Product-specific manufacturing energy consumption

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Sammandrag:

Examensarbetet är ett beställningsarbete av ABB Oy Wiring Accessories. Fabriken har installerat energimätare på el-matningarna till formsprutningsmaskinerna och uppgiften är att undersöka energiförbrukningen produktivs vid tillverkning. Målet är att få fram ett sätt att mäta energiförbrukningen enligt produkten som tillverkas. Syftet med arbetet är att kunna jämföra de olika produkters energiförbrukning och för att göra det möjligt att i framtiden kunna uppskatta energiförbrukningen vid tillverkning. Genom kvantitativ forskning har jag analyserat, behandlat och beräknat all insamlade data. Med hjälp av olika datorprogram som Excel, Enerkey och företagets interna program var det möjligt att tillverka en Excel tabell som kan räkna ut energiförbrukningen produktivs med hjälp av all behövliga data. Med hjälp av resultat från Excel beräkningarna är det möjligt att jämföra energiförbrukningen produkt vis och finna rekommendationer. Av resultaten framkommer att då produktionstiden är ineffektiv påverkar det energiförbrukningen negativt per produkt tillverkad. En del av examensarbetes resultat är Excel tabellen för beräkning av energiförbrukning. Även en jämförelse mellan en äldre och en nyare produktionslinje som tillverkar samma produkt har gjorts, vilket visar att den nyare har lägre energiförbrukning. Detta arbete innehåller mina egna rekommendationer för företaget baserade på vad jag har analyserat av resultaten från Excel tabellen. I detta examensarbete har målet och syftet uppnåtts och företaget kommer att ha nytta av detta arbete i framtiden.

Nyckelord:	ABB, formsprutning, energiförbrukning, elmätare, plastprodukter
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Abstract:

The thesis is a commissioned work by ABB Oy Wiring Accessories. The factory has recently installed energy meters on the electrical lines for the injection molding machines and the task is to examine the energy consumption according to product during manufacturing. The goal is to develop a way to measure energy consumption according to the product being manufactured. The purpose of the work is to be able to compare the energy consumption of the different products and to make it possible in the future to estimate the energy consumption during the production. Through quantitative research, I have analyzed, processed, and calculated all the data collected. With the help of various computer programs such as Excel, enerkey and the company's internal programs, it was possible to create an Excel table that can calculate the energy consumption productively with the help of all the necessary data. With the help of results from the Excel calculations, it is possible to compare energy consumption by product and find recommendations. The results shows that when the production time is inefficient, it has a negative impact on the energy consumption per part manufactured. A part of this thesis results is the Excel table that calculates the energy consumption. A comparison between an older and a newer production line that manufactures the same product has been made, where results shows that the newer line energy efficient. This work contains my own recommendations for the company based on what I have managed to analyze from the results in the Excel table. In this degree project, the goal and purpose have been achieved and the company will benefit from this work in the future.

Keywords:	ABB, injection moulding, energy consumption, electricity meters, plastic products
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Tiivistelmä:

Tämä lopputyö on tilaustyö ABB Oy Wiring Accessories:lle. Tehdas on asentanut energiamittarit ruiskuvalukoneiden sähkösyöttöjohtoihin. Tehtävänä on tutkia tuotekohtaista energiankulutusta tuotannossa. Tavoitteena on löytää tapa laskea energiakulutusta tuotettavassa tuotteessa. Työn tarkoituksena on pystyä vertaamaan eri tuotteiden energiakulutusta ja mahdollistamaan sen, että tulevaisuudessa voidaan arvioida tuotannon energiakulutusta. Kvantitatiivisen tutkimuksen avulla olen analysoinut, käsitellyt ja laskenut kaiken kerätyn datan. Eri tietokoneohjelmien kuten Excel, enerkey ja yrityksen sisäisten ohjelmien avulla on ollut mahdollista työstää Excel taulukko, joka pystyy laskemaan tuotekohtaisen energiakulutuksen. Excel taulukon tulosten avulla on mahdollista vertailla tuotekohtaista energiakulutusta ja löytää suosituksia. Tulokset osoittavat, että kun tuotantoaika on heikko, sillä on negatiivinen vaikutus tuotekohtaisen tuotannon energiakulutukseen. Osa tästä lopputyön tuloksista on Excel-taulukko, joka pystyy laskemaan energiakulutuksen. Vertailu samaa tuotetta tuottavien vanhempien ja uudempien tuotantolinjojen välillä on tehty ja tulokset vertailusta osoittavat, että uudempi linja on energiatehokkaampi. Tämä työ sisältää minun omia suosituksiani yritykselle perustuen siihen mitä olen pystynyt analysoimaan Excel taulukon tulosten perusteella. Tässä työssä sekä tavoite että tarkoitus on saavutettu ja yrityksellä tulee olemaan hyötyä tästä työstä tulevaisuudessa.

Avainsanat:	ABB, ruiskuvalu, energiankulutus, sähkömittarit, muovituotteet
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List of abbreviations used

AC = Alternating current

DC = Direct current

ETS = Emissions Trading System

EU = European Union

g = Grams

h = Hour

HVAC = Heating, ventilation, and air conditioning

kg = Kilogram

kN = Kilo Newton

kW = Kilowatt

kWh = Kilowatt-hour

kWh/kg = Kilowatt-hours per kilogram

LAN = Local Area Network

PPH = Products per hour

RMS = Root mean square

THD = Total Harmonic Distortion

TRMS = True-RMS

W = Watt

W/h = Watt-hour

FOREWORD

This degree thesis is a commissioned research about energy consumption with the objective to account product specific energy consumption at ABB Oy Wiring accessories. This research is commissioned by ABB Oy to support more accurate energy consumption knowledge and the ability to estimate the energy consumption in the future.

I would like to thank the company ABB Oy for this opportunity, it has been a pleasure working with the company and a special thanks to Pyry Karhu who arranged this opportunity.

I also want to thank my supervisor Harri Anukka from Arcada University of Applied Sciences.

Porvoo 20.5.2021

Kristian Andersson

1 INTRODUCTION

The EU climate strategy and emissions objective are a package of three objectives set for 2030 that is the key driver supported by two other objectives. The emissions target is divided further into emissions trading sector ETS 43% compared to the 2005 level and into member state-specific targets in non-ETS sectors with an average of 30% comp regelared to the 2005 level. The renewable energy target is binding at the EU level and the energy efficiency target is indicative at the EU level. (Energiateollisuus ry, 2021)

These objectives are based on the Council's previous policy outline on 80-95% emissions reduction by 2050. This policy is in line with the international agreement limiting the global warming with no more than two degrees. The emission reduction target of 40% 2030 compared to 1990 was issued in EU's commitment to Paris Agreement on climate change with a result to limit the global warming to 1.5 degrees. (Energiateollisuus ry, 2021)

1.1 Purpose, objective and research methods

As I have worked several summers at ABB Wiring accessories, I got offered the opportunity to research my thesis for ABB Oy. New energy meters were installed specific to the Injection molding machines in the fall of 2020. And in this way, I got the topic for my thesis work. There has been different energy consumption research before. This thesis intention is product specific energy consumption. The purpose of the thesis is to monitor and analyze energy meter data at a product specific level. The thesis objective is to find methods to calculate energy consumption on a product specific level and how to use the energy data to forecast the product lines energy consumption.

In this thesis I will be using quantitative research methods. A quantitative research method is the process of collecting and analysing numerical data. It can be used to find averages, different patterns and testing causal relationships. The literature I will be using is ABB's own material and energyconsumption theories. With the help of Tac vista, Enerkey and ABB's internal programmes are used to collect data in the factory. I will be

able to analyse the energy consumption on the different products by knowing when a specific product has been manufactured at a specific time. During this thesis I can use my knowledge from working earlier with the machines and read about to injection moulding machines and their energy consumption. After that I can analyse the data from the data collecting programmes. With the information gathered I can compare the different products and try to find critical energy consumption points in the manufacturing. I will also be comparing some of the products in two different production lines with different injection moulding machines.

1.2 The company ABB

The company ABB is a leading global technology company that energizes the transformation of society and industry to achieve a more sustainable future by connecting software to electrification, robotics, and automation. ABB have a history of excellence stretching back more than 130 years. ABB is driven by 110,000 employees in over 100 countries. (ABB, 2020).

1.2.1 Sustainability and sustainability strategy 2030

Sustainability is a key part of the company's purpose and the value that is created for the stakeholders at ABB. In ABB it is believed that sustainable development is a progress towards a healthier and prosperous world for today and future generations. To achieve the need to balance the society, the environment, and the economy by embed this approach to business across ABB's value chain. Through ABB's leading technologies and responsible business practices ABB also contribute to the United Nations sustainable development goals, of which ABB has always been a strong advocate. (ABB, 2020 b)

Over the coming decades, the pressure on our environment will only increase. Today's global population of 7.8 billion is expected to expand to 9.7 billion by 2050 according to the United Nations with 80 percent living in cities and placing enormous burdens on water, food, energy and transportation. With ABB's 2030 sustainability strategy, ABB are actively enabling a low-carbon society as well as working together with customers

and suppliers to implement sustainable practices across the value chain and the lifecycle of the products and solutions. ABB are equally committed to driving social progress along with the suppliers in our communities. The sustainability focus is a part of ABB's commitment to responsible business practices, which are at the centre of the comprehensive governance framework based on integrity and transparency which is underpinned in the integrity principles in ABB's code of Conduct. One of the key parts in the strategy is to contribute actively to a low-carbon society in line with the Paris Agreement and following the guidelines of science-based target initiative. The three main sustainability targets at ABB are to enable a low carbon society, to preserve resources and to promote social progress. (ABB, 2020 c)

1.3 Location ABB Oy Wiring Accessories

This thesis is a research for ABB Wiring Accessories located in Porvoo Finland. Figure 1 is a photo of the factory. This Factory unit develops, promotes, and manufactures electrical wiring accessories for homes and industry including the product families Jussi and IMPRESSIVO. The factory in Porvoo is regularly investing in new manufacturing and automation innovations to increase competitiveness. With the power from about 100 employees and 50 robots, 25 million of products are manufactured yearly. (ABB Oy, 2021 a)

Figure 1. Photo of ABB Wiring Accessories unit, (ABB Oy, 2021 a).

1.3.1 Energy efficiency

There is a clear link between energy efficiency and the environmental impact. In ABB one of the key goals is to improve energy efficiency in their day-to-day operations.
The entire factory as well as the wiring accessories unit is connected to the nationwide Enerkey program. The Enerkey program Monitors the factory's energy consumption in electricity, district heating and water. The electricity consumption is monitored separately for the productions and assembly processes, ventilation, and lightning so that different consumption targets can be controlled separately. The heat generated from the manufacturing process is used to heat the property using a heat recovery system. During the summer and the warmer months, the cooling energy can me manually reduced by opening hatches in the roof allowing warm air to be effectively removed. (ABB Oy, 2021 b)

1.3.2 Current energy consumption

The energy consumption in ABB Wiring accessories factory is always monitored and it is possible to get data from the main energy consumption meters. The energy consumption meters are divided into seven categories that can be measured: Offices, Assembly, Factory lightning, cooling, compressed air, Injection moulding and others. A comparison between 2020 and 2019 shows that there was a small decrease in total energy consumption in 2020. In the figures on next page figure 2 shows a comparison of the energy consumption in 2020 and 2019. Figure 3 shows that almost half of the total energy consumption is from injection moulding.

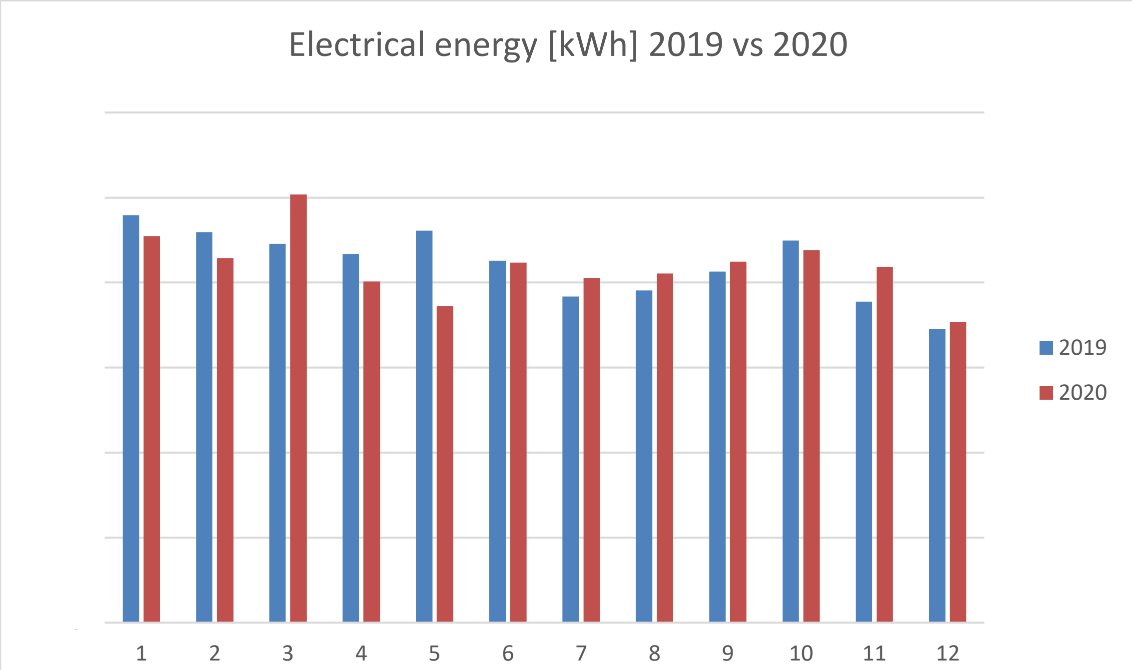


Figure 2. Electrical energy comparison between 2019 and 2020.

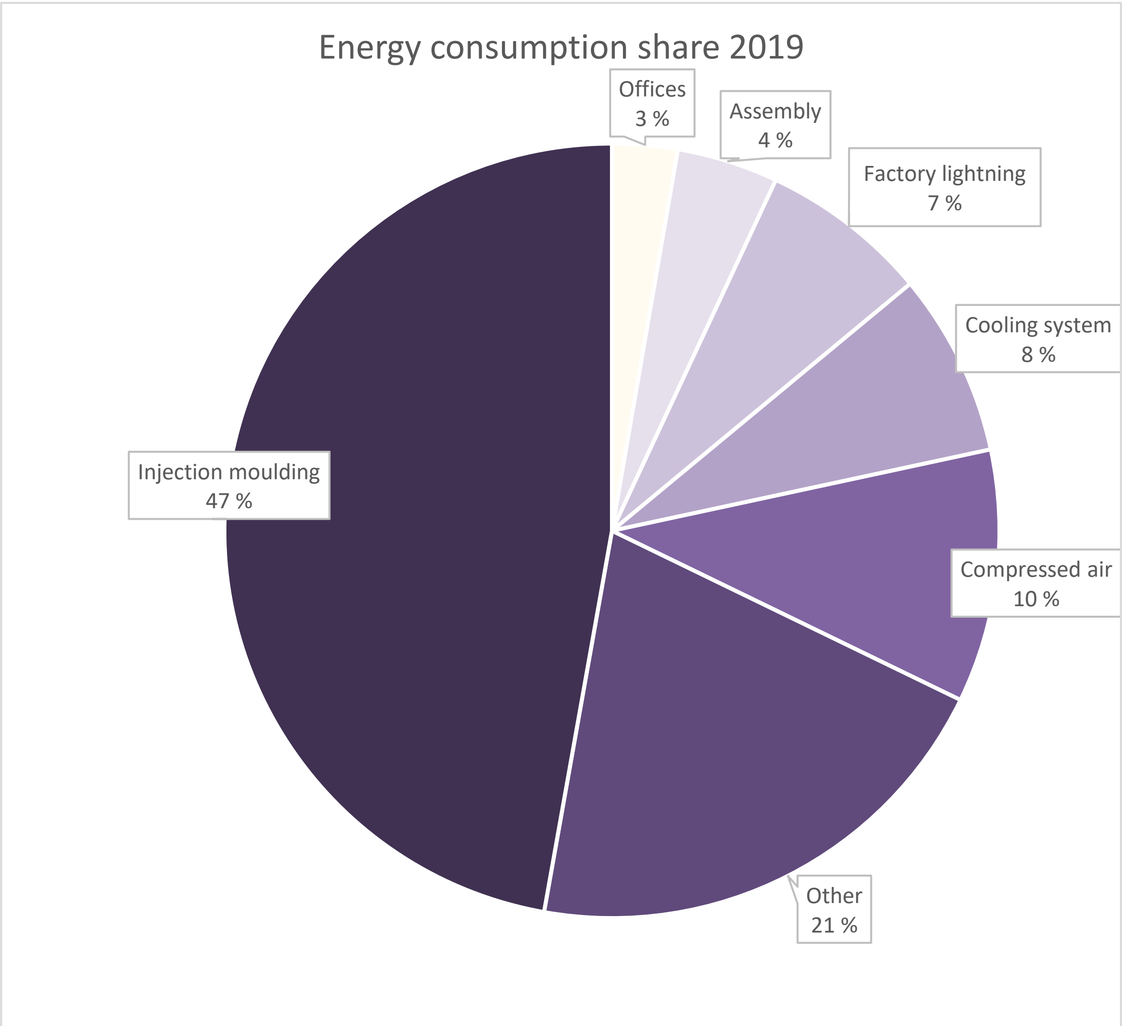


Figure 3. Pie chart over energy consumption in 2019 at the factory.

2 THEORY

This chapter processes some of the necessary theory about electricity measurements, Injection moulding machines and two of the computer programs used in this thesis. The section also contains the energy consumption meters used in this thesis.

2.1 Electricity meter technologies

This section about electricity meters goes through theory about TRMS metering and THD that is an important factor when measuring energy or electricity in factory environments. Because the energy meters installed to measure energy consumption used TRMS metering technique and calculates the THD to get a more accurate result.

2.1.1 True RMS meter

TRMS stands for True Root Mean Square and is a tool to measure AC current or AC voltage. This method can accurately measure both sinusoidal and non-sinusoidal AC waveforms, where a normal average responding multimeter can only measure a standard sinusoidal waveform. A sinusoidal wave is pure without distortion and a non-sinusoidal are waves with distorted irregular patterns such as spikes pulses triangles and other waves as seen in figure 4. (Fluke, 2021)

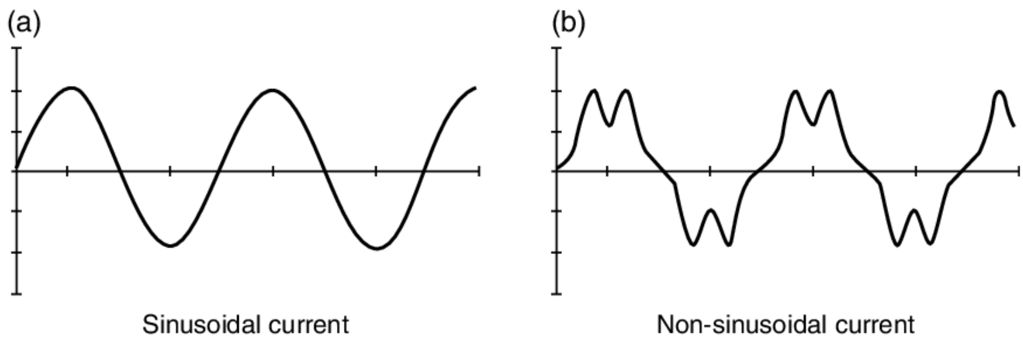


Figure 4. (a) Sinusoidal wave and (b) non—sinusoidal wave (Junwei, L, 2016).

RMS calculates the equivalent DC value of an AC waveform where an average meter uses an averaging mathematical formula to measure pure sinusoidal waves. A true-RMS meter can accurately measure the more complex non sinusoidal waves that can be distorted by computers or non-linear loads. Comparison of the meters can be seen in figure 5. Non-sinusoidal waves in circuits can be found in variable speed motor drives, electronic ballasts, computers, HVAC, and solid-state environments. In these environments the current can occurs in short pulses rather than a pure sinusoidal wave. (Fluke, 2021)

Multimeter type	Response to sine wave	Response to square wave	Response to single phase diode rectifier	Response to 3 ∅ diode rectifier
Average responding	Correct	10 % high	40 % low	5 % to 30 % low
True-rms	Correct	Correct	Correct	Correct

Figure 5. Average responding meter vs True-rms meter (Fluke, 2021).

2.1.2 Total Harmonic Distortion

Total harmonic distortion or THD is an important aspect to consider in power systems and should always be kept as low as possible. When the THD is low the power factor and efficiency is higher while there are lower peak currents. Low THD is an important feature in power systems and there are international standards ex. IEC 61000-3-2 that set limits on the harmonic currents in various classes of power equipment. (All about circuits, 2017)

A brief description of THD is that it is determined by summing all harmonic components of a signal and comparing the fundamental frequency. THD is created by all of the frequencies that have multiplies of the fundamental frequency but are not the fundamental frequency. To think about THD is when a perfect sine wave has no harmonic components, and the periodic signal looks like a perfect sine wave. The more harmonic components the more disruptions in the sine wave. THD standards for current are important because the high frequency current components have undesirable effects on

electrical systems, such as increased total currents, increased core losses in motors and electromagnetic interference with electronic equipment. (All about circuits, 2016)

To understand AC circuit analysis typically focuses on the power factor that is determined by the phase relationships between the voltage and current. Most electrical systems do not have loads with only resistors, inductors, and capacitors. Most electrical loads have some kind of power converters or a non-linear load. These components change the nature of the current and it is no longer sinusoidal. Since the current in the non-linear systems is still periodic this change in the current can be called harmonic distortion. The displacement factor is due to phase difference between voltage and current. (All about circuits, 2017)

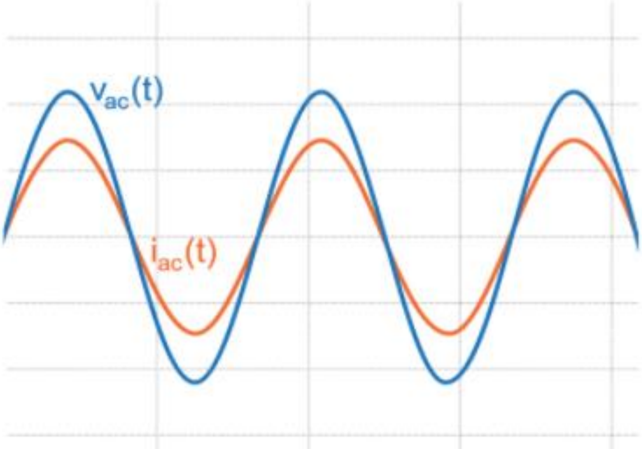


Figure 6. Example of a resistive load whitout harmonic distortion (All about circuits, 2017).

Voltage and current are in phase and have a smooth sinusoidal wave shown in figure 6. (All about circuits, 2017)

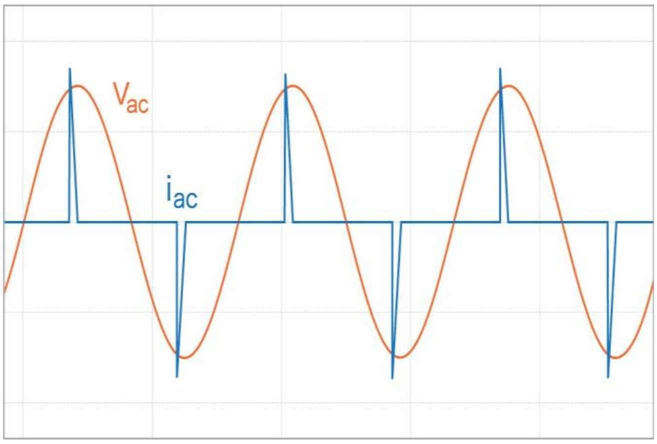
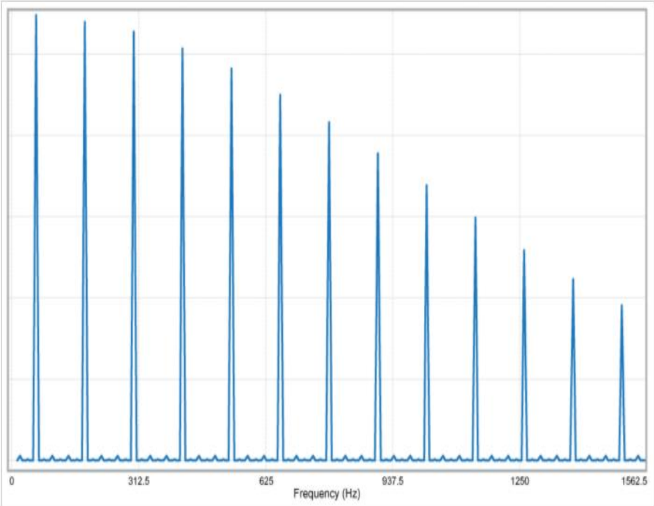


Figure 7. Voltage and current in a linear power supply with distortion in current (All about circuits, 2017).

Clear distortion in the harmonic current timeline but Is still periodical shown in figure 7. (All about circuits, 2017)



A lot of distortion in the current on a system with hundreds of AC/DC converters connected and contribution to harmonic distortion as shown in figure 8. (All about circuits, 2017)

Figure 8. Harmonics of current in a linear power supply (All about circuits, 2017).

2.1.3 ABB M2M and M4M

The installed energy meters in the factory are ABB M2M network analyzer, figure 9 and ABB M4M 20 network analyzer, figure 10. These network analyzers measure in real time the electrical parameters in single-phase or three-phase networks using TRMS-method and can verify the quality of the network using THD measurement. Through bidirectional metering of the energy and power in the 4^{th} quadrants it is possible to visualize the consumption in a single device. The devices communicate through TCP/IP and profibus using RJ45 or RS485 ports and digital pulse output.

Figure 9. ABB M2M (ABB, 2019).

Figure 10. ABB M4M 20 (ABB, 2021).

2.2 Injection moulding

Injection molding is one of the most commonly used processes to manufacture plastic parts. It is a cyclic process of rapid mold filling followed by cooling and ejection. The material, which is generally available as granulate, is plasticized in an injection unit and injected into a clamped mold under high pressure about 500 – 1500 bar. The advantage of injection molding is that this method is very economical for mass production. (Goodship, V. (ed.), 2020, ch.1) An injection molding machine can be fully electrical or fully hydraulic or a combination of both in a hybrid system.
(Goodship, V. (ed.), 2020, ch.5)

2.2.1 Injection moulding machine

The basic parts of the injection moulding machine are injection unit, machine base with hydraulic or electrics or a combine hybrid system, the control unit or operator interface and clamping unit. As seen in figure 11. (Goodship, V. (ed.), 2020, ch.1)

The injection moulding machine can be further broken down into specific important components shown in figure 12 on the next page.

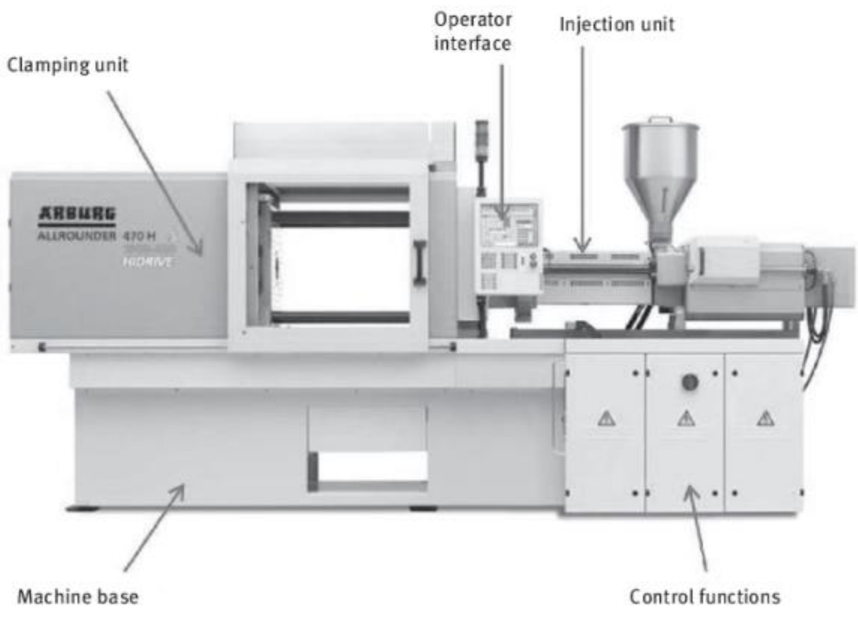


Figure 11. The basic parts of an injection moulding machine (Goodship, V. (ed.), 2020, ch.1).

Clamping unit - the part of the machine in which the mould is mounted. The unit provides force and movement

Fixed platen - the plate that does not move when the mould is closing.

Hydraulic clamp - the clamping unit is triggered by the hydraulic cylinder which is connected to the moving platen and providing the clamping force required to keep the mould closed.

Moving platen - the inner plate that moves during when the mould is closing

Ejector - ejects the moulded part from the tool and the mechanism is activated through the clamping unit

Mould (tool) - contains the cavity which material is injected into and consist of two halves

Tie rods - bars that links and align the fixed and moving platen

Injection unit - the part of the machine that feeds, melts, and injects the material into the mould.

Injection cylinder - the part which includes the screw, the nozzle, the feeding hopper, and the heaters.

Feeding hopper - the feeding hopper is where the plastic raw material is added for the molding process

Nozzle - the nozzle is the connection between injection cylinder and the mould tool.

Reciprocating screw - the screw that plasticizes and inject material

. (Goodship, V. (ed.), 2020, ch.3)

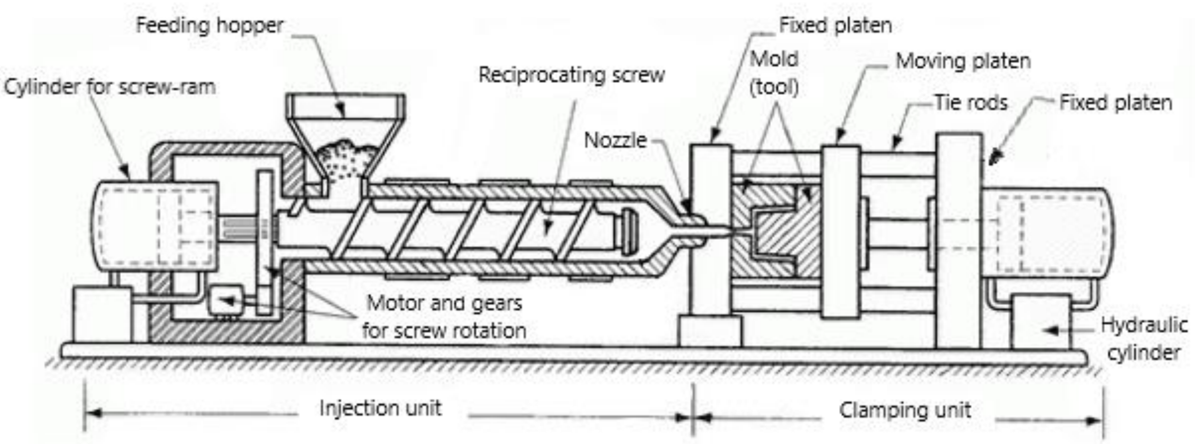


Figure 12. Sketch over the injection moulding machine's parts.

2.2.2 Hybrid injection moulding machine

The injection moulding machines can be driven by fully hydraulic systems, fully electrical system or hybrid combination with the advantages of both systems. For specific applications one drive system can be more advantageous over another.
(Goodship, V. (ed.), 2020, ch.5)

An alternative approach is to combine both drive concepts in a hybrid machine combined with an electrical clamping unit, an electrical dosing and hydraulic injection.
This example machine combines hydraulics with electrical drive. The movement of the moving platen, the injection unit heating and the screw movement are powered by electrical system. The functions within the mould tool ejection and core pulling as well as movement of the injection carriage are hydraulic. The injection unit consumes a considerable amount of energy and it can be more economic to use when electricity is cheap or self-produced by solar panels. Figure 13 shows the changeable parts in an injection moulding machine (Goodship, V. (ed.), 2020, ch.5)

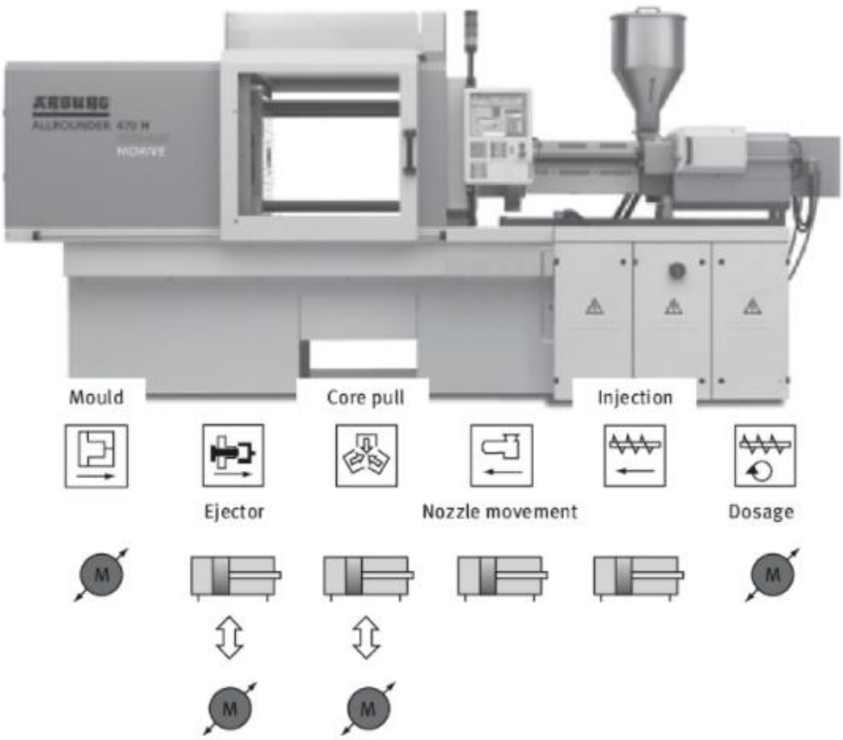


Figure 13. Picture showing which part that can be changed between hydraulic and electric (Goodship, V. (ed.), 2020, ch.5).

2.2.3 Injection moulding process

During the injection moulding process, the mould and the plasticizing area are separated from each other. The temperature in the plasticizing cylinder is maintained at the same level as the processing temperature. The mould temperature is cold enough for demoulding the injected moulded part. There are two different injection unit's available, piston injection unit and a screw piston injection unit (reciprocating) which is the most common method. (Goodship, V. (ed.), 2020, ch.1) This thesis includes only reciprocating method. The reciprocating screw machine process cycle can be divided into five stages shown in figure 14.

- **Stage 1** – the material is injected into the tool
- **Stage 2** – the screw turns and retract metering a specified weight of molten material. The previous injection is cooling in the tool.
- **Stage 3** – the injection unit moves back from the clamping unit
- **Stage 4** – the tool opens and reveal a cooled product
- **Stage 5** – the product is released from the tool and the cycle starts over.

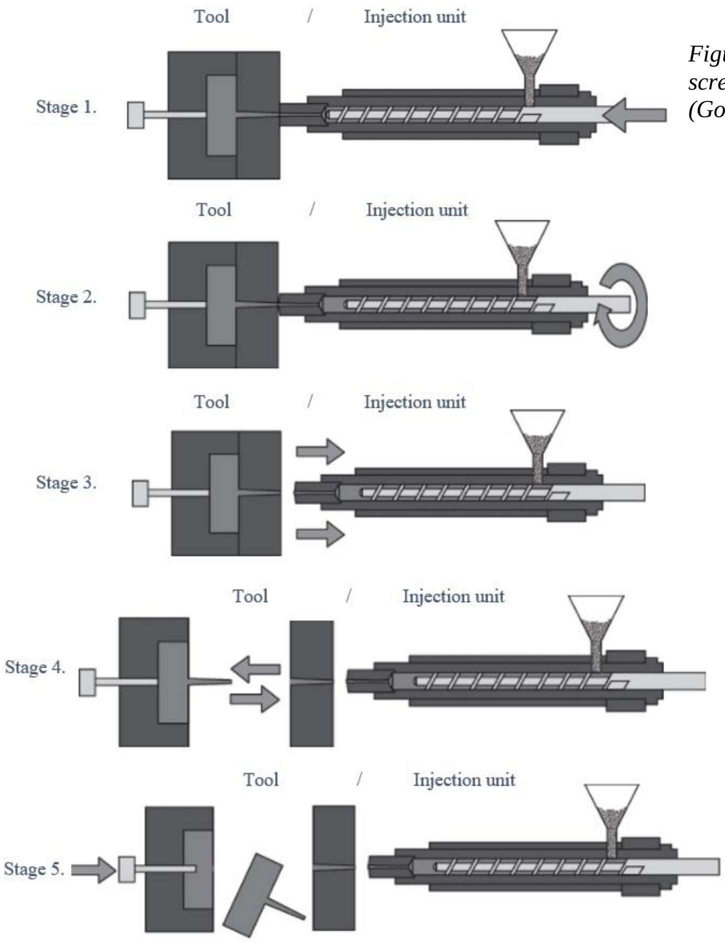


Figure 14. the five stages of the reciprocating screw process (Goodship, V. (ed.), 2020, ch.1).

(Goodship, V. (ed.), 2020, ch.1)
A single injection moulding cycle can be divided into three stages plastication, mould filling and cooling. (Goodship, V. (ed.), 2020, ch.1) figure 15 shows all the parts of the injection moulding cycle.

- Plastication is carried out in the injection unit. The aim is to produce a homogeneous melt for the next stage when the material enters the mould. Parameters which control these stages are cylinder temperature, screw back temperature and back pressure.

- Filling is when the injection unit delivers a specific preset amount of molten polymer (shot size) into the mould tool. The important moulding parameters are injections speed and injection pressure.

- Cooling is happening inside the tool when the filling of the tool is completed. When the part is cooled down the tool opens, and the part is ejected. Important parameters in this stage are packing pressure, time, and temperature.

(Goodship, V. (ed.), 2020, ch.1).

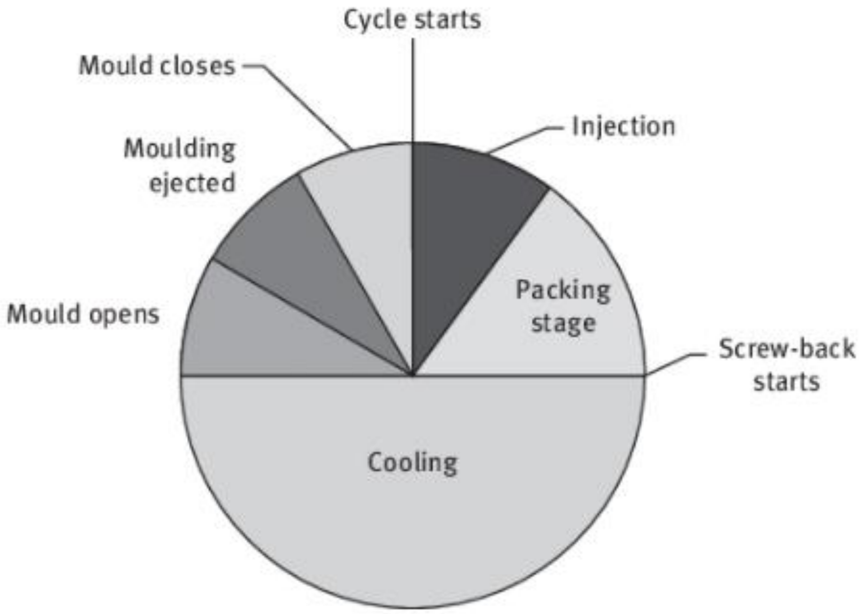


Figure 15. The injection moulding cycle explained in a piechart (Goodship, V. (ed.), 2020, ch.1).

2.2.4 Energy consumption in Injection moulding

Energy efficiency has become an increasingly important factor and continuing debate on hydraulic versus electric powered machines. The measurements of energy efficiency of the injection moulding process are given here.

In an alternating current, both circuit voltage and current are time dependent. Energy efficiency is measured by effective power that is:

$$Pt = V_t * \ I_t$$

therefore, the capacitive power in the AC circuit is:

$$Pt = \ V_t * \ I_t * cos\varphi$$

This is different from the actual installed power and concepts and should not be confused. Energy measurement requires the evaluation of all non-sinusoidal voltages and currents. Suitable measuring devices must be used that automatic determinates the important values of:

- phase shift cos φ
- supply frequency
- Energy requirement over a defined period
- average power

It is necessary that the machine and process is already thermally balanced.

The final relationship between energy requirements is:

Specific energy consumption (kWh/kg) = average power consumption (kW) * material throughput (kg/h)

$$kWh/kg = kW * kg/h$$

$$= kW * kg * 3{,}600$$

average power consumption (kW) * cycle time shot weight (kg) * 3,600

(Goodship, V. (ed.), 2020, ch.10)

Energy efficiency is typically measured in kWh/kg and is different for each molded part and have many different factors such as part weight, cycle time, machine size and machine efficiency. A research on *manufacturers saving potentials* made by skz plastics institute in Germany, gives a rough idea of how much energy an injection molding machine uses in this pie chart seen in figure 16. (Plastics Engineering, 2013)

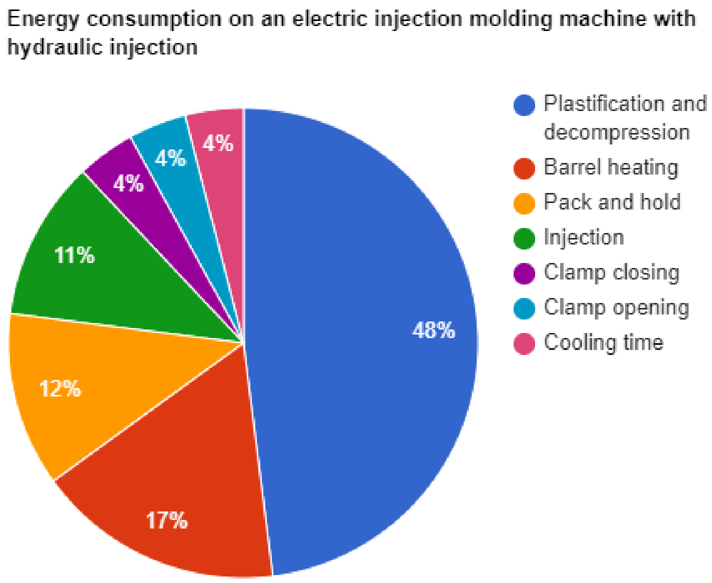


Figure 16. Pie chart over the energy consuming parts of an electric injection moulding machine (Plastics Engineering, 2013).

In the test a 100-ton electric press with hydraulic injection was tested. The piece it molded was an ABS storage trays with e time cycle of 16.9 seconds. The results showed that plasticization consumed most energy at almost half, 48% of the whole energy consumption followed by the heating at 17% and the clamp force at 12 % and injection force at 11%. Clamping motions and cooling time uses together 12% of the energy consumption. plasticization and heating are the main targets in energy savings. (Plastics Engineering, 2013)

2.3 Enerkey program

The program used to monitor the energy consumption in the factory unit is a system named Enerkey developed by Energiakolmio Oy. With the Enerkey it is possible to get energy consumption reports on an hourly and annual basis.

Enerkey is a market-leading Energy management system that is cloud based. EnerKey helps to identify emissions and energy saving potentials with automatic artificial intelligence and machine learning. All the consumption data, monitoring and managing is stored in one place. Enerkey is certified in the standards ISO 50001 and ISO 14001 that is the energy management requirements. (Enerkey, 2021)

2.4 Tac vista

The factory in Porvoo is using Tac Vista together with Enerkey program to monitor the energy consumption. Tac vista is also used to control the heating system, lighting and ventilation in the building.

TAC vista is a Building Energy Management system developed by Schneider electric.
With this system it is possible to monitor and control HVAC, lightning, access controls and different security features. Tac Vista have an open architecture that allows integration with third-party products. (Scneider Electric, 2021)
The program runs on windows with standard LAN on ethernet or fiber optics. The TAC Vista Server Is the server architecture where it communicates with the different TAC Vista monitors and load the data to TAC Vista Workstation. The Workstation displays operations through a graphical user interface where the user can access alarms, history logs and different reports. TAC menta is the name of the programming software tool for the physical TAC Xenta control units. (Scneider Electric, 2011)

3 METHOD

This section in the thesis goes through the methods and how the data was gathered. It gives information of how each different data is collected and calculated. Here the raw data from the preformed energy measurements are presented according to machine. Information about the plastic parts is presented in a table with all the products necessary information.

3.1 Data analysis methods

The collected data in this thesis is gathered from several different computing programs and ABB energy network analysis meters ABB M2M and ABB M4M20. Some of the data cannot be presented in this work because of confidential reasons. All the products and machines have been renamed in this thesis. The energy meters are installed on the powerlines for the injection moulding machines and separately from the automatics of the production's assembly lines. From the Energy meters it is possible to get the energy consumptions readings in real time. Received energy meter readings are stored and saved into tac vista. The readings of the energy consumption meters were controlled and compared with the program regularly to ensure that the readings are correct. Enerkey is used to follow up the whole consumption for the factory and all the meters can be found on the site where it is possible to get energy consumption readings from the energy meters online. Control measurements have been performed with clamp meters to compare with the network analyzers.

With the use of ABB: s own logistics program SAP it was possible to obtain information about the different products. Important information used from the program are product name and code, raw material, injection shot size and how many products the mould could make at an hourly rate.

Arrow machine track is the system used to track the injection moulding machines and production lines. The program tracks and stores data about all the production lines running times, faults, and installation times. Reports about the different production lines up and down times from a specific time or day can be obtained directly from the program.

Information used in from this program are the true automatic running time used in the calculations. Information about the injection moulding machines is gathered from the manufacturer's own technical specifications.

Enerkey program is used to follow up the whole consumption for the factory and all the meters can be found on the site where it is possible to get energy consumption readings from the energy meters online. It is possible to get graphics of the consumption data.

The calculations are calculated in Microsoft Excel. All the input data in Excel are the energy consumption meter readings in kW/h, injection shot size, products manufactured per hour, the real automatic running time. Output data are products manufactured during the time, kW/h per products manufactured converted to W/h, average W/h per product, total raw materials used and W/h / g of raw material.

3.2 Calculations

As mentioned earlier the calculations are performed in Excel together with the raw data material gathered from the different computer programs. The Excel table contains:

- Product
- Time and date for the metering
- Energy consumption during the metered time in kW/h
- The raw material
- Shot size in gram
- Pieces manufactured per hour
- Times in hours
- Automatic running time from arrow machine track
- Total pieces manufactured during the time

$$= Automatic\ running\ time\ (h) * Pieces\ manufactured\ per\ hour$$

- kW/h per pieces converted to w/h per pieces

$$= \left(\frac{Meter\ result\ kW/h}{Pieces\ manufactured}\right) * 1000$$

- Average kW/h per pieces manufactured

$$= \frac{Meter\ result\ (kW/h)}{Automatic\ running\ time\ (h)}$$

- w/h per gram

$$= \frac{meter\ result * 1000}{Total\ raw\ material\ used\ (g)}$$

- Total raw material used in grams

$$= total\ pieces\ manufactured * Shot\ size\ (g)$$

Machine group E: s Calculations were performed by with the formula below on each of the phases and then added together:

$$P_{tot} = U * I_{L1} + I_{L2} + I_{L3}$$

The current was measured every 5 minutes.

$$kW/h = P_{tot} * \frac{5}{60} h$$

This gives the result in kW/h per 5 minutes and the energy consumption can be calculated.

3.3 Performed measurements

All the measurements are gathered via ABBs energy meters that are connected to Enerkey via tac vista. The measurements data are gathered directly from Enerkey website where the data from the different meters are stored and can be downloaded. The products automatic running time is gathered from computer program Arrow machine track. One machine group does not have installed energy meters, but some measurements have been performed earlier with a clamp amperemeter.

Some of the power lines have been measured with a clamp amperemeter to ensure that the energy meter readings are correct. The metering period was between 8.4, 0.00 to 27.4, 2.00 with a total of 25 products and 33 energy metering's performed.

3.3.1 Machine A

During the measurement period there where 10 different plastic parts manufactured in Machine A in 11 metering periods. The automatic running time is gathered from reports in arrow machine track. The Injection moulding machine on this production line is an ENGEL ES 500 with a clamping force of 1000kN. Table 1 shows the metering results and figure 17 is a histogram of the measurement period.

Table 1. Machine A energy metering results

Product nr.	**time**	**Automatic Running time**	**Energy consumption per metered time**
11	4 h	4 h	54,5 kW/h
12	44 h	42,36 h	415 kW/h
12	18 h	15,45 h	195 kW/h
13	42 h	37,26 h	499,5 kW/h
14	35 h	25,15 h	411,5 kW/h
15	34 h	20,72 h	377,5 kW/h
16	12 h	6,41 h	143,5 kW/h
17	7 h	4,84 h	79,5 kW/h
18	55 h	52,79 h	683 kW/h
19	14 h	6,52 h	142 kW/h
20	15 h	15 h	179 kW/h

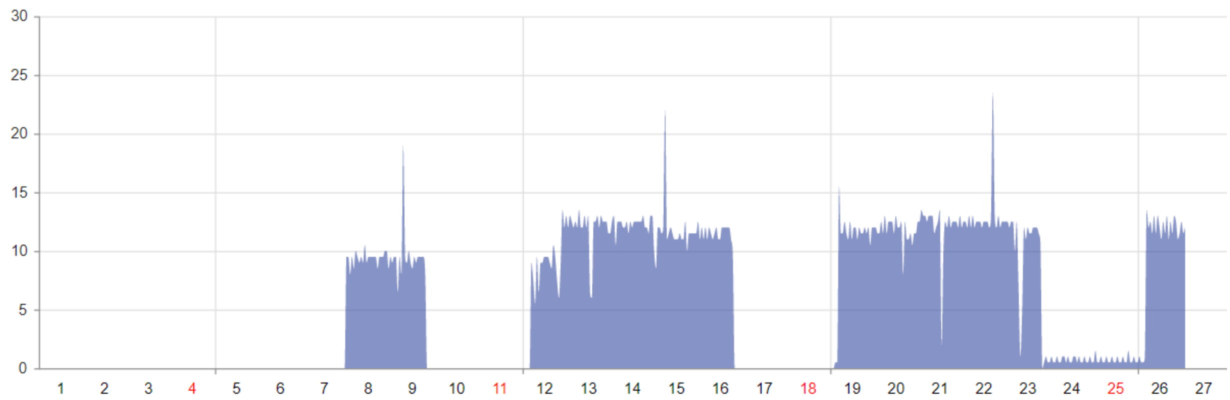


Figure 17. Histogram of machine A: s energyconsumption.

3.3.2 Machine B

During the measurement period there where 10 different plastic parts manufactured in Machine B in 10 metering's. The automatic running time is gathered from reports in arrow machine track. The Injection moulding machine on this production line is an ENGEL ES200 with a clamping force of 700kN. Table 2 shows the metering results and figure 18 is a histogram of the measurement period.

Table 2. Machine B energy metering results

Product nr.	**Measuring time**	**Automatic Running time**	**Energy consumption per metered time**
3	4,25	4,25 h	35 kW/h
3	48	42,6 h	362,5 kW/h
3	18	15,6 h	140 kW/h
4	8 h	7,52 h	60 kW/h
5	8 h	7,05 h	54,5 kW/h
6	3 h	2,65 h	21,5 kW/h
7	20 h	18,93 h	135 kW/h
8	29 h	26,48 h	171 kW/h
9	15 h	13,92 h	92 kW/h
10	9 h	7,81 h	52 kW/h

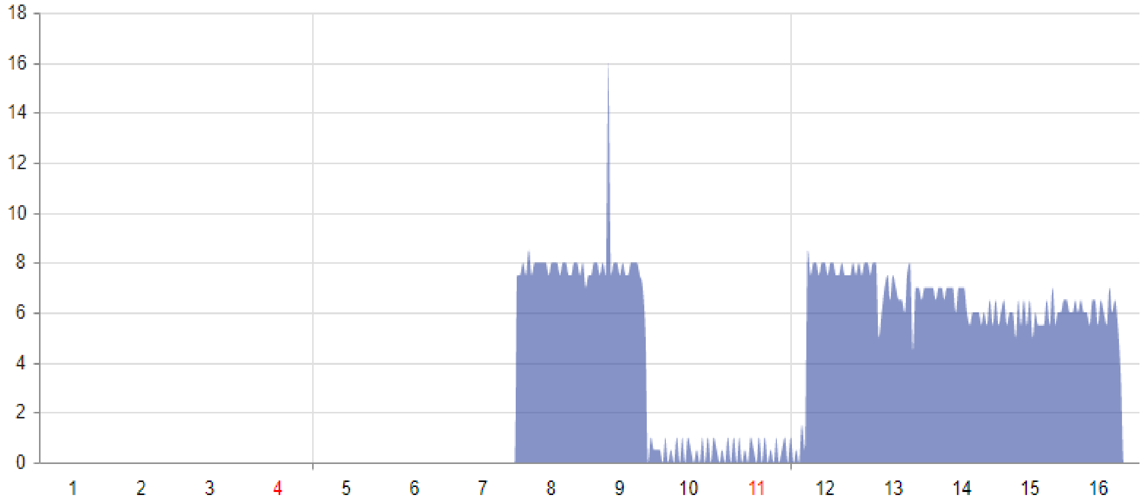


Figure 18. Histogram of machine B: s energyconsumption.

3.3.3 Machine C

During the measurement period there where 2 different plastic parts manufactured in Machine C in 4 metering's. The automatic running time is gathered from reports in arrow machine track. The Injection moulding machine on this production line is an ENGEL ES 330 with a clamping force of 800kN. Table 3 shows the metering results and figure 19 is a histogram of the measurement period.

Table 3. Machine B energy metering results

Product nr.	Measuring time	Automatic Running time	Energy consumption per metered time
1	1,5 h	1,5 h	15 kW/h
2	44 h	40,54 h	223,5 kW/h
2	57 h	54,53 h	290,5 kW/h
2	71 h	70,70 h	370 kW/h

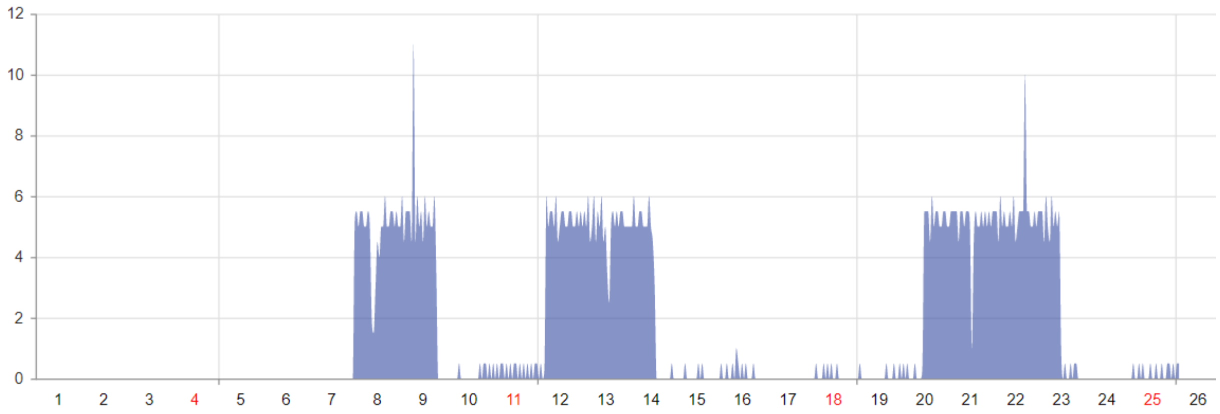


Figure 19. Histogram of machine C: s energy consumption.

3.3.4 Machine group D

During the measurement time period there where 4 different plastic products manufactured in Machine group D in 6 metering's. There are two injecting moulding machines working on the same production line to manufacture the product, also the assembly line's energy consumption is measured separately. The assembly line contains external heaters for the automatic line and packaging machine together with robots. The Injection moulding machines on this production line is an ARBURG 520 with a clamping force of 1300kN and an ARBURG 720 with a clamping force of 3200 kN. Table 4 contains measuring results.

Table 4. Machine group D energy metering results

Product nr.	Machine D-1	Machine D-2	Automatics	Automatic Running time	Energy consumption per metered time
21	367 kW/h	372 kW/h	621 kW/h	42,94 h	1360 kW/h
22.1	345,5 kW/h	348,8 kW/h	544 kW/h	29 h	1238,3 kW/h
22.2	195 kW/h	190,4 kW/h	257 kW/h	49,32 h	1718 kW/h
22.3	184 kW/h	182,4 kW/h	308,5 kW/h	19,69 h	674,9 kW/h
22.2	657 kW/h	636 kW/h	1072 kW/h	78,91 h	2365 kW/h
22.2	160 kW/h	163 kW/h	281,5 kW/h	59,51 h	604,7 kW/h

This graph in figure 20 contains all three of the energy meters. Red and blue is the injection moulding machines and green is the assembly line machines. The horizontal axis are the dates of April and the vertical represents the energy consumption in kW/h.

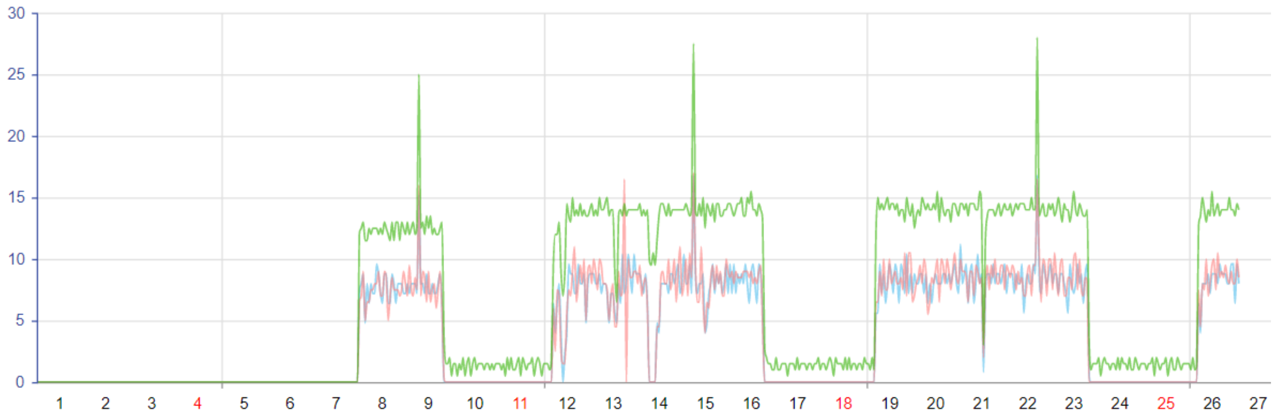


Figure 20. Histogram of machine group D: s energyconsumption.

3.3.5 Machine group E

The machines in group E Does not have any meters installed for the injection moulding machines. Some current measurements in ampere were performed in the fall of 2020. With the help of those earlier performed measurements it was possible to calculate the energy consumption. Some of the products that are manufactured in this production line are the same as in Machine group D. This gives an opportunity to compare a newer production line versus the older one. It was possible to gather historic information about the production lines running time compared when the measurements were performed with the help from arrow machine track. Ampere measurements were also performed on the automatics of the assembly line. The Injection moulding machines on this production line is an ENGEL VS 330 with a clamping force of 1200kN and an ARBURG ALLROUNDER 420 with a clamping force of 1000kN. Table 5 contains calculated and measured data from machine group E.

Table 5. Machine group E energy metering results

Product nr.	**Machine E-1**	**Machine E-2**	**Automatics**	**Automatic Running time**	**Energy consumption per metered time**
22.2	940 kW/h	468 kW/h	100,8 kW/h	38,79 h	1508,8 kW/h
22.4	703 kW/h	348 kW/h	75 kW/h	28,27 h	1126 kW/h

3.4 Plastics data

This section contains a table over the necessary information about the products manufactured in the injection moulding machines. Table 6 contains information about injection shot size, the raw material used, and the machine manufactured the plastic product.

Table 6. plastics data

Nr.	Machine	Raw material	Shot, g	PPH
1	Machine C	Polypropylene	13,78	707
2	Machine C	Polypropylene + color	9,22	212
3	Machine B	Polycarbonate	15,4	543
4	Machine B	Polycarbonate	13,18	543
5	Machine B	Polycarbonate	37,1	147
6	Machine B	Polycarbonate	60,5	140
7	Machine B	Polycarbonate	27,9	184
8	Machine B	Polycarbonate	15,5	194
9	Machine B	Polycarbonate	11,9	165
10	Machine B	Polycarbonate	12,9	180
11	Machine A	Polycarbonate	28,3	145
12	Machine A	Polypropylene	21	259
13	Machine A	Polycarbonate	45,32	314
14	Machine A	Polycarbonate	31,79	324
15	Machine A	Polycarbonate	34,41	116
16	Machine A	Polycarbonate	26,7	180
17	Machine A	Polycarbonate	15,5	180
18	Machine A	Polycarbonate	21,5	316
19	Machine A	Polycarbonate	34,41	218
20	Machine A	Polycarbonate	34,41	197
21	Machine D	Polypropylene + SEBS/TPS	94,13	450
22,1	Machine D	Polypropylene + SEBS/TPS	55,73	778
22,2	Machine D / E	Polypropylene + SEBS/TPS	55,725	778
22,3	Machine E	Polypropylene + SEBS/TPS	55,725	778
22,4	Machine E	Polypropylene + SEBS/TPS + color	57,12	778

4 RESULTS

All the results are presented in Appendix 1 that is the excel table where everything has been calculated. The total amount of parts manufactured, and total amount of raw material is hidden due to confidential reasons. With these results it is possible to compare and discuss the energy consumption in plastics parts manufacturing by injection moulding in the next chapter. The results from the excel are:

- Total parts manufactured (Hidden)
- kW/h per product
- W/h per product
- Average energy consumption
- W/h per gram material
- Total amount of material used (Hidden)

5 FINDINGS AND RECOMMENDATIONS

This section goes through some of the findings in the results and possible recommendations. All the compared results are calculated from appendix 1.

5.1 Findings

The newer production line with machine group D is more energy efficient than the older machine group E. When comparing the results, the newer line D's energy consumption is in average 5 kW/h lower than machine group E.

Prod. Nr.	**Machine Group**	**kW/h per piece**	**W/h per piece**	**Average kW/h**	**W/h per g**
22,1	D	0,0549	54,884	42,700	0,985
22,2	D	0,0448	44,773	34,834	0,803
22,3	D	0,0441	44,057	34,276	0,791
22,2	D	0,0385	38,523	29,971	0,691
22,2	D	0,0389	38,862	30,235	0,697
22,2	E	0,0500	49,994	38,895	0,897
22,4	E	0,0512	51,196	39,830	0,896

Table 7. Comparison between group D and E

One of the high impacts are stopping time when there are no products produced but the machines and assembly lines are still ready and waiting. The measurements with large differences by the metering time and automatic running time have a larger energy consumption. Like in table 8, when comparing group D: s first metering, the production time is bad. Also, when comparing product 2 manufactured in machine C it shows that when the time difference is larger the energyconsumption rises. Same patterns follow when comparing product 3 manufactured in machine B.

Table 8. Energyconsumption and time comparison

Prod. Nr.	**Machine Group**	**kW/h per piece**	**W/h per piece**	**Average kW/h**	**W/h per g**	**Time**	**Automatic time**
22,1	D	0,0549	54,884	42,700	0,985	44 h	29 h
22,2	D	0,0448	44,773	34,834	0,803	56 h	49,3 h
2	C	0,0260	26,005	5,513	2,821	44 h	40,54 h
2	C	0,0251	25,129	5,327	2,725	57 h	54,53 h
2	C	0,0247	24,686	5,233	2,677	71 h	70,7 h
3	B	0,0152	15,166	8,235	0,985	4,25 h	4,25 h
3	B	0,0157	15,671	8,509	1,018	45 h	24,6 h
3	B	0,0165	16,527	8,974	1,073	18 h	15,6 h

This thesis work resulted in a excel table that can be used in the future to calculate the energy consumption when manufacturing plastic products.

The choice of machine type and size has one of the biggest impacts on the energy consumption followed shot size. Injection moulding machines energy consumption is at highest during the plastication-decompression and heating. Machine B and C are almost the same size in clamping force, but machine C has a lower average energy consumption because of a smaller shot size. Machine A has the biggest clamping force and bigger shot sizes. Figure 21 on the next page shows a histogram over Machines A, B, C: s energyconsumption.

Table 9. Individual machines energy consumption comparison

Machine	Clamping force	Shot sizes	Average kW/h
A	1000 kN	20g - 45g	14,6 kW/h
B	700 kN	11g - 30g	7,6 kW/h
C	800 kN	10g - 13g	6,5 kW/h

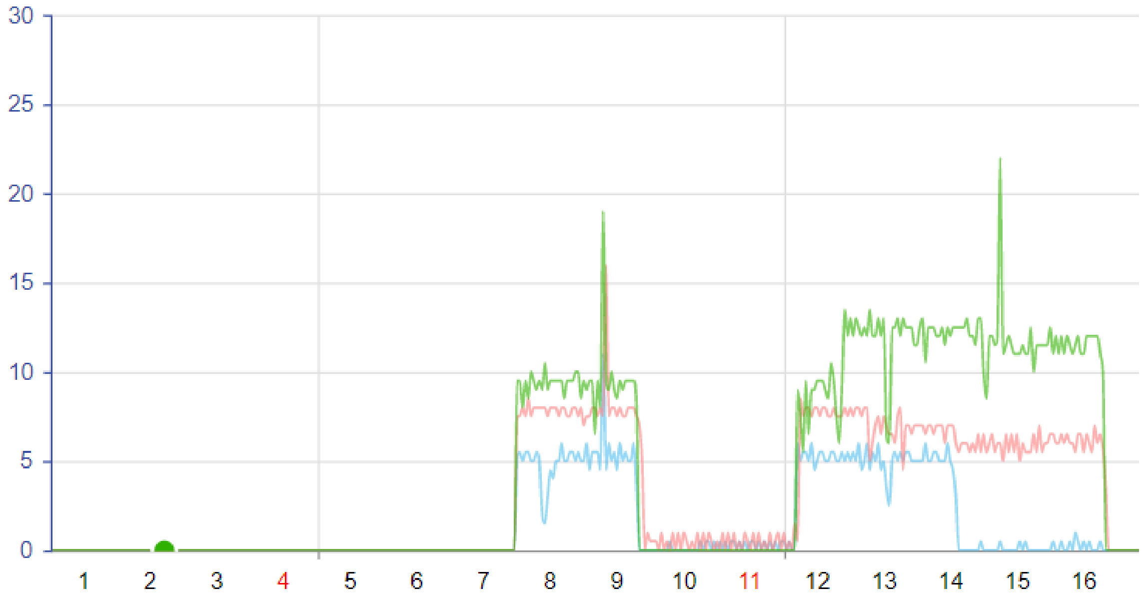


Figure 21. Green: Machine A, Red: Machine B, Blue: Machine C, Comparison on the energy consumption.

The results from the individual productions are hard to compare and the product should be manufactured in different machines and repeatedly to achieve more accurate results.

5.2 Recommendations

My recommendations based on my findings:

- It is worth to update older line to newer machines if considering in energy consumption perspective. When changing the machines to newer and more energy efficient, the environmental impact and carbon dioxide emissions are also lowered.

- If it is possible to reduce stopping time and increase automatic running time the manufacturing of the product has a lower energy consumption and therefore the energyconsumption per product made is lower. By inspecting the faults and eliminating them to achieve a better automatic running time, the efficiency for the product is increased and energy consumption is lowered.

- The excel calculation table that can be used in the future could be developed to an automatic tool that calculates the energy consumption of the manufacturing directly.

- To achieve a lower consumption for a product manufactured, the choice of machine should be made carefully while considering if a hybrid machine is a better option over a fully hydraulic.

6 CONCLUSION

This commissioned thesis work was created with aim to achieve a method to measure the energy consumption for specific products in the ABB factory Wiring accessories. With the new installed network analysis meters to measure the energy consumption of the injection moulding machines an opportunity to research product specific energy consumption occurred.

With all the data gathered from the energy meters, products information, and the running time for the machines, an excel table that could do simple but important calculations with all the necessary data was made during this thesis. With the excel table it was possible to start comparing the data gathered from the energy meters installed on the lines to the injection moulding machines.

There is an older line that does not have any energy meters installed, an already performed measurements in amperes made it possible to convert the result into kW/h. It was possible to compare the result with the newer production line for the same product. The conclusion of the comparing resulted in the newer production line being more energy efficient.

To increase the effectivity and lower the energy consumption the real running time is necessary to improve. When eliminating faults that stops the production lines the efficiency increases when at the same time the energy consumption per product is lowered.

With the use of all the data gathered it could be possible to develop an automatic system to monitor the products manufactured energy consumption directly with the other computer systems as all the different data is already on computers.

6.1 Svensk sammanfattning

Hållbarhet är en viktig del av företagets syfte och värde inom ABB. Hos ABB tror man på att hållbar utveckling är ett av framstegen mot en hälsosammare framtid. Genom ABB:s ledande teknologier och ansvarsfulla affärsmetoder bidrar ABB också till FN:s hållbara utvecklingsmål. (ABB, 2020 b)

Under kommande framtid kommer trycket på miljön bara att växa. Dagens befolkning på 7,8 miljarder förväntas växa upp till 9,7 miljarder år 2050. Enligt FN kommer 80 procent att vara bosatta i städer och öka behovet och pressen på vatten, mat, energi och transport. ABB:s hållbarhetsstrategi för 2030 möjliggör ett aktivt koldioxidsnålt samhälle och att arbeta tillsammans med kunder och leverantörer för att genomföra hållbara metoder. En av det viktigaste delarna i strategin är att följa med parisavtalet och följa riktlinjerna. De tre främsta hållbarhetsmålen inom ABB är att möjliggöra ett koldioxidsnålt samhälle, bevara naturens resurser och att främja sociala framsteg. (ABB, 2020 c)

EU: s klimatstrategi och utsläppsmål är ett paket med tre mål för 2030 som är den viktigaste drivkraften som stöds av de två andra målen. Utsläppsmålet är ytterligare uppdelat i utsläppshandelssektorn ETS 43% jämfört med 2005 och i medlemsstatsspecifika mål i icke-ETS-sektorer med i genomsnitt 30% jämfört med 2005-nivån. Målet för förnybar energi är bindande på EU-nivå och energieffektivitetsmålet är vägledande på EU-nivå. (Energiateollisuus ry, 2021)

Då jag har jobbat några somrar vid ABB Wiring Accessories, blev jag erbjuden att skriva detta ett examensarbete för ABB. Under hösten 2020 hade nya energikonsumtions mätare installerats på el matningarna till formsprutningsmaskinerna och på detta sätt uppstod rubriken för mitt examensarbete. I detta examensarbete använder jag mig av kvantitativ forskningsmetod. En kvantitativ forskning baserar sig på processen för att samla och analysera numeriska data. Det kan användas för att finna medeltal, olika mönster och för att testa förhållanden. Med hjälp av ABB:s olika datorprogram har jag samlat, analyserat, räknat och jämfört all data för att finna olika resultat.

Detta examensarbete är gjort för och vid ABB:s fabrik Wiring Accessories i Borgå i Finland. Fabriken tillverkar, utvecklar, marknadsför och sätter ihop el installationsmaterial. Fabriken i Borgå investerar regelbundet i nya tillverkningstekniker och auto-

mation för att höja konkurrenskraften. I fabriken finns 100 anställda med 50 robotar som producerar 25 miljoner produkter per år. (ABB Oy, 2021 a) När man ser figur 2. på sidan 13 som är ett diagram över energiförbrukningen år 2019, så kan man se att nästan hälften av energikonsumtionen består av formsprutning.

Mätarna som installerades för att övervaka energikonsumtionen för formsprutningsmaskinerna är av typen ABB M2M och ABB M4M20 dessa energimätare kallas nätverks analysatorer p.g.a. mätarna använder sig både av TRMS mätteknik och beaktar och räknar THD. TRMS är förkortning av true mean root square och kan exakt mäta både sinusformade och icke-sinusformade växelströms vågformer där en vanlig genomsnitts räknande multimeter kan endast mäta standard sinusformer. THD är förkortning av total harmonic distortion vilket betyder störningar som kan uppstå till exempel i fabriksmiljöer där det finns många harmoniska komponenter som ger störningar i frekvenserna. Desto mera komponenter desto mer störningar kan uppstå. Mätarna kommunicerar via TCP/IP med hjälp av vanlig nätverkskabel och digitala pulsutgångar.

Formsprutning är en av de vanligaste processer vid tillverkning av plastdelar. Det är en cyklisk process med snabb fyllning av formen, följt av kylning och lossning. Materialet är i allmänhet i form av små korn som smälter i en injektionsenhet och injiceras i en form med högt tryck ca. 500-1500bar. Fördelen med formsprutningens är att det är mycket ekonomisk för massproduktion. (Goodship, V. (red.), 2020, kap.1) En formsprutningsmaskin kan vara helt elektrisk, helt hydraulisk eller en kombination av båda i ett hybridsystem. (Goodship, V. (red.), 2020, kap.5)

Energieffektiviteten för en formsprutningsmaskin är i allmänhet mätt i kWh/kg och varierar enligt plastdel som är tillverkad och har många olika faktorer som plastdelens vikt, maskinens storlek och maskinens effektivitet. En undersökning *manufacturers saving potentials* av skz plastics institute i Tyskland ger en redovisning om hur mycket energi en formsprutningsmaskin använder i figur 17 på sidan 25. Figuren visar det att nästan häften 48% av energin går åt till mjukgörning av plasten och de komprimering följt av upphettning och klämkraften. Upphettning och mjukgörning av plasten är ställen där man kan försöka spara energi på. (Plastics Engineering, 2013)

Med hjälp av olika datorprogram och ABB:s energimätare var det möjligt att samla all nödvändiga data. En del av data samlat kan inte presenteras p.g.a. konfidentiella orsa-

ker. Alla produkter och maskiner har andra namn än i verkligheten. Energi mätarna samlar energi data i real tid. Mätarna är kopplade med programmet Tac Vista som sparar mätaravläsningen och laddar upp informationen till internetsidan Enerkey. Enerkey sparar allt mätarresultat från alla mätare i hela fastigheten och en uppföljning av energikonsumtionen är möjligt online. ABB:s interna program så som SAP och Arrow machine track samlas data om produkterna och tiden för produktionen. Med hjälp av tångamperemätare har kontrollmätningar gjorts.

Med all nödvändiga data samlat kan man nu göra en kalkyl med hjälp av Excel. Excel tabellen räknar följande: Hur många produkter har tillverkats per timme, kW/h per produkt tillverkad som konverteras till W/h, Medeltals förbrukningen i kW/h, W/h per produkt totala mängden råmaterial använt och W/h per gram material. Detta räknas på basen av energimätarens resultat i kW/h, injektions storleken i gram, hur många produkter kan tillverkas per timme, och den riktiga automatiska tillverkningstiden. Det här materialet presenteras med hjälp av tabeller och grafer maskinvis.

Resultaten presenteras i en tabell enligt produkt nummer i tabellen finns följande: Produkt nummer, Maskinen, kW/h per del, W/h per del, medeltals förbrukningen, W/h per g. Totala mängden produkter tillverkade och totala mängden rå material är dolda i detta arbete p.g.a. konfidentiella orsaker. Resultatet behandlas i kapitel 5, fynd och rekommendationer.

Bland fynden presenteras en jämförelse mellan maskingrupp D och E som tillverkar samma produkt. Maskingrupp E är en äldre produktionslinje medan Maskingrupp D är en nyare produktionslinje. Maskingrupp E har inte mätare installerade men mätningar har utförts manuellt hösten 2020. Resultatet av mätningarna visar att den nyare linjen har lägre energikonsumtion än den äldre. P.g.a. detta kan man anse det nödvändigt att uppdatera en äldre linje mot en nyare då det är frågan om energikonsumtion.

En av det större orsakerna till förhöjd energikonsumtion visar sig vara ifall den automatiska tillverkningstiden är låg jämfört med mätnings tiden. Detta beror på stopp i den automatiska produktionen och inga produkter tillverkas vilket resulterar i förhöjd energikonsumtion per produkt då värmen fortfarande är på och maskinerna väntar. Om man undersöker noga vad som utlöser fel och försöker eliminera onödiga fel kan än bättre produktionstid uppnås. Då ökar effektiviteten per produkt tillverkad och så sätt minskar

energikonsumeringen per produkt då maskinen inte väntar med upphettningen på medan felen åtgärdas.

Maskinens storlek ger grunden till energiförbrukningen desto större maskin desto mer förbrukning, följt av injektions storlek. För att kunna mäta en plastbits energikonsumtion så måste mätningar utföras i alla maskiner som den tillverkas i eftersom maskinerna har en egen grundförbrukning. Ifall man optimerar storleken för maskinen enligt produkten och överväger en hybrid maskin kan energiförbrukningen minska.

Detta arbete har även resulterat i en Excel tabell som nu kan användas för företaget att räkna ut produktens energikonsumtion vid ett enskilt tillverknings tillfälle. En utveckling för ett automatiserat system som ger ut resultat om energiförbrukningen direkt efter en tillverkning kunde vara möjlig då all annan data finns tillgängligt via befintliga datorprogram.

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APPENDICES

APPENDIX 1. all data and results

Product nr.	Machine	Material	Start time	End time	kW/h	Shot size g	PPH	Measuring time, h	Time arrow, h	kW/h per piece	W/h per piece	Average kW/h	w/h per g
1	C	Polypropylene	7.4 7:58	7.4 9:31	15	13,78	707	1,5	1,50	0,0141	14,144	10,000	1,026
2	C	Polypropylene + color	8.4 0:00	9.4 19:00	223,5	9,22	212	44	40,54	0,0260	26,005	5,513	2,821
2	C	Polypropylene + color	12.4 6:00	14.4 14:00	290,5	9,22	212	57	54,53	0,0251	25,129	5,327	2,725
2	C	Polypropylene + color	20.4 14:00	23.4 12.00	370	9,22	212	71	70,70	0,0247	24,686	5,233	2,677
3	B	Polycarbonate	7.4 7:58	7.4 12:12	35	15,4	543	4,25	4,25	0,0152	15,166	8,235	0,985
3	B	Polycarbonate	8.4 0:00	9.4 21.00	362,5	15,4	543	45	42,60	0,0157	15,671	8,509	1,018
3	B	Polycarbonate	12.4 6:00	12.4 23:00	140	15,4	543	18	15,60	0,0165	16,527	8,974	1,073
4	B	Polycarbonate	12.4 23:00	13.4 7:00	60	13,18	543	8	7,52	0,0147	14,694	7,979	1,115
5	B	Polycarbonate	13.4 7:00	13.4 15:00	54,5	37,1	147	8	7,05	0,0526	52,588	7,730	1,417
6	B	Polycarbonate	13.4 16:00	13.4 19:00	21,5	60,5	140	3	2,65	0,0580	57,951	8,113	0,958
7	B	Polycarbonate	13.4 20:00	14.4 15:00	135	27,9	184	20	18,93	0,0388	38,758	7,132	1,389
8	B	Polycarbonate	14.4 15:00	15.4 20:00	171	15,5	194	29	26,48	0,0333	33,287	6,458	2,148
9	B	Polycarbonate	15.4 20:00	16.4 11:00	92	11,9	165	15	13,93	0,0400	40,027	6,604	3,364
10	B	Polycarbonate	16.4 12:00	16.4 20:00	52	12,9	180	9	7,81	0,0370	36,990	6,658	2,867
11	A	Polycarbonate	7.4 7:58	7.4 12:12	54,5	28,3	145	4,25	4,25	0,0884	88,438	12,824	3,125
12	A	Polypropylene	8.4 0:00	9.4 20:00	415	21	259	42,36	42,36	0,0378	37,826	9,797	1,801
12	A	Polypropylene	12.4 14:00	13.4 7:00	195	21	259	18	15,45	0,0487	48,731	12,621	2,321
13	A	Polycarbonate	13.4 7:00	15.4 1:00	499,5	45,32	314	42	37,26	0,0427	42,694	13,406	0,942
14	A	Polycarbonate	15.4 1:00	16.4 12:00	411,5	31,79	324	35	25,15	0,0505	50,499	16,362	1,589
15	A	Polycarbonate	16.4 1300	20.4 5:00	377,5	34,41	116	34	20,72	0,1571	157,061	18,219	4,564
16	A	Polycarbonate	20.4 6:00	20.4 17:00	143,5	26,7	180	12	6,41	0,1244	124,372	22,387	4,658
17	A	Polycarbonate	20.4 17:00	20.4 23:00	79,5	15,5	180	7	4,84	0,0913	91,253	16,426	5,887
18	A	Polycarbonate	21.4 00:00	23.4 6:00	683	21,5	316	55	52,79	0,0409	40,943	12,938	1,904
19	A	Polycarbonate	23.4 7:00	23.4 21:00	142	34,41	218	14	6,52	0,0999	99,904	21,779	2,903
20	A	Polycarbonate	26.4 12:00	27.4 2:00	179	34,41	107	15	15	0,1115	111,526	11,933	3,241
21	D	Polypropylene + SEBS/TPS	8.4 00:00	12.4 10:00	1360	94,13	450	50	42,94	0,0704	70,382	31,672	0,748
22,1	D	Polypropylene + SEBS/TPS	12.4 11:00	14.4 8:00	1238,3	55,73	778	44	29,00	0,0549	54,884	42,700	0,985
22,2	D	Polypropylene + SEBS/TPS	14.4 8:00	19.4 11:00	1718	55,725	778	56	49,32	0,0448	44,773	34,834	0,803
22,3	D	Polypropylene + SEBS/TPS	19.4 12:00	20.4 9:00	674,9	55,725	778	22	19,69	0,0441	44,057	34,276	0,791
22,2	D	Polypropylene + SEBS/TPS	20.4 9:00	23.4 12:00	2365	55,725	778	83	78,91	0,0385	38,523	29,971	0,691
22,2	D	Polypropylene + SEBS/TPS	26.4 7:00	27.4 2:00	604,7	55,725	778	20	20,00	0,0389	38,862	30,235	0,697
22,2	E	Polypropylene + SEBS/TPS	12.10.20 11:30	14.10 02:30	1508,75	55,725	778	39	38,79	0,0500	49,994	38,895	0,897
22,4	E	Polypropylene + SEBS/TPS + color	14.4.20 2:30	15.10 8:00	1126	57,12	778	29,5	28,27	0,0512	51,196	39,830	0,896