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FEASIBILITY STUDY OF IMPLEMENTING AN INDUSTRIAL ROBOT FOR INDUCTION HARDENING MACHINE

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ABSTRACT

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The objective of the thesis was to make a feasibility study of implementing an industrial robot for the induction hardening machine.

Various industrial robots were studied and compared in the thesis to find a suitable robot. A cost analysis of using a human and the robot for that task and the practical demonstration of the appropriate industrial robot which is suitable for induction hardening were also made. Finally, articulated robot was chosen due to its good working area and enough working axis.

In this study qualitative research method was used. In-depth interview and participant observation process were employed in achieving the results. The result of the cost analysis between the human operator and the robot to run the induction machine showed witness that the use of the robot increases production and is more profitable.

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1 INTRODUCTION

The main objective of every thesis was to build up a theory or to test a theory that has already been built and the main objective for this thesis was to estimate the costs analyses of implementing industrial robot for the small induction machine at Bodycote, Vaasa.

Bodycote has been in the heat treatment industry ever since the year 1648 and currently the world's leading specialist in testing and thermal processing services. It is a provider of heat treatment, hot iso-static pressing, metallurgical coating and testing services to many manufacturing companies.

The small induction hardening machine at Bodycote Vaasa is mostly used for induction hardening of small components, the number of the these components can be about 5000 pieces and it require a lot of time to harden all these components.

The induction hardening section at Bodycote Vaasa is run by one shift which is approximately eight hours (8h). Due to this a delay in delivery time when a numerous amount of a particular component are to be treated. Therefore. this research considers the cost analyses of implementing an industrial robot to be run after the day activities and determine how it will help the management.

There are two induction hardening machines at Bodycote Vaasa: the big one for large components and the small one for small components. This research focuses on the small induction hardening machine

1.1 Main Objective

The main objective of this research was to estimate the total cost of implementing an industrial robot for the small induction hardening machine at Bodycote, Vaasa.

1.2 Secondary objective

The secondary objective was to come out with a clear decision based on the costs analyses, if the implementation of robot for the induction machine will lead to profit.

1.3 Research questions

Based on the discussion with experts about the issues involving in implementing an industrial robot, the following research questions have been defined:

1. How profitable will it be to implement an industrial robot for the small induction hardening machine at Bodycote, Vaasa?

2. How can the robot increase the time of delivery at Bodycote Vaasa?

3. How will the robot affect the working environment at Bodycote Vaasa?

2 THEORETICAL BACKGROUND

The theoretical background for the thesis is given next.

2. 1 Heat treatment

Heat treatment is mostly done with idea of increasing the physical strength of the material, but it can also lead in offering certain properties of materials that helps to achieve good manufacturing procedure, such as improving machinability, improve formability and restoring of ductility after a cold working operation. Heat treatment process has a vital role to play on the product aside improving the manufacturing processes it also boost the product performances by increasing toughness, strength or other desirable characteristics. /14/

The properties of a material can be changed by undergoing heat treatment process. Such properties can be the hardness, toughness, malleability, ductility, micro-structure and stress concentration. The type of property needed will determine the type of heat treatment process to be used. /35/

2.2 Types of heat treatment process

In order to obtain the right properties for a material or a component by heat treatment process, there are various types of heat treatment processes that are used to achieve these properties. Depending on the property require the material can undergo more than one heat treatment process. The following are heat treatment processes or methods being used for engineering materials:

2.2.1 Hardening

This is the process of heating steel just above its upper critical temperature or keeping it at an appropriate temperature until all partite is transformed into austenite, and then quenching it rapidly in water or oil. The carbon content of the steel determines the temperature at which austentizing will take place. /8/

The main reason of hardening is to increase the hardness of the work piece as possible. The hardness of the steel depends mostly on its hardenability and the amount of carbon it contains, the size of the material and the condition during the heat treatment process also has a little to do with the hardness. /32/

2.2.2 Tempering

This is the heat treatment method that is applied to a material which has been already hardened to optimize its ductility, toughness and reduce its brittleness. After hardening steel it becomes very hard and brittle, therefore tempering is carried out to relieve the brittleness or stresses in the martensite structure. The tempering process is carried out by heating the hardened material below its critical temperature (350 to 400 ºC) and then cooled slowly to allow the carbon to diffuse out of the body-centered tetragonal structure, in that optimizing its ductile and stable body-centered structure./21/

2.2.3 Annealing

This process is carried out to reduce hardness, remove residual stresses, optimizing toughness and re-gaining the ductility of a metal. It provides mechanical, electrical or magnetic properties for the material via the refinement of the grain structure. The process is carried out by heating the material just above its critical temperature or above austenitic phase and then cooled very slowly. During this process oxidation is carried out due to controlling the atmosphere by insert gas. /19/

2.2.4 Normalizing

After a material has undergone a manufacturing process such as wedding or forging the material grain structure become distorted. Therefore the normalizing process is carried out to refine the grain structure of the material thereby avoiding excessive softness in the material as well. The material is then heated just above its critical temperature (1100 ºC) and cooled in air. /19/

2.3 Induction heating

To stay competitive in today's market place, production effective and cost effectiveness are essential. Among the various sources of heat treatment methods in today manufacturing process (flame, oven, resistance and induction), induction heating is increasingly attractive option. Flame heating techniques produces a hard working environment with poor temperature control and requires a high level of operation skill; traditionally other heating system (oven) requires a huge investment and valuable floor space and must be continuously operated to avoid long steps of delays and resistance heating surfers from poor repeatability and unreliable content resistance./39/

Induction heating overcomes all the aforementioned sources of heat limitations, traditionally described as a quick none contact material heating method. Induction heating utilizes the unique properties of radio frequency energy, the area of spectrum below infrared and microwave. In a typical induction system RF power supply sends alternative current through a couple of coils generating a magnetic field. When the part (work piece) is placed in the coil circulating eddy current induce within the part flow against the electrical resistibility of the material and generate heat. Figure 1 shows a basic setup of induction heating. /39/

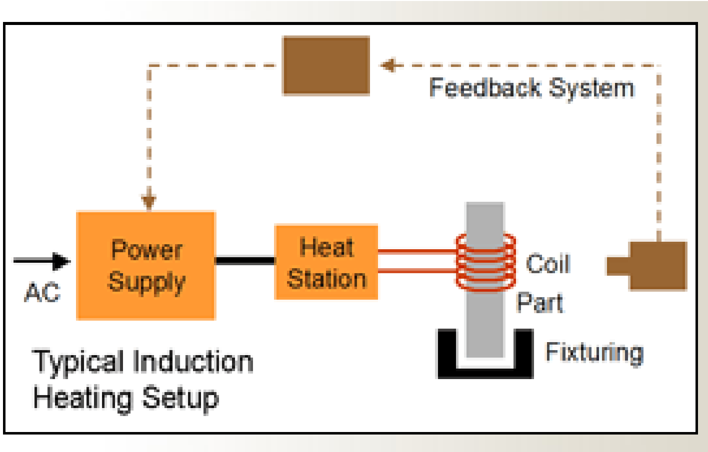

Figure 1. A basic induction heating setup. /18/

Figure 2 shows how these eddy currents flow against the electrical resistivity of the metal, generating precise and localized heat without any direct contact between the part and the inductor. The heating occurs with both magnetic and non-magnetic parts, referring the scientific formula known as Joules effect which expresses the relationship between heats produced by electrical current passed through a conductor. It is expressed as "Q = I2 x R x t" where Q is the amount of heat produced, I is the current flowing through the part (conductor), R is the electrical resistance of the part, and t = time". (39, 17)

In the process of heating the material, there is therefore no contact between the inductor and the part, and neither are there any combustion gases. The material to be heated can be located in a setting isolated from the power supply; submerged in a liquid, covered by isolated substances, in gaseous atmospheres or even in a vacuum. /39/

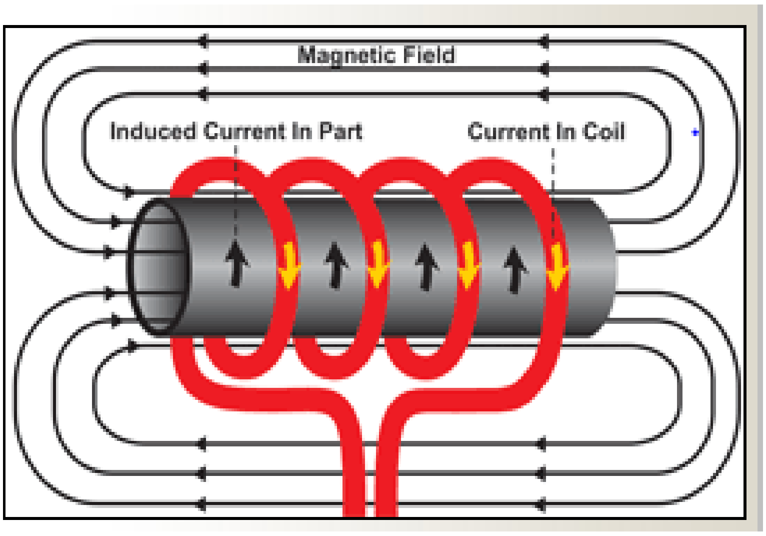

Figure 2. Eddy currents flowing against the electrical resistivity of the metal. /18/

Although induction is based on a well-known principle it is continuously being rediscovered because of the unique adventures. First and foremost induction is best, temperature about 1100 ºC can be produced in a second, induction is highly controllable and very selective, the exact amount of heat needed can be delivered precisely and exactly where needed without affecting surrounding areas or environment as shown in Figure 3. /39/

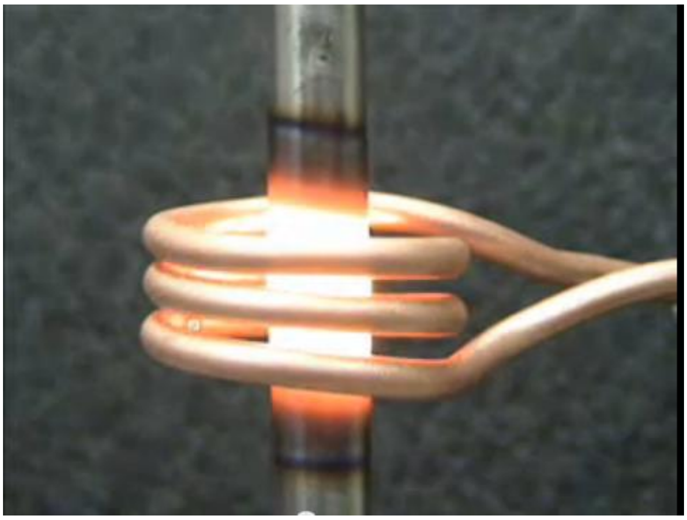

Figure 3. Using induction heat method to harden a specific metal part. /39/

2.3.1 Induction coils

An induction coil which is also called inductor, plays a very important role in the induction heating processes. The effect of the heating process mainly bases on the effectiveness of the coil, therefore the coil should be carefully or properly made, a quality material should be used. The coil should be maintained correctly and there should be the correct amount of power to achieve good induction heating process with high efficiency. /13/

Induction coils hold the whole installation of the induction heating process, therefore, it must be able to meet some standard requirements. Such requirements are a satisfactory or long life span, desirable production rate, a good conductivity of electricity, and the ability to stand the heat with less change in the part dimension. /15/

Induction coils differ from each other depending on the design, geometry, dimension and the material used to make it. The design or the number of coils depends on the nature of component to be heat treated. Figure 4 shows some different types of induction heating coils. /15/

Figure 4. Induction heating coil design. /9/

3 INDUSTRIAL ROBOTS

3.1 History of industrial robots

The word “Robot” was first introduced in 1920 by two Czech brothers Karel Capek and Josef Capek. Karel was a Czech writer who found it difficult or unpleasant to use the word *laboři* for his man-made creatures in a play. Then his brother Josef presented the Latin word *roboti* which means self-labor. The word was later coined to robotic by a science writer called Isaac Asimov when he decided to expand on that in 1944. /30/

Ever since man started thinking about machines the perception of human-like robot has been existence for hundreds of years. Engineers and science writers have elaborated on that till 1956 when Devol and Joe Engelberger, established a company with the name Unimation which was a shortened word from the two words Universal Animation. /27/

Devol and Engelberger came out with a brilliant idea derived the first industrial robot in 1959. Figure 5 showe the first industrial robot which was called Unimate; in 1967 Unimation installed the first industrial robot in Europe at Metallverken, Uppsland Väsby, Sweden. /27/

Figure 5. Unimate’s first industrial robot. /27/

Industrial robots are best defined by their actual work used for or their applications. Industrial robots are used for painting, wedding, assembling, pick and place, testing and for product inspections. /33/

3.2 Characteristic of industrial robots

Industrial robots have particular characteristics that make them function or perform as required. These characteristics of industrial robot includes sensing, movement, energy and intelligence

3.2.1 Sensing

Due to the automation application of robots it should first have a sensor (director) that will enable the robot to sense its surroundings or environment. Robots have different ways of sensing their surrounding which is not at the same as with humans. The robot can be provided with sensors such as light sensors (eyes), touch and pressure sensors (hands), chemical sensors (nose), hearing and sonar sensors (ears), and taste sensors (tongue) will make the robot awareness of its environment ./24/

3.2.2 Movement

One of the characteristics required in a machine as a robot is that it should be able to move within its working environment or premises. This movement can be rolling on wheels, walking on legs or propelling by thrusters. /24/

3.2.3 Energy

The energy used by the robot is counted as one of its important characteristics as the robot needs to be able to power itself. There are different ways it can be powered: robot might be solar powered, electrically powered, battery powered or hydraulically powered. The work of which the robot is designed to do or its function will determine the type of energy source to be used to power the robot. /24/

3.2.4 Intelligence

The most important among all the characteristics of robots is its intelligence. This is the area where programming enters into the scene. The robot is smart when it does exactly what it is supposed to do. The programmer then is a person who is to provide the robot its smartness. The robot therefore receives the program to determine what to do, when to do and how to do it. /28/

3.3 Types of industrial robot

There are various types of industrial robots and they are in different shape and size mostly based on their moving mechanism. They are designed to operate in a way that will help everyday manufacturing lives. The moving axes of the robot determines its mechanism and the ability of its movement is based on the number and arrangement of the moving axes. /25/

Industrial robots have different application and specifications, depending on the type of the industrial robot. There are different robotic configurations as well. Non-servo robots, servo robots, programmable robots and computer programmable robots are some basic types of industrial robots commonly used. /36/

A non-servo robot is mostly used to transport objects from one place to another. It does that by moving the object to a specified place after picking and then drops it. /36/

A servo robot has an amount of manipulators and effectors which makes is able to feature in a wider range. Servo robots have robotic outgrowths which make it function as the robot arms and hands, makes it flexible or boosting its flexibility and greater movement. /36/

A programmable robot has the capability of storing commands in a database which makes it to repeat the task given as much as required. A computer programmable robot is equally a servo robot that uses a computer to control through distance. /36/

3.3.1 Industrial robotics

Industrial robots are configured based on their movement and capabilities. There are different types of industrial robots used for industrial applications; industrial robots are mainly group in six different types which are Cartesian robot, SCARA robot, articulated robot, parallel robots, cylindrical robot and polar robot. /30/

3.3.2 Cartesian robot

The Cartesian robot due to its structure and design has different types of names such as linear robots or gantry robots. The kinematics of a Cartesian robot is of three axes (XYZ) and has some similarities with the milling machine. Cartesian robots are mounted on a linear track supported by a pillar around the working area. The design and structure of the robot makes it possible for large geometrical work to be easily handled. Cartesian robots are suitable used for palletizing and handling work, they are sometimes combined with articulated robots for a good combined kinematics. Figure 6 shows a Cartesian robot and its working area. /25, /30/.

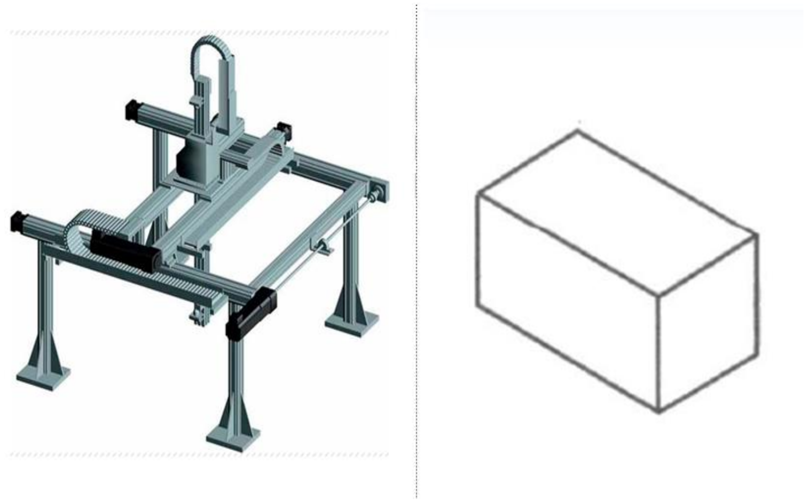

Figure 6. Cartesian robot and its working area /25/, /11/

3.3.3 SCARA robot

The name SCARA is an acronym which stands for: Selected Compliant Assembly Robot Arm. In some cases it is also referred to as Selected Compliant Articulated Robot Arm. A SCARA robot has a cylindrical working environment or work envelope as the same as that of the cylindrical robot but it has round ends as shown in Figure 7. It is mainly used for precision work within one plane; SCARA robots have two rotational joints with high horizontal stiffness. It has three axes (XYZ) which it can move within its working environment. They are used for pick and place applications but are very expensive due to their controlling software which requires inverse kinematics for linear interpolated movement. /25/, /30/, /27/

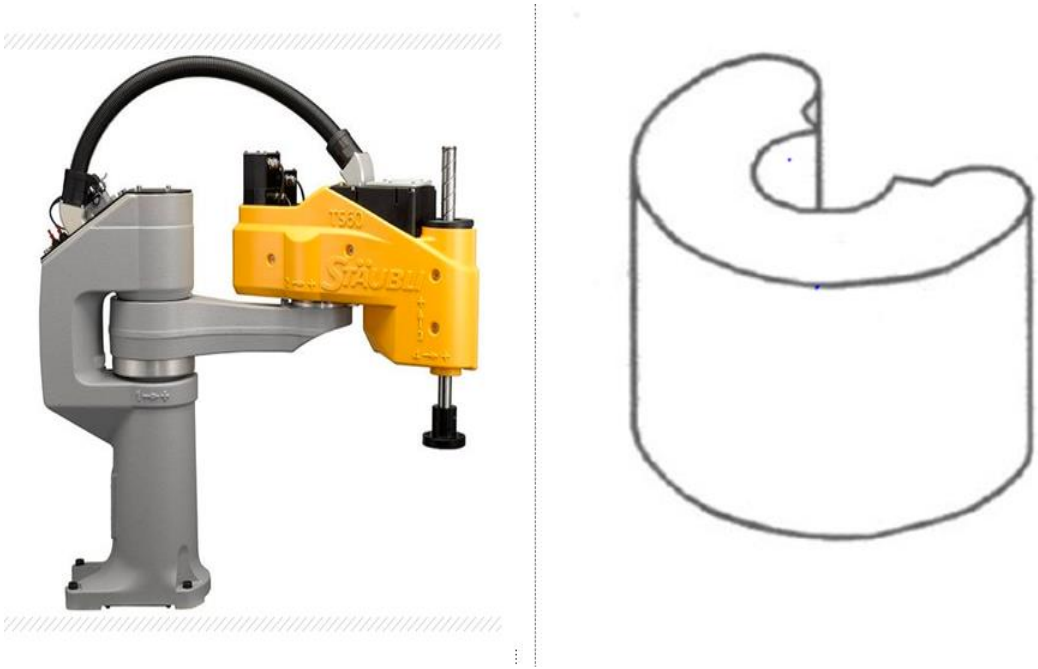

Figure 7. SCARA robot and its working area. /25/, /12/

3.3.4 Articulated robot

An articulated robot, which is sometimes called jointed-arm robot, has a six degree of freedom (six axes).They have rotary joints which allows it to turn back and forth within its working area; the joints are arranged in such a way that they support each other to perform the right work intended. The articulated robot has a spherical working area as shown in Figure 8. Because of the arrangement of the joints it requires a small working place and is flexible for different work applications. /25/, /30/

Figure 8. Articulated robot and its working area. /25/, /26/

3.3.5 Parallel or Delta robot

A Delta robot which is also called a parallel robot has a great many different applications as compared to the other robot configurations. Its configuration is a combination of rotational axes and parallelograms; it has a constrained base, end effector and number of legs which allows it to work within a dome-shaped working area as shown in Figure 9. With little weight the effector gains more stability but it has a small free moving area. They are mostly used for flight stimulators and also for picking items on fast conveyer belt. /32/, /30/

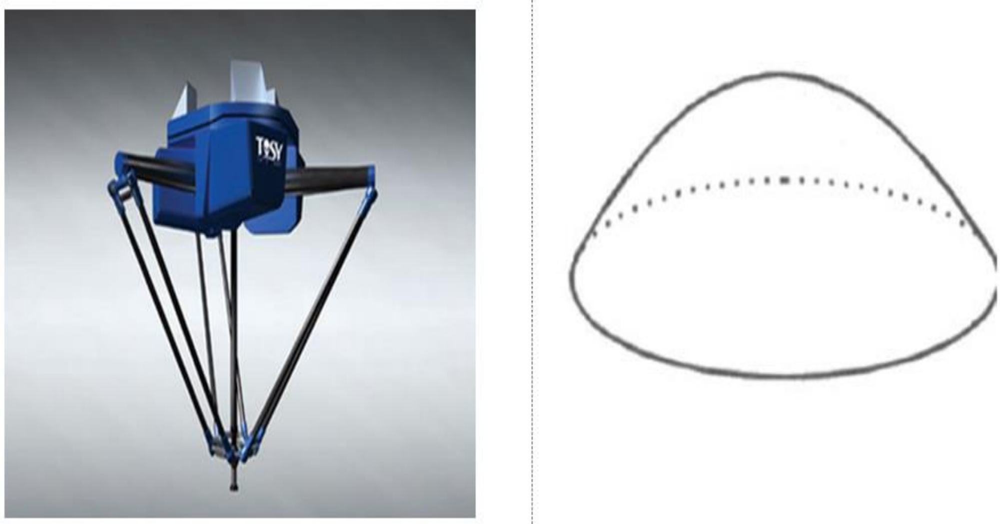

Figure 9. A parallel robot and its working area. /25/, /20/

3.3.6 Cylindrical robot

A cylindrical robot works within a round working area as shown in Figure 10. Its just like the SCARA robot but has three axes of movement of which two of its axes (Y and Z) are linear and has the third is rotational axis which rotates around the base. /30/

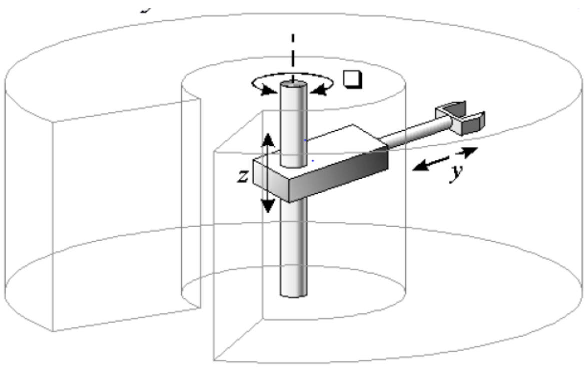

Figure 10. Cylindrical robot and its working area /2/

3.3.7 Polar robot

A polar robot is also called spherical robot, it has three degrees of freedom (three axes) of which two of axes are rotational and one linear as shown in Figure 11. It has a partial sphere work envelope of which the radius varies. Figure 12 shows a polar robot and its working area. /2/

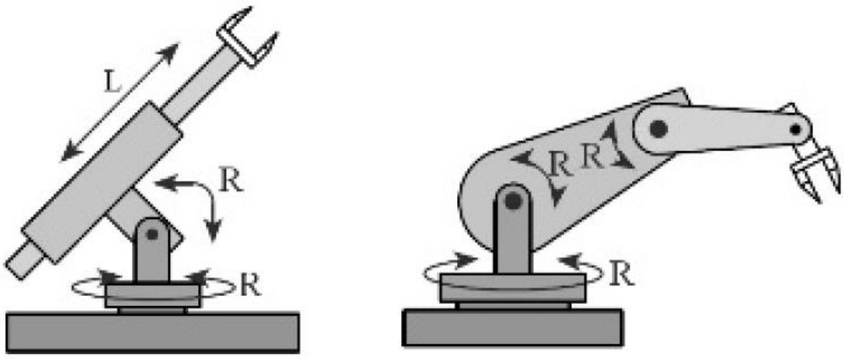

Figure 11. The working principles of the polar robot (coordinate system) /2/

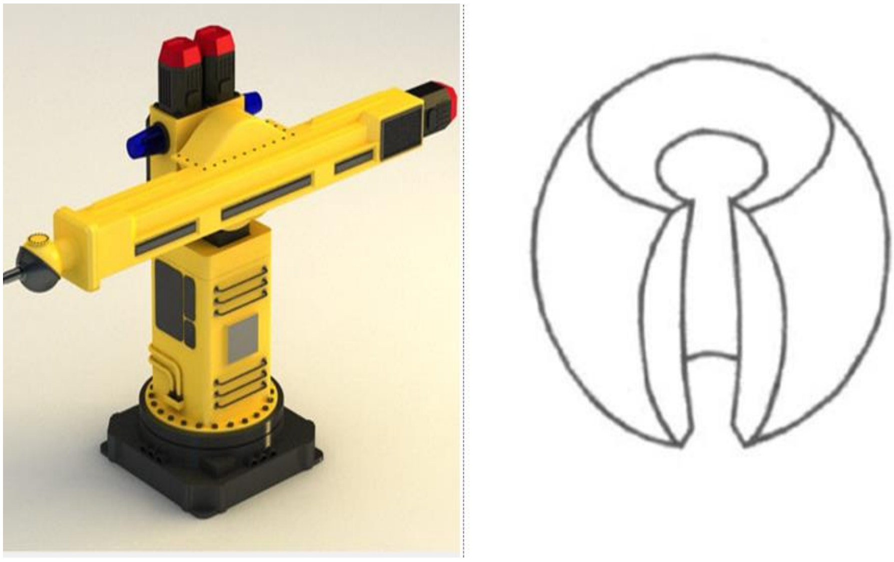

Figure 12. Polar robot and its working area /37/

3.4 Components of industrial robots

There are many automation machines that one may mistake for a robot due to the way they perform or work applications. For a machine to be classified as a robot it should have the following five components: arm, controller, drive, end effector, and a sensor./31/

3.4.1 The robotic arm

The robotic arm is the component of the industrial robot that has six degrees of freedom, though some industrial robots may not necessary have up to six degrees of freedom or some may have more depending on the type of applications their intend for. The robotic arm holds the whole structure of the system and contains some other components such as the wiring, cables and drives. The size of the end structure of the robotic arm also determines how large the working area of the robot can be. /31/

3.4.2 The robotic controller

The robotic controller serves as a brain of the industrial robots system, there by contain the entire system program and delivers information to some components such as the robot arm and other accessories. Robotic controllers are mostly placed behind the robotic arm. For easy manipulation by the user, a teach pendent is connected to the robotic controller. /31/

3.4.3 Robotic drives

Robotic drives are normally called motors; they are the engine that control the movement of the robot arms (axes) and lead them to their right intended positions. Normally, every arm or axis is designated for one specific motor. The accurate movement and intended position needed to be achieved by the robot arm rely on the precision of the robotic drives. There are different types of drives used for controlling industrial robot arm or axis; these drives can be hydraulic drives, electric drives or pneumatic drive. Each drive has its capacity of strength and speeds therefore there are chosen depending on the application of the industrial robot. /29/, /31/

3.4.4 Robotic end effectors

Robotic end effectors are in different shape and size for performing many tasks; they are always connected to the robot arm and serves as the robot arm hand. The end effectors are also known as tools and they have direct contact with the material being manipulated by the robot. Some examples of these tools are welding gun, gripers, vacuum pump, and magnets. /29/

3.4.5 Robotic sensors

Robotic sensors are more often chosen depending on the applications, accessories, and the working environment of the industrial robot. These sensors are put in place for safety purposes, especially when two robots are working hand in hand.

These sensors help the industrial robotic arm to identify its working environment. /29/, /31/

3.5 Reasons for using or investing in industrial robot

Manufacturing companies invest in industrial robots in order to reduce cost and increase their profit, to increase their productivity, to produce quality of work, to be competitive in the global market and in order to transfer dangerous and hard work that man cannot stand to a robot. These advantages of a robot have been the ultimate goals of manufacturing companies to invest in industrial robots.

The following list consists of the reasons of using industrial robots in manufacturing companies:

- Industrial robots are used to extend automated sequence continuously from one part to batch.
- Industrial robots can operate without supervision
- Industrial robots increase production uptime there by eliminating breaks that cause delays during the production
- Industrial robots can be placed in dangerous areas or unfriendly environments such as high temperature and dusty areas that are difficult for humans to work in addition they can be used for lifting heavy equipment.
- Industrial robots are used for good accuracy and constant quality works.

4 RESEARCH METHODOLOGIES

4.1 Research

Research is basically referred to a search of knowledge. Research is a scientific and systematic way of solving a particular problem or discovering answers to a specific problem. There are so many definitions by scholars pertaining to research; the Advanced Learner's Dictionary of Current English gives the definition of research as "a careful investigation or inquiry especially through search for new facts in any branch of knowledge." D. Slesinger and M. Stephenson in the Encyclopedia of Social Sciences also define research as "the manipulation of things, concepts or symbols for the purpose of generalizing to extend, correct or verify knowledge, whether that knowledge aids in construction of theory or in the practice of an art." /23/

The main purpose of research is to unveil answers to questions via a scientific procedures and application and to find out the fact and truth that has been covered and have become unknown to the society. However, every research has a specific objective and purpose of which at the end of the study should be clearly defined. /23/

Although every research has a specific objective and purpose, there are also specific motivations that drive people into research: Some people go-into research for the desire of getting an academic degree, pleasure of facing the challenges of discovering hidden information, to be glad of doing creative work, to be of a service to their society and others also are motivated to the fact they will be respected. /23/

However, there can be other motivations that drive people into research studies aside the aforementioned. Some people may go into a research study by the directive of government and their employers. Others also go into research study out of inquisitive thinking about new inventions./23/

4.2 Types of research methods

4.2.1Quantitatve research method

Various research methods are discussed next

Quantitative research is generally use of researches that are based on quantity measurement or numbers. Quantitative research it used to phenomena that can be conveyed in terms of quantity. This type of research in forms of converting data collection into numerical form for statistical calculations whereby conclusion can be drawn at the end. /23/, /3/

In process of quantitative research, the researcher can have more than one assumption questions (hypothesis). The researcher will also have to get different instruments and material, such as paper test, computer test and observation check list in order to get results for the questions. /23/

With quantitative research, data is collected in different ways. The data goes through a strict procedure and a statistical analysis. These are carried out of late by complex computer software. With the help of the analyses the researcher can evaluate the relationship between the different variables being used. /23/

A quantitative research method can also be done by the use of secondary data which is official statistics, by surveys in which case the researcher will prepare questionnaires or structured interviews for the targeted group of research and also by going through experiments. /23/

4.2.2 Qualitative research method

A qualitative research method is used for researches that are concerned with the quality phenomenon and not on the quantity, for instance making an investigations on how and why a particular machine is being used. /3/

The process of qualitative researching makes the researchers tend to be inductive that is they build a theory based on the data that have been collected by them during the process of researching. This makes the research move from specific to general and is known as bottom-up or inductive approach. /3/

In qualitative research, the researchers do not rely on their research on hypothesis that are pre-determined but they specifically identify a topic that they are willing to investigate and then are guided by a theory or a lay down procedure to achieve their aim(s). /3/

Although, the methods of collecting data and analyses in qualitative research are done according to a systematic form of procedure, yet it allows for more flexibility than that of the quantitative research method. The data are then collected in a form of text and it is based on observation and interaction with participants. These can be participant observation, in-depth interviews and focus group. /3/

The qualitative research method is usually applied to a smaller number of participants which may be due to the methods used, such as in-depth interviews that involve time and labour or sometime it is not necessary to involve a large number of people. /3/

Be it a smaller number of people involved or its degree of flexibility it does not make the research less scientific than the large number of people being used in the quantitative research and carried out in a rigid manner. This is due to the fact that the two methods are used for different objectives and their underlined philosophical assumptions are totally different. /3/

4.2.3 Mixed Research method

A mixed research method is the research method in which both qualitative research and quantitative research methods or techniques are used together on one particular study. Therefore this type of research method is a combination of inductive and deductive approach. /3/

During the feasibility studies on the implementation of industrial robot for induction hardening at Bodycote Vaasa, a qualitative research method was used, this method was employed by using an in-depth interview and participant observation process to achieve the results.

5 CASE COMPANY (BODYCOTE)

Bodycote is a thermal processing servicing company which can be found in 26 countries and 190 locations around the globe. The mother company was first established in Great Britain. /4/

Bodycote operates mostly in the northern part of America and Europe and has limited locations in the Middle and Far East. The United Kingdom has 14% of its total sales which sum up to $716 million and North America accounts for 40% of the sales. Meanwhile, the rest of Europe generates more than 45% of the total sales. Bodycote is currently led by CEO Stephen Harris. /16/

Bodycote has been in the heat treatment industry ever since the year 1948 and is currently the world’s leading specialist in testing and thermal processing services. It is a provider of heat treatment, hot iso-static pressing, metallurgical coat-ing and testing services to many manufacturing companies. /4/

Bodycote heat treatment LTD in Finland is the leading metal heat and surface processor in Finland, which operates in four locations in Vantaa, Pieksämäki, Tampere and Vaasa. In the year 2010, the company had 66 employees and its net sales amounted to EUR 9.4 million. /4/

Finland Bodycote Heat Treatment Ltd began its operations in the year 1946, when the Bofors Finland Oy Ab, founded the first hardening in Helsinki. Currently, the company is operating in four locations with their offices in the southern and central of Finland. /4/

The company’s office in Vantaa is set as the head office of Bodycote Finland. The head office is responsible for financial and administrative functions, but also technical support, international services, education, laboratory, and research activities. /4/

Each office has its own independent unit, which serves customers in the entire location to promote and help in achieving the company's goals and objectives.

Should there be difficulties or lack of a suitable method of processing in a branch of doing a particular service the products are transported to another branch that has the suitable processing method for the services to carry on. /4/

5.1 Bodycote Vaasa plant

Bodycote Vaasa plant was first established by Suomen Bofors in 1946 and sold to Uddenolm in the year 1987. Uddenolm then operated the plant for two years and also sold it to Brukens in 1989; finally in 1999 it was sold to Bodycote Oy.

Bodycote Vaasa plant is currently operating with twelve employees. The plant was fully integrated in Bodycote PLC in 1999; therefore the Vaasa thermal processing plant has been run fully automated controlled since the year 1999.

Bodycote Vaasa achieved a total sale of 2 million Euros in 2012 and estimated to increase by 5% in 2013. Although Bodycote Vaasa plant is a small plant as compared to the Vantaa and Tampere plants, yet due to its place of location and with regard to some big manufacturing companies being its customers makes it play an important role that cannot be overlooked.

Bodycote Vaasa offers a high quality, reliable and cost effective services to its customers irrespective of their size or market sector.75% of the company's work comes from Wartsila and its subcontractors. The company aims to provide quality and reliable services to its main customers and as well the rest of its customers.

5.2 Main processes carried out in Vaasa plant

Thermal processes improve the physical and chemical properties of metals and alloys. Such properties are strength, toughness, ductility, malleability, elasticity, good conductor of electricity shining and other more. Adding the required and right properties increases the life of the component as well.

In order to provide the right properties to the required component, there are many heat treatment processes that can be used to achieve the right properties. Bodycote as a whole has so many processes for achieving that but Bodycote Vaasa currently has five heating processes which are carburizing, case hardening, nitriding, nitrocarburising and induction hardening.

5.2.1 Carburizing

Carburizing is the process by which low carbon steel absorbs carbon during the heat treatment processes. This is done when the metal or steel is heated with material that is enriched with carbon, such as carbon monoxide. The carbon is thereby diffused into the steel to allow it to gain high carbon content which makes the steel very hard. The amount of carbon content and the depth of diffusion depend on how long the steel will be in the furnace and the temperature: more time and high temperature gives a great carbon content and high depth of diffusion. The carburizing process is applicable for low carbon steels and it increases the hardness of the outer surface of the steel thereby making the inner core retain toughness and ductility. /38/

5.2.2 Case hardening

Case hardening is an easy way of hardening steel and is much easier than hardening and tempering method of heat treating materials. The case hardening process is done by adding carbon to the surface of the steel to a required amount of depth. In this process the inner core of the steel remains soft whereas in the carbirizing the inner core becomes tough and ductile. /22/

5.2.3 Nitriding

Nitriding is a heat treatment process in which nitrogen is diffused into ferrous materials at a low temperature of about 500 to 600 °C. This heat treating process adds good qualities to the material, in that it makes the material resist wear, seizure, corrosion and fatigue. This process is applicable for all ferrous materials. /10/

5.2.4 Nitrocarburising

A nitrocarburising process is similar to the case hardening process in that the nitrocarburising process is a thermochemical diffusion in which nitrogen, carbon, and a little amount of oxygen atoms are diffuse into the surface of the steel. Nitrocarburising provides an anti-wear resistance to the surface of the steel and allows the steel to resist fatigue. Nitrocarburising makes it that plain carbon steels can replace low alloy steels. /5/

5.2.5 Induction hardening

Induction hardening is a case hardening process which is used to increase wear the resistance, surface hardness and fatigue life via a process of hardening only the surface layer of a component and keeping the core structure unaffected. The process is used in increasing the mechanical properties of ferrous materials at a specific required area /6/

Induction hardening has a number of benefits in that it is very good for components that are subjected to heavy loads. Induction hardening provides a high surface hardening and therefore gives the component the ability to handle extremely heavy loads without fracturing. Induction hardening provides a tough outer layer thereby softening the core which makes it capable to increase the fatigue strength of the component and makes it suitable for parts with torsional load force. Induction hardening is also good for surfaces with heavy sudden load or impact surface forces. The process provides a high surface hardness and deep case makes the material capable to carry heavy loads. /6/

Induction hardening is applied to components such as gears, shafts, axles, cam lobes, stampings and spindles. The process is carried out to harden a specific area of such parts. The process can be carried out with materials such as carbon steels, alloy steels, stainless steels, cast iron, gray iron, ductile iron and malleable iron.

The induction section at Bodycote Vaasa is employs two induction hardening machines as shown in Figure 13. The big one is used for hardening large and heavy components while the small induction hardening machine is used for smaller components that are of light weight.

Figure 13. A picture of the big and small induction hardening machine at Bodycote Vaasa.

The study is based on the small induction hardening machine. The small induction hardening machine is used for smaller components within the range of 80g to 1500g in weight. There can be thousands pieces of a particular component that need to be hardened by the machine and they are hardened individually one after another but with the same heating and handling time. Figures 14 and 15 show the side and front view of the small induction machine. A chuck and suitable holding device are provided for holding the work piece securely during the hardening process.

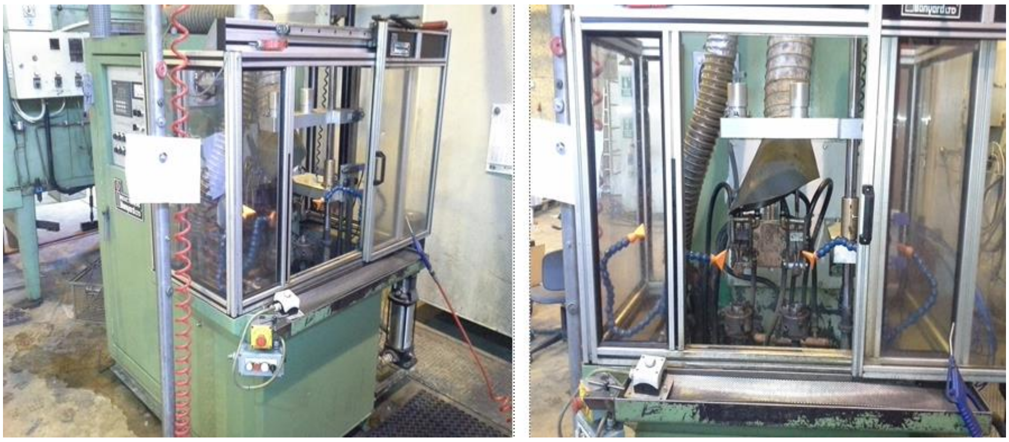

Figure 14. The front view of the small induction machine.

Figure 15. The side view of the small induction machine

5.3 Proposed robot to be used

After going through all types of industrial robots and knowing their working envelope, the number of axis for each and their functions, the articulated robot was chosen.

There are varieties of the articulated robot in terms of size and capacity, such as the 6kg articulated robots, 10kg articulated robots, 20kg articulated robots and 50kg articulated robot. Due to the nature of the induction hardening by the small machine the 6kg articulated robot was selected. Figure 16 shows a picture of a 6kg articulated robot.

Figure 16. 6kg articulated robot. /34/

The 6kg articulated robot is small in structure and therefore will perfectly fit the required space provided behind the induction machine and will be able to carry the expected load for hardening. Based on its structure and load capacity it was the best choice of robot to be used.

Because the company has experience with Fanuc robotics, Fanuc robot brand was selected, thus facilitating the programming of the robot.

Figure17. Application of articulated robot /29/

The robot is planned to be movable so that it can be taken away when not used and thus providing adequate space for other work processes around the induction section. The work piece will be arranged in a provided crate on a table or a well-designed structure. Figure 17 shows a typical example of how a robot is picking work pieces from a table.

Figure 18 shows how the induction hardening is currently done. The operator is standing in front of the induction machine whilst the work pieces are placed in a box behind him. He then takes the work piece and places it in the holder for hardening process and takes it after hardening. He does that till all the work pieces are hardened.

Figure18. The current arrangement in the process of the induction hardening.

6 COST ANALYSIS

6.1 Number of work pieces

The number of work pieces for the cost analyses of the study is based on three suggested work pieces (ABC) with handling time and hardening time of each of these pieces. We have estimated the number of work pieces that can be carried out by the robot and have compared the number to that of human. The average number of hours of the induction machine is estimated to be thousand five hundred (1500) per year. In all the three work pieces we estimated the sales of the services to be €105 per every hour. The variable cost of production both robot and human is estimated to be twenty percent (20%) of one our sales.

The robot will be working for eight hours a day if there are available work pieces to be worked on. The operation by human operator is also eight hours in a day and out of the eight hours one and half hours is for lunch and coffee breaks. Therefore the actual hours will be six and a half. Tables 1, 2 and 3 show all the information of the work pieces (ABC) should the robot is compared to a human operator to cover the average working hours per year.

Table 1 Work piece A

Features	Robot	Human
Total time	45 seconds	45seconds
Number of hours per year	500 hours	500hours
Number of work pieces	40,000 pieces	32,500 pieces

Table 2 Work pieces B

Features	Robot	Human
Total time	60 seconds	60seconds
Number of hours per year	500 hours	500 hours
Number of work pieces	30,000 pieces	24,375 pieces

Table 3 Work piece C

Features	Robot	Human
Total time per piece	90 seconds	90seconds
Number of hours	500hours	500 hours
Number of work pieces	20,000 pieces	16,250 pieces

6.1.2 A breakdown of the total cost of the robot

The installation price of the robot is €15,000. Robot tools or grippers are € 4,000: different gripper will be used for each work piece therefore the more there are different work pieces the cost increases. The table and crates that the work pieces will be arranged before the treating is estimated to be € 5,000. Before the robot will start the process, there will be human labor of two hours within a working day to arrange the work pieces in the crates and even test the hardness of the component. This labor cost is estimated to be € 9000 should the machine run for 1500 hours. The cost of installation of programmed is estimated to € 2000 for different work pieces. The maintenance cost is estimated to be € 1000; in reality the maintenance cost is not that much because the only maintenance to be done is to lubricate the robot once a year. Table 4 shows the list of features and their cost for installing the robot.

The total cost of the robot will be € 36,000 and the cost of labor when the machine is run for 1500 hours is € 4700.

Table 4 The total cost of installing the robot

Feature	**Cost**
Price of robot	€ 15000
Grippers or tools	€ 4000
Table and crates	€ 5000
Programmed installation	€ 2000
Maintenance cost	€ 1000
Cost of labour	€ 9000
Total cost	€ 36000

Table 5 Total work pieces with different heating and handling time

Features	**Robot**	**Human**
Total number of hours	1500 hours	1500 hours
Total number of pieces	90,000	73,125 pieces
variable cost =20% of sales	€ 0.35	€ 0.35
Fixed cost	€ 36,000	€ 47000
Total sales	€ 1.75 per piece	€ 1.75 per pie

The total variable cost is assumed to be 20% of the sales of 1500 hours, the robot and human have the same variable cost within working hours. Table 5 shows the total number of work pieces that can be done by both the robot and human within the average hours per year (1500) and the cost involved.

6. 1.3 The cost analysis for using robot

Table 6 shows the cost analysis of the hardening process should the machine be run by the robot was based on the assumed total work pieces with different heating and handling time as shown in Table 5. It entails the number of work pieces, sales, veritable cost, fixed cost, total cost and the income

Table 6 Cost analysis for using robot

Work piecs	Sales	Veriable cost	Fixedcost	Totalcost	Income
0	€ 0	€ 0	€ 36 000	€ 36 000	-€ 36 000
15000,00	€ 26 250	€ 5 250	€ 36 000	€ 41 250	-€ 15 000
30000,00	€ 52 500	€ 10 500	€ 36 000	€ 46 500	€ 6 000
45000,00	€ 78 750	€ 15 750	€ 36 000	€ 51 750	€ 27 000
60000,00	€ 105 000	€ 21 000	€ 36 000	€ 57 000	€ 48 000
75000,00	€ 131 250	€ 26 250	€ 36 000	€ 62 250	€ 69 000
90000,00	€ 157 500	€ 31 500	€ 36 000	€ 67 500	€ 90 000
105000,00	€ 183 750	€ 36 750	€ 36 000	€ 72 750	€ 111 000
120000,00	€ 210 000	€ 42 000	€ 36 000	€ 78 000	€ 132 000

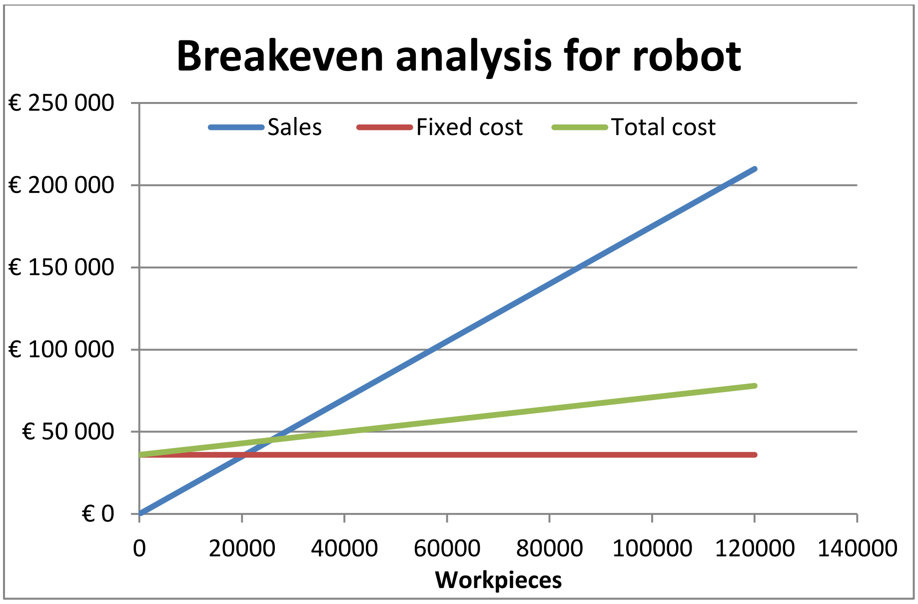

Figure19. Breakeven analysis graph for using the robot for induction hardening.

As illustrated in Figure 19 the number of work pieces the robot need to breakeven is 25714 with a cost of € 41,250. The breakeven point is where the sales line and the total cost lines meet.

6.1.4 The cost analysis for running the induction machine by human

Table 7 cost analysis of the hardening process should the machine be run by a human operator, this was based on the assumed total work pieces with different heating and handling time as shown in Table 5. It entails the number of work pieces, sales, veritable cost, fixed cost, total cost and the income.

Table 7 Cost analysis by using human

Work pieces	Sales	Viriable cost	Fixed cost	Total cost	Income
0	€ 0	€ 0	€ 47 000	€ 47 000	-€ 47 000
15000,00	€ 26 250	€ 5 250	€ 47 000	€ 52 250	-€ 26 000
30000,00	€ 52 500	€ 10 500	€ 47 000	€ 57 500	-€ 5 000
45000,00	€ 78 750	€ 15 750	€ 47 000	€ 62 750	€ 16 000
60000,00	€ 105 000	€ 21 000	€ 47 000	€ 68 000	€ 37 000
75000,00	€ 131 250	€ 26 250	€ 47 000	€ 73 250	€ 58 000
90000,00	€ 157 500	€ 31 500	€ 47 000	€ 78 500	€ 79 000
105000,00	€ 183 750	€ 36 750	€ 47 000	€ 83 750	€ 100 000
120000,00	€ 210 000	€ 42 000	€ 47 000	€ 89 000	€ 121 000

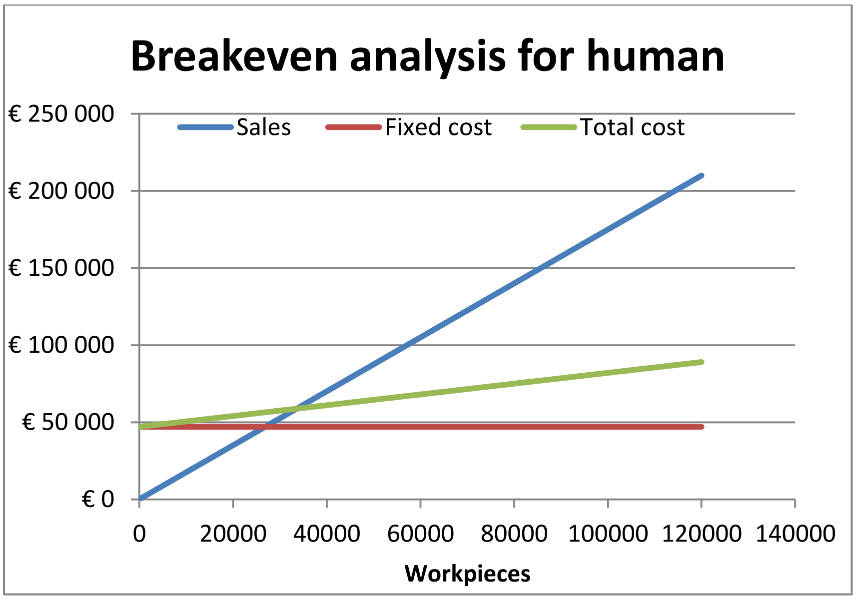

Figure 20. The breakeven analysis graph of using the induction machine by a human operator.

Figure 20 shows that 39167 work pieces and a cost € 57,500 are needed to breakeven when the induction machine is fully operated by a human operator.

7 CONCLUSIONS

This study was motivated by the need of analyzing the cost of implementing an industrial robot at Bodycote Vaasa heat treatment plant. The robot is intended to be used for induction hardening which is currently operated manually.

During the research we found out that implement automated machines or specifically robots do increase their profit of business organization and also makes work easier.

It was gathered from the research results that the robot will work on 90000 work pieces within the average working hours of the induction machine which is 1500 hours and with an income of € 90,000. However, the same number hours (1500) when used by a human operator will work on 73125 work pieces with an income of €56,550. Therefore, based on the analysis of this research we come to a conclusion that it will be worthwhile for Bodycote acquire the robot.

During this research, we found out the robot will work one and half hours more than a human operator every working day. This is to the fact that the robot will work constantly during the working day (eight hours) without lunch or coffee breaks. Therefore work output of the robot is consistent and more predictable as to determine the production delivery time.

During this research the plant manager of Bodycote Vaasa, Mr. Veli-Pekka Nurminen was interviewed and he assured to make the working environment of the robot conducive by providing the necessary educational training for his employees should the robot is implemented.

7.1 Limitations

The time allocated for conducting this thesis was very limited therefore there could have been more theoretical information, even though this gives a Clear view of the thesis. However, this research gives an overview of comparing robot and human operator for induction hardening. There could have been more accurate and precise results if the actual production data of the induction machine per year was given.

7.1.1 Recommendation

Although the need of implementing robot for induction hardening is worth, we recommend it should be implemented if there are enough work pieces to work on, that is, if the number of work pieces to work on during the year is. That is the critical number of work pieces to make the acquisition profitable.

In this case we recommend if there is not enough work for the robot then the induction hardening should be continued to be run by a human operator. If there is not work for a human operator at induction he can work at the main production line or do some other work for the company.

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APPENDIX I

Interview

Respondent: Mr. Veli-Pekka Nurminen, the Plant manager of Bodycote Låmpökåsittely Oy Vaasa. The interview was heard at the company premises in Vaasa, Finland in April 2013.

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APPENDIX II

Questionnaire guide for the interview

1. A brief background about Bodycote?

2. What is your current percentage in delivery efficiency?

3. How satisfied are your customers with current delivery time?

4. How many work pieces do you receive per week

5. How long does it take to work on them?

6. Why do you wont to implement industrial robot?

7. Will the robot affect other sections apart from induction section?

8. How likely are your employees ready to accept the introduction of a robot?

9. What measures have you designed to ensure that employees adapt to the introduction and use of a robot without resistance?