Newsham, G. R., Jones, C. C., Heerwagen, J., Myer, M., & Hunter, C. M, "Lighting quality and office work: two field simulation experiments," *Lighting Research and Technology*, vol. 38, no. 3, pp. 191-223, 2006.

[12] Lit, A., Young, R. H., Shaffer, M., "Simple reaction time as function of luminance for various wavelenghts," *Perceprion & Psychophysics*, vol. 10, no. 6, pp. 397-399, 1971.

[13] Veitch, J. A., "Lighting quality contributions from biopsychological processes," *Journal of the Illuminating Engineering Society*, vol. 30, no. 1, pp. 3-16, 2001.

[14] Rea, M. S., "Toward a model of visual performance: Foundations and data.," *Journal of the Illuminating Engineering Society,* vol. 15, no. 2, pp. 41-57, 1986.

[15] Juslén, H. T., Wouters, M. C. H. M., Tenner, A. D., "Lighting level and productivity: a field study in the electronics industry.," *Ergonomics,* vol. 50, no. 4, pp. 615-624, 2007.

[16] Chi, C., Lin, F., "A comparison of seven visual fatigue assessment techniques in three data-acquisition VDT tasks.," *Human factors,* vol. 40, no. 4, pp. 577-590, 1998.

[17] Rea, M. S., "Toward a model of visual performanc: A review of methodologies.," *Journal of the Illuminating Engineering Society.*, vol. 16, no. 1, pp. 128-142, 1987.

[18] Boyce, P. R., "On measuring task performance," *Coloration Technology,* vol. 127, no. 2, pp. 101-113, 2011.

# Job risk factors, musculoskeletal disorders and health among restaurant workers

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**Abstract. Aim.** The purpose of the study is to analyze job risk factors and prevalence of musculoskeletal disorders (MSDs) among waiters and waitresses. **Background.** The waiters and waitresses are serving clients dishing up food and drinks the whole day in standing position. They are more likely to suffer from lower back pain, enlarged blood vessels and knee troubles. To investigate the workers point of view the anonymous e-questionnaire was conducted. **Method.** The anonymous e-questionnaire was sent to 53 waiters and waitresses, working full time in the biggest Tartu conference centers in Tartu. The survey contained 69 questions about job risk factors, work environment, workload, MSDs and health behavior. Also the questions like "How to improve work environment?" were included. The changes of work efficiency among the workers during the working day were measured. **Results.** The results of the survey show that the waiters and waitresses are working long hours. The biggest problem of the job is lower back pain but only a few of participants of the survey have consulted the doctor. The second bigest problem is knee pain. None of the reasearched employees are currently smoking. **Conclusion.** More attention must be directed to job risk factors to diminish musculoskeletal disorders and health complaints among restaurant workers.

**Key words:** musculoskeletal disorders, standing position, night job, work environment

## INTRODUCTION

The waiters and waitresses are serving clients dishing up food and drinks the whole day in standing position. Studies have shown that workers with similar work pattern - standing job, walking, occational lifting, have problems with lower back pain and other musculoskeletal disorders [1,2]. Working in a standing posture on a regular basis can cause sore feet, swelling of the legs, varicose veins, general muscular fatigue, lower back pain, stiffness in the neck and shoulders, and other health problems [2]. To investigate the workers point of view an anonymous questionnaire was conducted.

The purpose of the study is to analyze job risk factors and prevalence of musculoskeletal disorders (MSDs) among waiters and waitresses.

## MATERIALS AND METHODS

To find out the job risk factors and musculoskeletal disorders the anonymous e-questionnaire was conducted. The e-questionnaire was based on modified CUPID (Cultural and Psychosocial Influences on Disability) survey [3]. The questionnaire contained 69 questions about job risk factors, work environment, workload, MSDs and

health behaviour. There were 22 employees who answered to the e-questionnaire, participants were between the ages 19 and 33.

The data analyses of demographic parameters and job risk factors were based on multiple-choice answers. General health was measured on ten-point Likert scale, where 0 was ‘’very bad-‘’ and 10 ‘’very good health’’. The symptoms were measured with ‘’yes-no’’ answers. The data analyse was carried out with statistical program MS Excel where descriptive parameters (mean ± SD) were analysed.

## RESULTS AND DISCUSSION

There were 22 participants who answered to the e-questionnaire . The average age of the study group was 24±3,9 years ranging between 19 and 33 years old. Most of the employees were aged 19 – 25. Avarege work day length was 9,7±2,1 hours, varying from 8 hours to 12 hours. The work hours varyed from 60 to 180 hours in the month. Four employees find work day to be too long, others find the workday length optimal. Only 8 employees do regular breaks during workday. 4 people do breaks when they can and others don’t do regular breaks during workday.

From the reasearch group none of the employees smoked but 5 employees have smoked regulary in the past. From the 22 people who participated in the survey most of the employees evaluate their health good. Two of the employees evaluated their health below average. From the 22 employees, 12 exercise regulary. The most popular trainings are group trainings (aerobics, pilates, finess) in the gym and running.

Workplace risk factors are shown in the figure 1. The figure 1 shows that the most dangerous job risk factor is getting burnt with an hot object.

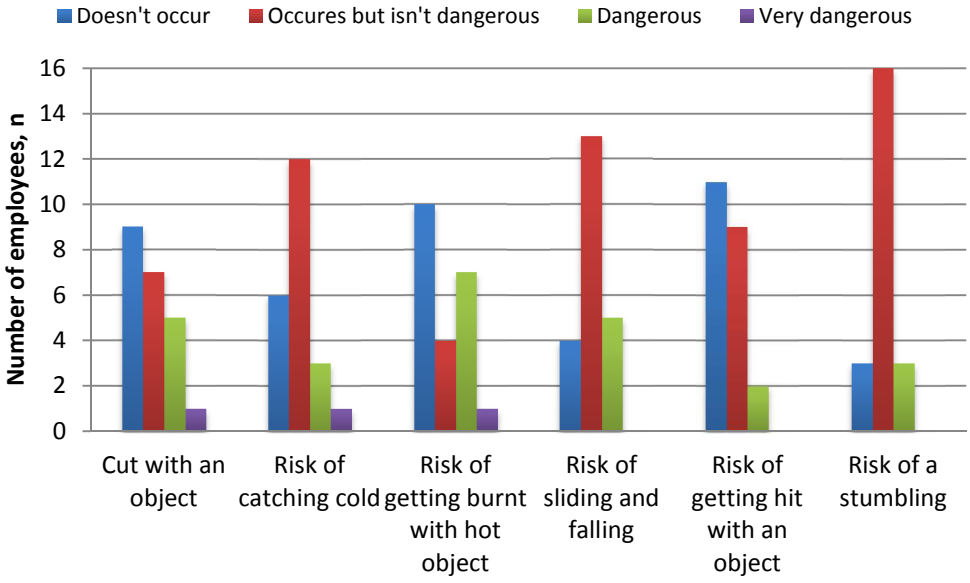


**Figure 1.** Assessment workplace risk factors

The most likley risk factor to occur is the risk of a stumbling and the risk of sliding and falling but majority of employees think that these risks are not dangerous. Only one person thinks that there are very dangerous risks at the workplace. These risks are a cut with an object like knife or broken glass, risk of catching cold because there are big freezers in the workplace where emloyees bring salads and raw materials and the risk of getting burnt with hot object. About half of participants mentioned that risk of getting hit with an object and risk of getting burnt with a hot object don't ever occur.

The prelavence of musculoskeletal disorders among restaurants' employees is shown in the figure 2.

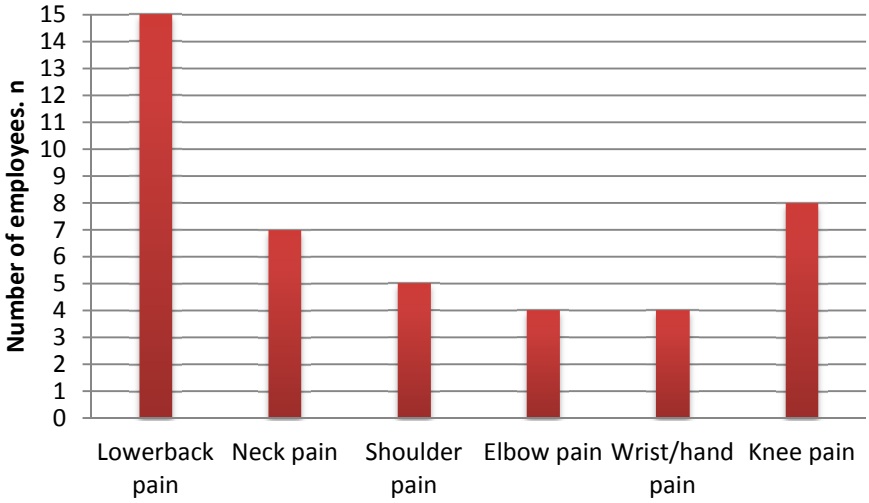


**Figure 2.** Prelavence of musculoskeletal disorders among employees

The most frequent musculoskeletal disorders to occur among waiters and waitresses was lower back pain. Two-third of employees who participated in the survey had lower back pain lasting more than one day. From 15 people who had had lower back pain 8 employees related the pain with work and only one of them had used sickleave because of the pain.

The second most troubeling musculoskeletal disorders among waiters and waitresses were knee pain and neck pain. One-third of employees had knee and neck pain lasting more than one day. From those 8 people only 3 of them related knee and neck pain with their work.

The lower back pain could be caused by lifting heavy things with back rather than legs. Working in such a non-ergonomic body posture and puts more stress on lower back region. The lower back pain could also be caused by working long hours in a standing posture.

To the question ''How to improve the working environment'' the workers answered: the training on how to do the work more ergonomically to minimize the health

risks; compression stockings and custom soles to lower the stress to legs; Stretch out exercise during the day or at the end of the day to the troubling muscle groups.

The most common symptoms are shown in the figure 3.

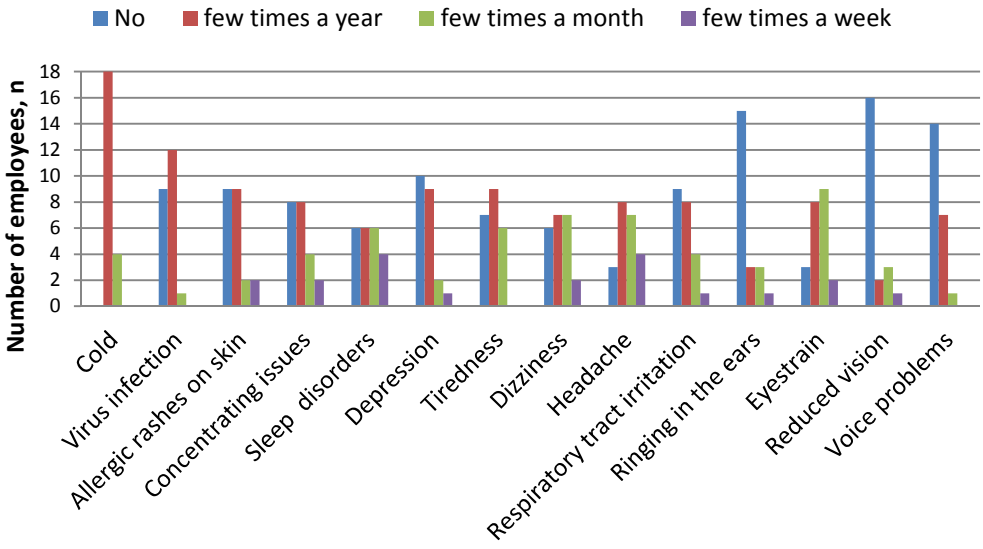


**Figure 3.** The most common disease symptoms and occure frequency

Most of participants are affected by catching cold more than a few times a year. Four employees cought cold few times a month in the past year. More than half of participants reported virus infections a few times a year. Eyestrain, sleep disorders and headache were the most frequent symptoms reported by the employees. Four participants had sleep disorders and headaches few times a week. Ringing in the ears, reduced vision and voice problems were the rarest reported symptoms. All except of one employee have been to work while sick.

## CONCLUSIONS

The very dangerous risk factors at the workplace would be a cut with an object like knife or broken glass, risk of catching cold and the risk of getting burnt with hot object.

The risk of a stumbling, sliding and falling are the most likley risk factor to occur in restaurant workplace.

The most frequent musculoskeletal disorders to occur among waiters and waitresses were lower back, neck and knee pain.

Most of employees are affected by catching a cold. Eyestrain, sleep disorders and headache were the most frequent symptoms reported by the employees

Ringing in the ears, reduced vision and voice problems were the least reported symptoms. The most problematic fact is that almost of all the employees with illness can’t take a sickleave.

## REFERENCES

[1] Shwn, S.H.,Sung, F.C., Su, C.H., Tsai, Y., Hsieh, V.C.R., Increased low back pain risk in nurses with high workload for patient care: A questionaire survey, 2016 [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1028455916300894 [Accessed 03 04 2017].

[2] Waters, T.R., Dick, R.B., Evidence of Health Risks Associated with Prolonged Standing at Work and Intervention Effectiveness, 2015. [Online]. Available: http://onlinelibrary.wiley.com/doi/10.1002/rnj.166/pdf [Accessed 03 04 2017]

[3] Coggon, D., et al., The CUPID (Cultural and Psychosocial Influences on Disability) Study: Methods of Data Collection and Characteristics of Study Sample, 2012. [Online]. Available: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0039820#references [Accessed 03 04 2017].